Assessment and Improvement of IPTV Service Availability in Vehicular Networks

Dissertation with the aim of achieving a doctoral degree
at the Faculty of Mathematics, Informatics and Natural Sciences
Department of Informatics
of Universität Hamburg

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Hamburg, 2017

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Monday 6^{th} February, 2017

Eidesstattliche Erklärung

Hiermit erkläre an Eides statt, dass ich, Sadaf Momeni, die vorliegende Dissertation selbst verfasst und keine anderen als die angegebenen Hilfsmittel benutzt habe.

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Abstract

Assessment and Improvement of IPTV Service Availability in Vehicular Networks

The increasing popularity of IP-based vehicular networks is currently leading to a strong interest in Internet Protocol TeleVision (IPTV) services offered to users in vehicles. For real-time communication services, such as live IPTV, the service quality as experienced by the users (QoE) is of particular importance. QoE of IPTV is strongly determined by the probability that a TV channel required by a user is unavailable upon its request, called Channel Blocking Probability (CBP). In this dissertation, we investigate the Channel Availability (CA) in IPTV services for vehicular users by means of comprehensive simulation experiments. For this propose, we have developed an own simulation tool which is based on a detailed IPTV user behavior model.

Moreover, we present an efficient and rather generally applicable analytical model in this dissertation that allows one to predict the blocking probability of TV channels, both for channel-switching-induced and handover-induced blocking events. We also validate our analytical model by means of simulation, and we introduce a new measure for QoE. Numerous case studies illustrate how the analytical model and our new QoE measure can be applied successfully for the dimensioning of IPTV systems.

Furthermore, there exist two significant challenges regarding the provisioning of IPTV services over vehicular networks: limited network bandwidth and the high rate of handover events. Therefore, channel blocking may either happen at a handover instant when a car changes its cell in the wireless access network or when an IPTV user within a cell changes the TV channel watched. Evidently, handover-induced channel blocking is particularly annoying for a user. Hence, we introduce two novel algorithms in this dissertation which try to reduce the handover-induced channel blocking probability significantly. Although, the second one tries to reduce the switching-induced channel blocking probability, too. Our algorithms rely on an a priori reservation of the currently watched channel in the neighboring cell before the user actually reaches the new cell. We also present comprehensive case studies to investigate how strongly an a priori channel reservation is able to improve the QoE for the IPTV vehicular users.

Kurzfassung

Die zunehmende Beliebtheit von IP-basierten Fahrzeugnetzen führt derzeit zu einem starken Interesse der Forschung an IP-basierten Fernsehendiensten (IPTV) in Fahrzeugen. Für Echtzeit-Kommunikationsdienste wie Live-IPTV ist die Servicequalität, wie sie die Anwender erlebt haben (Quality of Experience, QoE), von besonderer Bedeutung. QoE von IPTV wird stark durch die sog Kanalblockierungswahrscheinlichkeit (Channel Blocking Probability, CBP) bestimmt. Das bedeutet, dass ein Fernsehkanal, der von einem Benutzer benötigt wird, auf seine Anfrage hin ggf. nicht verfügbar ist. In dieser Dissertation untersuchen wir die Kanalverfügbarkeit (Channel Availability, CA) in IPTV-Diensten für Fahrzeugbenutzer mittels umfangreicher Simulationsexperimente. Es wurde ein eigenes Simulationswerkzeug entwickelt, das auf einem detaillierten IPTV-Nutzerverhaltensmodell basiert.

Darüber hinaus präsentieren wir in dieser Dissertation ein effizientes und eher allgemein anwendbares analytisches Modell, das es ermöglicht, die Blockierungswahrscheinlichkeit von TV-Kanälen für Blockierungser-eignisse vorherzusagen, die durch Kanalwechsel oder durch Handover verursacht sein können. Darüber hinaus validieren wir unser analytisches Modell mittels Simulation und führen ein neues Verfahren für QoE ein. Zahlreiche Fallstudien zeigen, wie das analytische Modell und unser neues QoE-Verfahren erfolgreich für die Dimensionierung von IPTV-Systemen eingesetzt werden können.

Darüber hinaus existieren zwei wichtige Herausforderungen hinsichtlich der Bereitstellung von IPTV-Diensten über Fahrzeugnetze: begrenzte Netzbandbreite und hohe Übertragungsgeschwindigkeiten. Kanalblockierung entweder zu einem Übergabezeitpunkt geschehen, wenn ein Fahrzeug seine Zelle in dem drahtlosen Zugangsnetz ändert, oder wenn ein IPTV-Nutzer innerhalb einer Zelle den beobachteten Fernsehkanal ändert. Daher führen wir in dieser Dissertation zwei neue Algorithmen ein, die versuchen, die Handover-induzierte Kanalblockierungswahrscheinlichkeit signifikant zu reduzieren. Unsere Algorithmen beruhen auf einer a priori-Reservierung des aktuell beobachteten Kanals in der benachbarten Zelle, bevor der Benutzer die neue Zelle erreicht. Zudem stellen wir umfassende Fallstudien vor, um zu untersuchen, wie stark eine a-priori-Kanalreservierung die QoE für die IPTV-Fahrzeugbenutzer verbessern kann.

Acknowledgements

This dissertation could not have been completed without the great support that I have received from so many people during my Ph.D. study. I wish to offer my most heartfelt thanks to the following people.

Firstly, I would like to express my sincere gratitude to my supervisor Prof. Dr. Bernd E. Wolfinger, for his excellent guidance and the continuous support of my Ph.D. study and related research, for his patience, motivation, and immense knowledge. I feel amazingly fortunate to have such a supervisor who is willing to teach me how to do high-quality research in a step by step manner. His guidance helped me in all the time of research and writing of this dissertation. I could not have imagined having a better supervisor for my Ph.D. study. He opened up invaluable research opportunities and taught me important lessons. He believed in my capabilities and provided me with all the support and flexibility which enabled me to finish my doctorate even with the birth of my child during my studies.

I would also like to thank my PhD committee members, Prof. Dr. Hannes Federrath, Prof. Dr. Walid Maalej and Prof. Dr. Djamshid Tavangarian to provide very useful hints for improving this thesis manuscript, which I have gladly embraced.

Moreover, I would like to thank all the members of the Telecommunication and Computer Networks Group (TKRN) for their support and friendship and for having provided a very welcoming atmosphere. I want to express my warm gratitude to the group members Ms. Katrin Köster, Dr. Torsten Runge, Mr. Alexander Beifuß, Mr. Andrey Kolesnikov, Mr. Robert Olotu, Dr. Alireza Abdollahpouri, Dr. Klaus-Dieter Heidtmann and Dr. Martin Lehmann. I would also like to extend my gratitude toward the friendly people in SVS Group for working at the same floor.

I owe thanks to a very special person, my husband, Hadi for his continued and unfailing love, support and understanding during my pursuit of Ph.D. degree that made the completion of my dissertation possible. You were always around at times I thought that it is impossible to continue, you helped me to keep things in perspective. I greatly value his contribution and deeply appreciate his belief in me. A special thank also goes to my little son, Ryan. His smiles encourage me to overcome the difficulties efficiently. I could not imagine doing my Ph.D. without you. You really gave me the reason to continue. Words would never say how grateful I am to both of you.

I acknowledge the people who mean a lot to me, my parents, Nayer and Shamseddin, for showing faith in me and giving me the liberty to choose what I desired. I salute you all for the selfless love, care and sacrifice you did to shape my life. Even though we are thousands of miles away, you were always there whenever I needed you. You can take all the credit for much of what I have achieved and what I will achieve in the future. Also, I express my thanks to my brothers Saman, Abdoreza and sister-in-law Zahra for their loving support. I consider myself the luckiest in the world to have such a lovely and caring family, standing beside me with their love and unconditional support.

Last but not the least, I would like to show my gratitude to Ms. Maryam Ghasemi who kindly supported and encouraged me to write this dissertation.

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Abbreviations

AP	**A**ccess **P**oint
aRCBH	**a**dvanced **R**eserve **C**hannel **B**efore **H**andover
BS	**B**ase **S**tation
BTV	**B**roadband-**TV**
CA	**C**hannel **A**vailability
CBP	**C**hannel **B**locking **P**robability
CIF	**C**ommon **I**ntermediate **F**ormat
CM	**C**hannel **M**anagement
HBP	**H**andover **B**locking **P**robability
HBR	**H**andover-related **B**locking **R**isk
HD	**H**igh **D**efinition
IGMP	**I**nternet **G**roup **M**anagement **P**rotocol
IP	**I**nternet **P**rotocol
IPTV	**I**nternet **P**rotocol **T**ele**V**ision
MPEG	**M**oving **P**icture **E**xperts **G**roup
MS	**M**obile **S**tation
RCBH	**R**eserve **C**hannel **B**efore **H**andover
QCIF	**Q**uarter **C**ommon **I**ntermediate **F**ormat
QoS	**Q**uality **o**f **S**ervice
QoE	**Q**uality **o**f **E**xperience
QVGA	**Q**uarter **V**ideo **G**raphics **A**rray
SBP	**S**witching **B**locking **P**robability
SBR	**S**witching-related **B**locking **R**isk
SD	**S**tandard **D**efinition
STB	**S**et-**T**op **B**ox

UBA	**U**ser **B**ehavior **A**utomaton
VANET	**V**ehicular **A**d-hoc **NET**work
VGA	**V**ideo **G**raphics **A**rray
VoD	**V**ideo on **D**emand

Dedicated To my Dear Parents, Husband and my Lovely Son

Chapter 1

Introduction

1.1 Motivation

During the last decade, using the Internet for various purposes like sharing information, business, watching TV and entertainment has become more and more popular. Along with the growing usage of the Internet, the television broadcast system was also developed by bringing the satellite, digital cable and HDTV services. There was an innovation in television systems by digitization technology to provide better quality and high definition images for the users.

Recently, offering TV programs via the Internet through an Internet Protocol Television (IPTV) service has become increasingly common. IPTV service provides multimedia services for any kinds of IP devices over Internet Protocol (IP) networks to watch Television whenever the users want. IPTV is strongly supposed to be one of the next killer applications over the Internet. There are many interests, particularly for service providers who are willing to extend and ensure their business models in developing a corresponding market effectively. IPTV is a quite new technology in the area of information and communications technology. It changed the concept of using television for its users and brought many new ideas and concepts in this area. IPTV is an outcome of merging Web and TV, and can be predicted to revolutionize the content delivery model and play a significant role in the next generation of TV systems. IPTV is a new form of traditional TV and appears as an alternative delivery system for traditional cable and broadcast systems. IPTV can prepare new aspects to traditional TV with increasing interactivity.

In general, IPTV is a combination of modern technologies in computing, networking and storage to deliver content through an IP network [5]. This system broadcasts various types of media content including text, graphic, audio and video files over an IP network to reach a large number of users. IPTV has changed the way of users to access information, knowledge and entertainment. It can be utilized in multiple sectors such as business, entertainment, communication, healthcare and education. IPTV may be integrated with an e-Learning system as a tool for supporting learning in education [6]. However, the successful deployment of the IPTV application and services essentially depends on a wide range of supporting technologies [7].

IPTV services for delivering TV content to viewers use the existing IP network. Video compression techniques are used to compress the video content, and this compressed data is transported to users using the existing IP networks as a Triple Play Service, which provides audio, video, and data services [8]. In spite of deployment of IPTV, the essential level of Quality of Service (QoS), Quality of Experience (QoE), security, reliability and interactivity are still needed to achieve IPTV user's satisfaction.

Traditional Television has been completely a broadcast-oriented facility. However now, with these new technologies users are no longer restricted to the broadcast programs of TV stations. They can use two-way communication by IPTV services, and they are capable of choosing the program according to their wish to see on demand, whenever, wherever, and on whatever device they want (TV, PC, smartphone, tablet, ...). IPTV is not only used as TV over the network but also provides some other value-added services, such as chat functions or other feedback mechanisms to allow the users for ratings or discussion forums on the shows. Therefore, according to the International Telecommunication Union Focus Group on IPTV (ITU-T FG IPTV) [9], IPTV service has been defined as follows:

- "IPTV is defined as multimedia services such as television/video/audio/text/ graphics/data delivered over IP-based networks managed to support the required level of QoS/QoE, security, interactivity and reliability."

In general, IPTV services can be divided into two different categories of applications: live streaming applications and on-demand applications. For the live streaming applications, there are forceful time restrictions for delivering the TV channels for the viewers. However, on the other hand, for Video-on-Demand (VoD) applications, there are no time limitations and stored video files are delivered to the users at the time they want.

IPTV has very flexible and interactive characteristics, because of the underlying interactive IP network which offers essential advantages including different ways of distributing the TV channels, such as broadcasting, multicasting or unicasting. It is possible to access to the electronic menu, fast forward, real-time rewind and billing management,

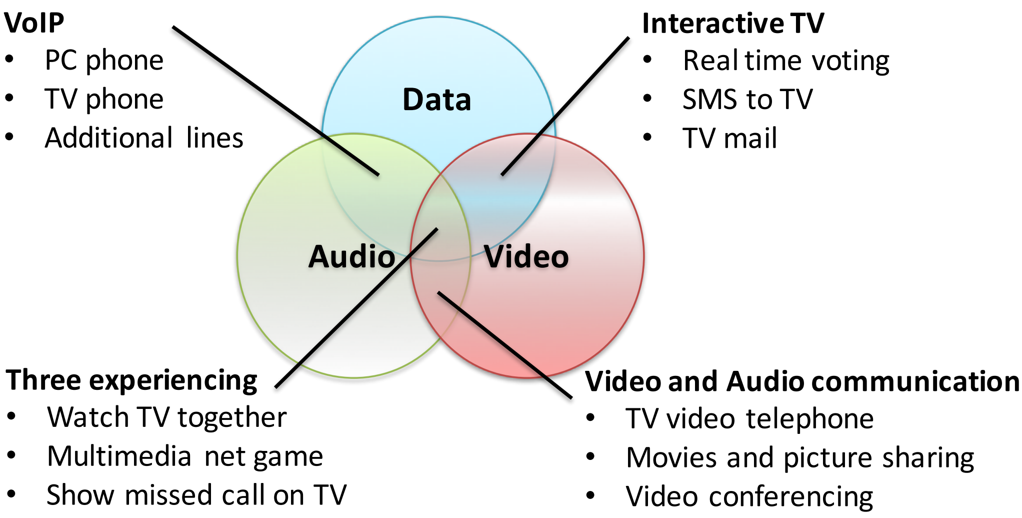

FIGURE 1.1: Applications for IPTV systems.

programming and other characteristics. As an IPTV service is based on the Internet, other content can also be accessed, such as online games, e-mail, electronic financial management, and so forth. Figure 1.1 depicts different types of IPTV applications.

A victorious technology should be cheap and user-friendly, and IPTV has that potential for the large section of society. Moreover, by applying this potential of IPTV services over vehicular networks, the users have a better chance to save time for doing some other activities during the car journey.

Some people are not able to buy a computer or do not know how to work with the computer. Nevertheless, they can use IPTV for their different goals [1]. We are going to describe some of the potential IPTV usages in the following:

- **Social networking**: With the ability to chat during the watching of TV it is possible to watch your favorite program with your friends.
- **Education**: It is possible to use regular TV as a medium of education with some effort in this area. Because regular TV is unidirectional, so with this value added services in an IPTV system it is bi-directional and is able to be used as an education environment particularly in some developing countries.
- **Travel and tourism**: You can buy your ticket by means of an IPTV service with your remote control, immediately just after watching a commercial advertisement about discount off ticket price.

- **Healthcare**: Access to the doctor for checkup or treatment is not easy for elderly people or people in remote locations in a rural area. IPTV can solve this problem by monitoring and treatment of patients and there is no need for them for leaving their home.
- **Financial services**: Another benefit of the bi-directional capability of IPTV is in the field of stock marketing and television banking. People who need to access to business or financial developments and news can easily use IPTV in this regard.
- **Instant feedback capability**: People are able to vote and elect an instant with also considering the security and privacy for them in IPTV systems.

It has been observed that day by day the number of mobile users with their devices which are also moveable is steadily increasing. Therefore, used technologies for mobile devices are becoming more powerful and common. In this situation, mobile applications also keep becoming more important. Mobile applications have a variety of usages like communication, business and education. According to the IDC survey [10], about 70% of organizations are currently deploying at least one mobile application [11]. Technology trends make mobile IPTV extend many IPTV services to mobile users [12, 13].

There has been growing interest to use IPTV technologies from fixed to mobile environment or even nowadays vehicular environment. On the other hand, with recent advances in vehicular networks and the advent of powerful mobile devices such as smart phones, IPTV services become practical in vehicular environments. Vehicular IPTV lets vehicular users get access to the offered IPTV services. In general, vehicular IPTV extends many IPTV services to vehicular users. However, it is an important aspect for a vehicular IPTV service to provide sufficient QoS and also QoE to maintain user satisfaction which is quite difficult to achieve in vehicular and wireless networks. We have a privilege for vehicular IPTV users in comparison to the mobile IPTV user, regarding terminal capability. Because they are sitting in the car, they do not have any problem for power consumption and energy saving on mobile devices. Although, there are still some problems for providing IPTV services for vehicular users, which are summarized in the following:

1. **Bandwidth**: IPTV applications are bandwidth hungry and bandwidth is a scarce resource in wireless environments. Therefore, careful allocation of resource bandwidth in vehicular IPTV is imperative.
2. **Handover process**: Numerous handover events and switching from one Base Station (BS) to the next one and service coverages are another significant problem of IPTV transmission for vehicular users.

3. **Nature of wireless environment**: There also exist some challenges related to the nature of specifications of wireless links like diversity in receivers' SNR (Signal-to-Noise Ratio), frequent packet loss, the vulnerability of physical factors and fluctuations in the link quality.

Therefore, in order to ensure the IPTV service performance (i.e. QoS and QoE), service providers have to carry out very careful dimensioning and planning work for their communication network.

1.2 Thesis Objectives and Contribution

Infotainment, combining information with entertainment, is a relatively recent neologism for a TV program, website feature, applications or other presentation that combines information with entertainment. Infotainment plays an important role, as on one hand this can provide useful information to the driver regarding the road and his/her trip. On the other hand, it can improve the user experience while driving and have fun during the car journey for the car passengers. IPTV services as an example of entertainment applications over vehicular networks are expected to play a significant role in the future of intelligent transportation systems and vehicular infotainment systems. IPTV has been becoming popular as it assures to deliver the content to users whenever they want. The next step is to provide this content wherever the users are. Although mobile IPTV has been greatly researched in the areas of communication, networking, human-computer interfacing and educational environments [5–7, 10–14], little research has been proposed on how to apply it for mobile users in vehicular networks. One of the major concerns for vehicular IPTV systems is that vehicular networks have often limited bandwidth capacity [15–17]. However, another great challenge for IPTV transmissions is a significant number of handover events during a car journey which can imply IPTV blocking situations and a decrease of QoE in IPTV systems. QoE is imperative as subscribers will choose for IPTV based on the level of offered QoE.

The overall objective of this thesis is to elaborate effective solutions to determine the TV Channel Availability (CA) in IPTV systems. Even though the effective bandwidth of the vehicular network is growing very rapidly, because IPTV is a bandwidth greedy application, there are still strong bandwidth limitations for IPTV services over vehicular networks. An IPTV service does not broadcast all the channels to the subscribers at the same time. Therefore, TV channel availability is one of the most significant factors to providing an acceptable level of QoE. In order to reach the overall goal, we try to investigate the challenges of Channel Availability (CA) in vehicular IPTV systems. The main objective of this thesis is to conduct research on wireless networks to provide seamless and smooth transmission for TV streams through vehicular environments. In particular, we focus on the following aspects: QoE, Simulation, Channel Blocking Probability, CA evaluation.

Objective 1: The first objective is to predict Channel Blocking Probability (CBP) and Channel Availability (CA) in highway scenarios with different traffic intensity and a varying number of TV channels offered to find out the CA of TV channels or the CBP. One of the main challenges is the limited bandwidth and moreover, this limited bandwidth has to be shared among the number of vehicles currently wishing to communicate in the same cell. Therefore, CA and CBP in each wireless cell depends on the number of users in each cell to receive IPTV service via the access networks which constitute the bottlenecks for high traffic density situations on highways. Thus, it is highly desirable to evaluate the probability that requested TV channels cannot be provided in vehicular IPTV systems. Comprehensive experiments are carried out by means of our own simulation tool to conduct the evaluations for numerous scenarios taking into account realistic IPTV user behavior.

Objective 2: As the second objective, we have to find a way that allows one to predict the blocking probability of TV channels for both channel-switching-induced, as well as for handover-induced blocking events. Here, the probability of bottlenecks regarding the available bandwidth in the cell is related to two items: First, the Switching-induced Blocking Probability (SBP), reflecting blocking because of TV channel switching events and the second one, the Handover-induced Blocking Probability (HBP), reflecting blocking because of handover events. With our analytical model, we introduce new measures for QoE in vehicular IPTV systems. Numerous case studies illustrate how the analytical model and our new QoE measures can be applied successfully for the dimensioning of IPTV systems, taking into account the QoE requirements of the IPTV service users in strongly different traffic scenarios.

Objective 3: Channel blocking in vehicular networks may either happen at handover moments when a vehicle is involved in a handover process or when an IPTV user within a cell switches the TV channel watched. Obviously, channel blocking related to a handover process is extremely annoying for an IPTV user. Therefore, we propose a solution to reduce the Handover-induced Blocking Probability (HBP) significantly. Our algorithm is based on a priori reservation of the currently watched channel in the neighboring cell before the user actually reaches this cell. We will investigate how strongly our new algorithm for pre-reservation of channels is able to decline the HBP in vehicular IPTV systems. Moreover, by generalizing our algorithm beyond reduction of the probability of handover-induced blockings, we try to reduce the number of switching-induced blockings at the same time. We propose this algorithm to try to adequately balance between all the handover-executing and channel-zapping users to increase the users' satisfaction with respect to bandwidth usage in the cell.

The contributions of this thesis comprise, e.g., simulation and analytical tools to study the availability of IPTV services in vehicular networks. Moreover, efficient algorithms are proposed to reduce the handover-induced TV channel blocking probabilities.

1.3 Thesis Structure

This thesis consists of thirteen chapters, which are aiming for coverage of all the mentioned objectives. In the following, we shortly present and summarize the content of each chapter.

Chapter 1: Introduction

Chapter 1 (current chapter) motivates the reader by different aspects of IPTV systems and the fast development of IPTV services. In this chapter, we explain the recent advances in the area of vehicular networks and mobile devices such as smart phones. These advances are the reason for a rapid growth of user demand for using IPTV services over vehicular networks. Moreover, this chapter motivates and describes in detail the objectives of offering IPTV services over vehicular networks. Eventually, the structure of this dissertation is given.

Chapter 2: Fundamentals

In Chapter 2, the necessary background knowledge and basic concepts regarding the vehicular networks and IPTV services and system architecture are presented. Moreover, we describe how to model switching and viewing behavior of an IPTV user during an active session. IPTV user behavior is an interesting and highly relevant topic for the IPTV service providers. In this chapter, we will also discuss about the Quality of Experience (QoE) of IPTV services which is an essential aspect for the IPTV subscribers. QoE has a strong impact when choosing adequate IPTV services for end users. QoE is extremely important and subscribers will choose IPTV services based on the QoE. Among QoE measures, TV channel availability (CA) and Channel Blocking Probability (CBP) are the most important in this work. High CBP can dramatically decrease the CA, and accordingly, QoE will be significantly declined. Section 2.5 is related to Objective 1 and we are going to analyze the assessment of QoE in detail for IPTV services in vehicular networks.

Chapter 3: A Simulation Tool to Assess IPTV Service Availability

Chapter 3 presents our simulation tool to evaluate CA and CBP in vehicular networks. With this simulation tool, we are able to predict the channel blocking probability due to handover events and channel switching within a given cell. Our simulation tool is written purely in C, to evaluate QoE for IPTV services over vehicular networks with a rather flexible applicability. An important characteristic of our simulator is its underlying realistic model for IPTV user behavior, which itself has been derived from comprehensive measurements of user behavior in existing IPTV systems. Accordingly, we describe the LoadSpec tool to explain how we model in detail IPTV user behavior focusing on channel switching events.

Chapter 4: Simulation-based Case Studies

By means of simulation experiments, we are going to determine the channel availability for vehicular IPTV users in Chapter 4. In this chapter, we conduct a set of experiments in different case studies in order to find out the suitable CA and CBP. Therefore, we are able to provide a decision support for the choice of suitable boundary conditions, which still lead to an acceptable level of the QoE for the users during their usage of IPTV service.

Chapter 5: An Analytical Model to Assess IPTV Service Availability

In the previous chapters we tried to predict IPTV service availability based on a simulation model. In Chapter 5, we elaborate an analytical model which is less detailed and much less complex than our simulation model. In this chapter, we introduce our analytical model which allows us to estimate the expected number of blocking events regarding channel switching requests or handover requests for vehicular users in order to evaluate the availability of vehicular IPTV services.

We consider the availability of an IPTV service for vehicular users in typical highway scenarios. Moreover, we present new measures for QoE to cover individual users and also the complete set of vehicular IPTV users. We execute numerous case studies to demonstrate clearly the advantages of investigations based on an analytical modeling approach as opposed to simulation-based experiments. In addition, we give a successful validation of our analytical model at the end of Chapter 6.

Chapter 6: Case Studies based on the Analytical Model

In Chapter 6, we conduct extensive case studies to indicate how the analytical model and our new QoE measures can be applied successfully for the dimensioning of IPTV systems. The goal of our analytical model is to find out the availability of IPTV services under different situations and boundary conditions in vehicular networks. In this chapter we are going to estimate the IPTV availability by means of two case studies by varying traffic scenarios and network technologies.

Chapter 7: Reserve Channel Before Handover (RCBH) Algorithm

Chapter 7 proposes the RCBH algorithm, with the aim to decrease the probability of handover blockings, and hence to reduce CBP accordingly by means of priority bandwidth reservation. In vehicular networks allocating the bandwidth efficiently is very important to support service continuity and service availability and to guarantee an acceptable level of QoE for IPTV users. Our RCBH algorithm tries to reduce the handover blocking to ensure continuous availability of a channel requested for a longer period, i.e. during a viewing-phase, by an IPTV user. Evidently, handover-related blocking is extremely annoying for an IPTV user, because the channel currently watched suddenly becomes unavailable. This situation is the worst case from point of view of the user with respect to the unavailability of TV channels, because it implies missing the program during the handover process. Therefore, effective management to keep the channel blocking probability small during the handover process of IPTV viewing users plays a significant role.

Our primary goal in order to improve QoE of IPTV service is to reduce the probability of handover-related blockings. The RCBH algorithm relies on a pre-reservation of the currently watched channel in the neighboring cell before the user actually reaches the new cell. We present in Chapter 7 comprehensive studies to consider how strongly the pre-reservation of channels is able to diminish HBP and in general CBP. So, in overall, RCBH increases the QoE of an IPTV system.

Chapter 8: Simulation Tool and Case Studies to Assess RCBH Algorithm

In Chapter 8, we present our proposed simulation tool for evaluating the RCBH algorithm. We elaborated this second simulation tool (besides the simulator introduced in Chapter 3) for analyzing IPTV services offered in vehicular networks with applying the RCBH algorithm. Our dedicated simulator, simulates the RCBH algorithm for IPTV users for various highway scenarios and it is suitable to determine both, switching- and handover-induced blocking events in vehicular networks. We describe the embedding of the algorithm into this simulation tool in detail in this chapter. Finally, in order to evaluate our new simulator, we carry out a very thorough testing phase for this simulator. We make a comparison between the RCBH simulation tool and our previous simulation tool, which we have presented in Chapter 3.

The simulation results for case studies to assess the RCBH algorithm are also given in Chapter 8. We execute a set of experiments in order to evaluate the performance of the RCBH algorithm to provide QoE for users at instants of handover-execution during the car journey. We consider the blocking probability and blocking risk in our experiments. Comprehensive simulation experiments have been carried out in this chapter to demonstrate that the RCBH algorithm is indeed able to reduce the probability of handover-induced channel blocking appreciably and thus it strongly improves QoE as observed by an IPTV user. The case studies cover different traffic scenarios, access networks based on different wireless technologies as well as various offers of TV channels.

Chapter 9: Advanced Reserve Channel Before Handover (aRCBH) Algorithm

In Chapter 9, the aRCBH algorithm has been proposed by means of generalized bandwidth reservation in order to improve the switching-induced blocking of RCBH algorithm which is described in Chapter 7. The policy of the RCBH algorithm is to keep the handover-induced blocking very low by reserving the channel for the user immediately after finding out that the user is going to view the specific channel. However, there are some situations in vehicular networks during which zapping users are not able to watch their new channel. This situation happens more often when we are applying the RCBH algorithm. Accordingly, the newly requested channel will be blocked because there is not enough free bandwidth in the cell and a large amount of the bandwidth is currently reserved for incoming users from the neighboring cell.

In this chapter, we introduce our aRCBH algorithm which tries to balance adequately between handover requests and new channel requests. Evidently, for providing an acceptable level of QoE, it is needed to reduce the probability of handover-induced blocking. Moreover, it is required to keep bandwidth utilization high at the same time for the zapping users. Therefore, by applying the aRCBH algorithm the user's satisfaction will increase with respect to bandwidth usage in the cell. In the aRCBH algorithm, we do not reserve the bandwidth immediately in the next cell for viewing users. We just reserve the bandwidth for the viewing users relatively shortly (namely ΔT time units) before they are leaving the current cell.

Chapter 10: Case Studies to Assess the aRCBH Algorithm

By means of simulation experiments, we present and discuss the simulation results of our proposed aRCBH algorithm as well as the comparisons with RCBH algorithm. In order to assess our new aRCBH algorithm regarding the reduction of switching blocking events, we conduct several experiments to investigate the Channel Blocking Probability

(CBP), the Switching-related Blocking Risk (SBR) and the Handover-related Blocking Risk (HBR) in Chapter 10.

Chapter 11: Summary and Outlook

In Chapter 11, as the chapter title indicates, a summary of all the studies in this dissertation is given. Moreover, an outlook is presented for possible topics which are still open and exciting for upcoming research work.

Chapter 2

Fundamentals

2.1 Vehicular Networks: Architecture and Applications

Considerable developments have taken place over the past few years in the area of vehicular communication systems. These days as more and more vehicles are equipped with devices to provide wireless communication capacities, interests on vehicular communications and networks have grown significantly [18]. So, vehicular networks represent one of the major subjects in the communication systems area and they are an important and emerging area of research in the field of vehicular technology. This kind of network has been newly attracting an increasing amount of attention from research and industry communities together due to the wide variety of services such as inter-vehicle video streaming, safe navigation support, business and digital entertainment applications, military or scientific applications, internet access and much more [19]. Many research activities and projects have been led in the area of vehicular networks. Many government projects have been implemented in the USA, Japan, and the European Union [20].

The premiere objective of using vehicular network technology was to create an accident-free environment at the first and observed as a key technology for enhancement of road safety and transportation efficiency through Intelligent Transportation Systems (ITS) [21]. Furthermore, it has been considered to be an enabler for wide emerging safety and access to information. Newly, there exists additional interest for research on the vehicular network infotainment that aims to increase user satisfaction in traffic and car journey and there are numerous entertainment applications which have become available recently [22, 23]. Newly, lots of automobile companies are looking for combining communication technologies in their vehicles for a different purpose in the field of safety, traffic information, comfort, assisted driving, entertainment and commerce.

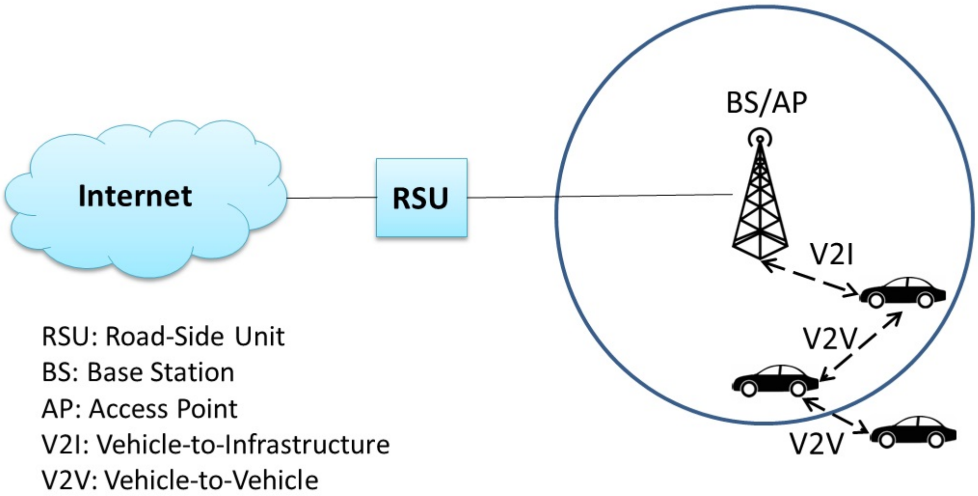

FIGURE 2.1: General model of vehicular networks.

2.1.1 Vehicular Network Communications

A vehicular network organizes and connects vehicles with each other, with mobile and fixed locations resources [24]. In general, two classes of vehicular networks can be distinguished: *Vehicle to Vehicle (V2V)* and *Vehicle to Infrastructure (V2I)*. While V2V deals with communication among vehicles themselves, V2I is concerned about transmitting information between a vehicle and the fixed infrastructure that is installed along the road [25]. On one hand, the typical manner to establish a vehicle to vehicle communication is to build-up wireless ad-hoc networks, in this case also called *Vehicular Ad-hoc NETworks (VANETs)* [26]. VANETs are an extreme case of Mobile Ad-hoc NETworks (MANETs). High speed and frequent network topology changes are the main characteristics of vehicular networks. These characteristics lead to special issues and challenges in the network design. On the other hand, the common approach to achieve vehicle-to-infrastructure communication is to build-up *Roadside Backbone Networks (RBNs)* with fixed access points along the roads which can be accessed by the vehicles by means of wireless communication [3]. So, vehicular networks are a challenging environment since they combine a fixed infrastructure (RBN), and ad-hoc communications among vehicles. As shown in Figure 2.1, the major goals of the vehicular networks are to enable Vehicle-to-Vehicle (V2V) and/or Vehicle-to-Infrastructure (V2I) / Road-Side-Unit (RSU) communications so as to provide more safety, comfort and entertainment to the car passengers [27].

2.1.2 Access Technologies of Vehicular Networks

Many technologies are related to the vehicle to infrastructure cooperation and may play a role in communicating between vehicles and infrastructure.

There are many access network technologies to support V2I communications, e.g., IEEE 802.11p, WiMAX, LTE.

- $IEEE802.11p$: IEEE 802.11p, cf. [28], is an approved amendment to the IEEE 802.11 standard to add wireless access in vehicular environments (WAVE). It defines enhancements to 802.11 (the basis of products marketed as Wi-Fi) required supporting Intelligent Transportation Systems (ITS) applications in the short-range communications between vehicles (V2V) or between the vehicles and the roadside infrastructure (V2I). This communication includes data exchange between (possibly high-speed) vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz. 802.11p will be used as the groundwork for Dedicated Short Range Communications (DSRCs). DSRC has been used for years for many types of short range dedicated links transmitting on various frequencies.
- $WiMAX$: Worldwide Interoperability for Microwave Access (WiMAX) technology is based on IEEE 802.16 and 802.16e standards for fixed and mobile wireless access in Metropolitan Area Networks (MAN) [29]. It can deliver data rates of 70Mbps, cover ranges more than 30km, and it can provide secure delivery of content and support mobile users at vehicular speeds [30].
- LTE: The Long Term Evolutionary access technology called LTE is quickly becoming the network technology of choice for 4G deployments around the world. The goal of LTE was to increase the capacity and speed of wireless networks using new DSP (digital signal processing) techniques and modulations that were developed around the turn of the millennium. A further goal was the redesign and simplification of the network architecture to an IP-based system with significantly reduced transfer latency compared to the 3G architecture. The LTE wireless interface is incompatible with 2G and 3G networks so that it must be operated on a separate wireless spectrum [31, 32].

2.1.3 Applications of Vehicular Networks

Vehicular networking has the potential of implementing a large variety of different applications related to vehicles, vehicle traffic, drivers, passengers and pedestrians. In particular, the applications are related to traffic safety, traffic efficiency and infotainment.

These applications are the outcome of the numerous innovations of a group of researchers and companies. In general, vehicular networking applications can be classified as three different groups: first, active road safety applications, the second one concerns traffic efficiency and management applications, and the third one represents infotainment applications [33].

1. Active road safety applications:

   The primary goal of vehicular networks was reducing the probability of traffic accidents and the loss of life of the car passengers. Therefore, many active road safety applications were developed for this purpose [34–39]. As many of the accidents were related to vehicle collisions, active road safety applications provide the helpful information for the drivers to avoid collisions. In these type of applications by sharing information between vehicles and the roadside units one tries to predict the collisions. This information can be provided by exchanging information between vehicles and Road Side Units (RSU) to predict collisions. Information can indicate vehicle position, intersection position, speed and distance heading. Furthermore, information exchange between the vehicles and RSUs is used to determine dangerous locations on roads, such as slippery sections or potholes [40, 41].

2. Traffic efficiency and management applications:

   The goals of traffic efficiency and management applications are to improve the vehicle traffic flow, traffic coordination and traffic assistance and to provide updated local information, maps and messages of relevance bounded in space and/or time [35]. This kind of applications are divided into the two categories:

   (a) Speed management to help the driver to manage the car speed and preventing the useless stop.

   (b) Cooperative navigation to increase the traffic efficiency by managing the navigation of vehicles.

3. Infotainment applications:

   Infotainment applications have the ability to establish a general purpose Internet access from cars in order to keep the car passengers entertained and informed, and they can potentially generate services and applications specifically for in-car use. They can be divided in two kinds of different services.

   - Cooperative local services:

     Cooperative local service applications are based on infotainment which can be gained from locally based services like point of interest notification, local electronic commerce and media downloading [35, 36, 39, 42].

- Global Internet services:

  This kind of applications are deepened on data which can be collected from global Internet services. In this category of application we have communities services such as insurance and financial services, fleet management and parking zone management and ITS station life cycle based on software and data updates [35, 36, 39, 42].

Many Internet related applications require continuous Internet connectivity. The continuous connectivity will be the most challenging problem in vehicles moving in an overlay networking environment. In this case, frequent change of switching from a current Access Point (AP) or Base Station (BS) to the next AP/BS may occur. Frequent change of switching AP degrades the network performance. The switching mechanism from one AP/BS to the next one is called handover and is executed according to a well-defined decision criteria. Handover is also known as handoff, and it is an event triggered whenever a vehicle moves from one AP coverage area to another AP coverage area, without loss or interruption of services. When a handover occurs within the same radio access technology this is known as horizontal handover. Handover which occurs among different radio access technologies refers to vertical handover [43].

Vehicular networks are currently being one of the main areas of studies all around the world and will be engaged to large deployments soon. Although there is much progress in the field of vehicular networks, there are many new topics which researchers did not face before, just like the new subjects in the area of infotainment applications. Entertainment systems can transform a monotonous trip to a delightful experience.

IPTV service application is a subclass of entertainment applications and it has been proposed to increase user satisfaction in traffic and car journey. In the literature, there are only a few proposals of multimedia applications over vehicular networks or even regarding vehicular IPTV services. However, some efforts to evaluate CBP for IPTV with different types of access networks have been done. In [44], J. Lai et al. proposed to decrease the CBP and to improve the channel availability in DSL-based access networks. J. Lai et al. [45] investigated the CBP not only in stationary but also in more realistic peak-hour scenarios and provided algorithms which allow one to reduce CBP efficiently. A. Abdollahpouri et al., in [2], suggested a realistic model to reflect the typical behavior of IPTV users and studied the influence of different channel popularities in WiMAX based IPTV systems. In particular, they have proposed a user behavior model reflecting, both, zapping and viewing periods. Momeni et al., in [46, 47], investigated the availability of IPTV services in roadside-backbone-networks with vehicle-to-infrastructure communication. In this effort, they assumed different access network technologies leading to strongly different sizes of cells in highway scenarios and predicted the resulting CBP.

There are some recent efforts on live video streaming and multimedia over VANETs in the literature [27, 48, 49]. Therefore, offering an IPTV service over a vehicular network and providing sufficient QoE for vehicular IPTV users is one of the quite new and challenging topics. The major recognized reason is the significant challenges which are imposed in IPTV transmission by the high mobility of the vehicles and network instability and scalability. Another problem is that in real-time IPTV services one may be losing a program because of delivering the TV channels over the vehicular network with an insufficient capacity of wireless links. Currently, vehicular network based IPTV services are considered to become very important in the future of ITS and vehicular infotainment systems.

2.2 IPTV Service and System Architecture

Television has become an indispensable device in approximately all the homes in all over the world. There are many developments in shape, size, number of offered channels and picture quality (standard definition to high definition) or even from fix TV to the mobile television. However, with all of these developments TV stayed as a broadcast medium with the one-way transmission for a long time from the service provider to the end-users. However, after several years of technology development, with rising the new generation of TV users and also with the quick progress of Internet technology, IPTV has begun to bring to consumers the new TV experience which goes beyond any traditional passive TV. The IPTV experience is being continuously enhanced with improvements in the underlying networks and computing systems. The successful deployment of IPTV applications and services on a large scale is essentially dependent on a broad range of supporting technologies [50].

IPTV services are becoming popular and are expected to expand rapidly in the near future. It is the new standard of television and entices a lot of attention from both industry and research communities. IPTV service offers multimedia streaming services with security, reliability, and relevant QoS/QoE [51]. IPTV is also defined as a service that includes multimedia services such as TV, video, audio, text, graphics, and data over IP-based networks.

IPTV is extremely different from traditional broadcast based TV in its transmission system. IPTV is a form of real-time video service that uses IP for delivering TV channels via a network. Conventional cable TV services transmit dozens of channels all at once via a fixed cable, the content of all channels flows into the subscriber's home, and the subscriber selects which channel to watch using a Set-Top Box (STB). However, in the IPTV system, a subscriber uses the STB to request for only the specific channel required at that time, and only the requested channel is transmitted. Typically, an IPTV service provider, due to the lack of network bandwidth, cannot transmit all the channels at the same time.

The main advantage of IPTV is its ability to provide a rich TV viewing experience to the users. IPTV services can be divided into two classes: *Video on Demand (VoD)* for stored content and *Broadband-TV (BTV)* for live TV channels. IPTV providers need different common standards for video encoding that are appropriate to the needs of the application and the user's TV screen. There are multiple video resolution formats such as QCIF, QVGA, CIF, VGA, SD, HD and meanwhile even UHD over a wide range of codec combinations such as MPEG2 and MPEG4. In general, higher performance levels will require a larger bandwidth to be supported by the infrastructure used for multicasting the data. Users in the vehicle are using TV screen devices with a rather small size and high performance of resolution is usually not very important for them.

IPTV has some features which include [52]:

- **Support for interactive TV**: The two-way capabilities of IPTV systems allow service providers to deliver interactive TV applications (standard live TV, HDTV, interactive games, high-speed Internet browsing).
- **Time shifting**: A mechanism for recording and storing IPTV content for later viewing, along with a digital video recorder.
- **Personalization**: The bidirectional communications with the IPTV system allow users to decide what they want to watch and when they want to watch it.
- **Low bandwidth requirements**: Service providers only stream the channel that the end user has requested instead of delivering every channel to every end user, thus conserving more bandwidth.
- **Accessible on multiple devices**: Consumers can use not only televisions but also their PCs and mobile devices to access the IPTV content.

On the other hand, IPTV needs to succeed supporting a couple of features in order to constitute more than just the delivery of television, VoD or audio content over a broadband network:

1. Interactivity made possible with the availability of an upstream channel, enabling the delivery of new kinds of services to the end user.
2. Personalization and Advertisement offer new kinds of business models to content providers and enhance the user's entertainment experience.

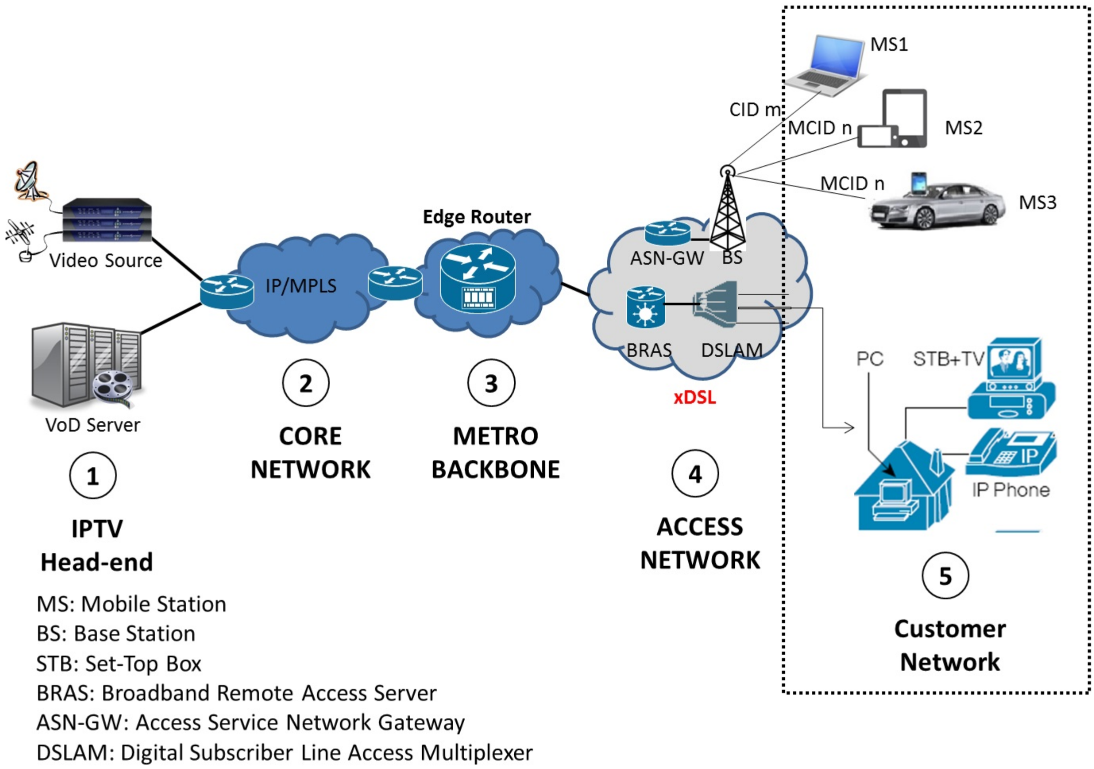

FIGURE 2.2: IPTV system architecture.

3. Portability/Mobility is important because the increasing number of mobile devices in use needs to be considered.

4. QoE assurances and media transport over managed networks are necessary to provide the same or better quality as that achieved in digital TV.

5. Converged Services combine features from different components (e.g. Telco and TV services) and enhances the consumer's rich media experience.

Figure 2.2 depicts a typical IPTV service network architecture which provides triple play services (i.e., voice, video and data) via different access networks. An IPTV system mainly consists of five different parts as shown in this figure. In the following, we discuss these components in detail.

1. **IPTV Head-end**: The head-end is part of an IPTV system that is responsible for acquiring, processing, encoding, and managing video content. It receives video from a variety of sources such as satellites. The head-end manages access to on-demand videos as well. It delivers video and content, i.e. the original TV channels, by means of IP multicast or unicast, to the core network which represents a high-speed communication infrastructure.

2. **Core Network**: The core network is the central network portion of a communication system. It primarily provides interconnection between several metro backbone networks. In order to reduce latency between the clients and the streaming servers and therefore improve the experienced QoS, core networks use fiber optic links. Core networks for IPTV systems can be fiber optic rings that can distribute simultaneously transmitted TV signals (live channels) throughout a large geographic area and provide connections to other media sources (such as direct connection to a television studio). The core network may also be used to provide individual connections to stored media programs (on-demand programming).

3. **Distribution Network (Metro Backbone)**: This subsystem interconnects the core network with the different access networks. Its main function is to multiplex the different service providers and to adapt the transport system to the specific characteristics of the subscriber loop. Therefore, the metro backbone must perform data transmission and switching tasks efficiently. Metro backbone is typically used to distribute the TV channels in a metropolitan area. The service provider can deploy local advertisement or local TV channels to a specific set of clients or provide on-demand video services to customers located in its region. Typical equipment in this part consists of the encoders for local TV channels, local advertisement inserters and video servers to stream on-demand video services.

4. **Access Network**: An access network is an essential portion of a communication network that allows individual subscribers or devices to connect to the metro backbone. The access network provides last mile delivery of the TV channels to the subscribers from the access network which may be DSL-based containing BRASes (broadband remote access servers) and DSL access multiplexers (DSLAMs). Alternatives for the access network could be WiMAX with components such as ASN-GW (access service network - gateway) connecting the edge router to a base station (BS) which may transmit the TV channels to the mobile users either using unicast (cf. CID for connection identifier) or multicast (cf. MCID for multicast CID). In case of a vehicular IPTV system, the mobile stations MS in Figure 2.2, would represent the devices in the cars which there will present the TV programs to the users. If WLANs or LTE would be used to deliver IPTV services in a vehicular network, the situation would be very similar to what is illustrated for WiMAX in Figure 2.2 and, therefore, it is not explicitly depicted in this figure to reduce complexity. The access network manages the user demands by using the return channel. The main requirement of an access network is to have enough bandwidth to support multiple IPTV channels as demanded by the currently active set of subscribers.

Nowadays, neither the core network nor the metro backbone (which might be an interconnection of several broadband networks) will become a bottleneck for the delivery of IPTV services. Therefore, let us assume that bottlenecks in the delivery of TV channels to their vehicular users will mainly result from the limited bandwidth of the access network.

5. **Subscribers**: Subscribers have access to the triple play services (i.e., voice, video and data). Subscribers connect to the access network via home PC(s), Set Top Boxes (STBs) or via mobile devices even during a car journey. The subscribers are sitting in the cars if we assume access via a V2I communication system, and their mobile devices may be connected to the access network either directly or have their own local network which enables indirect communication and information exchange between the user's device (e.g. TV set) and the access network. This direct or indirect communication allows accessing the available resources in the IPTV network.

2.2.1 IPTV vs. Internet TV

We distinguish IPTV from Internet TV (sometimes called Internet video) [53–55]. Moreover, understanding the differences may help to make a decision which one is better to use. The main similarity between IPTV and Internet TV is to use IP technology for video delivery [56]. One of the main differences between them is in the delivering method. Unlike IPTV, Internet TV delivers video for subscribers without using secure dedicated managed private networks which IPTV is the inverse. Consequently, Internet TV cannot ensure a guarantee for the TV quality since some of the IP packets may be delayed or lost since the Internet uses best-effort delivery. Evidently, IPTV services give a higher quality, reliability and more consistent viewing experience.

2.2.2 IPTV Market Trends

Currently, many developed economies have IPTV deployments. The world's leading markets for IPTV are Germany (by Deutsche Telekom), France (led by France Telecom Orange), South Korea, China and others. Several leading service providers (such as Verizon Fios TV, AT&T U-Verse TV, and others) in the U.S. have brought IPTV to the market. North America continues to show massive growth in IPTV in recent years. Consumer demand for IPTV seems to request for higher bandwidth options. The IPTV market has grown tremendously over the past few years, both regarding the number of subscribers as well as investments made by service providers. For example, recently several companies, such as the BBC and Time Warner Cable Inc., launched their applications to allow the users to watch live TV and catch up on their favourite television programs on their iPads, iPhones, and Android mobile devices [57].

Advances in IPTV technology enable a new model for service provisioning, moving from traditional broadcasting TV services to a new user interactive TV model. The change in users' behaviors from active to passive, content digitization allowing easier distribution, and broadband-enabled technologies have changed the TV experience. IPTV allows TV services to evolve into truly converged services, blending aspects of communications, social media, interactivity, and search and discovery in new ways. These efforts address the growing consumer demand for greater personalization and customization of TV experiences [5].

2.3 Vehicular IPTV

In the literature, several studies are addressing different aspects of a vehicular networks, such as: applications [58, 59], communication [34, 60–63], security [64], routing protocols [65], cloud computing in VANETs [66], and general aspects [67]. Moreover, there are also several approaches over vehicular communications. In aktive project [68], they try to improve both traffic safety and traffic flow. The objective of this project is to have a novel driver assistance system and traffic management system as well as C2C and C2I communication for cooperative vehicle applications.

Vehicular networks have been continuously updated to bring the new and useful features for the enjoyment and utility of a driver and his/her passengers. One of this feature is IPTV service, which provides infotainment with quite useful information for the driver and vehicle passengers. An example of enjoyment aspect of vehicular network is children who are able to watch a movie or their favorite programs in the car and, thus, may leave the driver being better able to concentrate on operating the vehicle. Moreover, passengers in a vehicle undertaking a long journey may better pass the time by viewing a TV program.

Rappaport [69] introduces an analytical model for improving the QoE and service availability for the vehicular user during their audio usage in the car journey. His analytical model is developed to characterize the handover problem in an environment where mobile platforms can support multiple independent calls. This method is used to find implicit handover parameters for systems in statistical equilibrium.

We give an overview of current and past projects dealing with in-vehicle multimedia networks in this section. Most projects aim at providing rear-seat entertainment for cars, as this can be seen as the driver for high-speed networks, due in turn, to the trends of the car industry.

- **Prototype of IDB-1394 Network:** The Nissan Corporation has designed a prototype of an in-vehicle network based on IDB- 1394 using a ring topology with a bandwidth of 400 Mbit/s which meets the demands for audio and video [70].
- **SCOOT-R:** Which is a subset of the European project ROADSENSE, is a framework for software development. It offers a framework for distributing tasks on multi-processing units architectures along with communication and synchronization services. It also includes additional support to verify real-time constraints and to implement fault-tolerant strategies [71, 72].
- **MOST networks in the car industry:** MOST Technology is a widely used multimedia network among European car makers and is already implemented in 38 vehicle models [73]. BMW is a member of a core group responsible for the development process of the MOST technology. Therefore, BMW applied the MOST into almost all BMW car series as a transfer network for audio signal [74]. Volvo Cars used also the MOST technology in their high-end products, they applied the MOST multimedia technology in Volvo XC90, Volvo C70 and Volvo S80 models [73].

Nowadays, with the development of wireless access network technology, it was a considerable interest for mobile users to use IPTV services. Then the IPTV users expanded from the home user to mobile users and through Mobile IPTV, users can enjoy IPTV services anywhere and even while on the move [75]. In our work, we extend this to anywhere they are, to establish IPTV over vehicular networks regions. Users are then able to use IPTV services even for long car journeys and in the very near future, numerous vehicles and not only top-of-the-range cars will be equipped with components allowing for a direct Internet connection via different wireless access network technologies like LTE [76] or WLAN [77]. So, IPTV is the next step in the development of Internet-Services over Vehicular Networks and an ambitious intention for researchers [12].

2.4 Behavior Model of IPTV User

In this section, we focus on the IPTV user behavior. One of the main part of IPTV service is to model IPTV user behavior. In a traditional TV transmission system (i.e., analog or digital terrestrial/cable/satellite TV systems), the service provider broadcasts all the channels at the same time for the users and the channels are available in the TV set or Set-Top-Box (STB) of users. Therefore, the user activities like channel switching have no impact on the provider network and the traffic load and, therefore, the demand for network capacity is not very challenging in traditional TV systems. For this reason, user behavior will not have an effect on traffic load or even channel blocking probability. Accordingly, it was not needed for traditional TV providers to analyze and investigate the behavior of their subscribers. However, the situation for the IPTV services is completely different. An IPTV delivery system uses IP multicast technology to transmit TV channel streams for the users. Each TV channel is relevant to a multicast stream. The channel switching activity for IPTV users forces extra load on the network. Therefore, switching and viewing behavior of an IPTV user during an active session has a significant influence on service availability. Hence, it is quite valuable for the IPTV service providers to investigate and analyze the IPTV user behavior.

2.4.1 Switching Model

In this subsection, we try to describe the model of switching behavior for a single user in detail. Our user behavior model is based on the channel popularity and user activity. Aggregate user behavior can be obtained from a combination of a specific percentage of users with different behaviors.

The behavior of an IPTV user is also dissimilar from the users of other IP-based applications. Figure 2.3 represents the typical behavior of an IPTV user during an ON period (active session). In this figure, switching events are carried out by the user during one hour (between 10 PM and 11 PM) are plotted. A switching event occurs when a user selects a new TV channel. Several consecutive switching events within a short period (e.g., less than 1 minute) indicate that the user is zapping TV channels to find something of interest. The number of previous TV channels before starting to view an interesting program is called zapping block.

As an example, in Figure 2.3, three zapping blocks with the size of 3, 2 and 8 can be observed for a one hour time interval. Take into account, the channel, which is viewed for a period longer than 1 minute (called viewing phase), is not included in the zapping block. The user meets a series of zapping periods followed by viewing periods. In general, the user switches between zapping activities and viewing phases. The user is in viewing phase whenever there is no switching event during a sufficiently large amount of time (e.g. 1 minute) [1].

It is important to divide the user behavior model into the "channel switching behavior" and "channel surfing behavior" [78]. For considering these two kinds of user behavior models it is needed to answer the following three questions:

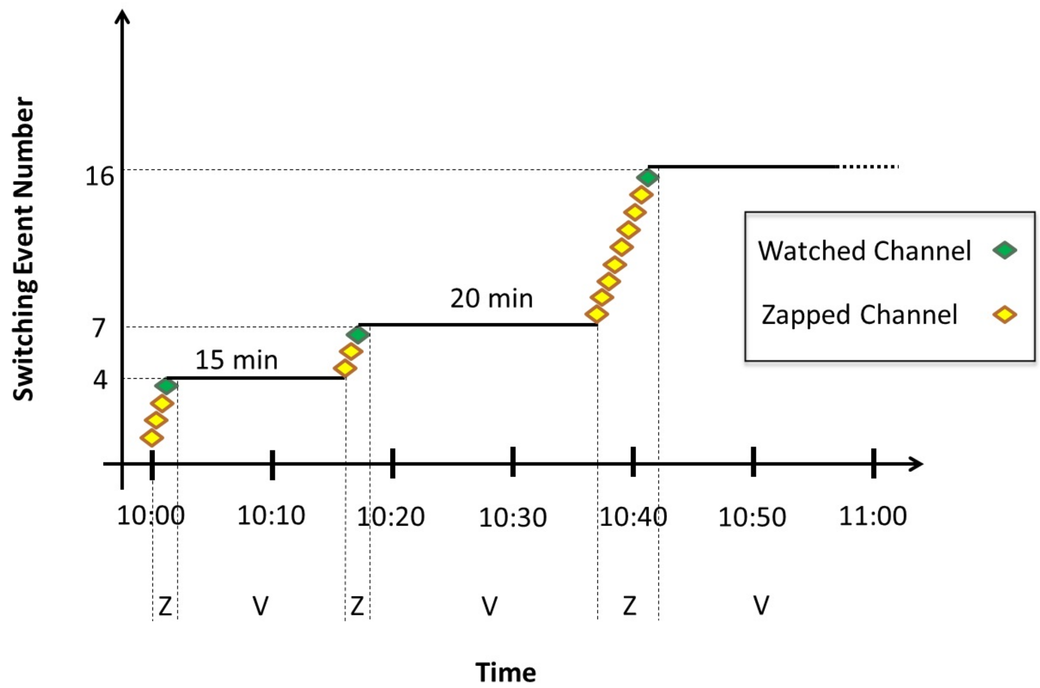

FIGURE 2.3: Channel Zapping (Z) and Viewing (V).

- **Q1:** How many TV channels will be switched by the IPTV user during the zapping block?
- **Q2:** How long does it take to switch a channel by the IPTV user? (Channel dwell time in viewing or zapping modes)
- **Q3:** Which TV channels will be selected by the user during his/her switching mode?

Figure 2.4, illustrates these three questions which **Q1** and **Q2** are regarding the channel switching behavior and **Q3** is about the channel surfing behavior.

To answer **Q1**, Lin and et al. [79] have investigated the user behavior based on a real IPTV service. The traces from a large-scale commercial IPTV service are used to find out the channel selection by the IPTV users in the real world. This investigation represents that each user generally switches 4 channels on average before he/she decides to view a particular channel. Moreover, 10% of users watch the first channel they switch to, while 10% of users switch more than 6 times before going to viewing phase.

For modeling the channel switching behavior, we apply the user model suggested by Abdollahpouri et al. [2]. They proposed a comprehensive IPTV user behavior model for IPTV services over DSL-based access networks. They introduce a User Behavior Automaton (UBA) model by means of the LoadSpec tool. We will describe

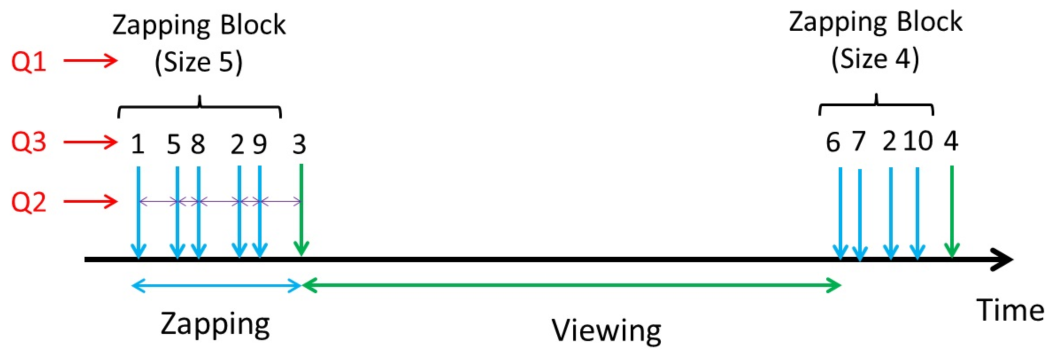

FIGURE 2.4: Three main questions in modeling switching behavior of a IPTV user.

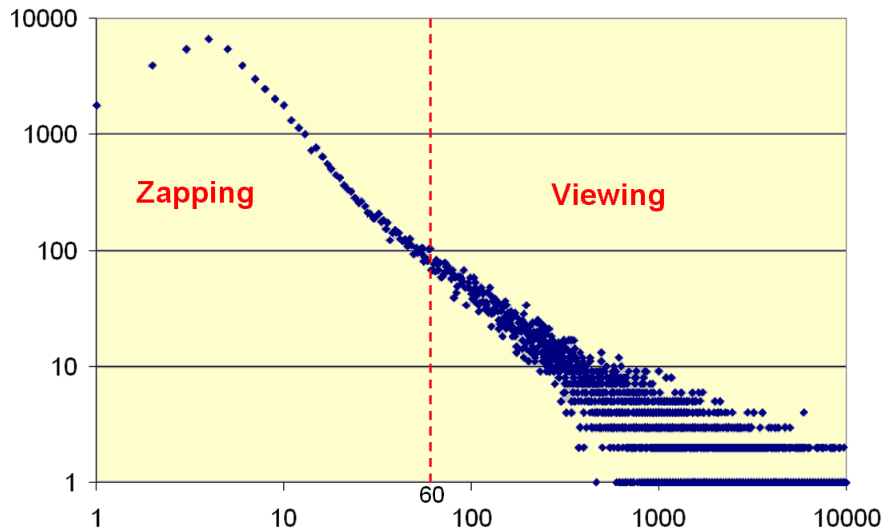

FIGURE 2.5: Channel dwell time in log-log scale ([1]).

the corresponding automaton in detail in Chapter 3, Section 3.1. The primary objective of the UBA model is to model the switching behavior of IPTV users as realistically as possible.

To answer **Q2**, we apply an empirical workload provided by Cha et al. [80]. They try to find the best fit probability distribution for channel holding times in viewing and zapping modes. Figure 2.5 depicts the total number of channel holding times in log-log scale (for about 65000 channel holding samples). The frequency of dwell time increases from 1 to 4 seconds and then decreases dramatically. In other words, most channel switching events happen about 4 seconds after the previous channel switch. Therefore, according to [80], we separate dwell times less than 60 seconds as zapping mode.

To answer **Q3**, IPTV users generally use a remote control with different buttons like up/down, toggle, preset, and numeric buttons. For choosing the channels by remote control there are two preferences, namely sequential and targeted switching. Sequential switching implies that the user's next channel is based on the UP and DOWN buttons on the remote controller of the users. Evidently, in this case the next channel will be determined by the currently or previously watched channel. In our work, because the vehicular IPTV users use only their smart phones or tablets and they do not have any remote control in their devices at the car, we do not consider the sequential switching to model our channel surfing behavior.

Targeted switching refers to how often a user watches a channel. It is important for vehicular IPTV users because they have only access to the numeric buttons to select their desired channel. On the other hand, empirical measurements illustrate that users' interest is not equally divided between all the offered TV channels for choosing their channel. Therefore, it is needed to find out the popularity channels in channel surfing mode for the IPTV users.

2.4.2 Channel Popularity Distribution

IPTV providers offer a large number of different TV channels. However, according to the measurements, IPTV users' interests are not evenly distributed on all the offered channels. A large number of the IPTV users will watch a small portion of offered channels according to the popularity of TV channels. Therefore, channel popularity is one of the most important features of the offered channels.

In this dissertation, because our main objective is evaluation and improvement of the channel availability (CA) and the channel blocking probability (CBP), therefore it is directly related to the channel popularity.

One of the most frequently used distributions for modeling the probability of a TV channel being selected by a user is Zipf distribution [81]. The Zipf distribution has an ability to represent the skewed popularity distribution of objects. In the experiments, the request probability p_i of the i-th popular channel is determined by the Zipf distribution and calculated by eq. (2.1).

$$p_i = \frac{1/i^{\Theta}}{\sum_{k=1}^{N}(1/k^{\Theta})}, \tag{2.1}$$

where N is the total number of distinct channels, k is their rank and θ is the Zipf parameter that determines the degree of popularity skew. When $\theta = 0$, all channels are

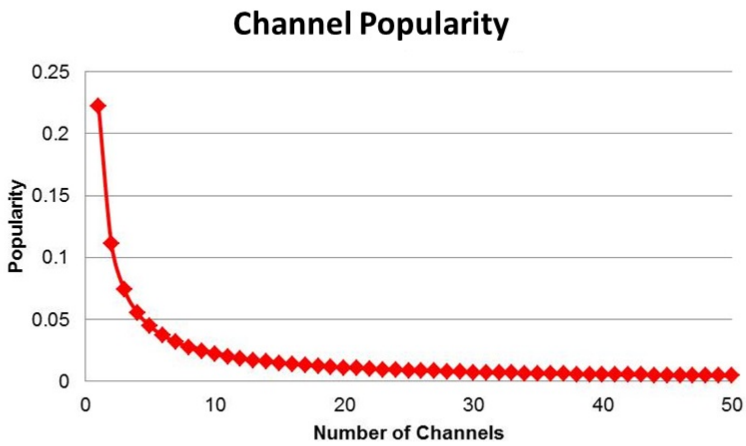

FIGURE 2.6: Zipf channal popularity distribution (N = 50, $\theta = 1$).

equally popular. As the value of θ increases, the popularity of channels is increasingly skewed. Figure 2.6 gives an example of Zipf distribution with parameter N = 50, $\theta = 1$.

2.5 Evaluation of Quality of Experience (QoE) of IPTV Services

Currently, one can observe a strong growth in the elaboration of vehicular network technologies [82, 83] and their usage to aid different applications which, in the beginning, were mainly focused to improve traffic safety [84]. Qian et al. [85] have proposed a network design framework which focuses on safety and security. Meanwhile, applications related to infotainment in vehicular networks [86] are getting more and more into the focus of researchers and developers. On the other hand, the number of vehicles which are equipped with low expenditure components to access the Internet are strongly increasing. Hence recently, infotainment services over vehicular networks are becoming more and more popular. As a consequence of this movement towards infotainment, IPTV services as an attractive class of infotainment services are strongly emerging in general IP-based networks and IPTV services will also be provided over vehicular networks. When IPTV services are offered the quality of the services as experienced by the end-users, which is called "Quality of Experience" (QoE) [87], is of utmost importance.

IPTV service environments have been rapidly changing along with the IPTV market growth and IPTV services are demanded for different kind of subscribers via different access networks. Therefore, service providers shift their focus from the Quality of Service (QoS) to users' Quality of Experience (QoE) which demonstrates the overall performance of a network from the user point of view. Therefore, it is necessary for IPTV service providers to provide sufficient Quality of Experience (QoE) from IPTV user's perspective.

Before the beginning of the multimedia communication era, plain factors like bandwidth, delay, loss or other network relevant factors were sufficient to evaluate Quality of Service (QoS) due to the fact that non-critical applications such as e-mail or file transfer were the provided services. Therefore, the bandwidth or the reliability of packet transmissions would probably be sufficient to indicate Quality of Service (QoS). However, today real-time Audio/Video applications are being spread on IP networks, and technical parameters are not able to distinguish exactly the quality of service as a human end user feels it. Users look for good perceptual quality that can be acquired from several parameters consisting of technical factors but what is more important now is users' experience. Network operators and service providers require allocating their resources while keeping user satisfaction, which will result in user loyalty and advantage for the business companies. Therefore, they need to take into account not only the Quality of Service (QoS) but also Quality of Experience (QoE).

By searching the literature, there are many different definitions of Quality of Experience (QoE) and Quality of Service (QoS). Some try to define the terms from business perspective whereas others do so from the technical point of view. Therefore, at first we need to define "Quality of Experience" and "Quality of Service" in order to clarify our understanding in this dissertation. According to the Raake et al. [88] definition, which we will use as our working definition of Quality of Experience (QoE) throughout this thesis is:

- **Quality of Experience (QoE)** is the degree of delight or annoyance of the user of an application or service. It results from the fulfillment of his or her expectations with respect to the utility and/or enjoyment of the application or service in the light of the user's personality and current state.

The QoE is including various parameters such as cost, reliability, availability, usability, and fidelity. But, in the context of this dissertation, QoE is the term used to explain the perception of end-users on how usable and available the corresponding service is. On the other hand, QoS, explains the ability of the network to provide a service with a certain service level to provide the best QoE to users efficiently.

QoE describes how a user perceives the usability of a service when it is in use. In other words it indicates how the user is satisfied with a service regarding usability, accessibility, retain ability and integrity of the service. QoE refers to the discernment of the user about the quality of a specific service or network. It is indicated in human feelings like "good", "excellent", "poor", etc. Although, QoS is actually a technical concept and it

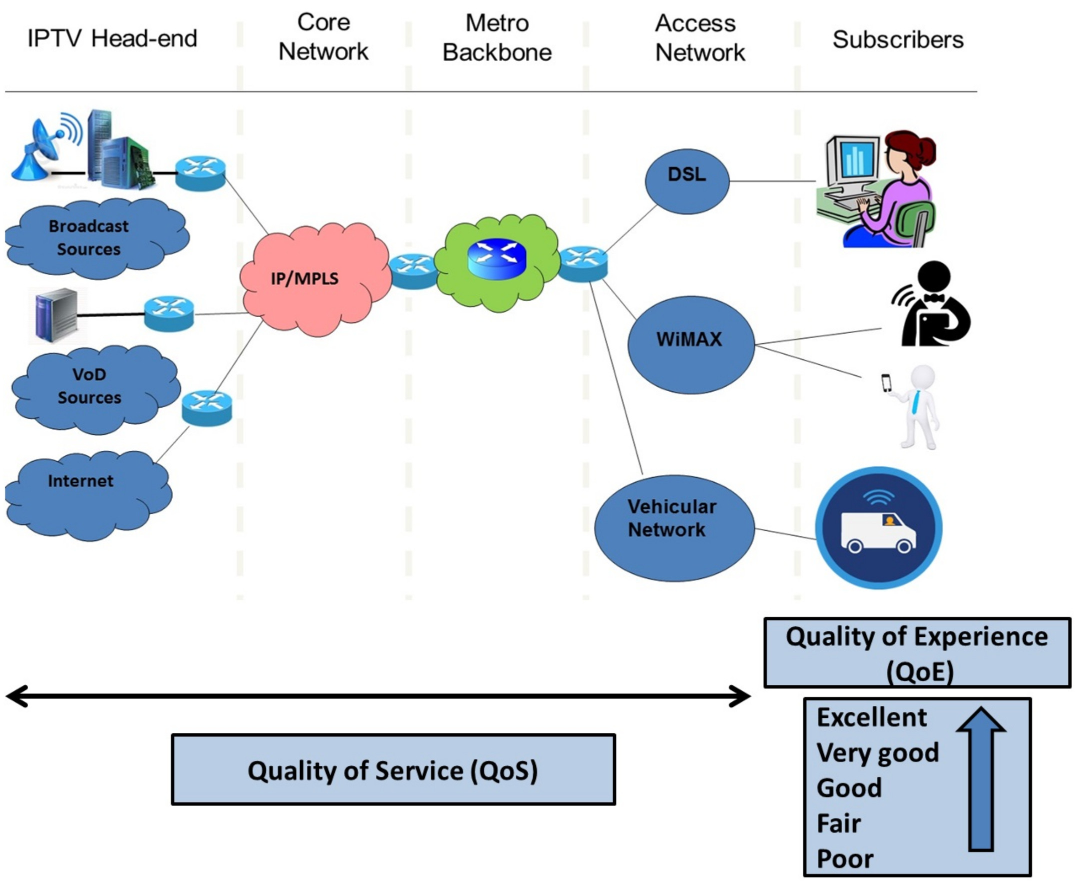

FIGURE 2.7: QoE and QoS for the network and the end-systems.

indicates network elements which a user is not interested to know about. The QoE and the QoS concepts are roughly illustrated in Figure 2.7.

The QoE also depends on the Video Quality (VQ), which can be affected by the network parameters like packet loss, one-way propagation delay, packet delay variation (jitter), out-of-order and reordered packets [89]. Moreover, it depends on other parameters, such as zapping time and synchronization time.

2.5.1 Aspect of QoE in Audio/Video Communications

Recently, multimedia services have become extremely popular and have been widely accessed via not only desktop and laptop computers but also via mobile devices. Audio/video transmission is considered an essential part of multimedia application services and it represents highly critical application services in the IP networks among others, and supports many popular services over the Internet. The usage of the multimedia applications is quickly increasing. Therefore, they are now very popular to use for different purposes like video conferencing, video on demand, telemedicine and e-learning.

However, it is important to provide a sufficient degree of QoS from a technical point of view and also QoE from a user's perspective in audio/video communications. Moreover, there is much diversity in hardware capabilities and network environments. Hence, it is necessary to satisfy all kind of users during their usage with different platforms, and it is important for service providers. Evidently, QoE in multimedia communication has received significant attention in recent years.

Newly, the main goal of studies regarding QoE in the context of audio/video communications in real-time was about the audio-visual quality of the audio/video stream which is offered to the human end-user. There are some QoE measurements to determine the audio-visual quality of the received stream by end users such as PESQ/PEAQ/PEVQ which are abbreviations for Perceptual Evaluation of Speech/Audio/Video Quality [90], and POLQA for Perceptual Objective Listening Quality Assessment [91]. Moreover, the important measure MOS for Mean Opinion Score [92] is often used.

An interesting approach regarding vehicular video surveillance was proposed by Bellalta et al. [93] as a dynamic adaptation of the video bit rate to maintain a certain level of video quality. The visual quality with low latency with the assistance of additional information obtained from the beaconing was studied by Vinel et al. [94]. Belyaev et al. [95] have also worked on vehicular video surveillance in VANETs (based on IEEE 802.p). They were concerned with the visual quality and its impairment by packet losses for evaluating the QoE by means of an error-resilience coding mechanism.

The audio-visual quality is also relevant to measuring the QoE in IPTV services over vehicular networks, in particular, because the TV channels are offered to the vehicular subscribers via wireless access networks and this may have a strongly negative impact on the quality of the stream delivered to the end users. In vehicular networks, we have two significant challenges for providing IPTV services with QoE guarantees:

1. The limited bandwidth which exists in the cells building the wireless access network.

2. The high rate of handover events during the car journey.

Zhou et al. [96] measure user satisfaction during usage of their media services, which are offered via peer-to-peer (P2P) based VANETs. In particular, they propose a scheme that solves content dissemination, cache update and fairness problems for P2P-based VANETs. However, unlike our studies, Zhou et al. don't consider IPTV services nor do they assume multicast for the provisioning of the media services. The audio-visual quality is only one aspect of IPTV service quality in vehicular networks. However, there is a more important aspect which is the availability of desired TV channels for the end users. Channel availability is of utmost importance from a user point of view regarding QoE measurement.

2.5.2 QoE Measures

Availability of TV channels for the vehicular IPTV user is very important because they move very fast which can lead to numerous handover events in the wireless access networks. On the other hand, due to the lack of network bandwidth, they may be experiencing bottleneck situations during their car journey. A bottleneck situation happens, e.g., in the case of a newly desired TV channel, during a channel switching event within a given cell, i.e. a change of the currently watched TV channel. It may also occur during a handover event when the currently watched channel can no longer be offered in the next cell for the IPTV user. This situation implies that TV channels may be temporarily unavailable which is particularly annoying in the case of a handover when a currently watched channel may become unavailable upon reaching a new cell.

There are some works in the literature to evaluate the availability of IPTV for different types of access networks. In particular, J. Lai has investigated availability-related QoE for DSL-based access networks [97] which offer IPTV to non-mobile users at their homes [44, 98]. Moreover, A. Abdollahpouri has done similar investigations for WiMAX-based access networks [99] via which IPTV is offered to either non-mobile or (slightly) mobile users [1]. More recent research, done by S. Momeni et al. [46, 47, 100], has been done to study the availability of IPTV now in the context of vehicular networks with their rather specific mobility models. All these investigations are exclusively based on the usage of simulation models.

In this dissertation, among the different possible QoE measures, we focus on TV Channel Availability (CA), because it is one of the most significant measures. So, channel availability is our objective to measure the QoE. Therefore, it is very important to measure it as realistically as possible. The ability to evaluate channel availability will give the IPTV service providers the overall level of subscriber satisfaction. To manage the QoE effectively, the availability of a IPTV service should be predicted and provide an acceptable level of QoE by the IPTV service providers.

In this subsection, we are going to present the Channel Availability (CA), Channel Blocking Probability (CBP) and also the important parameters for QoE measures. Traditionally, Channel Blocking Probability (CBP) is applied to denote the ratio of blocked user requests. A high CBP will extremely decline CA and consequently QoE. CBP consists of a sum of two terms, Switching Blocking Probability (SBP) and Handover

Blocking Probability (HBP). Thus, it is undoubted that decreasing of CBP is of great importance to providing an acceptable level of QoE.

IPTV users are undergoing some handover events during a typical period of viewing IPTV channels offered via a vehicular network. During the handover process, when a car crosses the border between two adjacent cells Z_k and Z_{k+1} or when a user is switching a channel, blocking of a TV channel may occur. If a user in a car (for which current handover takes place) watches a given TV channel i or is switching to channel i, three situations may occur:

1. Firstly, the user can continue to watch channel i, if either channel i is already broadcasted in the new cell Z_{k+1} reached (because $\geq$1 users are already watching channel i in cell Z_{k+1}).
2. If channel i is not yet transmitted in Z_{k+1} but there is enough free bandwidth left to broadcast channel i in addition to the other channels currently broadcasted in Z_{k+1}.
3. If channel i is not yet broadcasted in Z_{k+1} and there is not enough free bandwidth left in Z_{k+1} to broadcast channel i, then the user cannot continue to watch channel i in Z_{k+1}. We call this a blocking event because a request for a TV channel could not be satisfied and the request was “blocked”.

We define the overall Channel Blocking Frequency (CBF) having occurred during a time interval T as:

$$CBF(T) = \frac{nb(T)}{nr(T)} \tag{2.2}$$

where:

- $nb(T)$ = number of blocking events having occurred during interval T
- $nr(T)$ = number of all channel requests during T.

For $|T| \to \infty$, where $|T|$ denotes the length of interval T, CBF(T) will tend to the *Channel Blocking Probability (CBP)*, if we assume convergence of $lim_{|T|\to\infty}$ CBF(T).

Based on CBP, we define *Channel Availability (CA)* as follows:

$$CA = 1 - CBP. \tag{2.3}$$

Accordingly, HBP and SBP can be defined as follows:

- HBP $\triangleq$ the *Handover Blocking Probability* which is reflecting blocking because of handover events of vehicles using IPTV.
- SBP $\triangleq$ the *Switching Blocking Probability* which is reflecting blocking because of TV channel switching events.

Then:

$$CBP = HBP + SBP, \tag{2.4}$$

and

$$HBP = lim_{|T|\to\infty}\frac{nh(T)}{nr(T)}, \tag{2.5}$$

where $nh(T)$ = number of handover-induced blocking requests of all cars which are using IPTV during interval T.

$$SBP = lim_{|T|\to\infty}\frac{ns(T)}{nr(T)}, \tag{2.6}$$

where $ns(T)$ = number of switching-induced blocking requests of all cars which are using IPTV during interval T.

In the next chapter (Chapter 3), we will elaborate a simulation tool for analyzing IPTV services over vehicular networks. We apply our QoE measures in our simulation tool to assess the IPTV service availability for vehicular subscribers.

Chapter 3

A Simulation Tool to Assess IPTV Service Availability

Recently, channel blocking probability and channel availability have been evaluated for IPTV services for different kind of users via various access networks such as DSL [98], WiMAX [1] and Vehicular Ad-hoc NETworks (VANETs) [46] by applying simulation models. Therefore, to evaluate the performance and availability of IPTV services in vehicular networks, we also use a simulation model. We apply comprehensive scenarios for offering IPTV service for vehicular users driving on a highway to determine the channel availability and channel blocking for subscribers. A simulation is a flexible approach to evaluating the proposed algorithms and systems. With simulation we can analyze the results and find out how the proposed algorithm or system would behave.

Several tools are available for network simulations such as: ns-2 [101], JiST/SWANS [102], Shawn [103], GloMoSim [104] and OMNeT++ [105]. However, none of them qualifies as a vehicular networks simulator which would allow one to take into account car mobility in a detailed manner. They mostly concern about assessing the performance of routing, forwarding, MAC layer protocols, etc. of vehicular networks under realistic but unchangeable mobility scenarios. General achievement to integrate mobility is also to rely on stand-alone road traffic simulators, such as SUMO [106], MatSim [107] to use collected mobility traces specific to some geographical region. Moreover, these simulation tools have been designed to generate a system model including the lower layers of the protocol stack at a very high degree of detail. In vehicular IPTV services a simulation tool is necessary for proper evaluation of the service availability. Till now, none of the existing simulation tools fulfills all the requirements of vehicular IPTV services and they are not able to provide an adequate solution for analyzing IPTV services offered for vehicle-to-infrastructure communication networks. Consequently, we developed a new

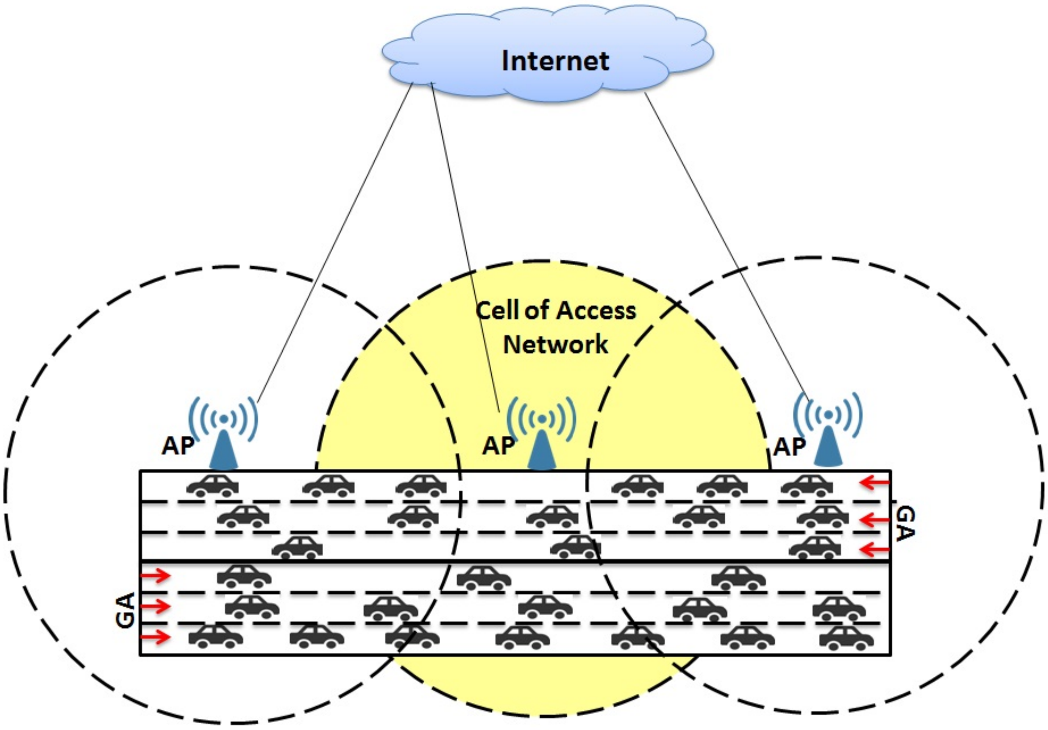

FIGURE 3.1: Simulation scenario.

simulation tool for evaluating IPTV services in vehicular networks. In this chapter we are going to present our simulation tool.

Our simulation tool is written purely in C and in order to elaborate an appropriate user behavior model, we apply the LoadSpec tool to generate aggregate traces for channel switching events for the vehicular IPTV users. LoadSpec has been elaborated in our TKRN research group during the recent past, cf. [108]. It can be used as a basis for an artificial load generator for various interfaces, and we are going to use it to model IPTV user behavior. It is capable of specifying realistic network traffic with different characteristics in a very straightforward and flexible manner.

We assume the following behavior of the vehicular IPTV users and treatment of users by the IPTV service provider. A car with 0 or at least 1 passenger (except the driver) watching IPTV, is entering a cell at the border of the geographical area (GA). TV is not switched on or off in a car during its way through GA. The system model as used in this dissertation is illustrated in Figure 3.1. A switching event occurs when a user selects a new TV Channel. User behavior for switching or viewing the channels is modeled according to a dedicated Trace file, which is generated by the LoadSpec tool. Moreover, choice of the TV channels is made corresponding to a Zipf distribution.

3.1 IPTV User Behavior Model based on the LoadSpec Tool

In this section, we focus on modeling IPTV user behavior by means of the LoadSpec tool. User behavior as we discuss in section 2.4, is imperative in IPTV systems and we need to model it for simulating the usage of an IPTV service. In a traditional TV transmission system, a service provider broadcasts all the channels at the same time for the users and the channels are available in the TV set or Set-Top-Box (STB) of users. Therefore, the traffic load and network capacity are not the greatest challenges in traditional TV systems, especially in cable or satellite networks. For this reason user behavior will not affect on traffic load or even the channel blocking probability. On the contrary, an IPTV delivery system uses IP multicast technology to transmit TV channel streams for the users. Each TV channel is relevant to a multicast stream. Therefore, the behavior of an IPTV user with respect to his/her switching and viewing activities during an active session has a significant influence on service availability and we are going to model it in the following.

For our simulation tool we need a trace file which reflects in detail IPTV user behavior and can be used as an input data. It will be generated by the LoadSpec tool. We use the LoadSpec tool to implement our user behavior model to produce a realistic workload of switching and viewing events for a typical IPTV user during an active session.

3.1.1 LoadSpec Formal Load Description Tool

Abdollahpouri *et al.* [2], introduced a User Behavior Automaton (TV-UBA) model to cover user activity and channel popularity in an IPTV system. This model is based on single typical IPTV users. In our work we apply Abdollahpouri's TV-UBA for modeling our vehicular IPTV users.

A UBA, U= $\{\varphi, T_\varphi\}$ is an extended finite automaton consisting of the set $\varphi = \{\varphi_i, \varphi_a, \varphi_b, \varphi_t\}$ of *macro-states* and the set T_φ of *transitions* between these macro-states, (cf. Figure 3.2).

- φ_i: *Initial state*, a load generation process every time starts with this state.
- φ_a: *Active state*, includes a number of member-states to generate the requests.
- φ_b: *Blocked state*, where the user waits for the reactions of the service system.
- φ_t: *Terminated state*, a load generation process will end with this state each time.

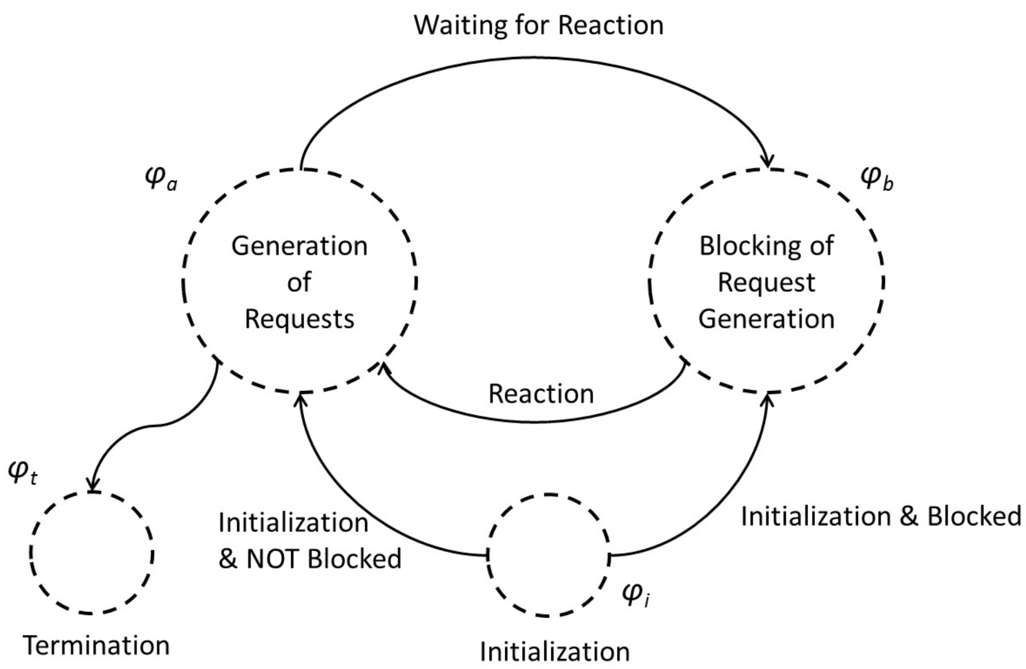

FIGURE 3.2: The set of the macro-states and the transitions between them [2].

Each arc in the user behavior graph represents the probability of moving from one state to another one. Every macro-state comprises a set of member-states and both, the initial and the termination state comprises of only one member-state (to start and to stop the load generation process). However, active-state and blocked-state might have different types of member-states depending on the number of requests and on the waiting for a reaction of the service system [2].

3.1.2 Explanation of the Model

According to the Abdollahpouri [2] user behavior automaton (TV-UBA) we are able to model the zapping and viewing activities for a single user. With starting to use IPTV or turning on the user's device (State S_i), the user will start by zapping the channels with the probability of P_z or it is possible to start with the viewing mode with probability of 1-P_z and watch a channel.

Figure 3.3 demonstrates the modeling of zapping and viewing. In zapping mode (also called the passing through a "zapping block"), a user switches to one or more channels before viewing a specific channel. Each of the states "View" or Z_i in Figure 3.3 represents a channel switching event. For instance, in Figure 3.3, state Z_2 means switching two channels before starting a viewing phase. After each zapping block a user will be back to the viewing mode. After watching a specific channel in viewing mode, the viewing user

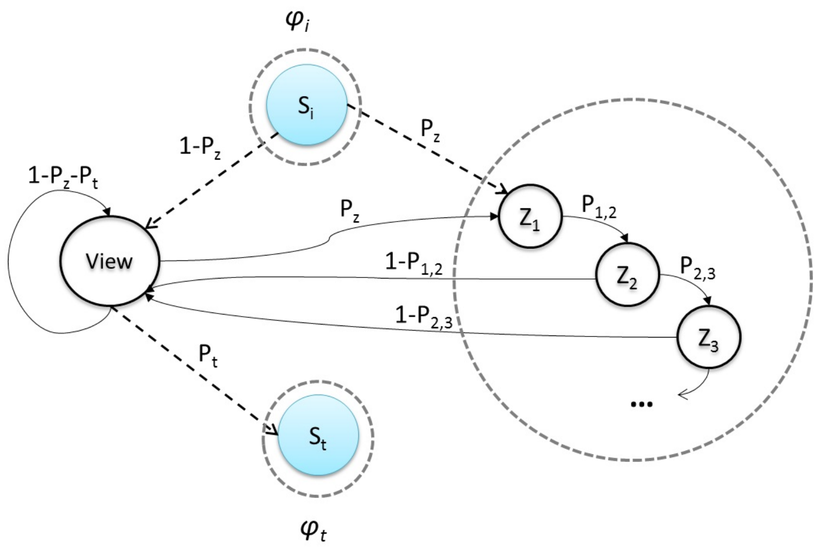

FIGURE 3.3: TV-UBA (User Behavior Automaton).

may terminate viewing with probability 1-P_z-P_t to view another channel or terminate watching IPTV with probability P_t or continue to zapping through channels to find something of interest.

Viewing mode and zapping mode with the Z_i states comprise of some request states (circle shape) and delay states (oval shape) as illustrated in Figures 3.4 and 3.5 which are a refinement of Figure 3.3.

We are going to define request states and delay states as follows:

- R-states: they are the only member-states of macro-state φ_a. In R-states a unique type of request will be generated. Each R-state is responsible for generating requests of exactly one type. Then immediately after generating the new request, the current state will be left. In our model the state RC has one attribute (C_i) which specifies the requested TV channel. States SW and TW have no attributes.

- D-states: represent a delay before the next request is generated or when a reaction of the service system is needed. This delay when it is a part of φ_a is corresponding to request inter-arrival times which models channel dwell time in zapping and viewing modes. Moreover, when it is a part of φ_b, a D-state indicates the channel switching delay. Delay times (with a granularity of one second) in delay states can be defined by a constant value, a probability distribution, or a trace file [2].

In addition, Table 3.1 describes in more detail the meanings, notations and parameters appearing in Figures 3.4 and 3.5.

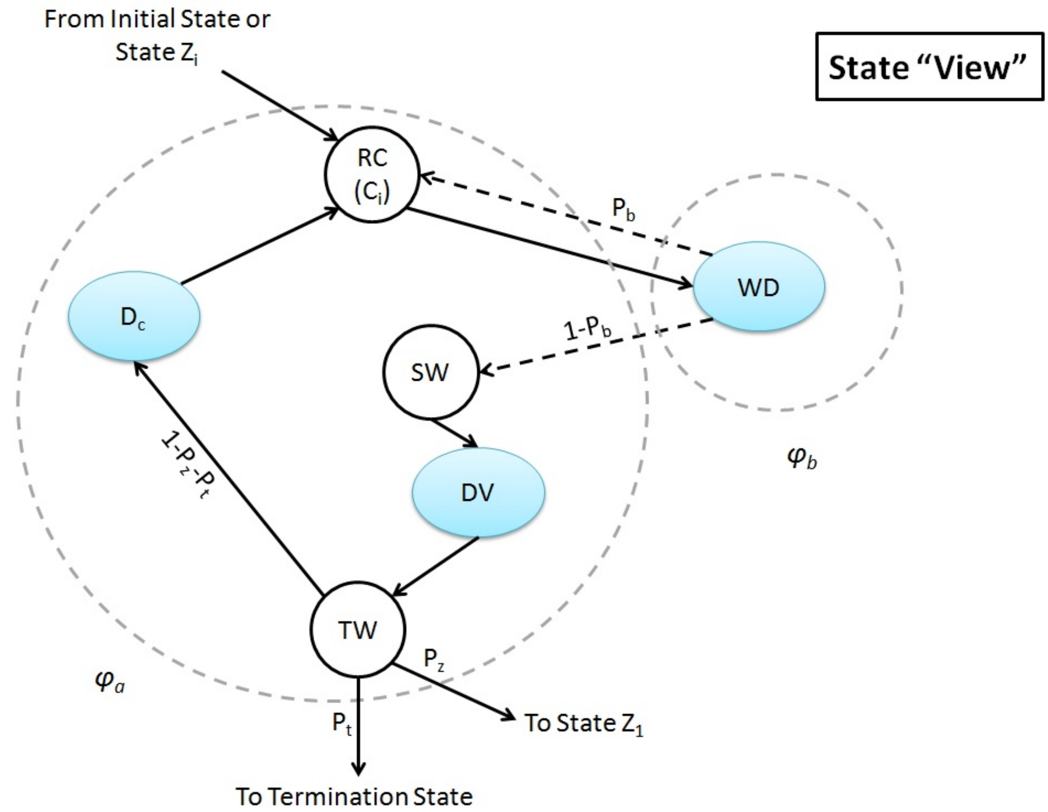

Figure 3.4: Viewing Mode.

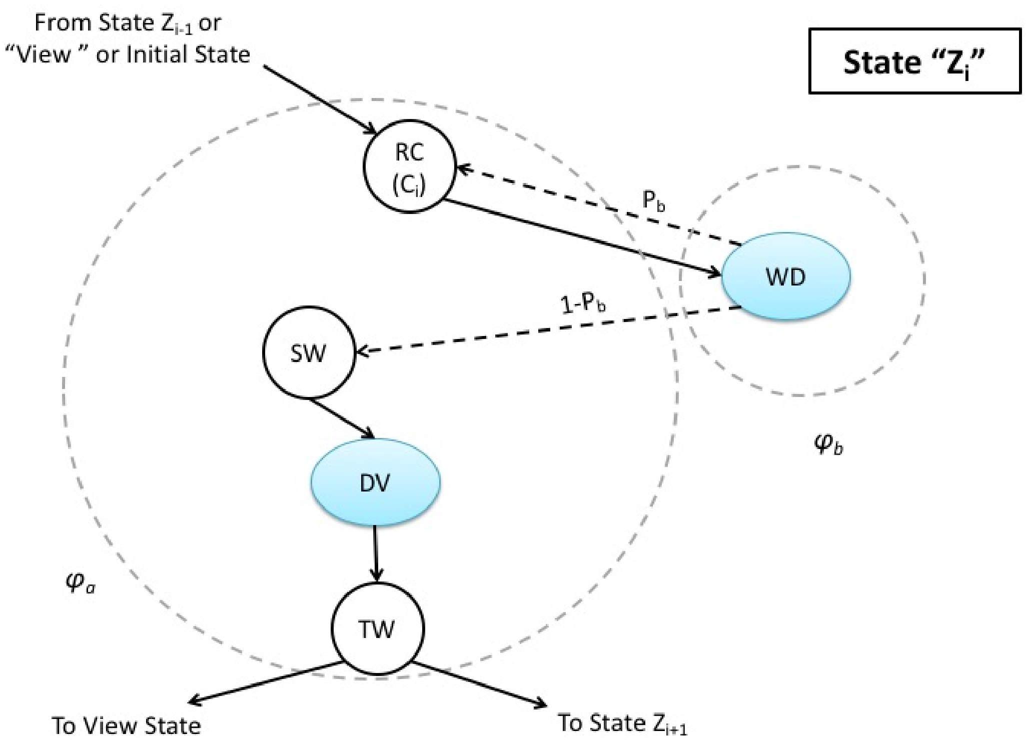

Figure 3.5: Zapping Mode.

TABLE 3.1: Notations and parameters used in IPTV-UBA (derived from [2]).

Class	**Notation**	**Description**
Request States	RC	Request a specific TV Channel. This request is mapped to an IGMP join command.
	SW	Start Watching the currently chosen TV channel.
	TW	Terminate Watching the currently chosen TV channel. This request is mapped to IGMP leave command.
Delay States	DV	Dwell time of the currently chosen channel in Viewing mode.
	DZ	Dwell time of the currently chosen channel in Zapping mode.
	D_c	Time (Duration) needed to choose the next channel in view state. This delay is used to model the cases when the user refers to EPG in order to make his/her decision about the next channel to watch.
	WD	Wait for Delivery of channel by the network (switching delay).
Additional States	S_i	Initialization State. This Macro-sate only consists of one member-state.
	S_t	Termination State. This Macro-sate only consists of one member-state.
Probabilities	P_b	Probability that the desired channel is blocked.
	P_z	Zapping Probability. P_z is effected by: genre, time-of-day, program popularity.
	P_t	Probability that a user terminates watching TV.

In zapping mode the input from RC sub-state comes from a previous zapping state or from viewing mode or initial state (for Z_1). In zapping mode, there are two possibilities for the users:

1. The user may continue switching and goes to the next zapping state thus staying in the zapping mode.
2. The user may go back to viewing mode after termination of the current zapping mode.

In viewing mode after termination, there are three possibilities to watch the current channel:

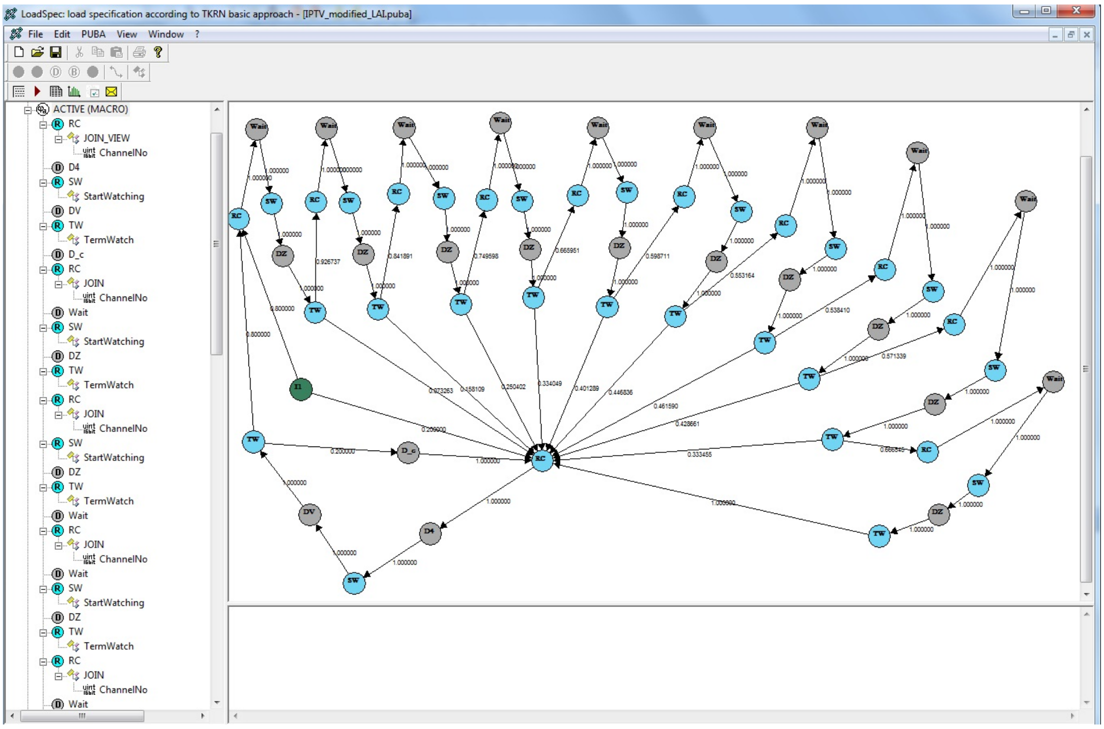

FIGURE 3.6: IPTV User behavior modeling by means of the LoadSpec tool.

1. Going to watch another channel and therefore staying still in viewing mode.

2. Start to switching a set of channels thus changing to the zapping mode.

3. Turn off the device.

3.1.3 TV-UBA Implementation with LoadSpec

With applying the LoadSpec load description tool we model our vehicular IPTV user behavior. We assume up to a maximum number of 30 channel switching events before viewing. The implementation of TV-UBA by means of LoadSpec is demonstrated in Figure 3.6. By way of example, Figure 3.7 shows a sample output of the user behavior model. Zapping blocks and viewing time are clearly distinguishable in this figure. Evidently, the user switches three channels and then is going to view the fourth channel in Figure 3.7. Finally, the user terminates the viewing mode and starts to zapping again to find something of interest.

3.1.4 An Output File of LoadSpec

LoadSpec generates a trace file as an input for our simulation tool for analyzing IPTV services offered in vehicular networks. This trace file indicates the behavior of vehicular

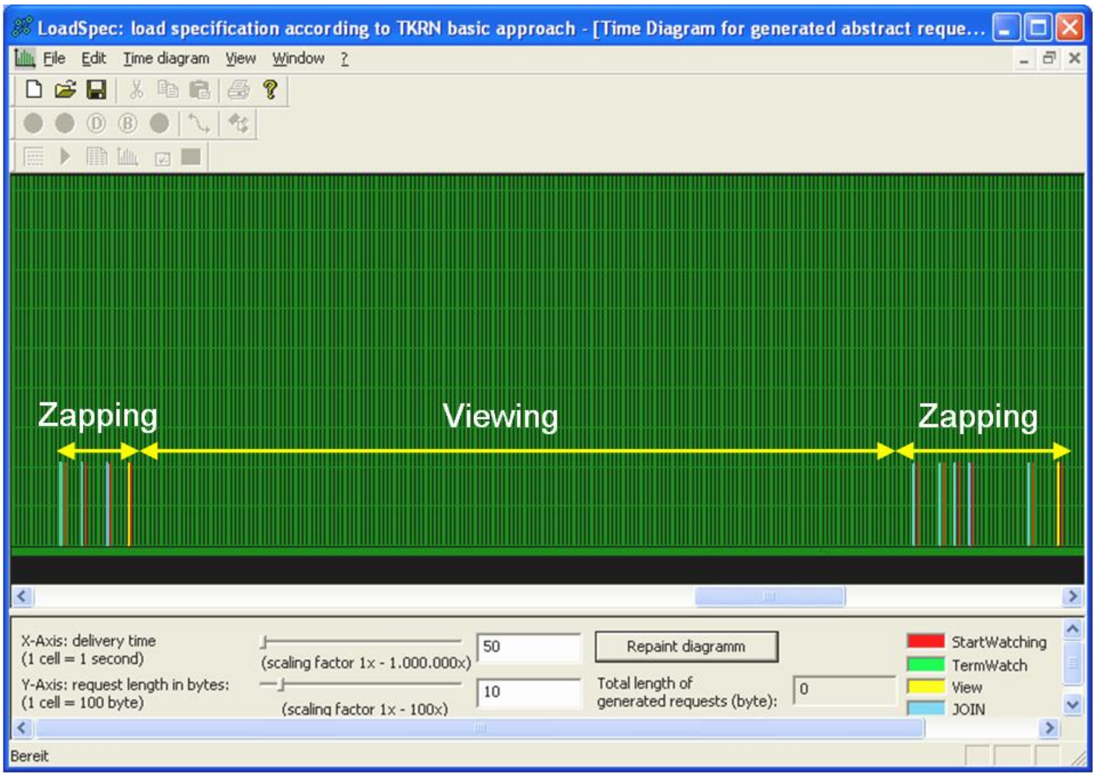

FIGURE 3.7: Output of the TV-UBA model in the LoadSpec tool [2].

users for modeling in our IPTV simulation tool. The trace files are independent of our IPTV simulation tool. The trace files consist basically of three columns as shown by way of example in Table 3.2.

The first column represents the time of different events for the users. The value of the timestamp is between 0 and total simulation time. The possible events for each user consist of:

- Turning on the device and start to watch IPTV for the first event of a user.
- Viewing.
- Zapping.
- Turning off the device or leaving the last cell at the border of the geographical area (cf. Figure 3.1) for the last event of a user.

The second column is generated by LoadSpec to show the UBA state. However, the third column is important and illustrates the switching and watching user behavior. We accept only the row entries in case the third column is not empty. There are two cases for the third column, “1” and “2”. “1” means the user is in viewing mode and “2” illustrates that user is in zapping mode. Therefore, each trace file gives all the information about the time of events (viewing or zapping) for the users.

Table 3.2: Trace file as an output of LoadSpec.

Timestamp	UBA State №	Behavior Mode №
0.000000	32	2
2.000000	33	-
10.482240	34	-
10.482240	32	2
12.482240	33	-
...	...	...
62330.743795	35	1
62332.743795	33	-
63827.785120	34	-
63827.885120	35	1
63829.885120	33	-
65240.069727	34	-
65240.069727	32	2
...	...	...

3.2 IPTV Simulation Tool

There are some simulation studies related to evaluating channel blocking probability and channel availability for IPTV services over DSL access networks by J. Lai [98]. The logic of J. Lai's [98] simulator is somehow similar to our simulator but for evaluating the QoE for IPTV service over vehicular networks we needed to develop a new simulation tool mainly in order to take into account user mobility. We elaborated a simulation tool for analyzing IPTV services offered in vehicular networks. Our simulation tool has been designed to generate a system model abstracting from the lower layers of the protocol stack because these details are not relevant to the QoE measures studied. Other vehicular simulators emphasize on the lower protocol layers as they have completely other research goals. Doing availability studies based on those simulators would be extremely inefficient, if possible at all. However, our new simulator differs from other vehicular simulators. It offers a very detailed model to specify IPTV user behavior, because modeling user behavior in a realistic manner is highly relevant for our type of studies. Our simulator is written purely in C and it works together with the LoadSpec tool to use the trace file for channel switching events for the vehicular IPTV users. Therefore, we are using our own tool for evaluating the availability of IPTV services.

For evaluating the availability and the blocking probability of IPTV services, we apply the trace file as a realistic model resulting from LoadSpec executions. We propose a *Monte-Carlo* simulation model based on the N-dimensional state vector below:

(UserNumberChannel[1], UserNumberChannel[2], UserNumberChannel[3], $\cdots$,

UserNumberChannel[N]).

This vector is used for recording the current status of each cell. For example, the ith element in UserNumberChannel[i] of the state vector indicates the current number of users watching channel i through this cell.

We need to take into account that the simulation experiment will experience a system transition phase as a "warming-up" stage before the system arrives in its steady state. For evaluating CBP and CA for the steady state the transient phase which happens at the beginning stage of the simulation should be eliminated from our acceptable results. It means that only the results in the steady stage are acceptable and when the system is not getting steady we can not consider the results.

We simulate the channel request arrival events in the cells, user departure in the cells events and handover events during a given observation interval (duration of simulation time). We update this state vector when the arrival request events, user departure events, leave channel events and handover events happen. However we do not change the value of the state vector when a blocking event happens. Blocking events occur when a user sends a request for channel i, and other channels (not including channel i) have occupied all the bandwidth in the current cell. So, we need to record the number of blocking events and the total number of channel requests (switching and handover) in the observed time interval. Now we are able to evaluate the CA and CBP for IPTV service over vehicular networks.

In the following, we describe the important events as *join* and *leave* events in the cell. These events will change the state vector and this is started by sending a corresponding request from the vehicular IPTV users. *Join* and *leave* events combined together make up some other events like switching a channel or handover process. Moreover, after these basic events, it is needed to update the state vectors and amount of bandwidth allocation.

3.2.1 Joining a Channel

When an IPTV user wants to view a channel C_i, it is needed to send out a *join*-request by the user's device to the AP/BS. This *join* message is a request to join the group of multicasted channel C_i. Internet Group Management Protocol (IGMP) is used by the IPTV devices to *join* multicast IPTV streams. The joining process inside a wireless cell is presented in Algorithm 1.

In line 1, the *join* request procedure will be started. In line 2, the primary part of starting this process is to send the *join*-request from IPTV user to AP. This *join*-request, consists of the desired channel nº (C_i). In line 3, the current AP receives a *join*(C_i)-request from the user's device. The AP first checks, whether the channel C_i is already transmitted in the cell (line 4). If this turns out to be true, the user will *join* to receive the channel C_i (line 5). Accordingly, the state vector will be updated by adding one user to the viewers of channel C_i (line 6). On the other hand, if channel C_i is not broadcasted yet, AP has to check whether a sufficient amount of free bandwidth BW_{Free} is left in the cell to transmit channel C_i (line 7). In case enough BW_{Free} is left, the user will join to the group of multicasted channel C_i (line 8), and the state vector will be updated by adding one user to the viewers of channel C_i (line 9). Moreover, it is required to increase BW_{Brdcst} and to recalculate BW_{Free} in the cell (lines 10-11). In the other case, C_i will not be broadcasted and thus be blocked (line 13). Joining a C_i in the cell, which is not already broadcasted, is accompanied by a reduction of free bandwidth (BW_{Free}) in the current cell.

Algorithm 1 *Join*-request process in wireless cell.

1: **procedure** *join*-REQUEST
2:     **REQUIRE:** sending *join*-request for channel C_i from user U_n to the AP
3:     AP receives a *join*(C_i)-request from U_n
4:     **if** channel C_i is already transmitted **then**
5:         User U_n, *join* to receive channel C_i
6:         Update the state vector by 1: UserNumberChannel[i]++
7:     **else if** there is enough BW_{Free} left in the cell **then**
8:         U_n *join* to receive channel C_i
9:         Update the state vector by 1: UserNumberChannel[i]++
10:         Raise BW_{Brdcst} by 1: BW_{Brdcst}++ in the cell
11:         Recalculate BW_{Free}
12:     **else**
13:         Desired channel cannot be delivered (i.e. it is blocked)
14:     **end if**
15: **end procedure**

3.2.2 Leaving a Channel

Leave message is also a basic event. It is used whenever the user *leaves* the group of a multicasted channel. This will happen every time the user zaps to another channel or leaves a cell during the handover process or even switches off the device. *Leave* message consists of a channel number (C_i), too. Obviously, by each *leave* message, more free bandwidth will be generated in each cell. The leaving process inside a wireless cell is demonstrated in Algorithm 2.

In line 1, the leaving process will be started. For starting the *leave* process, sending a *leave*-request from user U_n to the AP is needed (line 2). In line 3, in three cases the user will send the *leave* message to the AP:

1. User switches off the device (without being accompanied by a *join* message)
2. User leaves a channel C_i by switching to another channel C_j (with being accompanied by a *join* message for the current AP)
3. User leaves a cell during handover process (with being accompanied by a *join* message for the next AP)

If one case of these three turns out to be true, then the user sends a *leave* message to the current AP (line 4). Then, the state vector will be updated by decreasing one of the viewers of channel C_i (line 5). Finally, if the user is leaving a channel as the last user, then it increases the BW_{Free} in the current cell (lines 6, 7).

Algorithm 2 *Leave*-request process in wireless cell.

1: **procedure** *Leave*-REQUEST
2:     **REQUIRE:** sending *leave*-request for channel C_i from user U_n to the AP
3:     **if** ((User switches off the device) **or** (User leaves a channel C_i by switching to another channel C_j) **or** (User leaves a cell during handover process)) **then**
4:         User U_n sends a *leave*(C_i)-request to AP
5:         Update the state vector by a decrease of 1: UserNumberChannel[i]--
6:         **if** User is Leaving a channel as the last user **then**
7:             Raise BW_{Free} by 1: BW_{Free}++ in the cell
8:         **end if**
9:     **end if**
10: **end procedure**

3.2.3 Switching a Channel

Switching a channel is not an elementary event but it is in a combined event category. Switching a channel is always accompanied with a *join* message together with a *Leave* message. Figure 7.7 demonstrates an IPTV switching scenario. In this scenario, at first it is needed to send a switching channel message from user U_n to the AP. It is assumed that a user U_n is watching channel C_i and wants to switch to channel C_j. Then this user will send a *Switch* message as a combined event concluded as:

As already mentioned, switching a channel is a combination of the two basic events, *leave* message and *join* message. So, in the switching process, always a *leave* message is accompanied with a *join* message. Therefore, if a user wants to switch from channel C_i to channel C_j, it is needed to send a *Switch* message which is a combination of:

$$Switch(C_i, C_j) = Leave(C_i) \quad "followed \quad by" \quad Join(C_j). \tag{3.1}$$

So, here *join* and *leave* process will be executed according to the Algorithms 1 and 2.

3.2.4 Handover between Cells

Handover process in vehicular IPTV services refers to transferring a watching TV channel from the connected wireless cell to the next wireless cell. To start the handover process it is needed to send a *handover*-request from the user U_n to *leave* the current cell and accordingly, ask to *join* his/her current channel in the next cell. Each *handover*-request includes the following basic requests:

$$Handover(U_n, AP_k, AP_{k+1}, C_i) = Leave(C_i, AP_k) \quad "followed \quad by" \quad Join(C_i, AP_{k+1}). \tag{3.2}$$

Evidently, for each handover process it is needed to have enough free network bandwidth in the next cell to transmit the specific channel by the new base station of the next cell.

3.2.5 Requirements and Basic Assumptions

Without loss of generality, we assume the IPTV service over the vehicular network which is presented in Figure 3.8. As is shown in this figure, all the vehicular users are connected to the IPTV service via the Base Stations (BSs)/Access Points (APs).

We are going to present more information and general assumptions as well as important parameters regarding our IPTV simulator. It simulates very detailed items as described in the sequel.

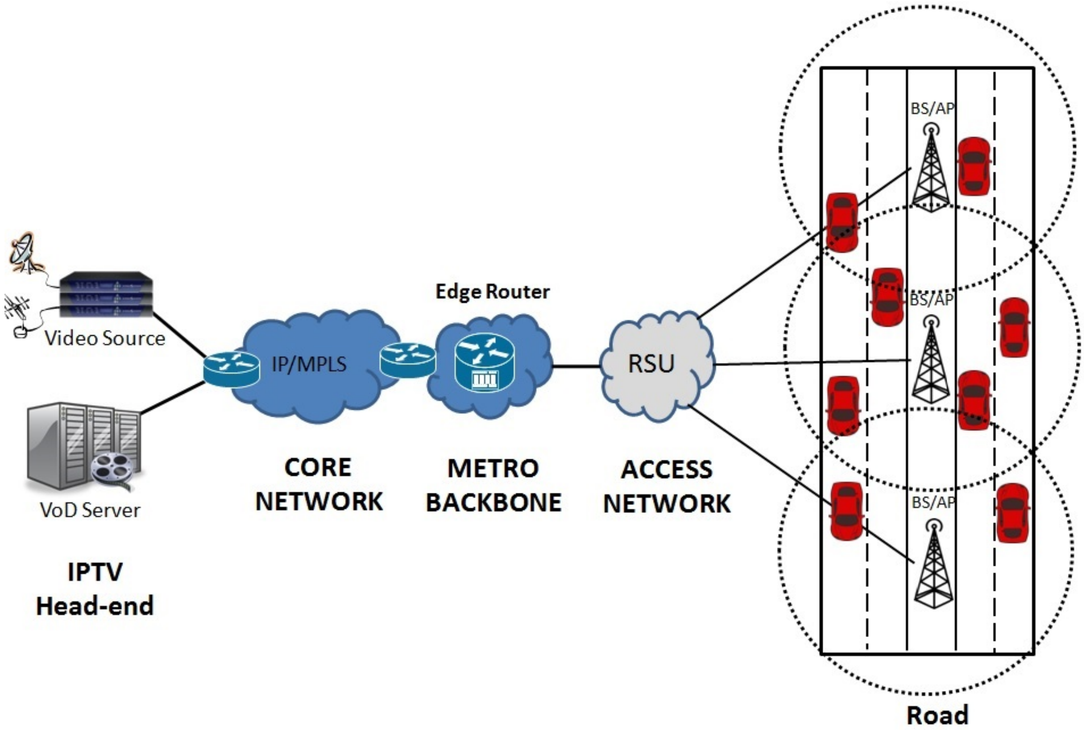

FIGURE 3.8: A typical vehicular network based IPTV system.

3.2.5.1 Simulator Setup

This simulator generates the cars in each lane of (typically) two directions according to the speed and average distance between the cars, in the given time interval. However, not in all of the cars there exist passengers who are watching IPTV and only some percentage of them are IPTV subscribers. Therefore, for generating the cars during the duration of simulation time, we need to set these parameters in our simulator:

- $SP_{[i]}$: Average speed of a vehicle in each lane i per direction [km/h].
- $d_{avg[i]}$: Average distance in lane i between two adjacent vehicles [m].
- $d_{max[i]}$: Maximum distance in lane i between two adjacent vehicles [m].
- $d_{min[i]}$: Minimum distance in lane i between two adjacent vehicles [m].
- D_{cell}: Diameter of each cell.

So, it is easy to simulate different scenarios with different traffic density to assess the IPTV service availability according to the:

- Traffic Density ($TD_{[i]}$): Average number of vehicles in each cell (per lane i and per direction).

And it will be calculated by:

$$TD_{[i]} = \frac{D_{cell}}{d_{avg[i]}}. \tag{3.3}$$

It is also required to determine the number of IPTV subscribers in a cell and the number of channels offered by the IPTV service provider:

- α: Probability that a vehicle will use IPTV service.
- N: Number of TV channels offered in total.

Moreover, it is needed to set the road information parameters as:

- dir: Number of directions of the road (typically, dir=2).
- k: Number of lanes in each direction of the road.

A part of the simulation code for the basic setup is shown by way of example as follows:

```
#define SIM_DURATION (3600*2) //second

#define NUM_LANES_PER_DIRECTION 3// k=3
#define NUM_DIRECTION 2 // two directions
#define CLUSTER_DIAMETER 3000.0 //meter
#define OUTER_SPEED (150.0/3.6) //m/s
#define MIDDLE_SPEED (120.0/3.6)//m/s
#define INNER_SPEED (90.0/3.6)//m/s
#define OUTER_MIN_DISTANCE 20 //meter
#define MIDDLE_MIN_DISTANCE 15 //meter
#define INNER_MIN_DISTANCE 10 //meter
#define OUTER_AVG_DISTANCE 30 //meter
#define MIDDLE_AVG_DISTANCE 25 //meter
#define INNER_AVG_DISTANCE 20 //meter
#define OUTER_MAX_DISTANCE 40 //meter
#define MIDDLE_MAX_DISTANCE 35 //meter
#define INNER_MAX_DISTANCE 30 //meter
#define IPTV_USAGE 0.1
#define CHANNEL_NUM 100 //N
```

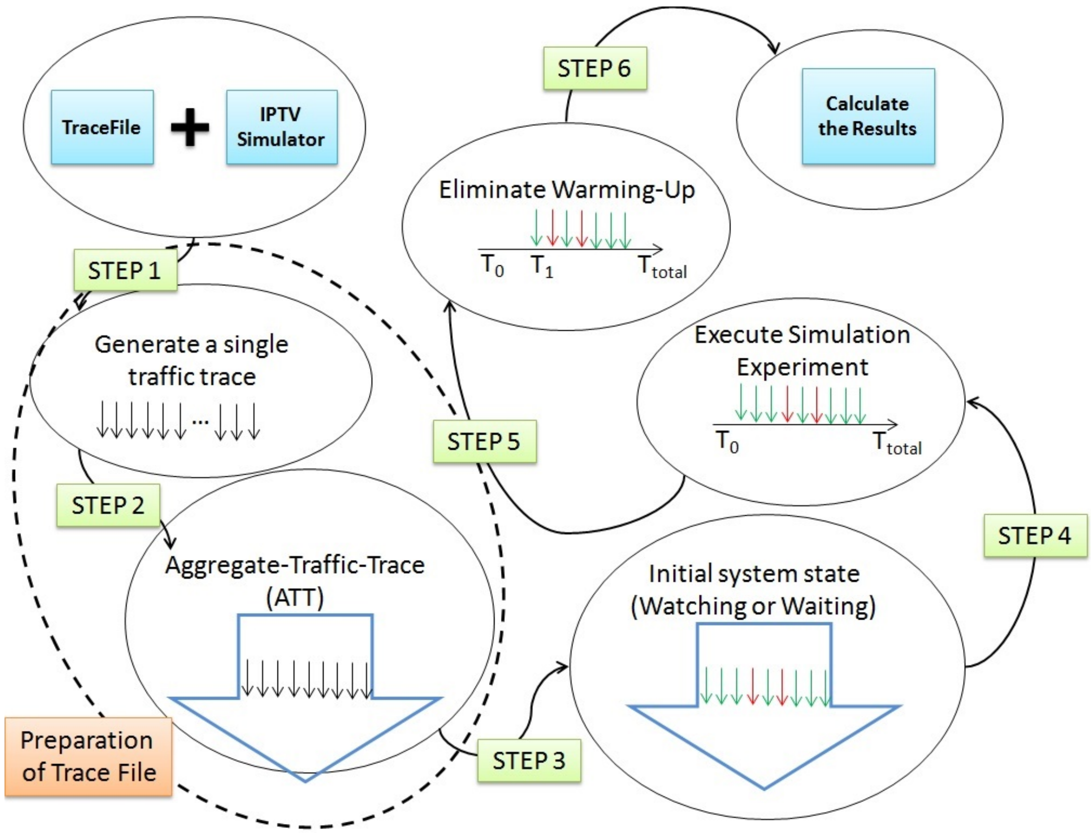

FIGURE 3.9: Logic of our simulation tool.

Now, we are able to simulate various scenarios with our IPTV simulation tool. This simulation model is based on the state vector and it considers the behavior of each single IPTV user. In the sequel, we are going to describe the logic of the simulation tool which follows the steps below and is illustrated also in Figure 3.9:

- **STEP 1:** Generate a single traffic trace for each single vehicular IPTV user as a user behavior model according to the specified time interval which each user spends to pass the cell (by means of LoadSpec trace files).
- **STEP 2:** Create an Aggregate-Traffic-Trace (ATT) to aggregate all the single traffic traces together for the given simulation time duration. In the simulation all the user's behavior (like requesting or leaving the channel) is according to the traffic trace which is derived from **STEP 1**. ATT is the multiplexing of all the single traces and is developed for aligning and overlapping the traffic traces derived from all the vehicular IPTV users in the particular simulated highway.
- **STEP 3:** Determine the initial system state of the specified time duration in a realistic manner. This step is a significant subject for simulating vehicular IPTV systems. Because at first, it is necessary to determine what the initial states of all vehicular users would be like. Two states are possible, the watching state (zapping

or viewing) and the waiting state. If a user is in watching state, it is needed to assign the channel to the user who is currently watching. In this simulation tool, we rely on an efficient method to generate the initial state. The main concept of this method is to assign a channel i randomly for a single vehicular user according to the channel popularity using zipf law distribution. If there is not bandwidth left to support the requested channel i demanded by this user, the user would have to be in a waiting state, otherwise the user will be in watching state and being watching the assigned channel i. This procedure will be repeated until every vehicular IPTV user in this closed system has been assigned a specific channel or the user has to start in the waiting state and has to watch channel 0.

- **STEP 4:** Start to simulate this closed system according to the ATT (**STEP 2**), from the system initial instant T_0 to the end of the simulation time (T_{total}). Real-time system state will change during the simulation according to the different features. All these changes will be recorded by means of various variables and metrics.

- **STEP 5:** Eliminate the transition phase (cf. interval [T_0, T_1] in Figure 3.9) as a "warming-up" stage. Because to reach accurate results for evaluating CBP and CA, we can only consider the interval during which the system is in steady state.

- **STEP 6:** At the end of the given simulation time, it is possible to calculate the CA, CBP, SBP and HBP (cf. definitions in Subsection 2.5.2) based on the statistical data. All the channel blocking events will be recorded during the simulation time.

For giving more information regarding our simulation model to evaluate the channel availability and channel blocking probability for IPTV service over the vehicular network a Pseudo-code is needed. Therefore, at the first we define some notations to simplify the understanding of our Pseudo-code. In Table 3.3, there are some notations to introduce the algorithm of our IPTV simulation tool.

Each user for watching channel i needs to join the multicast group of the channel i. Therefore, the user sends a join request for channel i at first to ask if it is possible to join this multicast group. On the other hand, for leaving channel i it is also needed to send a leaving message by the user. As a result, in the case of switching a channel by the user, it is required to leave the current channel and then join to the newly requested channel. These two messages will be sent together. In our work each Switch Request (SR) or Handover Request (HR) is a join message for a new channel in the current cell or for the current channel in a new cell.

The Pseudo-code of the algorithm for evaluating CBP is represented below:

TABLE 3.3: Variables of simulation algorithm.

Notations	Descriptions
R	Request
HR	Handover Request
NR	New Request
BW_c	Total bandwidth available for IPTV in cell c
L	Leaving

```
/* Pseudo-code for evaluating CA and CBP for vehicular IPTV service in each
single cell */
int main()
{
...
/*System initialization*/
Single_Trace_Generation();  // for all users
ATT = Aggregate-Traffic-Trace();
Initial_State_Determination();
ATT_pointer = ATT;  // the 1st node in Aggregate-Traffic-Trace (ATT) list
while(ATT_pointer!=NULL)  // still in simulation time duration {
//warming-up stage
Transient_Phase();
//evaluation CBP in steady state
 if (Cell is steady state) {
/*channel request arriving process*/
 if ((ATT_pointer->event) is channel request event R) {
  CounterTotalRequest++;
        if (R is a Handover Request) {
                CounterHandoverRequest++;
                i = the channel number requested by HR;
                if (UserNumberChannel[i]==0) {
//no one is currently watching this channel in new cell
        if (bandwidth left in new cell is sufficient) {
                ACCEPT(HR);
                UserNumberChannel[i]++;
                }
                else {
//not enough bandwidth left in new Cell
                REJECT(HR);
                CounterBlockedHandoverRequest++;
                }
                }
        else {
//at least one user is watching the channel in new cell
                ACCEPT(HR);
                UserNumberChannel[i]++;
```

```
                }
                }
else if (R is a Switching Request) {
        CounterSwitchingRequest++;
        i = the channel number requested by SR;
        if (UserNumberChannel[i]==0){
//no one is currently watching this channel in current cell
                if (bandwidth left in current cell is sufficient) {
                        ACCEPT(SR);
                        UserNumberChannel[i]++;
                        }
                        else {
//not enough bandwidth left in current Cell
                        REJECT(SR);
                        CounterBlockedSwitchingRequest++;
                        }
                        }
        else {
//at least one user is watching the channel in current cell
         ACCEPT(SR);
         UserNumberChannel[i]++;
                }
                }
}
/*Handover Process OR Leaving Channel*/
        else if ((ATT_pointer->event) is user departure event D) {
        i = the channel number previously watched by the user;
        UserNumberChannel[i]--;
        }
//Move to the next event in ATT list
        ATT_pointer =   ATT_pointer->next;
        }
        }
/* Calculation of the Channel Blocking Probability */
HBP = CounterBlockedHandoverRequest / CounterTotalRequest;
SBP = CounterBlockedSwitchingRequest / CounterTotalRequest;
CBP = HBP + SBP;
CA = 1 - CBP;
}
```

3.2.5.2 Real Test Bed for Vehicular IPTV Services

There are practical achievements for vehicle-to-infrastructure communications to build-up Roadside-Backbone-Networks (RBNs). At the University of Rostock a RBN architecture was elaborated including early prototype implementations assuming fixed access nodes along the roads that can be accessed by the vehicles using wireless communication [3]. This infrastructure is mainly based on a wireless roadside backbone architecture. However, the architecture is able to be updated in order to reflect requirements of the (technological) practical experience. Therefore, this platform is suitable to be used for broadcasting IPTV or other multimedia services for vehicular users.

This infrastructure has a length of about 30 km and is located at parts of the Autobahn (German highway) A19 / A20 near Rostock as shown in Figure 3.10. Rostock is situated in the north-eastern part of Germany in the federal state Mecklenburg-Western Pomerania.

To the best of our knowledge, up to now, there are not any practical test beds regarding vehicle to RBN connection to investigate the IPTV services over vehicular networks in real experiments. Therefore, this test bed is an immense requirement on test and R&D activities for availability of IPTV services over vehicular networks.

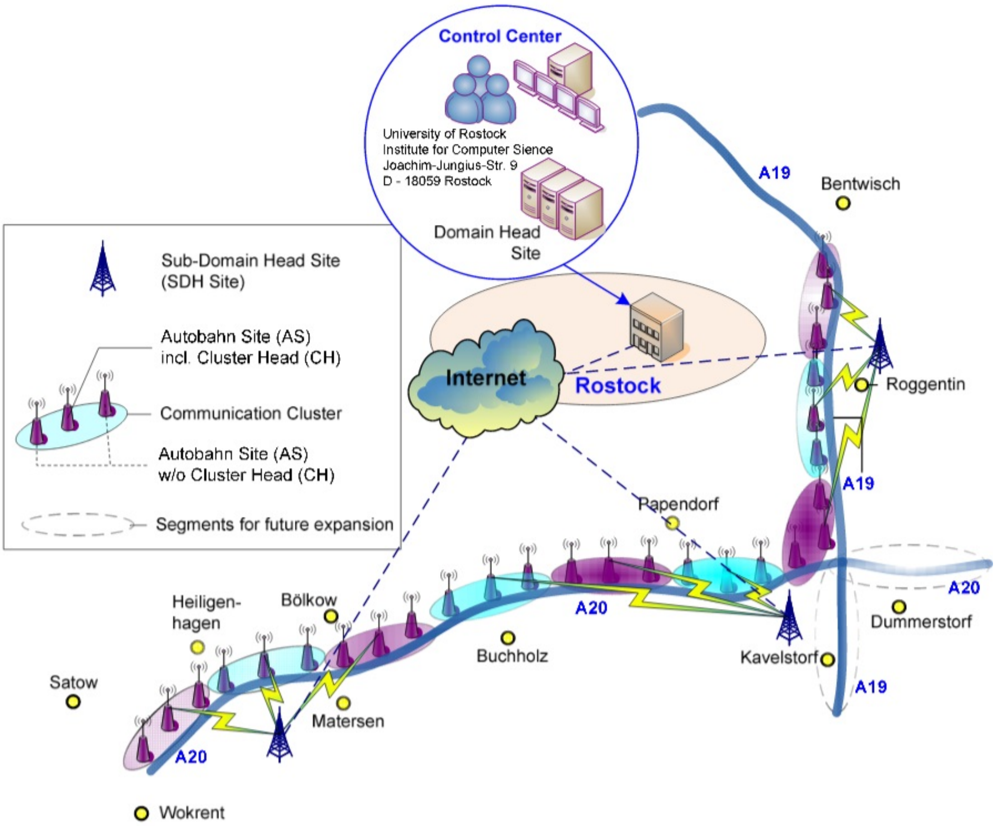

FIGURE 3.10: Roadway arrangement for the RBNs ([3]).

Chapter 4

Simulation-based Case Studies

In this chapter three case studies (cf. Sections 4.1, 4.2 and 4.3) are conducted to evaluate the CBP and CA for different possible highway scenarios. In these case studies, we apply all the previous assumptions and simulation models which were given in Subsection 2.5.2. Furthermore, we give more related assumptions for each case study in this chapter.

An essential part of IPTV services, as already described in Section 2.5, is to offer an acceptable level of QoE. By increasing the CBP, CA will be decreased. Therefore, QoE can significantly degrade. Thus, CBP and CA are two major metrics in the area of QoE for IPTV services. For providing QoE for vehicular IPTV services, there are two significant challenges, the limited available bandwidth in the vehicular access network and a large number of handover events during the car journey.

In this work, for measuring QoE, we need to focus on CBP and CA. Hence, finding the answers to the following questions is critical for us.

- What are the main factors having an impact on CA and CBP in an IPTV service for vehicular users?
- Which access network technology causes the lowest CBP and highest CA?
- What proportion of the channel blocking events is due to handover and what is due to TV channel switching?
- How many TV channels can be offered by the IPTV service provider for still providing acceptable QoE to the subscribers?

Now we are able to find the answers by means of simulation experiments with different case studies, to provide acceptable QoE for the IPTV users in the vehicular networks.

4.1 Case Study I: Variation of Traffic Intensity and Cell Sizes

In the case study I, we want to evaluate the impact of vehicle traffic density and number of lanes on CBP and CA in IPTV services in highway scenarios. In our experiments, we consider different traffic densities. We observe CBP and CA as two important measures of the QoE. For more specific details regarding blocking events, it is required to find out which kind of events (channel switching or handover process) was causing the TV channel blocking. Therefore, we consider not only the CBP but also the blocking values resulting for SBP and HBP individually.

Please note that the n^{th} entry of average speed $SP_{[i]}$ is always combined with the n^{th} entry of average distance $d_{avg[i]}$, i.e. specially, if $SP_{[i]}$= 0km/h then $d_{avg[i]}$= 10m or if $SP_{[i]}$= 180km/h then $d_{avg[i]}$= 46m. Moreover, the average distance always ranges between +/- 4m (truncated exponentially distributed). The 10 different traffic densities (Table 4.1) are obtained by investigating the 10 different average distances between neighboring vehicles. As what concerns the speed associated to the different lanes we have assumed that if speed is not larger than 80km/h then $SP_{[i]}$= constant $\forall i$ and if speed is larger than 80km/h then still $SP_{[1]}$= $SP_{[2]}$ but, if a 3^{rd} lane exists, $SP_{[1]}$= $SP_{[2]}$= $SP_{[3]}$ – 20km/h.

4.1.1 Case Study I: Experimental Setup

In our experiments, we consider different traffic intensity on a highway with a variable number of lanes and different cell sizes with different access network technologies. In our experiments, vehicles are generated for each lane in each direction. At first, we describe the experimental setup for a case study I in Table 4.1.

N as the total number of provided TV Channels is 100, which is a typical number of TV Channels for IPTV service providers to offer for their subscribers. The bandwidth reservation and diameter of each cell is chosen according to related access network and IPTV system characteristics. In our work, we suppose CIF standard for the quality of the video for all the channels. We also assume the probability of choosing each channel is according to Zipf distribution. In this case study, we did some experiments to figure out, which channel availability can be expected with varying the lanes number, traffic density and various access network technologies with different cell sizes.

Table 4.1: Parameter values for Case Study I.

Notations	Descriptions	Values
N	Number of TV channels offered in total	100
BW_c	The overall bandwidth reservation for IPTV service (bandwidth required per TV Channel: 500 kb/s, constant bit rate / CBR)	20 Mb/s (sufficient for parallel transmission of 40 TV Channels)
D_{cell}	Diameter of each cell	3000, 7500, 12000 m
k	Number of lanes in each direction of the highway	2, 3
$SP_{[i]}$	Average speed of a vehicle in each lane i per direction [km/h]	0, 20, 40, 60, 80, 100, 120, 140, 160, 180
$d_{avg[i]}$	Average distance in lane i between two adjacent vehicles [m]	10, 14, 18, 22, 26, 30, 34, 38, 42, 46
α	Probability that a vehicle will use IPTV service	0.2 (as we consider higher values to be unrealistic)
θ	Zipf parameter	1.3
I	Number of different cell traffic densities assumed in our study	10
$TD_{[i]}$	Traffic density: average number of vehicles in each cell (per lane i and per direction)	$TD_{[i]} = \frac{D_{cell}}{d_{avg[i]}}$

4.1.2 Case Study I: Results Obtained and their Interpretation

The simulation results are plotted in Figures 4.1, 4.2 and 4.3 as the evaluated channel blocking probability against the cell traffic density in different access network technologies. Confidence intervals are based on a confidence level of 95% in all experiments. The results show that with decreasing the distance between vehicles, accordingly, cell traffic density will increase, and this leads to a growth of CBP. In particular, to reduce the distance between adjacent vehicles, the speed of the vehicles has to be decreased, too (for details cf. Table 4.1).

Evidently in the figures, the percentage of blocking events resulting from handover (HBP) and also the percentage of blocking events arising from channel switching (SBP) are depicted with the CBP results. As is to be expected, both, CBP and SBP raise when we increase cell traffic density and the number of lanes. This increase of CBP and SBP is

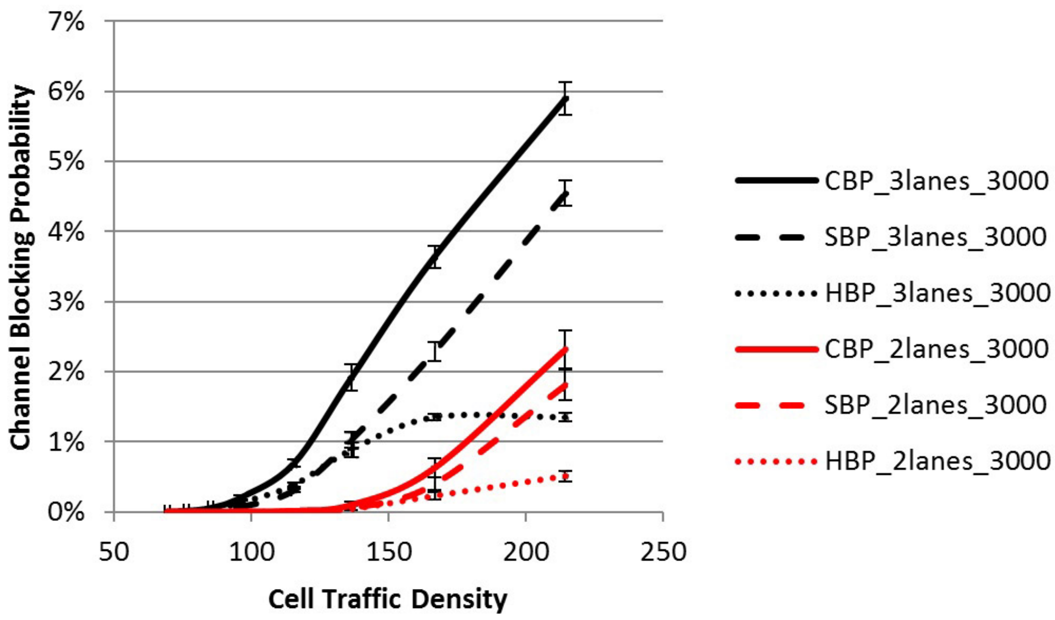

Figure 4.1: CBP results for 3km cell size against cell traffic density.

valid for all of the access network technologies because we have more IPTV users in each cell. On the other hand for HBP, the shapes of the curves tend to be slightly different. Interestingly, Figure 4.3 shows that for a cell size of 12 km and high cell traffic density, nearly all of the TV channel blocking is due to channel switching events.

We assume that the maximum acceptable threshold for CBP is 1%. Therefore, in case of 3 km cell size for 2 and 3 lanes respectively the maximum number of cars in each lane will be about 180 and 125 cars in each lane. For 7.5 km cell size, only for 2 lanes with 187 cars per lane (on average) the CBP is still acceptable. However, for a cell size of 12 km, the 1% requirement can no longer be fulfilled.

4.2 Case Study II: Variation of Mobility Scenarios (MS)

By means of simulation experiments, we are going to evaluate the channel availabilities for various scenarios assuming boundary conditions as realistic as possible. In these different scenarios, we are varying the usage of IPTV service for the subscribers, the number of cars per km and access network technologies. Then, we are able to make a decision regarding which situation will still provide an acceptable QoE for the IPTV users in the vehicular network.

In case study II, we want to evaluate the impact of different access network technology with various cell sizes and vehicle traffic densities (vehicles per km) on channel blocking probability and channel availability in highway scenarios. The traffic density in this case

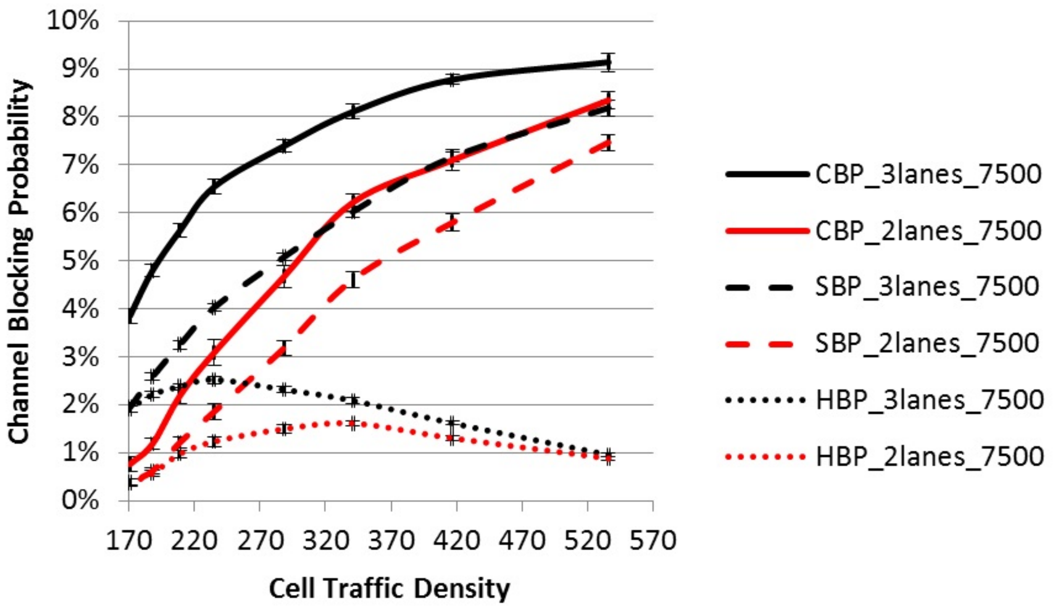

Figure 4.2: CBP results for 7.5km cell size against cell traffic density.

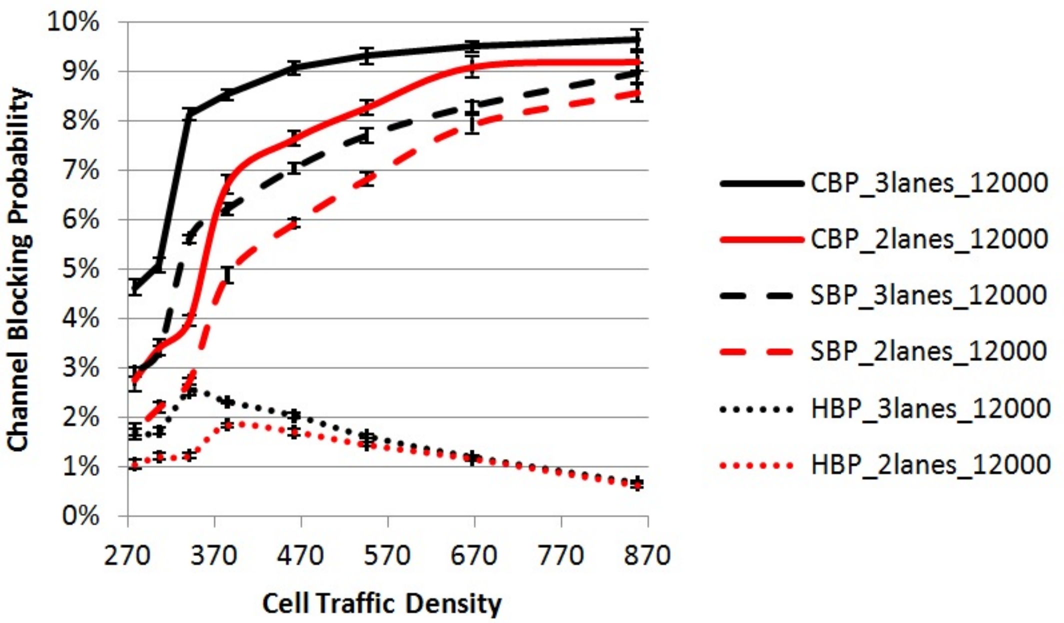

Figure 4.3: CBP results for 12km cell size against cell traffic density.

TABLE 4.2: Parameter values for Case Study II.

Notations	Descriptions	Values
N	Total number of provided TV channels in the mobile IPTV system	100
D_{cell}	Diameter of each cell	3000, 7500, 12000 m
α	Probability that a vehicle will use IPTV service	0.2, 0.1
Θ	Zipf parameter	1.3
MS1, MS2, MS3, MS4	Mobility Scenario	Given in sections 4.2.1, 4.2.2, 4.2.3, 4.2.4

study is given in "cars per km" to simplify the language though also other entities like lorries, motorcycles, etc. will drive on the highway.

In this section, like case study I (cf. Section 4.1), the average speed SP is also combined with the average distance between adjacent vehicles. We assume that, in the worst case of the traffic situation when all vehicles are stuck in a traffic jam and can move only very slowly, (assuming a speed on lane i of $SP_{[i]}$ = 10 km/h) then the average distance between neighbor vehicles on lane i is $d_{avg[i]}$ = 10 m and we suppose in the best traffic situation $SP_{[i]}$= 160 km/h and $d_{avg[i]}$= 55 m. Moreover, the actual distance always varies +/-5 m around the average. This case study consists of four different Mobility Scenarios (MS) (cf. subsections 4.2.1, 4.2.2, 4.2.3, 4.2.4) which have been obtained by considering the 11 different average distances between neighboring vehicles.

Now, we executed the experiments to figure out, which channel availability can be expected for a different number of vehicles per kilometer in various access network technologies and cell sizes. Table 4.2 summarizes the essential experimental boundary conditions assumed in case study II.

4.2.1 MS1: Traffic Jam on Highway

In MS1, we assume the worst case scenario in a serious traffic jam. Speed is 10 km/h for all the lanes. All lanes here means 2 or 3 lanes per direction and accordingly 4 or 6 lanes in total for both directions. We suppose the highway for this scenario is characterized by an extremely high traffic density. Average distance between vehicles is $d_{avg[i]}$ = 10 m for all lanes, i.e. the actual distance between neighboring vehicles varies in the range 10 m

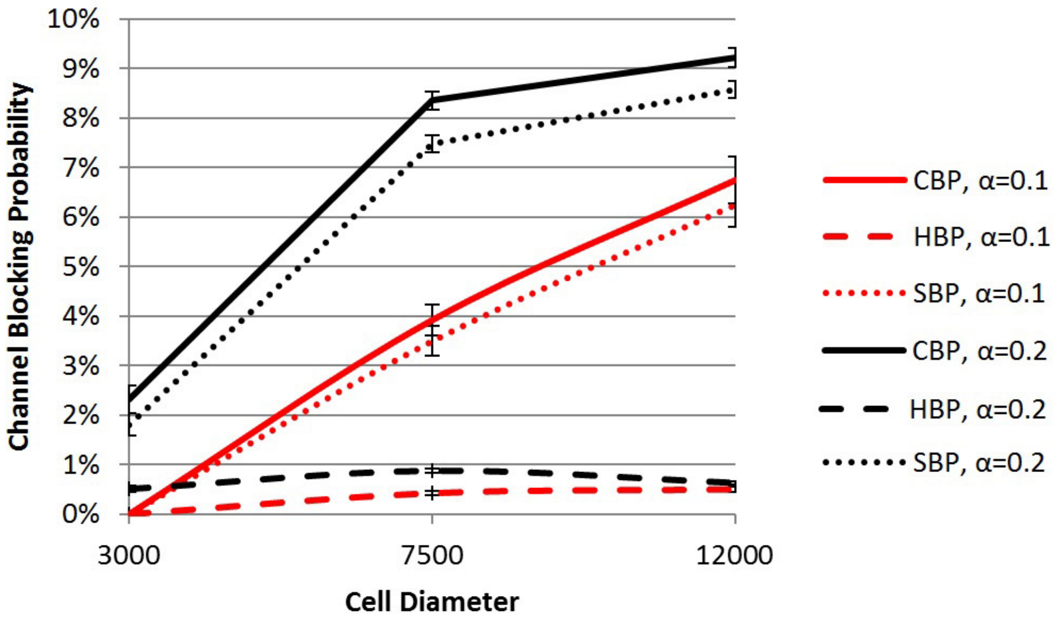

FIGURE 4.4: CBP results for 400 cars per km on 2 lanes highway in MS1.

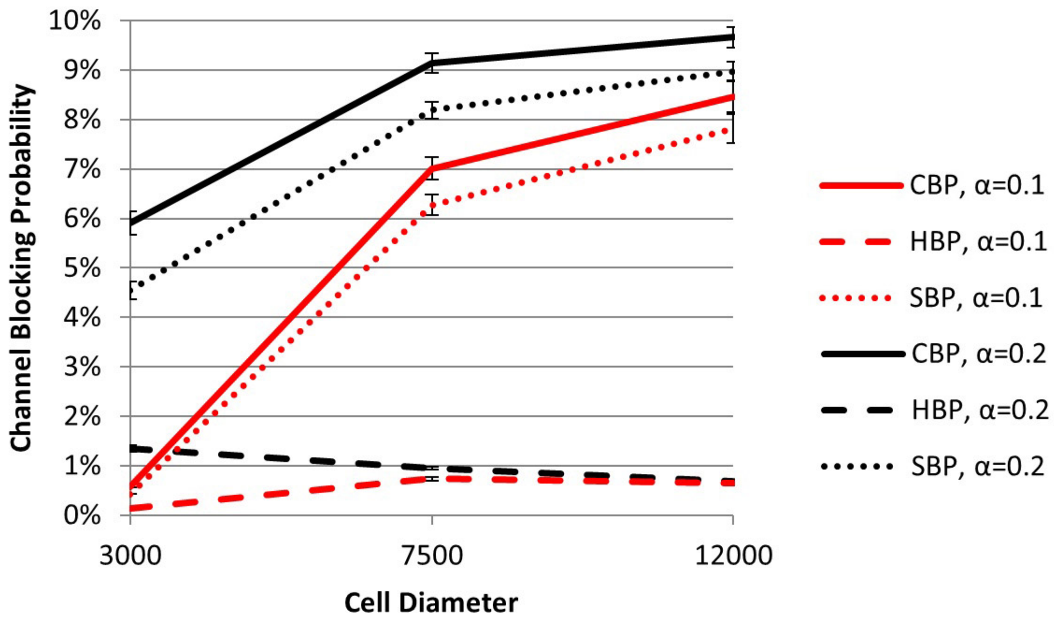

FIGURE 4.5: CBP results for 600 cars per km on 3 lanes highway in MS1.

+/-5 m. Hence, on the average, there are 100 cars per lane and per km (Figures 4.4 and 4.5).

4.2.2 MS2: High Traffic Density on Highway

In MS2, we investigate the channel availability for IPTV services in case of a high traffic density highway. We assume the highway has 3 lanes per direction and that $SP_{[1]}= 80$

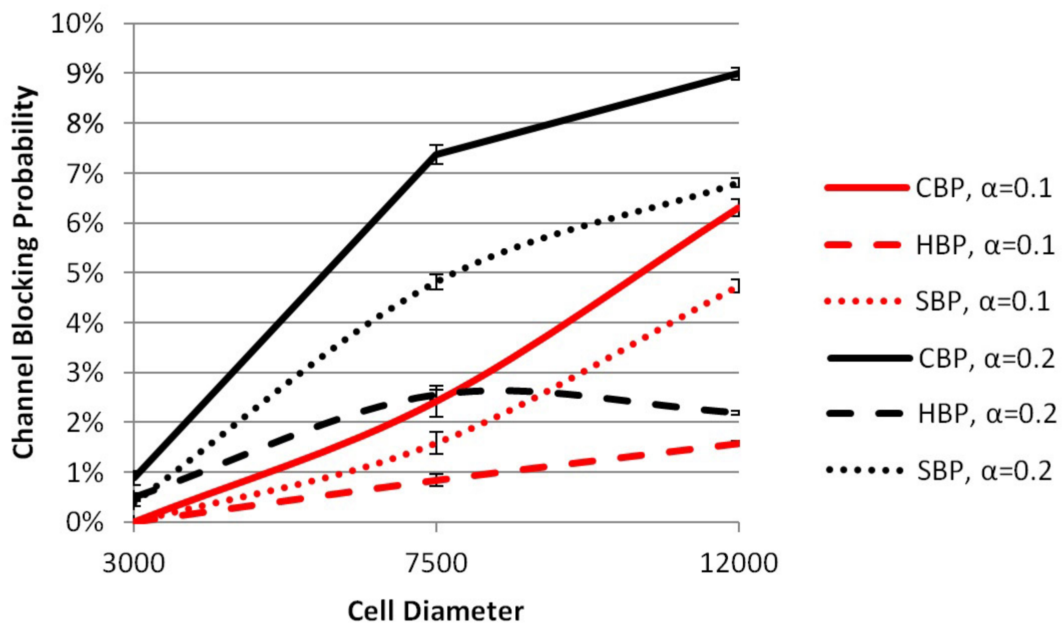

FIGURE 4.6: CBP results for 232 cars per km on 3 lanes highway in MS2.

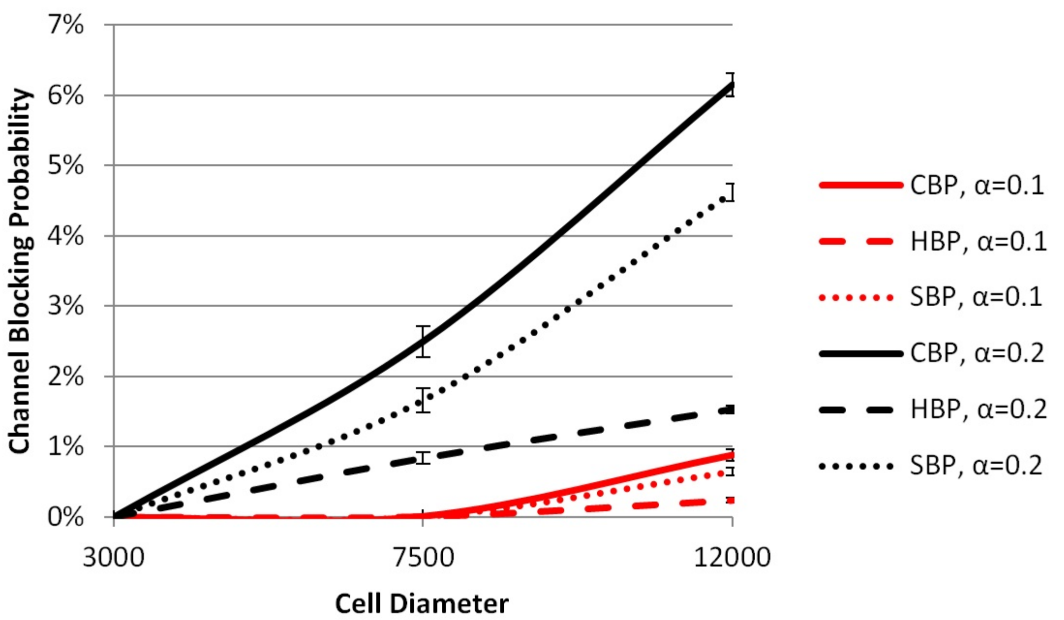

FIGURE 4.7: CBP results for 116 cars per km on 3 lanes highway in MS2.

km/h and $SP_{[2]}$=$SP_{[3]}$= 100 km/h, respectively, and the minimum distances between the vehicles on the 3 lanes are $d_{avg[1]}$= 20 m and $d_{avg[2]}$= $d_{avg[3]}$= 30 m (same for each direction). In this scenario we consider three different distances between vehicles. We have achieved this scenario with minimum $d_{avg[i]}$, 2×minimum $d_{avg[i]}$ and also 4×minimum $d_{avg[i]}$. Here again the actual distances vary in the range +/-5 m (Figures 4.6, 4.7 and 4.8).

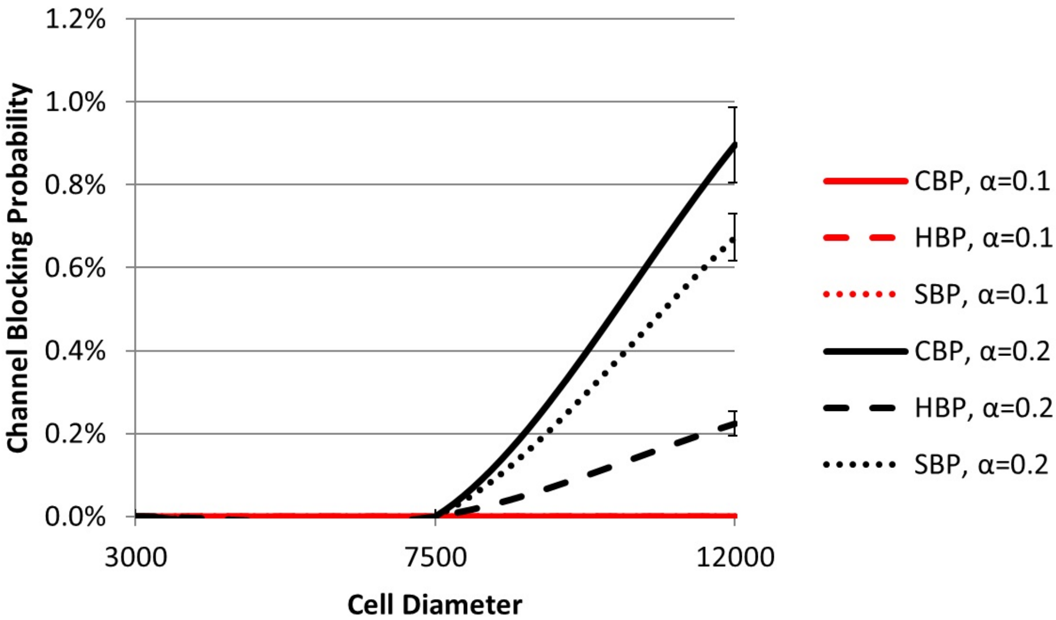

Figure 4.8: CBP results for 58 cars per km on 3 lanes highway in MS2.

4.2.3 MS3: Medium Traffic Density on Highway

MS3 scenario is for the medium traffic density situation. Evidently, there are 3 lanes per direction, $SP_{[1]}$= 100km/h, $SP_{[2]}$= 120 km/h and $SP_{[3]}$= 140km/h, respectively, where the minimum distances between the vehicles are $d_{avg[1]}$= 30m, $d_{avg[2]}$= 40m and $d_{avg[3]}$ = 50m. Same as in the previous scenario we investigate three different distances between vehicles as minimum $d_{avg[i]}$, 2×minimum $d_{avg[i]}$ and also 4×minimum $d_{avg[i]}$ in this mobility scenario (Figures 4.9, 4.10 and 4.11).

4.2.4 MS4: Low Traffic Density on Highway

In MS4 we evaluate the low traffic density situation in highways. In this MS we assume $SP_{[1]}$= 110 km/h, $SP_{[2]}$= 140 km/h and $SP_{[3]}$ = 160 km/h and accordingly the minimum distances between the vehicles are $d_{avg[1]}$= 35 m, $d_{avg[2]}$= 45 m and $d_{avg[3]}$= 55 m. Three different distances of minimum $d_{avg[i]}$, 2×minimum $d_{avg[i]}$ and also of 4×minimum $d_{avg[i]}$ are studied in this scenario (Figures 4.12 and 4.13).

4.2.5 Case Study II: Results Obtained and their Interpretation

The simulation results with 95% confidence intervals are depicted in Figures 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12 and 4.13. As can be seen in all the results by increasing the distance between vehicles with different speeds, accordingly, traffic density will decrease

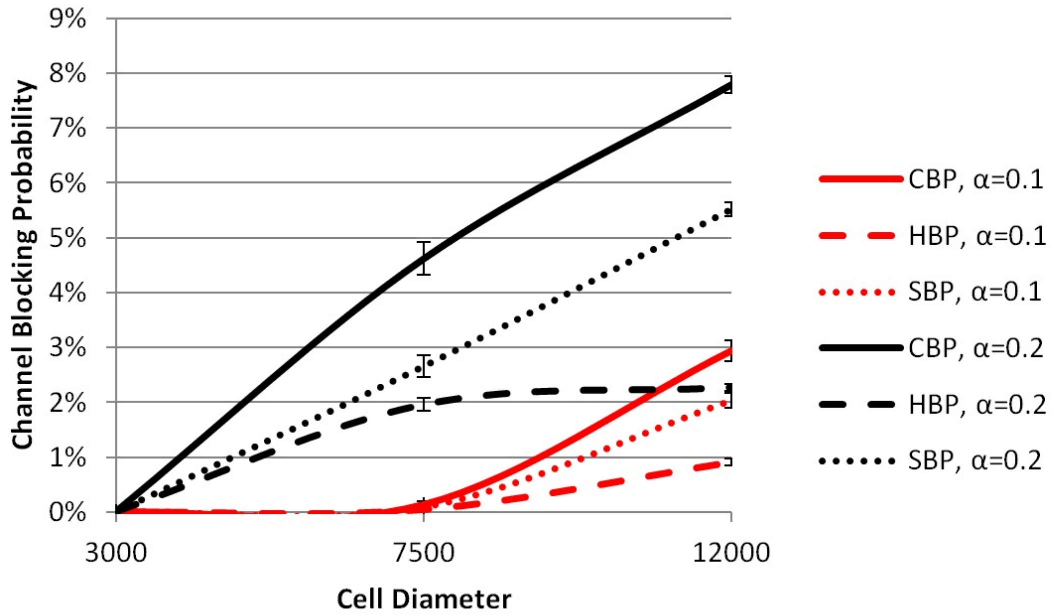

Figure 4.9: CBP results for 156 cars per km on 3 lanes highway in MS3.

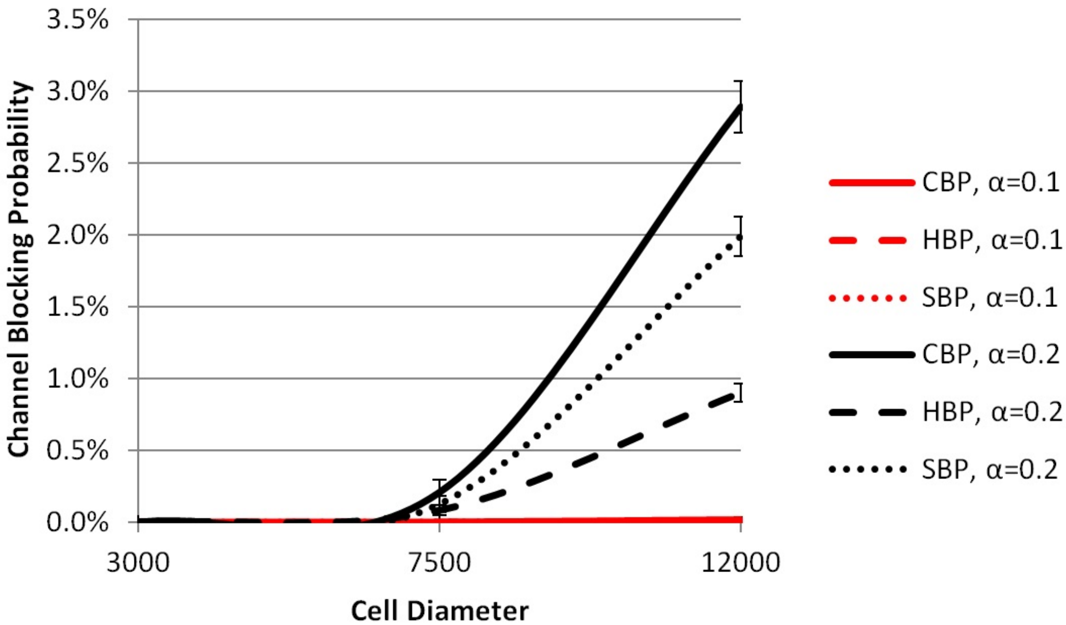

Figure 4.10: CBP results for 78 cars per km on 3 lanes highway in MS3.

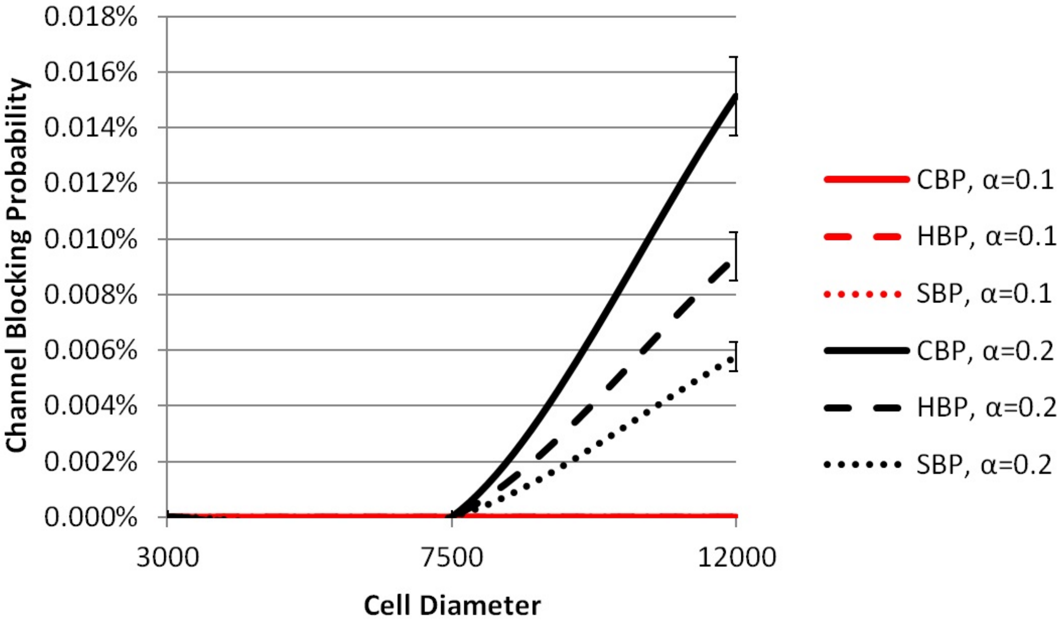

FIGURE 4.11: CBP results for 39 cars per km on 3 lanes highway in MS3.

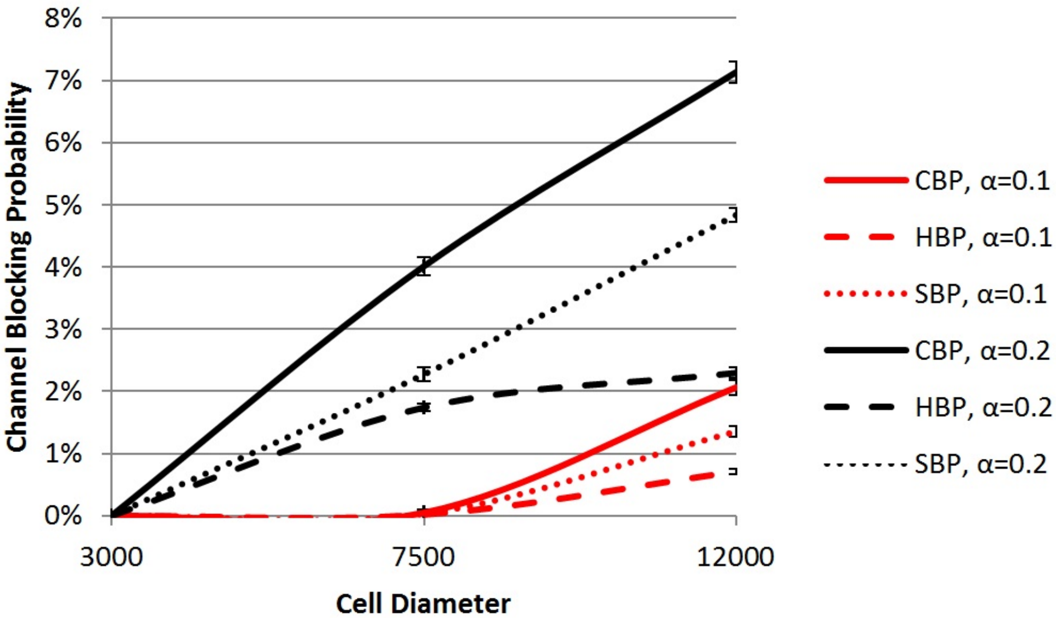

FIGURE 4.12: CBP results for 136 cars per km on 3 lanes highway in MS4.

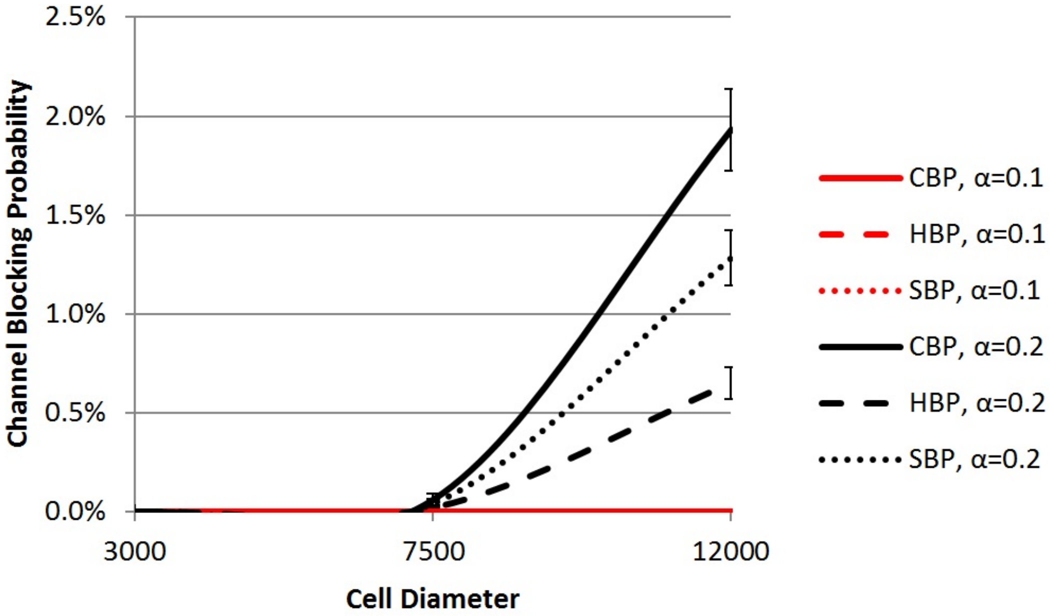

FIGURE 4.13: CBP results for 68 cars per km on 3 lanes highway in MS4.

and this implies a decrement of CBP. To put this in a more clear way, with increasing the distance between adjacent vehicles the speed of the vehicles will increase too. We notice that in all the figures in addition to the CBP results, the percentage of blocking events resulting from handover (HBP) and also the percentage of blocking events resulting from channel switching (SBP) are plotted. Therefore, in each figure, there are two types of results (red and black color) each of which is corresponding to the usage of IPTV services as a value of α.

As is to be expected, with the growth of offered traffic density, CBP and SBP will both increase for all of the access network technologies which means that we are having more IPTV users per cell. However, for HBP results the shape of the curves could be slightly different. With the increase of cell size and high traffic density, almost all of the TV channel blocking is due to channel switching events.

The maximum acceptable threshold for CBP in our work is assumed to be 1%. As can be observed, the worst case for Figures 4.4 and 4.5 for all cell sizes the 1% requirement can no longer be fulfilled for $\alpha = 0.2$, and only the scenario with a cell diameter of 3 km and also with $\alpha = 0.1$, still reaches the acceptable CBP.

Figures 4.6, 4.7 and 4.8 represent the results for the high traffic situation. With both values of α, only a cell size of 3 km still satisfies an acceptable blocking probability in the scenario of minimum distance between vehicles. With raising the distance between vehicles to 2×minimum $d_{avg[i]}$ in the case of $\alpha = 0.2$, only 3 km cell diameter still respects allowable CBP, but for $\alpha = 0.1$ and also 4×minimum $d_{avg[i]}$, all the cell sizes achieve an adequate channel availability. Cell size diameters of 3 km and 7.5 km still meet the CA requirement. For 4×minimum $d_{avg[i]}$ all the cell sizes offer an acceptable CBP.

The results for medium traffic density are illustrated in Figures 4.9, 4.10 and 4.11. For α = 0.2 only scenarios with 3 km cell diameter and for $\alpha = 0.1$, cell diameters of 3 km and 7.5 km lead to an acceptable value of CBP, with 2×minimum $d_{avg[i]}$, for $\alpha = 0.2$, cell diameters of 3 and 7.5 km and for $\alpha = 0.1$ and also 4×minimum $d_{avg[i]}$ all the cell sizes keep CBP below the threshold of still acceptable quality.

Figures 4.12 and 4.13 depict the results for low traffic density. We consider that the situation is similar to the medium traffic density. The scenario MS4 leading to 34 cars per km (4×minimum $d_{avg[i]}$) is not depicted by an own figure because here, CBP (and therefore also SBP and HBP) is negligibly small, in particular, CBP remains below 0.01%.

4.3 Case Study III: Variation of Number of TV Channels

In the case study III, we are going to find out various factors which have an impact on CA and CBP. Evidently, this is quite important for an IPTV service provider. Therefore, we want to provide decision support for the service providers offering an IPTV service. In general, in this section, we focus on the effect of different probabilities of using IPTV and also increasing the number of TV channels which is provided by the IPTV service provider on the channel blocking events and thus on the availability of the IPTV service for vehicular users.

With this case study we want to answer these questions:

- **Q1:** What is the impact of using different access network technologies and accordingly cell sizes?
- **Q2:** What happens if we increase the number of lanes of the highway?
- **Q3:** What happens when the number of channels offered by the service provider is growing? For how many channels the acceptable threshold of CBP is still fulfilled?
- **Q4:** What happens when the probability of using IPTV is increasing? Or in other words, the parameter α is getting larger?

Table 4.3: Parameter values for Case Study III.

Notations	Descriptions	Values
N	Total number of provided TV channels in the mobile IPTV system	40, 60, 80, 100
k	Number of lanes in each direction of the highway	2, 3
SP_i	Average speed of a vehicle in each lane i per direction [km/h]	90 (lane 1), 120 (lane 2), 150 (lane 3)
$d_{avg[i]}$	Average distance in lane i between two adjacent vehicles [m]	20 (lane 1), 25 (lane 2), 30 (lane 3)
$d_{max[i]}$	Maximum distance in lane i between two adjacent vehicles [m]	30 (lane 1), 35 (lane 2), 40 (lane 3)
$d_{min[i]}$	Minimum distance in lane i between two adjacent vehicles [m]	10 (lane 1), 15 (lane 2), 20 (lane 3)
α	Probability that a vehicle will use IPTV service	0.2 (Section 4.3.2), 0.1 (4.3.3)

4.3.1 Case Study III: Experimental Setup

Except number of provided channels N, and the density and speed parameters which are now fixed, the simulation parameter values are the same as in the previous case studies for all experiments in this case study. In our experiments, we varied the number of TV channels offered by the IPTV service provider, the probability of using IPTV service, the number of lanes of the highway and also the cell sizes in different access network technologies. The further assumptions and essential experimental boundary conditions for case study III are summarized in Table 4.3. A set of simulation experiments has been conducted to answer the above questions.

4.3.2 Case Study III: Results Obtained for Probability α=0.2

The simulation results demonstrate the effect of varying the number of lanes, the number of TV channels provided, the probability of IPTV usage and access network technologies in Figures 4.14, 4.15 and 4.16. In this section, the results are given with 95% confidence intervals, too. The curves in Figure 4.14 are depicting the values of CBP whereas SBP, HBP are illustrated by Figures 4.15 and 4.16. As it is to be expected, by increasing the number of the lanes and the number of TV channels provided, CBP will also be increased. Also, it is observable with raising the cell size according to the various access network technologies we suppose (namely IEEE 802.11p, WiMAX and LTE), the handover-induced blocking probability (HBP) decreases but switching-induced blocking probability (SBP) will increase.

Now with these experiments, we are able to obtain answers to the questions Q1-Q3.

- **A1:** Access networks with large area coverage will boost the channel availability (CA).
- **A2:** With increasing the number of lanes, CA will decrease, and CBP will increase.
- **A3:** With raising the number of TV channels provided, CA will decline, and CBP will grow. Therefore with applying 1% channel blocking probability threshold in our IPTV service we figure out:
  - For 12km cell size: assuming a 3 and 2 lanes highway scenario the number of TV channels (N) which still can be provided with sufficiently high availability is about N = 45 (for 3 lanes) and N = 46 (for 2 lanes).
  - For 7.5km cell size: a 3 lanes highway requires N $\leq$ 47, and N $\leq$ 60 for 2 lanes to be still acceptable.
  - For 3km cell size and a 3 lanes highway we may still accept a N$\approx$80 and, with this cell coverage, with 2 lanes we even don't have any significant number of blocking events.

4.3.3 Case Study III: Results Obtained for Probability α=0.1

The simulation results for α= 0.1 are illustrated in Figures 4.17, 4.18 and 4.19. The results include 95% confidence intervals. The results for CBP are illustrated in Figure 4.17 and evidently SBP and HBP results are shown in Figures 4.18 and 4.19. Again, it is observed that by incrementing the number of lanes and the number of TV channels provided, CBP will grow, too. The results for increasing the cell size by changing the access network technologies is exactly like the previous scenario (cf. subsection 4.3.2). Handover-induced blocking probability (HBP) increases much less quickly than the switching-induced blocking probability (SBP). Therefore, all the answers from A1-A3, are also acceptable here for Q1-Q3.

Let us now answer to the question Q4:

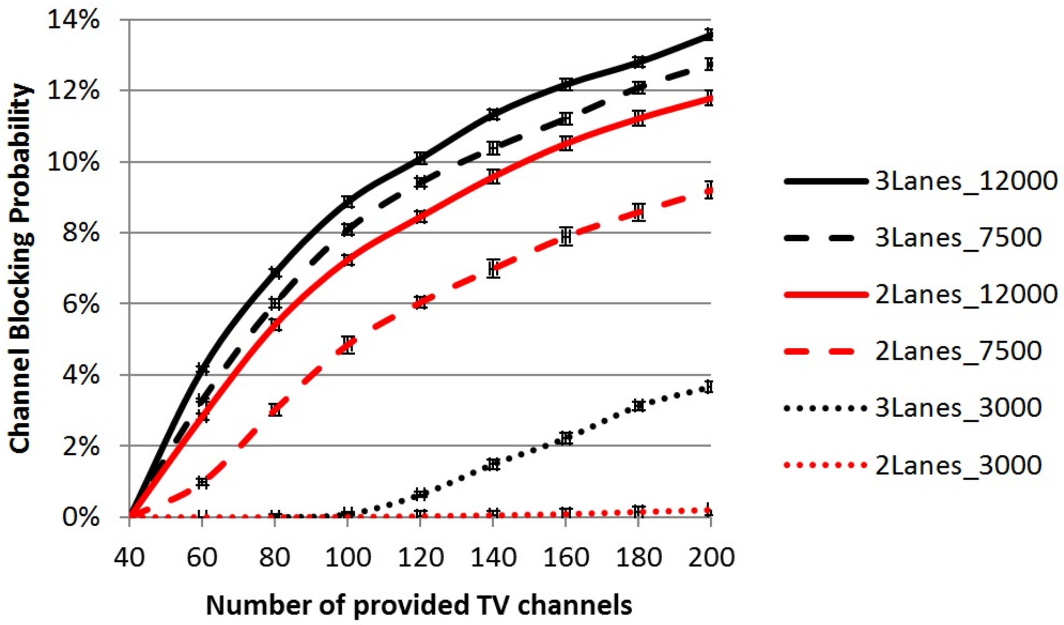

FIGURE 4.14: CBP results against number of TV channels.

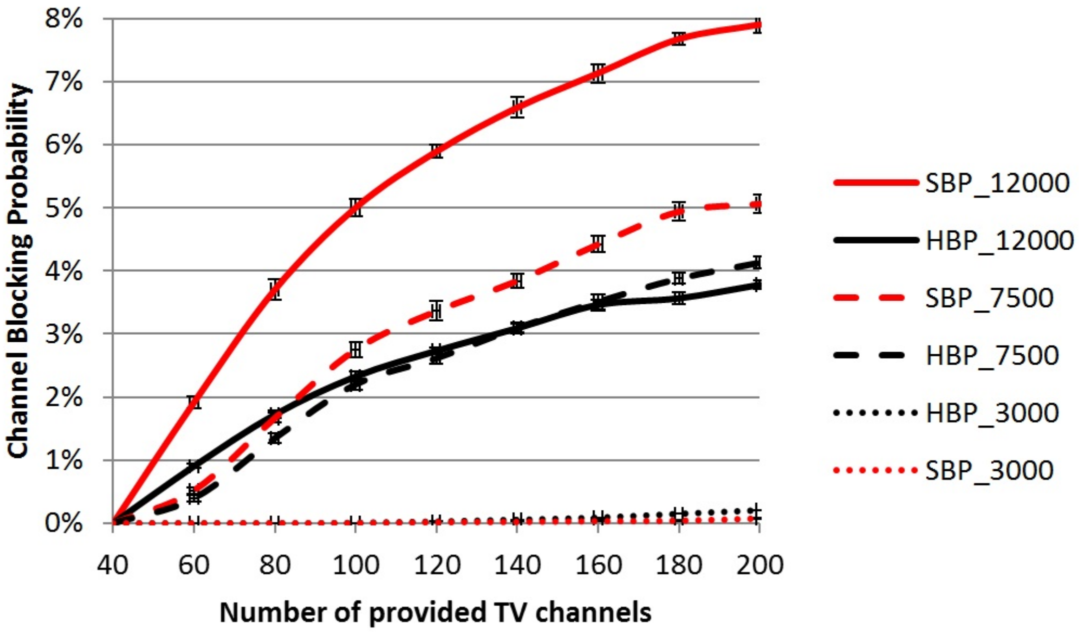

FIGURE 4.15: HBP and SBP for 2 lanes highway results against number of TV channels.

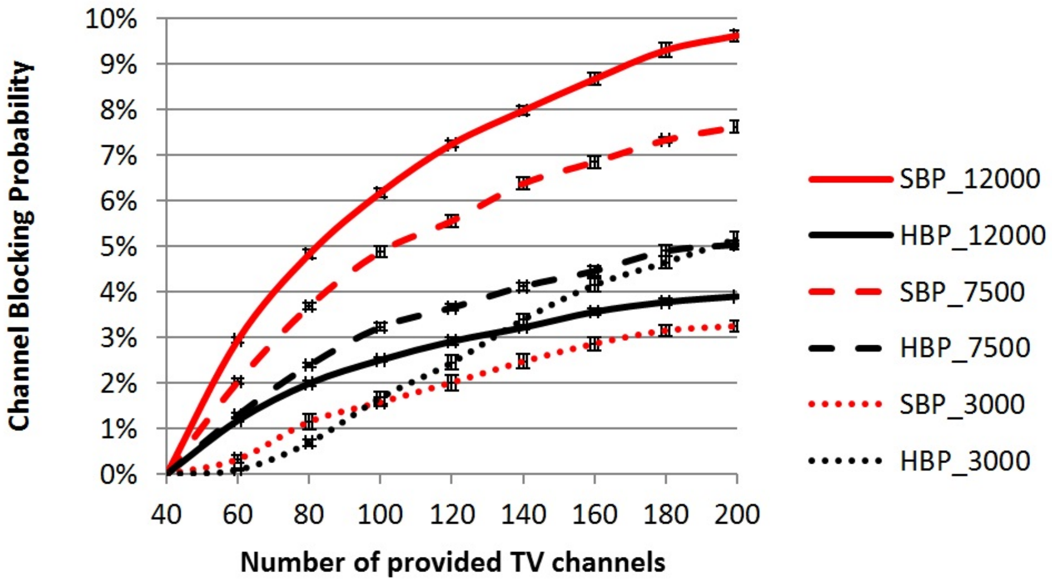

FIGURE 4.16: HBP and SBP for 3 lanes highway results against number of TV channels.

- **A4:** When the probability of IPTV users (α) decreases, all the blocking events (CBP, HBP and SBP) will decrease and CA will increase.

Therefore by reducing the value of α from 0.2 to 0.1, we can satisfy the acceptable 1% threshold for more IPTV users in a cell with the smaller value of α. Therefore, we observe that:

- For 12km cell size: assuming a 3 and 2 lanes highway scenario the number of TV channels (N) which still can be provided with sufficiently high availability is about N=48 (for 3 lanes) and N=75 (for 2 lanes).
- For 7.5km cell size: a 3 lanes highway requires N $\leq$ 68, and for 2 lanes, N $\leq$ 100 to be still acceptable.
- For 3km cell size, for 2 lanes as well as for 3 lanes highway, we even don't have any serious blocking events.

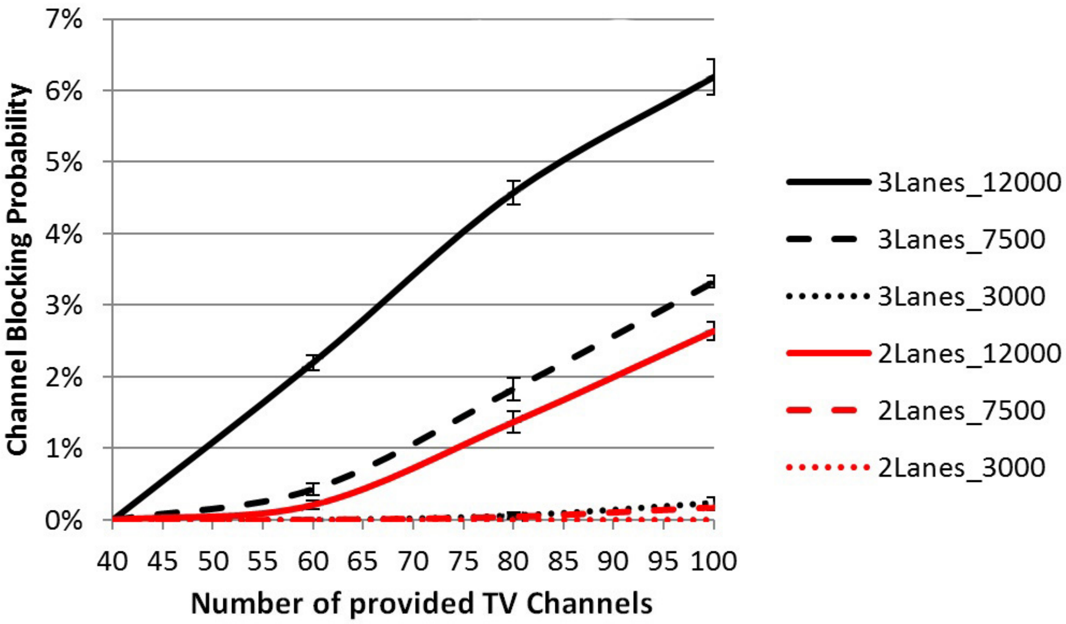

Figure 4.17: CBP results against number of TV channels.

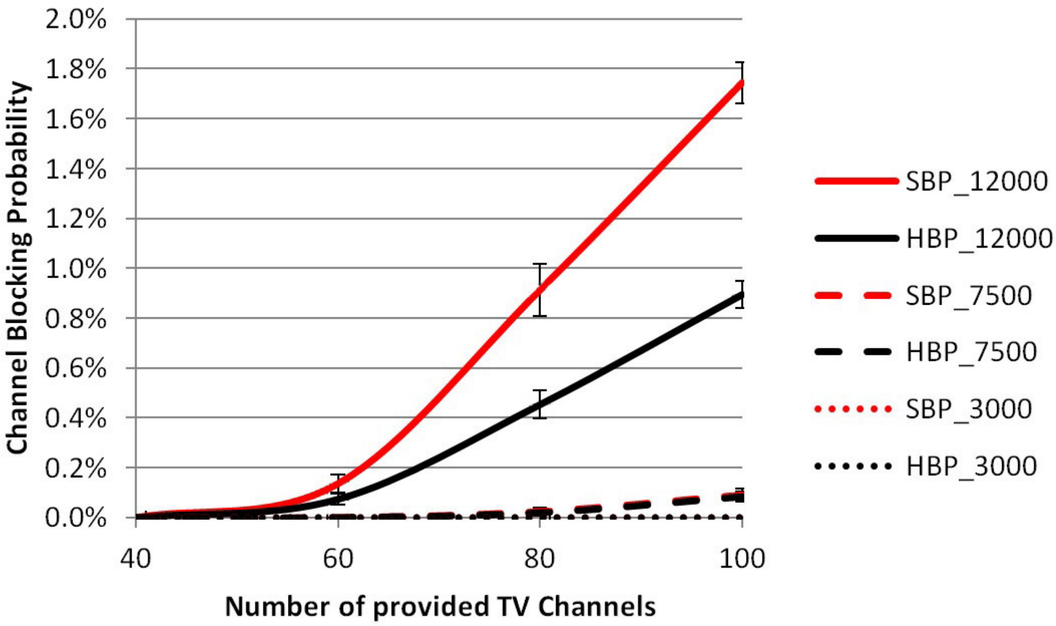

Figure 4.18: HBP and SBP for 2 lanes highway results against number of TV channels.

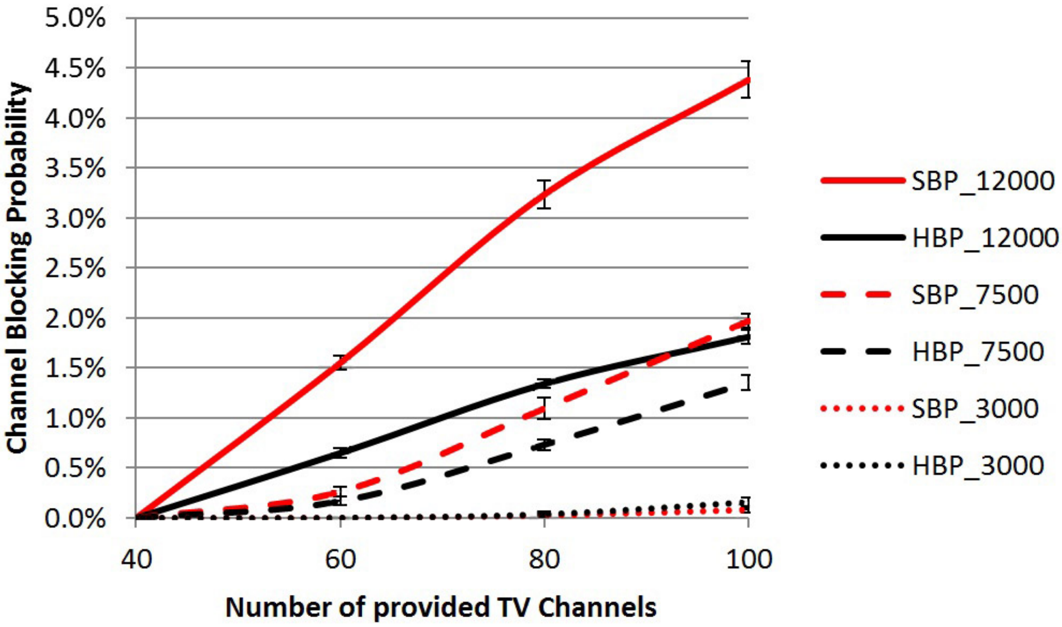

Figure 4.19: HBP and SBP for 3 lanes highway results against number of TV channels.

Chapter 5

An Analytical Model to Assess IPTV Service Availability

Up to this chapter, this thesis tried to predict IPTV service availability based on a rather detailed simulation model, which takes into account the behavior of IPTV users in detail. In order to simplify the availability predictions considerably, the supervisor of this thesis (Prof. Bernd E. Wolfinger) together with the author of this thesis et al. decided to elaborate a less detailed, but at the same time also much less complex, analytical model. The main results with respect to this analytical model have already been published in [4, 109, 110].

To the best of our knowledge, up to now, there are not any other studies for predicting QoE for vehicular IPTV services by means of an analytical model.

In this chapter, we want to summarize in a rather condensed manner our analytical model which allows us to estimate the blocking events regarding switching request or handover process for vehicular users in order to evaluate the availability of vehicular IPTV services [109]. We investigate the assessment of IPTV service for vehicular users in typical highway scenarios. In this chapter, besides elaborating our analytical model we introduce new measures for QoE. Our QoE measures are able to cover both, individual as well as the complete set of vehicular IPTV users. Finally, we present the successful validation of our analytical model by means of simulation at the end of this chapter.

To evaluate the analytical model, we apply the method of Monte Carlo simulation. Therefore, we could call our analytical model also a hybrid model (i.e. combination of analytical and simulation model). In any case, we stay with the notion of "analytical model" because all parts of our analytical model are strictly based on mathematical calculations.

5.1 Requirements and Basic Assumptions

At the first, to introduce the analytical model, some preparations have to be realized. These parameters are directly underlying our analytical model and in general they can be divided into the following three categories:

- Traffic-related parameters.
- Access networks parameters.
- IPTV service parameters.

Table 5.1 is given to simplify the understanding of our text.

TABLE 5.1: Analytical model variables and parameters.

Class	Notation	Description
Traffic-related parameters	k	Number of lanes in each direction of the highway
	L_i	Each lane of the highway
	v_i	Speed of a vehicle in each L_i, assumed to be constant for each L_i [km/h]
	d_i	Distance between two adjacent vehicles in L_i, assumed to be constant for each L_i [m]
	$d_{min,i}$	minimum acceptable distance between adjacent vehicles in L_i [m], it is dependent on v_i and d_i
Access networks parameters	c_r	Radius of the cells [m]
	BW_c	Maximum bandwidth available in a cell to distribute TV channels, assumed to be constant
	N_c	Number of IPTV users in a cell
IPTV service parameters	N	Number of TV channels offered in total
	α	Probability that a vehicle will use IPTV service
	p_i	Probability that channel i is required according to the Zipf distribution with parameter θ

5.2 Measures to Assess IPTV Service Availability

With our analytical model, we can determine all the QoE measures for the IPTV users. In the analytical model, we distinguish between measures which are related to the set of all IPTV users and those which concern only individual users. Therefore, we are able to measure the QoE for both, individual users and also all the users together. One of the advantages of applying the analytical model to assess the availability of IPTV services for vehicular users is to execute a large variety of scenarios with different levels of traffic utilization, various characteristics of wireless access networks used or different IPTV user behavior.

These measures will be interesting for the IPTV service providers. With these measures, providers are able to offer an acceptable level of QoE for all users which is quite valuable for each service provider.

5.2.1 QoE Measures Related to All Users

To calculate the characteristics and QoE measurements for all the users, at the first we need to define a time interval T for offering the IPTV service for all the users.

$$T = [t_1, t_2], \quad t_2 > t_1, \quad |T| = t_2 - t_1 \tag{5.1}$$

Let furthermore denote:

- *nr(T)*: *number of* all *channel requests* issued by all users in interval T.
- *nb(T)*: *number of* all *channel requests* which cannot be satisfied by the IPTV service provider and they are *blocked*. They were issued by all users in interval T.
- $nr_h(T)$: *number of handover-related requests* issued by all users in interval T.
- $nr_s(T)$:*number of switching-related requests* issued by all users in interval T.

Therefore,

$$nr_h(T) + nr_s(T) = nr(T). \tag{5.2}$$

Moreover:

- $nb_h(T)$: *number of* blocked *handover-related requests*
- $nb_s(T)$: *number of* blocked *switching-related requests*

Therefore,

$$nb_h(T) + nb_s(T) = nb(T). \tag{5.3}$$

Now, based on these variables, we can define a set of channel blocking frequencies for interval T:

- $CBF(T) \triangleq \frac{nb(T)}{nr(T)}$ which we call *overall channel blocking frequency*
- $HBF(T) \triangleq \frac{nb_h(T)}{nr(T)}$ called *handover-related channel blocking frequency*
- $SBF(T) \triangleq \frac{nb_s(T)}{nr(T)}$ called *switching-related channel blocking frequency*

We now assume the limit $|T|\to\infty$ and get:

- $CBP \triangleq \lim_{|T|\to\infty} CBF(T)$ called *overall channel blocking probability*
- $HBP \triangleq \lim_{|T|\to\infty} HBF(T)$ called *handover-related blocking probability*
- $SBP \triangleq \lim_{|T|\to\infty} SBF(T)$ called *switching-related blocking probability*

and finally we define channel availability (CA) for all users as:

$$CA \triangleq 1 - CBP. \tag{5.4}$$

5.2.2 QoE Measures Related to Individual Users

In this section, we will elaborate our analytical model which focuses on the assessment of those QoE measures for individual users. Evidently, QoE measures for individual users are dependent on the driving behavior of the car, and QoE is related to the speed of the car in which IPTV is used. The QoE measures for individual users allow us to carry out very specific evaluations such as finding out the mean number of blockings to be expected per hour and per IPTV user, which evidently is related to the vehicle velocity of v (km/h). In this subsection, we are going to introduce the parameters and variables regarding the QoE measures.

- $bph(v)$: *Expected number of channel blockings per hour* experienced by a user permanently using the IPTV service and driving *at a* constant *speed of* v.

- bph_s : *Expected number of switching-related blockings per hour* experienced by a user permanently using the IPTV service.
- $bph_h(v)$: Similar to bph_s but now for *handover-related blockings per hour* (instead of switching-related blockings).

In our new measure, the speed v of a vehicle has a direct impact on the number of handovers per hour. Evidently, speed plays a major role in calculating the Δ_{ho} which is the time between successive handovers for a vehicle with a speed of v for driving through a cell with diameter $2{\cdot}c_r$.

$$\Delta_{ho} = \frac{2 \cdot c_r}{v} \frac{[km]}{[km/h]} = \frac{2 \cdot c_r}{v}[h]. \tag{5.5}$$

This formula shows that bph_h is a function of v. If the value of CBP which is experienced by the IPTV users in different vehicles during one hour is identical, then bph_s remains independent of v. In our studies, we assume that the CBP value of adjacent cells will remain identical if the traffic scenario, the access network and the IPTV service characteristics of both cells stay identical.

5.3 The Analytical Model Elaborated

Our analytical model to determine the availability of IPTV services over vehicular networks is based on the following five steps:

STEP1: Determining the number of IPTV users

The first step is to determine the mean number of IPTV users N_c to be expected in the wireless cell considered. N_c is dependent on the traffic scenario, the cell diameter and the percentage of IPTV usage (α). In other words, N_c is actually a function of k, d_i and c_r. The first step for evaluating the QoE of IPTV services by means of our analytical model is to find out the value of N_c. The expected number N_c of IPTV users in a cell can be derived in a straightforward manner as follows:

We assume a cell with a diameter of $2{\cdot}c_r$, which overall contains *2k* lanes (k lanes in each direction) denoted by L_i, i.e. $i \in \{1, 2, ..., 2k\}$. We also assume d_i as a mean distance between adjacent vehicles (driving on L_i) in the cell. Therefore, we can predict the number of vehicles on each lane according to the:

$$N^{\underline{o}}\, of\, cars\, per\, L_i = \frac{2 \cdot c_r}{d_i}.$$

Then, we need to figure out the number of IPTV users per lane which is related to the percentage of IPTV usage:

$$N^{\underline{o}}\, of\, IPTV\, users\, per\, L_i = \alpha \cdot \frac{2 \cdot c_r}{d_i}.$$

Now, with considering of k lanes per direction, we can calculate the mean number of IPTV users in each cell. Please take into account that in the following formula $\lceil\ x\ \rceil$ denotes the "ceiling function", which we use to get an integer value for N_c.

$$N_c = \left\lceil \sum_{i=1}^{2k} \alpha \cdot \frac{2 \cdot c_r}{d_i} \right\rceil. \tag{5.6}$$

STEP2: Determining the probability of accessing the different IPTV channels

Let now denote P_i the probability that exactly i different channels would be required to satisfy the current demands of all users in the given cell.

In STEP2, we are going to determine the probabilities P_i for given total number of channels N and we assume N_c IPTV users in the cell. Evidently, i is the number of different channels which is required to satisfy the channel requests of N_c users in a case of offering N TV channels for the vehicular users. We perform N_c successive draws of TV channels and we repeat our experiment applying Monte Carlo simulation [111], i.e. repeating the draws for numerous times to calculate the probabilities P_i.

If BW_c different channels can be multicasted in parallel, the probability P^* that we get into a state where no bandwidth for a new channel would be available is:

$$P^* = \sum_{i=BW_c+1}^{N} P_i \tag{5.7}$$

Figure 5.1 demonstrates the P^* according to the STEP2 by way of example. Our assumptions in this figure are as follows:

- $N = 50$
- $BW_c = 30$
- $N_c = 150$
- P_i, $i \in \{1, 2, ..., 50\}$.

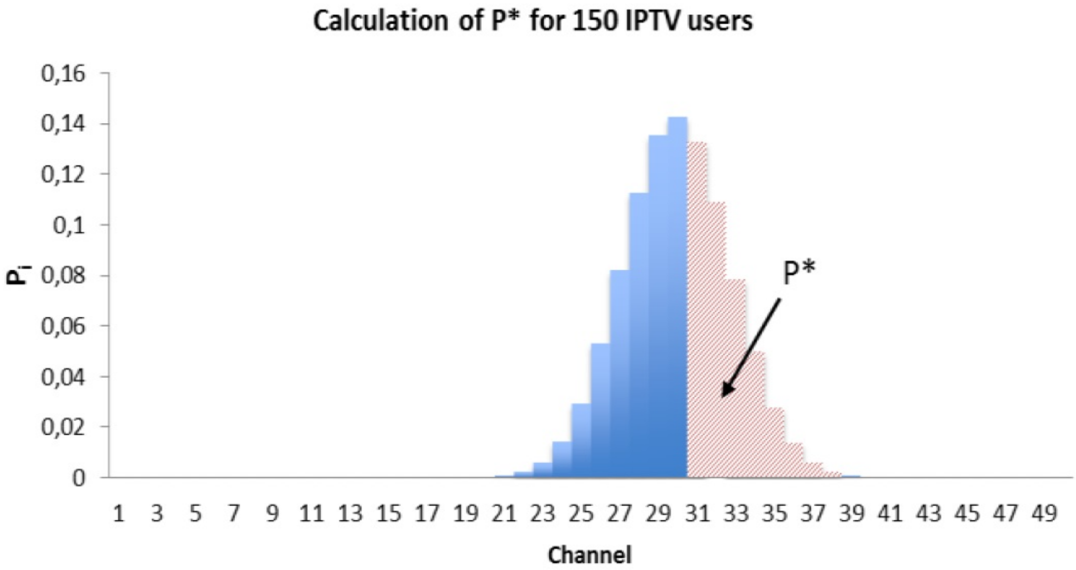

FIGURE 5.1: P^* for $N = 50$, $BW_c = 30$ and $N_c = 150$ according to STEP2 ([4]).

STEP3: Determining the CBP

The aim of the third step is to determine the channel blocking probability (CBP) by means of Monte Carlo simulation. We assume CBP = CBP(N_c) for a given number N_c of IPTV users which we have calculated in STEP1. CBP(N_c) will be dependent on total bandwidth (BW_c), the total number of TV channels which is offered by the service provider (N) and also depend on the specified user behavior.

By observing the CBP for a given traffic scenario, we realized that the value of CBP would evolve over time and the amount of CBP will tend to decrease. Therefore, it is needed to divide the CBP into two phases namely an "*early period*" (or "early phase") and a "*late period*" (or "late phase").

This classification for CBP is because in the early phase there is a chance for choosing an unpopular channel by a user. However, after a while in the late phase, all the popular channels tend to be transmitted in the cell and thus BW_c is allocated to the popular channels. Therefore, according to the channel popularity, the users tend to ask for popular channels which are already available in the cell. Hence, in this situation at late phase the channel blocking probability (CBP) will decrease in comparison with the early period.

In this step we divide our analytical model into the two submodels for the observed traffic situation:

- Early period for example during the 1^{st} hour of simulation time.

- Late period for example during 4^{th} to 5^{th} hour of simulation time.

However, in the real world for observing the traffic situation, it is important to know that the situation will not remain the same after the 5 hours because of the peak hour traffic situation or traffic situation at night.

(a) *Late period of traffic scenario observed*

The probability (CBP) that a newly requested channel cannot be delivered when there is not any free capacity for broadcasting the new request according to the late period of our analytical model, will be calculated as follows: We determine the probability (CBP) that a newly requested channel cannot be delivered which happens with probability

$$CBP(N_c) = P^* \cdot \sum_{j=BW_c+1}^{N} p_j, \tag{5.8}$$

where p_j denotes the watching probability of TV channel C_j.

(b) *Early period of traffic scenario observed*

We now propose our second analytical model, again based on Monte Carlo simulation, to find out the channel blocking probability for the early period of traffic scenario observed. In this model, we need also P^*, according to the STEP2 (formula 5.7).

With this model, we determine the probability that a newly requested channel cannot be delivered to the first IPTV user when the user switches his/her channel at the bottleneck situation. Bottleneck situation happens when the total bandwidth is allocated to BW_c different TV channels and there is not enough bandwidth to transmit the new channel in parallel. Obviously, this situation happens very early at an early period of our observation time interval.

We define some parameters (needed to calculate the channel blocking probability in early period) as follows:

- $Z_i \triangleq$ mean number of draws (of desired TV channels) until i different channels are required for the first time (similar to the way we calculate P^*).
- $Z^* \triangleq$ the mean number of draws until the complete bandwidth BW_c will be exhausted for the first time, i.e. $Z^* = Z_i$ with $i = BW_c$.

Then, a specific channel C_j being requested during the $(Z^*+1)^{th}$ channel switching event, during a situation when the complete bandwidth is exhausted, will be unavailable, *iff* channel C_j had not been drawn during the first Z^* draws but it is desired just now. This happens with probability: $p_j\ (1-p_j)^{Z^*}$, as we assume independent behavior of IPTV users.

Therefore,

$$CBP(N_c) = P^* \cdot \sum_{j=1}^{N} p_j \cdot (1-p_j)^{Z^*}. \tag{5.9}$$

Obviously, we need the N_c in the early phase, while P^* which is used on the right-hand side of formula (5.9) is dependent on the number of IPTV users in the cell (N_c).

STEP4: Determine the rate r_s

In STEP4, we are going to determine the rate r_s for a given user. The r_s refers to the switching-induced blockings per hour and it is dependent on ΔT (given in [h]) which denotes the mean time between successive channel switching events. The mean number of switching events per hour is $\frac{1}{\Delta T}$ and accordingly r_s will be calculated as:

$$r_s = bph_s = \frac{1}{\Delta T} \cdot CBP \left[\frac{blockings}{h}\right] \tag{5.10}$$

STEP5: Determine the rate r_h

In STEP5, we want to figure out the rate r_h, for a given user driving at a speed of v. The r_h refers to the handover-induced blockings per hour and it is dependent on the cell diameter besides the car speed. The mean number of handover events per hour is $\frac{v}{2 \cdot c_r}$ and accordingly r_h will be calculated as:

$$r_h = bph_h(v) = \frac{v}{2 \cdot c_r} \cdot CBP \left[\frac{blockings}{h}\right] \tag{5.11}$$

STEP6: Determine the number of channel blockings

In this subsection, we want to determine the expected number of channel blockings per hour for an individual user. This number of channel blockings can be calculated as follows:

$$bph(v) = bph_s + bph_h(v). \tag{5.12}$$

5.4 Model Test and Validation

We proposed our analytical model which is based on the two variants, early and late period models. These two models cover completely different periods of the traffic scenario. Table 5.2 summarizes all the QoE measures determined based on our analytical model. The validation of our analytical model relies on tests. Several tests were run on our analytical model by means of the Monte Carlo simulation tool and comparing outputs obtained with sets of experimental boundary conditions for which results can be calculated by hand. In some cases, the comparison can prove that we gain a perfect agreement between the model results and the results expected a priori. Since our goal of this comparison is to validate the prediction accuracy of our analytical model, we find out now that our model is sufficiently realistic.

In this section, we are going to validate our analytical model with a set of experiments. Our main goal is to find out if our new model is sufficiently valid. Therefore, we compare the results from the analytical model with our existing simulator which we had developed to support our research on IPTV service availability in vehicular networks in the past [46, 47, 100]. We have also explained this simulator tool in Chapter 3 in detail.

For validating the analytical model, we perform two sets of experiments. We divided these experiments into the series I and II (5.4.1 and 5.4.2). In each series, we distinguished the results in the early period and late periods obtained by using the analytical model and the simulation model.

Our assumptions in all the experiments are given in Table 5.3.

5.4.1 Series I of Validation Experiments

The objective of series I of validation experiments is to figure out whether our analytical models are close enough to reality. To answer this question, we varied the cell sizes and at the same time we kept the traffic situation and the characteristics of the IPTV service constant. So, all other assumptions regarding traffic on the motorway, the wireless network used and characteristics of the IPTV service offered were the same both for the simulation model and the analytical model.

We assume the traffic parameters as illustrated in Table 5.4.

The other assumptions for the analytical model and the simulation model are given as follows:

- Simulation model:

TABLE 5.2: Measures to assess availability of IPTV service in our analytical model.

Type of User	**Notation**	**Value**
All Users	CBP	$P^{*}=\sum_{i=BW_c+1}^{N} P_i$
		Late Period: $CBP(N_c)= P^{*} \cdot \sum_{j=BW_c+1}^{N} p_j$
		Early Period: $CBP(N_c)= P^{*} \cdot \sum_{j=1}^{N} p_j \cdot (1-p_j)^{Z^{*}}$
	SBP	$lim_{\|T\| \to \infty} \frac{nb_h(T)}{nr(T)}$
	HBP	$lim_{\|T\| \to \infty} \frac{nb_s(T)}{nr(T)}$
Individual User	$bph(v)$	$bph_s + bph_h(v)$
	bph_s	$bph_s = r_s = \frac{1}{\Delta T} \cdot CBP \left[\frac{blockings}{h}\right]$
	$bph_h(v)$	$bph_h(v) = r_h = \frac{v}{2 \cdot c_r} \cdot CBP \left[\frac{blockings}{h}\right]$

Table 5.3: Parameter values for all the validation experiments.

Notations	Descriptions	Values
N	Number of TV channels offered in total	100
BW_c	The overall bandwidth reservation for IPTV service	40
k	Number of lanes in each direction of the highway	3
θ	Zipf parameter	1.3

Table 5.4: Parameter values for Series I of validation experiments.

Notations	Descriptions	Values
v_i	Speed of a vehicle in each lane i per direction [km/h]	90, 120, 150
d_i	Distance in lane i between two adjacent vehicles [m]	15, 20, 25
c_r	cell size radius	3 km, 5 km, 7 km

- Behavior of individual users was modeled in detail.
- Collecting the results in the simulation model starts directly after the end of the initial transient phase. For this purpose we introduce Δt as follows:

  $t_0 \triangleq$ Instant directly after transition phase when the system arrives in its steady state.

  The simulation results which we observed in the early period were taken from the time interval [t_0, t_0+30min] and for a late period from the interval [1h, 2h]. Therefore, the total observed period for collecting the results is [t_0, 2h].

- Analytical model:
  - Behavior of individual users was NOT modeled but only their aggregated behavior, in particular a value $\Delta T = 1/20[h] = 3[min]$ was chosen.

The obtained results from analytical model and simulation model are given in Table 5.5. As can be seen, the results for the analytical model are divided into the two columns named AM_e and AM_l, for early and late periods. *SM* represents the obtained results from the simulation model. As demonstrated in Table 5.5, the results for AM_l as we expected a priori are always smaller than the AM_e results. Because, in the late period, most of the popular channels are broadcasted in the cell and there is a greater chance that other users select the channel among the currently already broadcasted channels.

TABLE 5.5: CBP results for AM_e, AM_l and SM models and the deviations in Series I.

Series I					
	CBP [%]			Deviation [%]	
c_r [km]	AM_e	AM_l	SM	Relative	Absolute
3	8.716	5.833	2.916	50.009	2.917
5	12.644	8.463	6.75	20.241	1.713
7	12.645	8.464	8.393	0.839	0.071

Moreover, AM_l value is much closer to the simulation model SM in all the experiments. On the other hand, AM_e values typically represent an upper bound for the CBP values in all the experiments since there is a chance that some unpopular channel occupy the bandwidth capacity and there was no free bandwidth to broadcast the popular channels. Hence, we would recommend to the IPTV service providers to use the AM_e as a rather reliable upper bound for CBP.

Relative deviation and absolute deviation are also calculated in Table 5.5. These amounts will be obtained as follows:

- Relative deviation between CBP of AM_l and SM is calculated as follows:

$$RelativeDeviation[\%] = \frac{CBP(AM_l) - CBP(SM)}{CBP(AM_l)} \cdot 100[\%] \tag{5.13}$$

  and accordingly,

- Absolute deviation between CBP of AM_l and SM is calculated as follows:

$$AbsoluteDeviation[\%] = (CBP(AM_l) - CBP(SM)) \cdot 100[\%] \tag{5.14}$$

Now for validating the analytical model by means of comparing it with a simulation model, in Table 5.5, the amount for a late period (AM_l) by the means of relative deviation parameter for $c_r = 3$ km is large and suspicious. However, with increasing the cell size relative deviation reaches a better value and for $c_r = 5$ km this value becomes acceptable and for $c_r = 7$ km, the agreement between CBP (AM_l) and CBP(SM) is perfect. Anyway, for this validation, it is important to remind that CBP(SM) is not a point but rather a confidence interval of a non-negligible size which makes deviations even more acceptable.

5.4.2 Series II of Validation Experiments

Evidently, in series I, the relative deviation for AM_l for $c_r = 3$ km was pessimistic, and we are going to fix this in Series II. In this validation experiment, we vary the traffic

TABLE 5.6: Parameter values for Series II of validation experiments.

Traffic Situation	Notation	Values
Low Utilization	v_1, v_2, v_3	80, 130, 150
	d_1, d_2, d_3	30, 40, 50
Medium Utilization	v_1, v_2, v_3	80, 100, 120
	d_1, d_2, d_3	20, 30, 40
High Utilization	v_1, v_2, v_3	10, 15, 20
	d_1, d_2, d_3	10, 15, 20

situation on the motorway. We observe the blocking events for three different traffic situations. Apart from traffic situation which has been summarized in Table 5.6, all the other assumptions here are the same as in series I of the validation experiments. The comparisons between AM_e, AM_l and SM are also analogous to those of Series I.

Table 5.7 illustrates the CBP results of series II of validation experiments. As demonstrated, the results for low and medium utilization are completely perfect and there is an accurate agreement between CBP(AM_l) and CBP(SM) as even the first digit after the comma is identical. The amount of -800 for the relative deviation in the case of low traffic utilization is only because the value of AM_l and SM are very close to each other. Even, for high utilization, the relative deviation may still be acceptable. Again, one should be taking into account the fact that there is uncertainty in CBP(SM), cf. non-negligible confidence interval size.

TABLE 5.7: CBP results for AM_e, AM_l and SM models and the deviations in Series II.

SERIES II					
	CBP [%]			Deviation [%]	
Utilisation	AM_e	AM_l	SM	Relative	Absolute
Low	0.004	0.002	0.018	(-800)	-0.016
Medium	0.633	0.424	0.422	0.472	0.002
High	12.536	8.398	5.626	33.008	2.772

Finally, to conclude from these two series of validation experiments, we can say that, we had a perfect agreement in three of six scenarios investigated. We have got also pessimistic results for AM_l from the three other scenarios, but still applicable to estimate CBP with reasonable precision. We performed several additional validation experiments in which we observed similar deviations. Though, in all of our validation experiments, the absolute deviation between CBP(AM_l) and CBP(SM) was less than 3% and in most cases even less than 2% which can be judged as rather good news.

In this chapter, we have investigated the quality of experience (QoE) of IPTV services in vehicular networks from the point of view of human end users. Unlike Chapter 3, which was based exclusively on simulation models, in this chapter with our analytical model (which includes two submodels for early period and late period) we are able to predict the comprehensive QoE easily for IPTV usage in vehicular networks. We have also validated our analytical model by means of comparing it to our significantly more detailed and therefore more realistic simulation model.

Chapter 6

Case Studies based on the Analytical Model

In Chapter 5, we presented our analytical model in detail with an in-depth validation and testing of this model. In this chapter, we are going to conduct extensive case studies to demonstrate how the analytical model and our new QoE measures can be applied successfully for the dimensioning of IPTV systems. In particular, we now present two case studies based on our analytical model. The objective of our analytical model is to estimate the availability of IPTV services in vehicular networks for a broad diversity of scenarios. The variety of traffic scenarios is quite relevant to the QoE requirements of the IPTV service for vehicular users. Moreover, with these availability predictions, service providers are able to provide an acceptable level of QoE for their IPTV users.

In this chapter, we present Case Studies I and II (in Sections 6.1 and 6.2) to predict the availability of an IPTV service for very different traffic scenarios and network technologies.

6.1 Case Study I: Blocking Probability in Different Traffic Scenarios

In the first case study, we are going to evaluate the impact of a varying number of offered IPTV channels on the QoE for IPTV subscribers in vehicular networks. In the case study I, we will assume very different traffic scenarios. This is interesting for IPTV service providers, because they can evaluate the IPTV availability for subscribers. Transmitting the IPTV service without any serious blocking events is important. Therefore, it is needed to observe the IPTV service in strongly different traffic scenarios, while in reality traffic situations may diverse a lot during a time interval with a duration of, e.g. 1 hour

Table 6.1: Traffic situations and values for Case Study I.

Traffic Situation	Notation	Values
Low Utilization	v_1, v_2, v_3	80, 130, 150
	d_1, d_2, d_3	30, 48, 56
Medium Utilization	v_1, v_2, v_3	80, 100, 120
	d_1, d_2, d_3	30, 37, 45
High Utilization	v_1, v_2, v_3	10, 15, 20
	d_1, d_2, d_3	10, 10, 15

or more. In particular, at early periods of a traffic scenario, it is more important to provide QoE for the users. Especially, in the early period, there is a chance that the popular channels are not available yet and accordingly the blocking of requests may happen more often during this period than later on.

Therefore, with this situation predicting the blocking probability in an IPTV system may be particularly relevant for IPTV service providers in order to provide an acceptable level of QoE.

Hence, the objective of this case study is to determine the relation between an increasing number of offered IPTV channels and the QoE measures in a cell with fixed bandwidth. In our analytical model determining the QoE is possible based on the bph_s and $bph_h(v)$ parameters, which we described in detail in Section 5.2.2 for modeling the early and late period in different traffic scenarios.

In our analytical availability predictions we will observe bph_s and $bph_h(v)$ separately, since our analytical model allows us to discuss the results with respect to different QoE thresholds for both values.

Our traffic situation is based on three different traffic situations as follows:

All the assumptions in case study I are summarized in Tables 6.1 and 6.2. According to our expectation, increasing the number of channels the probability of blocking events as predicted by bph_s and $bph_h(v)$ will grow. This happens because, if we assume that bandwidth is fixed, by increasing the N the probability that a requested channel is not available yet will be increased. In the following two subsections we discuss the results of bph_s and $bph_h(v)$ separately.

6.1.1 Results Obtained for bph_s and their Interpretation

Figure 6.1 (cf. also [109]) illustrates the results for bph_s for both of our analytical models. The results in this figure include a QoE threshold for switching-induced blockings per

TABLE 6.2: Parameter values and notations for Case Study I.

Notations	Descriptions	Values
N	Number of TV channels offered in total	40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150
k	Number of lanes in each direction of the highway	3
c_r	cell size (radius)	5 km
BW_c	The overall bandwidth reservation for IPTV service	40
θ	Zipf parameter	1.3
α	Probability that a vehicle will use IPTV service	0.1
ΔT	The mean time between successive channel switching events	1/20 [h] (= 180 [s])

hour of using the IPTV service without pauses.

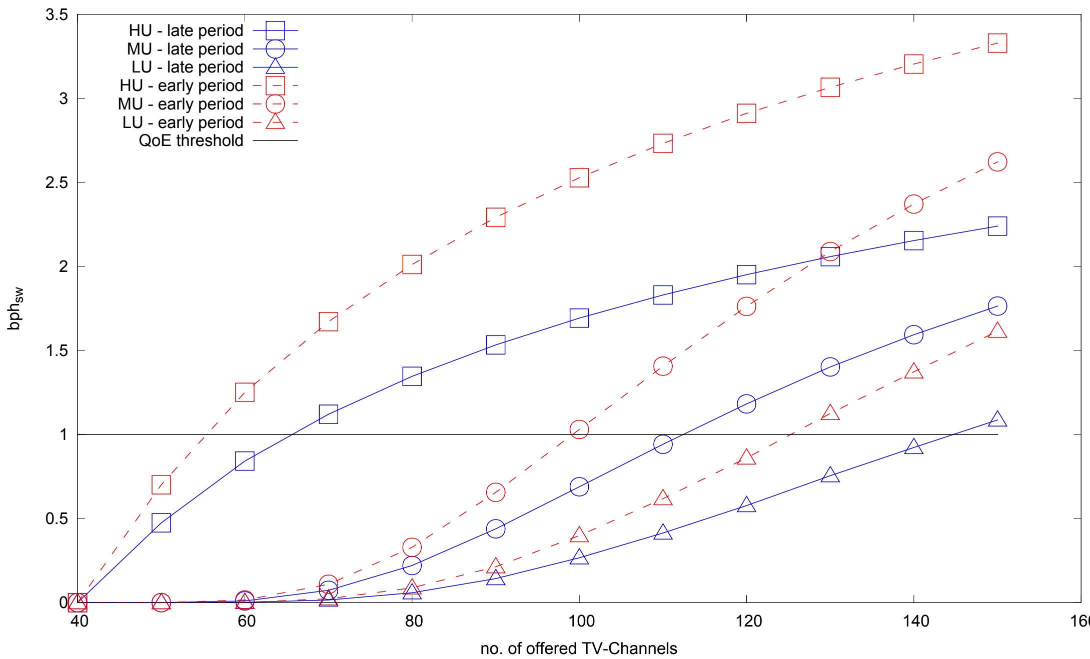

FIGURE 6.1: bph_s results against the number of TV channels for early and late periods.

For presenting the obtained results from Figure 6.1, we have decided to split our result interpretation into four different parts. First of all, we want to consider the differences between the various traffic scenarios. Then we are going to compare the number of blockings per hour as predicted by our two analytical models for early and late periods, which we will call "*submodels*" in the following. Then, we will observe the impact of a growing number of offered channels, on the results. Finally, we discuss the implications for the QoE threshold introduced in this figure.

1. Obviously, by raising the number N of offered TV channels in a case that the total bandwidth in the cell is fixed, the bph_s will significantly increase in both submodels. Moreover, as can be seen in this figure, by increasing the value of N in both submodels the HU and MU curves are approaching relatively close to each other, which is an unexpected behavior.

2. The results in Figure 6.1, illustrate the impact of the different traffic scenarios on the QoE measure bph_s. Moreover, from the point where a blocking situation occurs, the curves for high utilization, medium utilization and low utilization are on top of each other. In their respective submodels for both late and early periods they never cross each other and the curve for HU is always above the curve of MU, which itself is always above the curve of LU. This was to be expected: Higher utilization implies more subscribers which leads to a greater probability of the occurrence of a blocking situation and therefore also to a greater blocking probability at a switching event.

3. Evidently, by comparing the two submodels we find out that the curves for HU, MU and LU for the early period are always above their counterparts in the submodel covering the late period. The reason for this is that the late period model considers a situation in which the most popular channels tend to be broadcasted already, however the early period model is considering an initial situation, when still quite a few channels with low popularity are broadcasted. It is one of the worst cases in the cell that popular channels are blocked because some unpopular channels are currently transmitted and therefore they consume a precious part of the limited bandwidth. This situation may happen quite often in the early period submodel and therefore blocking in this submodel occurs more often than in the other submodel and the curves are always above the corresponding curves for the late period.

4. In our work, we assume that only one blocking per hour during the channel switching for an individual user is acceptable. Therefore, according to our assumption, we define the QoE threshold in Figure 6.1 to be 1. Evidently, the obtained results in this figure give very precious information what boundary conditions could still allow one to fulfill such a (harsh) QoE requirement. Figure 6.1 covers in detail a lot of different TV channel availability aspects for vehicular IPTV users during their usage of IPTV services. The results include the predicted probabilities of

blocking events when the highway is not densely populated and also during traffic jam situations.

6.1.2 Results Obtained for $bph_h(v_i)$ and their Interpretation

In this subsection, we want to discuss the probability of handover-induced blockings per hour for distinctive lanes in different traffic scenarios. These obtained results are based on our two submodels and they are illustrated in Figures 6.2 and 6.3 (cf. also [109]) respectively for early and late periods. As is evident from the figures, the general behavior of the two submodels by increasing the number of offered channels (N) is identical. A more detailed interpretation regarding these figures will be described in the following:

Figures 6.2 and 6.3 show the blocking probability per hour for distinctive lanes in different traffic scenarios. What is recognizable the easiest is the similarity between both figures. Moreover, we closely study the development of the specific curves due to the rise in the number of offered channels, and we finish our discussion taking a look at the implications of the QoE threshold introduced for handover-induced blockings.

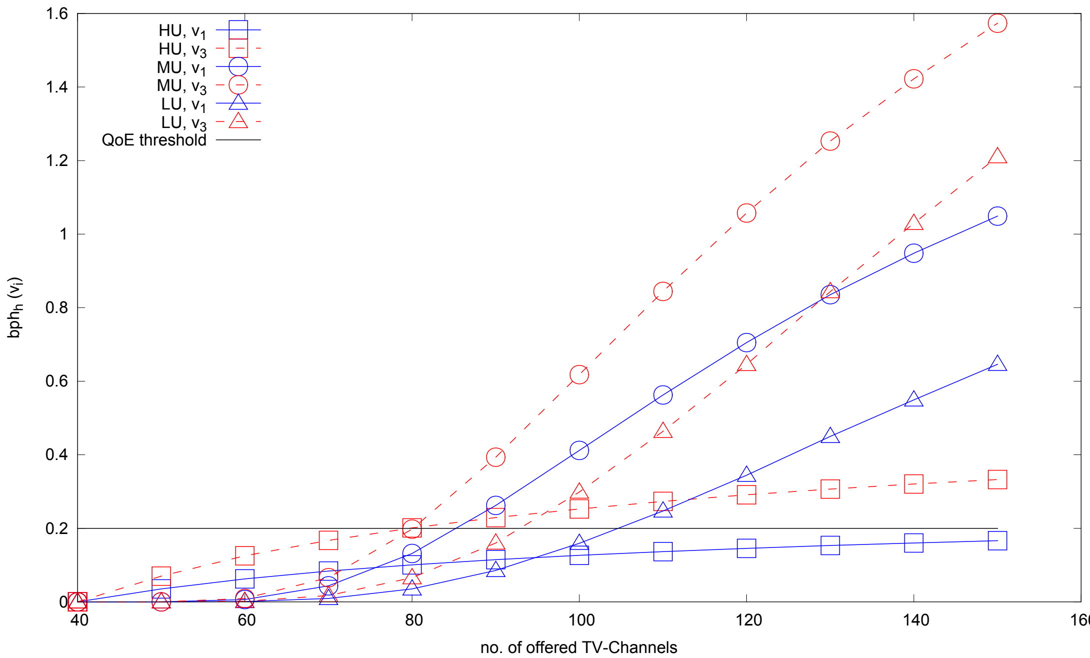

FIGURE 6.2: $bph_h(v_i)$ results against the number of TV channels for early period.

1. According to our assumption, we weighted channel blockings due to handover events as being five times worse than those ones occurring due to channel switching events. Therefore, the acceptable QoE threshold for $bph_h(v_i)$ is less than 0.2 in this case study. This is because loosing the channel during the viewing phase is

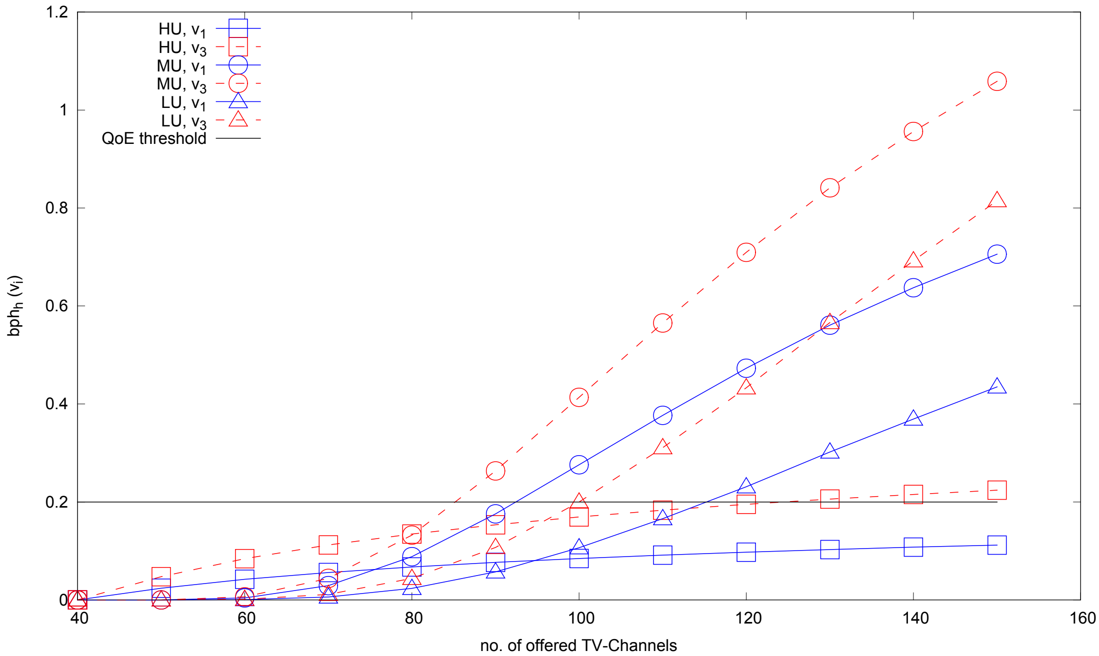

FIGURE 6.3: $bph_h(v_i)$ results against the number of TV channels for late period.

more annoying for users than a channel being temporarily inaccessible during the switching process.

2. As demonstrated in both Figures 6.2 and 6.3, except the values of $bph_h(v_i)$, which are smaller in the late period, all the other behavior of these curves is very similar. When one curve is above, below or intersecting another one at a certain position on the x-axis, the corresponding curve also behaves the same in the other figure. This similarity between these figures was quite unexpected.

3. According to our expectation within their traffic scenario vehicles moving with a faster speed on the inner lanes (v_3) have a greater probability for handover-induced blocking events than the slower vehicles in their respective traffic scenario.

4. In both Figures 6.2 and 6.3, in case of the HU scenario, the values of $bph_h(v_i)$ for speeds (v_1) and (v_3) stays astonishingly small for all N. Moreover, in both figures, the values obtained for the LU scenario remain smaller than those for the MU scenario for (v_1) and (v_3) and again for all N. Last but not least, for N≥100 the $bph_h(v_i)$ values, v_i fixed, are smallest for HU and largest for the MU scenario (with LU values in between). And, again, this holds for both speeds (v_1) and (v_3).

6.2 Case Study II: Impact of Cell Size on CA

The main goal of carrying out case study II is to find out the best access network technology to provide an acceptable level of QoE for IPTV subscribers. The access network technology has a great impact on the channel blocking events because it has a direct impact on the cell sizes. Please take into account that the cell size implies positive and negative effects on the IPTV transmission. Smaller cell sizes, on one hand, make handovers more frequent which may have a negative impact on handover-induced blockings, while on the other hand, smaller cells allow one to allocate the bandwidth to a lower number of subscribers which leads to a reduced CBP value.

In this case study we consider the effect of different cell sizes on both QoE measures bph_s and $bph_h(v)$ in both, early and late period submodels. We are going to find out the acceptable QoE threshold by varying the cell sizes. We predict that in a smaller cell because there exist less subscribers, the blocking probabilities due to channel-switching (bph_s) should stay smaller. In the case study II, the total number of offered TV channels (N) is fixed and we reuse all the boundary conditions, traffic scenarios and parameters that were used in case study I with only two minor changes:

- Constant parameters:
  Number of channels $N = 100$.
- Variable parameters:
  $c_r \in \{3, 4, 5, 7.5, 10\}$ km.
- Throughout the complete Case Study II Medium Utilisation (MU), as defined in Case Study I, was used.

Figure 6.4 (cf. also [109]) represents the bph_s and $bph_h(v_i)$ for different cell sizes. The obtained results from this figure are given as follows:

1. Our prediction that increasing the cell size will increase bph_s, is confirmed by this figure. As it is clear, the results for $c_r = 3$ km, are really near zero and are not visible in this picture. Evidently, in this figure when we increase the cell size, the number of blocking events will increase, too. However, there exists only a relatively small difference between the results for 7.5 km and 10 km cell size. This illustrates that already at 7.5 km a traffic scenario is reached, where a blocking situation is common.

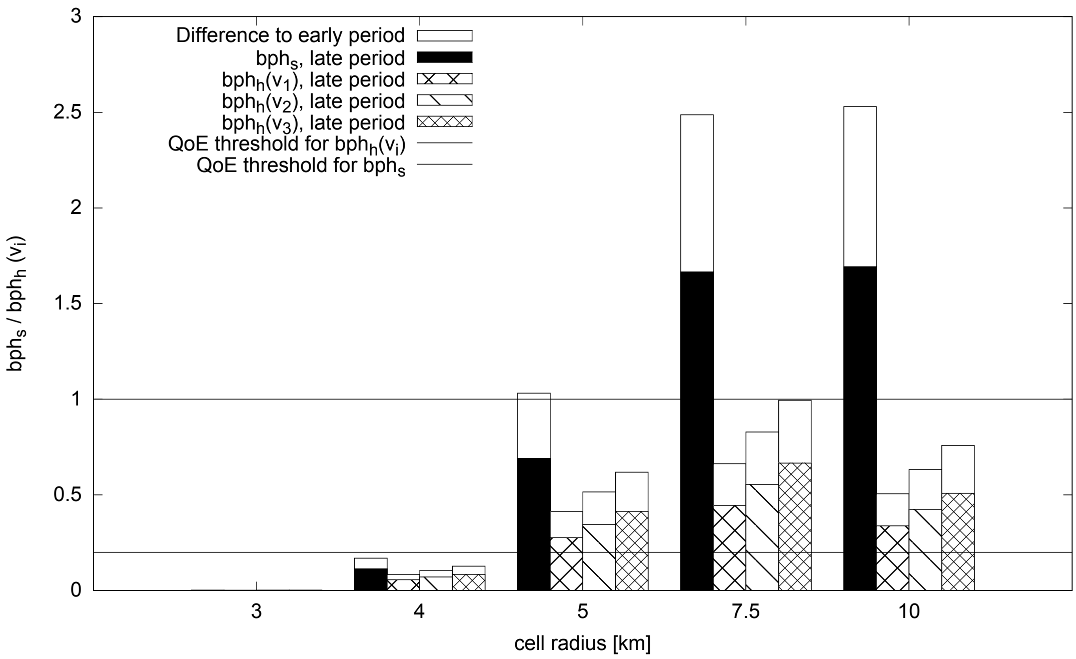

FIGURE 6.4: bph_s and $bph_h(v_i)$ results against the different cell sizes and speed.

2. As shown in Figure 6.4, our expectation regarding the impact of cell size on the $bph_h(v_i)$ is not correct and there is not smaller $bph_h(v_i)$ in bigger cells. Because, by growing the cell, it will be more crowded and accordingly the probability of the occurrence of a blocking situation increases and therefore the probability for blocking events during handover becomes greater when the cell size is increased.

3. As demonstrated in Figure 6.4, we have two different contributions to the overall QoE, characterized by bph_s and $bph_h(v_i)$. For the bph_s threshold, up to a cell radius of 5 km all the submodels with all speeds are acceptable. However, for 7.5 and 10 km radius of cell sizes, bph_s for the late period does not satisfy the threshold limit of 1. For the $bph_h(v_i)$ threshold, only for the radius of cell size $\geq$ 5 km is reaching an acceptable frequency of blocking events.

Case studies I and II, clearly showed that we are able to directly use the analytical models in order to test whether a QoE threshold for switching-induced (bph_s), handover-induced ($bph_h(v_i)$) blocking events will be respected by a given scenario of an IPTV system comprising a specific combination of traffic situation, cell properties and characteristics of the IPTV service. The obtained results from these case studies demonstrated that the number of blocking events might quite significantly differ in the early and the late period of a scenario. Moreover, these results may represent valuable information for IPTV service providers to make decisions related to the provisioning of QoE.

Chapter 7

Reserve Channel Before Handover (RCBH) Algorithm

In this chapter we present the RCBH algorithm to reduce handover-induced blocking by means of a priori bandwidth reservation. Bandwidth resources are precious and scarce in wireless and vehicular networks. Consequently, efficient bandwidth allocation is needed to support service continuity, service availability and guarantee acceptable quality of experience (QoE) for users of vehicular IPTV services. Indeed, the support of uniform broadcasting of IPTV service during the entire course of watching TV programs, whereas the user is on the move by vehicle is a challenging issue. The next generation of wireless networks will support IPTV services that require different QoE requirements according to their usage as a mobile or vehicular user. Therefore, there exists a strong demand for efficient and accurate resource allocation.

Channel blocking or unavailability of IPTV services in vehicular networks may have two reasons:

1. First, a currently watched channel may not be available because of a bandwidth bottleneck in the newly reached cell at the time when a handover occurred. When an IPTV user drives from one cell to a neighboring cell, a handover takes place and the user requests a channel from the new AP, and if all the available resources to transmit channels are busy, handover blocking takes place.
2. Or the second case is when a newly requested channel may not be available (again as a consequence of bandwidth limitations) when a user within his current cell switches to a new TV channel.

It is clear that a handover-related blocking is particularly annoying for an IPTV user, because the channel currently watched suddenly becomes unavailable. This situation is the worst case from point of view of the user with respect to the unavailability of TV channels, because it implies missing the program during the handover process. Therefore, effective management to keep the channel blocking probability small during the handover process of IPTV viewing users plays a significant role. Our primary goal in order to improve QoE of IPTV service is to reduce the probability of handover-related blockings. To the best of our knowledge, no proposal yet exists in the literature which tries to decrease the number of handover-related blockings in vehicular networks offering an IPTV service. Therefore, we are going to reduce the handover-related CBP by reserving the channel currently watched by a user a priori in the neighboring cell that a given car will drive in. When a vehicular user attempts to execute a handover from one cell to the next cell, he may meet channel blocking due to the lack of bandwidth resources in the next cell. From a user's point of view, the blocking of a currently watched TV program is more unpleasant than the blocking of a newly requested program. Therefore, it is highly desirable that a vehicular network must give higher priority to the handover-related TV channel requests as compared to new channel requests. Thus, we propose that handover requests are prioritized over new channel requests.

In this chapter, a new admission control scheme is introduced to provide high QoE for vehicular IPTV users. We present our novel algorithm proposing a priori reservation of TV channels and call this algorithm RCBH (Reserve Channel Before Handover), to give priority to the handover users by reserving the bandwidth during the car journey. Therefore it reduces the Handover Blocking Probability (HBP) accordingly improving Channel Availability (CA) and overall QoE. The main objective of our RCBH algorithm is to allocate the scarce bandwidth carefully between new users (new channel requests) and viewing users during their road trip. Therefore, we focus on the decrease of the HBP as one of the main QoE requirements.

There is an important subject in wireless communication regarding call blocking probability (or forced-termination). In case of lack of bandwidth, handover-related channel requests may be blocked, and therefore QoE or QoS will be decreased. In order to support ongoing calls and prevent the system from potential blocking, Hutchens *et al.* [112], reserved the bandwidth for incoming users from neighboring cells to reduce HBP for different network topologies by means of an adaptive bandwidth reservation algorithm. Oliver *et al.* have also presented a variable bandwidth reservation scheme in [113] to give priority to the handover calls over new calls. They also evaluated their mechanism for significantly decreasing HBP by infinite two-dimensional Markov chains. Epstein *et al.* [114], proposed the admission control of heterogeneous users in a wireless environment. The admission control policies admit both new and handover users. In this hybrid reservation policy, they were combining the complete sharing and the complete partitioning policies. They examined in [114], that this policy is useful to decrease the handover blocking probability. In [115] authors gave priority to handover calls over new calls, such that the handover blocking probability is improved without seriously degrading the switching blocking calls. Naghshineh *et al.* in [116], for limiting the handover blocking probability proposed the call admission control. This call admission control algorithm estimates the possible number of handover users from adjacent cells to make a call admission decision. There are also some other reservation-based efforts to decrease handover blocking probability in the literature [117–123]. In the literature, there are not yet many researches regarding vehicular IPTV services. We have worked on availability of IPTV services over vehicular networks [46, 47, 100, 109], but we are not aware of any research by other authors regarding reserving channel for decreasing handover blocking probability to improve QoE for vehicular IPTV users.

7.1 Quality of Experience Measures with Applying RCBH for IPTV

In a vehicular network with a cellular infrastructure in a motorway scenario, a vehicle can drive along the road, and may undergo a large number of handover events during a car journey. When a user is handed over to a new cell, not enough bandwidth may be left to continue his watching phase of a TV channel due to the lack of network bandwidth in the new cell reached. So, it is possible for service providers to apply the RCBH algorithm to keep the number of handover-induced blockings down. With using the RCBH algorithm the channel will less often be blocked because the channel is already reserved before his/her arrival. Therefore, it is clear that there is a need to develop a “Reserve Channel Before Handover” Algorithm (RCBH) for vehicular IPTV services. The main concept of our RCBH algorithm is giving priority to the handover-related channel requests over new channel requests to enable handover-executing users to watch their program with lower handover blocking probability. Thus, the objective of RCBH is to ensure continuous availability of a channel requested for a longer period (called viewing phase) by a user to increase the QoE for IPTV.

The components and communications between APs and user-devices in the cells enable APs to reserve a priori a channel for a user in neighboring cells. A channel will not be reserved in advance for a zapping user but it is also this chance for them when they are in a switching phase, to switch to already broadcasted or reserved channels. This holds in particular if zapping to specific channels (likewise viewing them) is determined by Zipf’s law, cf. equation 2.4.2.

Our focus on QoE is based on the availability of IPTV services, Therefore to measure QoE, Channel Blocking Probability (CBP) is important for us. We classified the blocking events into two groups, one group due to handover and another one due to channel switching within a given cell. We also need to define some other parameters and assumptions according to the QoE measures. We assume $T = [t_1, t_2]$ as a time interval, where $t_2 > t_1$ and |T| = t_2 - t_1 denotes the length of T.

Let further denote

- nr_h(T),
- nr_s(T),
- nb_h(T),
- nb_s(T),

the number of requests as they were already defined in Chapter 5, Subsection 5.2.1.

Then, we define

$$\text{HBF(T)} \triangleq \frac{nb_h(T)}{nr_h(T) + nr_s(T)}$$

i.e. handover-induced blocking frequency during T (related to all events when a channel is required for a user, either due to handover or due to switching), and

$$\text{SBF(T)} \triangleq \frac{nb_s(T)}{nr_h(T) + nr_s(T)}$$

i.e. switching-induced blocking frequency during T (again related to all events when a channel is required for a user).

We assume that for |T| $\to \infty$ the frequencies converge to the corresponding probabilities and thus we get:

$$\text{HBP} = \lim_{|T|\to\infty} \text{HBF(T)}$$

and

$$\text{SBP} = \lim_{|T|\to\infty} \text{SBF(T)},$$

called *Handover-induced* and *Switching-induced Blocking Probability*, respectively.

And, evidently also

$$\begin{aligned}\text{CBP} = \text{HBP} + \text{SBP} &= \lim_{|T|\to\infty} (\text{HBF(T)} + \text{SBF(T)}) \\ &= \lim_{|T|\to\infty} \frac{nb_h(T) + nb_s(T)}{nr_h(T) + nr_s(T)}\end{aligned}$$

In other words, HBP and SBP are related to the portion of CBP which occurs either as a consequence of blockings at handover events or at switching events. That is why HBP + SBP = CBP. In addition to HBP, SBP and CBP, the general risk of channel blocking during the handover process for a single IPTV is interesting for us. Therefore, we are going to find out this risk in this chapter. We define this risk by HBR, which again is determined regarding a channel blocking probability.

We denote

$$\text{HBR} = \lim_{|T|\to\infty} \frac{nb_h(T)}{nr_h}$$

and call it *handover-related blocking risk.*

Obviously, it is also important for us to discover the risk of a blocking event when a single user switches his/her channel. Thus, we represent

$$\text{SBR} = \lim_{|T|\to\infty} \frac{nb_s(T)}{nr_s}$$

as a *switching-related blocking risk.* It is notable here, that $HBR + SBR \neq CBP$ for $HBR > 0$ and $SBR > 0$.

We are going to find the risk of handover and switching events in this chapter, because with applying our RCBH algorithm we need to find out HBR and SBR to evaluate the QoE.

7.2 Requirements and Basic Assumptions

The proposed RCBH algorithm uses both local and remote information, and allocates bandwidth in the cell where a requested channel receives and reserves bandwidth in the oncoming neighboring cell. When a user moves to a new cell necessitating a channel handover, the reserved bandwidth in the cell that the user is moving into is used to support the handover connection. In addition, every time a viewing user moves to a new cell, bandwidth is reserved in the next new neighboring cell, and the bandwidth for viewing the current channel in the cell which is left at present is released. Further, the proposed algorithm distinguishes viewing users and zapping users, and reduces the

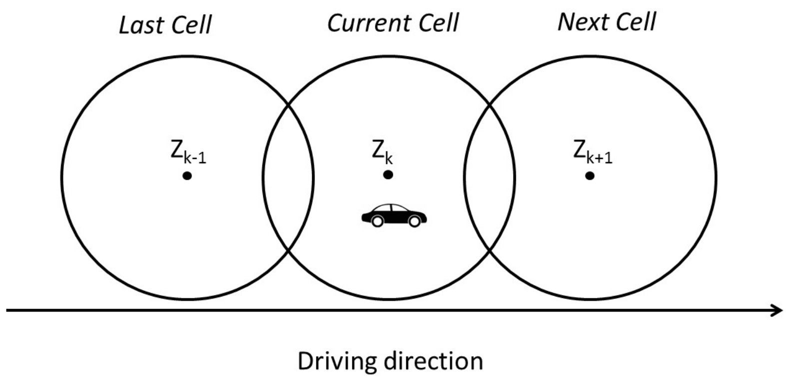

Figure 7.1: Construction of cells and defining driving direction.

priority for assigning bandwidth to zapping users in order to provide higher quality of experience for the viewing users.

7.2.1 Required Structures for the RCBH-Algorithm

For presenting our RCBH algorithm, we also need to define "current", "next" and "last" cell according to the Figure 7.1 and to give a short description about the components used within the algorithm. Then, we are going to explain the *join*, *leave* and *reserve* procedures and finally describe the *handover* event. Obviously, the current cell is the one in which the user is at present. We will use Z_k referring to the current cell. Depending on the driving direction of the user the "next" cell is defined as the one for the user upcoming and adjacent to the "current" cell. Without loss of generality, we declare it as Z_{k+1}. Finally the "last" cell (in the sense of previous cell) is the one just left by the user, of course adjacent to the "current" cell as well. We will name the last cell Z_{k-1}. Please note that the next cell which a vehicle will reach can be determined in a straight-forward manner as we limit ourselves to the consideration of motorway scenarios without taking into account the (typically small number of) vehicles, leaving the motorway at exits or the alternative paths possible at motorway intersections.

7.2.1.1 Channel Management (CM)

For reserving channels in the next cell we have foreseen a component, called Channel Management (CM), in cells. In general, we need CM for communication between IPTV users and the IPTV service provider. There are two kinds of CM in each cell and it is a basic communication component in both, the mobile devices (CMM) and the stationary Access Point (AP) in the cell (CMZ). CM being present in the AP, exactly one per cell

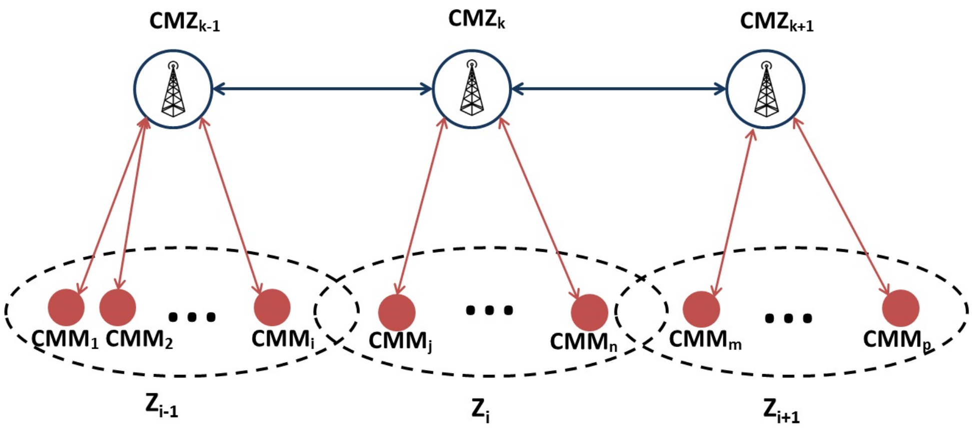

Figure 7.2: Channel Management communication.

Z, which is responsible for distributing (unicast or multicast) the requested TV channels in their cell as a CMZ. CMZ also includes a Call Admission Control (CAC) to accept or reject a channel for broadcasting. CM is also present in the mobile station (vehicle users which can access IPTV) as a CMM. Consequently, we have two types of communications, communication between CMZs to exchange information among APs and the other one, i.e. communication between CMM and CMZ, for contacting vehicle users as a mobile station within the common cell in which AP and the mobile station are located. Figure 7.2 illustrates channel management (CM) communications between CMM and CMZ. CMZ is responsible of broadcasting channels for the users in cell *Z* and also bandwidth reservation for oncoming users from neighbor cells.

The CMZs make use of three lists, Reserve List (RL), Broadcast List (BL), Channel Broadcasting List (CBL) and also one Call Admission Control (CAC) which is illustrated in Figure 7.3.

Reserve List (RL):

Reserve list contains all the information about reserved channels for upcoming viewing users from neighboring cells. It is used by CAC to control and assign bandwidth for reserved channels or broadcasting channels for current users. RL has two columns as shown in Table 7.1. All the offered channels are listed up in the first column from 1 to N. The second column demonstrates the reserved channels for the users with unique IP-addresses as the user-entries. RL has all the details regarding reserved channels for CAC to assign the bandwidth for reserved channels.

Broadcast List (BL):

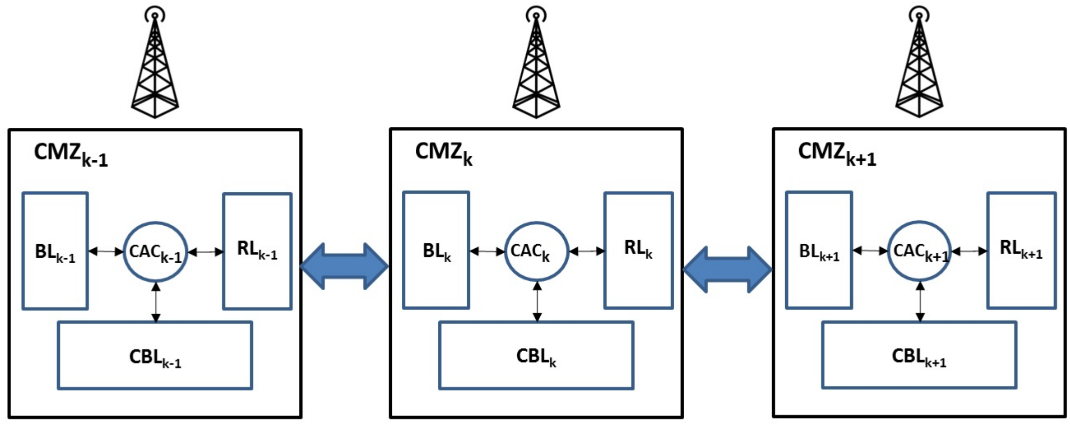

FIGURE 7.3: Components of each CMZ.

TABLE 7.1: Reserve List (RL).

Channel Nº	**Reserved for**
001	IP_address$_1$ IP_address$_4$
002	—
003	IP_address$_{16}$ IP_address$_9$
004	IP_address$_{20}$
005	—
...	...
100	IP_address$_{42}$

TABLE 7.2: Broadcasting List (BL).

Channel Nº	001	002	003	004	005	006	...	100
State	20	6	0	-2	10	-2	...	1

In addition to the RL list, CAC should keep a Broadcasting List (BL) which contains the current demand for all the channels offered by the IPTV service. BL consists of all the information about all broadcasting channels for all current users including viewing or zapping users in the current cell shown by way of example in Table 7.2.

Three states are possible for each channel. They are defined as "-2", "0" and "≥ 1". When the state is "-2" it means that the channel is not broadcasted yet. When the state is "0" it means that the channel was broadcasted already but currently there is no request for broadcasting of this channel at this cell. "$n \geq 1$" denotes the number of users that are watching this channel currently.

$$State = \begin{cases} -2 & \text{Channel currently not broadcasted} \\ 0 & \text{Channel was broadcasted, but now nobody is watching this channel} \\ n \geq 1 & \text{Channel currently broadcasted for n users, n}\geq\text{1} \end{cases}$$

Call Admission Control (CAC):

There is also a Call Admission Control (CAC) in each CMZ for controlling the admission of allocating or reserving the channels for all the users. In CMZ all the arriving requests (zapping or handover) from users will be received by CAC and CAC will decide whether to accept or to block the requests. In general, CAC has the following features:

1. CAC combines *BL* and *RL* lists for making a new list (CBL) for CMZ to decide whether to accept or to block the receiving requests.
2. CAC uses its local information about the lists and also the information of *RL* lists from neighboring cells.
3. CAC distinguishes zapping and viewing users. CAC gives higher priority to viewing users for decreasing Handover Blocking Probability (HBP) and to provide continuous connection for the users who possibly are currently viewing their favorite program by using the IPTV service.
4. CAC assigns the bandwidth between zapping and viewing users adaptively, and the portions of this two kinds of users is not fix and the amount of reserved bandwidth or broadcasting bandwidth is based on the current network requests and the present state of the IPTV service (e.g. free bandwidth available).
5. CAC blocks the requests from zapping users in case the bandwidth is needed for viewing users from neighboring cells to provide higher QoE.
6. CAC is distributed and performed at each CMZ of Access Point (AP) in a distributed manner.

Channel Broadcast List (CBL):

A new list denoted as Channel Broadcast List (CBL), is made by CAC with combining the *BL* and *RL* lists together. All the information about requested channels (broadcasting

Table 7.3: Channel Broadcast List (CBL).

Channel Nº	**Recipient$_{ID}$ [flag]**	**Expiration of Reservation**
001	IP_address$_1$ [R]	10:44
	IP_address$_5$ [V]	-
002	-	-
003	IP_address$_7$ [Z]	-
	IP_address$_3$ [R]	10:46
004	IP_address$_8$ [R]	10:50
...	...	...
100	IP_address$_{33}$ [Z]	-

Meaning of the Flags:
R: user has reserved this channel
V: user is viewing the requested channel
Z: user is in zapping mode, watching this channel only for a short time

or reserving) are stored in the CBL list. It is a concrete list in which all the detailed information regarding channels and users and expiration time is included. The CBL consists basically of three columns as shown by way of example in Table 7.3. All the channels offered by the service provider are listed up in the first column from 1 to N. In the second column the user-entries with IP-address are saved. A flag is also attached to the IP-address in this list, which specifies the user mode. The difference between CBL and BL lists is in this column and by combining the BL and RL, determines that a channel is reserved or broadcasted in one list. The third column is only present for the users with flag [R], and shows the expiration time of reserved channels.

CBL Flags

In this section we give more details about the second column. We describe the meaning of the flags in the CBL list. Three states are possible for the attached flag and they are denoted as:

1. Zapping [Z],
2. Viewing [V],
3. Reserved [R].

CAC distinguishes between zapping and viewing users in BL list. CAC inserts all the BL entries attached with a corresponding flag, [V] for viewing and [Z] for zapping, into the

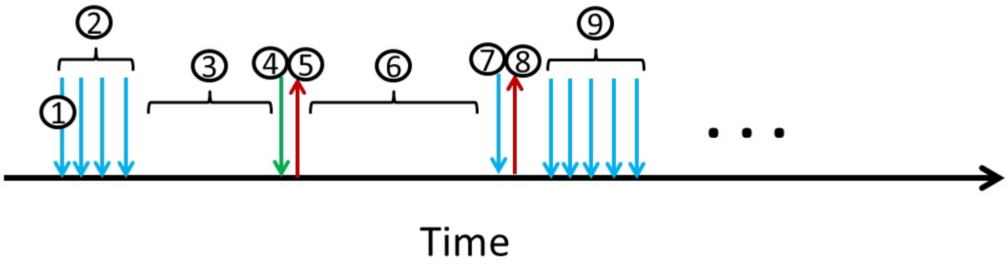

FIGURE 7.4: Example of user's flag changes.

CBL list. CAC also inserts the RL entries with flag [R] to demonstrate that this channel is reserved for the user of a neighboring cell. It also adds the expiration time in the third column of this list for reservation entries. A reservation will remain valid according to this given time. At the end, we have a comprehensive list to reserve bandwidth with the RCBH algorithm.

Each user may experience these three different modes ([V], [Z] and [R]) during watching IPTV in a vehicle. At first, when a user starts to watch IPTV he/she is in zapping mode with flag [Z]. After having quickly switched to other channels, the user selects a channel to view, then the mode changes from [Z] to [V]. According to [100], when a user is continuing to watch a specific channel for time-slot ΔT which is minimum one minute, he/she is now in a viewing phase and the user's CMM will send a viewing-flag-message to the current CMZ to change the flag from [Z] to [V]. After changing the flag to [V], the current CMZ will send a reservation request to the next CMZ and the entry for this user in the next cell will be extended with flag [R]. It is clear that there is no reservation for a zapping user [Z] in the next cell, and there is no way for a user to get from the [Z] state to the [R] state immediately. However, when the flag changes to [V], it is necessary to reserve the channel for this user in next cell.

Figure 7.4 demonstrates an example of changing flags along the time for user U_n. Each state is defined as follows:

1. User U_n joins the IPTV service and starts to watch his/her first channel with flag [Z].
2. User U_n is in zapping phase and finds something of interest to view with flag [Z].
3. Time-slot ΔT and U_n is still watching a specific channel C_i.
4. After ΔT U_n is in viewing phase with flag [V].

5. Inform the current cell to send a reservation request for channel C_i to the next cell and add it with flag [R] in the next cell (if this is possible at present time).

6. User U_n continues to view channel C_i.

7. Then user U_n sends another request for watching channel C_j, and again is changing the flag to [Z].

8. Inform the current cell to cancel the previous reservation request for channel C_i in the next cell for U_n.

9. Again start zapping with flag [Z].

And the user will change the states continuously during watching vehicular IPTV services.

In the RCBH algorithm for communicating among the CMM and CMZ, they exchange some messages between each other. These messages are divided into two kinds of communications as follows:

1. $CMZ_k \leftrightarrow CMZ_{k+1}$:

   (a) `Reserve`(C_i, IP-address, t_{exp}):
   Reserve Channel C_i until time expiration t_{exp} for the mobile device with the given IP-address.

   (b) `Cancel-Reserve`(C_i, IP-address):
   Cancel reservation of C_i for mobile device with given IP-address.

   (c) `Change-Reserve`(C_i, C_j, IP-address):
   Change the channel currently reserved (C_i), for the given IP-address to the newly reserved channel C_j.

   (d) `Handover-Process`(C_i, IP-address): Release C_i in the previous cell and continue to view C_i in the new cell for the mobile device with given IP-address.

2. $CMM \leftrightarrow CMZ$:

   (a) $CMM \rightarrow CMZ$:

   - `Join`(C_i):
     Join multicast group of TV channel C_i.
   - `Leave`(C_i):
     Leave multicast group of TV channel C_i.
   - `Viewing`(C_i):
     View as a member of multicast group of TV channel C_i.

- `Switch`(C_i, C_j):
  Switch from multicast group of TV channel C_i to C_j.
- `Handover`($U_n, CMZ_k, CMZ_{k+1}, C_i$):
  User U_n from multicast group of TV channel C_i will inform the CMZ_k and CMZ_{k+1} to do `Handover-Process`.

(b) $CMZ \to CMM$:

- `Broadcast of TV Channels`:
  Data transfer from AP to the IPTV users.

7.2.1.2 Bandwidth Allocation

RCBH algorithm combines the bandwidth reservation for upcoming users and admission control for current users in the cells to guarantee QoE requirements for IPTV services. CAC is employed to calculate the amount of reserved bandwidth and broadcasted bandwidth to find out the free bandwidth. Finally, according to the CBL, which has been produced by CAC, all the information about the users and channels are available and CMZ is able to accept, block or reserve channels. Capacity in all the Z cells is fix and the total capacity of each AP is BW_Z bandwidth units (given in the number of channels which can be multicasted at the same time). Figure 7.5 shows the block diagram of bandwidth allocation in CMZ of cell Z, and used to reserve or to broadcast the requested channels for users. Figure 7.5, shows at first, those requests from CMM of vehicular users which are received by the current CMZ. CMZ can distinguish between reservation requests from neighboring CMZ and requests (handover or new) from current CMM users. If it is a reservation request it will be delivered to the CAC to be added in RL list and to allocate the bandwidth for reservation BW_{Res}. In the second case, if it is from current users, CAC divided the requests according to handover requests or new requests from zapping users. If it is initiated by a handover user, CAC will check whether bandwidth is reserved for this user (U_n). In case, this is true, it means that bandwidth is allocated already and with accepting the request the user is able to continue watching his/her channel in the new cell without any interruption. It is only needed to change the flag from [R] to [V], RL to BL lists and BW_{Res} to BW_{Brdcst}. If bandwidth is not reserved for this handover user, he/she is like the zapper users for the RCBH algorithm. If bandwidth is available in BW_{Free}, the request will be immediately accepted and the channel will be transmitted and the bandwidth BW_{Brdcst} for it will be allocated. If the user is new, we set the flag [Z] for it and if it is a handover user without pre-reservation the flag will be set to [V] for it. Obviously, if there is no bandwidth left in BW_{Free}, the request will be blocked. These mechanisms are applied at each CMZ of AP in a distributed manner.

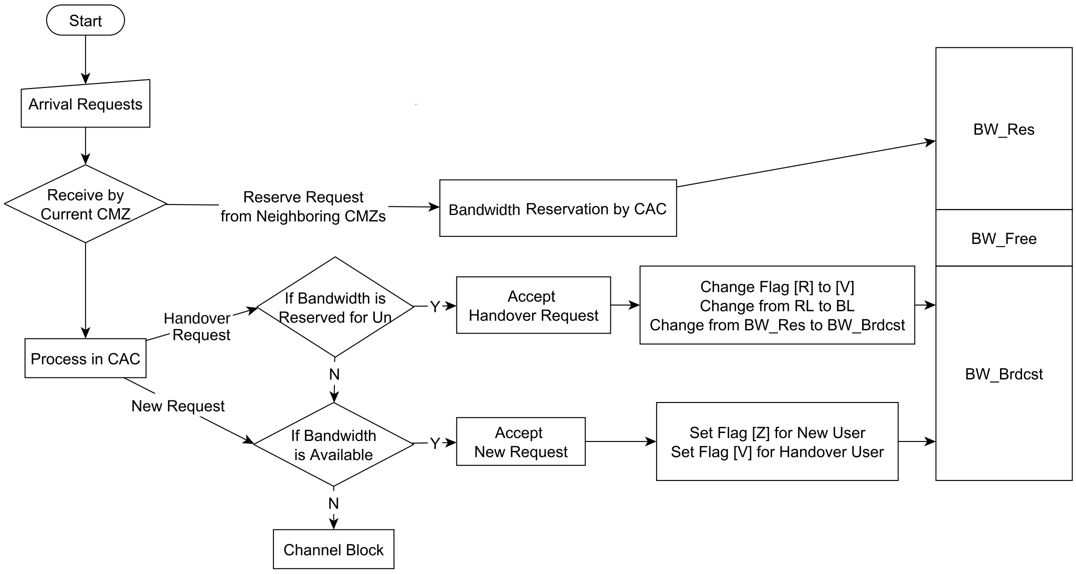

FIGURE 7.5: Block diagram of bandwidth allocation in CMZ of cell Z.

The amount of free bandwidth BW_{Free} in a cell Z is important to decide whether to accept or block the channel requests. Therefore to determine the number of different allocated channels, BW_{Alloc} for broadcasted BW_{Brdcst} or reserved BW_{Res} is needed. BW_{Alloc} can be calculated by summing up all channels with at least one entry in the second column of CBL list. Therefore, BW_{Alloc} is always smaller or equal than the total bandwidth capacity BW_{Total} in each cell. In Figure 7.6, the bandwidth partitions are illustrated for each cell. As a result the calculation for BW_{Free} in each cell Z is as follows:

$$\mathrm{BW}_{Alloc} = \mathrm{BW}_{Res} + \mathrm{BW}_{Brdcst}. \tag{7.1}$$

$$\mathrm{BW}_{Free} = \mathrm{BW}_{Total} - \mathrm{BW}_{Alloc}. \tag{7.2}$$

There are also a lot of recalculations for BW_{Free} and BW_{Alloc} in cell Z during broadcasting IPTV services for the users according to the different events and arrival requests in CMZ.

7.2.2 Elementary and Combined Events for Updating CMZ and Lists

Join and *leave* events are elementary events for channel managements (CMM and CMZ). These events will change the entries in the lists of CMZ and this is started by sending from CMM side. *Join* and *leave* events constitute some combined events in each cell for IPTV users for switching a channel, reserving a channel and executing handover between cells. After these two elementary events, recalculating bandwidth assignment

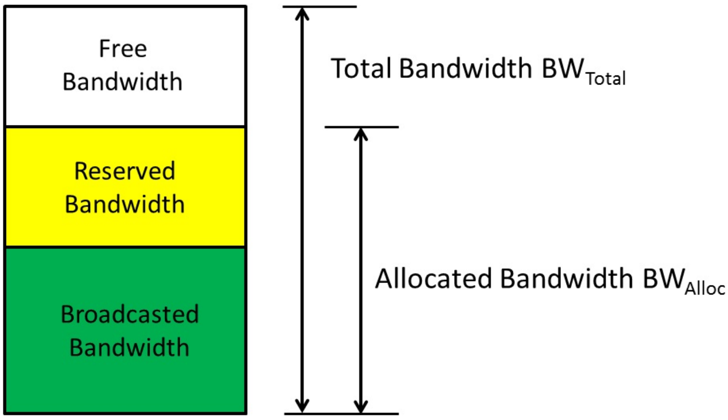

FIGURE 7.6: The bandwidth partitions for each cell.

and updating the new status of the CMZ lists is needed. In this section we are going to explain these two elementary *join* and *leave* events and accordingly the combined events in the cell Z when applying the RCBH algorithm.

7.2.2.1 Joining a Channel

Join process is used when a new IPTV subscriber joins a group of multicasted channels. A vehicular IPTV user sends a *join*-request via his/her CMM to the current CMZ for joining the channel C_i. If channel C_i is already transmitted or reserved, the user will *join* to receive the channel C_i. Or, if this channel is not multicasted or reserved yet but there is still a sufficient amount of free bandwidth, channel C_i will be multicasted and the vehicular user will *join* to them. The joining process inside a specific CMZ_k is presented in Algorithm 3 in detail.

The *join* request procedure will be started at line 1. Line 2 shows that the essential part of starting this process is to send the *join*-request from CMM to CMZ. With this *join* request the desired channel nº (C_i) and also a unique user ID (U_n) will be sent from CMM_n to the CMZ_k. Then the current CMZ_k receives a *join*(C_i, U_n) request from the CMM_n of user U_n in line 3. First, CMZ_k checks, whether the channel C_i is already reserved for user U_n by searching in CBL list (line 4). If this condition will be true, the existing reserving-entry in the CBL_k will be modified by changing the reserve flag [R] to the viewing flag [V] (line 5). This is followed by deleting the reservation-expiration time (line 6) and also removing this user entry from RL and adding into the BL by CAC (line 7). Finally, at this moment a *reservation*-request is needed to send to the CMZ of the next arriving cell (CMZ_{k+1}) by the current cell's CMZ_k (line 8). If there is no reserving entry for this specific user U_n in CBL_k, there is a chance that channel C_i is already viewed or reserved by other users (U_*) (line 9). Then user U_n is going to watch the channel C_i with the flag [Z] (line 10). There is no need to increase the BW_{Brdcst} and accordingly increasing BW_{Alloc} for this user entry.

It is also possible, that no entry (neither broadcast nor reservation) exists for channel C_i in the CBL_k. In this case, the current CMZ_k has to check if there is some free bandwidth (BW_{Free}) still left in the current cell Z_k to transmit C_i for U_n (line 11). If there is enough BW_{Free} available, then CMZ_k adds the user to CBL_k with a zapping flag [Z] and also adds this user in BL by CAC (line 12). Furthermore, bandwidth assignment will be updated by increasing BW_{Alloc} by adding this channel to BW_{Brdcst} and BW_{Free} will be recalculated in cell Z (lines 13-14). In all other cases, C_i will not be broadcasted and will be blocked (line 16). After joining channel C_i in the current cell, which is not already broadcasted or reserved, recalculation of bandwidth is by increasing of BW_{Alloc} and decreasing of BW_{Free} in the current cell. It is clear that the free amount of bandwidth is really important in IPTV systems. BW_{Free} is also raised by the *leave* users who currently leave the cell or switch their presently watched channel in the current cell.

Algorithm 3 *Join*-request process in CMZ.

1: **procedure** *join*-REQUEST
2: **REQUIRE:** sending *join*-request from CMM to CMZ
3: Receive a *join*(C_i, U_n)-request from CMM_n
4: **if** Corresponding reservation-entry in CBL existing **then**
5: Change flag from [R] to [V]
6: Delete the reservation-expiration time in CBL
7: Removing from RL and adding into the BL by CAC
8: Send a *reservation*(C_i,U_n)-request to the next CMZ
9: **else if** C_i is reserved or viewed by other users **then**
10: Add U_n[Z] to the desired channel C_i
11: **else if** there is enough BW_{Free} left in the cell **then**
12: Add U_n[Z] to the desired channel C_i
13: Raise BW_{Alloc} by 1: BW_{Brdcst}++ in the cell Z
14: Recalculate BW_{Free}
15: **else**
16: Desired channel cannot be delivered (i.e. it is blocked)
17: **end if**
18: **end procedure**

7.2.2.2 Leaving a Channel

Leave message as well as, *join* message is an elementary event in each cell and consists of a channel number (C_i) and a user ID (U_n), too. The *leave* process is used when a current IPTV subscriber leaves the group of multicasted channel. A *leave* message is sent by CMM_n of user U_n to notify the CMZ about leaving channel C_i. This message will be sent by a user in the case of a user switching off the device the user will send only a *leave* message to the current CMZ. Otherwise, a *join* message is first sent to CMZ for requesting the new channel, along with a *leave* message for the old channel. When a user zaps to another channel or leaves a cell during a handover process, it will send a *leave* message for the current channel C_i no longer needed followed by a *join* message for the new channel C_j now requested.

The leaving process inside a particular CMZ_k is presented in Algorithm 4. In line 1, the leaving process will be started. For starting this process, sending a *leave*-request from CMM to CMZ is needed (line 2). In line 3, in three cases the user will send a *leave* message to the CMZ:

1. User switches off the device (without being accompanied by a *join* message).
2. User leaves a channel C_i by switching to another channel C_j (with being accompanied by a *join* message for the current CMZ).
3. User leaves a cell during handover process (with being accompanied by a *join* message for the next CMZ).

If a user is in one of these three cases, then CMM_n sends a *leave* message to the current CMZ_k (line 4). Afterward, the CMZ_k updates the CBL_k and BL_k by removing respective entries (line 5). Thus, the (C_i, U_n) entry will be deleted. If the user is leaving a channel as the last user, then it increases the BW_{Free} in the current cell (line 6, 7). Up to here, all the updates and calculations were the same for both kinds of users (viewing-mode and zapping-mode). However, now (line 9), if the user was in viewing mode with the flag [V], then the current CMZ_k will send a cancel reservation message to the next CMZ_{k+1} cell. Therefore, it is needed to update the CBL_{k+1} and RL_{k+1}, if U_n is the last entry for channel C_i in CMZ_{k+1} (line 12). Then BW_{Free} in the next cell CMZ_{k+1} is increased by the capacity of one channel (line 13). Again, the recalculation of BW_{Free} is paramount for the RCBH-Algorithm.

7.2.2.3 Switching a Channel

Switching a channel is not an elementary event but it is in a combined event category. Switching a channel is always accompanied with a *join* message together with a *Leave* message. Figure 7.7 demonstrates an IPTV switching scenario. In this scenario at first it is needed to send a switching channel message from CMM_n to CMZ_k. It is assumed that a user U_n is watching channel C_i and wants to switch to channel C_j. Then, this user will send a *Switch* message as a combined event concluded as:

Algorithm 4 *Leave*-request process in CMZ.

procedure *Leave*-REQUEST
    REQUIRE: sending *leave*-request from CMM to CMZ
    if ((User switches off the device) **or** (User leaves a channel C_i by switching to another channel C_j) **or** (User leaves a cell during handover process)) **then**
        CMM_n sends a *leave*(C_i, U_n)-request to CMZ_k
        CMZ_k updates CBL_k and BL_k by removing the entry for (C_i, U_n)
        if User is Leaving a channel as the last user **then**
            Raise BW_{Free} by 1: $BW_{Free}{++}$ in the cell CMZ_{k+1}
        end if
        if User is in viewing-mode with flag [V] **then**
            CMZ_k sends a cancel reservation message to the next CMZ_{k+1} cell
            Update CBL_{k+1} and RL_{k+1} by removing the reservation entry in CMZ_{k+1}
            if User is the last entry for channel C_i in CMZ_{k+1} **then**
                Raise BW_{Free} by 1: $BW_{Free}{++}$ in next CMZ_{k+1} cell
            end if
        end if
    end if
end procedure

$$Switch(C_i, C_j) = Leave(C_i) \quad \text{"}followed \quad by\text{"} \quad Join(C_j). \tag{7.3}$$

This message will be sent from CMM of a mobile user device. At first, a *Leave* message for channel C_i will be processed in CMZ_k and then, if possible, this user U_n will join the group of multicast related to channel C_j.

The above scenario is used for zapping users with flag [Z]. However, with applying the RCBH algorithm, after sending a *switch* message from IPTV user, some other event is also needed. As shown in Figure 7.8, after leaving channel C_i by a viewing user U_n with flag [V] in CBL_k, a *cancel-reservation* request will be sent to the next CMZ_{k+1} cell. This message will be processed in CAC of the next cell and finally this user entry will be deleted from CBL_{k+1} and from RL_{k+1}.

7.2.2.4 Reserving a Channel

In RCBH algorithm the primary goal is to reserve a channel for a viewing user to keep the channel during the handover process to provide a continuous connection. Therefore, after changing the flag of user U_n from [Z] to [V], CMZ of the current cell will send a *reservation*-request (C_i, U_n) to the next CMZ for reserving the bandwidth for this oncoming user. Algorithm 5 demonstrates all the details during the reservation process in the cells. In line 1, it shows that the reservation-request will be started in the CMZ of the current cell. In line 2, the essential parts of *reservation*-requests are defined. So, it

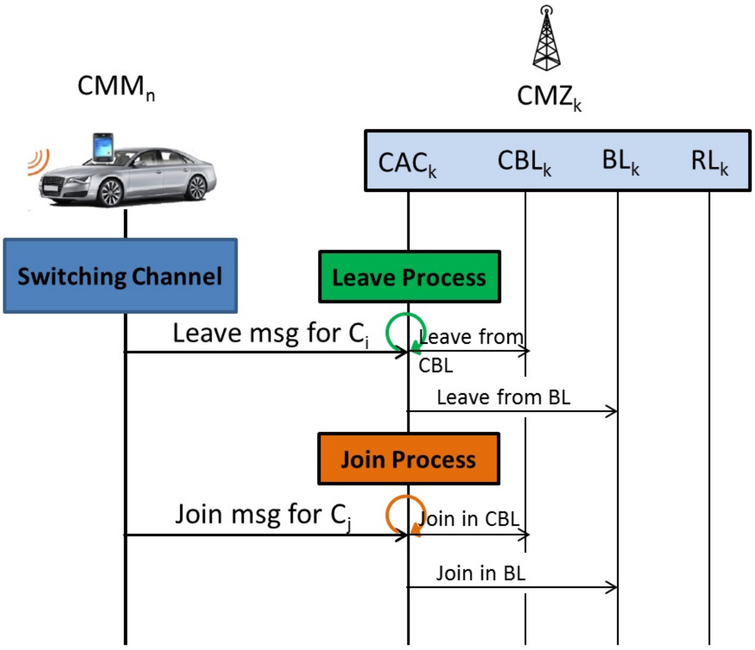

FIGURE 7.7: IPTV switching scenario.

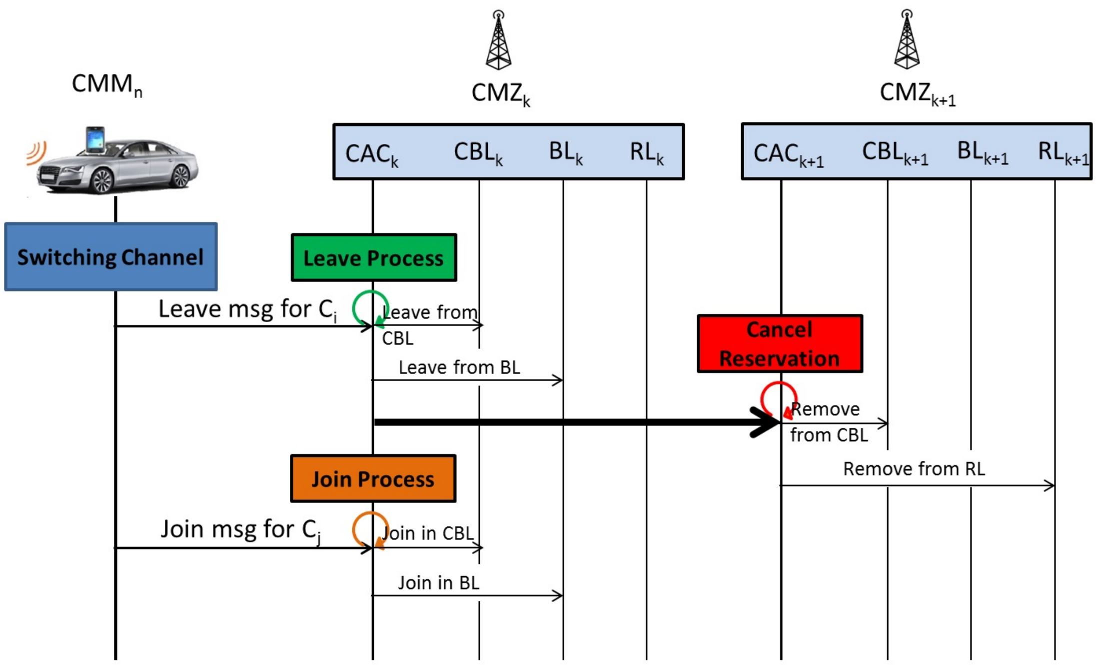

FIGURE 7.8: IPTV switching scenario with applying RCBH algorithm.

is needed to change the flag of user U_n from [Z] to [V]. When a user is with a viewing flag, it shows that he/she has interest to watch this program and we need to provide the resource for this user to view channel C_i continuously during the handover process. Then a *reservation*(C_i,U_n)-request will be sent to the next cell to reserve channel C_i for this user U_n (line 3). If this channel C_i is reserved or viewed by another user in the next cell k+1 (line 4), it is needed to add U_n[R] for channel C_i in CBL_{k+1} (line 5) and also adding (C_i,U_n) in RL_{k+1} (line 6). Else, if C_i is not reserved or viewed by other users in CMZ_{k+1} (line 7), it is required to check if there is free bandwidth left in the next cell to reserve the channel C_i (line 8). If yes, the channel will be reserved and added in CBL_{k+1} and RL_{k+1} (lines 9-11). Then, free bandwidth and allocated bandwidth in cell k+1 will be calculated in lines 12 and 13. Finally, if there is not enough bandwidth in next cell, RCBH is not able to reserve the bandwidth for user U_n (line 15).

Algorithm 5 *Reservation*-request process in CMZ.

1: **procedure** *Reservation*-REQUEST
2:     **REQUIRE:** Changing the flag of user U_n from [Z] to [V] in current cell
3:     CMZ_k sends a *reservation*(C_i,U_n)-request to the CMZ_{k+1} of next cell
4:     **if** C_i is reserved or viewed by other users in CMZ_{k+1} **then**
5:         Add user U_n for channel C_i with flag [R] in CBL of CMZ_{k+1}
6:         Add (C_i,U_n) into the RL of the next cell
7:     **else if** C_i is not reserved or viewed by other users in CMZ_{k+1} **then**
8:         **if** there is enough BW_{Free} left in the CMZ_{k+1} **then**
9:             Reserve channel C_i for U_n of the next cell
10:             Add user U_n for channel C_i with flag [R] in CBL of CMZ_{k+1}
11:             Add (C_i,U_n) into the RL of the next cell
12:             Raise BW_{Alloc} by 1: BW_{Res}++ in the next cell k+1
13:             Recalculate BW_{Free} of cell k+1
14:         **else**
15:             Do not reserve the channel
16:         **end if**
17:     **end if**
18: **end procedure**

RCBH is able to reserve the bandwidth for viewing users only for a time interval which is given in CBL. This mechanism is very useful to stop holding a free bandwidth (BW_{Free}) in the next cell for a long time. Two undesirable situations are possible for uselessly occupying of free bandwidth in the next cell. The first situation is when the user takes a break in a parking bay but still needs to view the requested channel in the current cell, therefore RCBH should cancel the reservation after expired time. The second situation happens when the user is in a traffic jam. It is also the same as the previous case and there is no need to reserve the channel after time expiration because the arrival time of users in the next cell is not clear for CMZs. Thus, the RCBH will cancel the reservation for this kind of users to avoid blocking free bandwidth in the next cell.

7.2.2.5 Handover between Cells

Each IPTV handover process requires network bandwidth to transmit the required channel by the new base station of the next cell. Therefore, minimizing the handover blocking will increase QoE in IPTV services. In a handover process there are two kinds of IPTV users (viewing users and zapping users). In RCBH algorithm we are going to provide the bandwidth for oncoming viewing users from neighboring cells to decrease the number of handover blockings. This is reasonable, because missing the program for viewing users during the handover process is annoying but for zapping users handover blocking is not that much unpleasant. Thus, the priority is by viewing users in the RCBH algorithm. To start the handover process it is needed to send a *handover*-request from CMM_n of user U_n to the current CMZ_k and ask to join his current channel in the next cell. Each *handover*-request includes the following elementary requests:

$$\begin{aligned} &Handover(U_n, CMZ_k, CMZ_{k+1}, C_i) = \\ &\quad Leave(C_i, CMZ_k) \quad \text{"}followed \quad by\text{"} \quad Join(C_i, CMZ_{k+1}). \end{aligned} \tag{7.4}$$

In the case that a user is in viewing phase with flag [R], it is also required to cancel the reservation in the next cell. Therefore, the *handover*-request for a viewing user is:

$$\begin{aligned} &Handover(U_n[R], CMZ_k, CMZ_{k+1}, C_i) = \\ &Leave(C_i, CMZ_k) \quad \text{"}followed \quad by\text{"} \quad Join(C_i, CMZ_{k+1}) \quad \text{"}followed \quad by\text{"} \\ &\qquad\qquad\qquad\qquad \text{Cancel-Reservation}(U_n, CMZ_{k+1}, C_i). \end{aligned} \tag{7.5}$$

Algorithm 6 *Handover*-request process for two cells.

```
procedure Handover-REQUEST
    REQUIRE: User U_n sends Handover-request (U_n, CMZ_k, CMZ_{k+1}, C_i) to the current cell
    CMZ_k receives the Handover-request from user U_n for the new CMZ_{k+1} cell
    Leave(C_i, U_n) in CMZ_k
    Join(C_i, U_n) in CMZ_{k+1}
    if U_n is in viewing phase with flag [R] in CBL_k then
        if C_i is reserved for U_n in CMZ_{k+1} then
            Delete reservation(C_i,U_n) in CBL_{k+1} and RL_{k+1} at next cell CMZ_{k+1}
        end if
    end if
end procedure
```

Figure 7.9 shows the details of a handover process for the user U_n between two cells. More detail of this process is given in Algorithm 6. The *Handover*-request procedure

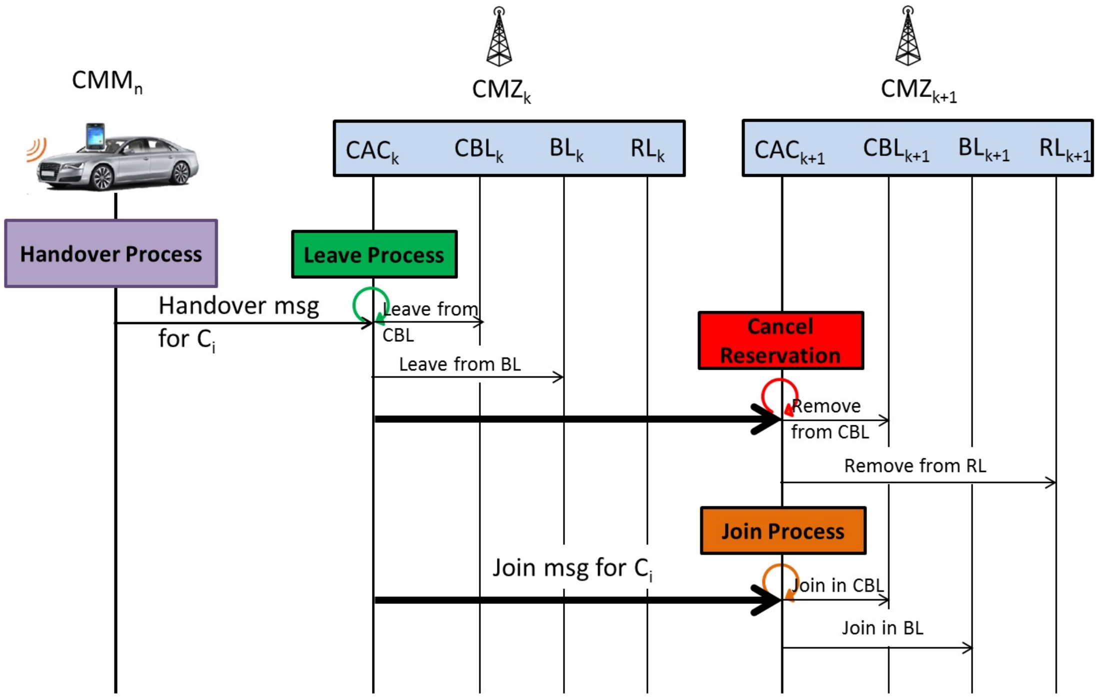

FIGURE 7.9: IPTV handover process scenario for viewing users in RCBH algorithm.

starts in line 1. At first, it is required that the user U_n sends *Handover*-request (U_n, CMZ_k, CMZ_{k+1}, C_i) to the current cell (line 2). The handover process will be started by receiving the *Handover*-request by CMZ_k (line 3). Then the user U_n leaves channel C_i in CMZ_k and will join channel C_i in CMZ_{k+1} of new cell. For this mechanism it is needed to send *Leave*-request and *Join*-request together, these two requests will be processed according to the Algorithm 3 and Algorithm 4 (lines 4, 5). If this user is in the viewing phase with flag [R] and the channel is reserved for this user in the next cell, it is necessary to delete this reservation in the next cell (lines 6-8).

Chapter 8

Simulation Tool and Case Studies to Assess RCBH Algorithm

8.1 Simulation Model Introduction

The performance of the proposed RCBH algorithm in Chapter 7 is evaluated through simulations of realistic vehicular network environments. The simulated network consists of the (possibly numerous) vehicular users and three wireless cells. Each wireless cell is equipped with the AP/BS in the center of each cell. Cars or other vehicles are generated at the border of the geographical area (GA) and they can drive in one of the possible two directions without possibility to turn the direction. Each car has 0 or at most 1 passenger who uses IPTV. Our system model for the RCBH algorithm is depicted in Figure 8.1. By means of simulation, in this chapter we are going to investigate whether the RCBH algorithm provides small handover blocking probability and whether high CA and accordingly good QoE will be achieved.

Pursuant to Chapter 7, for simulating our novel RCBH algorithm the following features are underlying this algorithm:

1. The RCBH algorithm combines bandwidth reservation and bandwidth allocation control to provide QoE.
2. It uses both local information from the current cell and remote information from the neighboring cells to find out whether a new or handover-induced channel request should be accepted or blocked.

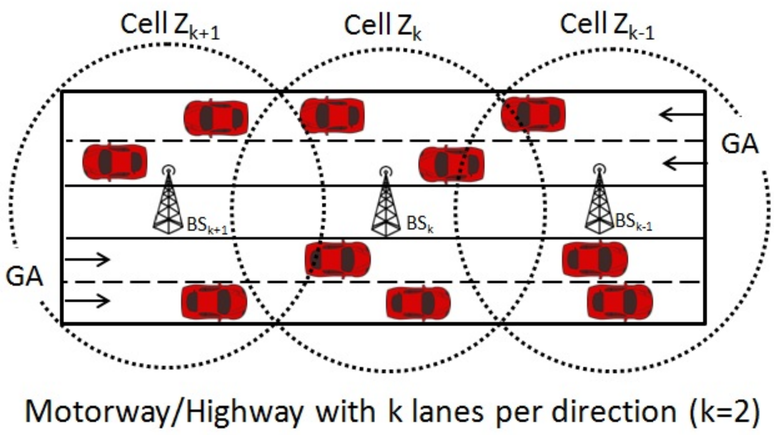

Figure 8.1: RCBH simulation model.

3. It is adaptive, that means the RCBH algorithm adjusts the amount of reserved bandwidth and the bandwidth used to serve new channels based on the current channel request situations.

4. It distinguishes viewing users from zapping users. It gives higher priority to the viewing users when they produce handover-oriented requests as opposed to zapping users who are frequently switching channels and are looking to find something of interest.

5. It reduces the allocated bandwidth for zapping users to provide higher QoE for the viewing users.

6. It is distributed, that means the RCBH algorithm is performed at each cell in a distributed manner.

8.2 State Vectors in the Simulation Model

For evaluating the RCBH algorithm, we have developed a Monte Carlo simulation model to reflect the version of RCBH, which has been described in detail in Chapter 7. Therefore, we elaborate a dedicated simulator to simulate highway scenarios. The new simulator is an extended version of our comprehensive IPTV simulator described in Chapter 3. We elaborated this simulation tool for analyzing IPTV services with reserving bandwidth for communication networks of VANET type. This simulation tool has been designed to reserve the bandwidth already a significant time before the IPTV users will be arriving in the new cell. The extended simulator offers all the reservation together with managing the bandwidth in a very detailed model. It is also written in C and we apply the LoadSpec tool to use the trace file for channel switching events for vehicular subscribers.

For evaluating the improvement of HBP in vehicular IPTV services, we apply the trace file (cf. section 3.1.4) as a realistic IPTV user model for our extended simulator. In this simulator, we also apply a *Monte-Carlo* simulation model. However, we use here two different state vectors for simulating the RCBH algorithm.

The first state vector, being denoted by **BL-VECTOR**, is dedicated for the group of channels which are broadcasted now and viewed by the users currently. This BL-VECTOR represents the broadcast list (BL) in each cell:

(BLUserNumberChannel[1], BLUserNumberChannel[2], BLUserNumberChannel[3], $\cdots$*, BLUserNumberChannel[N]).*

The second state vector, denoted as **RL-VECTOR**, is allocated for reserving the group of channels which are reserved for viewing users from neighboring cells. This RL-VECTOR illustrates the reserve list (RL) in each cell:

(RLUserNumberChannel[1], RLUserNumberChannel[2], RLUserNumberChannel[3], $\cdots$*, RLUserNumberChannel[N]).*

Evidently, in both state vectors, the ith element demonstrates the current number of users watching or reserving channel i.

However, we do not change the value of the state vector when a blocking event happens. The only possibility for blocking the user is to offer him/her a replacement channel till he/she sends a new request according to the trace file.

There are some events which have impacts on the BL-VECTOR and the RL-VECTOR as follows:

- After receiving each new channel request by the users, BL-VECTOR$_k$ will be updated.
- If the new user is going to continue his viewing phase, updating of RL-VECTOR$_{k+1}$ is also needed.
- After getting a leave message for the current channel, BL-VECTOR$_k$ will be immediately updated.
- If the leaving user was in viewing phase, updating RL-VECTOR$_{k+1}$ is also needed.
- After terminating the execution of a handover process, BL-VECTOR$_k$ and BL-VECTOR$_{k+1}$ will be updated.
- If the user involved in the handover was in viewing phase, updating RL-VECTOR$_{k+1}$ is also needed.

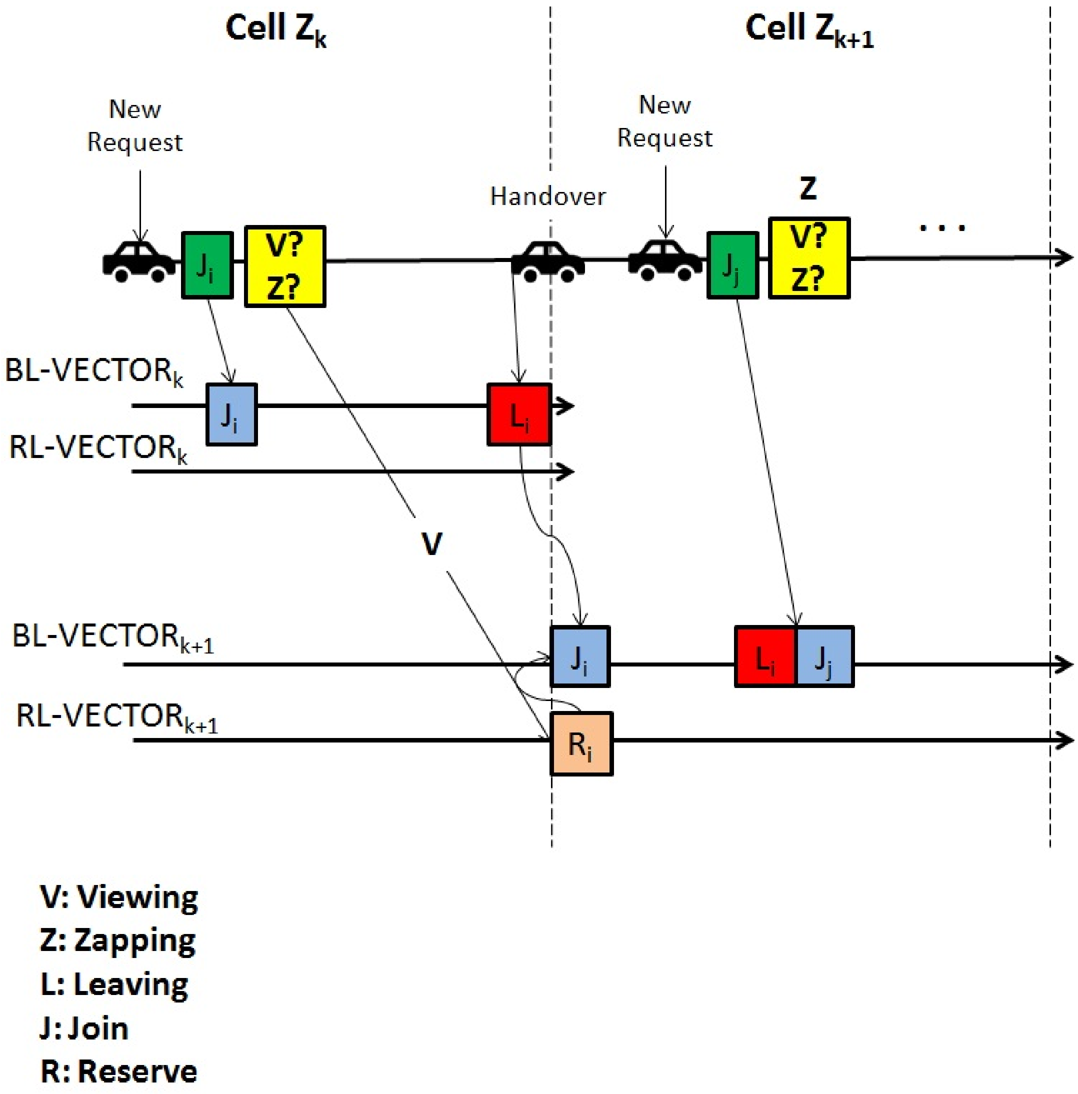

FIGURE 8.2: Example of recording events in the vectors.

Figure 8.2 represents an example of recording the events during the car journey of a user through the cells. Each event will be recorded as follows:

- User U_n starts watching the IPTV service in cell Z_k. Therefore, U_n sends a new request for a channel C_i.
- User U_n joins to the group of multicasted channel C_i.
- This event will be recorded in **BL-VECTOR** of the current cell as a joining to channel C_i.
- Then, it is necessary to check whether this user is in viewing phase or in zapping phase.

- When U_n is in viewing phase, it is needed to reserve channel C_i for him/her in the next cell. Hence, channel C_i will be reserved in the **RL-VECTOR** of the next cell.
- The next event for user U_n will happen at the handover process during the crossing of the boundary between neighboring cells. At this moment, channel C_i will be deleted from **BL-VECTOR**$_k$ and will be added to the **BL-VECTOR**$_{k+1}$. Evidently, after U_n will arrive to the new cell Z_{k+1}, reservation in the new cell should be deleted from **RL-VECTOR**$_{k+1}$ and added to **BL-VECTOR**$_{k+1}$.
- Then, the user U_n sends a new request for channel C_j in the new cell. Again, it is needed to leave channel C_i and joining channel C_j and recording both of these events in **BL-VECTOR**$_{k+1}$.
- It will be checked again if this user is in viewing phase or in zapping phase. Because now this user is in zapping phase, it is not needed to reserve the channel C_j for this user in the next cell.

The Pseudo-code of the RCBH algorithm for evaluating channel blocking and channel availability is summarized in the following. All the assumptions for preparation of the trace files for the simulation are according to Chapter 3.

```
/* Pseudo-code for evaluating channel blocking and channel availability for
vehicular IPTV service in each single cell */
int main()
{ ...
/*System initialization*/
Single_Trace_Generation();  // for all users
ATT = Aggregate-Traffic-Trace();
Initial_State_Determination();
ATT_pointer = ATT;  // the 1st node in Aggregate-Traffic-Trace (ATT) list
while(ATT_pointer!=NULL)  // still in simulation time duration {
//warming-up stage
Transient_Phase();
//evaluation channel blocking in steady state
 if (Cell is steady state) {
/*channel request arriving process in CMZ*/
 if ((ATT_pointer->event) is channel request event R) {
  CounterTotalRequest++;
        if (R is a New Request (NR)) {
                CounterSwitchingRequest++;
                i = the channel number requested by NR;
//UserNumberChannelZ[BL] state vector for BL channels in cell Z
//UserNumberChannelZ[RL] state vector for RL channels in cell Z
if ((UserNumberChannelZ[BL][i]==0)&&(UserNumberChannelZ[RL][i]==0)) {
//no one is currently watching or reserving this channel in cell Z
```

```
        if (bandwidth left in cell Z is sufficient) {
                ACCEPT(NR);
                UserNumberChannelZ[BL][i]++;}
        if(User is in viewing phase){
//it is needed to reserve channel i for U in cell Z+1
//UserNumberChannelZ+1[BL] state vector for BL channels in cell Z+1
//UserNumberChannelZ+1[RL] state vector for RL channels in cell Z+1

if ((UserNumberChannelZ+1[BL][i]!=0)||(UserNumberChannelZ+1[RL][i]!=0))
UserNumberChannelZ+1[RL][i]++;
else if (bandwidth left in cell Z+1 is sufficient)
UserNumberChannelZ+1[RL][i]++;}
else {
//not enough bandwidth left in cell Z
                REJECT(NR);
                CounterBlockedSwitchingRequest++;}}
/*Handover Process*/
else if (R is a Handover Request (HR)) {
CounterHandoverRequest++;
i = the channel number requested by HR;
UserNumberChannelZ[BL][i]--;
if (UserNumberChannelZ+1[RL][i]!=0){
//channel i is already reserved for this user
ACCEPT(HR);
UserNumberChannelZ+1[RL][i]--;
UserNumberChannelZ+1[BL][i]++;}
else if((UserNumberChannelZ+1[BL][i]==0)&&(UserNumberChannelZ+1[RL][i]==0))
{
//no one is currently watching or reserving this channel in cell Z+1
        if (bandwidth left in cell Z+1 is sufficient) {
                ACCEPT(HR);
                UserNumberChannelZ+1[BL][i]++;}}
else {
//not enough bandwidth left in cell Z+1
                REJECT(HR);
                CounterBlockedHandoverRequest++;}}}}
/*Leaving Channel in cell Z*/
        else if ((ATT_pointer->event) is user leaving event L) {
        i = the channel number previously watched by the user;
        UserNumberChannelZ[BL][i]--;}
//Move to the next event in ATT list
        ATT_pointer =   ATT_pointer->next;}}

/* Calculation of the Channel Blocking Probability */
HBP = CounterBlockedHandoverRequest / CounterTotalRequest;
SBP = CounterBlockedSwitchingRequest / CounterTotalRequest;
HBR = CounterBlockedHandoverRequest / CounterHandoverRequest;
SBR = CounterBlockedSwitchingRequest / CounterSwitchingRequest
```

```
CBP = HBP + SBP;
CA = 1 - CBP; }
```

8.3 Comparison between RCBH and Previous Simulation Tools

For elaborating an RCBH simulator, we extended our IPTV simulator described in Chapter 3. The RCBH simulation tool has been designed for analyzing CBP and CA for vehicular IPTV services using bandwidth priority reservation. In this section, in order to evaluate our new extended IPTV simulator, we carry out a very thorough testing phase for this simulator. Up to now, there are no other measurement tools regarding real IPTV services over vehicular networks available for us in order to validate our new RCBH simulator. On the other hand, from our point of view, it is necessary for us to test and validate the RCBH simulator. Therefore, we are going to apply the following approaches for testing of our simulator:

1. An in-depth code inspection covering the whole simulation program which led to a very thorough static debugging of the simulator.
2. Checking of important partial results determined during the simulation experiments, such as the values of nr_h(T) and nr_s(T), which can also be determined directly by using simple analytical calculations.
3. Executing many reasonable tests in order to obtain the simulation results.
4. Finally and last but not least, we performed several case studies for testing and comparing with our original existing IPTV simulator (as presented, e.g., in [46, 47]) and we found after comparison that the results obtained by this simulator fully agree with the results achieved with the new, extended version of the simulator covering RCBH. In the RCBH algorithm, we used a version in which priority reservation of TV channels in neighboring cells is only executed with probability β to compare both simulators fairly. Therefore, for the comparison test studies, we used the results of the RCBH simulator for $\beta \rightarrow 0$.

Let us now shortly summarize some of the results of the test case studies as mentioned in point 4 of the list. All the assumptions are the same in both simulation tools and throughout the comparison experiments, we varied the cell size only. All our assumptions for this comparison are presented in Table 8.1.

TABLE 8.1: Parameter values for the test comparison case study.

Notations	Descriptions	Values
N	Number of TV channels offered in total	100
BW_c	Total bandwidth available for IPTV in cell c	20 Mb/s (sufficient for parallel transmission of 40 TV Channels)
D_{cell}	Diameter of each cell (i.e. cell size)	5000, 7000, 9000, 10000 m
k	Number of lanes in each direction of the highway	3
$SP_{[i]}$	Average speed of a vehicle in each lane i per direction [km/h]	90 (lane 1), 120 (lane 2), 150 (lane 3)
$d_{min[i]}$	Minimum distance in lane i between two adjacent vehicles [m]	10 (lane 1), 15 (lane 2), 20 (lane 3)
$d_{avg[i]}$	Average distance in lane i between two adjacent vehicles [m]	20 (lane 1), 25 (lane 2), 30 (lane 3)
$d_{max[i]}$	Maximum distance in lane i between two adjacent vehicles [m]	30 (lane 1), 35 (lane 2), 40 (lane 3)

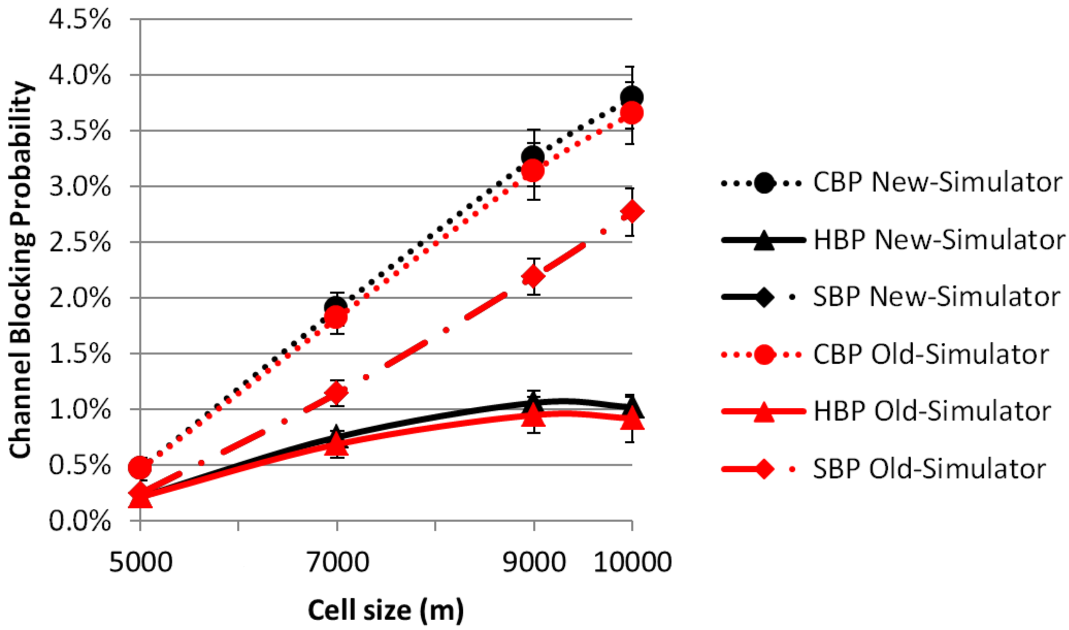

FIGURE 8.3: Channel blocking probability against different cell sizes.

In this scenario to compare both simulation tools, we have only varied the cell size. The goal of this scenario is to determine whether the simulation tool to model our new proposed RCBH algorithm is close enough to the original simulation or not. By using this scenario and changing the cell size, we measure the characteristics of the different wireless access networks via which the IPTV services are offered. Figure 8.3 shows the CBP, HBP and SBP values of our two simulation tools as a function of the different cell sizes (in [m]). The obtained results are given with 95% confidence intervals. The simulation results demonstrate that we achieved nearly perfect agreement between the two different simulation tools, therefore the results obtained by our new simulation tool work perfectly and are acceptable. Moreover, additional test comparison studies showed also similar results.

8.4 Case Studies to Assess the RCBH Algorithm

In this section, we present and discuss the case studies and simulation results to evaluate our proposed RCBH algorithm. Several sets of experiments were carried out in order to assess the performance of reserving the probably needed channel before the corresponding channel user will be arriving in the neighboring cell and to compare it with the case of not reserving bandwidth in advance. We also consider the RCBH algorithm in different scenarios. For evaluating RCBH and providing QoE for handover executing users during the car journey, we will look at blocking probability and blocking risk measures characterizing the QoE. We conduct this evaluation by performing two different scenarios. The main goal of these two case studies is to investigate the Channel Blocking Probability (CBP), Switching-related Blocking Risk (SBR) and Handover-related Blocking Risk (HBR) with applying the RCBH algorithm.

8.5 Case Study I: Variation of Number of the IPTV Users

The aim of the first case study is to investigate the impact of applying the RCBH algorithm for reserving bandwidth for viewing in the different traffic situations. We varied the number of cars per km in this case study to figure out the efficiency of RCBH algorithm in medium and low traffic density. It should be noted that all the assumptions not related to the traffic for low and medium traffic density are identical, and we use them in comparison with a traffic jam scenario, which then would represent a high traffic density (if we only distinguish three classes of traffic densities). All the assumptions of the experiments are given in Table 8.2. The distance d between vehicles is calculated according to a truncated exponential distribution for an interval with speed-dependent

Table 8.2: Parameter values for Case Study I.

Notations	Descriptions	Values
N	Number of TV channels offered in total	100
BW_c	Total bandwidth available for IPTV in cell c	20 Mb/s (sufficient for parallel transmission of 40 TV Channels)
D_{cell}	Diameter of each cell	10 km
k	Number of lanes in each direction of the highway	3
M-$SP_{[i]}$	Speed of a vehicle in each lane i [km/h] for Medium traffic density on highway	80 (lane 1), 100 (lane 2), 120 (lane 3)
L-$SP_{[i]}$	Speed of a vehicle in each lane i [km/h] for Low traffic density on highway	90 (lane 1), 120 (lane 2), 150 (lane 3)
M-$d_{[i]}$	Average distance in lane i in Medium traffic density between two adjacent vehicles [m]	30 (lane 1), 37 (lane 2), 45 (lane 3)
L-$d_{[i]}$	Average distance in lane i in Low traffic density between two adjacent vehicles [m]	35 (lane 1), 45 (lane 2), 50 (lane 3)
α	percentage of the IPTV users	10%
θ	Zipf parameter	1.3
β	percentage of applying the RCBH algorithm	(0, 20, 40, 60, 80, 100)%

bounds (for details, cf. [47]). On the other hand, we also consider the effect of applying a different percentage of β. We are going to figure out the blocking probability or risk for the vehicular IPTV users in highway scenarios with a variation of the probability (β) of performing RCBH in different traffic densities. The probability β is realized in the following straight-forward manner, i.e. whenever RCBH could be applied to an arbitrary IPTV user it is only executed with probability β. Moreover, there are two important questions that we want to answer:

- **Q1:** What happens when we reserve the channels only for some small percentage of the IPTV users?
- **Q2:** What value of β is providing the best QoE for watching the TV programs smoothly and without losing a currently watched program during the handover process?

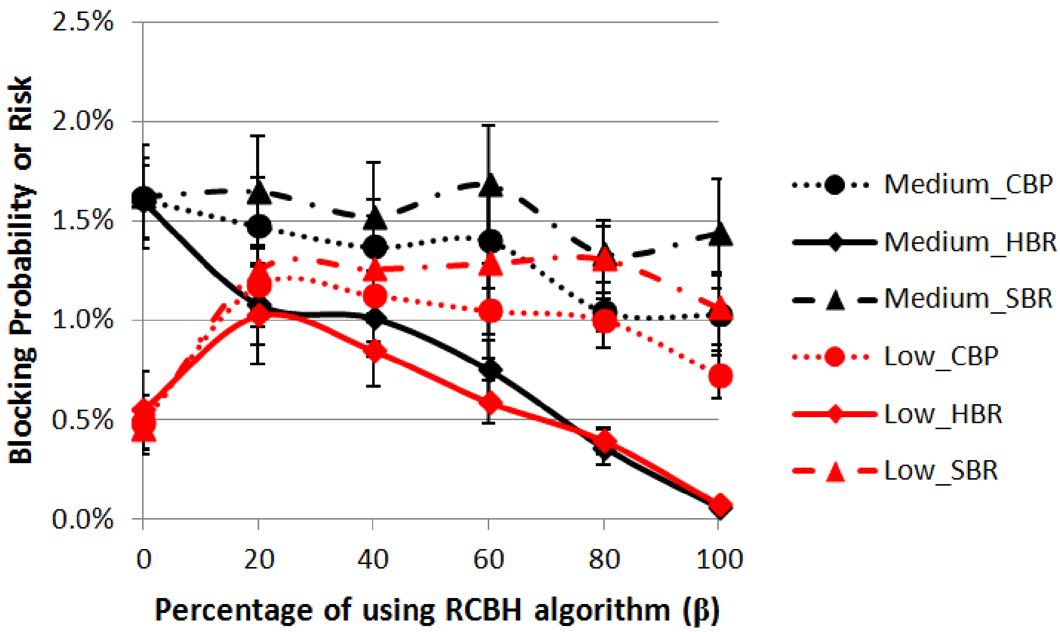

FIGURE 8.4: CBP, SBR and HBR results against different value of β.

8.5.1 Case Study I: Results Obtained and their Interpretation

We execute a set of experiments in order to answer the above questions. The simulation results for these experiments with 95% confidence intervals are plotted in Figure 8.4. In this figure, CBP, SBR and HBR are plotted against different values of β (ranging from 0% to 100%, with the step-size of 20%).

The observations from Figure 8.4 are listed more specifically as follows:

- With growing traffic density, CBP, SBR and HBR also increase. In this case, there are more users in a cell and therefore, more blocking events occur.
- With applying the RCBH algorithm to reserve the currently viewed channel a priori for all IPTV users (β=100%), the risk of a channel being blocked during the handover process is near zero. It means that our proposed RCBH algorithm reduces significantly the handover blocking probability and risk. Accordingly, the RCBH does increase the channel availability and QoE for both low and medium traffic density scenarios. Now, question **Q1** can be answered.
- In medium traffic density situations, SBR and in general CBP will be decreased. The simulation results for medium traffic density curves illustrate that with applying the RCBH algorithm for all users this will imply that the blocking probability and blocking risks will nearly be eliminated. Because in medium traffic density with more users, the popular channels are very often already reserved by the viewing

users. Therefore, the zapping users have a good chance to select the newly required channels among the reserved channels. As we use the Zipf distribution for all simulated users (viewing user and zapping user) there is a big chance for zapping users, to choose between already broadcasted or reserved channels during their zapping phase. So, results imply a decrement of SBR and thus SBP.

On the other hand, in the scenario of low traffic density, zapping users are not experiencing the same situation as in a medium traffic density situation. Channels reserved or viewed, are not necessarily the most popular channels and there is a chance for broadcasting unpopular channels in the case of fewer users in the cell.

In order to answer the question **Q2** and comparing the two methods (reserving bandwidth versus non-reserving bandwidth), it is necessary for us to distinguish between viewing users and zapping users. Our main goal is to provide a high channel availability for our viewing users. Therefore, we are going to keep a channel for the viewing users for a longer period of time, and we give a higher priority to our handover users. The value of HBR is important in our work and we try to decrease HBR and evidently increasing QoE for users in a viewing phase.

We observed from the simulation results that:

- For a medium traffic situation, β should be at least 20%. Increasing the percentage of reserving channels is directly related to the decreasing of HBR, which implies that there is a high probability, that only unpopular channels are blocked.
- For improving the SBR and CBP with using the RCBH algorithm in medium traffic situations, only the reservations beyond 75% are working well.
- As can be seen in Figure 8.4 for low density traffic scenarios, evidently the percentage of using the RCBH algorithm has to be at least 75% to reduce the HBR. Because by reserving the channels for all users, most of the popular channels have a good chance to be reserved by incoming viewing users from neighbor cells. Therefore, the handover requests will not be blocked by applying the RCBH algorithm for all the users. However, if we only reserve the bandwidth for a fewer percentage of incoming viewing users from neighbor cells and setting $\beta = 20\%$, there is a non-negligible probability of choosing unpopular channels by zapping users. Moreover, to make it even worse, if a user in viewing phase chooses an unpopular channel, this channel will block free bandwidth (BW_{Free}) in the next cell.
- In general, it is visible with increasing β we get the best QoE and meet our design goal.

TABLE 8.3: Parameter values for Case Study II.

Notations	Descriptions	Values
D_{cell}	Diameter of each cell	5, 15 km
$SP_{[i]}$	Speed of a vehicle in each lane i [km/h] V_{avg} (V_1, V_2, V_3)	**60** (50, 60, 80), **80** (70, 80, 100), **100** (80, 100, 140), **120** (100, 120, 160), **140** (120, 140, 180)
$d_{[i]}$	Average distance in lane i between two adjacent vehicles [m] (d_1, d_2, d_3)	(20, 40, 40)
β	percentage of applying the RCBH algorithm	100%

8.6 Case Study II: Variation of Cell Sizes and Car Speeds

In case study II, we are going to run this scenario with applying the RCBH algorithm for all IPTV users with fix β=100%. The purpose of performing this case study is to analyze the impact of different cell sizes and car speeds on the CBP, SBR and HBR results.

In this experiment, except cell diameter D_{cell}, the speed $SP_{[i]}$ and the distance between the cars $d_{[i]}$, which are given new parameter values (as summarized in Table 8.3), all other simulation parameter values are the same as in case study I. In case study II, we varied speed and distance between the cars such that in each experiment the number of the cars in a cell in general is constant even for two different cell sizes.

In the second case study, we try to answer another two essential questions for the IPTV service providers:

- **Q3:** What is the influence of the cell size and accordingly the number of users in each cell on CBP, SBR and HBR results?
- **Q4:** What is the influence of the car speed on the blocking probability and blocking risks due to the channel switching or handover process with a given fixed number of IPTV users in each cell? Evidently, car speed is strongly determined by the current traffic situation and not so much by the type of car observed nor by the personality of the driver.

8.6.1 Case Study II: Results Obtained and their Interpretation

The simulation results are given in Figure 8.5, where we plot the CBP, SBR and HBR against the growth of average speed [km/h]. Again, all the simulation results included for case study II are with 95% confidence intervals. It is evident to see that:

- With increasing the cell size the number of IPTV users will also increase. The curves for 5 km as example of small cells are below the calculations for cells with the 10 km cell size exemplifying large cells. In the bigger cell, users spend more time to pass the cell and therefore have more time for zapping through the IPTV channels in each cell. Therefore, to answer **Q3**, it is evident when there are more users in bigger cells, the switching-induced blocking risk and the blocking probability will be increased.
- With increasing the lane speed, the CBP, HBR, and SBR values will reduce extremely. Because by raising the average speed each user has less time to spend in each cell. Consequently, they have less switching requests in each cell. Therefore, the CBP and SBR will be decreased by increasing the average speed. Thus, based on the observed result that when we are raising the speed, the overall blocking will decrease, **Q4** can be answered.

Very gratifying is the fact, that using the RCBH algorithm reduces the probability for handover blockings to nearly zero.

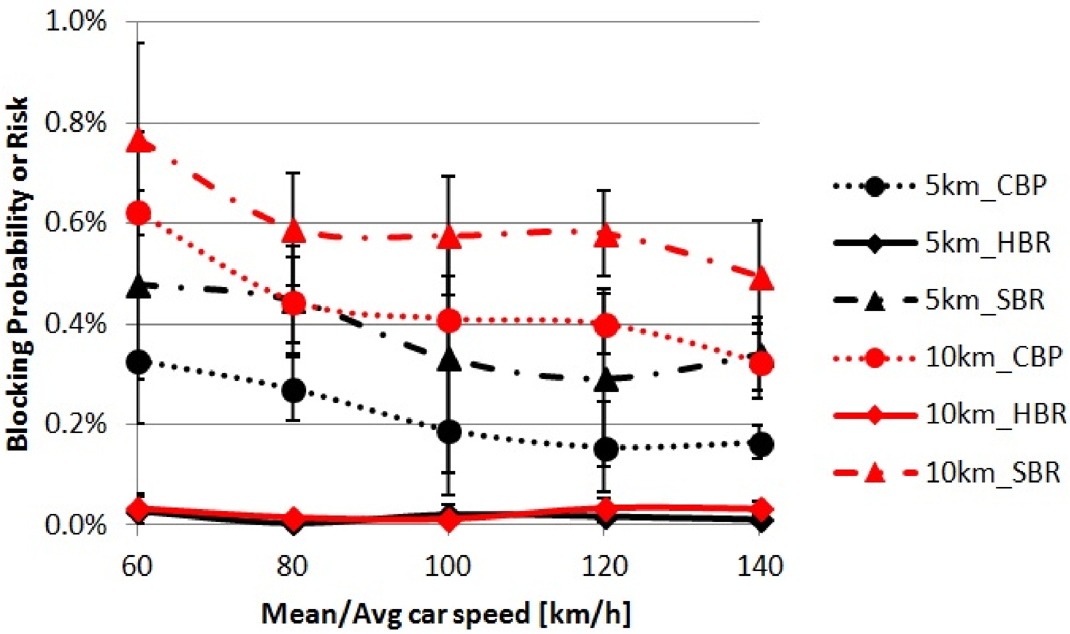

FIGURE 8.5: CBP, SBR and HBR results against different average speed.

Our comprehensive case studies I and II, have shown that the RCBH algorithm is able to significantly reduce the probability of handover-induced channel blockings. With this achievement by the RCBH algorithm, QoE will increase strongly. The case studies cover different traffic scenarios, access networks based on different wireless technologies as well as various offers of TV channels. The interesting part of the simulation results implies that in quite a few scenarios, RCBH reduces not only the handover-related but also the switching-related blocking risk. The reduction of SBR is a highly pleasing result because it shows that RCBH quite often implies a win-win situation as it can reduce the number of handover-related blockings without having to pay a price for this in terms of an increased number of switching-related blockings.

Chapter 9

Advanced Reserve Channel Before Handover (aRCBH) Algorithm

In this chapter we present the aRCBH algorithm to reduce handover-induced blocking by means of generalized bandwidth reservation. In vehicular IPTV services, limiting handover-induced blocking within an acceptable value is a paramount QoE issue because vehicular subscribers should be able to keep the TV program they are currently viewing even during their handover process from one cell to another. In vehicular networks, bandwidth management during the handover process has been one of the most important and challenging issues. Evidently, it is significant for vehicular users to keep their currently viewed TV program during handover, which also reduces the number of handover blockings during their journey.

In earlier work we introduced RCBH which has been presented in Chapter 7 and [124]. The RCBH algorithm attempts to reduce handover-induced blocking through reserving the channel for the user immediately after finding out that the user is in viewing phase. However, with this policy, there exist some situations in a wireless cell during which zapping users are not able to watch their new channel. The reason for such channel blocking events could be that there is not free bandwidth in the cell because the bandwidth is currently reserved for incoming users from the neighboring cell. Therefore, one of the most important goals regarding QoE is reducing handover-induced blocking, while at the same time efficiently keeping high bandwidth utilization. In this chapter, we are presenting our *advanced RCBH* (aRCBH) algorithm which tries to adequately balance between all (handover and new) TV channel requests and therefore increase the user's satisfaction with respect to bandwidth usage in the cell.

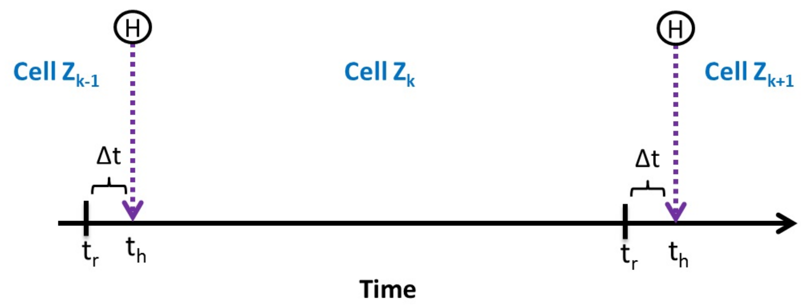

FIGURE 9.1: Time interval Δt before the expected handover event denoted by H.

In aRCBH, for balancing the bandwidth allocation between new users and handover users, we generalize the bandwidth reservation. In case of the aRCBH algorithm, we do not reserve the bandwidth immediately in the next cell for viewing users. We just reserve the bandwidth for the viewing users shortly (i.e. ΔT time units) before they are leaving the current cell.

9.1 Requirements and Basic Assumptions

All the assumptions regarding Channel Management (CM), Reserve List (RL), Broadcast List (BL), Call Admission Control (CAC) and bandwidth calculation in the aRCBH algorithm are the same as with the RCBH algorithm. Channel Broadcast List (CBL) also plays the same role, but there exists a difference between these two algorithms regarding changing the flags in the second column.

9.1.1 Time Interval Δt

In the aRCBH algorithm, according to the Figure 9.1, we have a new parameter which we call Δt. We try to ensure that, aRCBH is able with this new feature to increase QoE for all the users (viewing and zapping). Δt denotes the time interval directly before starting the handover process at the beginning of which we need to reserve the bandwidth for incoming viewing users in the next cell.

So, we assume that the channel will only be reserved for viewing users during the time interval:

$$\Delta t = [t_r, t_h], \quad t_h > t_r, \quad and \quad we \quad define: \quad \Delta T = t_h - t_r,$$

where

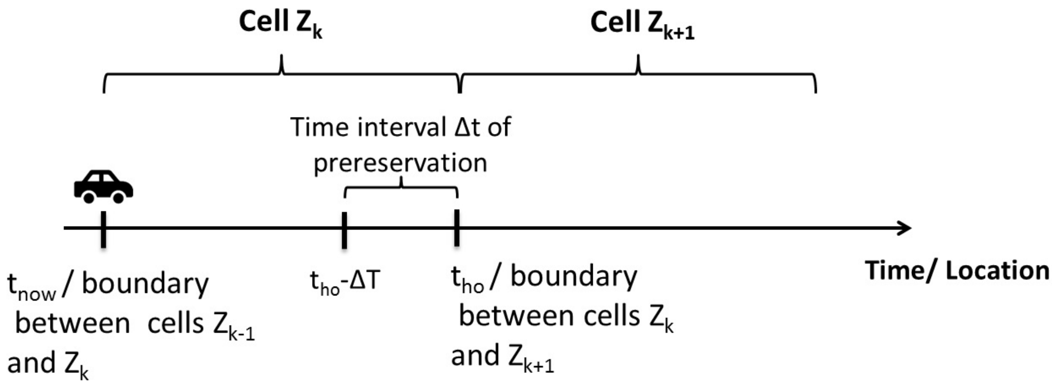

FIGURE 9.2: An example of time interval of prereservation.

- t_r: time of starting bandwidth reservation in the next cell for a user as soon as he/she is reaching a viewing phase,
- t_h: time of starting the handover process and changing both cells.

Figure 9.2, gives you more information regarding the time interval Δt. In this figure:

t_{ho} is the expected instant of handover for a given vehicle driving at a given average speed.

- t_{ho} can, e.g., be calculated for a vehicle which enters a given cell Z_k with diameter d (assuming the vehicle will drive through Z_k with average speed S).

t_{ho} can be determined as follows:

$$t_{ho} = t_{now} + \frac{d}{S}. \tag{9.1}$$

Evidently, a time instant t can be mapped in a straight-forward way to locations on the highway where the car is expected to be at time t. In our example, e.g., at time t_{ho} the vehicle considered is expected to be at the boundary between cells Z_k and Z_{k+1}.

As what concerns the a priori reservation of a channel for an IPTV user in the neighboring cell (Z_{k+1}) this reservation can be done extremely early, e.g., already immediately after cell Z_k is reached or very late, e.g., only shortly before cell Z_{k+1} is reached.

We assume that we choose a constant value of ΔT and do the a priori reservation in the interval

$$T \triangleq [t_{ho} - \Delta T, t_{ho}], \quad where \quad 0 < \Delta T \leq \frac{d}{S}.$$

The advantages of early and late reservation in the next cell are as follows:

- Early trial to do a priori reservation in Z_{k+1}:

  Bandwidth currently occupied in Z_{k+1} may be quite different from the situation which exists in Z_{k+1} at the time t = t_{ho} - ϵ, $\epsilon > 0$, ϵ very small.

- Late trial to do a priori reservation in Z_{k+1}:

  We do not block bandwidth in Z_{k+1} (as a consequence of reservation) as heavily as for a large ΔT; this is true in particular if d is large (i.e. large cell size) or S is small (i.e. very low speed of vehicle).

We assume only one trial of a priori bandwidth reservation. In particular, this trial is made at the first instant during time interval T at which our considered IPTV user reaches a viewing phase for channel C_i and then we try to do an a priori reservation for C_i in Z_{k+1}. This reservation for C_i will be successful if (at least) one of the following conditions holds:

1. C_i is currently already multicasted in Z_{k+1} anyway.
2. C_i is currently already prereserved in Z_{k+1} by any other user.
3. A sufficient amount of bandwidth is available in Z_{k+1} to prereserve C_i.

Otherwise, prereservation of C_i in Z_{k+1} will not be successful.

We do also expect different behavior of the IPTV service for different values of ΔT.

- $\Delta T = \frac{d}{S}$:

  We try to do the prereservation in Z_{k+1} as soon as we reach cell Z_k and start a viewing phase. So, we do not really apply our new aRCBH algorithm but still the original ("old") RCBH algorithm. Therefore, the results regarding CBP, HBP and SBP should be identical with RCBH results.

- $\Delta T = \epsilon > 0$, ϵ very small:

  Here, we expect that a priori reservation will have no effect at all because the bandwidth situation typically will not change significantly during the interval $[t_{ho}$ - ϵ, $t_{ho}]$ for a very small value of ϵ. Therefore, the results regarding CBP, HBP and SBP should be identical with the results for the case when we are not using RCBH nor aRCBH at all.

9.1.2 Channel Broadcast List (CBL) Flags

As we introduced CBL list in subsection 7.2.1.1 with a given example of it in Table 7.3, there have been three possible states for the attached flag in CBL for aRCBH and RCBH as follows:

1. Zapping [Z],
2. Viewing [V],
3. Reserved [R].

In aRCBH, too, all the vehicular IPTV users can be in one of those three states. However, the only difference between aRCBH and RCBH is switching from [V] to [R]. Each user by starting to use the IPTV service for the first time, reaches the [Z] flag as a zapping user. Then, this user after switching through several channels may finally find something of interest and then will change his/her flag from [Z] to [V] thus becoming a viewing user. In our new policy, it is not needed to reserve the channel for this user at this time. Therefore, there is greater chance for the new user in the next cell to do some zapping in the next cell. In the aRCBH algorithm, just ΔT seconds before starting the handover process the user's flag will be checked. And, if the user is in viewing phase with the flag [V], the specific channel will be reserved (if currently possible) with the flag [R] for this user in next cell.

Figure 9.3 presents an example of changing flags along the time for user U_n with applying the aRCBH algorithm. Each state is defined as described below:

1. User U_n joins the IPTV service and starts to watch his/her first channel with flag [Z].
2. User U_n is in zapping phase and finds something of interest to view with flag [Z].
3. Time-slot 1 minute is reached and U_n is still watching a specific channel C_i.

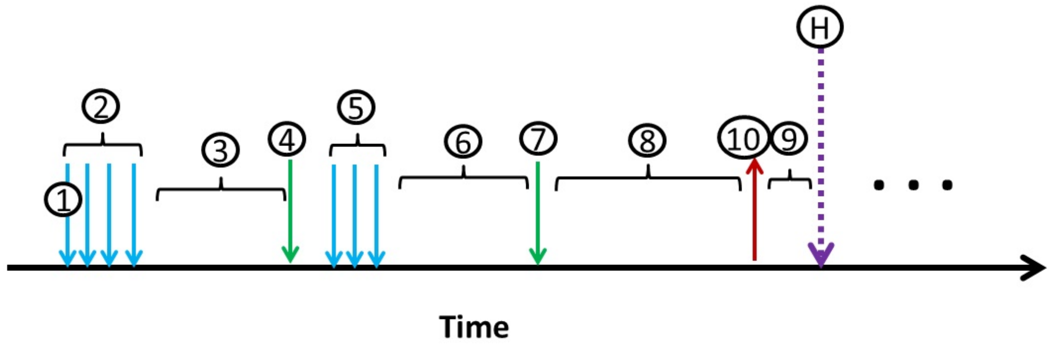

FIGURE 9.3: Example of user's flag changes in the aRCBH.

4. User U_n is now in viewing phase with flag [V].
5. After viewing channel C_i, U_n decides to start zapping again and switches his/her program with the flag [Z]. The advantage of the aRCBH algorithm is to avoid from occupying the bandwidth for neighboring viewing users at an early time at which it is rather uncertain whether they will be holding the currently viewed channel until they will be reaching the next cell.
6. After time-slot 1 minute is reached and U_n is still watching a channel C_j.
7. Now, U_n is in viewing phase with flag [V].
8. User U_n continues to view channel C_j.
9. Just shortly before arriving at the new cell or ΔT s before the handover process is expected to occur, reservation will be checked.
10. If U_n has flag [V] the next cell will be informed to reserve channel C_j for user U_n with flag [R].

9.1.3 Joining a Channel

As we described in subsection 7.2.2.1, all IPTV users need to *join* a group of multicasted channels for watching their requested channels. *Join* request for the aRCBH algorithm is the same as in case of the RCBH algorithm. However, after joining the requested channel the sequel in aRCBH is different. The joining process for the aRCBH inside CMZ and CMM is explained in Algorithm 7 thoroughly.

Line 1, is the starting point of the *join* request procedure. Sending the *join*-request from CMM to CMZ is the trigger of starting the *join* request process (line 2). Each *join* request includes the desired channel nº (C_i) and also a unique user ID (U_n). Therefore, by sending each *join* request from CMM_n of user U_n, a *join*(C_i, U_n) message will be received by the current CMZ_k (line 3). At the first step, it is required that CMZ_k tests whether the channel C_i is already reserved for user U_n by searching in CBL list (line 4). If there exists a reservation entry for channel C_i in the CBL_k, it is needed to modify this entry by changing the reserve flag [R] to a viewing flag [V] (line 5). Moreover, the reservation-expiration time in the third column of CBL_k should be deleted (line 6). Meanwhile, the (C_i, U_n) entry will be removed from RL list and will be added into the BL by CAC (line 7).

Else if, there is no reserving entry for channel C_i with specific user ID U_n in CBL_k, it is an opportunity for user U_n that channel C_i is already viewed or reserved by other users (U_*) (line 8). If yes, user U_n is going to watch the channel C_i with the flag [Z] (line 9). In this case, because the bandwidth is already allocated for channel C_i, there is no need to increase the BW_{Brdcst} and accordingly increasing BW_{Alloc} for this joining process.

It is also possible that no entry (neither broadcast nor reservation) exists for channel C_i in the CBL_k. In this case, the current CMZ_k has to check if there is some free bandwidth (BW_{Free}) still left in the current cell Z_k to transmit C_i for U_n (line 11). If there is enough BW_{Free} available, then CMZ_k adds the user to CBL_k with a zapping flag [Z] and also adds this user in BL by CAC (line 12). Furthermore, bandwidth assignment will be updated by increasing BW_{Alloc} by adding this channel to BW_{Brdcst} and BW_{Free} will be recalculated in cell Z (lines 13-14). In all other cases, C_i will not be broadcasted and will be blocked (line 16). After joining channel C_i in the current cell, which is not already broadcasted or reserved, recalculation of bandwidth is done by increasing of BW_{Alloc} and decreasing of BW_{Free} in the current cell. It is clear that the free amount of bandwidth is critical in IPTV systems. BW_{Free} is also raised by the *leave* users who currently leave the cell or switch their presently watched channel in the current cell.

Finally, at this moment a *reservation*-request is needed to be sent to the CMZ of the next cell the user will move to (CMZ_{k+1}) by the current cell's CMZ_k (line 8).

9.1.4 Leaving a Channel

Leave message is the second elementary event in each cell. The *leave* message is sent from the users to inform the CMZ to leave the group of the multicasted channel. IPTV user (U_n), sends a *leave* message by his/her CMM_n to the current CMZ, to notify the CMZ that he/she is switching off the device. The other possibility for sending a *leave* message is when the user is switching from channel i to j. Then it is needed firstly to send a *leave* message for channel i and then a *join* message for the new channel j. The

Algorithm 7 *Join*-request process in CMZ.

procedure *join*-REQUEST
    REQUIRE: sending *join*-request from CMM to CMZ
    Receive a *join*(C_i, U_n)-request from CMM_n
    if Corresponding reservation-entry in CBL existing **then**
        Change flag from [R] to [V]
        Delete the reservation-expiration time in CBL
        Removing from RL and adding into the BL by CAC
    else if C_i is reserved or viewed by other users **then**
        Add U_n[Z] to the desired channel C_i
    else if there is enough BW_{Free} left in the cell **then**
        Add U_n[Z] to the desired channel C_i
        Raise BW_{Alloc} by 1: BW_{Brdcst}++ in the cell Z
        Recalculate BW_{Free}
    else
        Desired channel cannot be delivered (i.e. it is blocked)
    end if
end procedure

last possibility for receiving a *leave* message from CMM_n is during the handover process. U_n sends a *leave* message to the old CMZ accompanied with a *join* message for the new cell.

In Algorithm 8, we will describe the leaving process in the CMZ_k at the specific cell. In line 1, the leaving process will be started. The requirement of starting this process is sending a *leave* request from CMM to CMZ (line 2). In three cases the user will send the *leave* message to the CMZ (line 3):

1. User switches off the device (without being accompanied by a *join* message).
2. User leaves a channel C_i by switching to another channel C_j (with being accompanied by a *join* message for the current CMZ).
3. User leaves a cell during handover process (with being accompanied by a *join* message for the next CMZ).

If a user is in one of these three cases, then CMM_n sends a *leave* message to the current CMZ_k (line 4). Subsequently in line 5, CBL_k and BL_k will be updated by CMZ_k, by removing the relevant entry for (C_i, U_n). After deleting the entry, if U_n was the last watching user of channel C_i, then it is needed to recalculate the bandwidth allocation by increasing the free bandwidth BW_{Free} in the current cell (line 6, 7).

It is also necessary to check whether channel C_i is reserved for U_n in the next cell. Therefore, in line 9, it will be controlled if the user was in viewing mode with the flag [V] and also this user will leave the current cell during the next ΔT seconds.

Then the current CMZ_k will send a cancel reservation message to the next CMZ_{k+1} cell (line 10). By receiving the cancel reservation message in the next cell, CMZ_{k+1} will update CBL_{k+1} and RL_{k+1} by deleting the reservation entry for (C_i, U_n) (line 11). It is also needed to recalculate the bandwidth allocation in the next cell, which has to be done if reservation for user U_n was the only entry for channel C_i, in all the lists of the CMZ_{k+1} (line 12). If it is true, in line 13 the free bandwidth BW_{Free} in the next cell CMZ_{k+1} is increased by the capacity of one channel.

Algorithm 8 *Leave*-request process in CMZ.

1: **procedure** *Leave*-REQUEST
2: **REQUIRE:** sending Leave request from CMM to CMZ
3: **if** ((User switches off the device) **or** (User leaves a channel C_i by switching to another channel C_j) **or** (User leaves a cell during a handover process)) **then**
4: CMM_n sends a *leave*(C_i, U_n)-request to CMZ_k
5: CMZ_k updates CBL_k and BL_k by removing the entry for (C_i, U_n)
6: **if** User is leaving a channel as the last user **then**
7: Raise BW_{Free} by 1: BW_{Free}++ in the cell CMZ_{k+1}
8: **end if**
9: **if** (User is in viewing-mode with flag [V]) **and** (is expected to leave the current cell during the next ΔT s) **then**
10: CMZ_k sends a cancel reservation message to the next CMZ_{k+1} cell
11: Update CBL_{k+1} and RL_{k+1} by removing the reservation entry in CMZ_{k+1}
12: **if** User is the last entry for channel C_i in CMZ_{k+1} **then**
13: Raise BW_{Free} by 1: BW_{Free}++ in next CMZ_{k+1} cell
14: **end if**
15: **end if**
16: **end if**
17: **end procedure**

9.1.5 Switching a Channel

Switching a channel is included in two elementary events, *leave* message and *join* message. In the aRCBH algorithm, the switching process is the same as in case of the RCBH algorithm, and if the user will not leave the current cell during the next ΔT s, it is not needed to send a reservation or cancel the reservation in the next cell. Therefore, according to our assumption a user U_n is watching channel C_i and wants to switch to channel C_j. Then, user U_n will send a *Switch* message which is a combination of:

$$Switch(C_i, C_j) = Leave(C_i) \quad \text{"}followed \quad by\text{"} \quad Join(C_j). \tag{9.2}$$

So, here *join* and *leave* process will be executed according to the Algorithms 7 and 8.

9.1.6 Reserving a Channel

The main objective of the aRCBH algorithm is to reserve the bandwidth for viewing users whereas, the bandwidth in the next cell is not occupied for a user who is not there in the next few minutes. Therefore, with the new policy in the advanced RCBH (aRCBH) algorithm, we give a greater chance to the zapping users to find free bandwidth and therefore to zapping with less channel blockings whereas we still try to reserve the bandwidth for incoming viewing users.

In the aRCBH algorithm, reservation typically is not done immediately after changing the flag to [V]. In this algorithm, CMZ waits till the user is sufficiently close to the border of each cell and when ΔT seconds remain before this user is expected to leave the cell, CMZ will check whether the user is in viewing phase. Moreover, if the user is with the flag [V], then the reservation of the bandwidth in the next cell will happen (if currently possible).

Algorithm 9 describes the reservation process in the aRCBH algorithm in detail. The *reservation* request starts in the CMZ of the current cell (Line 1). Line 2 shows that the essential part of starting the *reservation* process is to reach the time interval ΔT s before the handover process started. Then, CMZ_k will check whether the user is in viewing mode with the flag [V] (line 3). Now is the time for CMZ_k to send a *reservation*(C_i,U_n)-request for the next cell to reserve channel C_i for this user U_n (line 4). If the channel C_i is already reserved or viewed by another user in the cell k+1, then user U_n will be added to the channel C_i entry in RL_{k+1} and also in CBL_{k+1} with flag [R] (lines 5, 6 and 7).

Else, if C_i is not reserved or viewed by other users in the CMZ_{k+1} of the next cell (line 8), it is necessary to check the free bandwidth BW_{Free} in the next cell for reserving channel C_i for incoming user U_n (line 9). If there is enough bandwidth in BW_{Free}, channel C_i will be reserved for this user in the next cell and it will be added to the CBL_{k+1} and RL_{k+1} lists (lines 10-12). Then it is needed to recalculate the bandwidth assignations by increasing allocated bandwidth BW_{Alloc} and BW_{Res} in cell k+1 (lines 13 and 14). Eventually, if there is not free bandwidth in cell k+1, aRCBH is not able to reserve channel C_i for U_n in the next cell (line 16).

In aRCBH algorithm as an advanced reservation algorithm, reserving the bandwidth only happens for viewing users who are in the time interval Δt, i.e. ΔT seconds before the handover process is expected to occur. It means that reservation is done only for viewing users which are expected to be leaving the current cell very soon. The new policy is very effective to avoid holding a free bandwidth BW_{Free} in the next cell for a long time and blocking the zapping users in the next cell. This is an appropriate idea because there are some undesirable situations by reserving a channel immediately after changing

Algorithm 9 *Reservation*-request process in CMZ.

```
procedure Reservation-REQUEST
    REQUIRE: User U_n arrived at the time interval Δt, i.e. ΔT s before the expected start of the handover process
    if User is in viewing-mode with flag [V] then
        CMZ_k sends a reservation(C_i,U_n)-request to the CMZ_{k+1} of next cell
        if C_i is reserved or viewed by other users in CMZ_{k+1} then
            Add user U_n for channel C_i with flag [R] in CBL of CMZ_{k+1}
            Add (C_i,U_n) into the RL of the cell k+1
        else if C_i is not reserved or viewed by other users in CMZ_{k+1} then
            if there is enough BW_Free left in the CMZ_{k+1} then
                Reserve channel C_i for U_n of the next cell
                Add user U_n for channel C_i with flag [R] in CBL of CMZ_{k+1}
                Add (C_i,U_n) into the RL of the next cell
                Raise BW_Alloc by 1: BW_Res++ in the next cell k+1
                Recalculate BW_Free of cell k+1
            else
                Do not reserve the channel
            end if
        end if
    end if
end procedure
```

a flag from [Z] to [V]. In the case of changing the flag to [V] at the beginning of entering into the current cell, especially in case of large cells there might be a quite long time for occupying unnecessarily a lot of free bandwidth in the next cell. Another possibility is when the viewing user starts for zapping in the current cell and the user is not going to view his/her presently watched channel until reaching the new cell. In this case, it may happen that users generating new requests in the next cell have less chance to watch their requested channel. Therefore, the bandwidth in the next cell may be occupied by incoming users some of which will switch their channel before arriving to the new cell. So, the aRCBH algorithm will prevent allocating bandwidth by unnecessary reservations for too long time intervals during the car journey.

9.1.7 Handover between Cells

Handover process in the aRCBH algorithm is also exactly like in case of the RCBH algorithm and a *handover*-request should be sent by CMM_n of user U_n to the current CMZ_k to start the process. The *handover*-request contains the following elementary requests:

$$\begin{aligned} &Handover(U_n, CMZ_k, CMZ_{k+1}, C_i) = \\ &\quad Leave(C_i, CMZ_k) \quad \text{"followed by"} \quad Join(C_i, CMZ_{k+1}). \end{aligned} \tag{9.3}$$

And if, the bandwidth is reserved for user U_n in the new cell, the *handover*-request for this user is included:

$$\begin{aligned} &Handover(U_n[R], CMZ_k, CMZ_{k+1}, C_i) = \\ &Leave(C_i, CMZ_k) \text{ "followed by" } Join(C_i, CMZ_{k+1}) \text{ "followed by" } \\ &\qquad Cancel\text{-}Reservation(U_n, CMZ_{k+1}, C_i). \end{aligned} \tag{9.4}$$

9.2 IPTV Simulation Model with Applying the aRCBH Algorithm

Simulation of IPTV systems applying the RCBH algorithm has been previously studied in Chapter 8. Unlike the proposed RCBH algorithm where the reservation for viewing users happened immediately after changing the flag to [V], the aRCBH algorithm uses the time variable to reserve the bandwidth ΔT seconds before arriving at the new cell. Further, in the new scheme, the bandwidth resource in the new cell is not allocated for a possibly very long time for arriving users. Therefore, in aRCBH, QoE guarantees can be given not only for viewing users but better channel availability is possible for zapping users, too.

In order to evaluate our proposed aRCBH algorithm, we generalized our Monte Carlo simulation model for the RCBH algorithm to gain the generalized advanced simulation model for simulating the aRCBH algorithm. The new simulator is an advanced version of our comprehensive IPTV simulator applying the RCBH algorithm which is explained in Chapter 8.

In the aRCBH algorithm, Call Admission Control (CAC) in each CMZ reserves the channel in the next cell for arriving users in their viewing phase just ΔT seconds before being expected to start the handover process. Therefore, with this new policy of CAC, QoE will be guaranteed for a larger set of IPTV users (namely those in zapping and in viewing phase) in IPTV vehicular networks. With the aRCBH algorithm, we achieve as much as possible bandwidth utilization in the cell. Therefore, it is conceivable that the new policy in the aRCBH algorithm might be very precious and lead to improved service availability for IPTV service providers.

9.2.1 State Vectors in the aRCBH Simulation Model

In this work, for modeling the IPTV user behavior, we employ the trace file (cf. section 3.1.4) as a realistic IPTV user model for our aRCBH simulator.

In this advanced simulator, we apply two different state vectors as we already used them in the RCBH simulator.

BL-VECTOR as a broadcast list (BL) in each cell:

(BLUserNumberChannel[1], BLUserNumberChannel[2], BLUserNumberChannel[3], $\cdots$*, BLUserNumberChannel[N]),*

and **RL-VECTOR** as a reserve list (RL) in each cell:

(RLUserNumberChannel[1], RLUserNumberChannel[2], RLUserNumberChannel[3], $\cdots$*, RLUserNumberChannel[N]).*

Obviously, in both state vectors, the ith element represents the current number of users watching or reserving channel i.

There are some events which have effects on the BL-VECTOR and on the RL-VECTOR as follows:

- After receiving each new channel request by the users, BL-VECTOR$_k$ will be updated.
- After a user is entering in the time interval Δt before the handover, if the user is in viewing phase, updating of RL-VECTOR$_{k+1}$ is also needed.
- After receiving a leave message for the current channel, BL-VECTOR$_k$ will be updated immediately.
- After terminating the execution of a handover process, both vectors, BL-VECTOR$_k$ and BL-VECTOR$_{k+1}$ will be updated.
- If the user involved in the handover was in viewing phase, updating RL-VECTOR$_{k+1}$ is also needed.

In figure 9.4 we demonstrate an example of recording the events during the car journey of an IPTV user through the cells. Each event will be recorded as follows:

- User U$_n$ starts watching the IPTV service in cell Z$_k$. Therefore, U$_n$ sends a new request for a channel C$_i$.
- User U$_n$ joins to the group of multicasted channel C$_i$.
- This event will be recorded in **BL-VECTOR** of the current cell as a joining to channel C$_i$.

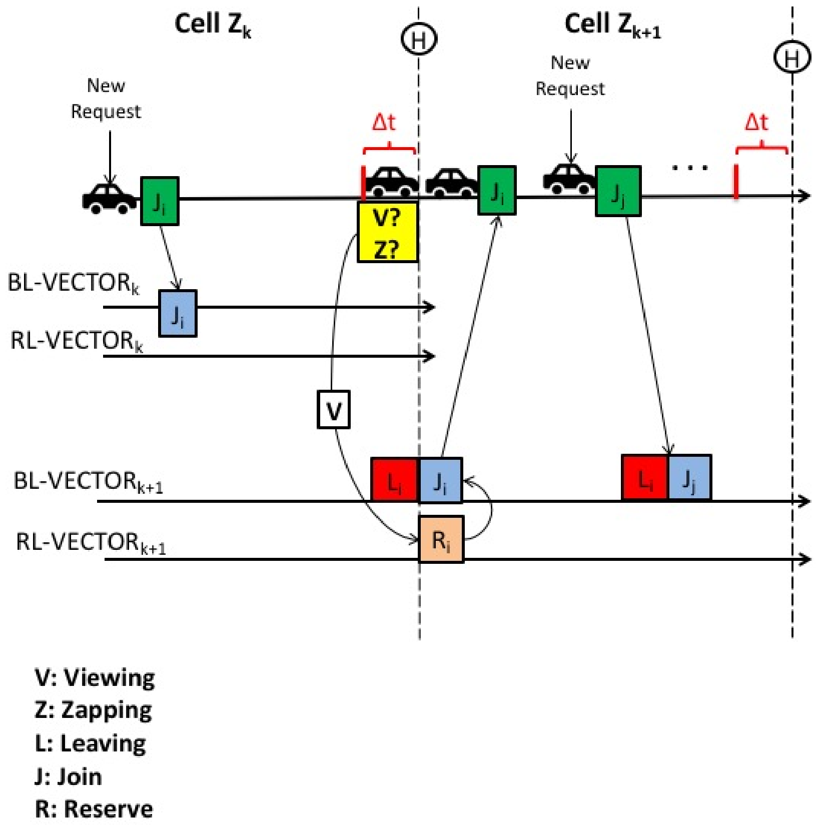

Figure 9.4: Example of recording events in the vectors of the aRCBH algorithm.

- CAC in CMZ will wait till the user will reach the time interval Δt, i.e. ΔT seconds before starting the handover process.

- Now at this cell border, it is needed to reserve channel C_i for him/her in the next cell. Therefore, if available bandwidth allows, channel C_i will be reserved in the **RL-VECTOR**$_{k+1}$ of the next cell.

- After handover process, channel C_i will be deleted from **BL-VECTOR**$_k$ and will be added to the **BL-VECTOR**$_{k+1}$. Accordingly, this reservation entry in the new cell should be removed from **RL-VECTOR**$_{k+1}$.

- Then, the user U_n sends a new request for channel C_j in the new cell. Again, it is needed to update **BL-VECTOR**$_{k+1}$ as a consequence of the events “leaving channel C_i” and “joining channel C_j”.

- It is not required to check the user phase after each new request and updating **RL-VECTOR**$_{k+1}$ by adding the specific channel when the user is not leaving the cell sufficiently soon.

The Pseudo-code description of the aRCBH algorithm for evaluating CBP and CA is given in the following. All the assumptions for the preparation of the trace files in this advanced simulator are according to Chapters 3 and 8.

```
/* Pseudo-code for evaluating CBP and CA by applying aRCBH algorithm for
vehicular IPTV service in each single cell */
int main()
{ ...
/*System initialization*/
Single_Trace_Generation();  // for all users
ATT = Aggregate-Traffic-Trace();
Initial_State_Determination();
ATT_pointer = ATT;  // the 1st node in Aggregate-Traffic-Trace (ATT) list
while(ATT_pointer!=NULL)  // still in simulation time duration {
//warming-up stage
Transient_Phase();
//evaluation channel blocking in steady state
 if (Cell is steady state) {
/*channel request arriving process in CMZ*/
 if ((ATT_pointer->event) is channel request event R) {
  CounterTotalRequest++;
        if (R is a New Request (NR)) {
                CounterSwitchingRequest++;
                i = the channel number requested by NR;
//Cell Z = current cell
//Cell Z+1 = next cell
//UserNumberChannelZ[BL] state vector for BL channels in cell Z
//UserNumberChannelZ[RL] state vector for RL channels in cell Z
if ((UserNumberChannelZ[BL][i]==0)&&(UserNumberChannelZ[RL][i]==0)) {
//no one is currently watching or reserving this channel in cell Z
        if (bandwidth left in cell Z is sufficient) {
                ACCEPT(NR);
                UserNumberChannelZ[BL][i]++;}
else {
//not enough bandwidth left in cell Z
                REJECT(NR);
                CounterBlockedSwitchingRequest++;}}
/*Reserving Process in Time Interval delta_T*/
if((User is in viewing phase)&&(User is expected to leave the current cell
 in next delta_T s)){
//it is needed to reserve channel i for U in cell Z+1
//UserNumberChannelZ+1[BL] state vector for BL channels in cell Z+1
//UserNumberChannelZ+1[RL] state vector for RL channels in cell Z+1
if ((UserNumberChannelZ+1[BL][i]!=0)||(UserNumberChannelZ+1[RL][i]!=0))
UserNumberChannelZ+1[RL][i]++;
else if (bandwidth left in cell Z+1 is sufficient)
UserNumberChannelZ+1[RL][i]++;}
```

```
/*Handover Process*/
if (R is a Handover Request (HR)) {
CounterHandoverRequest++;
i = the channel number requested by HR;
UserNumberChannelZ[BL][i]--;
if (UserNumberChannelZ+1[RL][i]!=0){
//channel i is already reserved for this user
ACCEPT(HR);
UserNumberChannelZ+1[RL][i]--;
UserNumberChannelZ+1[BL][i]++;}
else if((UserNumberChannelZ+1[BL][i]==0)&&(UserNumberChannelZ+1[RL][i]==0))
{
//no one is currently watching or reserving this channel in cell Z+1
        if (bandwidth left in cell Z+1 is sufficient) {
                ACCEPT(HR);
                UserNumberChannelZ+1[BL][i]++;}}
else {
//not enough bandwidth left in cell Z+1
                REJECT(HR);
                CounterBlockedHandoverRequest++;}}}}
/*Leaving Channel in cell Z*/
        else if ((ATT_pointer->event) is user leaving event L) {
        i = the channel number previously watched by the user;
        UserNumberChannelZ[BL][i]--;}
//Move to the next event in ATT list
        ATT_pointer =   ATT_pointer->next;}}
/* Calculation of the Channel Blocking Probability */
HBP = CounterBlockedHandoverRequest / CounterTotalRequest;
SBP = CounterBlockedSwitchingRequest / CounterTotalRequest;
HBR = CounterBlockedHandoverRequest / CounterHandoverRequest;
SBR = CounterBlockedSwitchingRequest / CounterSwitchingRequest
CBP = HBP + SBP;
CA = 1 - CBP; }
```

Chapter 10

Case Studies to Assess the aRCBH Algorithm

We introduced our new advanced algorithm to achieve generalized bandwidth reservation in Chapter 9. In this chapter, two case studies (Case Study I and II) are conducted, aiming to investigate the Channel Blocking Probability (CBP), Switching-related Blocking Risk (SBR) and Handover-related Blocking Risk (HBR) if we apply our new generalized algorithm. We are going to evaluate our aRCBH algorithm through the following case studies. This will allow us to illustrate the potential of our aRCBH algorithm to decrease the number of handover-induced blockings as well as the switching-induced blockings of vehicular IPTV services and consequently to improve the QoE for the subscribers.

10.1 Case Study I: Variation of ΔT and Traffic Density

In this section, we present and discuss the simulation results of our proposed aRCBH algorithm for different sizes of time interval ΔT, car speeds and also different traffic density. Furthermore, we compare the aRCBH algorithm with RCBH algorithm and also without any reservation policy to find out the efficiency of our new algorithm. With applying this case study, we want to provide decision support for using an aRCBH algorithm for reserving bandwidth for users being in a viewing phase not immediately after changing the user's flag to the viewing phase, and reserving the channel for viewing users just ΔT seconds before the handover process is expected to happen. In this case study, we consider medium and low traffic density with various distances between two adjacent vehicles in each cell.

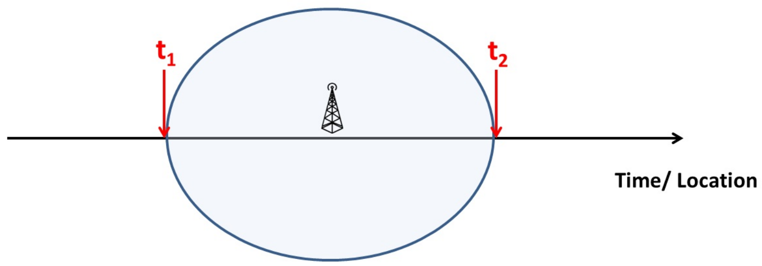

FIGURE 10.1: Time duration for passing the cell.

The distance d [m] between vehicles as it is described in detail in [47], is calculated according to a truncated exponential distribution for an interval with speed-dependent bounds. Moreover, the time duration for passing the cell by the user is related to the car speed and cell size. On the other hand, knowing the expected sojourn time of a car in the cell is necessary for this case study to find out the meaningful values of ΔT. In our work, we assume the time duration in the cell according to the Figure 10.1 and we have to take into account that this time duration may be different for each lane.

$$\tau(v_i) = t_2(v_i) - t_1(v_i), \tag{10.1}$$

where v_i denotes the speed of cars driving on lane i.

Moreover, accordingly:

$$\tau(v^*) = t_2(v^*) - t_1(v^*), \tag{10.2}$$

where v^* is fastest speed of cars on any lane.

Therefore, the time interval ΔT for our case study can be varied between:

$$0 < \Delta T < \tau(v^*), \tag{10.3}$$

where, evidently, $\tau(v^*)$ is different for different cell sizes and different v^*.

In this case study, we want to evaluate the impact of doing the channel reservation ΔT seconds before the expected handover event by applying the aRCBH algorithm and vehicle traffic densities in highway scenarios on blocking probability or risk. Moreover, we want to compare it with the non-reserving policy and also with RCBH algorithm.

By performing this case study, we are going to answer the three following important questions.

- **Q1:** What is the impact on the channel availability when we are applying the aRCBH algorithm?
- **Q2:** What is the impact of traffic density on the aRCBH algorithm?
- **Q3:** What value of ΔT satisfies best all kind of users (handover and zapping) in the cell?

Table 10.1 summarizes the essential experimental boundary conditions assumed in the case study I.

We simulated our scenario with different values of time interval ΔT. In Table 10.2, we present the different values chosen for time interval ΔT (in seconds) for low and medium traffic densities for this case study. Please take into account that "0" means without any reservation and the last column represents the $\tau(v^*)$ for both traffic densities.

10.1.1 Case Study I: Results Obtained and their Interpretation

A set of simulation experiments has been conducted in order to answer the above questions (i.e. Q1, Q2 and Q3). Figures 10.2 and 10.3 demonstrate the simulation results with 95% confidence intervals. The curves are plotted showing the evaluated CBP, HBR and SBR against different values of ΔT, which ranged from 0% to $\tau(v^*)$. The value of $\tau(v^*)$ in these simulation results, represents that reservation will happen immediately after the user is in viewing phase. Or in other words, it is identical to the RCBH algorithm.

The observations from Figures 10.2 and 10.3 are listed below:

- When the traffic density increases, CBP, HBR and SBR also grow because more users are in a cell. Therefore, also more blocking events will occur in each cell.
- Evidently, in Figures 10.2 and 10.3, the results represent that CBP, SBR and HBR is decreasing by using the aRCBH algorithm for both traffic situations (medium and low). Moreover, the results demonstrate that applying the aRCBH algorithm for all users (handover and zapping) will imply that the blocking probability and blocking risks will decrease significantly. This improvement of QoE by the aRCBH algorithm will be true for different values of ΔT. The reason for this seems to be that the popular channels are already reserved by users in the viewing phase and

Table 10.1: Parameter values for Case Study I.

Notations	Descriptions	Values
N	Number of TV channels offered in total	100
BW_c	Total Bandwidth available for IPTV in cell c	20 Mb/s (sufficient for parallel transmission of 40 TV Channels)
D_{cell}	Diameter of each Cell	12 km
k	Number of lanes in each direction of the highway	3
M-$SP_{[i]}$	Speed of a vehicle in each lane i [km/h] for Medium traffic density on highway	60 (lane 1), 80 (lane 2), 100 (lane 3)
L-$SP_{[i]}$	Speed of a vehicle in each lane i [km/h] for Low traffic density on highway	100 (lane 1), 120 (lane 2), 150 (lane 3)
M-$\tau(v_i)$	Minimum time for passing each cell at the fastest line for Medium traffic density	432 (s)
L-$\tau(v_i)$	Minimum time for passing each cell at the fastest line for Low traffic density	288 (s)
M-$d_{[i]}$	Average distance in lane i in Medium traffic density between two adjacent vehicles [m]	15 (lane 1), 25 (lane 2), 35 (lane 3)
L-$d_{[i]}$	Average distance in lane i in Low traffic density between two adjacent vehicles [m]	30 (lane 1), 40 (lane 2), 50 (lane 3)
α	percentage of the IPTV users	10%
θ	Zipf parameter	1.3

Table 10.2: Time interval ΔT for Case Study I.

Medium Traffic Density	0	50	100	200	300	432
Low Traffic Density	0	30	60	100	200	288

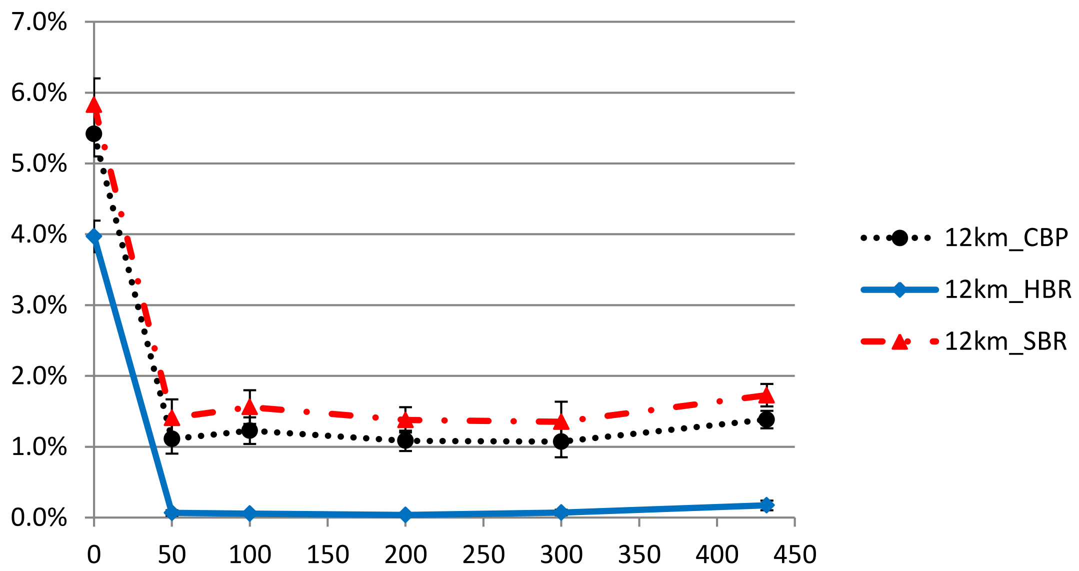

FIGURE 10.2: Channel blocking results for 12km with medium traffic density.

the zapping users have a better chance to select the channels among the reserved channels. On the other hand, in contrast with RCBH algorithm, the bandwidth in the new cell will not be occupied for a long time and therefore we give a chance for zapping users to watch also some unpopular channels. Furthermore, the risk of a channel being blocked during the handover process by applying the aRCBH is near zero. So, question **Q1** can be answered here.

- In order to answer question **Q2**, in medium traffic density, there are more users and accordingly the chance of broadcasting and reserving the popular channels will be high. However, in low traffic density, the situation is not the same as in case of the medium traffic density and there is a better chance to broadcast or to reserve unpopular channels in the case of fewer users in the cell. Therefore, by applying the aRCBH for the medium traffic density the blocking probability and blocking risk will be decreasing significantly.

- As can be seen in Figures 10.2 and 10.3, for all values of time interval ΔT, the blocking risk and probability will be decreased. However, if we reserve the channel relatively shortly before the handover will be executed for the user, the efficiency will be increased and we receive better QoE for all the charts. Hence, to answer question **Q3**, the optimum value of ΔT is the answer.

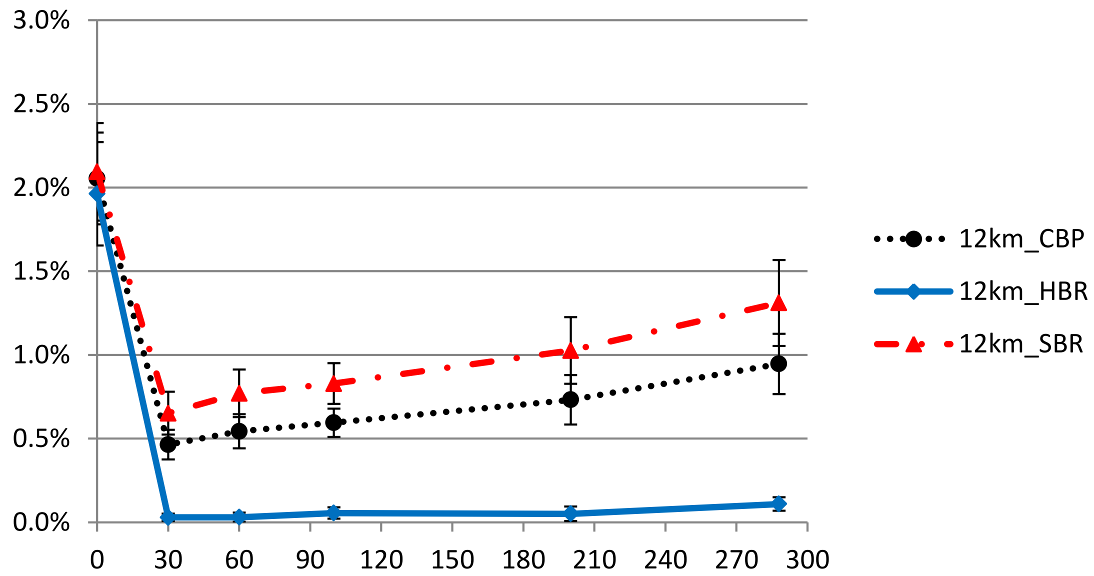

FIGURE 10.3: Channel blocking results for 12km with low traffic density.

10.2 Case Study II: Variation of ΔT and the Cell Sizes

In the second case study, we consider different cell sizes and accordingly due to the usage of different access network technologies we have various numbers of vehicles in each cell. In this case study, we keep the traffic density constant. The further assumptions for the simulation experiment of case study II are given in Table 10.3. In these simulation experiments, we try to find an answer for questions which would be kind of interesting for an IPTV service provider to selecting the access network technology. Furthermore, the different values chosen for time interval ΔT are shown in Table 10.4.

The main question to be answered by Case Study II is:

- **Q4:** What is the impact of the aRCBH algorithm in case of the different cell sizes (access network technology) to providing channel availability?

10.2.1 Case Study II: Results Obtained and their Interpretation

We conduct a set of experiments in order to answer the above question. We simulate scenarios with two different cell sizes, with 95% confidence intervals, and the results are given in Figures 10.4 and 10.5. In particular, the results have been obtained by increasing the cell size, and therefore the number of IPTV users will grow and this leads to an increment of blocking probability and risk. The figures focus on the variation of ΔT value, and the results show that the most effective time for reservation for different

TABLE 10.3: Parameter values for Case Study II.

Notations	Descriptions	Values
D_{cell}	Diameter of each Cell	15, 18 km
L-$SP_{[i]}$	Speed of a vehicle in each lane i [km/h] for Low traffic density on highway	100 (lane 1), 120 (lane 2), 150 (lane 3)
L-$d_{[i]}$	Average distance in lane i in Low traffic density between two adjacent vehicles [m]	30 (lane 1), 40 (lane 2), 50 (lane 3)
15-$\tau(v_i)$	Minimum time for passing each cell at the 15 km cell size	360 (s)
18-$\tau(v_i)$	Minimum time for passing each cell at the 18 km cell size	432 (s)

TABLE 10.4: Time interval ΔT for Case Study II.

15km Cell Size	0	30	100	200	300	360
18km Cell Size	0	30	100	200	300	432

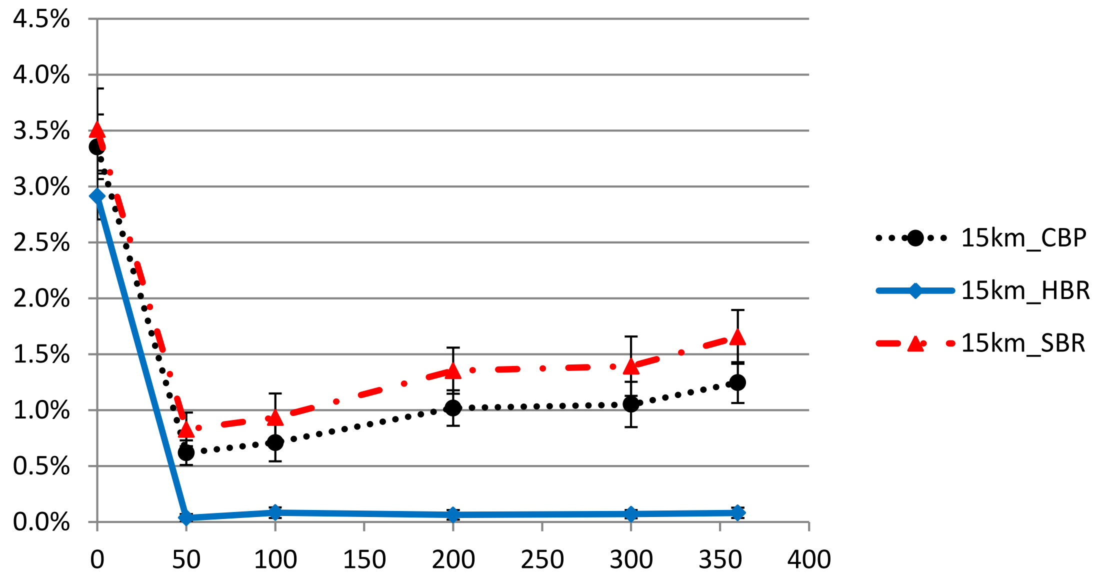

FIGURE 10.4: Channel blocking results for 15km with low traffic density.

cell sizes is just really near to the predicted handover time and for both of them the optimum value of ΔT is ΔT=30 seconds.

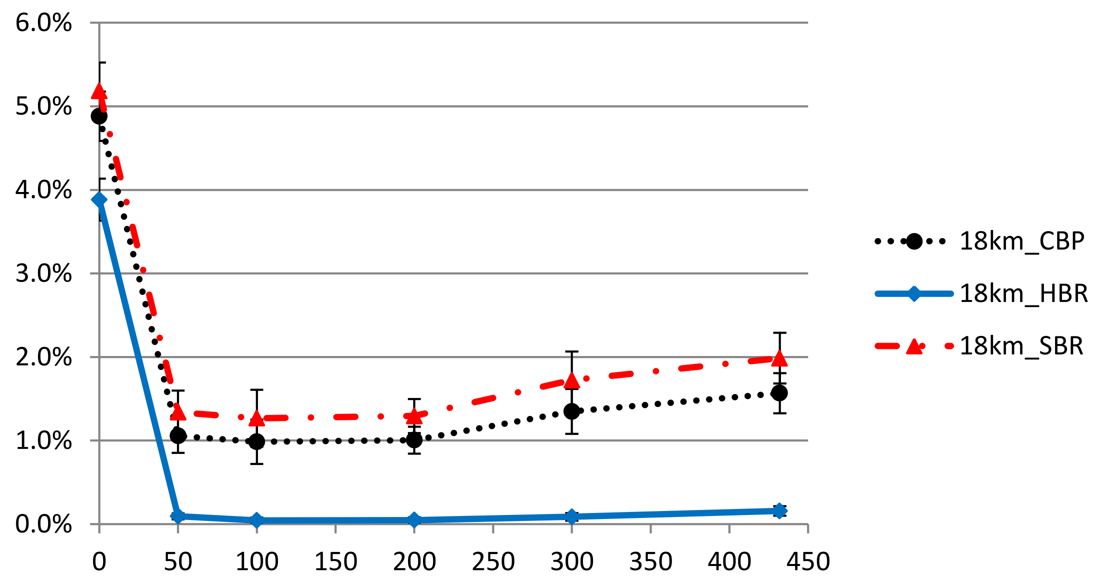

FIGURE 10.5: Channel blocking results for 18km with low traffic density.

10.3 Case Study III: Variation of ΔT and the Vehicle Speeds

The goal of case study III is to analyze the impact of different vehicle speeds on the CBP, HBR and SBR results. Except the cell diameter D_{cell}, the distance between the cars $d_{[i]}$ and the speed $SP_{[i]}$, all other simulation parameter values are the same as in the Case Study I (cf. Section 10.1). The new parameters are given in Table 10.5. In this case study, we varied the speed for each lane and distance between the cars such that in each experiment the number of the cars in a cell in general is constant. Moreover, the different values chosen for time intervals ΔT are given in Table 10.6.

In the third case study, we try to answer the following question for the IPTV service provider:

- **Q5:** What is the impact of the vehicle speed on the blocking probability and different blocking risks with a given fixed number of IPTV users in each cell? Evidently, the time duration for passing each cell (τ) is strongly determined by vehicle speed and it is also strongly necessary to take a decision for the best time interval ΔT for a reservation of the channels for the users.

10.3.1 Case Study III: Results Obtained and their Interpretation

Figures 10.6, 10.7, 10.8, 10.9 and 10.10 depict CBP, SBR and HBR results for different average speed $SP_{[i]}$ against the growth of the time interval ΔT (s). Again, in this case study all the simulation results are given including their 95% confidence intervals.

TABLE 10.5: Parameter values for Case Study III.

Notations	Descriptions	Values
D_{cell}	Diameter of each Cell	12 km
$SP_{[i]}$	Speed of a vehicle in each lane i [km/h] V_{avg} (V_1, V_2, V_3)	**60** (50, 60, 80), **80** (70, 80, 100), **100** (80, 100, 140), **120** (100, 120, 160), **140** (120, 140, 180)
$d_{[i]}$	Average distance in lane i between two adjacent vehicles [m] (d_1, d_2, d_3)	(20, 40, 40)
$\tau_{SP_{[60]}}$	Minimum time for passing each cell with average speed 60km/h	540 (s)
$\tau_{SP_{[80]}}$	Minimum time for passing each cell with average speed 80km/h	432 (s)
$\tau_{SP_{[100]}}$	Minimum time for passing each cell with average speed 100km/h	308 (s)
$\tau_{SP_{[120]}}$	Minimum time for passing each cell with average speed 120km/h	270 (s)
$\tau_{SP_{[140]}}$	Minimum time for passing each cell with average speed 140km/h	240 (s)

TABLE 10.6: Time intervals for different values of average speed in Case Study III.

$\mathbf{SP_{[60]}}$	0	30	50	200	300	540
$\mathbf{SP_{[80]}}$	0	30	100	200	300	432
$\mathbf{SP_{[100]}}$	0	30	50	100	200	308
$\mathbf{SP_{[120]}}$	0	30	50	100	200	270
$\mathbf{SP_{[140]}}$	0	30	50	100	150	240

- We observe that the reservation of the channel even immediately after finding out that the user is in viewing phase improved the QoE (τ seconds). However, it is visible in general, with decreasing of the value of ΔT that the number of blocking events will decrease. Our experimental results represent that if the channel reservation for the viewing users by aRCBH algorithm is executed just shortly before the handover process, we get the best achievement regarding the improvement of QoE for vehicular IPTV users.
- By increasing the vehicle speed and applying the aRCBH algorithm for vehicular IPTV users, we observe that the blocking probability and risk decrease significantly.

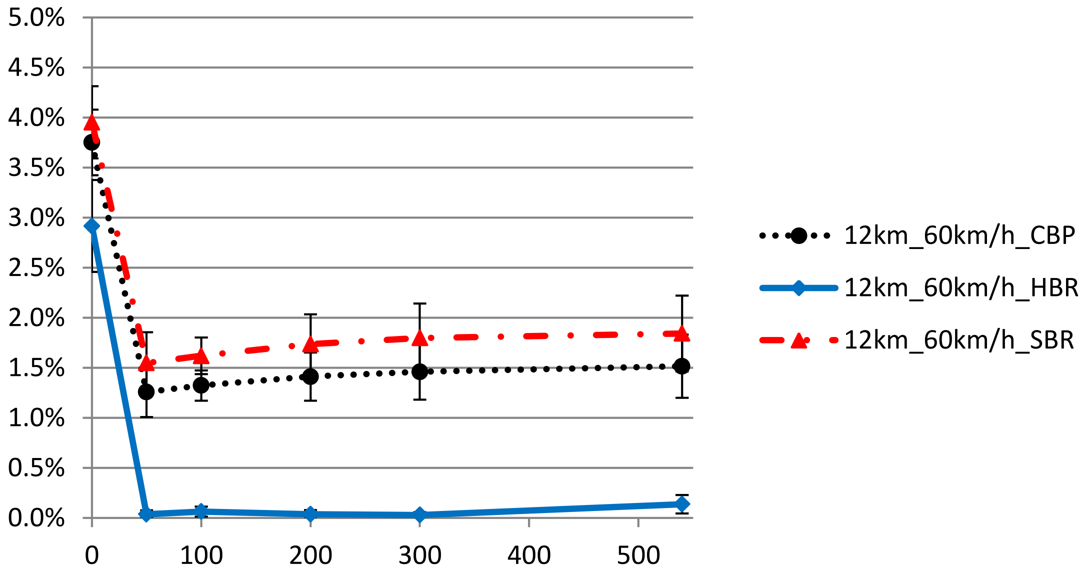

FIGURE 10.6: Channel blocking results for vehicle with average speed 60 km/h.

To answer **Q5**, it is evident that by raising the vehicle speed v, there is a decrement in the value of $\tau(v)$. Therefore, the IPTV users spend less time in the cell. So accordingly, they have less switching requests in each cell and more handover requests. Hence, applying aRCBH with an optimum amount of ΔT, improves the QoE considerably for all kind of users.

- In Figure 10.10, the results show that for the fast vehicles with an average speed of $\text{SP}_{[140]}$, the time interval (ΔT) should be 50 seconds and not 30 seconds. Because they drive very fast, they need more time before the handover process to complete the reservation process in the next cell.

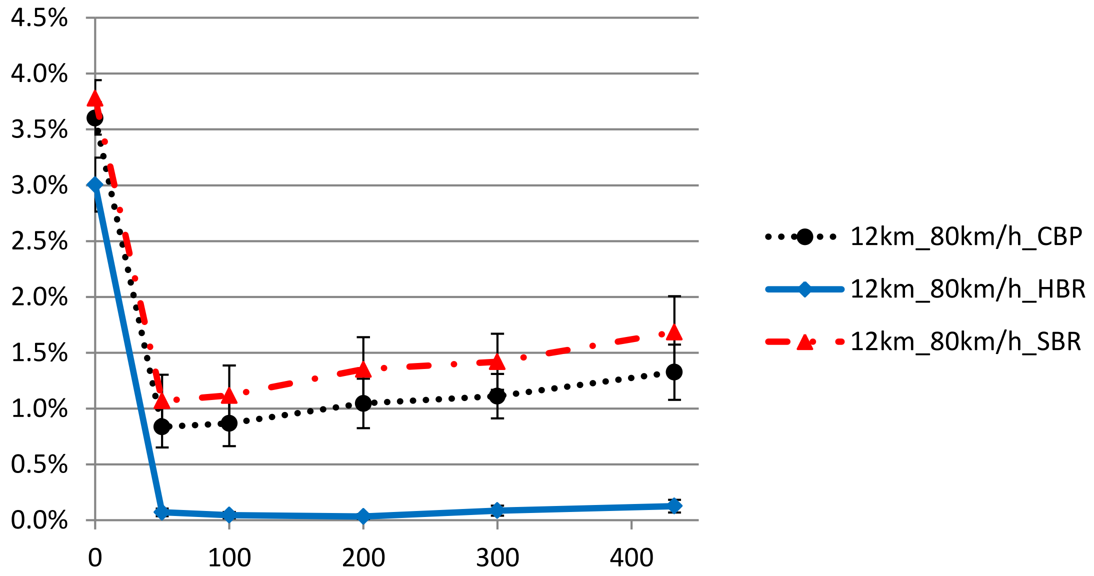

Figure 10.7: Channel blocking results for vehicle with average speed 80 km/h.

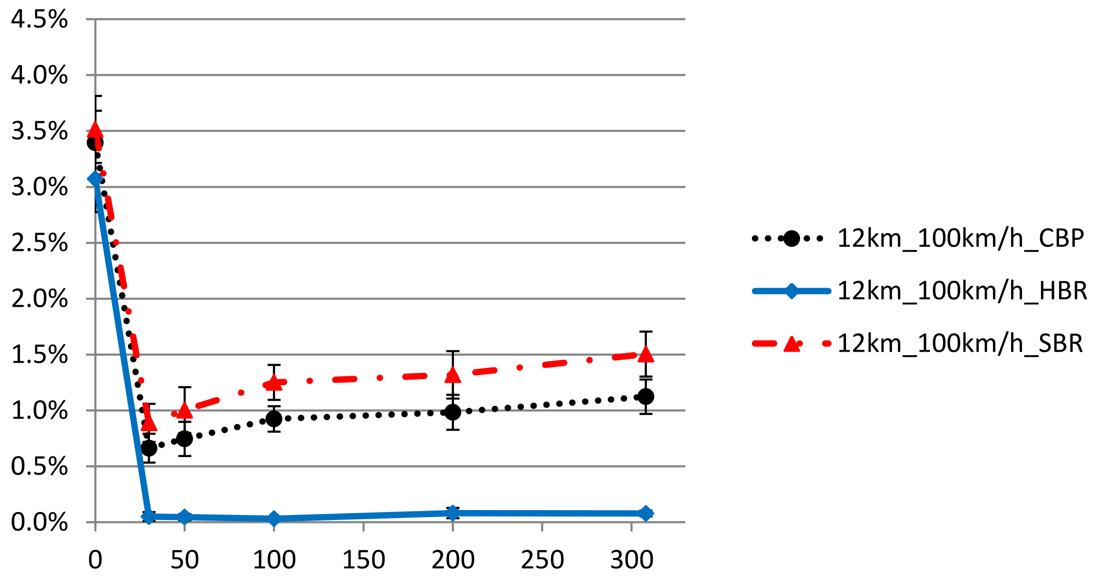

Figure 10.8: Channel blocking results for vehicle with average speed 100 km/h.

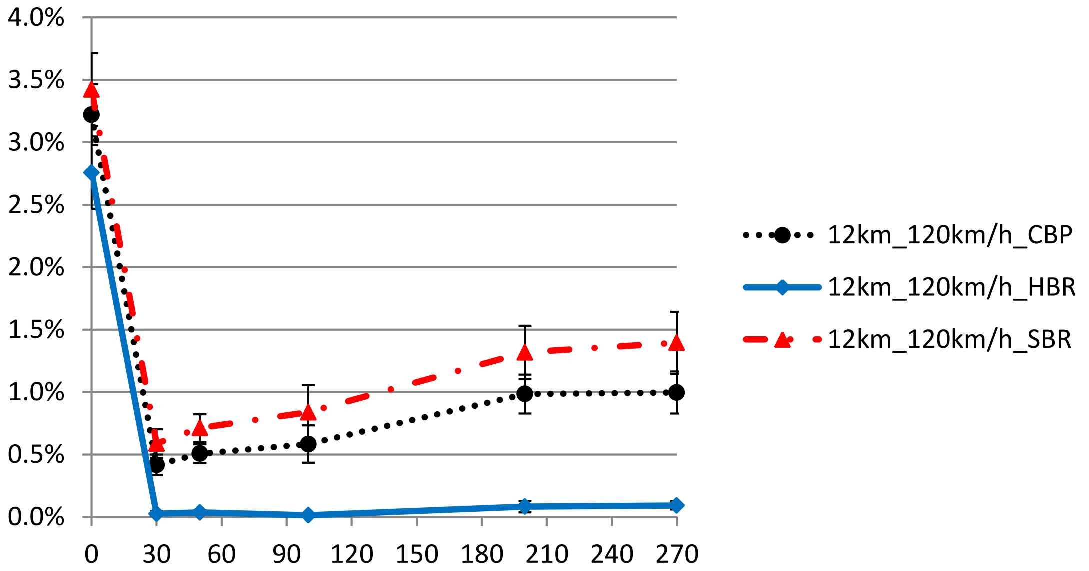

FIGURE 10.9: Channel blocking results for vehicle with average speed 120 km/h.

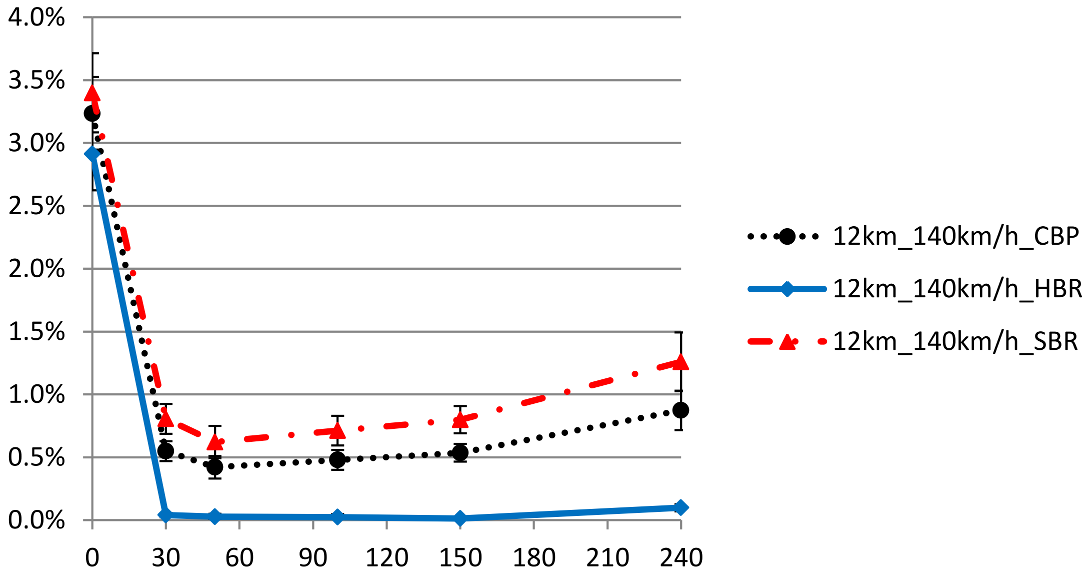

FIGURE 10.10: Channel blocking results for vehicle with average speed 140 km/h.

Chapter 11

Summary and Outlook

The closing chapter of the dissertation summarizes our work concerned with the availability of the IPTV services over vehicular networks. Moreover, potential avenues for future research are proposed.

Entertainment applications are getting increasingly significant in vehicular networks. On the other hand, IPTV is a growing technology that will be one of the interesting entertainment applications for the users and it has a very strong growth rate. However, any change requires a good reason to upgrade, so IPTV has to provide users with some new and innovative features to improve their experience in front of the TV and mobile devices and push them to switch finally to IPTV.

At first, we have discussed the motivation of this work in chapter 1, which was followed by the presentation of the overall objectives. In Section 1.2, we addressed the challenges in assessment and improvement of IPTV service availability in vehicular networks. We presented our three main objectives regarding achieving the desired QoE levels in vehicular IPTV networks in this dissertation. We focus mainly on the following objectives:

1. Evaluating the CA and CBP by means of several dedicated simulation models.
2. Predicting the blocking probability of TV channels for channel-switching-induced and handover-induced blocking events by means of an efficient analytical model.
3. Improving the QoE by applying our two algorithms to pre-reserving the channels before users are actually arriving in a neighboring cell (to decrease the number of blocking events in the cells).

After that, we have introduced the fundamentals and basic concepts regarding vehicular networks and IPTV services. Furthermore, we have elaborated the IPTV user behavior in detail. In Section 2.4, we describe that the channel switching activities of IPTV user imposes extra load on the network. Hence it is important to investigate the user behavior model.

11.1 Summary of Evaluating the CA and CBP with Our Simulation Model

Users will choose IPTV based on the QoE. Moreover, among QoE measures, TV channel availability is one of the most significant. The general contribution of Chapters 3 and 4 have been a quantitative evaluation of the availability of IPTV services in vehicular networks where availability is expressed by the probability that a requested TV channel can indeed be offered at that time. In these chapters, we have tackled the problem of analyzing in detail the QoE achievable for IPTV services in vehicular networks regarding channel blocking probability. For this purpose, we have elaborated a simulator for vehicular networks with a rather flexible applicability which has been presented in Chapter 4. This simulation tool allows us to predict the blocking probability of TV channels on one hand when a user switches between TV channels and in addition at instants of handover when the corresponding vehicle reaches a new cell. An important characteristic of our simulator is its underlying realistic model for IPTV user behavior which itself has been derived from comprehensive measurements of user behavior in existing IPTV systems.

In order to achieve the first objective (cf. Section 1.2), we investigated the availability of IPTV services with executing a large variety of case studies in Chapter 4, based on the following scenarios:

- Variation of traffic intensity.
- Variation of cell sizes.
- Variation of access network technologies.
- Variation of using the IPTV service.
- Variation of number of cars per km.
- Variation of number of TV channels offered.
- Variation of number of lanes.

For each scenario, detailed case studies have been carried out. The results achieved by our simulator, have demonstrated that it is indeed possible to predict the CA and CBP under different situations of IPTV services. The case studies showed how our QoE evaluation by our IPTV simulator could help the service providers to offer the acceptable level of QoE for their vehicular subscribers.

11.2 Summary of Predicting the CA and CBP with Our Analytical Model

In Chapters 5 and 6, our goal is to achieve the second objective (cf. Section 1.2). Therefore, we have investigated in-depth the QoE as it is offered to human end-users of IPTV services in vehicular networks. In particular, we have been able to elaborate a rather realistic analytical model which is available in two model variants namely for all the users and for an individual user. Our analytical model is easily applicable and allows us to derive comprehensive QoE predictions for IPTV usage in vehicular networks. We have successfully validated our analytical model by means of comparing it to a significantly more detailed and therefore more realistic simulation model. Our numerous case studies were based on variation of:

- Traffic scenarios.
- Network technologies.

The case studies demonstrate clearly the advantages of investigations based on an analytical modeling approach as opposed to simulation-based experiments. Moreover, the studies show how these types of models can be used to obtain valuable decision support for an IPTV service provider. Last but not least, we have introduced new measures for QoE which take into account the disadvantages of handover-induced blocking events as opposed to switching-induced TV channel blockings. These new measures, in particular, allow one to quantify the strongly negative impact of handover-induced blockings.

11.3 Improving the QoE with Pre-Reserve Channels Algorithms

An important insight gained from the studies is that in vehicular networks a large portion of blocking events results from handover events. These blocking events are especially problematic because it means that the currently watched TV channel quite often will no longer be available to the user after a handover, which leads to a highly annoying degradation of the QoE for IPTV users in vehicular networks. Therefore, we tried to reduce the probability of IPTV channel blocking occurring after handover events in order to reach the objective 3 (cf. Section 1.2).

In the Chapters 7, 8, 9 and 10 we have tackled the difficult and challenging problem of reducing the probability for handover-induced blockings in IPTV services offered to vehicular users. Our approach has been based on the idea to execute an a priori reservation of currently viewed TV channels in the neighboring wireless network cell for vehicles driving on a motorway. Our RCBH and aRCBH algorithms are based on reserving the currently viewed channel shortly before the actual handover has been occurring.

RCBH and aRCBH have been embedded in our existing simulator (Chapter 3) to determine both, handover-related as well as switching-related channel blocking risk. Comprehensive case studies have shown that the RCBH algorithm is indeed able to significantly reduce the probability of handover-induced channel blockings and thus it strongly improves QoE as observed by an IPTV user. The case studies cover different traffic scenarios, access networks based on different wireless technologies as well as various offers of TV channels. Unexpectedly, in quite a few scenarios, RCBH not only reduces the handover-related but also the switching-related blocking risk. This is a highly pleasing result because it shows that RCBH quite often implies a win-win situation as it can reduce the number of handover-related blockings without having to pay a price for this regarding an increased number of switching-related blockings.

The mechanism of RCBH algorithm is based on trying to reduce handover-induced blocking through reserving the channel for the user immediately after finding out that the user is going to view a specific channel. As the RCBH case studies have also demonstrated, there is some situation in which zapping users are not able to watch their new channel. Therefore, we felt the need to generalize the RCBH algorithm. In the generalized aRCBH algorithm, we did not allocate the free bandwidth for the neighboring cell at a very early instant. Instead, we try to adequately balance between all handover and zapping users to increase the user's satisfaction with respect to bandwidth usage in the cell. In particular, one of the most important goals regarding QoE in the aRCBH algorithm is reducing the number of handover-induced blockings, while at the same time efficiently keeping high bandwidth utilization.

By generalizing the bandwidth reservation in the aRCBH algorithm, we do not reserve the bandwidth immediately in the next cell for viewing users. We just reserve the bandwidth for the viewing users shortly (i.e. ΔT time units) before they are leaving the current cell. By this new policy, as indicated by numerous case studies, it is possible to decrease the handover-induced blockings as well as switching-induced blockings for the users. Moreover, accordingly, one is able to increase the QoE for all the IPTV users.

Of course, we should mention that the fact of restricting oneself to motorway scenarios (though it is an important use-case for IPTV) leads to assumptions which are quite favorable for the RCBH algorithm (e.g. regarding the rather simplified mobility model as compared to general traffic situations).

11.4 Outlook

In this dissertation, we focused on evaluating the CBP and CA and also improving the channel blocking probability by a priori channel reservation. Due to space and time limitations, we cannot go into depth in every aspect of the study in this dissertation. Therefore, there are some further research topics which are interesting and could be conducted in our future work.

We should notice that the current IPTV user model as it is applied in this dissertation is based on measurements of user behavior of non-mobile IPTV users. Therefore, it is needed as future work to adapt (a large set of) new measurements to characterize the behavior of mobile IPTV users or even vehicular users. Moreover, as an outlook, it would be kind of interesting to integrate the RCBH and aRCBH algorithms in real IPTV systems for vehicular networks as soon as those systems are available which would also enable us to validate our currently used simulation models.

Last but not least, it would be desirable to extend our simulation models to scenarios beyond motorways, i.e. covering situations in which the IPTV users are passengers of cars driving in a general network of roads (including rural roads, city roads, etc.).

This dissertation has elaborated the comprehensive simulation tool and analytical model as well as innovative algorithms to effectively improve the QoE for various kinds of users (handover-executing or zapping users). All the evaluation and prediction regarding channel availability and also improving the channel availability are precious and exciting for IPTV service providers to achieve a desired level of QoE for their subscribers. We hope that our evaluation, prediction and improvement of channel availability in our work, can help the IPTV service providers to manage the challenging problem of how they are allocating their valuable network bandwidth resources in an efficient manner and evidently to increasing the users' satisfaction by increasing the QoE.

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