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# Availability evaluations for IPTV in VANETs with different types of access networks

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**Abstract**

Vehicular ad hoc networks (VANETs) represent a quickly emerging area of communication that offers a wide variety of possible applications, ranging from safety to entertainment. Internet Protocol Television (IPTV) services as an entertainment application over VANETs is considered to play an important role in the future of intelligent transportation systems and vehicular infotainment systems. Quality of experience (QoE) has a strong impact when choosing adequate IPTV services for end users. Among QoE measures, TV Channel Availability (CA) is utmost important. In this work, we investigate the channel availability in IPTV services offered to vehicular users *via* different access network technologies. We focus on different traffic intensities and various number of TV channels and we predict the CA of TV channels and the Channel Blocking Probability (CBP) to be expected. The comprehensive simulation experiments for motor-highway scenarios are achieved by means of an own simulation tool which is based on a detailed IPTV user behavior model.

**Keywords:** IPTV systems; Wireless access networks; VANETs; Quality of experience; Simulation; Channel availability; Channel blocking probability

## 1 Introduction

VANETs are a kind of wireless ad hoc networks that are intended for vehicles to communicate with each other and possibly with a roadside infrastructure to provide numerous applications varying from transit safety to driver assistance and Internet access. In VANETs, nodes have high mobility, long battery life and specific, strongly restricted, mobility patterns. As shown in Figure 1, the major goals of the VANET are to enable vehicle-to-vehicle (V2V) or vehicle to infrastructure (V2I)/Road-Side-Unit (RSU) communications so as to provide more safety, comfort and entertainment to the passengers [1].

Many research efforts in the area of VANETs try to increase transportation safety, efficiency and security. Lately, the focus in this research area moved also towards VANET infotainments that aim to increase user satisfaction during car journeys. IPTV service over VANETs is an attractive feature to many IPTV service providers by transmitting television programs through IP-based wireless networks. VANET-based IPTV services are considered to play a very important role in the future of vehicular infotainment and intelligent transportation systems. Vehicular IPTV aims to make the traditional IPTV and related services available to users anywhere, anytime also during the car journey. The vehicular IPTV services can be provided using different types of access networks. The vehicular IPTV user may connect with mobile WiMAX, IEEE 802.11 and LTE networks or other wireless networks.

An essential aspect of IPTV services is the QoE achieved. Channel blocking probability (CBP) quantifies the ratio of unsuccessful user requests when demanding a TV channel. A high CBP can dramatically decrease the channel availability (CA), and therefore can significantly decline QoE. Hence, CA and CBP are some of the most important metrics regarding QoE of IPTV.

In vehicular IPTV, the limited available bandwidth in the wireless access network and the large number of handover events during the car journey, are the main causes of IPTV blocking and decreasing QoE in IPTV systems. QoE is extremely important as subscribers will choose for IPTV based on the QoE. In the literature, there are not yet many researches regarding vehicular IPTV services.

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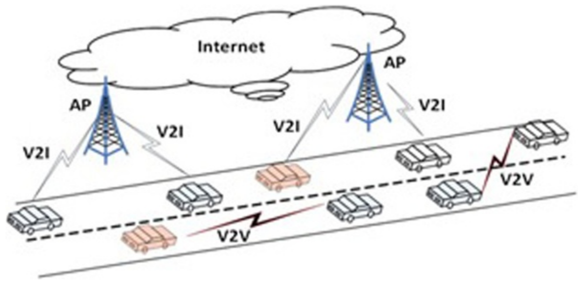


**Figure 1 General model of vehicular networks.** AP: access point.

However, some efforts to evaluate CBP for IPTV with different types of access networks have been done. In [2], J. Lai et al. proposed to decrease the CBP and to improve the channel availability in DSL-based access networks. J. Lai et al. [3,4] 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 [5], 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 [6], investigated the availability of IPTV services in roadside-backbone-networks with vehicle-to-infrastructure communication. In this effort, they assumed small size of cell coverage in highway scenarios and predicted the resulting CBP but unlike the current study, presented in this paper, they did not look at different access network technologies leading to strongly different sizes of cells. There are some recent efforts on live video streaming and multimedia over VANETs in the literature [7-9]. There also exist practical achievements for vehicle-to-infrastructure communications to build-up roadside-backbone-networks (RBNs): At the University of Rostock, an RBN architecture was elaborated including early prototype implementations assuming fixed access nodes along the roads that can be accessed by the vehicles by means of wireless communication [10]. It is also suitable to use this infrastructure for broadcasting IPTV or other multimedia services for vehicular users.

In this paper, which is a revised and extended version of [11], we focus on the CA and CBP as our QoE measure of interest, and ask the following questions:

- What are the main factors having 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 call blocking events is due to handover and what is due to TV channel switching?
- What is the number of TV channels which still can be offered by the IPTV service if the resulting QoE has to stay above a given threshold?

We conduct a set of experiments in two different case studies in order to answer the above questions. As an improvement of our earlier research, published in [11], the case studies of this paper are now based on more realistic traffic assumptions. Moreover, the new experiments allow one to judge the impact of different cell sizes on CA and CBP for strongly varying traffic densities in a comprehensive and significantly more transparent manner than the case studies of [11].

The remainder of this paper is organized as follows: Section 2 presents vehicular ad hoc networks and IPTV. In Section 3, the scenarios and basic simulation assumptions will be motivated and specified. The results of our case studies will be presented and interpreted in Sections 4 and 5. Finally, we conclude in Section 6.

## 2 Vehicular ad hoc networks and IPTV

### 2.1 VANETs and access network technologies (LTE, WiMAX, IEEE 802.11p)

VANET is a new technology which has taken enormous attention in the recent years. In VANETs, vehicles communicate with roadside units (RSUs), referred to as vehicle-to-infrastructure (V2I) communications. In addition, vehicles can communicate with each other in an infrastructureless mode, referred to as vehicle-to-vehicle (V2V) communications. In general, the duration of existence of each link is very limited, due to high dynamics in the network's topology.

VANETs are an extreme case of Mobile ad hoc NETworks (MANETs). High speed and the already mentioned frequent network topology changes are the main characteristics of vehicular networks. These characteristics lead to special issues and challenges in the network design.

Recently, there has been a strong interest in developing networking techniques for moving vehicles, to enable either wireless communication between vehicles, or between vehicles and roadside infrastructures. Generally, three types of applications are appearing [12]. First, communications between vehicles can enable various traffic safety and traffic information applications, developing the need for ad hoc communication between vehicles [13-15]. Second, vehicles can serve as mobile sensors, providing a broader range of sensed information involving information related to the vehicle, driving condition, road condition, traffic and environment [16,17]. Third, the ability to do a general-purpose Internet access from vehicles can keep the vehicle passengers entertained and informed and can potentially generate services and applications specifically for in-vehicle use [18-20].

Many technologies are related to 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.

- *IEEE*802.11*p*: IEEE 802.11p, cf. [4], 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 to support Intelligent Transportation Systems (ITS) applications in the short-range communications between vehicles (V2V) or between the vehicles and the roadside infrastructure (V2I). This 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) [21]. It can deliver data rates of 70 Mbps, cover ranges in excess of 30 km, and it can provide secure delivery of content and support mobile users at vehicular speeds.
- *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.

### 2.2 IPTV

IPTV services are becoming popular and are expected to rapidly expand in the near future. IPTV is defined as a service that includes multimedia services such as TV, video, audio, text, graphics, and data over IP-based networks.

We define an IPTV network as the interconnection of several broadband networks that are capable to support the required bandwidth for video delivery (in particular, delivery of TV channels). In addition, an IPTV network topology can be split into five main parts: IPTV head-end, core network, metro backbone, access network and subscribers (cf. Figure 2).

The IPTV *head end* (1) or a video-on-demand (VoD) server is responsible of delivering video and content, i.e. the original TV channels, to the core network which represents a high-speed communication infrastructure. The *core network* (2) distributes the video streams from the head end to the metro backbone. The *metro backbone* (3) interconnects the core network with the different access

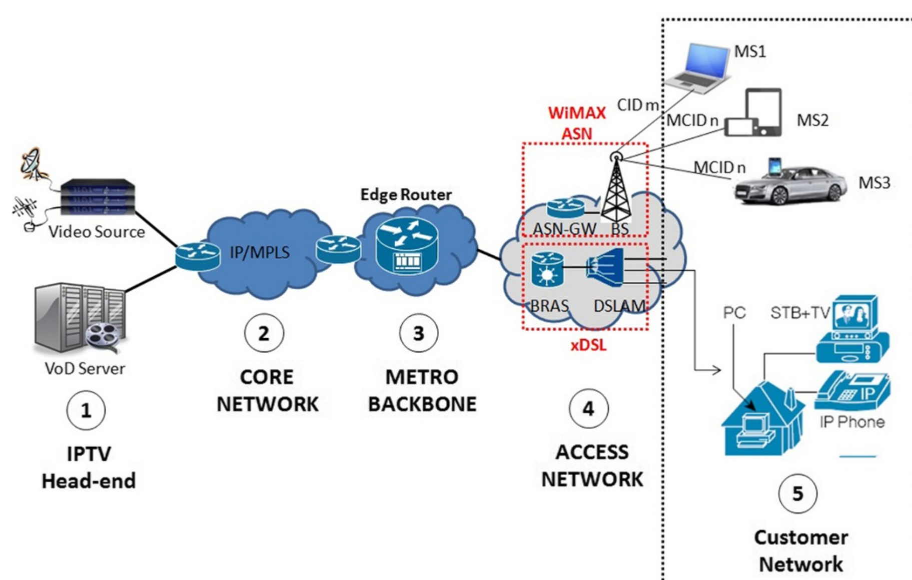


**Figure 2 Main components of a VANET-based IPTV system.**

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. The elements that transport the multimedia content to the end users (subscribers) form the *access network* (4) 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 VANET-based IPTV system, the mobile stations MS in Figure 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 VANET, the situation would be very similar to what is illustrated for WiMAX in Figure 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. Finally, the *subscribers* (5), e.g., sitting in the cars if we assume access *via* a V2I communication system, 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.

### 2.3 Channel availability in VANET-based IPTV systems

In the analog cable TV network, all the channels are available simultaneously for subscribers. Analog cable TV transmits all the channels at once *via* a fixed cable to the subscribers, and each active subscriber then chooses a channel for viewing by using a set-top box (STB). Therefore, channel change is almost instantaneous. But IPTV differs significantly from analog cable TV, in its transmission system. In the IPTV system, a subscriber uses the STB to request for only the specific channel required at that time, and only the required channel is transmitted to this user (possibly by means of multicast).

To make the IPTV services a success, it is required to guarantee a certain level of QoE. Therefore, it is critical for an IPTV service provider to ensure an acceptable level of QoE. Subscribers will choose IPTV based on the QoE. Among QoE measures, TV channel availability (CA) is one of the most significant. Thus, it is highly desirable to evaluate the probability that requested TV channels cannot be provided, namely the CBP, in IPTV systems. A high CBP will dramatically degrade CA and consequently QoE. For providing QoE and CA for vehicular IPTV users, there are two major challenges: lack of network bandwidth and a possibly large number of handover events during the car journey.

The focus of this paper is on IPTV service availability and therefore modeling the details of the lower layer communication protocols (as done, e.g. in [22]), is dispensable in our studies. The fact that we consider VANETs and not mobile networks in general has a strong impact on the resulting mobility model being quite specific in highway scenarios.

## 3 Scenario investigated by means of simulation

IPTV services can be divided into two groups: Video on demand (VoD) for stored contents and Broadband-TV (BTV) for live TV channels. In an IPTV system, the TV channels are distributed towards the subscribers by using either IP unicast or multicast. In general, unicast is applied for VoD and multicast is used for BTV service for the delivery of live TV channels.

In our simulation model, vehicles entering the cell at the border of the geographical area (GA) are assumed to contain either 0 or at least 1 passenger watching TV (of course, the driver should not watch!). TV is not switched on or off in a car during the car journey along the complete highway sector observed. The system model as used in our work is demonstrated in Figure 3. A switching event happens when a user chooses a new TV channel. TV channels will be selected according to a Zipf distribution [23] which has an ability to represent the skewed popularity distribution of objects. The request probability $P_i$ of the $i$th popular channel is determined by the Zipf distribution and calculated as

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

where $N$ is the total number of distinct channels, $k$ is their rank and $\Theta$ is the Zipf parameter that determines the degree of popularity skew. When $\Theta$ is 0, all channels are equally popular. As the value of $\Theta$ increases, the popularity of channels is increasingly skewed. For $\Theta$, we choose a value of 1.3 which is realistic according to measurements of IPTV user behavior (cf. [5,24]).

When a user switches between channels, several sequential switching events in a short period of time represent that the user is zapping TV channels to find something interesting to view [5]. A zapping block denotes the number of consecutively demanded TV channels before starting to watch an interesting program. Starting to watch the first channel, which is then viewed for a time period longer than 1 min represents the start of a viewing

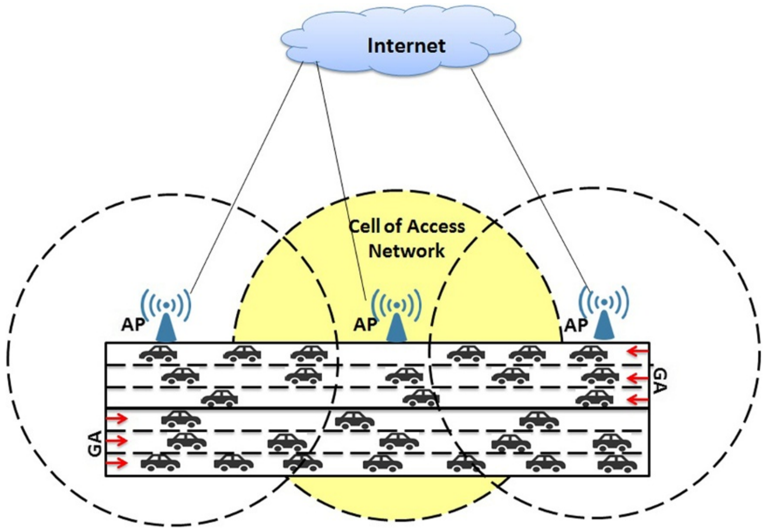


**Figure 3** Simulation scenario.

phase and is not contained in the zapping block. The user switches between zapping activities and viewing phases.

In addition to the switching of channels (zapping or normal switching from one channel viewed to another), during the viewing phase, users are undergoing a number of handover events when changing their cell within the vehicular network. During handover, when a car passes the border between two adjacent cells C1 and C2, blocking of a TV channel may occur.

When a vehicular IPTV user is in viewing phase and watches a given TV channel P, two situations may happen:

Firstly, the user can continue to watch channel P, if P is already broadcasted in the new cell C2 reached, because channel P has been watched already by other users in cell C2, or if P is not yet transmitted in C2 but there is enough free bandwidth remaining to broadcast P as well as the other channels already broadcasted in C2. However, if P is not yet broadcasted in C2 and there is not enough free bandwidth left in C2 to broadcast P, then the user cannot continue to view P in C2. 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:

$$\mathrm{CBF}(T) = \frac{\mathrm{nb}(T)}{\mathrm{nr}(T)},$$

where $\mathrm{nb}(T)$ = number of blocking events having occurred during interval T and $\mathrm{nr}(T)$ = 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)*.

Based on CBP, we define *channel availability (CA)* as follows:

$$\mathrm{CA} = 1 - \mathrm{CBP}.$$

Let *HBP* now denote the *Handover Blocking Probability* which is reflecting blocking because of handover events of vehicles using IPTV, and let *SBP* denote the *Switching Blocking Probability* which is reflecting blocking because of TV channel switching events. Then:

$$\mathrm{CBP} = \mathrm{HBP} + \mathrm{SBP},$$

and

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

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

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

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

We elaborated a simulation tool for analyzing IPTV services offered in communication networks of VANET type. This simulation tool has been designed to generate a system model abstracting from the lower layers of the protocol stack because they are not relevant to the QoE measures studied. However, unlike other VANET simulators, our tool offers a very detailed model to specify the 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 we are using the LoadSpec tool to generate aggregate traces of channel

**Table 1 Parameter values for first case study**

| Notations | Descriptions | Values |
|---|---|---|
| N | Total number of provided TV channels in the mobile IPTV system | 100 |
| B | 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) |
| $D_{\text{cell}}$ | Diameter of each cell | 3,000, 7,500, 12,000 m |
| $\alpha$ | Probability that a vehicle will use IPTV service | 0.2, 0.1 |
| $\Theta$ | Zipf parameter | 1.3 |
| MS1, ..., MS4 | Mobility scenario | Given in paragraphs 4.2, ..., 4.5 |

switching events for the vehicular IPTV users. LoadSpec has been elaborated in our TKRN research group [25]. It is an artificial load generator for different interfaces, and it is capable of producing realistic network traffic with different characteristics in a very simple and flexible manner. Other simulators for VANETs (such as ns-2 [26], JiST/SWANS [27], Shawn [28], GloMoSim [29] and OMNeT++ [30]) emphasize on the lower protocol layers as they have completely different research goals. Doing availability studies based on those simulators would be extremely inefficient, if possible at all. Therefore, we are using our own tool for evaluating the availability of IPTV services (cf. Sections 4, 5).

## 4 Case study I: variation of traffic density and cell sizes

By means of simulation experiments, we now want to determine the channel availabilities for various scenarios assuming boundary conditions as realistic as possible. So, we are able to provide decision support regarding the question whether the QoE to be expected is acceptable for the IPTV users in the VANET. As suggested before we will look at CBP and CA as measures characterizing the QoE. In order to know more precisely which kind of events (channel switching or handover, respectively) lead to TV channel blocking, we not only look at CBP but also at the values resulting for SBP and HBP.

In the first case study, we want to evaluate the impact of different cell sizes and vehicle traffic densities (vehicles per kilometer) on CBP, SBP, HBP and CA in highway scenarios. The traffic density is given in 'cars per km' in order to simplify the language though also other entities like lorries, motorcycles, etc. will drive on the highway.

Please note that average speed SP is always combined with the average distance between adjacent vehicles. For example, in the worst case of the traffic situation (in which all vehicles are stuck in a traffic jam and can move only very slowly, if at all, where we assume a speed on lane $i$ of $SP_{[i]}$ = 10 km/h) then the average distance between adjacent vehicles on lane $i$ (denoted by $d_{\text{avg}[i]}$) is $d_{\text{avg}[i]}$ = 10 m and in the best traffic situation (i.e. if $SP_{[i]}$ = 160 km/h) we assume $d_{\text{avg}[i]}$ = 55 m. Moreover, the actual distance always varies +/- 5 m around the average. The different mobility scenarios (MS) (cf. description of scenarios MS1, ..., MS4 in paragraphs 4.2, ..., 4.5) are obtained by investigating the 11 different average distances between neighboring vehicles.

### 4.1 Experimental setup

In our experiments, we consider different traffic density on a motor highway with various numbers of vehicles per km in cells of different sizes (due to the usage of different access network technologies). In our experiments, vehicles are generated for each lane in each direction.

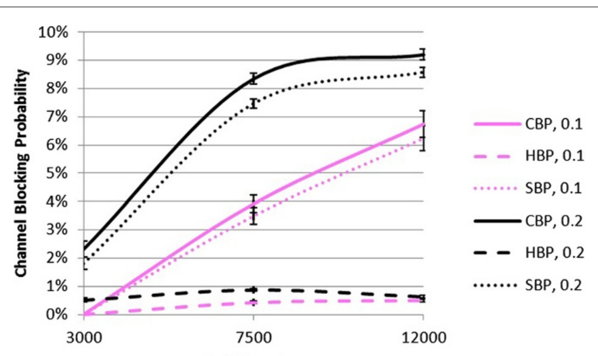


**Figure 4 CBP results for 400 cars per km.** On a two-lane highway against access network technologies (MS1).

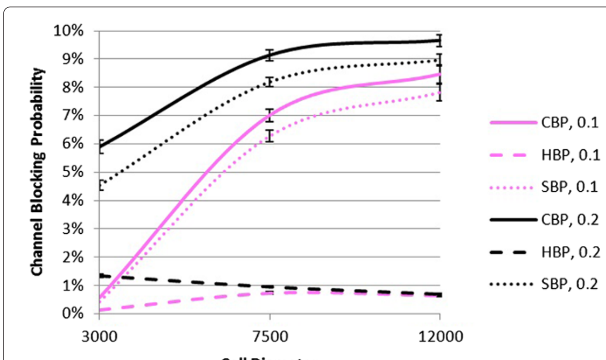


**Figure 5 CBP results for 600 cars per km.** On a three-lane highway against access network technologies (MS1).

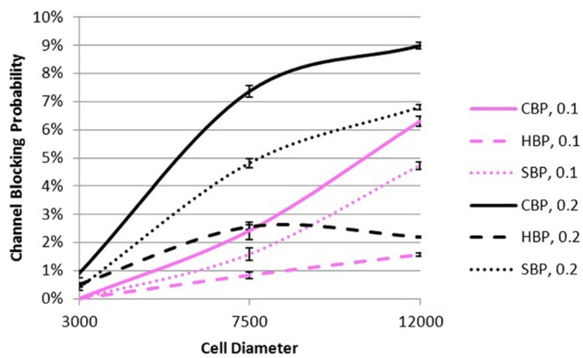


**Figure 6 CBP results for 232 cars per km.** On a three-lane highway against access network technologies (MS2).

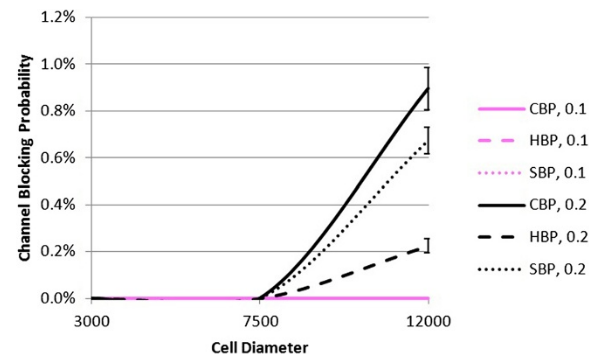


**Figure 8 CBP results for 58 cars per km.** On a three-lane highway against access network technologies (MS2).

Before presenting the results, we describe the experimental setup.

The total number of provided TV channels is 100, and this is a typical number of TV channels which are currently provided by IPTV service providers. We assume the quality of video is according to the CIF standard for all the channels and the probability to select each channel is according to the Zipf distribution. Moreover, the user model assumed for IPTV user behavior is according to [5]. As mentioned, in this case study, we executed experiments to find out, which channel availability can be expected if there exist different number of vehicles per kilometer (i.e. assuming different traffic densities) and if we would use different access network technologies with different cell sizes. Table 1 summarizes the essential experimental boundary conditions assumed in case study I.

### 4.2 MS1: traffic jam on highway

This is the worst case scenario assuming a serious traffic jam. Speed is 10 km/h on all lanes (here, two or three lanes per direction, i.e. four or six lanes in total for both directions) and the motor highway is characterized by an extremely high traffic density. Average inter-vehicle distance on all lanes is 10 m, i.e. the actual inter-vehicle distances vary in the range 10 +/- 5 m; therefore, on the average, there are 100 cars per lane and per km.

### 4.3 MS2: high traffic density on highway

Now, let us look at a high traffic density situation. We assume the highway has three lanes per direction and that $SP_{[1]}$ = 80 km/h and $SP_{[2]} = SP_{[3]}$ =100 km/h, respectively, and the minimum distance between the vehicles on the three lanes are $d_{avg[1]}$ = 20 m and $d_{avg[2]} = d_{avg[3]}$ = 30 m (same for each direction). Besides investigating situations with exactly these minimum distances, we are going to study this scenario with 2 × Minimum $d_{avg[i]}$ and also 4 × Minimum $d_{avg[i]}$. Again, the minimum distances are denoting means and the actual distances vary +/- 5 m.

### 4.4 MS3: medium traffic density on highway

This is in the medium traffic density situation. In this case, again assuming three lanes per direction, $SP_{[1]}$ = 100 km/h, $SP_{[2]}$ = 120 km/h and $SP_{[3]}$ = 140 km/h,

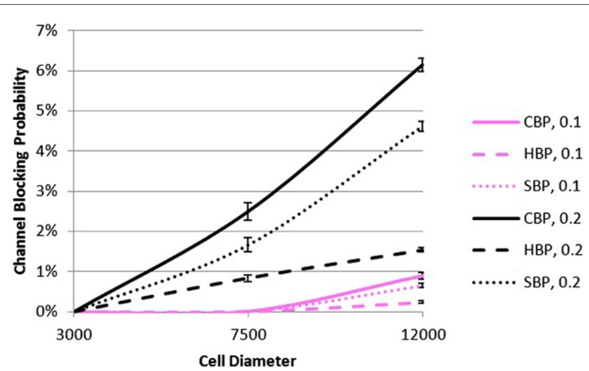


**Figure 7 CBP results for 116 cars per km.** On a three-lane highway against access network technologies (MS2).

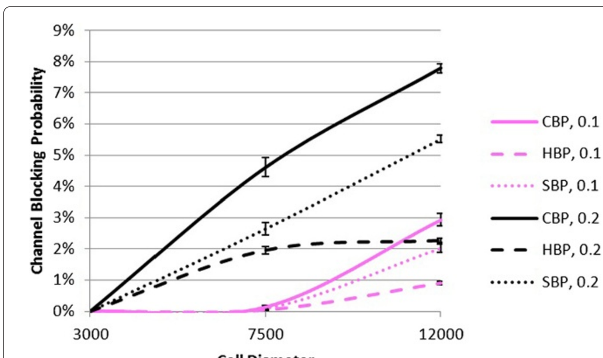


**Figure 9 CBP results for 156 cars per km.** On a three-lane highway against access network technologies (MS3).

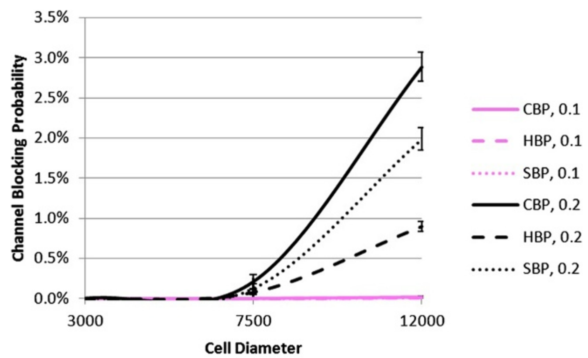


**Figure 10 CBP results for 78 cars per km.** On a three-lane highway against access network technologies (MS3).

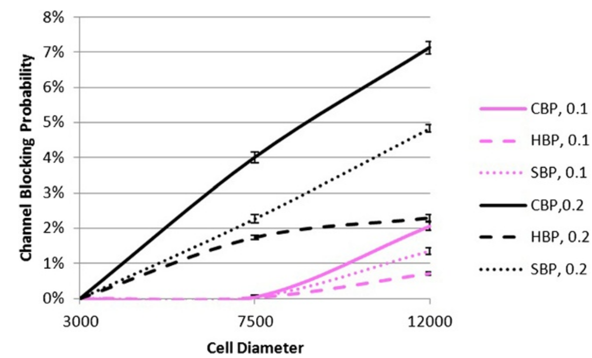


**Figure 12 CBP results for 136 cars per km.** On a three-lane highway against access network technologies (MS4).

respectively, where the minimum distances between the vehicles are $d_{\text{avg}[1]} = 30$ m, $d_{\text{avg}[2]} = 40$ m and $d_{\text{avg}[3]} = 50$ m. Different distances of 2 × Minimum $d_{\text{avg}[i]}$ and also of 4 × Minimum $d_{\text{avg}[i]}$ are also considered again in this mobility scenario.

### 4.5 MS4: low traffic density on highway

Now, we look at the low traffic density situation. In this mobility scenario, we assume $\text{SP}_{[1]} = 110$ km/h, $\text{SP}_{[2]} = 140$ km/h and $\text{SP}_{[3]} = 160$ km/h, respectively and thus the minimum distances between the vehicles are $d_{\text{avg}[1]} = 35$ m, $d_{\text{avg}[2]} = 45$ m and $d_{\text{avg}[3]} = 55$ m. Moreover, different distances of 2 × Minimum $d_{\text{avg}[i]}$ and also of 4 × Minimum $d_{\text{avg}[i]}$ are also studied in this scenario.

### 4.6 Results obtained and their interpretation

Experimental results are depicted in Figures 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13. Confidence intervals are based on a confidence level of 95% in all experiments. In general, the results have been obtained by increasing the distance between vehicles with different speeds; accordingly, traffic density will reduce and this leads to a reduction of CBP. More specifically, in order to increase the distance between adjacent vehicles the speed of the vehicles has to be increased too. The figures not only present the CBP results obtained but also the percentage of blocking events resulting from handover (HBP) as well as the percentage of blocking events resulting from channel switching (SBP). As is to be expected, both, CBP and SBP increase when we increase traffic density and this holds for all of the access network technologies (because of having more IPTV users per cell). For HBP, the shape of the curves could be slightly different. With growth of cell size and high traffic density, nearly all of the TV channel blockings are due to channel switching events.

Let us now assume that the maximum acceptable threshold for CBP is 1%. Then, in the worst case, as one can see in Figures 4 and 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 (with $\alpha = 0.1$) still reaches the acceptable CBP. Figures 6, 7 and 8 depict the results for the high traffic situation. With both values of $\alpha$, only a cell size of 3 km leads to an acceptable blocking probability in the minimum inter-vehicle

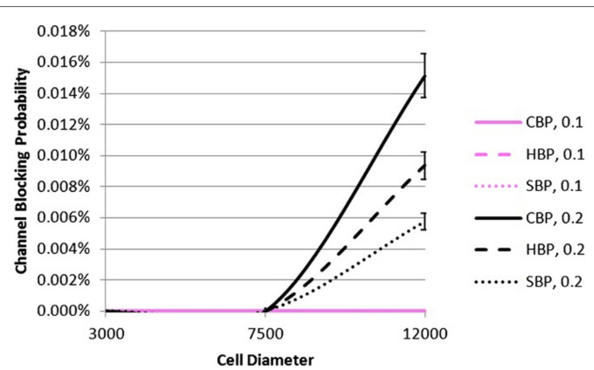


**Figure 11 CBP results for 39 cars per km.** On a three-lane highway against access network technologies (MS3).

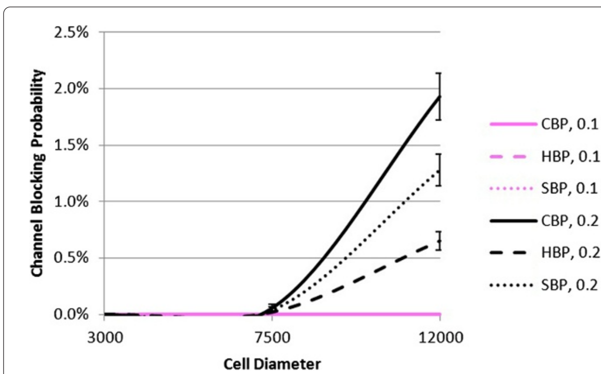


**Figure 13 CBP results for 68 cars per km.** On a three-lane highway against access network technologies (MS4).

**Table 2 Parameter values for second case study**

| 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) |

distance scenario. With increasing the distance between vehicles to 2 × Minimum $d_{avg[i]}$ in the case of $\alpha$ = 0.2, only 3 km cell diameter has the allowable CBP, but for $\alpha$ = 0.1 and also 4 × Minimum $d_{avg[i]}$, all the cell sizes achieve an adequate CA. Cell size diameters of 3 and 7.5 km still meet the CA requirement. For 4 × Minimum $d_{avg[i]}$ all the cell sizes offer an acceptable CBP. In Figures 9, 10 and 11, the results for medium traffic density are shown. For $\alpha$ = 0.2, only scenarios with a 3-km cell diameter and for $\alpha$ = 0.1, cell diameters of 3 and 7.5 km keep their CBP below the threshold, 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 lead to an acceptable value of CBP. Figures 12 and 13 illustrate the charts for low traffic density. We observe 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 illustrated by an own figure because here, CBP (and therefore also SBP and HBP) is negligibly small - CBP below 0.01%.

## 5 Case study II: variation of number of TV channels offered, lanes and cell sizes

In the second case study, we try to find out in which way various factors have an impact on CA and CBP. This evidently would be a quite important and relevant question for an IPTV service provider. In particular, we would like to know what is the effect of 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.

### 5.1 Experimental setup

Except the 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 first case study for all experiments of the second case study. In our experiments, we varied the number of TV channels offered by IPTV service provider, the number of lanes of the highway as well as the cell sizes in different access network technologies. The value of $\alpha$ was kept constant, assuming $\alpha$ = 0.1. The essential experimental boundary conditions underlying case study II are summarized in Table 2.

### 5.2 Results obtained and their interpretation

The simulation results demonstrate the implication of varying the number of the lanes, the number of TV channels provided and access network technologies in Figures 14, 15 and 16. Again, the results are given with 95% confidence intervals. The curves in Figure 14 are depicting the values of CBP whereas SBP, HBP are illustrated by Figures 15 and 16. It is observed that, as it is to be expected, when increasing the number of the lanes and the number of TV channels provided, CBP will be increased, too. As can be seen, with increasing the cell size

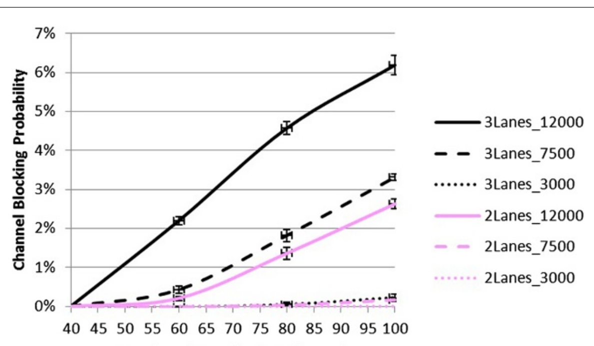


**Figure 14 Channel Blocking Probability results.** Against number of TV channels offered for different cell sizes and number of lanes.

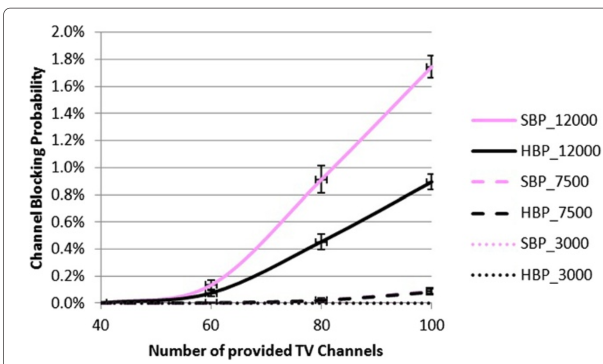


**Figure 15 HBP and SBP results for highway with two lanes.** Against number of TV channels offered for different cell sizes.

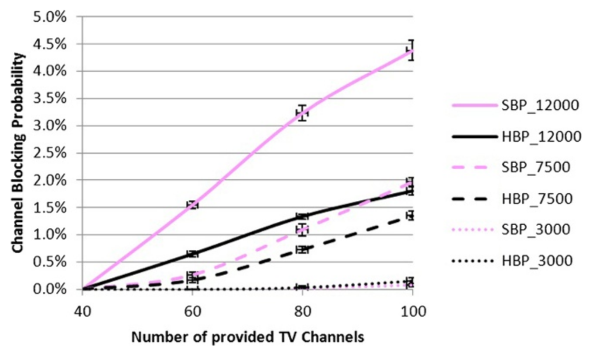


**Figure 16 HBP and SBP results for highway with three lanes.** Against number of TV channels offered for different cell sizes.

according to the different access network technologies we assumed (namely IEEE 802.11p, WiMAX and LTE), the handover-induced blocking probability (HBP) increases much less quickly than the switching-induced blocking probability (SBP). Our questions can be answered with these experiments: access networks with small area coverage will boost the channel availability (CA). However, if we increase the number of lanes and the number of TV channels provided, CA will decrease and CBP will increase. Taking again a maximum channel blocking probability threshold of 1% in our IPTV service, we observe that

- For the 12-km cell size: assuming the three- and two-lane highway scenarios, the number of TV channels ($N$) which still can be provided with sufficiently high availability is about $N = 48$ (for three lanes) and $N = 75$ (for two lanes).
- For the 7.5-km cell size: a three-lane highway requires $N \leq 68$, and for a two-lane, $N \leq 100$ is still acceptable.
- For the 3-km cell size, for two-lane as well as for three-lane highways, we even do not have any significant number of blocking events.

## 6 Conclusion

The general contribution of this paper has been a quantitative evaluation of the availability of IPTV services in VANETs where availability is expressed by the probability that a requested TV channel can indeed be offered at that time. More specifically, the main results achieved by us comprise elaboration of a dedicated simulation tool, which allows us to determine CBP based on a detailed model of IPTV user behavior; execution of a large variety of case studies, e.g. investigating the influence of different access network technologies, traffic densities, etc.; in-depth investigations of the reasons for channel blocking to occur, namely due to handover or due to TV channel switching events.

As future work, we plan to elaborate algorithms which help to reduce channel blocking due to handover because this kind of blocking has a very negative impact on the QoE of IPTV users; to investigate scenarios which assume rural roads instead of the motor-highway scenarios on which this paper has put its focus; last but not least, it will be interesting to study also the impact of infotainment applications, other than IPTV, on the performance and availability of different types of access networks in VANETs.

### Competing interests

The authors declare that they have no competing interests.

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