A Generalized Approach to Predict the Availability of IPTV Services in Vehicular Networks Using an Analytical Model

Bernd E. Wolfinger [1)], Edgar E. Báez [2)], Nico R. Wilzek [3)]

[1), 3)] Department of Computer Science,
Telecommunications and Computer Networks
University of Hamburg
Hamburg, Germany
e-mail: wolfinger@informatik.uni-hamburg.de,
4wilzek@informatik.uni-hamburg.de

[2)] Superior School of Computing
National Polytechnic Institute ESCOM-IPN,
Mexico City, Mexico
e-mail: ebaeze0700@alumno.ipn.mx

Abstract— **Currently, an increasing number of vehicles are getting equipped with components which offer the possibility of an Internet access with low expenditure. Therefore, entertainment services in VANETs are becoming more and more important. An interesting class of entertainment services comprises IP television (IPTV) services and, therefore, studies regarding the quality of experience (QoE) for IPTV in VANETs are becoming increasingly relevant. Such QoE analyses also constitute the main goal of this paper where we focus on QoE in terms of availability of IPTV services. Up to now, studies of IPTV service availability in VANETs have primarily been executed based on simulation models. In this paper, we make use of analytical models to predict availability of IPTV for VANET scenarios. For this purpose, we have elaborated an analytical model of rather low complexity which, nevertheless, is rather realistic as we will show by means of comprehensive validation studies. In addition, we propose a general proceeding which makes use of our analytical model and can be applied as a straight-forward approach to predict the availability of IPTV services in a flexible and efficient manner. Case studies demonstrate how our analytical model can be applied by a provider of IPTV services, offered via VANETs, in order to satisfy QoE requirements regarding the service availability as given by the IPTV users.**

Keywords- Vehicular networks; IPTV; QoE; service availability; analytical model; validation.

I. INTRODUCTION

Current predictions for the car market claim that, in 2016, more than 80 % of all new cars sold will have access to the Internet (e.g., FOCUS Online [5]). Therefore, one can expect that the usage of Internet services by car passengers will become more and more wide-spread in the near future. Besides search-, information- and communication services also entertainment services (such as IPTV or Video-on-Demand) will probably play a significant role [3]. For that reason, quality assessment of Internet services with real-time requirements (as they are present, e.g., in IPTV services offered in vehicular ad-hoc networks – or VANETs for short) is getting increasingly important. Therefore, this topic is in the main focus of this paper.

Quality of service provisioning is relevant, in particular as it is experienced by the (human) end-users and thus it is denoted by Quality of Experience (QoE) [9]. In case of IPTV services, QoE on the one hand refers to the quality of the received audio/video stream as perceived by the end-user [15]. But, on the other hand, it also comprises the degree of availability with which the user is able to access the IPTV service [8]. As a measure of availability, we will take the probability that a desired TV channel can indeed be provided to the corresponding user though the bandwidth in the (access) network may be quite limited. Availability studies for IPTV services have been done in the past (by means of simulation models) in particular for DSL based access networks [7] as well as for WiMAX based access networks [1].

As currently no vehicular networks offering IPTV services are available to us for carrying out measurements, the only alternative for corresponding service availability studies is the use of models. To the best of our knowledge, up to now, only very few models exist which allow one to predict the availability of IPTV services in VANETs. Detailed simulation models have been elaborated and applied in case studies by Momeni et al. [10] [11]. Moreover, in recent past, first successful trials have been undertaken to predict IPTV availability in VANETs by means of analytical models, cf. Wolfinger et al. [16].

This paper now significantly extends the results of [16] as we carry out an in-depth validation of the analytical model and, as a major new contribution, it presents a generalized procedure which allows us to predict the IPTV availability in a straight-forward manner for very different traffic scenarios and network technologies. We also apply our procedure in various comprehensive case studies.

The paper is structured as follows: Section II will give a short overview on IPTV services offered via VANETs including the availability measures which we will apply. The analytical model used will be introduced in Section III followed, in Section IV, by a thorough validation of this model. A generalized procedure for a highly efficient usage of this model then is presented in Section V. Application of the generalized procedure will be illustrated in the case studies of Section VI. These studies also show how our model can support a provider of an IPTV service (offered via a VANET) in dimensioning and configuring a network which satisfies the given QoE requirements of the IPTV subscribers.

II. IPTV SERVICES IN VANETS AND AVAILABILITY MEASURES FOR THEIR ASSESSMENT

A. *Provisioning of IPTV Services in VANETs*

Two main classes of vehicular networks are typically distinguished: networks supporting vehicle-to-vehicle (V2V) and those supporting vehicle-to-infrastructure (V2I) communication. For our studies, only V2I configurations are relevant because communication between vehicles is not of interest to us. V2I communication can be achieved in two variants which differ in the way how users in the vehicles can get access to the Internet: in the first variant (V1), the mobile station (e.g., a smart phone) could be communicating via a non-IP-based public mobile network and from there get access to the Internet. In the second variant (V2), the mobile station would access a dedicated road-side unit (RSU) via the base station (BS) / the access point (AP) of its local cell and from there get direct access to IP based routers (cf. proposal and prototype for so-called road-side backbone networks using RSUs to interconnect the Internet with the vehicles as described, e.g., by Krohn et al. [6]). In this paper, we assume that the IPTV services which we analyze are provided in networks in which Internet access is established according to variant V2. Different network technologies (such as WLAN, LTE, WiMAX) can be used in principle to achieve communication between the mobile stations (in the vehicles) and the base station resp. access point in the corresponding cell. From point of view of IPTV service, provisioning different network technologies in the access network can have a strong impact on the service quality because they will typically support very different data rates and lead to very different cell sizes.

In the vehicular networks which we investigate, the fact that ad-hoc networking is possible between vehicles is not really important for us. On the contrary, we are mainly interested in the delivery of IPTV services to the vehicles by means of vehicle to infrastructure (V2I) communications. Nevertheless, we argue that the IPTV service delivery studied in this paper does not only cover vehicular networks, but also VANETs and, accordingly, we use the formulation “IPTV Services in VANETs” throughout this paper.

If an IPTV service is offered in a network with V2I communication where Internet access is achieved by means of RSUs (as assumed in our studies) the basic network architecture will comprise the main components as depicted by Figure 1:

- the IPTV Head-end, where all the TV channels are available which can be demanded by the IPTV users,
- that part of the Internet which is used to make communication between the Head-end and the set of RSUs possible (this subsystem could be the IP based network of an ISP providing the IPTV service),
- the access network representing the infrastructure for communication between an RSU and the mobile stations within the cells for which RSU is responsible.

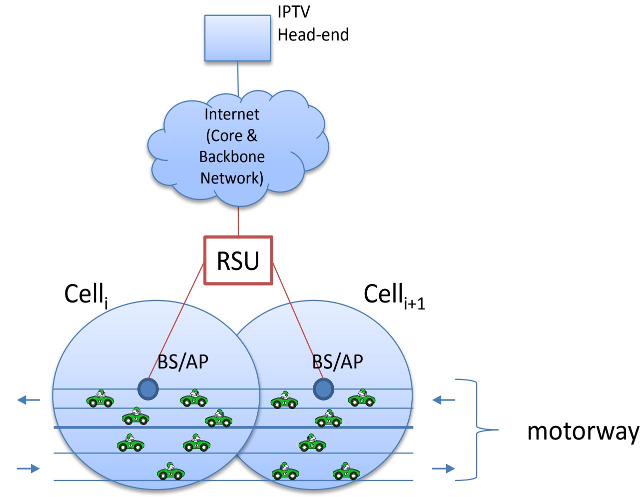


Figure 1. Basic architecture of an IPTV system for users of vehicular networks

Provisioning of IPTV services typically makes use of multicast (e.g., IP multicast [13]) leading to the advantage that a TV channel having been desired in an access network has only to be provided once by the corresponding RSU even in the case that the TV channel is currently watched by more than one user in this cell. A TV channel is no longer transmitted in a cell as soon as the last user watching this channel releases the channel (e.g., because he/she switches to another channel or is involved in a handover thus leaving the cell or the user may temporarily terminate usage of the IPTV service).

As a consequence of the limited data rate (bandwidth) of the cells representing the access networks it is, of course, possible that a TV channel newly desired by a user cannot be provided at that moment when the request for the channel is issued. This happens exactly in the case that the desired channel currently is not yet delivered in the cell AND the total transmission capacity available for IPTV is completely exhausted currently because of having to transmit other channels. If a request for channel delivery has to be denied, we say that the channel is “blocked” for the user and call this event a *“blocking (event)”*.

So, we see that studies of IPTV service availability in VANETs which are based on detailed models will require that the corresponding models reflect

- the bandwidth utilized for IPTV at any instant,
- the list of TV channels currently being multicast in the corresponding cell
- the behavior of the IPTV users in terms of the time instants at which TV channels are switched/changed and in terms of the id. (e.g., channel number) of the channel newly demanded.

Former investigations with respect to a realistic characterization of IPTV user behavior [1] [2] have shown that the popularity of TV channels can be approximated quite well by Zipf distributions [12].

In particular, the probability p_i that the *i*-th popular channel is requested is determined by the Zipf distribution as follows:

$$p_i = \frac{1/i^{\theta}}{\sum_{k=1}^{N} (1/k^{\theta})}$$

where N denotes the total nº of different channels offered, k is their rank and θ is the Zipf parameter reflecting the degree of popularity skew. A value of $\theta = 1.3$ is realistic according to measurements of IPTV user behavior [1].

B. *Measures for IPTV Availability*

The following two reasons exist that an IPTV user will demand a TV channel within a cell:

(1) A *channel-switching event*: Here, the user will demand a new channel to which he currently switches to (e.g., because he is "zapping" through a sequence of channels at time durations of just a few seconds or after he terminates a "viewing phase" with duration of several minutes or even hours during which he has received and watched just a single TV channel).

(2) A *handover event*: Here, the car will change the cell and, as a consequence, the channel currently received by a user in this car will no longer be needed by him in the "old" cell left but it will be needed in the "new" cell reached now.

In both cases, blocking of the desired channel may occur. Thus, we distinguish:

– *switching-induced* or *switching-related blocking*, and

– *handover-induced* or *handover-related blocking*.

Therefore, three channel blocking probabilities are of interest to us:

- *Channel Blocking Probability* (CBP) referring to all blocking events
- *Switching-induced Blocking Probability* (SBP) referring only to blockings being a consequence of channel switching
- *Handover-induced Blocking Probability* (HBP) referring only to blockings being a consequence of handover events.

As it is usual, we can approximate the three probabilities by the relative frequencies of the corresponding blockings choosing an observation interval which is sufficiently large.

Let T = [t1, t2] denote the observation interval and |T|=t2-t1 its length.

Let further denote:

- $\#r(T)$: nº of all channel requests issued by all users in T
- $\#r_h(T)$: nº of all handover-related requests in T
- $\#r_s(T)$: nº of all switching-related requests in T
- $\#b(T)$: nº of all blocked requests (blockings) in T
- $\#b_h(T)$: nº of all handover-related blockings in T
- $\#b_s(T)$: nº of all switching-related blockings in T.

Based on these variables, we can now define the following channel blocking frequencies for the interval T:

- CBF(T) $\triangleq \frac{\#b(T)}{\#r(T)}$ denoting the *overall channel blocking frequency*
- HBF(T) $\triangleq \frac{\#b_h(T)}{\#r(T)}$ denoting the *relative frequency of handover-related blockings*
- SBF(T) $\triangleq \frac{\#b_s(T)}{\#r(T)}$ denoting the *relative frequency of switching-related blockings.*

Evidently,

$$\mathrm{HBF(T)} + \mathrm{SBF(T)} = \frac{\#b_h(T)}{\#r(T)} + \frac{\#b_s(T)}{\#r(T)} = \frac{\#b_h(T) + \#b_s(T)}{\#r(T)} = \frac{\#b(T)}{\#r(T)} = \mathrm{CBF(T)}$$

and – as the relative frequency converges to the probability for an interval length |T| tending to infinity:

$$\mathrm{CBP} = \lim_{|T| \to \infty} \mathrm{CBF(T)}$$
$$\mathrm{HBP} = \lim_{|T| \to \infty} \mathrm{HBF(T)}$$
$$\mathrm{SBP} = \lim_{|T| \to \infty} \mathrm{SBF(T)}$$

which implies that also CBP = HBP + SBP holds.

Instead of CBP we can alternatively use

$$\mathrm{CA} \triangleq 1 - \mathrm{CBP}$$

denoting the overall *channel availability*.

III. AN ANALYTICAL MODEL TO PREDICT TV CHANNEL AVAILABILITY

In [16], an analytical model was elaborated which is the basis of this paper. This analytical model is used to determine CBP and it is able to take into account various traffic scenarios, access network technologies and IPTV service characteristics.

To present this model in this section and in the following sections we use the variables and model parameters as introduced in Table I.

The basic ideas underlying the analytical model are the following ones:

TABLE I. LIST OF PARAMETERS AND VARIABLES USED

	Variable/ parameter	**Meaning**
Traffic-related variables	k	number of lanes per direction
	v_i	speed of vehicles on lane L_i assumed to be constant for this lane (in [km/h])
	d_i	distance between adjacent vehicles on L_i assumed to be constant for this lane (in [m])
	$\bar{d}$	mean distance between adjacent vehicles (averaged over all lanes)
Cell-related variables	C_r	radius of cell (in [m])
	BW_c	bandwidth available for IPTV service in cell c
	N_c	number of IPTV users in cell c
IPTV-related variables	N	number of TV channels offered in total
	α	percentage of vehicles using IPTV
	p_i	probability that channel i is required (according to Zipf distribution with parameter θ)

(1) Calculate the probability that the system is in a state in which blocking can occur, also called a *"potential blocking state"*.
(2) Calculate the probability that a currently unavailable channel is demanded when the system is in a "potential blocking state".

Calculation of CBP in our analytical model is based on the following four steps:

- STEP 1: Determine the probabilities P_i that, for given N and N_c, exactly i different channels are needed to satisfy the channel requests of N_c users, if N different channels are offered. P_i can be estimated by the relative frequency f_i that N_c users require exactly i different channels, where f_i can be determined in a straight-forward manner by means of Monte-Carlo simulation [4] [14]. Throughout this paper, all of our Monte-Carlo experiments are repeated one million times and, therefore, the size of the sample to calculate f_i is 10^6.
- STEP 2: Assume a certain cell bandwidth BW_c available for IPTV and determine P^* as probability that N_c users require more than BW_c different TV channels. So, P^* denotes the probability that the system is in a "potential blocking state".
- STEP 3: Assume that an IPTV user will require a new channel (channel number determined according to Zipf distribution) and determine the probability that the number of the channel demanded is larger than BW_c , which happens with probability

$$\sum_{\mathrm{i} > \mathrm{BW_c}}^{\mathrm{N}} \mathrm{p_i}$$

- STEP 4: We determine the probability (*CBP*) that a newly requested channel cannot be delivered which happens with probability

$$\mathrm{CBP} = \mathrm{P}^* \bullet \textstyle\sum_{\mathrm{i}>\mathrm{BW_c}}^{\mathrm{N}} \mathrm{p_i} \,,$$

  if we make the favorable assumption that, in case of a "potential blocking situation (state)", exactly those channels are transmitted in the corresponding cell, which are the BW_c most popular ones.

  Remark: It should be noted that, astonishingly, the (favorable) assumption that "if the system is in a potential blocking state then just the most popular channels are transmitted" is quite realistic indeed. This has been observed by us in simulation experiments based on detailed models of IPTV services in VANETs (cf. simulation models described in [11] and also used during our model validation in Section IV). □

Figure 2 illustrates STEP 1 and STEP 2, by way of example, if we assume $N = 50$, $BW_c = 30$, $N_c = 150$. This figure depicts the histogram for P_i , $i \in \{1, 2, \ldots, 50\}$.

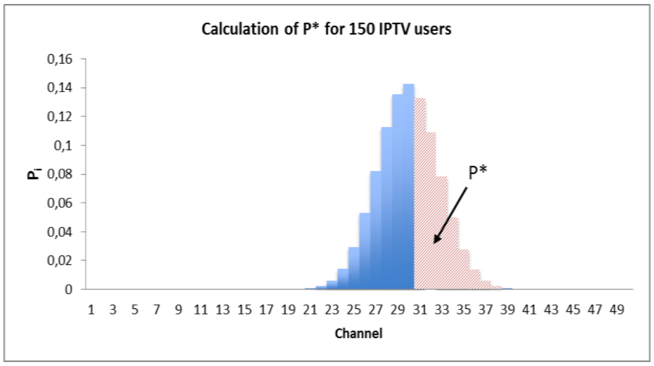


Figure 2. Determination of P^* for $N = 50$ and $BW_c = 30$ according to STEPs 1 and 2 of our calculation algorithm for the analytical model ($N_c = 150$).

IV. MODEL VALIDATION

What is left is the validation of our analytical model. We validate it by means of simulation and care mainly about the late (stationary) phase and situations where CBP ≤ 0.1, because we assume that if CBP > 0.1 this means that QoE is too low anyway and, therefore, model accuracy is not really important for those cases.

We validate the model by means of two series of experiments and observed good agreement between the analytical model and the simulation results. Therefore, we consider the analytical model as being sufficiently realistic. Of course, our validation phase is limited by the fact that we do not have any access to measurements regarding IPTV service availability in vehicular networks because those systems currently do not yet exist. So, we find it acceptable to rely on IPTV service availability predictions based on a detailed and (hopefully) sufficiently realistic simulation model.

A. Series I of Validation Experiments

In Series I, we changed N_c (the number of users in the cell) and kept N (the number of channels available) and BW_c (the maximum number of channels that can be broadcasted at the same time) constant per set of experiments, with $N = 50$ and $BW_c = 30$ for *set 1* of Series I and $N = 100$ and $BW_c = 40$ for *set 2*. As can be seen in Table II, the analytical model and the simulation model are matching quite well with a few minor outliers at $N_c = 200$ in both sets. Also, the values of the analytical model in set 1 do not increase as fast as the values of the simulation model (with increasing N_c).

B. Series II of Validation Experiments

In Series II, we kept the number of users per cell constant ($N_c = 300$) and changed N (the number of channels available) and BW_c (the maximum number of channels that can be broadcasted at the same time). We, again, observe a good agreement between the analytical model and the simulation results, with a few minor outliers at higher values for N, where the analytical model is a close upper bound; for details regarding the deviations, cf. Table III.

TABLE II. SERIES I OF VALIDATION EXPERIMENTS

Series I: Set 1 N=50 BW_C=30

	CBP		Deviation	
N_C	AM	SM	Relative [%]	Absolute
100	0,0011	0,0024	-118,18182	-0,0013
200	0,0506	0,0339	33,003953	0,0167
300	0,0577	0,0549	4,8526863	0,0028
400	0,0578	0,0615	-6,4013841	-0,0037
500	0,0578	0,0649	-12,283737	-0,0071

Series I: Set 2 N=100 BW_C=40

	CBP		Deviation	
N_C	AM	SM	Relative [%]	Absolute
100	0,00008	0,00009	-12,5	-0,00001
200	0,068	0,0327	51,911765	0,0353
300	0,0846	0,0642	24,113475	0,0204
400	0,0843	0,0832	1,3048636	0,0011
500	0,0843	0,0869	-3,084223	-0,0026

V. A GENERALIZED APPROACH TO PREDICT CHANNEL BLOCKING PROBABILITIES

In the following, our goal will be to use our analytical model, presented in Section III, to predict with only very little expenditure the availability of IPTV services in VANETs. In particular, our approach should cover a broad spectrum of traffic situations and of network technologies used to establish the access network for vehicle to RBU communication and, last not least, it should also cover numerous characteristics of the IPTV service offered.

Calculation of CBP based on our analytical model yields to the following formula:

$$\mathrm{CBP} = P^* \bullet \sum_{i>BW_c}^{N} p_i\,,$$

and this shows that CBP can be seen as a product of only two terms T_1 and T_2 with

TABLE III. SERIES II OF VALIDATION EXPERIMENTS

Series II N_C=300

	CBP		Deviation	
N, BW_C	AM	SM	Relative [%]	Absolute
20, 10	0,1157	0,1364	-17,891098	-0,0207
20, 15	0,0456	0,0501	-9,8684211	-0,0045
50, 20	0,1099	0,1222	-11,191993	-0,0123
50, 30	0,0577	0,0529	8,3188908	0,0048
75, 30	0,0942	0,0956	-1,4861996	-0,0014
75, 40	0,0607	0,0424	30,14827	0,0183
75, 50	0,0074	0,0057	22,972973	0,0017
100, 50	0,0473	0,0251	46,934461	0,0222
100, 60	0,0016	0,0017	-6,25	-1E-04
150, 50	0,0889	0,0533	40,044994	0,0356
150, 60	0,0381	0,0182	52,230971	0,0199
150, 70	0,0011	0,0009	18,181818	0,0002

$$T_1 \triangleq P^* \quad \text{and} \quad T_2 \triangleq \sum_{i>BW_c}^{N} p_i$$

If we fix the value of the parameter θ in the Zipf distribution used to model IPTV user behavior, it becomes evident that

$$T_1 = T_1(N, N_c, BW_c) \quad \text{and} \quad T_2 = T_2(N, BW_c).$$

Therefore, it is possible to characterize T_1, as well as T_2 by means of elementary sets of curves. Moreover, T_1 is a general upper bound for CBP because

$$T_1 = P^* > P^* \bullet \sum_{i>BW_c}^{N} p_i = \mathrm{CBP}$$

This is why the sets of curves related to term T_1 (resp. P*) are of particularly strong interest. Similarly, T_2 is an upper bound of CBP, too.

A. *Characterization of term T_1, i.e., P**

Here, we want to investigate the influence of the

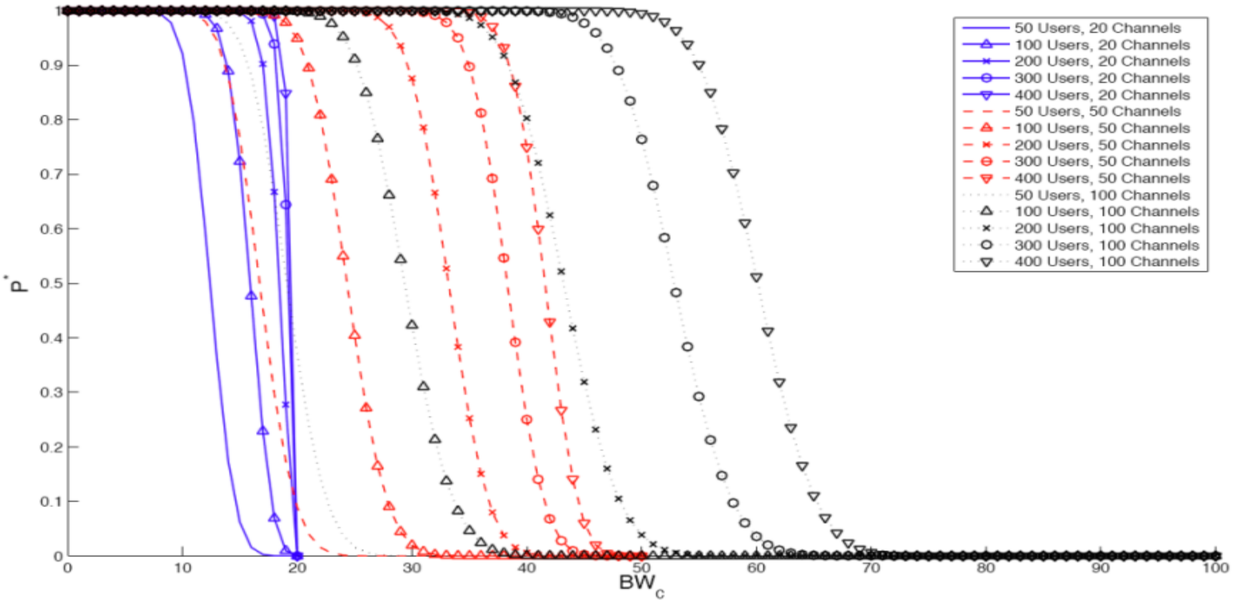
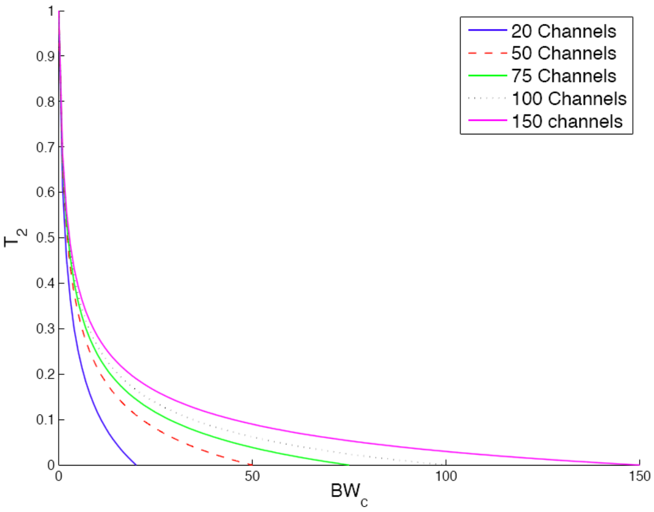


Figure 3. P* as a function of BW_c for different values of *N* and different cell populations N_c of IPTV users



F igure 4. T_2 as a function of BW_c for different values of N

available bandwidth BW_c on P* assuming that a certain number N of channels is offered and that the number N_c of IPTV users in the cell varies. In this study of P*, we assume $N \in \{20, 50, 100\}$ because $N = 20$ presents a small, $N = 50$ a medium and $N = 100$ a quite large number of channels offered.

Moreover, we suppose $N_c \in \{50, 100, 200, 300, 400\}$ because in realistic scenarios (e.g., for $\alpha = 0.05$) one nearly always will have no more than 400 IPTV users in a single cell (cf. below). Evidently, variation of BW_c only makes sense in the interval $[1, N]$.

Fig. 3, e.g., directly shows that if $N = 100$ channels are offered, spending a bandwidth $BW_c = 70$ for IPTV will lead to a negligible value of P* and, therefore, also to a negligibly small CBP for all realistic cell populations considered by us ($N_c \leq 400$). And even a bandwidth $BW_c = 65$ reserved for IPTV will ensure that CBP < 10 % holds, if again $N_c \leq 400$ can be assumed.

B. *Characterization of term T_2*

As T_2 is no longer dependent on N_c, investigations concerning this term become even more straight-forward than for T_1. In particular, the dependency of T_2 on the bandwidth BW_c reserved for IPTV can be directly depicted for a given value of N.

TABLE IV. N_c AS A FUNCTION OF $\bar{d}$ AND C_r

$\bar{d}$ \ C_r	1 km	3 km	5 km	10 km
5 m	120	360	600	1200
10 m	60	180	300	600
20 m	30	90	150	300
50 m	12	36	60	120
100 m	6	18	30	60

Figure 4 shows those dependencies for $N \in \{20, 50, 75, 100, 150\}$. This figure provides in-depth insight regarding the difficult decision of how much bandwidth should be spent for a given number N of offered channels. As examples, let us look at the case of $N = 20$ where it seems to be a good idea to choose $BW_c \geq 18$ (at least), for $N = 75$ a bandwidth of at least $BW_c = 50$ seems to be desirable and for $N = 150$ a chosen bandwidth of $BW_c \leq 80$ seems to be quite risky.

C. *Expected number of IPTV users in a cell*

The number N_c of IPTV users to be expected in a cell will just depend on:

- average distance $\bar{d}$ between two adjacent vehicles (driving in the same lane), where the avg. is taken over all lanes
- the nº of lanes per direction (k)
- the probability that in a vehicle IPTV is used (α)
- the cell radius (C_r).

In particular, N_c can be easily determined as follows:

$$N_c = \alpha \bullet 2k \bullet 2C_r / \bar{d}$$

If we set $\alpha = 0.05$ and $k = 3$ to be constant and if we vary $\bar{d} \in \{5\text{m}, 10\text{m}, 20\text{ m}, 50\text{ m}, 100\text{ m}\}$ and assume cell radiuses of $C_r \in \{1\text{ km}, 3\text{ km}, 5\text{ km}, 10\text{ km}\}$, we get N_c values as depicted by Table IV. We see that with our assumptions, which we consider to be quite realistic, the value of N_c varies between 6 and 1200. We also can observe that rather

TABLE V. CHANNEL BLOCKING PROBABILITY (*CBP*) FOR DIFFERENT COMBINATIONS OF N, BW_c VALUES AND DIFFERENT N_c VALUES

CBP									
(N, BW$_c$) \ N$_c$	**50**	**75**	**100**	**125**	**150**	**200**	**300**	**400**	**500**
(20, 15)	0,0028	0,0175	0,033	0,0411	0,0442	0,0455	0,0456	0,0456	0,0456
(50, 20)	0,0098	0,0712	0,1043	0,1094	0,1099	0,1099	0,1099	0,1099	0,1099
(50, 30)	0	0,00002	0,0011	0,0086	0,0243	0,0506	0,0577	0,0578	0,0578
(75, 30)	0,000001	0,0011	0,0193	0,0585	0,0843	0,094	0,0942	0,0942	0,0942
(75, 50)	0	0	0	0	0	0,00003	0,0074	0,0302	0,038
(100, 50)	0	0	0	0	0,00001	0,0024	0,0473	0,0616	0,0619
(100, 60)	0	0	0	0	0	0	0,0016	0,0227	0,0414
(150, 60)	0	0	0	0	0	0,0002	0,0381	0,0717	0,073
(150, 70)	0	0	0	0	0	0	0,0011	0,0293	0,0563
(150, 80)	0	0	0	0	0	0	0	0,0009	0,0162

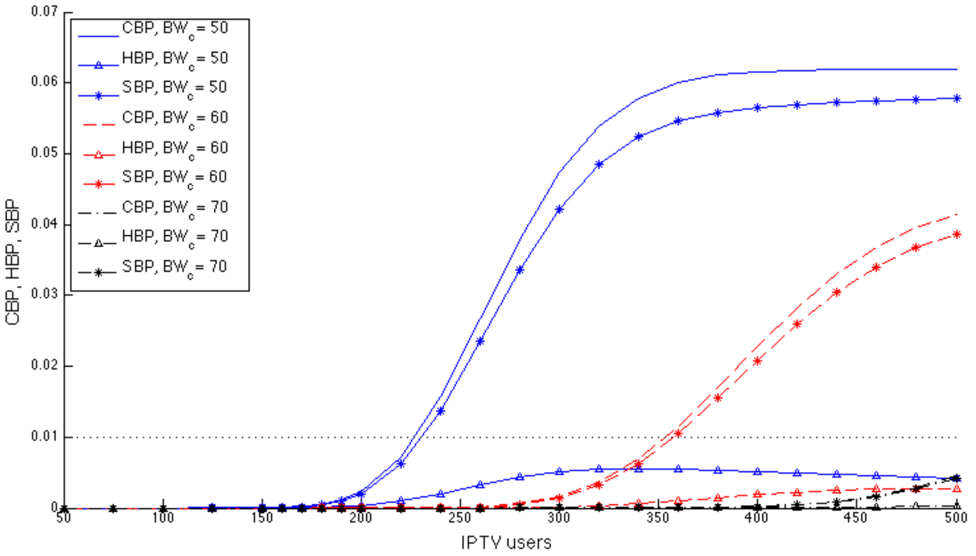


Figure 5. *CBP, HBP* and *SBP* for different values of BW_c in dependence of N_c

different combinations of parameter values will lead to the same value of N_c which facilitates the characterization of P* and thus also of CBP.

D. *Straight-forward calculation of CBP for numerous scenarios of IPTV in VANETs*

Combining the results achieved in this section up to now, we are able to propose a generalized proceeding which allows us to predict CBP for nearly any scenario of interest with nearly negligible expenditure (if we compare this with a CBP prediction based on simulation models for assessing IPTV availability in VANETs).

In particular, Table IV showed us which N_c to assume to be realistic and the results of Fig. 3 and 4 can be directly combined (i.e., T_1 and T_2 can be multiplied) to determine CBP. Table V contains CBP predictions based on our analytical model for numerous scenarios of IPTV in VANETs. The results of Table V cover a broad spectrum of traffic situations (low, medium and high traffic load up to traffic jam), of access network technologies used having an impact on C_r and BW_c and of characteristics of the IPTV service (e.g., number *N* of channels offered).

To summarize, the results obtained in this section can allow one to significantly improve the understanding of the main factors and their mutual dependencies which influence IPTV availability in VANETs.

VI. CASE STUDY

In the previous section, we have shown how it is possible to determine CBP just as a function of *N*, N_c and BW_c, where, of course, N_c itself is a function of $\overline{d}$, C_r, *k* and α. We now want to indicate how the handover- and the switching-induced blocking probabilities HBP and SBP can be determined based on CBP.

A. *Calculation of #ho$_{ph}$*

Let #ho$_{ph}$ denote the total number of handovers per hour of all vehicles using IPTV and leaving a given cell. We assume a mean speed of those vehicles of $\overline{v}$ and a mean distance between adjacent vehicles of $\overline{d}$, a cell radius C_r, *k* lanes per direction, as well as an IPTV watching probability of α. With these assumptions we can directly calculate N_c (cf. Section V.C.).

#ho$_{ph}$ can be determined in a straight-forward manner as follows:

$$\#\mathrm{ho}_{\mathrm{ph}} = \alpha \bullet 2\mathrm{k} \ \frac{\overline{v}\,[\frac{km}{h}]}{\overline{d} \bullet 10^{-3}\ [km]} = \alpha \bullet 2\mathrm{k} \ \frac{\overline{v}}{\overline{d} \bullet 10^{-3}}\ [\frac{1}{h}]$$

B. *Calculation of #sw$_{ph}$*

Let #sw$_{ph}$ denote the total number of switching events per hour of all N_c vehicles using IPTV in a given cell. Let us assume a mean time Δt [min] between two successive channel switching events, where Δt = 3 [min].

Then, #sw$_{ph}$ can be determined as follows:

$$\#\mathrm{sw}_{\mathrm{ph}} = \frac{60}{\Delta t} \bullet \mathrm{N_c}\ [\frac{1}{h}]$$

C. *Calculation of HBP and SBP*

HBP can be determined based on #ho$_{ph}$, #sw$_{ph}$ and CBP as follows:

$$\mathrm{HBP} = (\mathrm{CBP} \bullet \#\mathrm{ho}_{\mathrm{ph}})/(\#\mathrm{ho}_{\mathrm{ph}} + \#\mathrm{sw}_{\mathrm{ph}})$$

Correspondingly:

$$\mathrm{SBP} = (\mathrm{CBP} \bullet \#\mathrm{sw}_{\mathrm{ph}})/(\#\mathrm{ho}_{\mathrm{ph}} + \#\mathrm{sw}_{\mathrm{ph}})$$

D. *Case Studies*

Let us now apply the formulae for HBP and SBP to concrete scenarios for VANETs offering IPTV service.

We assume a medium traffic situation with $k = 3$, $\overline{d} = 50$ m, $\overline{v} = 120$ km/h (averaged over all 2k lanes), $C_r = 5$ km, $N = 100$, $\alpha = 0.05$, $BW_c \in \{50, 60, 70\}$.

Fig. 5 shows the values of CBP, SBP and HBP in dependence of N_c for the 3 values assumed for BW_c. Of course, increasing N_c just corresponds to increasing the cell radius C_r. Curves for SBP have been included in Fig. 5 because of our trial to facilitate result interpretation, though the SBP curves are a direct consequence of the two other ones as SBP is just the difference SBP = CBP – HBP.

Among others, Fig. 5 shows that for $BW_c = 70$ CBP remains rather small for all values of N_c considered and even for $N_c = 500$ the value of CBP still remains well below 0.005. Results such as in Fig. 5 may be highly valuable for a provider of an IPTV service in VANETs because they allow one to answer questions such as:

- How many users are acceptable in a cell if a certain bandwidth BW_c is available for IPTV and we want to keep CBP below a certain threshold? The threshold for CBP could be 0.01 as it is indicated in Fig. 5 and we can observe that if $BW_c = 50$ then $N_c \leq 220$ is still acceptable or if $BW_c = 60$ then $N_c \leq 350$ will still lead to the desired QoE.
- How strongly will HBP, SBP and CBP depend on N_c (N_c here mainly being a function of the cell size)?
- How much does an increase of BW_c help in reducing the blocking probabilities?
- What proportion of CBP is due to handover respectively switching events, i.e., how much does handover-related blocking “hurt” QoE?

VII. SUMMARY AND OUTLOOK

The goal of this paper has been to evaluate the availability of IPTV services in VANETs based on an analytical modeling approach. The analytical model elaborated allows one to predict TV channel availability in a quite flexible and highly efficient manner (if, e.g., compared to simulation models). Our comprehensive validation studies indicate that the analytical model achieves a satisfactory degree of validity. The general proceeding for making use of the model demonstrates that studies are possible in a straight-forward manner covering strongly different scenarios. The proceeding proposed is primarily based on a highly relevant discovery made by us, namely, that we realized that the terms T_1 and T_2 , the product of which yield CBP, (cf. Section V) are both upper bounds of CBP. The case studies illustrate how the general proceeding for efficient experimentation can lead to a valuable understanding of the main factors influencing (switching- as well as handover-induced) TV channel blocking probabilities in VANETs.

In our future research, we plan to elaborate an algorithm which allows one to reduce the probability of handover-induced channel blockings (at the expense of an increasing number of switching-induced blockings). Such an algorithm seems to be highly desirable in order to alleviate the strongly negative impact, which handover-induced blockings may have onto QoE in the provisioning of IPTV services in VANETs.

REFERENCES

[1] A. Abdollahpouri, QoS Aware Live IPTV Streaming Over Wireless Multi-hop Networks. Shaker Verlag 2012.

[2] A. Abdollahpouri, B. E. Wolfinger, J. Lai, and C. Vinti, Modeling the Behavior of IPTV Users with Application to Call Blocking Probability Analysis. Praxis der Informationsverarbeitung und Kommunikation 2012, 35 (2), pp. 75-81.

[3] A. Baiocchi and F. Cuomo, Infotainment services based on push-mode dissemination in an integrated VANET and 3G architecture. Journal of Communications and Networks, April 2013, 15 (2), pp. 179-190.

[4] W. L. Dunn and J. K. Shultis, Exploring Monte Carlo Methods. Elsevier Science 2011.

[5] FOCUS Online: 80 Prozent der Neuwagen mit Internet. www.focus.de/auto/news/revolution-im-auto-bis-2016-haben-80-prozent-der-neuwagen-internet_id_4216763.html (last access: Dec. 18, 2014).

[6] M. Krohn, R. Daher, M. Arndt, and D. Tavangarian, Aspects of roadside backbone networks. 1st Internat. Conf. Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology, Wireless VITAE 2009, pp.788-792.

[7] J. Lai, Evaluation and Improvement of TV Channel Availability for IPTV Services. Shaker Verlag 2012.

[8] S. Malkos, E. Ucar, and R. Akdeniz, Analysis of QoE key factors in IPTV systems: Channel switching. 5th Internat. Conf. on Application of Information and Communication Technologies (AICT2011), October 2011, Baku, Azerbaijan, pp. 1-5.

[9] S. Möller and A. Raake, (eds.), Quality of Experience: Advanced Concepts, Applications and Methods. Springer 2014, pp. 11-35.

[10] S. Momeni, J. Lai, and B. E. Wolfinger, Availability Evaluation of IPTV Services in Roadside Backbone Networks with Vehicle-to-Infrastructure Communication. 9th Internat. Wireless & Mobile Computing Conference. IWCMC 2013, IEEE Cagliari, Sardinia, Italy, 2013, pp.1727-1732.

[11] S. Momeni and B. E. Wolfinger, Availability Evaluation of IPTV in VANETs with different types of access networks. EURASIP Journal on Wireless Communications and Networking, Springer Open Journal, 2014: 117 (15 July 2014).

[12] M. E. J. Newman, Power Laws, Pareto Distributions and Zipf’s Law. Contemporary Physics 2005, 46 (5), pp.1-3.

[13] RFC 1112: Host Extensions for IP Multicasting. August 1989.

[14] R. Y. Rubinstein and D. P. Kroese, Simulation and the Monte Carlo Method. 2nd ed., Wiley 2007.

[15] J. P. Urrea Duque and N. Gaviria Gomez, Quality assessment for video streaming P2P application over wireless mesh network. XVII Symposium of Image, Signal Processing, and Artificial Vision (STSIVA2012), September 2012, Antioquia, Colombia, pp. 99-103.

[16] B. E. Wolfinger, A. Hübner, and S. Momeni, A Validated Analytical Model for Availability Prediction of IPTV Services in VANETs. Electronics 2014, 3, pp. 689-711; doi: 10.3390/electronics3040689.