

An Analytical Model and an Efficient Tool to Predict the Availability of IPTV Services in Vehicle-to-Infrastructure Networks

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Abstract— Entertainment services such as IP television (IPTV) are becoming increasingly important in vehicular ad-hoc networks (VANETs), which implies a strong need for quality of experience (QoE) studies. Therefore, in this paper we introduce analytical models to predict QoE of IPTV in VANET scenarios. Unlike earlier QoE research for IPTV, which has been mainly related to audio/video quality, our focus is on IPTV service availability. To evaluate our analytical models we offer a tool (ACTIVE) that can be used in a flexible and efficient manner. The paper also describes the architecture and the main components of the tool as well as its graphical user interface. Case studies based on our ACTIVE tool demonstrate how our models can be applied by a provider of IPTV services in order to satisfy QoE requirements regarding the service availability as given by the IPTV users. Moreover, some of the results are also of interest to the individual IPTV users.

Keywords- Vehicular networks; IPTV; QoE; service availability; analytical model; model evaluation tool; 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 [9]). 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 [5]. 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) [16]. In case of IPTV services, on the one hand, QoE refers to the quality of the received audio/video stream as perceived by the end-user. So, most of the existing studies concerned with QoE in the context of audio/video communications with real-time

constraints have been related to audio-visual quality, which is judged by well-known QoE measures, such as PESQ/PEAQ/PEVQ (perceptual evaluation of speech/audio/video quality) [7] or by means of MOS (mean opinion score), a method that directly relies on the subjective judgement of the human end-users [25]. Belyaev et al. [6] propose an interesting approach for a dynamic adaptation of the video bit rate in order to maintain a certain level of video quality in a scenario of a vehicular video surveillance system (based on IEEE 802.p [12]). Here, QoE is evaluated in terms of visual quality and its impairment by packet losses.

Of course, the audio-visual quality is also relevant in the context of vehicular networks, more so, because the TV channels are offered to the corresponding car passengers via wireless access networks. And this may have a strongly negative impact on the quality of the stream delivered to the IPTV users.

Zhou et al. [28] measure user-satisfaction when users access media services 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 presented in this paper, Zhou et al. do not consider IPTV services, nor do they assume multicast for the provisioning of the media services.

Besides the audio/video quality of the delivered TV channels, QoE is also influenced strongly by the delay it takes to switch from one channel to another, which usually is called *channel switching delay*. Several studies try to reduce these switching delays, cf. [2].

Last but not least, QoE in vehicular networks also comprises the degree of availability with which the user is able to access the IPTV service [15]. From the users' point of view the availability of TV channels may be even more important than the audio-visual quality of the IPTV service. 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 [14] as well as for WiMAX based access networks [2].

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 – and not analytical models as in the current paper – have been elaborated and applied in case studies by Momeni et al. [17]. 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. [27]. Other existing analytical models to predict QoE for IPTV, such as [11], [19], and [21], have a completely different emphasis: they are again concerned with audio-visual quality and not with channel availability. Moreover, in [11], users are watching TV via home networks and are not mobile at all and, in [19] the emphasis is on (low level) QoS and not on QoE, and finally, in [21], an architecture of an IPTV system is suggested for mobile devices, which is shown to satisfy some basic QoS/QoE requirements. Even most of the simulation tools that exist for studying vehicular networks [23] are quite useless as a basis for doing availability analyses, because they include very detailed submodels for the network services used but, on the other hand, user behavior is reflected in a rather superficial manner.

In a recently published paper [1], we significantly extended the results of [27] as we carried out an in-depth validation of the analytical model and, as a major new contribution, we presented a generalized procedure that allows us to predict the IPTV availability in a straightforward manner for very different traffic scenarios and network technologies. We also applied our procedure in various comprehensive case studies. The current paper is a thoroughly revised and considerably extended version of our earlier publication [1]. We now not only present a class of analytical models but also various upper bounds for the unavailability of requested TV channels. Moreover, the newly developed ACTIVE tool is introduced, which is able to predict the availability of an IPTV service in vehicular networks in a very flexible and highly efficient manner. The ACTIVE tool not only provides the values for availability measures being of interest to providers of IPTV services but also those ones that are related to the channel availability as experienced by individual IPTV users. The availability measures cover both, blocking of TV channels during handover as well as during switching events.

The paper is structured as follows: Section II will give a short overview on IPTV services offered via VANETs including the availability measures that we will apply. The analytical model used will be introduced in Section III followed, in Section IV, by a thorough validation of this model. Our analytical models will be embedded in a model evaluation tool (ACTIVE), the architecture and user interface of which will be described in detail in Section V. A generalized procedure for a highly efficient usage of our models and the ACTIVE tool then is presented in Section VI. Application of the generalized procedure will be illustrated in the case studies of Section VII. 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 that 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 [20] are typically distinguished: networks supporting *vehicle-to-vehicle* (V2V) and those supporting *vehicle-to-infrastructure* (V2I) communication. V2V infrastructures are mainly used to improve vehicular safety [4]. 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 that 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 Gladisch et al. [10] and Krohn et al. [13]). In this paper, we assume that the IPTV services 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, 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 [26] 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 Fig. 1:

- the IPTV Head-end, where all the TV channels are available that can be demanded by the IPTV users,
- that part of the Internet that is used to make communication between the Head-end and the set of

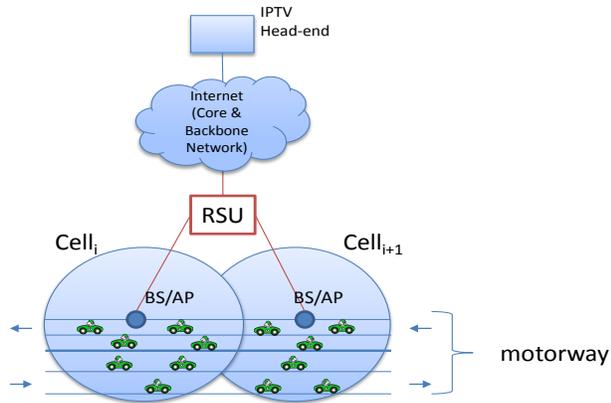


Figure 1. Basic architecture of an IPTV system for users of vehicular networks

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.

Provisioning of IPTV services typically makes use of multicast (e.g., IP multicast [22]) 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 that 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 [2] [3] have shown

that the popularity of TV channels can be approximated quite well by Zipf distributions [18].

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

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

where N denotes the total n° 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 [2].

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 that is sufficiently large.

Let $T = [t_1, t_2]$ denote the observation interval and $|T|=t_2-t_1$ its length.

Let further denote:

- $\#r(T)$: n° of all channel requests issued by all users in T
- $\#r_h(T)$: n° of all handover-related requests in T
- $\#r_s(T)$: n° of all switching-related requests in T

- #b(T): n^o of all blocked requests (blockings) in T
- #b_h(T): n^o of all handover-related blockings in T
- #b_s(T): n^o 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,

$$\begin{aligned}
 \text{HBF}(T) + \text{SBF}(T) &= \frac{\#b_h(T)}{\#r(T)} + \frac{\#b_s(T)}{\#r(T)} = \\
 \frac{\#b_h(T) + \#b_s(T)}{\#r(T)} &= \frac{\#b(T)}{\#r(T)} = \text{CBF}(T) \quad (2)
 \end{aligned}$$

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

$$\begin{aligned}
 \text{CBP} &= \lim_{|T| \rightarrow \infty} \text{CBF}(T) \\
 \text{HBP} &= \lim_{|T| \rightarrow \infty} \text{HBF}(T) \\
 \text{SBP} &= \lim_{|T| \rightarrow \infty} \text{SBF}(T)
 \end{aligned}$$

which implies that also CBP = HBP + SBP holds.

Instead of CBP we can alternatively use

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

denoting the overall *channel availability*.

III. AN ANALYTICAL MODEL TO PREDICT TV CHANNEL AVAILABILITY

In [27], 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:

- (1) Calculate the probability that, for a given cell c, currently all bandwidth BW_c available for IPTV service is used to distribute required TV channels. In such a situation of lacking free bandwidth, the demand for a new channel (which is currently not yet transmitted in cell c) may have to be denied. This means that the transmission of the newly demanded TV channel may become blocked. Therefore, we call the cell as being in a “*potential blocking state*”.
- (2) Calculate the probability that a currently unavailable channel is demanded when the cell is in a “*potential blocking state*”.

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])
Cell-related variables	\bar{d}	mean distance between adjacent vehicles (averaged over all lanes)
	C _r	radius of cell (in [km])
	BW _c	bandwidth available for IPTV service in cell c
IPTV-related variables	N _c	number of IPTV users in cell c
	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)

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 [8], [24]. 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 10⁶.
- 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

$$\sum_{i > BW_c}^N p_i \quad (3)$$

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

$$\text{CBP} = P^* \cdot \sum_{i > BW_c}^N p_i, \quad (4)$$

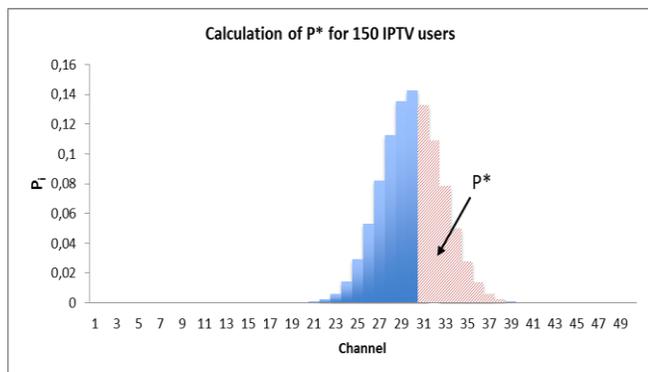


Figure 2. Determination of P^* for $N = 50$ and $BW_c = 30$ according to STEPs 1 and 2 of our calculation algorithm for the analytical model ($N_c = 150$).

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 [17] and also used during our model validation in Section IV). □

Fig. 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 , $i \in \{1, 2, \dots, 50\}$.

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 $CBP \leq 0.1$, 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 rather 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.

Comparisons with alternative analytical models for CBP predictions related to IPTV services in VANETs, developed by other researchers, have not been possible for us as, to the best of our knowledge, no such models do yet exist.

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 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 ($N_c = 300$ for *set 1* of Series II and $N_c = 400$ for *set 2* of Series II). We changed N (the number of channels available) and BW_c (the maximum number of channels that can be broadcasted at the same time). Again, we observe a rather good agreement between the analytical model and the simulation results, with a few outliers at higher values for N , where the analytical model is a close upper bound; for details regarding the deviations, see Table III.

TABLE II. SERIES I OF VALIDATION EXPERIMENTS

Series I: Set 1 $N=50$ $BW_c=30$				
N_c	CBP		Deviation	
	AM	SM	Relative [%]	Absolute
100	0.0011	0.0024	-118.1818	-0.0013
200	0.0506	0.0339	33.0040	0.0167
300	0.0577	0.0549	4.8527	0.0028
400	0.0578	0.0615	-6.4014	-0.0037
500	0.0578	0.0649	-12.2837	-0.0071

Series I: Set 2 $N=100$ $BW_c=40$				
N_c	CBP		Deviation	
	AM	SM	Relative [%]	Absolute
100	0.00008	0.00009	-12.5000	-0.00001
200	0.0680	0.0327	51.9118	0.0353
300	0.0846	0.0642	24.1135	0.0204
400	0.0843	0.0832	1.3049	0.0011
500	0.0843	0.0869	-3.0842	-0.0026

TABLE III. SERIES II OF VALIDATION EXPERIMENTS

Series II: Set 1 $N_c=300$				
N, BW_c	CBP		Deviation	
	AM	SM	Relative [%]	Absolute
20, 10	0.1157	0.1364	-17.8911	-0.0207
20, 15	0.0456	0.0501	-9.8684	-0.0045
50, 20	0.1099	0.1222	-11.1920	-0.0123
50, 30	0.0577	0.0529	8.3189	0.0048
75, 30	0.0942	0.0956	-1.4862	-0.0014
75, 40	0.0607	0.0424	30.1483	0.0183
75, 50	0.0074	0.0057	22.9730	0.0017
100, 50	0.0473	0.0251	46.9345	0.0222
100, 60	0.0016	0.0017	-6.2500	-0.0001
150, 50	0.0889	0.0533	40.0450	0.0356
150, 60	0.0381	0.0182	52.2310	0.0199
150, 70	0.0011	0.0009	18.1818	0.0002

Series II: Set 2 $N_c=400$				
N, BW_c	CBP		Deviation	
	AM	SM	Relative [%]	Absolute
20, 10	0.1157	0.1381	-19.2770	-0.0223
20, 15	0.0456	0.0510	-11.8653	-0.0054
50, 20	0.1099	0.1218	-10.8434	-0.0119
50, 30	0.0578	0.0595	-3.0232	-0.0017
75, 30	0.0942	0.1033	-9.6317	-0.0091
75, 40	0.0619	0.0556	10.2112	0.0063
75, 50	0.0302	0.0199	34.2131	0.0103
100, 50	0.0616	0.0435	29.4651	0.0182
100, 60	0.0227	0.0128	43.5143	0.0099
150, 50	0.0900	0.0754	16.1957	0.0146
150, 60	0.0717	0.0382	46.7156	0.0335
150, 70	0.0293	0.0134	54.1613	0.0159

V. THE ACTIVE TOOL TO EVALUATE OUR ANALYTICAL AVAILABILITY MODELS

In this section we will introduce our recently developed tool, the „Availability Calculator of TV Channels for IPTV Services in Vehicular Networks“, or for short: ACTIVE.

ACTIVE is a means to simply and quickly calculate CBP and other IPTV related availability measures, with high precision and high efficiency.

A. Requirements to the Tool

The requirements we asked of this tool included:

- (1) A simple and intuitive graphical user interface.
- (2) The tool should be flexibly applicable, calculating the results for a great number of combinations of parameter values with low expenditure.
- (3) In addition to CBP, these results should include the most important IPTV related availability measures for

- a. *the total of all IPTV users.* These QoE measures are especially interesting for the IPTV service provider.
- b. *an individual user, taking the speed of the vehicle into consideration.* These QoE measures are especially interesting for IPTV users and those (e.g., the IPTV service provider) who need the users' view.

There were a few ways we ensured that these requirements were met:

1. The tool has two different modes: one for high precision – the *simulation mode* – and one for high efficiency – the *approximation mode*.
2. The simulation mode takes - just as the name implies - the input and runs a new Monte Carlo simulation with 10^6 iterations for highest precision. To increase efficiency, if the exact values / value combinations for (N_c, N) and (BW_c, N) are saved, then the results are calculated directly without the need of a simulation.
3. The approximation mode uses a priori saved intermediate results of the simulations to calculate the results, which is done instantly, thus with maximum efficiency. To increase precision, every time the program runs the 10^6 Monte Carlo simulations in simulation mode, the new intermediate results will be saved, thus making the – already very precise – approximation mode more and more precise.
4. To keep the GUI simple and intuitive, the tool is a single window application, with all the settings on the left side, allowing a simple and flexible, parallel input of the parameters as well as the choice of mode. All results are shown on the right side of the same window at a glance. In approximation mode, the results of the next lower saved N_c and next higher saved N_c (corresponding to the N_c value that was asked for) are shown at the same time. If the difference of corresponding values (e.g., the “lower” CBP and the “higher” CBP) exceeds 20% the values will be shown in **maroon**.
5. To maximize flexibility, the tool accepts the input of the 8 parameters already introduced in Table I, with p_i and \bar{d} not being input parameters but being calculated in the simulation and based on the d_i respectively. Also the input for both N_c as well as d_i are optional. N_c can easily be given directly or be calculated by the program, the value is shown directly below the parameter and updated “live” during parameter input for maximum clearness. N_c is then a function of k , C_r , α , d_i (or v_i). Same goes for d_i , if no d_i values are given, the tool will calculate values using the v_i .
6. The tool will show the results for 24 IPTV related availability measures in total.

The input data, which is used by the ACTIVE tool to produce the TV service availability results, is shown in

detail by Fig. 6 (cf. “Parameter input” section, left-side bottom part of the “Settings”).

The main intermediate data computed by ACTIVE comprises in particular P^* , cf. eq. (4), and the probabilities p_i , $i \in \{1, 2, \dots, N\}$, cf. Table I.

In particular, the following results are provided by the ACTIVE tool:

- a) For the total of all IPTV users, there is CBP (Channel Blocking Probability), SBP (Switching-induced Blocking Probability) and HBP (Handover-induced Blocking Probability) and
- b) For an individual user, there is bph_s (blockings per hour, switching-induced), bph_h (blockings per hour, handover-induced) and bph (blockings per hour in total).
- c) These results are all given
 1. for the next lower saved N_c and next higher saved N_c (corresponding to the N_c value that was asked for) and also
 2. for the “late” model, when the traffic evens out, which is the model discussed in this paper and the “early” model right after the lanes were empty and the traffic for this road started (cf. model presented in [27]). So, ACTIVE actually exceeds the model discussed in this paper and implements also a second one.

B. Tool Architecture and Internal Process Flows

With Fig. 3 we would like to present a brief overview on the architecture and the internal mechanics of the tool.

The user specifies the mode of operation and the parameters, which will be received by the *evaluation module*.

This module will give N_c , N and BW_c to either the database module - if approximation mode was selected - or the simulation module - if simulation mode was selected - and will get the corresponding intermediate results (“vector P”, “zipf”: the vector with the popularities for the N channels and “Z*”, a value used exclusively by the early model) as return. It will then calculate the results and display them in the GUI.

If the *simulation module* is asked for the intermediate results, it will start a new Monte Carlo simulation with 10^6 iterations, by creating a new java thread from SwingWorker. This new thread calls the external program “runSimulation”, which is written in python but compiled as an .exe. The new intermediate results will be given to the evaluation module for further processing and to the database module for storage.

If the *database module* is asked for the intermediate results, it will just return the corresponding results it either read from the database at program start-up or got from the simulation module. At program termination it will write all values back to the database. This database consists of three

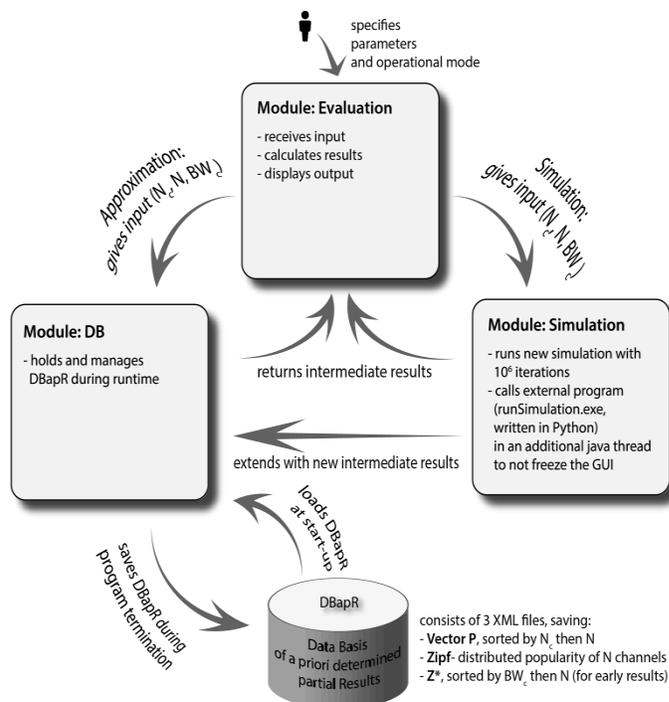


Figure 3. The internal mechanics of ACTIVE

XML files: “vectorP.xml”, “zipf.xml” and “zStars.xml”, which save their values, respectively.

Remark: The authors plan to provide their ACTIVE tool to interested researchers as an open source product as soon as it is completely finalized, i.e., before spring 2016 (cf. TKRN Web pages at the University of Hamburg).

C. Graphical User Interface

Fig. 4 shows the GUI in its entirety, as it looks on start-up. On the left side you see the settings panel. On top is the choice between approximation and simulation mode, as discussed. If you choose “Approximation” the results will be shown instantly, if you choose “Simulation” a new Monte Carlo simulation with 10^6 iterations will start and may take up to an hour, depending on the input of N_c and BW_c (on a 3 GHz processor core). The start button will change to a cancel button, the progress will be shown in the progress bar below the settings and the result panels, as shown in Fig. 5 and at the end of the simulation you will hear a “beep” sound for convenience. Below the choice of mode is the area for parameter input.

The variables N , BW_c , k , C_r , v_i are obligatory, d_i is always optional and below d_i you see a drop-down menu where you can choose between setting a value to N_c directly (“Set N_c manually”) and setting a value to α , letting N_c be calculated (“Calculate N_c ”). If you choose “Calculate N_c ”, the calculated value for N_c will be shown just below the value for α and will automatically update while you change the values for k , C_r , v_i , d_i or α .

On the right side is the result panel.

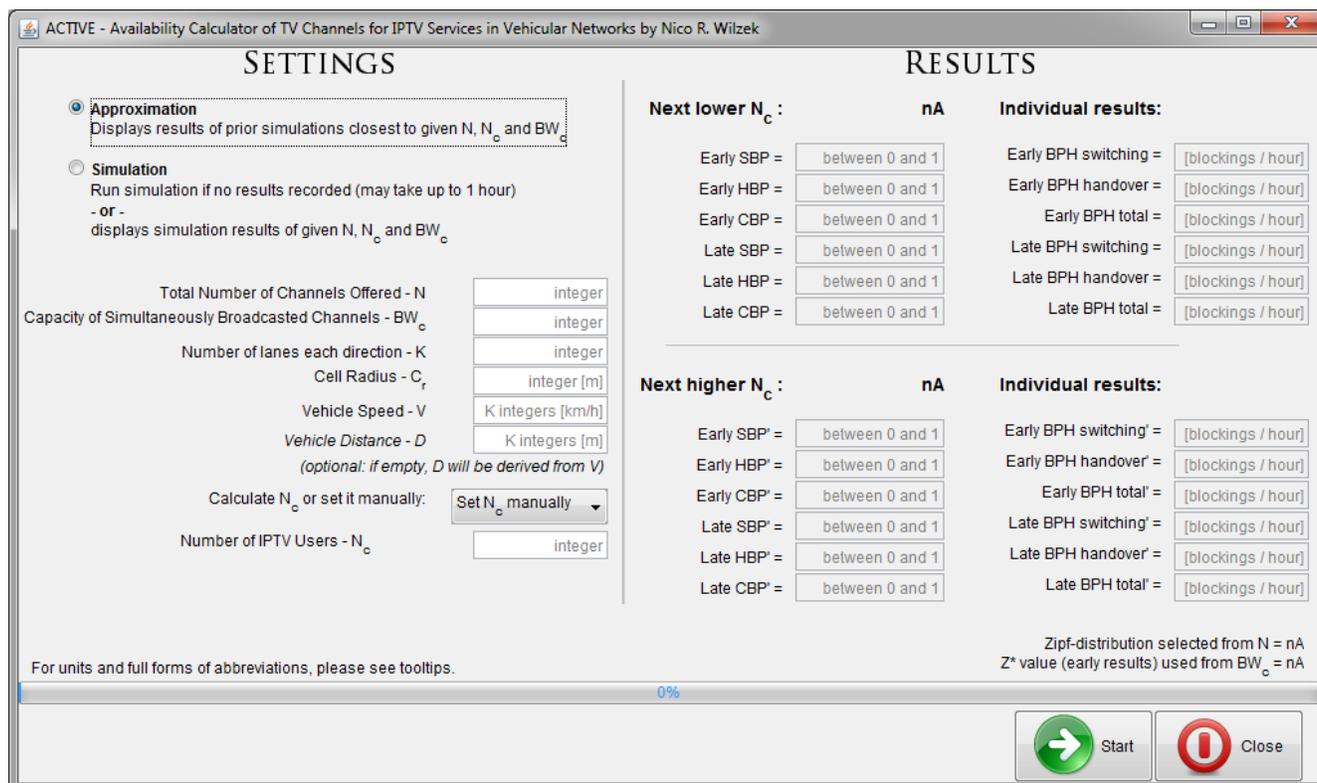


Figure 4. The GUI of ACTIVE at start-up

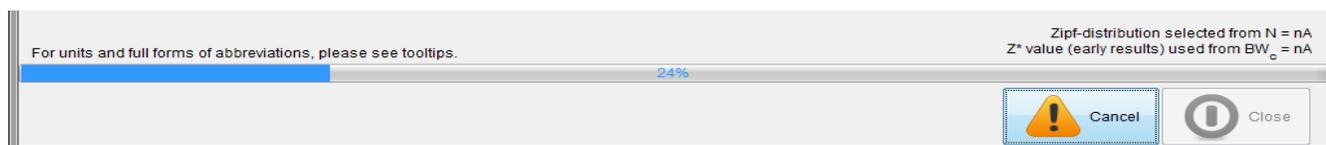


Figure 5. Change in GUI during simulation

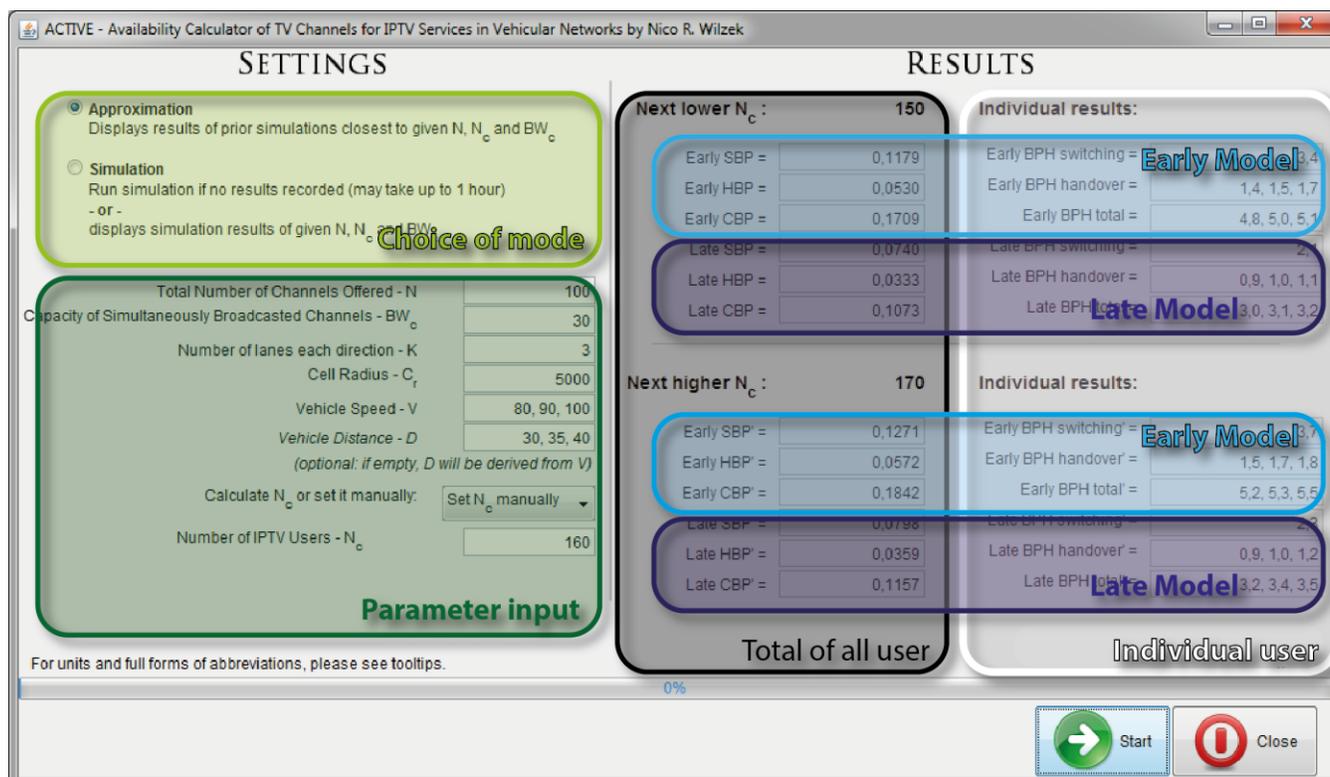


Figure 6. The (logical) partitioning of ACTIVE's GUI

If you split the result panel into left and right, you would find the results for the total of all users to the left and for an individual user to the right; if you split into top and bottom, you would find the results for the next lower saved N_c on top and the next higher saved N_c on the bottom.

Furthermore, you can split the halves for next higher/lower saved N_c into top and bottom again, and you would find the results for the “early” model (additionally implemented to the model of this paper) on top and the results for the “late” model (discussed in this paper) on the bottom.

The complete (logical) partitioning is shown in Fig. 6.

D. A Sample Session

Let us use the tool for a specific scenario. We are interested in getting the results fast – if the given results are not close enough to the given scenario, we can still change our opinion. The scenario is a motorway with three lanes each direction. The cars drive faster on the inner lane, but not by a lot, let us say they drive 90 km/h on the outer lane, 100 km/h on the middle lane and 120 km/h on the inner lane. There is no easy way for us to measure the distances of the cars, traffic situation is dense (i.e., there is no unused space without cars), but they seem to have normal distances for their speed (that is the speculation of ACTIVE if no d_i is given).

We know that the IPTV service provider offers 100 channels in cells with 5 km radius, but can only stream 30 different ones at a time. Also, we assume that about every 20th vehicle will make use of the IPTV offer (but do not

know the total number of users who make use of it).

To use the tool we just follow these 3 easy steps:

1. Keep/ change the mode setting to “Approximation”.
2. Set input parameters by
 - a. entering all values we have (except α , if α is hidden behind the drop-down menu), ignoring d_i and N_c , because we do not know the values for these parameters (the distances between adjacent vehicles and the total number of users),
 - b. choosing “Calculate N_c ” in the drop-down menu (since we do not know the total number of users, but the amount of IPTV users relative to all vehicles: every 20th),
 - c. entering the value for α in % (every 20th = 5%), the number of users will be updated while we type, directly below our input.
3. Press the start button.

The results will be displayed immediately on the right side of the GUI.

Fig. 7 shows all steps and the corresponding results. Since all results are maroon in color it means the difference in results between the next lower saved N_c and the next higher saved N_c is more than 20%. We can now either choose to run the simulation by clicking on “Simulation” and then on “Start” to get more precise results, or say the N_c value that we asked for is close enough to one of the saved results. We would recommend the latter, since 78 is really close to 77.

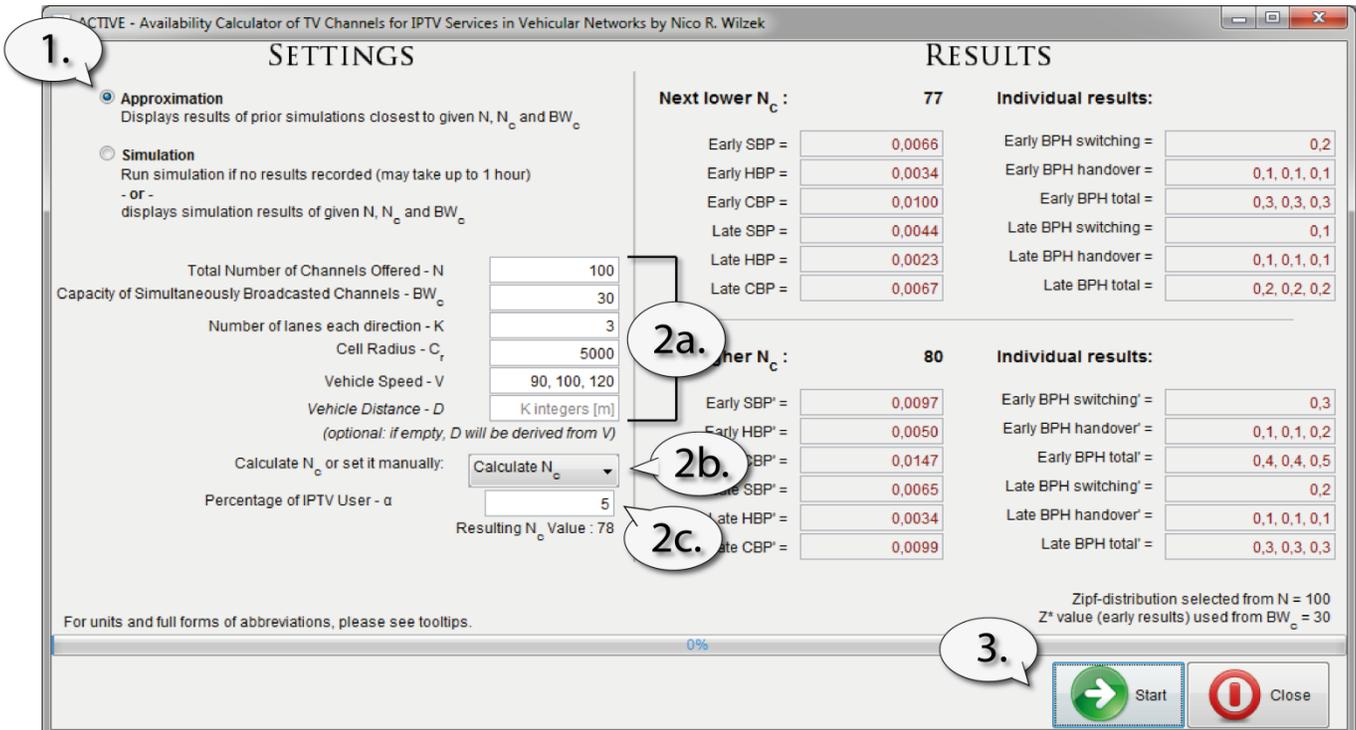


Figure 7. The 3 steps of the sample session

VI. CBP BOUNDS AND PARAMETER STUDIES

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:

$$CBP = P^* \cdot \sum_{i>BW_c}^N p_i, \tag{5}$$

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

$$T_1 \triangleq P^* \text{ and } T_2 \triangleq \sum_{i>BW_c}^N p_i \tag{6}$$

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

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

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

$$T_1 = P^* > P^* \cdot \sum_{i>BW_c}^N p_i = CBP \tag{7}$$

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, because

$$T_2 = \sum_{i>BW_c}^N p_i > P^* \cdot \sum_{i>BW_c}^N p_i = CBP \tag{8}$$

Consequently, this also implies that

$$\min(T_1, T_2) > CBP$$

is a third and, in general, an even tighter upper bound of CBP.

A. Characterization of Upper Bound T_1 , i.e., P^*

Here, we want to investigate the influence of the 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 $[1, N]$.

For example, Fig. 8 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 Upper Bound 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

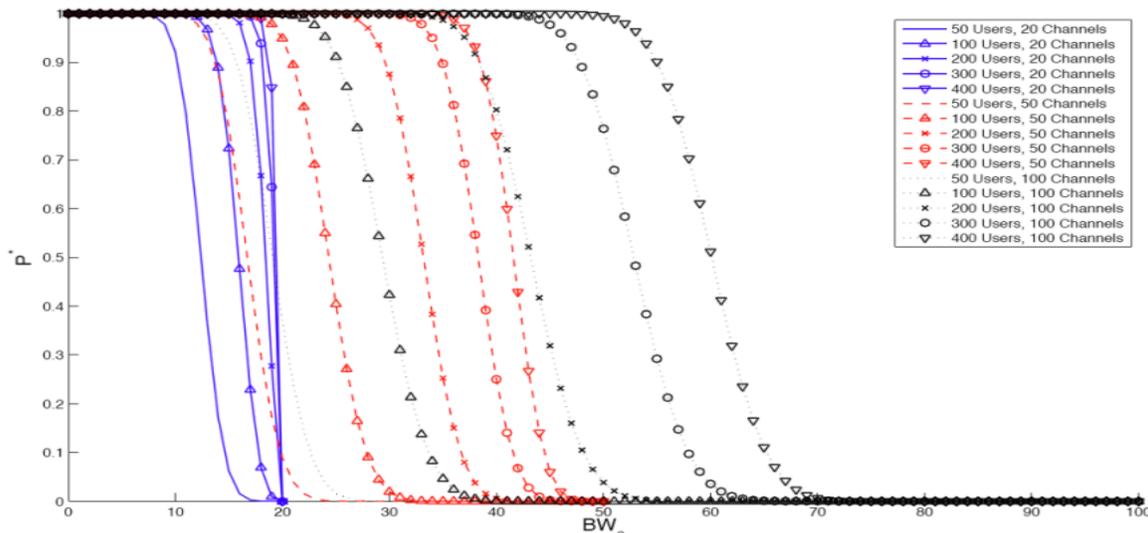


Figure 8. P^* as a function of BW_c for different values of N and different cell populations N_c of IPTV

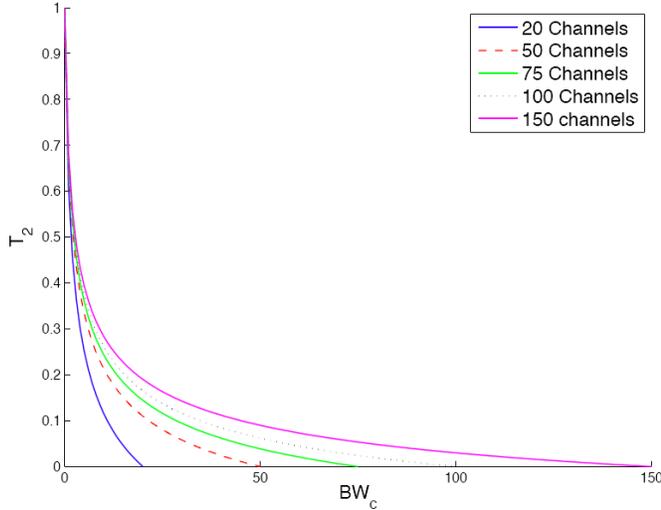


Figure 9. T_2 as a function of BW_c for different values of N

bandwidth BW_c reserved for IPTV can be directly depicted for a given value of N .

Fig. 9 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. Characterization of Upper Bound $\min(T_1, T_2)$

So far, we have discussed about how we can use the terms T_1 and T_2 as upper bounds of CBP separately. However, we are now interested in investigating the tighter upper bound $\min(T_1, T_2)$. So, we might ask the question: When does T_1 fit the best as upper bound of CBP and when does T_2 ? In order to avoid this uncertainty, we can define the function $\min(T_1, T_2)$ as a general and tighter upper bound as we stated before.

Fig. 10 depicts the behavior of the $\min(T_1, T_2)$ function. In this figure it becomes evident in which situations one term applies as upper bound and when the other one does, since we can see the inflection point at every curve.

From this figure, we can claim that when the resources are extremely scarce (w.r.t. the users in the system), T_2 fits the best as upper bound of CBP, however, when the resources are not that scarce, T_1 fits the best.

D. 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:

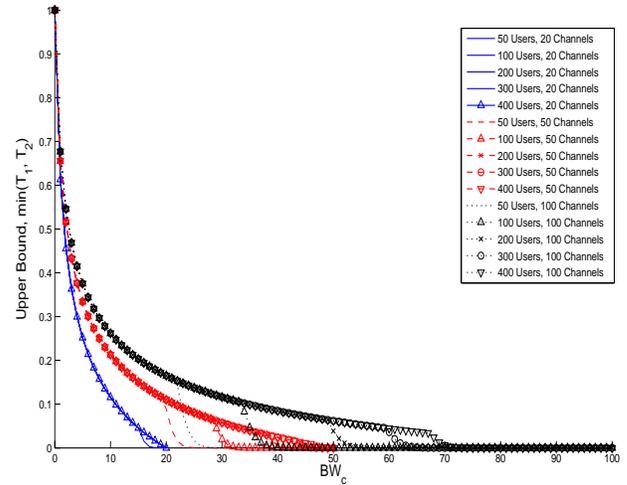


Figure 10. The upper CBP bound $\min(T_1, T_2)$ as a function of BW_c for different values of N and different cell populations N_c

- average distance \bar{d} between two adjacent vehicles (driving in the same lane), where the avg. is taken over all lanes
- the n^o 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:

$$N_c = \alpha \cdot 2k \cdot 2C_r / \bar{d} \quad (9)$$

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 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.

TABLE IV. N_c AS A FUNCTION OF d AND C_r

$\bar{d} \backslash C_r$	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

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

CBP									
$(N, BW_c) \backslash N_c$	50	75	100	125	150	200	300	400	500
(20, 15)	0.0028	0.0175	0.0330	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	0.0011	0.0193	0.0585	0.0843	0.0940	0.0942	0.0942	0.0942
(75, 50)	0	0	0	0	0	0.00003	0.0074	0.0302	0.0380
(100, 50)	0	0	0	0	0	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	0.0730
(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

E. 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 that 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 what N_c values to assume to be realistic and the results of Figs. 8 and 9 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.

VII. CASE STUDIES

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 \bar{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. Handover-induced Blockings: 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 \bar{v} and a mean distance between adjacent vehicles of \bar{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 VI.D.).

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

$$\#ho_{ph} = \alpha \cdot 2k \frac{\bar{v} \left[\frac{km}{h} \right]}{\bar{d} \cdot 10^{-3} [km]} = \alpha \cdot 2k \frac{\bar{v}}{\bar{d} \cdot 10^{-3}} \left[\frac{1}{h} \right] \quad (10)$$

For single IPTV users we thus obtain:

$$bph_h(v) = \#ho_{ph}(v) \cdot CBP, \quad (11)$$

if $bph_h(v)$ denotes the *number of handover-induced blockings per hour* experienced by a single user in a vehicle driving with speed v .

B. Switching-induced Blockings: 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 $\Delta t = 3$ [min].

Then, $\#sw_{ph}$ can be determined as follows:

$$\#sw_{ph} = \frac{60}{\Delta t} \cdot N_c \left[\frac{1}{h} \right] \quad (12)$$

For single IPTV users we thus obtain:

$$bph_s = \#sw_{ph} \cdot CBP, \quad (13)$$

if bph_s denotes the *number of switching-induced blockings per hour* experienced by a single user.

And, evidently, the *total number of blockings per hour* experienced by a single user in a vehicle driving with speed v is expected to be

$$bph(v) = bph_h(v) + bph_s. \quad (14)$$

C. Calculation of HBP and SBP

HBP can be determined based on $\#ho_{ph}$, $\#sw_{ph}$ and CBP as follows:

$$HBP = (CBP \cdot \#ho_{ph}) / (\#ho_{ph} + \#sw_{ph}) \quad (15)$$

Correspondingly:

$$SBP = (CBP \cdot \#sw_{ph}) / (\#ho_{ph} + \#sw_{ph}) \quad (16)$$

which again confirms that: $HBP + SBP = CBP$. (17)

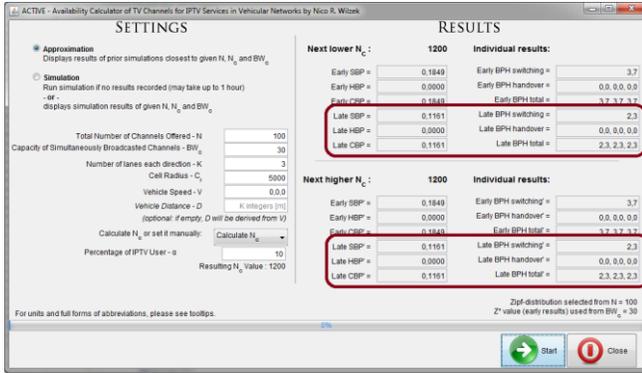


Figure 11. Case study results obtained based on the ACTIVE tool

D. Case Studies

We will now use the ACTIVE tool to study different scenarios of interest in three case studies, switching our focus to the results for individual IPTV users for the first two of our studies. We will keep our focus on the model for the „late phase“, which are highlighted in Fig. 11.

The first two case studies will both be about a traffic jam. In the *first study* we will explore how much the IPTV service provider would need to increase the bandwidth for the TV channels, if the provider wishes to keep a certain level of QoE during a traffic jam (for example for places well known for their frequent traffic jams). The *second case study* will explore when the QoE will raise to an acceptable level while the traffic jam slowly dissolves and the speed of the users increases. We suggest a $bph \leq 2$ as an „acceptable level“ (i.e., on average 1 blocking every 30 min). The *third case study* shows how to use the tool to gain information about highly fluctuating traffic scenarios.

We assume a traffic scenario with three lanes per direction on a motorway, which makes it likely enough to create traffic jams frequently: $N = 100$, $k = 3$, $C_r = 5$ km, $v = 0$ km/h (since traffic jam), $\alpha = 0.1$. These parameters imply that $N_c = 1200$ (which is a huge increase from the expected $N_c \leq 320$ we would have with $v = 50$ km/h). With $v = 0$ km/h the program assumes $d = 5$ m, if no value for d is given. Let us assume this value is realistic in a traffic jam.

Case Study 1: During Traffic Jam

Since $v = 0$ km/h, bph_h will obviously stay 0, which results in $bph_s = bph$. So, for the rest of the case study we will only talk about the relationship between BW_c and bph_s . This relationship is shown in Fig. 12 as a graphical representation. We observe that for $BW_c \geq 30$ the decrease of bph_s is approximately linear.

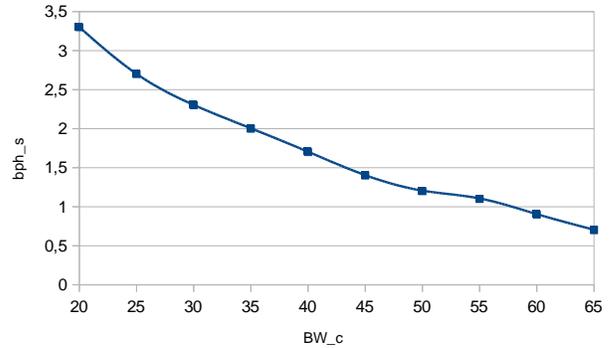


Figure 12. Corresponding bph_s to given BW_c

Figures like that are very useful for IPTV service providers and users alike, because they show in a simple manner, what bandwidth you need for a certain QoE or what QoE to expect given a certain bandwidth, e.g., that you need about a bandwidth of 35 TV channels to drop under a bph_s of 2 blockings per hour. That is surprisingly low for such a huge increase in number of users.

Case Study 2: During Traffic Jam Termination

Assuming v slowly increases at the end of a traffic jam phase, we expect that bph_h will increase and bph_s will decrease in such a manner that bph will decrease.

Using the information learned from the first case study, we investigate those influences in detail for the three scenarios $BW_c \in \{40, 50, 60\}$. The results are shown in Tables VI - VIII and Fig. 13 summarizes the dynamic evolution of bph_s , bph_h and bph for all three scenarios in Case Study 2. Since v changes exactly the same in every lane, the values for all three lanes will be identical and, therefore, will be shown only once.

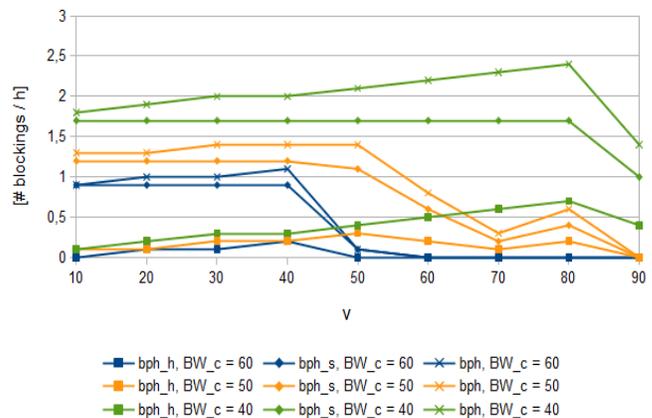


Figure 13. Corresponding bph to given v

TABLE VI. Results for scenario 1 of the traffic jam termination

Scenario 1: $BW_c = 40$			
v	bph _h	bph _s	bph
10	0.1	1.7	1.8
20	0.2	1.7	1.9
30	0.3	1.7	2.0
40	0.3	1.7	2.0
50	0.4	1.7	2.1
60	0.5	1.7	2.2
70	0.6	1.7	2.3
80	0.7	1.7	2.4
90	0.4	1.0	1.4

TABLE VII. Results for scenario 2 of the traffic jam termination

Scenario 2: $BW_c = 50$			
v	bph _h	bph _s	bph
10	0.1	1.2	1.3
20	0.1	1.2	1.3
30	0.2	1.2	1.4
40	0.2	1.2	1.4
50	0.3	1.1	1.4
60	0.2	0.6	0.8
70	0.1	0.2	0.3
80	0.2	0.4	0.6
90	0	0	0

TABLE VIII. Results for scenario 3 of the traffic jam termination

Scenario 3: $BW_c = 60$			
v	bph _h	bph _s	bph
10	0.0	0.9	0.9
20	0.1	0.9	1.0
30	0.1	0.9	1.0
40	0.2	0.9	1.1
50	0.0	0.1	0.1
60	0	0	0
70	0	0	0
80	0	0	0
90	0	0	0

Surprisingly enough, the results of Case Study 2 show that different traffic situations lead to very similar numbers of blockings, but there is always one speed where both bph_s and bph_h significantly drop ($BW_c = 40$: 80 km/h, $BW_c = 50$: 50 km/h, $BW_c = 60$: 40 km/h). These figures are very valuable to IPTV service providers, because you can easily answer a number of questions, including

- How long after a traffic jam will the QoE actually decrease, since the handover-induced blockings increase and the switching-induced blockings have not decreased yet?
- To which degree will the traffic jam need to dissolve for the QoE to become acceptable?
- What bandwidth will be needed to keep both, the QoE decrease after the traffic jam and the time for the QoE needed to increase to a certain level, acceptably small?

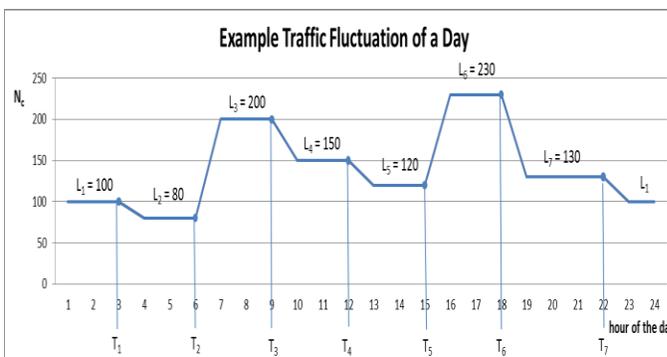


Figure 14. Example traffic fluctuation for case study 3

Case Study 3: Highly Fluctuating Traffic Scenario

This case study pays tribute to the fact, that the traffic situation can fluctuate strongly over time and will show how to use the ACTIVE tool accordingly.

Let us assume a traffic fluctuation over a day as shown in Fig. 14. As you can easily see, the traffic fluctuates over the course of the day, but is nearly constant for a few hours during several time intervals, so in our example scenario we get seven different levels of load.

Let $N_{c,i}$ be the mean number of IPTV users in cell c while the load is at level L_i .

We now use our analytical model to predict CBP for the dynamic fluctuating traffic scenario at the marked times, which represent the end of the level of load L_i .

We keep assuming $N = 100$ (and $BW_c = 30$) for this case study, too.

With ACTIVE we can easily and quickly get the CBP of all $N_{c,i}$ by entering successively the values for each L_i . The results of CBP as a function of N_c are shown in Table IX as well as in Fig. 15. And these results have been directly used to illustrate the daily CBP variation in Fig. 16.

Results as those shown by Fig. 16 are valuable for IPTV service providers, because they give answers quickly to a variety of questions, including but not limited to:

- What is the worst CBP/ QoE to be expected during the observed time interval (and when will it occur)?

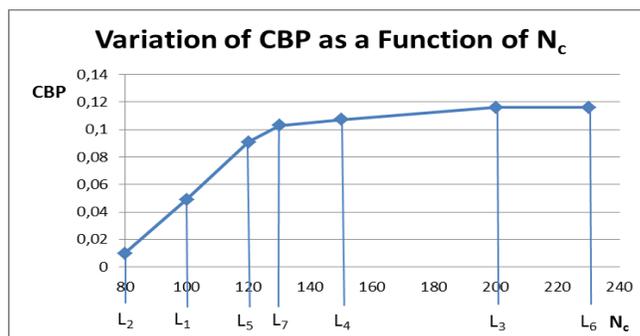


Figure 15. CBP values of the L_i from case study 3

TABLE IX. Resulting CBP for the seven $N_{c,i}$

N_c	CBP
80	0.0099
100	0.0490
120	0.0908
130	0.1030
150	0.1073
200	0.1161
230	0.1161

- Which changes in N_c have what kind of impact on CBP?
- How does the watched time interval partition into time slots with different QoE? In our example we see (cf. Fig. 16) that the day is basically partitioned into a night part with better QoE and a day part with worse QoE. The two rush hours do not seem to have a big impact on QoE.

VIII. SUMMARY AND OUTLOOK

In this paper, we have tackled the challenging and difficult problem to predict the availability of IPTV services in vehicular networks. In particular, we have elaborated a class of analytical models that have been successfully validated by means of existing simulation models. The analytical models indicated that it is possible to obtain a quite realistic prediction of IPTV service availability by means of using just a few elementary parameters comprising, e.g., number of TV channels offered, number of active IPTV users in the corresponding vehicular network cell and total bandwidth available for IPTV in the cell. We also have presented a tool (ACTIVE) that allows us to determine IPTV service availability in a straight-forward and very efficient manner. The tool is based on our class of analytical models and it makes heavy use of a repository of partial results having already been calculated in advance to lay these results in stocks. Later, upon demand, the a priori determined partial results can be combined in a flexible manner to obtain an overall availability result for a new set of system parameters (regarding traffic situation, user behavior and IPTV service characteristics). Numerous case studies show how the ACTIVE tool can be used and they prove our claim that availability prediction by means of our analytical model and the new calculation method is highly efficient. What could take hours to be determined by executing simulation experiments can now be calculated in only a few seconds – and this can be done without loss of a significant amount of prediction accuracy as has been shown by our validation experiments. It is worth to be mentioned that our analytical modeling approach also directly covers the situation, that the watching probabilities p_i of the TV channels are not determined by means of a Zipf distribution but have been measured in an existing IPTV

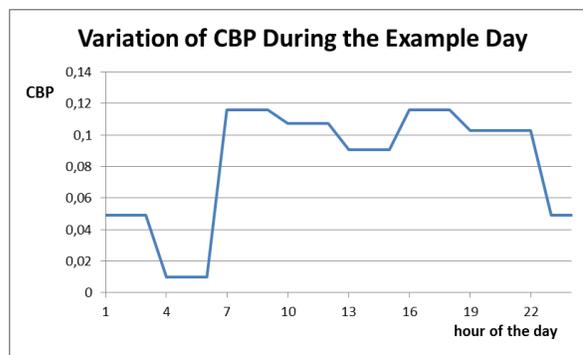


Figure 16. Variation of CBP during the example day.

system as relative frequencies of channel accesses. This makes our model even more realistic.

In our future research related to IPTV in vehicular networks, we plan to investigate scenarios assuming IPTV in vehicles on rural roads (instead of motorways). An additional interesting research topic will be how IPTV user behavior will change if the users are passengers in cars instead of watching TV as “coach potatoes” being at home.

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