IMPROVE CHANNEL AVAILABILITY IN VEHICULAR IPTV SYSTEMS BY A HYBRID TRANSMISSION SCHEME

Lai Junyu[1], He Bing[1], Sun Guolin[1], Fang Weiwei[2], Qin Kaiyu[1]

[1]University of Electronic Science and Technology of China, Chengdu 610054, China
[2]Beijing Jiaotong University, Beijing 10044, China
laijy@uestc.edu.cn, binghe@uestc.edu.cn, guolin.sun@uestc.edu.cn, kyqin@uestc.edu.cn, wwfang@bjtu.edu.cn

Abstract: One important factor restricting the capacity of IPTV service over vehicular-to-infrastructure (V2I) networks is the limited radio resource reserved on the road-side-units (RSUs). This paper elaborates a hybrid video transmission scheme to improve the channel availability in vehicular IPTV systems. The advanced scalable video coding (SVC) technique is applied to encode TV channels. SVC layers are transmitted in different modulation and coding schemes (MCSs), so as to provide differentiated robustness and resource utility efficiency. The hybrid transmission scheme intelligently delivers SVC layers to vehicles via either pure V2I or inter-vehicle relay connections. Comprehensive simulation experiments are conducted and show that, compared to the legacy V2I transmission scheme, the proposed hybrid scheme can effectively enhance user quality of experience (QoE) by significantly increasing channel availability, with only slightly deteriorating the transmission delay for the enhancement layers.

Keywords: network modeling, multimedia applications, resource management, QoE, channel availability

1 Introduction

IPTV service in vehicular networks can provide passengers with live TV access on-the-road, and is regarded as one of the most promising multimedia applications in the future intelligent transportation systems. Communications in vehicular networks can typically be classified into V2I and vehicle-to-vehicle (V2V) modes. Firstly, the V2I mode relies on a series of RSUs which are built-up along the roads and can be accessed by vehicles via wireless communications. Secondly, the common manner to establish V2V communications is to build MANET, which in the context of vehicular network is called VANET.

Stemming from the fact that vehicular IPTV is a live video streaming service, which has to be delivered to users in real-time, i.e., with strictly limited transmission delay, service providers prefer to transmit the TV channels in pure V2I mode. However, the radio resources on RSUs are usually quite restricted, and when i.e., increasingly more TV channels are provided, radio resource shortage will pose a tough challenge. The users may consequently suffer from deteriorated channel availability and degraded QoE. Aiming at solving this problem, this paper adopts the advanced SVC technique to encode every IPTV channel in multiple SVC layers (including one base layer and at least one enhancement layer). Since different SVC layers typically possess non-identical weights, RSUs transmit SVC layers in different MCSs, so as to provide differentiated robustness and resource utilization efficiency. The major contribution of this work is attributed to the elaboration of a hybrid IPTV transmission scheme with the purpose of improving the channel availability in a resource restricted vehicular network. The hybrid scheme intelligently delivers SVC layers to different vehicles via either pure V2I or inter-vehicle relay connections (including both V2I and V2V communication modes). Comprehensive simulation experiments are carried out and the results show that, compared to the pure V2I transmission scheme, the proposed hybrid scheme can greatly enhance user QoE by effectively improving channel availability, with only slightly increasing the transmission delay for the enhancement layers.

The remaining part of this paper proceeds as follows. Sect. 2 introduces the related work. Then, the basic vehicular network architecture and the user behaviour model are discussed in Sect. 3. After that, as the paper's major contribution, a hybrid video transmission scheme for vehicular IPTV system is derived in Sect. 4. In Sect. 5, the performance of the hybrid scheme is evaluated by means of simulation. Finally, summary and outlook are given in Sect. 6.

2 Related work

Channel availability is an essential QoE performance metric in IPTV systems, which is closely related to call blocking probability (CBP). Earlier publications have already provided well-known exact or approximate analytical algorithms for the CBP calculation in the context of unicast and multicast scenarios. In addition, simulation based evaluation serves as another option. In Refs. [1-2], J. Lai et al. proposed a link state-vector-based model to simulate IPTV systems in detail. Besides, a TCAC scheme [2], Ref. [3] was also proposed to decrease the CBP and to improve the channel availability in both static and peak-hour scenarios. Those works, however, focused on IPTV in fixed wireline / wireless networks, where users rarely move while watching.

In vehicular networks, video steaming transmitted via

978-1-4799-4734-8 /14/$31.00 ©2014 IEEE

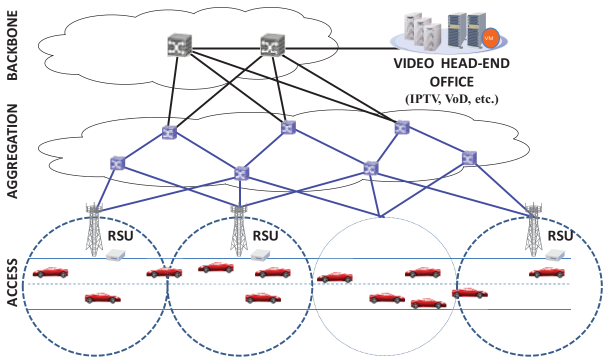


Figure 1 A typical vehicular IPTV network architecture

both V2I and V2V modes have attracted much attention [4], [5], [6], [7] proposed a scheme to deliver layered video information through wireless heterogeneous vehicular networks, where the mobile stations fail to receive all layers can learn the layer information from neighbors and regain the information through relaying using VANETs. Xing et al. [5] derived an adaptive video streaming scheme for video streaming services in the highway scenario. Relying on cooperative relay among vehicles, a vehicle can download video data using a direct link or a multi-hop path to the RSUs. Momeni et al. [6] investigated the TV channel availability in vehicular IPTV services (in pure V2I mode) with different traffic intensity and a varying number of TV channels offered to find out the acceptable availability of TV channels or the CBP. Hu et al. [7] investigated the BPRA problem for the layered video multicast in VANETs. The most relevant work is Ref. [5]. Nevertheless, Ref. [5] focused on unicast video service while this paper considers IPTV provisioning by means of multicast.

3 IPTV service offered via vehicular networks

3.1 Typical vehicular IPTV network architecture

Fig. 1 illustrates a typical vehicular IPTV network, which adopts a hierarchical architecture and consists of three different levels, namely backbone network, aggregation network, and access network. Video head-end office (VHO) is connected to the backbone network via very-high-speed optical links, and is the source of all the provided live TV channels. It can also be the source of other video-on-demand (VoD) resources. The backbone level and the aggregation level are typically tree-topology-based; the underline physical links can be either wireline (i.e., optical fibre) or wireless (i.e., millimetre wave) depending on the practical capacity requirements and budgets. In the access network part, a number of RSUs are linearly deployed along the road where the IPTV service is offered to the vehicles. Different from the conventional cellular networks, the signal coverage areas of RSUs are linear along the road. The coverage zones of two neighbouring RSUs should be tightly adjacent to make sure vehicles will not experience signal disruptions when crossing the boundaries in between.

In the access network, vehicular network supports two types of communication modes, i.e., V2I and V2V. To avoid excessive transmission delay, service providers usually adopt the V2I mode, which means that, all the TV channels are directly transmitted from the RSUs to vehicles by means of multicasting, without any intermediate relay facilities.

3.2 User behavior model

Previous research efforts on IPTV user behaviour modelling [8], [9], [10], [11] mainly dealt with fixed wireline / wireless IPTV systems, where the term fixed indicates that IPTV users usually sit still at home while watching IPTV programs. Note that the screen size of conventional TV sets is much larger than that of on-board units (OBU) and the link quality in the fixed access network is generally more stable and robust than that in the vehicular access networks. Consequently, user behaviour in vehicular IPTV systems may be quite different from that we observe in fixed IPTV systems. Those existing IPTV user models cannot straightforwardly be used; significant modifications should be conducted for the vehicular scenarios. Based on the IPTV-UBA model proposed in Ref. [10], this paper carries out the two important extensions:

- Taking user mobility into consideration. While driving, the vehicles continuously run across the linearly distributed RSU cells from one to another. IPTV users may experience periodic changes of signal qualities; the changing frequency depends on vehicle speed, and cell diameter. Once a user enters into a cell, the corresponding RSU should take the responsibility of streaming the user its ongoing channel. Thus, user mobility can result in traffic load changes in vehicular access networks.
- Disabling the user sequential zapping behaviour. Due to unstable access link quality, the channel switching latency in vehicular network is much longer than that in fixed IPTV systems. The vehicular IPTV users are not likely to endure the continuous delays owing to conducting the sequential zapping. Most probably, users will no longer zap TV channels, but instead resort to the advanced electronic program guidance (EPG) menus offered by service providers to fast locate TV channels of interest.

4 A hybrid transmission scheme for vehicular IPTV networks

Traditional vehicular IPTV systems employ the V2I transmission mode only. However, the radio resource reserved on each RSU tends to be insufficient as more TV channels are provided. It is therefore essential to explore the potential of the V2V communication mode to mitigate the radio resource consumptions on RSUs. This section elaborates an intelligent hybrid video transmission scheme for SVC encoded TV channel streams, aiming at increasing the TV channel availability.

Table I Different MCS profiles for 4-layered SVC scheme

MCS No	SVC Layer	Modulation and Code Rate	Coverage Diameter
1	Layer 1	BPSK,1/2	1 600 m
2	Layer 2	QPSK,3/4	1 200 m
3	Layer 3	16QAM,3/4	800 m
4	Layer 4	64QAM,3/4	400 m

4.1 Principles of the scheme

The hybrid scheme assumes that, all the provided TV channels are encoded by the SVC technique. SVC decomposes a higher quality video stream into multiple subsets, representing a lower quality in spatial resolution, a lower video signal quality, a lower temporal resolution, or a combination thereof. Assume that each TV channel is divided into N SVC layers, including *one* base layer and *N-1* enhancement layer(s). Usually, a specific enhancement layer *i* can be decoded only with all of its lower layers (i.e., layer *1* to *i-1*), since decoding an upper layer needs the information derived from one or more of its lower layers.

Different SVC layers do not contribute the same to the user perceived video quality, which leads to non-identical importance of SVC layers. Aiming at efficiently using the restricted radio resources on RSUs, different MCSs can be applied for different SVC layers when they are synchronously multicasted via RSUs in vehicular access networks. Typically, the base layer is of more importance than any enhancement layers, while a higher enhancement layer is less essential than its lower layer. Therefore, higher robust (lower efficient) MCS

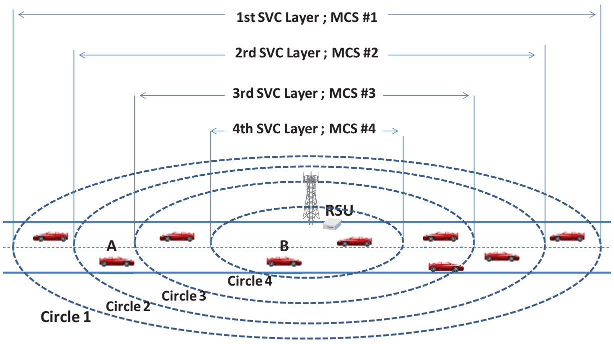


Figure 2 SVC layers encoded with different MCS profiles

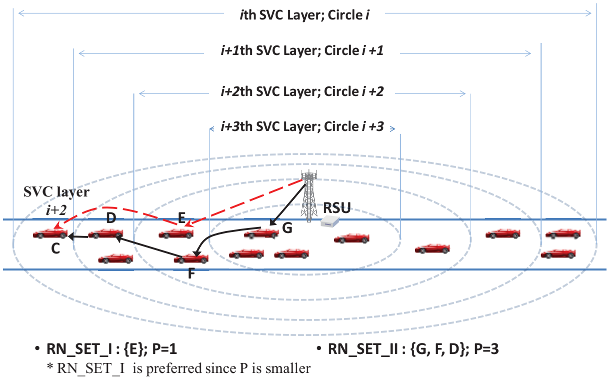


Figure 3 Principle illustration of the RNS algorithm

profiles are employed by the lower SVC layers and vice verse. Fig. 2 demonstrates an example where each IPTV channel is encoded to 4 SVC layers, each of them is multicasted via RSUs independently with a different MCS profile (listed in Table I). The dotted circles refer to the coverage zone of each layer. A vehicle can correctly decode a different set of SVC layers based on its current location. For instance, in Fig. 2, vehicle A can only decode up to the 2nd layer, while there should be no problem for vehicle B to decode the 4th layer.

In order to let vehicle A to successively receive and decode the *4*th layer without consuming extra radio resources on RSUs, the proposed hybrid transmission scheme takes advantages of the V2V mode. Particularly, for a vehicle C located in between the *i*th and the *i+1*th circles, one or multiple vehicles in between the RSU and C are selected as the intermediate node(s) for relaying a higher enhancement layer *j* (*j*>*i*) from the RSU to C in a hop-by-hop manner. This is the principle of the hybrid scheme. Additionally, two vital algorithms adopted in the scheme are further discussed below.

The first is the relay nodes selection (RNS) algorithm. There are two different roles for each vehicle to play, namely the relay node (RN) and the terminate node (TN). A specific vehicle can either be the TN role only, or play both the TN and RN roles concurrently (i.e., receiving SVC layer *a* of channel *x*, while relaying SVC layer *b* of channel *y* for another vehicle). When a vehicle *C*, locating in between the SVC circles *i* and *i+1*, is requesting SVC layer *i+2* of channel *z*, the RNS algorithm will be triggered. Assume that there are *m* vehicles in between the RSU and *C* , the RNS algorithm will randomly choose $P(P \leqslant m)$ out of them to act as RN(s), with satisfying the constraints below:

- The maximal V2V transmission distance is D_{V2V}.
- Owing to computational power limitation, each vehicle, when playing the RN role, cannot simultaneously serve for more than *Q* TNs.
- The preferred RN set is with the smallest value of *P*, among all the possible RN sets.

Fig. 3 demonstrates the RNS algorithm's principle.

The second is the relay nodes update (RNU) algorithm. Due to vehicles' high mobility, the vehicular access network topology is constantly changing. The RNU algorithm is thus conducted to maintain the ongoing hybrid transmission connections. There are two major occasions the RNU algorithm should be triggered. Firstly, a vehicle drives cross the boundaries of the SVC circles. When a RN is driving away from the RSU and is running cross the SVC circle *i*, the RN may no longer serve its corresponding TN for layer *i*, since it cannot directly receive layer *i* from the RSU anymore. Secondly, the vehicle driving speeds may be different from one to another, the distance between two V2V connected vehicles may grow beyond the maximal V2V transmission range D_{V2V}. The RNU algorithm will then be triggered to randomly selecting other suitable RN(s) to replace the outdated one(s).

4.2 Advantages and disadvantages

Obviously, applying this hybrid transmission scheme can enhance the channel availability without extra radio resource consumptions on RSUs. This gain, however, is not achieved without any cost. The scheme's evident disadvantage lies in the additional transmission delay introduced to the enhancement layers, this delay mainly attributes to the time spent on conducting the relay node selection and update processes. For the sake of computational simplicity, this paper assumes that each time of relay node selection / update (no matter being successful or not) will spend a time period of $\triangle T$. Then, the establishment of a multi-hop V2V relay connection with conducting n times of relay node selection and update will produce a relay establish delay of $n\triangle T$.

5 Performance evaluation

This paper considers three different performance measures for the proposed scheme, namely enhancement layer availability (ELA), channel availability (CA), and relay establish delay (RED). ELA is defined as the average ratio of the period that a specific enhancement layer i is successfully received & decoded by a vehicle when driving in the simulated zone, and is evaluated by:

$$\mathrm{ELA}_i=\frac{\sum_{j=1}^{K} t_{i,j}}{\sum_{j=1}^{K} T_j} \quad (1)$$

K is the total number of IPTV users driving through the road during the simulation. T_j is the time user j spends on going across the simulated zone, while $t_{i,j}$ denotes SVC layer i's available time period for user j.

Since each layer contributes to a different extent to the gross video quality. Denote w_i to be the weight of the ith SVC layer, then CA can be calculated by:

$$\mathrm{CA}=\sum_{i=1}^{N} ELA_i \cdot w_i \quad (2)$$

ELA and CA represent the pros of the proposed scheme, while RED demonstrates its cons. RED refers to the extra time delay on average, owing to establishing the relaying connections per SVC layer per vehicle, and can be defined as:

$$\mathrm{RED}_i=\sum_{j=1}^{K} red_{i,j}/K \quad (3)$$

$red_{i,j}$ is the ith layer's relay establish delay for user j.

5.1 Simulation introduction

This paper resorts to simulation to evaluate the aforementioned performance metrics. The simulation scenario is shown in Fig. 4, which contains three adjacent RSU cells. Vehicles drive along the road bi-directional with constant speed V and exponentially distributed inter-vehicle distance d. Besides, the notations and simulation parameters are given in Table II

A dedicated *Monte Carlo* simulator written in pure C

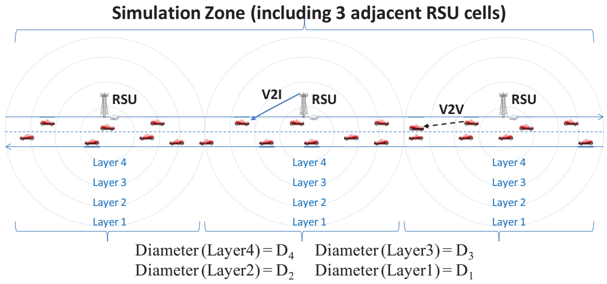


Figure 4 Illustration of the simulation scenario

language has been developed, and the *LoadSpec* tool is used to generate aggregate traces of channel switching events for the vehicular IPTV users. LoadSpec is an artificial load generator for different interfaces and it is capable of producing realistic network traffic with different characteristics in a very simple and flexible manner. The simulation logic is as follows:

- **Step_1**. Use LoadSpec to generate a set of single traces for all the simulated vehicles. Align and combine them in time axis to form the aggregate trace, with considering the different instances when those vehicles enter into the simulated zone. The aggregate trace contains two types of events, namely channel switching and boundary cross events (i.e., a vehicle drives across different SVC layer coverage circles).
- **Step_2**. Start to conduct the simulation according to the aggregate trace. Firstly, when a channel switching event happens on a TN, for the currently available SVC layers, the corresponding RN(s) will be directly employed to transmit the new channel, for each of these presently unavailable SVC layers, the RNS algorithm will be triggered to locate RN(s). Secondly, when a boundary cross event arrives, if the vehicle is a TN, the RNU algorithm will be conducted for that vehicle; if this vehicle additionally plays a RN role, the RNU algorithm will also be carried out for its corresponding TN(s).
- **Step_3**. After the simulated system changes from transient-state to steady-state, a set of variables and arrays are used to record the statistics such as the enhancement layer available time per layer per user, the relay establish delay per layer per user, etc.
- **Step_4**. When the simulation times up, calculate the three performance metrics, i.e., ELA, CA, and RED, according to the recorded statistics in Step_3.

Table II Notations and simulation parameters

Notation	Description	Value
M	Total number of Provided IPTV channels	30
N	Number of SVC layers	4
w_i	Weight of SVC layer i	w_1=0.4, w_4=w_3=w_2=0.2,
p_i	Popularity of channel i	Zipf's distribution with θ=1.3
a	Probability of a vehicle uses IPTV services	0.4

D_i	Coverage diameter of SVC layer *i* in V2I mode	cf. Table I
D_{V2V}	Maximal V2V transmission distance	300 (m)
V	Vehicle speed in each direction	20,40,60,80,100,120,140,160 (km/h)
D_{cell}	Diameter of each cell	1 600 (m)
d_{avg}	Average distance between two neighbouring vehicles	14, 18, 22, 26, 30, 34, 38, 42 (m)
d_{max}	Maximal distance between two neighbouring vehicles	18, 22, 26, 30, 34, 38, 42, 46 (m)
d_{min}	Minimal distance between two neighbouring vehicles	10, 14, 18, 22, 26, 30, 34, 38 (m)
TD	Traffic Density: average number of vehicles in each cell per direction	$TD = D_{cell} / d_{avg}$
P_{max}	Max. num. of RNs selected by RNS algorithm	2
Q	Max. num. of TNs each RN can serve simultaneously	3
S	Max. repeating times of selecting RN in RNS/RNU	2
T_{sim}	Simulated time duration	7 200 (s)
$\triangle T$	Time of RN selection / update	0.2 (s)

5.2 Simulation results

Experimental results are plotted in Figs. 5(a), 5(b), and 5(c) (in which the confidence intervals given are based on a confidence level of 95%). Particularly, Fig. 5(a) presents ELA against traffic density (TD) with and without using the proposed scheme. As can be seen, for the higher enhancement layers, greater increases can be observed, and for the scenarios using the proposed scheme, ELA increases slowly as TD grows. Fig. 5(b) illustrates the gross CA against TD, and compares it with the scenarios where the hybrid scheme is not used. Note that the hybrid scheme can effectively enhance the CA up to 26% without consuming any additional radio resources on RSUs. Additionally, the scheme performs better as TD increases, which means more vehicles (IPTV users) in the road is practically preferred from the scheme's perspective. In Fig. 5(c), RED against the TD is plotted for all the 4 SVC layers. As is shown, only slight increases of RED can be observed, even at the maximum, i.e., around 0.18 seconds for layer 4 at *TD*=57.14.

6 Conclusions

This paper focused on improving channel availability of vehicular IPTV systems, where TV channels are transmitted directly from RSU to vehicles. Advanced SVC techniques is used in this paper to encode each single TV channel into multiple layers with different weights, and these SVC layers are then transmitted in non-identical MCSs to provide differentiated robustness and resource utility efficiency for different SVC layers. As the major contribution, this paper elaborates a hybrid TV channel transmission scheme, which can adaptively delivers the SVC layers to vehicles through either pure V2I connections or inter-vehicle relay connections. Comprehensive simulation experiments demonstrate that, compared to the pure V2I transmission scenarios, the derived hybrid scheme is capable of substantially optimizing QoE by increasing the channel availability, with only slightly deteriorating the transmission delay of the enhancement layers.

Our planned work, in the future, is to further improve the scheme's performance. In particular, optimizations of the RNS & RNU algorithms and taking account of TV channel popularity's influences will be the focus.

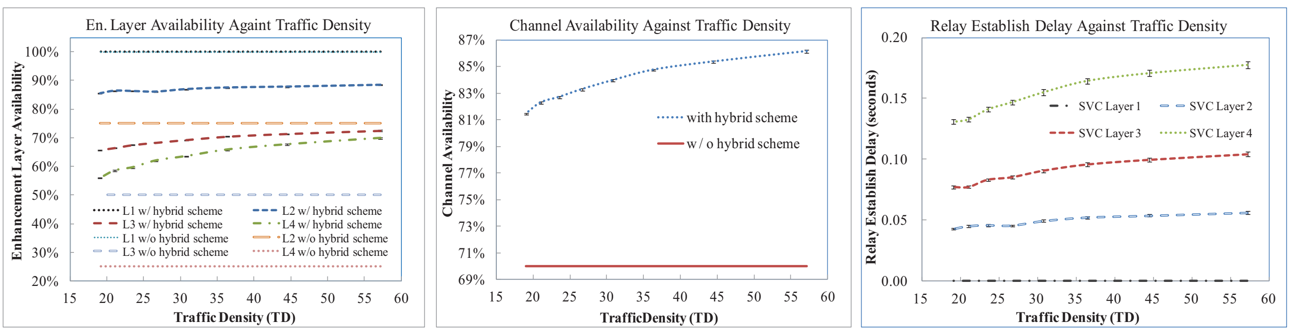
References

[1] Lai, J., Wolfinger, B.E. and Heckmueller, S. (2010) Decreasing Call Blocking Probability of Broadband TV Services by a Channel Access Control Scheme, Proc. Intern. Conf. on Ultra Modern Telecommunications and Control Systems, Moscow, Russia, pp. 1-9

[2] Lai, J., Wolfinger, B.E. and Heckmueller, S. (2011) Decreasing Call Blocking Probability of Broadband TV Services in Networks with Tree Topology, Proc. SPECTS2011, The Hague, Netherlands, pp. 196-204.

[3] Lai, J., Wolfinger, B.E. and Heckmueller, S. (2012) Decreasing the Call Blocking Probability of Broadband IPTV Services in Stationary and Peak-hour Scenarios, Journal of Networks, vol.7, no.11, pp. 1714-1727.

[4] Cheng, HY., Gau, V., Huang CH., and Hwang, JN. (2012) Adaptive Video Streaming with Inter-Vehicle Relay For Highway VANET Scenario ,Expert Systems with Applications, vol. 39, pp. 8356-8368.



(a) ELA against traffic density **(b)** CA against traffic density **(c)** RED against traffic density

Figure 5 Simulation results of ELA, CA and RED

[5] Xing, M., and Cai, L. (2012) Advanced Formation and Delivery of Traffic Information in Intelligent Transportation Systems, Proc. of IEEE ICC 2012, Ottawa, Canada, pp. 5168-5172.

[6] Cheng, HY., Gau, V., Huang CH., and Hwang, JN.(2013) Availability Evaluation of IPTV Services in Roadside Backbone Networks with Vehicle-to-Infrastructure Communication, Proc. of IEEE IWCNC 2013, Cagliari, Sardinia, Italy.

[7] Hu, M., Zhong, Z., and Chang, CY.(2013) A Multicast Scheduling Approach for Layered Video Service in Vehicular Ad Hoc Networks, Proc. of IMIS 2013, Taichung, Taiwan, ROC.

[8] Cha, M., Rodriguez, P., Growcroft, J., Moon, S. and Amatriain, X. (2008) Watching Television Over an IP Network, Proc. ACM IMC, Vouliagmeni, Greece, pp. 71-84.

[9] Qiu, T., Ge, Z., Lee, S., Wang, J., Xu, J. and Zhao, Q. (2009) Modeling User Activities in a Large IPTV System, Proc. IMC'09, Chicago, USA, pp. 430-441..

[10] Abdollahpouri, A., Wolfinger, B.E., Lai, J. and Vinti, C. (2011) Elaboration and Formal Description of IPTV User Models and Their Application to IPTV System Analysis, Proc. MMBnet2011, GI/ITG Workshop, Hamburg, Germany, pp. 67-79.

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