SVC-based Video Streaming over Highway Vehicular Networks with Base Layer Guarantee

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***Abstract*—In this paper, we target the resource allocation and layer selection problem for the realtime video streaming over highway scenario, by employing Scalable Video Coding (SVC) for the video contents. Especially, we take the freeze-free playback as one of the constraint as well. Since the formulated resource allocation and SVC layer selection problem is NP-hard, we propose the Resource Allocation and Layer Selection with Base layer guarantee (RALSB) algorithm to solve this problem in two phases: the Base layer Guarantee (BG) phase, and the Resource allocation and SVC layer selection (RS) phase. Simulation results show that the proposed RALSB can prevent/reduce the playback freeze in typical scenarios.**

***Index Terms*—Vehicular Networks, Scalable Video Coding, Video Streaming, Resource Allocation.**

I. Introduction

Intelligent Transportation System (ITS) is receiving significant research attention nowadays. As one of the most important enabling technologies in ITS [1], vehicular network [2] is firstly introduced to improve the road safety by employing two transmission categories, i.e., Vehicle-to-Infrastructure (V2I) communications which enable vehicles to communicate with Road Side Units (RSUs), and Vehicle-to-Vehicle (V2V) communications which enable vehicles to communicate with each other.

In the literature, the base layer guaranteed video streaming over vehicular networks has not been well investigated. The freeze-free playback is required in many video streaming instances, which is a very important issue related to the Quality of Experience (QoE). Comparing with the conventional networks, video streaming in vehicular networks is challenged by the following limitations. At first, the wireless channel suffers from the time-varying fading, shadowing and interference, which leads to high variation over link throughput and thus the video quality. Second, the communication is also challenged by the high mobility and dynamic nature of vehicular networks. To address such challenges, we employ the Scalable Video Coding (SVC) to improve the perceived video quality in the vehicular networks video streaming.

However, SVC video streaming over vehicular networks has two challenges due to the limited network resource. The first one is how to assign the limited network resource for multiple video users, thus the resource allocation problem. The second challenge is how to decide the SVC layer level for the received video, thus the SVC layer selection problem.

Regarding the resource allocation problem, each resource segment can be assigned for only one user. However, each user wants to get more resource segments to buffer enough number of Group Of Pictures (GOPs) for current/further playback. How to assign the limited number of resource segments among all video users to support a smooth playback is a great challenge.

Since the videos are encoded with SVC, each GOP has multiple layer levels. With the limited network resource, whether to buffer more GOPs with lower SVC layer levels, or less GOPs with higher SVC layer levels is non-trivial. The first choice promises a smooth playback for further GOPs, while the second enables the playback of the current GOP with higher video quality. Especially, how to prevent the playback freeze, thus the base SVC layer level guarantee problem, is emphasized in this paper as well.

The contributions of this paper are as follows:

- The SVC-based video streaming over vehicular networks with base SVC layer level guarantee constraint problem is investigated and formulated. We consider the formulated problem in two phases, thus the BG phase to provide base layer guarantee and the RS phase to target the resource allocation and SVC layer selection.
- We propose a Resource Allocation and Layer Selection with Base layer guarantee (RALSB) algorithm to solve the base layer guarantee problem with a simple but effective mechanism in the BG phase. In the RS phase, we employ the same mechanism as RALS algorithm which is proposed in our previous work [3].
- The proposed RALSB algorithm is evaluated in extensive simulations. Simulation results show that RALSB can prevent/reduce playback freeze in all scenarios.

The rest of this paper is structured as follows: We introduce the related works in Section II. Then the system model is presented in Section III. Formulation and the proposed RALSB algorithm are discussed in Section IV and V. Simulation results are shown in Section VI. At last, the paper is concluded in Section VII.

II. Related Work

In our perspective, SVC can offer us a new point of view of the video streaming issue over vehicular networks. In the literature, SVC coding scheme is well investigated by researchers, focusing on conventional networks. Schaar *et al.* [4] developed the cross-layer optimization strategies for HCCA-based video streaming using SVC. Ji *et al.* [5] investigated the problem of scheduling and resource allocation for multiuser video streaming over downlink OFDM channels, in which the video is encoded by SVC.

Although SVC coding scheme has been introduced to the conventional networks, explicating SVC for video streaming in vehicular networks is not trivial in literature. Xing *et al.* [6] proposed relay selection and adaptive SVC layer selection schemes over the highway VANET scenario. Xu *et al.* [7] developed a dynamic programming based algorithm for the resource allocation problem of scalable video streaming over VANETs [8]. They focus on a small window size of GOPs and one user cannot buffer more video data when this window size is full, even though the network resource is redundant. Belyaev *et al.* [9] proposed a low-complexity unequal packet loss protection and rate control algorithm for scalable video coding for road surveillance applications. We investigated the SVC video streaming over vehicular networks in our previous work [3]. The resource allocation and SVC layer selection problem is solved with the proposed RALS algorithm. However, many playback freeze is found in RALS. In this paper, we improve the playback freeze with the proposed RALSB algorithm.

III. System Model

A. System Architecture

We establish our highway scenario as follows, shown in Fig. 1. The highway road is bidirectional, straight and has multiple lanes. RSUs are located along the road. Assume that the information of the vehicular users in each RSU's coverage, such as locations, directions and velocities, is shared by the adjacent RSUs.

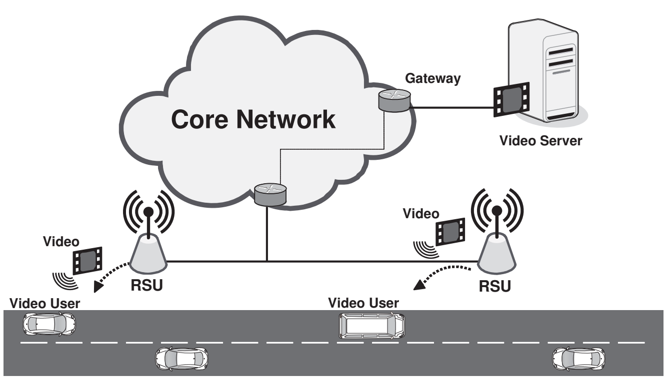


Fig. 1. Video streaming over vehicular networks.

Our algorithm executes in a round-by-round fashion. The length of time for each round is T. For each highway road, usually there is a speed limit for the vehicles running on it. We let T be the duration that is needed for one vehicle to go through the RSU coverage with the highest speed.

We focus on the coverage of only one RSU. Suppose t_0 is the start time of one round. Denote $\mathcal{I}$ as the set of video users that can communicate with the RSU in the time period $[t_0, t_0{+}T]$, and want to watch realtime videos via the vehicular networks. The number of video users is defined as I, there is $I :=\mid \mathcal{I} \mid$. The network resource is shared by all these users.

B. Video Coding Model

In our system model, the videos are encoded by the SVC scheme in the unit of GOP. Each GOP contains a fix number of frames and has multiple layers. We assume the duration of each GOP is uniform for all users, and the playback of each GOP is synchronized. The playback time of each GOP is denoted as t_{GOP}.

Denote the number of SVC layers for user i as L_i. Let L be the maximum number of layers among all users, thus $L = \max\{L_i \mid 1 \leq i \leq I\}$. If we want to decode one GOP with layer level l, we need to receive all the layers from layer 1 to layer l, due to the nested dependency among layers. We define the sum data volume from layer 1 to layer l of each GOP as $d_{i,l}$, which stands for the data needed to decode one GOP at SVC layer level l. Remark that the layer level 0 stands for freeze.

During the time period $[t_0, t_0 + T]$, J GOPs will be played by each user, where $J := \lceil T/t_{GOP} \rceil$. Furthermore, each video user also pre-buffers a few number of GOPs, in order to support a smooth playback after one user runs out of the communication range. The number of pre-buffered GOPs of each user is the same, denoted as B. Each user cannot buffer unlimited number of GOPs, since the video data is captured/generated in realtime.

Before we execute our algorithm at time t_0, the users may have already buffered some SVC layers of different GOPs in the previous round. Denote $\vec{l}^{init} := \{l_{i,j}^{init} \in \{0, 1, 2, ..., L_i\} \mid 1 \leq i \leq I, 1 \leq j \leq J + B\}$ as the initial received layer status vector. $l_{i,j}^{init}$ is the initially received SVC layer level of GOP j for user i. After the execution of our algorithm, the layer selection vector $\vec{l} = \{l_{i,j} \in \{l_{i,j}^{init}, ..., L_i\} \mid 1 \leq i \leq I, 1 \leq j \leq J + B\}$ represents the expected received layer status at the end of $t_0 + T$.

The base layer guarantee constraint requires that $l_{i,j} \geq \max\{l_{i,j}^{init}, 1\}$, for $1 \leq \forall i \leq I, 1 \leq \forall j \leq J$.

C. Resource Model

In this paper, we employ centralized MAC layer control over the vehicular networks. The access to the medium is divided into small resource segments. Such resource segments can be comprehended similarly as the resource blocks employed in the Orthogonal Frequency-Division Multiplexing (OFDM) based networks, the Transmission Opportunities (TXOPs) allocated by Hybrid coordination function Controlled Channel Access (HCCA) in 802.11e, or time slots given by Time Division Multiple Access (TDMA). For simplification, we assume that all the resource segments are derived from the time domain.

We assume the time duration of each resource segment is fixed and there are M resource segments in the duration of one GOP. The integer constant M is defined as the GOP time/Resource segment time (G/R) coefficient. The number of resource segments is $K = MJ$. Let $\mathcal{K}$ be the set of resource segments.

Denote $\vec{\alpha} := \{\alpha_{i,k} \in \{0,1\} \mid 1 \leq i \leq I, 1 \leq k \leq K\}$ as the resource allocation vector. We assign the resource segment k for the user i when $\alpha_{i,k}$ equals one and vice versa. Define the data volume contained in resource segment k when it is assigned to user i as $d^{seg}_{i,k}$. $d^{seg}_{i,k}$ is related with the data rate between i and the RSU, which is directly corresponding to the distance between i and the RSU varying through time. The time is indicated in the resource segment index k, since the network resource is derived from the time domain.

D. Utility Model

We define the utility of user i's GOP with the SVC layer level l as $u_{i,l}$. The utility values can be comprehended as the quality of the videos, or the quality of human experience when watching these videos, etc.

Our objective is to maximize the system utility, i.e., $\sum_{i=1}^{I}\sum_{j=1}^{J+B}(u_{i,l_{i,j}} - u_{i,l^{init}_{i,j}})$. Since $l^{init}_{i,j}$ is a fixed value, we can eliminate $u_{i,l^{init}_{i,j}}$ in the expression.

IV. Formulation

We define $d^{rec}_{i,j}$ as the received data before the playback of GOP j, i.e.,

$$d^{rec}_{i,j} := \sum_{k=1}^{MV_j} \alpha_{i,k} d^{seg}_{i,k}, \quad 1 \leq i \leq I, 1 \leq j \leq J+B, \tag{1}$$

where V_j is defined as

$$V_j := \begin{cases} j, & 1 \leq j \leq J; \\ J, & J < j \leq J+B. \end{cases} \tag{2}$$

The meaning of V_j is that, since $\{J+1, ..., J+B\}$ are pre-buffered GOPs and there is no more resource segment to assign by the RSU after GOP J, the received data before the playback of the pre-buffered GOPs is equal to the received data before the playback of GOP J. We define $\vec{d}^{rec}_i := \{d^{rec}_{i,j} \mid 1 \leq j \leq J+B\}$ as the received data vector for user i.

The problem formulation is presented as follows,

$$\max_{\{\vec{\alpha},\vec{l}\}} \sum_{i=1}^{I}\sum_{j=1}^{J+B} u_{i,l_{i,j}}, \tag{3}$$

subject to

$$\sum_{j=1}^{\tau}(d_{i,l_{i,j}} - d_{i,l^{init}_{i,j}}) \leq d^{rec}_{i,\tau}, \quad 1 \leq i \leq I, \quad 1 \leq \tau \leq J+B, \tag{3C1}$$

$$\max\{l^{init}_{i,j}, 1\} \leq l_{i,j} \leq L_i, \quad 1 \leq i \leq I, 1 \leq j \leq J+B, \tag{3C2}$$

$$\alpha_{i,k} \in \{0,1\}, \quad 1 \leq i \leq I, 1 \leq k \leq K, \tag{3C3}$$

$$\sum_{i=1}^{I} \alpha_{i,k} \leq 1, \quad 1 \leq k \leq K. \tag{3C4}$$

Constraint (3C4) shows the constraint that each resource segment cannot be assigned for more than one user. The base layer guarantee constraint is shown in (3C1). Constraint (3C1) shows the network resource constraint for the SVC video playback. Before the playback of GOP j, the user should have already received enough data to playback the GOPs $\{1, ..., j\}$ with the selected SVC layer level $l_{i,j}$. The base layer guarantee constraint is expressed in (3C3), in which the SVC layer selection $l_{i,j}$ is always greater than SVC layer level 1, thus the base layer.

The problem shown by Eq. (3) is an integer linear problem and NP-hard. In order to get a solution that has comparable utility value with the optimal solution, and can be computed in polynomial time, we introduce the proposed algorithm.

V. Algorithm

We propose the RALSB algorithm to solve the resource allocation and SVC layer selection problem with the base layer guarantee constraint. The original problem expressed in Eq. (3) is solved in two phases: BG phase and RS phase.

In BG phase, a simple but effective method is proposed to solve the base layer guarantee problem. We guarantee that for each video user i and each GOP j, the assigned SVC layer level $l_{i,j}$ is equal to or higher than the base layer (layer 1). Remark that when we assign SVC layer level $l_{i,j}$ for user i's GOP j, all SVC layers up to layer $l_{i,j}$ should be transmitted, otherwise this GOP cannot be decoded, due to the nested dependency of SVC. Base layer guarantee makes sure that the video playback is smooth, thus no freeze happens during the entire playback time.

In RS phase, we employ a similar mechanism as proposed in our previous work [3], which is denoted as Resource Allocation and Layer Selection (RALS) algorithm. The basic idea of RALS is to solve the resource allocation and SVC layer selection problems using greedy-based and dynamic programing methods respectively.

The details of RALSB are presented as follows.

A. BG Phase

For GOP j, the video data regarding j should have been already buffered before the playback starts. Otherwise the video playback will freeze, which is contradictory to the base layer guarantee constraint. In order to let all video users have enough data to play j with at least base SVC layer level, we should let the users who have not received the base layer data get the resource segments with higher priority. Assume the playback of j starts at t_j, we focus on the resource segments that will be allocated in $[t_{j-1}, t_j]$, thus the resource segments that will be allocated during the playback of the previous GOP $j-1$. We have $t_{j-1} = t_j - t_{GOP}$, where t_{GOP} is the playback time of each GOP as we already stated in the Section III-B. Denote the set of users that have not received the base layer data for GOP j at t_{j-1} as $\mathcal{I}_j^{BG}$. We have $\mathcal{I}_j^{BG} := \{i \mid l_{i,j}^{t_{j-1}} = 0,\ 1 \leq i \leq I\}$, where $l_{i,j}^{t_{j-1}}$ is the SVC layer level of GOP j at time t_{j-1}, thus the layer selection result limited by the network resource before t_{j-1}.

According to the definition of G/R coefficient M, given in Section III-C, there are M resource segments in $[t_{j-1}, t_j]$. Denote the resource segments set as $\mathcal{K}_j := \{M(j-1)+1, ..., Mj\}$. We assign these resource segments for the video users in $\mathcal{I}_j^{BG}$ with the highest priority. The resource segments are assigned one by one to the video user $i^\star$, who has the highest data volume contained in each resource segment k. We have

$$i^\star = \arg\max\{d_{i,k}^{seg} \mid i \in \mathcal{I}_j^{BG}\}, \quad (4)$$

where $d_{i,k}^{seg}$ is the data volume contained in k for user i, which is defined in Section III-B.

Assume that there are Z video users in $\mathcal{I}_j^{BG}$, thus $Z := |\mathcal{I}_j^{BG}|$. The video users in $\mathcal{I}_j^{BG}$ are sorted with the descending order of $d_{z,\bar{k}}^{seg}$ values, where $\bar{k}$ is defined as the resource segment in the middle of $\mathcal{K}_j$, we have $\bar{k} := M(j-1)+\lceil M/2 \rceil$. By this way we do the base layer guarantee efficiently while assigning resource segments for video users in $\mathcal{K}_j$ from the beginning to the end.

Now we calculate how many resource segments will be used to provide the base layer guarantee, and how many resource segments will be remained for further resource allocation steps. Define the index of the last resource segment used to transmit the base SVC layer of video user z in $\mathcal{I}_j^{BG}$ as c_z. Define $c_0 := M(j-1)$, and

$$\begin{aligned} c_z := \min\{\nu \mid & \sum_{k=c_{z-1}+1}^{\nu} d_{z,k}^{seg} \geq d_{z,1}, \\ & c_{z-1}+1 \leq \nu \leq Mj,\ 1 \leq z \leq Z\}. \end{aligned} \quad (5)$$

Remark that $d_{z,1}$ is the required data volume to decode user z's GOP with SVC layer level 1, which is defined in Section III-B.

When the base layer guarantee is finished, some additional resource segments, thus $\{c_Z+1, ..., Mj\}$, are not assigned for any video user in $\mathcal{I}_j^{BG}$. We name this subset of $\mathcal{K}_j$ as the *additional set*, and denoted as $\mathcal{K}_j^+$. For the subset of $\mathcal{K}_j$ in which the resource segments are all used to provide the base layer guarantee, we name it as the *inflexible set*. This subset is denoted as $\mathcal{K}_j^-$, and there is $\mathcal{K}_j^- := \{c_0+1, ..., c_Z\}$.

The base layer can be guaranteed using the aforementioned mechanism, when the network resource is sufficient to let each user to do so. However, there are cases that even though all resource segments are used, the RSU cannot transmit all base layers regarding the limited network resource, especially there are many video users in the RSU's coverage. In this case, there are $\mathcal{K}_j^- = \mathcal{K}_j$ and $\mathcal{K}_j^+ = \emptyset$. The problem expressed in Eq. 3 will have no feasible solution, but the proposed RALSB can reduce the playback freeze compared with RALS in this case as well.

B. RS Phase

We solve the problems that how to assign the resource segments in the *additional set*, thus $\mathcal{K}_j^+$, for the video users in $\mathcal{I}$, and how to select SVC layer level for each GOP in this section. We employ a similar mechanism with RALS, which is proposed in our previous work [3] in this phase.

In RALS, the resource allocation is transformed to a problem that to maximize a monotone submodular function subject to a matroid constraint, and is done using the greedy algorithm. Each resource segment k is assigned for the video user who has the biggest $d_{i,k}^{seg}$ value. It is proved that the greedy algorithm achieves a $(1-1/e)$-approximation of the optimal resource allocation.

For the SVC layer selection, we employ the Dynamic Programing (DP) method to solve this problem. DP provides the optimal SVC layer selection solution in pseudo polynomial time. The entire RALSB algorithm is expressed in Algorithm 1.

Algorithm 1: RALSB Algorithm

```
initialization;
for j = 1 : J do
    BG phase:
    Build the set of users that have not received the base layer data
    I_j^BG;
    for k = M(j − 1) : MJ do
        if I_j^BG is empty then
            Let K_j^+ = {k, ..., MJ};
            break;
        end
        Assign resource segment k for user i*, which is defined in
        Eq. (4);
        if i* has been assigned enough data for base layer then
            Delete i* from I_j^BG;
        end
    end
    RS phase:
    Assign resource segments in K_j^+ and select SVC layer levels using
    the greedy and DP algorithms as same as RALS;
end
```

As a summary, RALSB solves the base layer guarantee problem with a simple but straightforward method in BG phase, and solves the resource allocation and SVC layer selection problems with the greedy and DP algorithms in RS phase.

VI. Simulation Results

A. Simulation Setup

In the simulation, we use JSVM [10] as the SVC encoder. We encode two video sequences, thus *Kendo* and *Pantomime* [11] in our simulation. The parameters related to the video sequences can be found in TABLE I. We use the PSNR value as the utility value. The PSNR value is calculated between the perceived video that decoded at the user side and the ground truth (original video) at the server side.

TABLE I
Parameter Setting of Video Sequences

Sequence	Layer	Resolution@FPS	Datarate	PSNR
Kendo	1	256×192@8	74.468	28.1496
	2	512×384@32	297.652	37.2694
	3	1024×768@32	710.404	39.2136
Pantomime	1	320×240@8	154.9760	20.1870
	2	640×480@16	590.3520	24.3703
	3	1280×960@32	1755.0160	40.8527

We focus on a 2000-meter-long road within one RSU's coverage. The RSU is located at the middle point of the road, refer to Fig. 1. The parameter settings of the highway vehicular network scenario are shown in TABLE II. In the simulation, vehicles are randomly distributed on the road following the uniform distribution. Assume that there are enough lanes to allow all vehicles to run with different velocities without crash.

Let T be the time cost when one vehicle runs through the 2000 m road with the highest speed limit 120 kmph. We have $T = 60$ s. The duration of each GOP is 0.5 s. Moreover, each vehicle has pre-buffered 10 GOPs before we run the simulations. Each buffered GOP has the base SVC layer level. Notice that these initially buffered GOPs are employed to support a smooth playback at the beginning stages of the simulation, and relevant statics are not counted in the simulation results.

We conduct the simulation for as long as $5T$, thus 5 rounds. Suppose we begin the simulation at time 0, we collect the results data regarding time interval $[4T, 5T]$.

B. Analysis

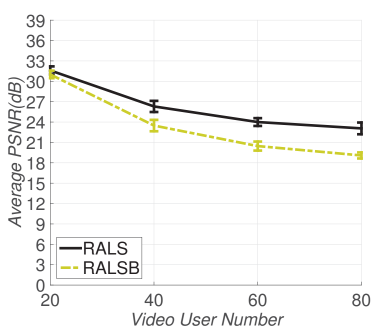


Fig. 2. The average PSNR values varying the number of video users.

We present the performance of RALSB and compare with the RALS without base layer guarantee algorithm in this section. The average values calculated from 10 runs, as well as the maximum and minimum limits of each average value, are shown in the figures.

TABLE II
Parameter Setting for the Highway Scenario

Road length (m)	2000
Velocity of vehicles (kmph)	random in [80, 120]
Distance from RSU to the road (m)	10
Bandwidth (Mhz)	10
Transmission power (mW)	100
Noise (W)	10^{-9}
Duration of each round T (s)	60
Duration of GOP (s)	0.5
Duration of resource segment (ms)	0.5
GOP number J	120
#Pre-buffer GOPs B	10

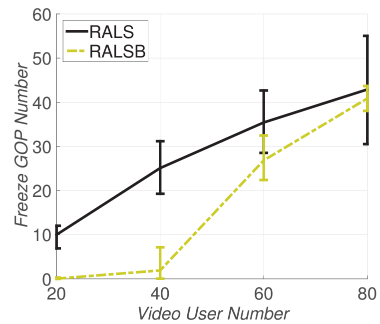
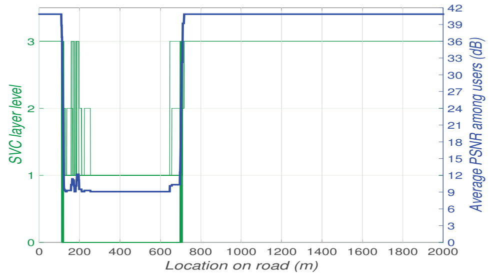


Fig. 3. The average playback freeze GOP number varying the number of video users.

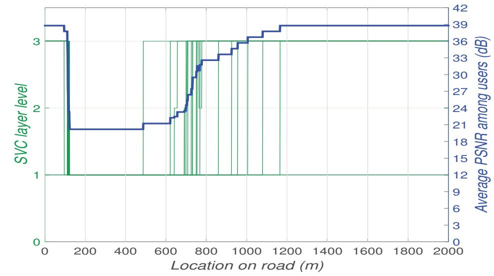
At first, we investigate the average PSNR values over each video user and each GOP in Fig. 2. Although RALS without base layer guarantee has better performance for all four scenarios than RALSB obviously, we find that when the number of video users are not much, thus for 20 video users scenario, the average PSNR values are quite close. The reason is that when there is only a small number of users sharing the network resource, usually every user can receive a high quality video, and the performance difference between two schemes is not much.

Figure 3 shows the number of freeze GOPs for 20, 40, 60 and 80 video users scenarios. It is easy to tell that RALSB has much fewer freeze GOPs than RALS without base layer guarantee. When the video users are not many, like in 20 and 40 users scenarios, the base layer guarantee scheme works quite well. However, when the video users are many, like 60 or 80 video users, RALSB will consume a lot of resource segments to reduce the number of freeze GOPs. But the limited network resource does not allow all users receive base layer video data. As a result, a lot of freeze happened in RALSB as well, and the freeze GOP number is similar to that of RALS without base layer guarantee when there are 80 video users.

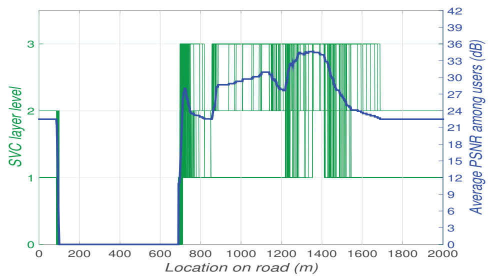
Figures 4(b) and 4(d) show the SVC layer level distributions and average PSNR value curves of RALSB for 20 and 80 video users scenarios. In 20 users scenario, we find that RALSB has no freeze GOP in [100, 600] m interval, but the average



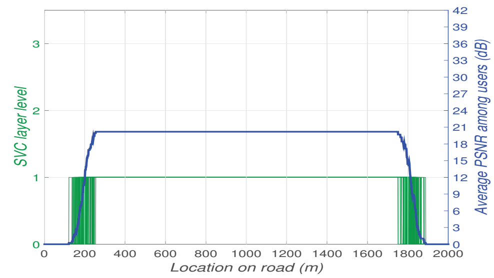
(a) RALS for 20 users scenario.



(b) RALSB for 20 users scenario.



(c) RALS for 80 users scenario.



(d) RALSB for 80 users scenario.

Fig. 4. SVC layer distributions and average PSNRs over 2000 m road.

PSNR values in [600, 1200] are lower than that of RALS without base layer guarantee, which is shown in Fig. 4(a). For 80 users scenario, we notice that almost all users have the base layer level GOP in the interval [200, 1800] m. However, higher SVC layer levels are not found, and the playback freeze is not evitable in [0, 200] m and [1800, 2000] m. Because when we try to let the users that far from the RSU receive enough data for the base layer level playback, the base layer guarantee constraint cannot be achieved even though we assign all resource segments for them, due to the poor channel condition.

VII. Conclusion

In this paper, we investigate the SVC-based video streaming over highway vehicular networks with base layer guarantee constraint. The RALSB algorithm is proposed to solve this problem in two phases, thus BG and RS. In the BG phase, the base layer guarantee problem is solved with a simple but effective algorithm, and the resource allocation and SVC layer selection problems are solved with the greedy and DP algorithms in the RS phase. The performance of RALS is evaluated by extensive simulations. As shown in the simulation results, RALSB prevents the playback freeze in 20 video users scenario, while the existing work suffers from the playback freeze in all scenarios. Even though the playback freeze is not evitable in other scenarios, RALSB can reduce the number of freeze GOPs compared with the RALS without base layer guarantee scheme.

Acknowledgments

This work was supported in part by JSPS Kakenhi Grant Number 16H02817.

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