MMS-MVN: a multimedia multicast scheduling method for multi-hop vehicular networks

Miao Hu* and Zhangdui Zhong

State Key Laboratory of Rail Traffic Control and Safety,
Beijing Jiaotong University,
Beijing 100044, China
Email: humiao@outlook.com
Email: zhdzhong@bjtu.edu.cn
*Corresponding author

Chih-Yung Chang

Tamkang University,
25137, Taiwan
Email: cychang@mail.tku.edu.tw

Abstract: Emerging technologies for vehicular ad hoc networks (VANETs) have aroused tremendous attentions in both the safety and entertainment related applications. In this paper, the multimedia multicast scheduling design problem for multi-hop vehicular networks is studied. Many previous works on multimedia scheduling problem focused on the design for one-hop networks or multi-hop networks with fixed relay stations. However, for multi-hop vehicular networks, with the possibility that each vehicle can be selected as relay and various channel conditions etc., the optimal scheduling scheme is hard to obtain. We develop a heuristic scheduling algorithm to approach the performance of the intractable optimal scheduling scheme. Simulation results show that performance of the proposed heuristic algorithm approaches the optimal results and shows some good properties against other algorithms, which verifies the contribution of our work.

Keywords: layered multimedia; multicast schedule; multi-hop transmission; vehicular ad hoc networks.

Reference to this paper should be made as follows: Hu, M., Zhong, Z. and Chang, C-Y. (2015) 'MMS-MVN: a multimedia multicast scheduling method for multi-hop vehicular networks', *Int. J. Ad Hoc and Ubiquitous Computing*, Vol. 20, No. 4, pp.237–248.

Biographical notes: Miao Hu received his BE from the School of Electronic and Information Engineering, Beijing Jiaotong University in 2011. Currently, he is working toward the PhD in State Key Laboratory of Rail Traffic Control and Safety and School of Electronic and Information Engineering, Beijing Jiaotong University. In 2013, he was a Visiting Scholar in Tamkang University, Taipei, Taiwan. His current research interests are in the field of vehicular communication networks, mobile ad hoc networks, sparse signal processing etc.

Zhangdui Zhong is a Professor and Advisor of PhD candidates in Beijing Jiaotong University. He is now a Director of School of Computer and Information Technology and a Chief Scientist of State Key Laboratory of Rail Traffic Control and Safety in Beijing Jiaotong University. He is also a Director of the Innovative Research Team of Ministry of Education, and a Chief Scientist of Ministry of Railways in China. He is an Executive Council Member of Radio Association of China, and a Deputy Director of Radio Association of Beijing. His interests are wireless communications for railways, control theory and techniques for railways, and GSM-R system. He has authored/co-authored seven books, five invention patents, and over 200 scientific research papers in his research area. He received Top 10 Science/Technology Achievements Award of Chinese Universities.

Chih-Yung Chang is currently a Full Professor with the Department of CSIE at Tamkang University, Taiwan. He is a Member of the IEEE and the ACM. His current research interests include internet of things, wireless sensor networks and vehicular ad hoc networks.

This paper is a revised and expanded version of a paper entitled 'A multicast scheduling approach for layered video service in vehicular ad hoc networks' presented at *Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2013 Seventh International Conference on*, Taichung, Taiwan, 3–5 July, 2013.

1 Introduction

The newly developed information technology has made the vehicular networks a big difference compared with the traditional one. In the past serval years, dedicated short range communication (DSRC) has shown a picture for the more intelligent, safe, and comfortable driving feeling. As an important aspect for future vehicular networks, researches on the entertainment related service arouse much attention. Among all the valuable questions, the tradeoff between transmission capability and limited time/frequency resource has always been an essential issue, which triggers our following study.

For multimedia transmission service, video coding schemes have attracted great concerns of many researchers. Compared with the traditional direct transmission schemes, scheduling with precoded multimedia cannot only enhance the scheduling efficiency but improve the scheme's adaptability. The coding scheme used in this paper is the H.264/SVC standards. It divides multimedia to be transmitted into several subset streams. The decomposition of them will conduct user's different experience, usually higher definition visual enjoyment obtained with more provided layers correspondingly.

In this paper, a multimedia multicast scheduling problem is focused in multi-hop vehicular networks. Multimedia materials are supplied to the vehicles for some public or commercial reasons. The target for both the content subscribers and serviced customers is to acquired the data as much as possible. However, this goal might be influenced by the density of infrastructure's construction, the coding scheme, the modulation scheme, and the available hop counts etc. Based on variant environment settings, a heuristic adaptive multimedia scheduling algorithm is proposed.

Many previous works paid much attention on the layered multimedia transmission scheduling problem. Most of them considered the scheduling design for single hop networks (Wu et al., 2010; Li et al., 2012; Hua et al., 2013; Kozica et al., 2012; Gopala et al., 2004; Huang et al., 2009, 2010, 2012), which cannot be directly extended to the design in multi-hop networks. As for the transmission scheduling design for multi-hop networks, most existing works were proposed based on the additional constructed relay stations, such as researches by Sheu et al. (2013), Kuo (2009) and Kuo et al. (2010). However, in most multi-hop networks, especially for the emergency networks or vehicular networks, relay station construction will be costly and impossible. In consequence, the mobile stations (MSs) or on board units (OBUs) might not guarantee to be covered by the base stations (BSs) or road side units (RSUs). This in turns leaves the possibility and necessity for multi-hop transmission. Therefore, the scheduling transmission scheme should be redesigned to adapt to that in multi-hop networks, which is the main task of this paper.

The contributions of this paper mainly contain the following three aspects:

- *Multi-hop vehicular networks with sparse RSU construction.* Most previous proposed algorithms were proposed based on assumption with fixed relay stations, which might be somewhat unrealistic for the vehicular networks. In this paper, transmission patterns with more than two hops and particularly selected mobile relay station strategy for vehicular networks will be regarded as candidate.
- *Layered multimedia transmission scheduling influenced by multi-parameters.* In this paper, multiple influential factors are jointly considered including coding scheme selection principle, the unicast/multicast/anycast selection principle, the available modulation and coding scheme (MCS) selection principle, the relay selection principle etc. We extracted instinct characteristics from all above mentioned parameters to have a full sight on the total transmission scheduling for the MMS-MVN problem.
- *A heuristic algorithm for the extracted MMS-MVN problem.* Referring from the above mentioned two paragraphs, the MMS-MVN problem is restricted by many parameters, which increase the difficulty of this problem. A heuristic adaptive scheduling scheme is proposed in this paper to fit for different environment parameters.

The remainder of this paper is organised as follows. Section 2 presents the related works on multimedia transmission scheduling. Afterwards, the system model and the detailed description of multimedia transmission scheduling problem for this paper is shown in Section 3. Targeted at this problem, a heuristic scheduling algorithm is proposed in Section 4. To verify the accuracy of the algorithm proposed in this paper, simulations and numerical results are carried out in Section 5. Last but not least, Section 6 concludes this paper and gives a future extension proposal.

2 Related works

As for the previous works on the multimedia transmission scheduling, they were summarised into three parts, including multimedia transmission scheduling without layered coding, layered multimedia transmission scheduling in one hop, and layered multimedia transmission scheduling in multi-hop. Related works of these three parts will be organised in the following three subsections respectively.

2.1 Multimedia transmission scheduling without layered coding

Multicast resource allocation and scheduling has attracted growing attention in the literatures. Some researchers proposed solutions applying specially designed coding method for the multicast transmission scheduling. She et al. (2007) introduced a two-level superposition coded multicasting scheme (2-level SCM) for solving the resource allocation problem. In another way, Chen et al. (2012) paid their attention on Resource allocation for multicast services with joint fine-granularity-scalability (FGS) video coding and unequal error protection (UEP) Reed-Solomon (RS) coding scheme in single hop networks. However, both of the two approaches applied coding strategy at the physical (PHY) layer which needs hardware/firmware modifications in the transceiver device. In contrast to the solution in PHY layer, the design of resource allocation in the MAC level, which is more flexible and implementable, has attracted more attentions.

2.2 Layered multimedia transmission scheduling in one hop

Since the resource allocation problem for layered video transmission is always found NP-hard, some more time effective algorithms were proposed. Researchers Wu et al. (2010) and Li et al. (2012) proposed a two-step dynamic programming solution with pseudo-polynomial time complexity. Similarly, Hua et al. (2013) and Hua et al. (2013) proposed a novel block scheduling scheme aiming to address the P2P layered video streaming. Algorithm containing a soft priority function was proposed, which was more effective in terms of bandwidth utilisation and video quality. At the same time, Kozica et al. (2012) used results from rate-distortion theory to provide a bound on the achievable performance for the multicast rate optimisation problem.

Base on the concept of opportunistic multicasting proposed by Gopala et al. (2004), some researchers put forward multicast resource allocation approaches for balancing network throughput and average delay. Huang et al. (2009) proposed a resource allocation algorithm which provides enhanced quality of service (QoS) and efficiency for layered video multicast. The proposed algorithm assigned the most appropriate MCSs to each transmission link for providing the best video quality to as many users. Afterwards, Huang et al. (2012) developed an advanced opportunistic scheduling mechanism called opportunistic layered multicasting (OLM). This mechanism achieved high efficiency in terms of user satisfaction by sequentially determining the appropriate MCS and choosing appreciate video layer for each multicast. Huang et al. (2010) proposed reception-rate-tracking opportunistic multicast scheduling (ROMS) jointly considering the subscriber schedule and resource allocation.

Li et al. (2012) proposed a framework including joint video source-channel coding and optimisation. They introduced a temporal-spatial content distortion metric to build adaptive layer structure, so as to serve mobile users with heterogeneous QoS requirements. At the same time, joint Fountain coding protection is introduced so as to provide flexible and reliable video stream and dynamic programming approach is used to obtain optimal layer broadcasting policy. However, these studies were proven to be valid in the environment where videos can only be applied in single hop networks. Apparently, these schemes usually cannot accomplish equivalent performance in networks supporting multi-hops transmission.

2.3 Layered multimedia transmission scheduling in multi-hop

Resource allocation solutions for multicast transmission in WiMAX scenario were presented in Kuo (2009), Kuo et al. (2010) and Sheu et al. (2013). Kuo (2009) designed the dynamic resource allocation (DRA) algorithm to cope with the multicast transmission resource allocation problem. The DRA algorithm allocated available resource in a heuristic way aiming at maximising the number of recipients. Hereafter, Kuo et al. (2010) proposed a dynamic station selection (DSS) algorithm with the same target as that in 2009 by effectively conserving resource consumption. The proposed approach modelled the multi-hop network as the tree topology and decided the lowest resource-consuming path for data multicast among the SSs, RSs, and BS. Recently, the allocation scheme proposed by Sheu et al. (2013) applied greedy methods to achieve low computational complexity while incorporating the table-consulting mechanisms to avoid redundant resource allocation.

However, although the above proposed schemes already considered the diversities of multicast and multi-hop transmission, some challenges remain. Firstly, fixed RSs must be constructed to support system requirement, which will be costly for the implementation in real scenes. Moreover, all the referred literatures studied the multicast resource allocation problem in two-hop transmission environment and did not extend the research scope to the multi-hop transmissions. Similar to the extension from direct transmission to transmission with relays, schemes on multicast resource allocation for fixed relays supported networks usually cannot accomplish equivalent performance in networks supporting multi-hops transmission where any receiver can be treated as a forwarding station as well.

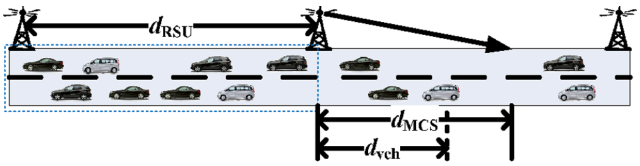
3 System model and problem formulation

This section introduces the system model and the MMS-MVN problem to be solved in this paper. Firstly, the vehicular wireless communication scenario is proposed and some assumptions are made. Then the problem along with the layered multimedia delivering in VANETs is formulated and analysed as well.

3.1 System model

Vehicles are assumed moving on an unidirectional road, where the RSUs are deployed at equal intervals of d_{RSU}, which is greater than their service range. The service range is determined by the transmission mode, including the transmission power and modulation/coding schemes etc., which will be discussed later in this section. As shown in Figure 1, the highway scenario can be regarded as an simple example of the system model. Moreover, the deployment for more complex vehicular system model is some kind of similar to that in highway. This is mainly because of the multi-hop transmission scheduling is mainly determined by the position information, which does not have tight relation with the mobility pattern or the system model.

Figure 1 A simple example for vehicular system model used in this paper (see online version for colours)



The mobility model used in this paper is based on the traffic flow theory from May (1990), which has been selected due to its accuracy in modelling vehicles travelling in both highway and city scenarios stated by Alasmary et al. (2013). Each vehicle has a uniformly distributed random initial speed $S \sim U(s_{\min}, s_{\max})$, where $s_{\min}$ and $s_{\max}$ are the minimum and maximum allowed speeds in the highway, respectively. When possible, each vehicle increases its speed by a random acceleration a that is randomly selected in $[a_{\min}, a_{\max}]$; otherwise, it holds a minimum safe distance to the vehicle ahead. If the vehicle has to reduce its speed, it chooses a random deceleration value $d \sim U(d_{\min}, d_{\max})$, where $d_{\min}$ and $d_{\max}$ are the minimum and maximum deceleration values, respectively. It can be seen from the mobility model that once a vehicle reaches its desired speed (e.g., $s_{\max}$), it maintains that speed until it has to reduce it as needed (e.g., the vehicle ahead reduced its speed). During the periodic broadcast, we focus on the speed transitions and avoid transmitting the constant speed vector (which can be easily compressed to a single speed value).

Considering the multimedia delivering service in VANETs, we assume n vehicle drivers expect subscribing one certain popular video material. Since the construction of RSUs is costly, vehicles cannot guarantee accessing the nearby RSU directly in most previous researches, such as Hung et al. (2012) etc. and hence they may access the nearby RSU through multi-hop transmission style. Although the links between vehicles and RSU (or vehicles themselves) are wireless, the RSUs can exchange information with each other by communicating through wired network (such as fibre etc.). Moreover, the on-board navigation device (such as GPS or Galileo etc.) is assumed installed on almost every vehicle and all the vehicles' positions are known to the nearby RSU. That is, each RSU knows the number of subscribers and their positions p_i ($i = 1, 2, \ldots, |\mathbf{N}|$) within its service region.

Multicast is applied instead of unicast considering the resource conservation for duplicated information transmission. Since the system may be of multi-hop, the sender can be either RSU or any vehicle selected as relay. Moreover, different modulation mode can be applied on each hop. According to the protocol of WiMAX or LTE-A, there are seven MCSs available for one hop, including BPSK 1/2, QPSK 1/2, QPSK 3/4, 16-QAM 1/2, 16-QAM 3/4, 64-QAM 2/3, and 64-QAM 3/4. The choice for candidate modulation mode depends on the corresponding channel quality form RSU to subscriber, RSU to relay, or relay to subscriber. As for the channel quality, it is assumed that only the large scale fading is considered. That is, the channel quality is inversely proportional to the distance between transceivers. The pathloss channel model states that P_r is a decreasing function of the distance r between the transmitter and the receiver, and can be represented as a power law cited by Prasad (1998)

$$P_r(r) = c(r/r_0)^{-\eta}, \tag{1}$$

in which r_0 is a reference distance, η is the pathloss exponent, and c depends on the transmitted power and the characters of transceivers. Obviously, the received signal strength P_r is a monotonously decreasing function of the transmission distance r for the pathloss channel model.

For the transmission effeteness, video to be transmitted is coded according to the H.264/SVC standard which allows a video to be divided into one base video layer for supplying the basic video quality and several enhancement layers for providing higher definition quality. Subscribers who receive more layers must pay more while watching the video with higher quality. Passengers, who subscribe for the multimedia service, can send a request to nearby RSU directly or through multi-hop relay forwarding. It should be noted that one enhancement video layer is viewable if and only if all inferior layers are received previously base on the decoding characteristic of H.264/SVC video layers.

3.2 General scheduling design

The target can be represented as the multimedia multicast scheduling problem for multi-hop vehicular networks (MMS-MVN). The object of this paper is to achieve the highest benefits in accordance with corresponding multimedia scheduling scheme. Define benefits in this paper as the profits obtained by the multimedia content provider.

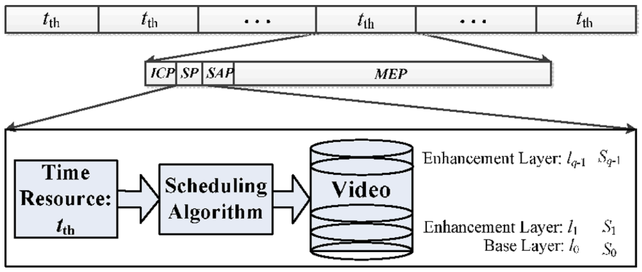
The scheduling design will perform in partitioned time intervals. In each interval, the time resource scheduled by the proposed algorithm should be clearly identified in advance. Moreover, it should be constrainted because of the rapid changing graph characteristics for vehicular networks. Denote t_{th} as the feasible time resource and its value is set as a constant. Therefore, the time line is partitioned into a number of independent time intervals, as shown in Figure 2. Each time interval t_i restricts the available time resource for multicast resource allocation in the ith scheduling. As shown in Figure 2, in each scheduling interval, four phases are executed, including *ICP*, *SP*, *SAP* and *MEP* as described below.

- *Information collection phase (ICP)*. At the beginning of each time segment, information collections needed for each RSU to execute the following phases are gathered, including the positions of subscribers, the required number of the layers of the video for each subscriber, and the speeds of all vehicles etc..
- *Scheduling phase (SP)*. The multicast transmission scheduling decision is made in this phase, where our proposed transmission scheduling scheme is applied.

- *Scheduling announcement phase (SAP).* After the multicast transmission decision is determined, each RSU broadcasts the scheduling information to all vehicles in its service region.
- *Multicast execution phase (MEP).* In this phase, the RSU transmits the contents of each video layer in a way determined in the *SP*.

Afterwards, algorithms for the decision on multicast transmission resource allocation scheduling in *SP* are proposed. In the ith scheduling segment, the goal is to obtain q video layer transmission schemes aiming at obtaining the highest benefits.

Figure 2 An overview of the total video scheduling scheme in time line (see online version for colours)



3.3 Problem formulation

Suppose that the multimedia to be transmitted is divided into q layers, the multicast scheduling scheme can be mathematically written as $S = \{S_0, S_1, ..., S_{q-1}\}$ for one certain interval. The transmission scheme for the ith layer S_l includes the number of transmission hops n_l and the modulation scheme selected for each transmission hop $m_i, i = 1, 2, \ldots, n_l$.

As shown in Figure 2, the proposed scheduling algorithm takes the time resource for each interval as input and aims to produce the output set S_l for each video layer l $(l = 0, 1, \ldots, q-1)$. More specifically, a video layer transmission scheme S_l includes three main parameters: the number of hops, the MCS for each hop, and the vehicles selected as relays except for the first hop. The farthest vehicle in the coverage of the $(i-1)$th hop will be selected as the relay for the ith hop. In this way, the range of the coverage area is maximised. It can be easily learned that the number of vehicles receiving the video will increase with expand of service region, increasing the obtained profits rise. Therefore, each video layer transmission scheme S_l for the lth video layer consists of two parameters, including the number of hops n_l and the MSC applied to each hop $m_l^{(i)}, (i = 1, 2, \ldots, n_i)$. That is,

$$S_l = \{n_l, m_l^{(i)}, (i = 1, 2, \ldots, n_l)\}. \tag{2}$$

It can be seen that two parameters affect the performance of the transmission scheme. A large number of hops can apply the best modulation with highest transmission rate but raise the forwarding time overhead. Each number of hops should be taken into consideration for evaluating its required transmission time. Another important parameter is the modulation applied to each hop when a certain number of hops has been taken into consideration. Notations used in the optimisation formulations are defined in Table 1.

Table 1 List of mainly used notations

Notation	*Description*
d_{RSU}	The service range for each RSU
q	The number of video layers
l	Index of a video layer
$\mathbf{N}$	The set of subscribers in the given region
p_i	The position for the ith subscriber
$\mathbf{N}_l$	The set of admitted users for layer l
$\mathbf{M}$	The set of MCS
n_l	The number of transmission hops for layer l
n_{th}	The upper bound of transmission hop counts for each layer
$m_l^{(i)}$	The MCS selected in the ith hop for layer l
t_{th}	Available time resource for an interval
$v_{\min}, v_{\max}$	The minimum and maximum speed limits
ρ	The vehicle flow rate in the given region
β	The efficiency transmission indicating parameter

The MMS-MVN problem can be formulated as follows:

Maximise

$$\sum_{l=0}^{q-1} |\mathbf{N}_l| \cdot b_l. \tag{3}$$

Subject to

Basic full coverage constraint:

$$\mathbf{N_0} = \mathbf{N}, \tag{4}$$

Decoding dependence constraint:

$$\mathbf{N}_l = \bigcap_{i=0}^{l} \mathbf{N}_i, \ l = 1, \ldots, q-1, \tag{5}$$

Available resource constraint:

$$\sum_{l=0}^{q-1} t_l \leq t_{\text{th}}, \tag{6}$$

MSC selection constraint:

$$m_l^{(i)} \in \mathbf{M}, \ i = 1, 2, \ldots, n_l, \tag{7}$$

Maximum hop count constraint:

$$1 \leq n_l \leq n_{\text{th}}, \ l = 1, \ldots, q-1. \tag{8}$$

In this formulation, the objective function (3) maximises the total acquired profits from the layered transmission of the target video, where $|\mathbf{N}_l|$ denotes the number of admitted users for the lth coded layer and b_l means the benefits obtained for each reception. Constraint (4) restricts that each subscriber in the certain RSU's service region must receive the base layer's information in order to maintain the goal of basic quality of video service. Constraint (5) ensure the fact that the lth video layer information can be valid if and only if the prior l layers are successfully received. Constraint (6) restricts that the available time resource are limited within the total video playing time t_{th}. Constraint (7) denotes the available MCS for each hop and the number of hop counts is limited according to constraint (8), where $m_l^{(i)}$ denotes the MCS for the ith hop in the transmission of the lth layer and n_l means the number of transmission hops.

3.4 Time complexity analysis

We state that the complexity results of the MMS-MV problem in the following theorem.

Theorem 1: *The MMS-MVN problem shown in equations* (3)–(8) *is NP-hard.*

Proof: The optimal scheduling scheme can be obtained by enumerating all feasible and qualified scheduling schemes. Let n_{space} denote the number of elements in solution space and it can be represented as following.

$$n_{\text{space}} = \sum_{l=1}^{q-1} \frac{1}{l!} \prod_{k=1}^{l+1} \left(\sum_{n=1}^{n_{\text{th}}} \mathrm{C}_{n \times k}^{n} + 1 + k \right). \tag{9}$$

Since the number of potential solutions grows exponentially with respect to the number of layers q, the size of available MCSs n_M and the maximum hop counts n_{th}, it is obviously an NP-hard problem.

4 A heuristic algorithms for MMS-MVN problem

In the previous section, the MMS-MVN problem is proven to be NP-hard. Since the time resource should be consumed predominantly in the *MEP* instead of *SP*, it is unbearable if the proposed algorithm cannot be finished in polynomial time. Therefore, a heuristic algorithm for the MMS-MVN problem, is proposed in this section to solve the problem in polynomial time while maintaining a satisfaction with the obtained results compared with the optimal solution.

Corresponding to the two goals mentioned in the subsection of problem formulation, the SP can be further divided into two sub phases shown below:

- *Basic-full-coverage (BFC) sub-phase*: To confirm the basic full coverage requirement, all the subscribers must receive the base layer video streams. Let t_{b} denote the time required for executing operations in the *BFC* sub-phase. The time resource remained for the next sub-phase should be $t_{\text{th}} - t_{\text{b}}$.
- *Benefits-maximisation-oriented (BMO) sub-phase*: In this sub-phase, the goal is set as achieving as much profits as possible within the time resource constraint $t_{\text{th}} - t_{\text{b}}$. A heuristic algorithm will be proposed to implement this phase step by step, aiming at obtaining an approaching optimal solution within polynomial time.

4.1 Basic-full-coverage (BFC) sub-phase

The goal of *BFC* sub-phase is to guarantee that any vehicle who subscribes the target multimedia service will receive the base layer streams at least. Recall that the overall object in equation (3) on obtaining benefits as much as possible in constrained time resource t_{th}. As for the *BFC* sub-phase, the objective changes into minimising the time consumed for base layer transmission t_0 with the constraint that basic demands for all $|\mathbf{N}|$ subscribers are satisfied. That is, the maximisation problem for *BFC* sub-phase can be rewritten as follows.

$$\begin{aligned} \text{Minimise} \quad & t_0 \\ \text{Subject to} \quad & \mathbf{N_0} = \mathbf{N}, \\ & t_0 \leq t_{\text{th}}, \\ & m_0^{(i)} \in \mathbf{M}, i = 1, 2, \ldots, n_0, \\ & 1 \leq n_0 \leq n_{\text{th}}. \end{aligned} \tag{10}$$

Firstly, the *BFC* sub-phase calculates out the set of available hop counts for full coverage target. Let the upper and lower bounds of the available hop set are denoted by $n_0^{\max}$ and $n_0^{\min}$ respectively, which can be obtained as follows:

$$n_0^{\max} = \min\{\lceil d_{\text{RSU}} / (\beta \cdot d_{m_1}) \rceil, n_{\text{th}}\}, \tag{11}$$

$$n_0^{\min} = \lceil d_{\text{RSU}} / (\beta \cdot d_{m_{n_{\mathbf{M}}}}) \rceil. \tag{12}$$

where β means the efficiency transmission indicating parameter. The physical meaning for the existence of β is that it cannot be guaranteed that there is at least one vehicle on the transmission edge. For example of the right part in Figure 2, d_{MCS} and d_{veh} are symbolised as the transmission distance and the distance between possible farthest vehicle and RSU respectively. Variable β is just defined as $d_{\text{veh}}/d_{\text{MCS}}$ in this special case.

According to the traffic flow theory, there is a relation between the traffic flow rate ρ and the vehicle density λ. That is,

$$\rho = \lambda \cdot v. \tag{13}$$

Suppose that $d = d_{\text{MCS}} - d_{\text{veh}}$, then $\beta = 1 - d/d_{\text{MCS}}$. With the pre-known flow rate and minimum and maximum speed limits, the number of vehicle in a certain distance d can be expressed as:

$$E\{N_d\} = \rho \cdot d \cdot \frac{\ln v_{\max}/v_{\min}}{v_{\max} - v_{\min}}. \tag{14}$$

The condition for the impossibility of relay vehicle candidate is $E\{N_d\} = 1$. Substituting equations 13 and 14 into this one, we can obtain that

$$\beta = 1 - \frac{v_{\max} - v_{\min}}{d_{\text{MCS}} \cdot \rho \cdot \ln v_{\max}/v_{\min}}. \tag{15}$$

All available MCS schemes are ordered m_k in proportional to its transmission range r_k. The hop count of the optimal scheduling scheme on transmitting the base layer must lies in the interval $[n_0^{\min}, n_0^{\max}]$. Obviously, if $n_0^{\min}$ is greater than n_{th}, the *BFC* sub-phase may not achieve.

After obtaining the feasible hop count interval, the *BFC* sub-phase shows as follows. Two further split procedures, including the initial procedure and the progressive procedure, are introduced as follows.

The initial procedure

Initially, the scheduling scheme S_0 is preset with one hop transmission in MCS with minimum transmission range. The specific operation for the initial procedure is shown as following: $\forall n \in [n_0^{\text{min}}, n_0^{\text{max}}]$,

$$S_0^{\text{ini}}(n) = \{n_0 = n, m_0^{(i)} = m_1, i = 1, 2, \ldots, n\}. \tag{16}$$

Afterwards, comparison is carried out between the time resource consumed for the initial scheme t_0^{ini} and the constraint time resource t_{th}. When $t_i^{\text{ini}} > t_{\text{th}}$, it illustrates that the time resource is overused and the basic full coverage target cannot achieve. However, it is assumed having a near one high probability of achieving the basic full coverage. Therefore, condition $t_0^{\text{ini}} \le t_{\text{th}}$ is always true, which means that the *BFC* targets can always be true. Especially, there are residual time resource which can be more fully utilised if $t_0^{\text{ini}} < t_{\text{th}}$. Afterwards, the refining procedure for the residual time resource is introduced.

The progressive procedure

In the refining procedure, several refining loops are carried out to find one near optimal scheduling scheme for the basic layer transmission. In each loop, four heuristically progressive steps are stated in detail as follows.

Step 1: Obtain the current scheduling scheme

In the refining procedure, one current scheduling scheme is determined firstly. Initial scheme S_0^{ini} is taken as current scheme for the first loop. For loop afterwards, the scheduling scheme selected in the $(r-1)$th loop is set as the current scheme for the rth loop. The current scheduling scheme can be denoted as $S_0^{\text{cur}}(n, r)$ with n hops in the ith loop.

Step 2: Find feasible set of candidate schemes

The key point of constructing feasible set of candidate schemes is by modifying the transmission in one hop into MCS with a one higher order. Let $\mathbf{S}_0^f(n, r)$ denote the feasible set of candidate transmission schemes with n hops for the rth loop. Through the definition $\mathbf{M}$, the potential benefits increase with the order. For example, supposed that $m_0^{(i)} = m_k$ currently, the scheme for the ith hop can be modified into m_{k+1}. It should be noted that this principle may produce more than one feasible candidate schemes and the number of the candidate set is equal to the transmission hop counts n. Among the set for the rth loop, one scheme should be selected effectively according to principle in step 3.

Step 3: Select one candidate scheme in $\mathbf{S}_0^f(n, r)$

Here the attributes in *improvement weight efficiency* of layer transmission scheme in $\mathbf{S}_0^f(n, r)$ is defined. That is, $\forall S_0 \in \mathbf{S}_0^f(n, r)$

$$w_0^{\text{imp}}(n, r) = \frac{|\mathbf{N}_0| \cdot b_0 - |\mathbf{N}_0^{\text{cur}}(n, r)| \cdot b_0}{t_0 - t_0^{\text{cur}}(n, r)}. \tag{17}$$

After obtaining the set of all feasible refining schemes, our algorithm chooses the candidate scheme with the highest weight efficiency. That is, in the decision making part for each loop, the improvement scheme with the maximum weight value is chosen.

$$S_0^{\text{sel}}(n, r) = \underset{S_0 \in \mathbf{S}_0^f(n,r)}{\arg \max}\ w_0^{\text{imp}}(n, r). \tag{18}$$

The refining process following the above proposed principle is carried out step by step. The optimal ending condition is when the basic full coverage requirement is achieved. For a certain hop count n, this scheme is define as the optimal one for the *BFC* sub-phase. That is, when *BFC* is achieved in the rth loop,

$$S_0^{\text{opt}}(n) = S_0^{\text{sel}}(n, r). \tag{19}$$

However, this ending condition cannot be guaranteed. For example, the available time resource may run out while the basic full coverage is not achieved. This case cannot be further polished because of the system capacity, which is ignored in this paper.

After obtaining the most appropriate schemes for all available hop counts, one with the highest transmission efficiency is chosen as the optimal one. That is, the one with the minimum transmission time is selected.

$$S_0^{\text{opt}} = \underset{S_0 \in \mathbf{S}_0^{\text{opt}}}{\arg \min}\ t_0. \tag{20}$$

The algorithm for the *BFC* sub-phase is shown in Algorithm 1 in detail. After obtaining the bounds of available hop counts, the initial procedure is obtained in line 3 while the progressive optimising procedure locates in lines 4–21. Finally, the optimal scheduling scheme can be obtained as S_0^{opt} in lines 22–25. Correspondingly, the time resource consumed with S_0^{opt} is symbolised as t_b.

4.2 Benefits-maximisation-oriented (BMO) sub-phase

After providing all subscribers the base layer multimedia streams, the next step is to design enhancement layer multicast transmission schemes $S_l, (l = 1, 2, \ldots, q-1)$. The goal of the *BMO* sub-phase is to obtain the highest profits within the remaining time resource $t_{\text{th}} - t_{\text{b}}$. Based on the benefits from the *BFC* sub-phase, the optimisation problem for the *BMO* sub-phase can be rewritten as follows.

$$\begin{aligned}
&\text{Minimise} \quad \sum_{l=1}^{q-1} |\mathbf{N}_l| \cdot b_l \\
&\text{Subject to} \quad \sum_{l=1}^{q-1} t_l \le t_{\text{th}} - t_0^{\text{opt}}, \\
&\qquad \forall l \in \{1, 2, \ldots, q-1\}, \\
&\qquad \mathbf{N}_l = \bigcap_{i=0}^{l} \mathbf{N}_i, \\
&\qquad m_l^{(i)} \in \mathbf{M}, i = 1, 2, \ldots, n_0, \\
&\qquad 1 \le n_l \le n_{\text{th}}.
\end{aligned} \tag{21}$$

Algorithm 1 : Procedure for *BFC* sub-phase

Input $t_{\text{th}}, n_0^{\min}, n_0^{\max}$
for $n \in [n_0^{\min}, n_0^{\max}]$ **do**
  $S_0^{\text{ini}}(n) = \{n_0^{\text{ini}} = n, m_{0,\text{ini}}^{(1:n)} = m_1\}$
  for each loop r **do**
    if $r == 1$ **then**
      $S_0^{\text{cur}}(n,r) = S_0^{\text{ini}}(n)$
    else
      $S_0^{\text{cur}}(n,r) = S_0^{\text{sel}}(n,r-1)$
    end if
    for $i = 1 : n_0^{\text{cur}}(n,r)$ **do**
      $\{n_0^{\text{cur}}(n,r), \text{sub}\{m_0^{(i)}\} = \text{sub}\{m_{0,\text{cur}}^{(i)}(n,r)\} + 1\} \to \mathbf{S}_0^f(n,r)$
    end for
    for all $S_0 \in \mathbf{S}_0^f(r)$ **do**
      $S_0^{\text{sel}}(r) = \arg\max\ w_0^{imp}(r)$
    end for
    if Basic full coverage is achieved **then**
      $S_0^{\text{opt}}(n) = S_0^{\text{sel}}(n,r)$
      break
    end if
  end for
end for
for all $S_0 \in \mathbf{S}_0^{\text{opt}}(n)$ **do**
  $S_0^{\text{opt}} = \arg\min\ t_0^{\text{opt}}(n)$
end for
Output S_0^{opt}

Similar with the algorithm for the *BFC* sub-phase, the *BMO* sub-phase contains two procedures, the initial procedure and the progressive procedure as follows. Two further split procedures, including the initial procedure and the progressive procedure, are introduced as follows.

The initial procedure

Initially, only the first enhancement layer l_1 is preset with one hop transmission in MCS with minimum transmission range. The specific operation for the initial procedure is shown as following:

$$S_1^{\text{ini}} = \{n_0 = 1, m_0^{(1)} = m_1\}. \tag{22}$$

$$S_i^{\text{ini}} = \{n_0 = 0\}, \forall i \in \{2,3,\ldots,q-1\}. \tag{23}$$

The reasons for setting this kind initial scheme as above mainly lie in leaving more refining possibility for the next step's procedure. Moreover, the obtained results can be more optimal for not constraining the initial step too much.

Afterwards, comparison is carried out between the time resource consumed for the initial scheme $\sum_{l=1}^{q-1} t_l^{\text{ini}}$ and the constraint time resource $t_{\text{th}} - t_0^{\text{opt}}$. When $\sum_{l=1}^{q-1} t_l^{\text{ini}} > t_{\text{th}} - t_0^{\text{opt}}$, it illustrates that the time resource is overused and the enhancement layers cannot be allowed to transmit. If $\sum_{l=1}^{q-1} t_l^{\text{ini}} = t_{\text{th}} - t_0^{\text{opt}}$, it means the initial scheme is just the optimal scheme for enhancement layers. Otherwise, condition $\sum_{l=1}^{q-1} t_l^{\text{ini}} < t_{\text{th}} - t_0^{\text{opt}}$ is always true, which means that there are residual time resource which can be more fully utilised. Afterwards, the refining procedure for the residual time resource is introduced.

The progressive procedure

In the refining procedure, several refining loops are carried out to find the optimal transmission scheduling schemes for the enhancement layers. In each loop, four progressive heuristically steps are stated in detail as follows.

Step 1: Obtain the current scheduling scheme

In the refining procedure, one current scheduling scheme is determined firstly. Initial scheme S_l^{ini} is taken as current scheme for the first loop. For loop afterwards, the scheduling scheme selected in the $(r-1)$th loop is set as the current scheme for the rth loop. The current scheduling scheme can be denoted as $S_l^{\text{cur}}(r)$.

Step 2: Find feasible set of candidate schemes

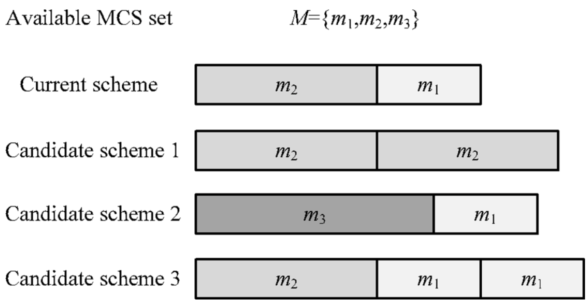
Let $\mathbf{S}_l^f(r)$ denote the feasible set of candidate transmission schemes for layer l in the rth loop. The principle of choosing candidate video layer transmission schemes can be divided into two aspects. In choosing the candidate scheme set, two principles are proposed including:

- *Refining MCS* $m_l^{(i)}$. Through the definition $\mathbf{M}$, the potential benefits increase with the order. Supposed that $m_0^{(i)} = m_k$ currently, the scheme with $m_0^{(i)} \in \{m_{k+1}, \ldots, m_{n_\mathbf{M}}\}$ belongs to the total candidate transmission schemes.
- *Adding hop count* n_0. It is more understandable that adding a hop count to the previous scheme can acquire more profits. Moreover, the MCS for this new hop is set as m_1.

One example for the generation of candidate scheme set is shown in Figure 3. The first two schemes generates according to principle (1), while the third one is obtained for the second constraint. It should be noted that principle (1) may produce more than one feasible candidate schemes and the number of the candidate set may increase with the transmission hop counts. However, it is considered to be reasonable since the calculation complexity with $O(n_0)$. However, not all the produced schemes can satisfy the conditional constraints. The decoding dependence constraint should be satisfied. After obtaining schemes according to principles (1) and (2), the process for identifying whether it is appropriate based on the decoding dependence constraint. Obviously, the first enhancement layer dose not have any constraints because of the basic full coverage constraint. However, for enhancement layers l_2 to l_{q-1}, schemes satisfying the following constraint can be treated as the candidate schemes.

$$|\mathbf{N}_l^f(r)| \le |\mathbf{N}_{l-1}^{\text{cur}}(r)|. \tag{24}$$

Figure 3 One example for the generation of candidate scheme set in BMO sub-phase



Step 3: Select one candidate scheme in $\mathbf{S}_l^f(r)$

Here the attributes in *improvement weight efficiency* of layer transmission scheme in $\mathbf{S}_0^f(r)$ is defined. That is, $\forall S_l \in \mathbf{S}_l^f(r)$

$$w_l^{\text{imp}}(r) = \frac{\sum_{l=1}^{q-1} |\mathbf{N}_l| \cdot b_l - \sum_{l=1}^{q-1} |\mathbf{N}_l^{\text{cur}}(r)| \cdot b_l}{t_l - t_l^{\text{cur}}(r)}. \quad (25)$$

In the decision making part for each loop, the improvement scheme with the maximum weight value is chosen and applied.

After obtaining the set of all feasible refining schemes, our algorithm chooses the candidate scheme with the highest weight efficiency. That is,

$$S^{\text{sel}}(r) = \underset{S_l \in \mathbf{S}_l^f(r)}{\arg\max}\; w_l^{\text{imp}}(r). \quad (26)$$

The refining process following the above proposed principle is carried out step by step. The optimal ending condition is when the basic full coverage requirement is achieved. However, this condition cannot be guaranteed and the exceptional circumstances are analysed. This can be further divided into two cases. The first one is that the available time resource runs out while the basic full coverage is not achieved. This case cannot be further polished because of the system capacity. Otherwise, the second case is that no more candidate scheme can be obtained before achieving the basic full coverage. That is, principle (2) may not work when the current hop count equals to n_{th}. Different from the first case, some refining procedure can be carried out as follows.

The algorithm for the basic-full-coverage sub-phase is shown in Algorithm 2 in detail. After obtaining the bounds of available hop counts, the scheme with identical MCS is calculated in lines 2–18 while the refining procedure locates in lines 19–33. In consequence, the scheduling schemes for all enhancement layers by our proposed algorithm can be obtained as: $S_1, S_2, \ldots, S_{q-1}$.

5 Performance evaluation

This section compare performance of the proposed heuristic algorithm (HMMS-MVN) with results from brute force, algorithm with fixed relay assistance, and best effort algorithm with one optional MCS scheme. Obviously, the brute force solution can obtain the targeted optimal scheduling scheme. However, considering high time complexity for the enumerating algorithm, it is not perfect and unsuitable for the real scenario, which needs real-time processing ability. Algorithm with fixed relays construction refers from the GWA algorithm proposed by Sheu et al. (2013) and is modified to be applied in the scenario assumed in this paper. The modification is that consecutive RSs are deployed with a distance equal to the longest transmission range of the MCS scheme from set M. Moreover, algorithm with one optional MCS scheme is carried out as a comparison. The major parameters are shown in Table 2.

Algorithm 2 : Procedure for *BMO* sub-phase

1: **Input** t_{th}, q
2: $S_1^{\text{ini}} = \{n_1^{\text{ini}} = 1, m_{1,\text{ini}}^{(1)} = m_1\}$
3: **for** $l = 2 : q-1$ **do**
4: $\quad S_l^{\text{ini}} = \{n_l^{\text{ini}} = 0\}$
5: **end for**
6: **for each loop** r **do**
7: $\quad$ **for** $l = 1 : q-1$ **do**
8: $\quad\quad$ **if** $r == 1$ **then**
9: $\quad\quad\quad S_l^{\text{cur}}(r) = S_l^{\text{ini}}$
10: $\quad\quad$ **else**
11: $\quad\quad\quad S_l^{\text{cur}}(r) = S_l^{\text{sel}}(r-1)$
12: $\quad\quad$ **end if**
13: $\quad\quad$ **for** $i = 1 : n_l^{\text{cur}}(r)$ **do**
14: $\quad\quad\quad \{n_l^{\text{cur}}(r), \text{sub}\{m_l^{(i)}\} = \text{sub}\{m_{l,\text{cur}}^{(i)}(n,r)\} + 1\} \to \mathbf{S}_l^{cf}(r)$
15: $\quad\quad$ **end for**
16: $\quad\quad \{n_l^{\text{cur}}(r)+1, m_l^{(n_l^{\text{cur}}(r)+1)} = m_1\} \to \mathbf{S}_l^{cf}(r)$
17: $\quad\quad$ **for all** $S_l \in \mathbf{S}_l^{cf}(r)$ **do**
18: $\quad\quad\quad$ **if** $l \geq 2$ **&** $|\mathbf{N}_l| \leq |\mathbf{N}_{l-1}^{\text{cur}}(r)|$ **then**
19: $\quad\quad\quad\quad S_l \to \mathbf{S}_l^f(r)$
20: $\quad\quad\quad$ **end if**
21: $\quad\quad$ **end for**
22: $\quad\quad$ **for all** $S_l \in \mathbf{S}_l^f(r)$ **do**
23: $\quad\quad\quad S_l^{\text{sel}}(r) = \arg\max\; w_l^{\text{imp}}(r)$
24: $\quad\quad$ **end for**
25: $\quad$ **end for**
26: $\quad$ **if** t_{th} is used up **then**
27: $\quad\quad$ **for** $l = 1 : q-1$ **do**
28: $\quad\quad\quad S_l = S_l^{\text{sel}}(r)$
29: $\quad\quad$ **end for**
30: $\quad\quad$ **Break**
31: $\quad$ **end if**
32: **end for**
33: **Output** $S_1, S_2, \ldots, S_{q-1}$

In Figures 4–7, performance against different percentage of available multicast time resource from our proposed heuristic algorithm and three comparing algorithms is shown. While in Figures 8 and 9, they represent the performance of acquired benefits and corresponding benefits efficiency against different number of coded layers from the four different scheduling algorithms.

Table 2 Main parameters in simulation

Parameter	*Description*	*Value*
d_{RSU}	The service range for one RSU	1000–10000 m
λ	The density of vehicles	0.05-0.5 veh/m
v_{min}, v_{max}	The minimum and maximum speed limits	60,120 km/h
β	The efficiency transmission indicating parameter	0.75–0.95
ρ	The vehicle flow rate	0.5–5 veh/s
q	The number of video layers	2–10
M	The feasible set of MCS	BPSK QPSK 16-QAM 64-QAM
R	The transmission rate for MCS set	2.048 4.096 10.24 20.48 40.96 kbps

Figure 4 The acquired benefits against the available multicast time resource (see online version for colours)

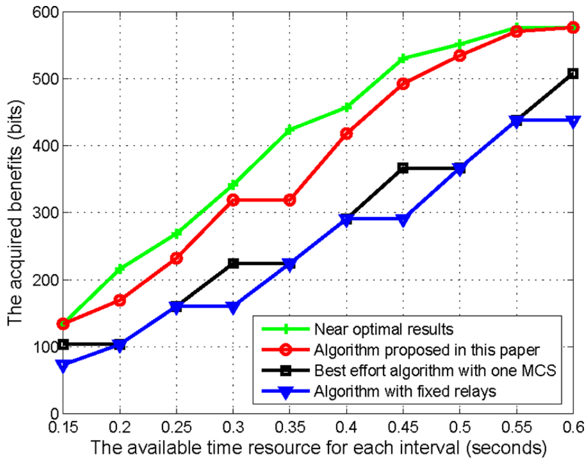
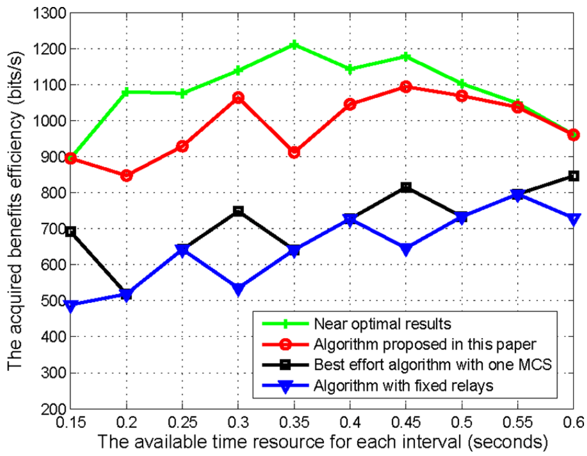


Figure 5 The acquired benefits per available multicast time resource against the available multicast time resource (see online version for colours)



In Figure 4, it can be seen that the acquired benefits rise with the increase of available multicast time resource. Among the four tested scheduling algorithms, the optimal algorithm can access the highest benefits undoubtedly. As for the other three other algorithms, results from HMMS-MVN achieve the highest scores, which approaches the optimum results. Meanwhile, results from scheduling with fixed relays obtain the lowest performance. This is reasonable because that the fixed relay selection candidate set will limit the scalable performance for the MCS set. Therefore, even with one available MCS in random relay selection environment, the results show a better performance with the same reason. This figure also shows a simulation level proof for the performance of the heuristic algorithm proposed in this paper.

Figure 6 The proportion of occupied time resource against the available multicast time resource (see online version for colours)

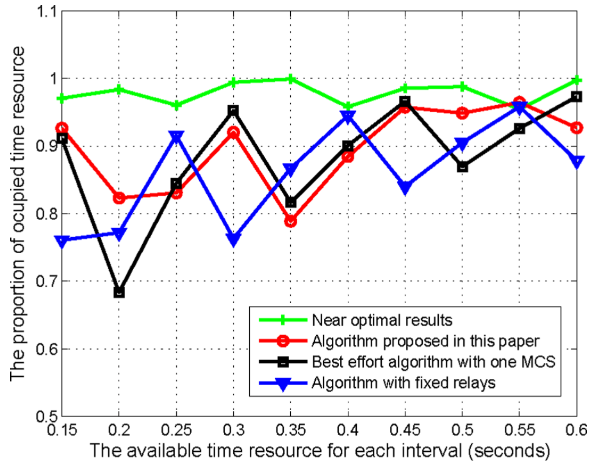


Figure 7 The acquired benefits per occupied multicast time resource against the available multicast time resource (see online version for colours)

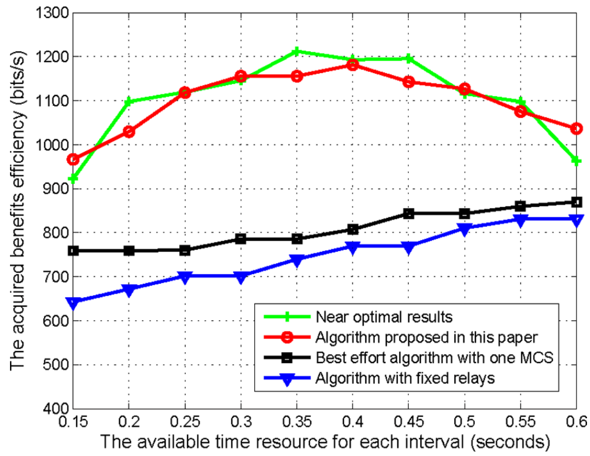


Figure 5 represents the performance corresponding benefits efficiency and the proportion of time consumed against different percentage of multicast time resource with the four different scheduling algorithms. It can be seen that the results of benefits efficiency show a similar tendency with that in Figure 4. While in Figure 6, the performance of occupied time percentage is shown. It can be seen that the optimal results consume the highest percentage of available time resource. As for results from the other three algorithms, the proportion varies below that for the optimal results. Then for the results in Figure 7, it shows that the real efficiency for the four algorithms. Different with results above, results from our algorithm show the excellent performance approaching to the optimal efficiency, exceeding the three others.

Figure 8 The acquired benefits against different number of coded layers (see online version for colours)

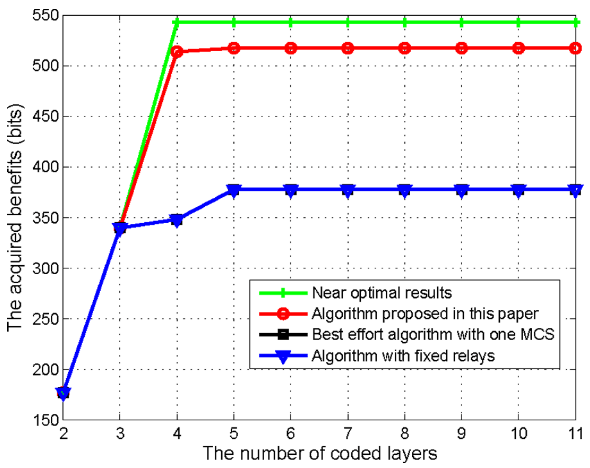
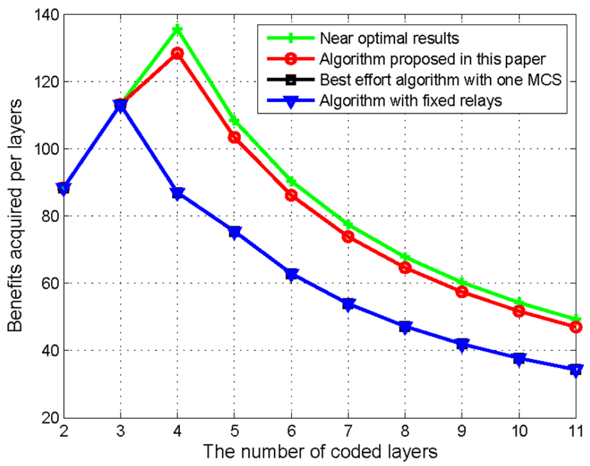


Figure 9 Benefits acquired per layer against different number of coded layers (see online version for colours)



In Figure 8, it can be seen that the acquired benefits show a non-decreasing tendency with the increase of coded layers. When the transmitted multimedia material is divided into more than five layers, the acquired benefits will not increase. This is reasonable because that more layers will need more bandwidth to support, which leads to the redundancy for the coded higher definition Among the four tested scheduling algorithms, the optimal algorithm can access the highest benefits, which is identical to the previous results. As for the other three heuristic algorithm, results form scheduling algorithm in this paper, get the highest scores compared with the other two, which approaches the optimal results. Results from scheduling with fixed relays obtain the lowest performance.

6 Conclusion and future proposal

In this paper, a heuristic algorithm is proposed to schedule layered media multicast transmission in VANETs. Parameters, including the number of coded layers, the number of available multicast time resource, the number of MCSs, the wireless channel conditions etc., are taken into account. Although many influential factors are considered, there are also some extension space left.

- The channel condition is considered to be idealised in this paper, which can be extended to more accurate and complex conditions. In this paper, the large scale pathloss fading model is used, which is some kind of too perfect. In the real wireless environment, the large scale fading also includes shadowing caused by the fade of high buildings and trees. Moreover, the small scale caused by reflection and diffraction etc. should also be taken into account.
- Possibility for parrel transmission. Obviously, the transmission between different layer leaves the possibility for parrel transmission. For one special frequency band, the interference should be avoided to guarantee the quality of respective transmission.
- Possibility for multichannel transmission. The IEEE 1609.4 Standard for wireless access in vehicular environments (WAVE) has been proposed to enhance the performance of vehicular networks with multi-channel operations. Moreover, the existence of multi-frequency band will increase the efficiency of parrel transmission.

The possible modification directions on this paper may vary and the listed points will be our future works.

References

Alasmary, W. and Valaee, S. (2013) 'Compressive sensing based vehicle information recovery in vehicular networks', *Wireless Communications and Mobile Computing Conference (IWCMC), 2013 9th International*, pp.700–705.

Chen, L. and Wang, X. (2012) 'Resource allocation for multicast services with joint FGS video coding and UEP RS coding scheme in single frequency networks', *Vehicular Technology Conference (VTC Fall), 2012 IEEE*, pp.1–5.

Gopala, P.K. and Gamal, H.E. (2004) 'Opportunistic multicasting', *Signals, Systems and Computers, 2004. Conference Record of the Thirty-Eighth Asilomar Conference on*, Vol. 1, pp.845–849.

Hua, K.L., Chiu, G.M., Chin, T.L., Pao, H.K., Cheng, Y.C. and Su, G.M. (2013) 'A novel scalable video streaming system on P2P networks', *Computing, Networking and Communications (ICNC), 2013 International Conference on*, pp.676–680.

Hua, K.L., Chiu, G.M., Pao, h.K. and Cheng, Y.C. (2013) 'An efficient scheduling algorithm for scalable video streaming over P2P networks', *Computer Networks*, Vol. 57, No. 14, pp.2856–2868.

Huang, C.W., Wu, p.H., Lin, S.J. and Hwang, J.N. (2009) 'Layered video resource allocation in mobile WiMAX using opportunistic multicasting', *Wireless Communications and Networking Conference, WCNC 2009. IEEE*, pp.1–6.

Huang, S.M., Huang, C.W., Wu, P.H., Hwang, J.N., Gau, V. and Chen, Y.C. (2010) 'Resource efficient opportunistic multicast scheduling for IPTV over mobile WiMAX', *Vehicular Technology Conference (VTC 2010-Spring), 2010 IEEE 71st*, pp.1–5.

Huang, C.W., Huang, S.M., Wu, P.H., Lin, S.J. and Hwang, J. N. (2012) 'OLM: opportunistic layered multicasting for scalable IPTV over mobile WiMAX', *Mobile Computing, IEEE Transactions on*, Vol. 11, No. 3, pp.453–463.

Hung, L.L., Chang, C.Y., Chen, C.C. and Chen, Y.C. (2012) 'BUFE-MAC: a protocol with bandwidth utilization and fairness enhancements for Mesh-Backbone-based VANETs', *Vehicular Technology, IEEE Transactions on*, Vol. 61, No. 5, pp.2208–2221.

Kozica, E. and Kleijn, W.B. (2012) 'A quantization theoretic perspective on simulcast and layered multicast optimization', *Networking, IEEE/ACM Transactions on*, Vol. 20, No. 2, pp.585–593.

Kuo, W.H. (2009) 'Recipient maximization routing scheme for multicast over IEEE 802.16j relay networks', *Communications, 2009. ICC '09. IEEE International Conference on*, pp.1–6.

Kuo, W.H. and Lee, J.F. (2010) 'Multicast recipient maximization in IEEE 802.16j WiMAX relay networks', *Vehicular Technology, IEEE Transactions on*, Vol. 59, No. 1, pp.335–343.

Li, P., Zhang, H., Zhao, B. and Rangarajan, S. (2012) 'Scalable video multicast with adaptive modulation and coding in broadband wireless data systems', *Networking, IEEE/ACM Transactions on*, Vol. 20, No. 1, pp.57–68.

May, A.D. (1990) *Traffic Flow Fundamentals*, Prentice Hall.

Prasad, R. (1998) *Universal Wireless Personal Communications*, Artech House Publishers.

She, J., Hou, F., Ho, P.H. and Xie, L.L. (2007) 'IPTV over WiMAX: key success factors, challenges, and solutions [advances in mobile multimedia]', *Communications Magazine, IEEE*, Vol. 45, No. 8, pp.87–93.

Sheu, J.P., Kao, C.C., Yang, S.R. and Chang, L.F. (2013) 'A resource allocation scheme for scalable video multicast in WiMAX relay networks', *Mobile Computing, IEEE Transactions on*, Vol. 12, No. 1, pp.90–104

Wu, P.H., Hu, Y.H. and Hwang, J.N. (2010) 'Optimal layered video IPTV multicast streaming over IEEE 802.16e WiMAX systems', *Vehicular Technology Conference (VTC 2010-Spring), 2010 IEEE 71st*, pp.1–5.