

Propagation-based Content Dissemination for Social Mobile Interactive Multimedia Services

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ABSTRACT

With the fast development of mobile communication technologies and increased capabilities of smart terminals, the multimedia service has become one of the most attractive applications in mobile Internet. And the combination of social-based mobile multimedia and mobile peer-to-peer (P2P) network has attracted increasing research interests in recent years. However, how to deploy large scale P2P-based social multimedia applications over MANETs has become a big challenge. In this paper, we propose a Propagation-based Content Dissemination solution for Social Interactive Multimedia services over MANETs (PSIM). In PSIM, the video content propagation problem is formulated as an Epidemic Information Dissemination (SIR) model. Based on the chunk-based dissemination model and analysis, a novel Propagation-based Video Chunk Demands Estimation Algorithm and a Stability-based Cooperative Carrier Selection Mechanism are proposed to estimate the video chunk demands and choose stable cooperative cache nodes, respectively. Simulation results show how PSIM achieves better performance in comparison with another state-of-art solution.

Keywords

Social Network, Interactive Multimedia, Cooperative Cache, MANETs

1. INTRODUCTION

Mobile Ad-hoc Networks(MANETs) has become a significant wireless communication technology in future heterogeneous network environment due to its robust, scalability and self-organizing[1][2][3][4]. Recent years, the Internet has wit-

nessed the blossom of social network applications (eg. Renren, Facebook), and a large number of new social-based applications have been fostered into MANETs, including social interactive multimedia service[5][6][7]. Unlike the traditional multimedia streaming service, the interactive multimedia services allow user's VCR-like operations and provide interactions between users with social relationship, which meets the demands of user free access to the interested video content. According to Wang *et al.*[8], social interactive multimedia services will dominate the future multimedia traffic over Internet. P2P technologies make use of users' upload bandwidth to compensate the bandwidth of traditional C/S architecture, which has become a main trend for future VoD service[9][10]. How to provide high quality P2P-based social interactive multimedia in wireless environment has become a hot topic[11, 12, 13]. Wang *et al.* in [14] have showed that the user preference of video has small-world characteristics. Shen *et al.* in [9] proposed Social-Tube, including locality-aware video pre-fetching mechanism, the chunk-based delivery abilities enhance policies, and buffer management algorithm. In [15], Cheng *et al.* designed a social media sharing system which utilizes social reciprocity to increase the user sharing efficiency, and employs peer-assisted designs to distribute video streams with low server cost.

Due to the high dynamic of wireless environment, how to deploy large scale P2P-based social applications over MANETs has become a big challenge, numerous solutions have proposed. In [16], Xu *et al.* proposed a novel P2P-based video sharing solution over VANETs by using 4G networks as a compensate. In [17], Chen *et al.* proposed SPOON, a community-based P2P content file sharing solution in disconnected mobile ad-hoc networks, groups the users which have common interests in shared files and frequent interactions as a community. Bandara *et al.* in [18] proposed a community-based cache mechanism to enhance both community-wide and system-wide lookup performance. In [19], a novel ant-inspired mini-community-based video sharing solution (AMCV) has been proposed for on demand services in wireless mobile networks. In AMCV, a multiple mini-communities based on the video content is constructed which aims to reduce resource maintenance costs and enhanced the

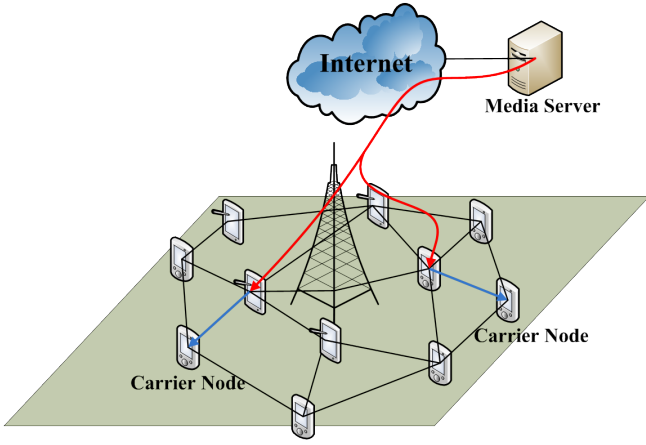


Figure 1: The architecture of PSIM

overall solution scalability. Besides, in our previous work [7], we proposed a novel performance-aware mobile community-based VoD streaming solution (PMCV), a newly designed mobile community detection scheme to group together the mobile users with similar behavior in terms of playback and movement. Based on mobile community, collaborative storage and video resource mechanism are proposed.

However, all these solutions focus on the static conditions, trying to capture the static pattern of propagation, which is not suitable for diverse user behaviors with social context, thus leads to a low performance of VoD sharing system. In this paper, we propose **Propagation-based Content Dissemination solution for Social Interactive Multimedia over MANETs (PSIM)** to achieve the high performance of large scale video sharing system over MANETs. The architecture of PSIM is shown in Fig. 1. In PSIM, media server not only provides the initial video content for end user, but also gathers the query information in the whole system. Besides, media server estimates the video content demands and notices the relatively stable mobile nodes to cache the video content with large demands based on the algorithm we proposed. In the Problem Formulation section, we first formulate the video content propagation problem as a SIR epidemic model, aims to analyse the user playback behavior pattern evolution with time varying. In PSIM Detail Design section, because of the parameter cannot be obtained directly in practical, we propose a novel *Propagations-based Video Chunk Demands Estimation Algorithm* which aims to estimate the video chunk demand in a realistic environment. A *Stability-based Carrier Selection Mechanism* is also proposed to choose a number of stable mobile nodes which are responsible to cooperatively cache the most needed content in system. Simulation results show how PSIM achieves better performance in comparison with another state-of-art solution.

2. PROBLEM FORMULATION

As discussed above, the video propagation in wireless network has social network characteristics, thus, in order to analyse the video chunk dissemination, we can formulate the video dissemination problem as a SIR model[20]. In our model, all nodes in the network are divided into three

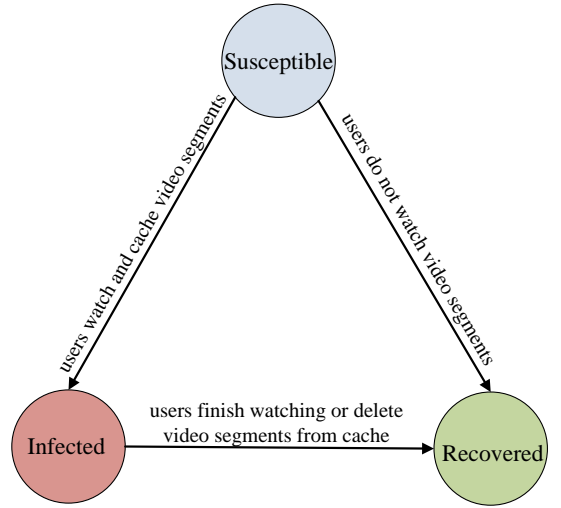


Figure 2: Propagation mechanism based on SIR model

types: Susceptible, noted by S , represents the nodes which have some probabilities to be infected. Infected, noted by I , represents the nodes which have been infected and tend to infect others. And Recovered, noted by R , represents the nodes that have been cured or already died, which means the recovered nodes cannot affect on the spread of diseases. Fig. 2 shows the video propagation mechanism based on the SIR model. The propagation mechanism is defined as in Eq. (1):

$$\begin{cases} S(i) + I(j) \xrightarrow{\lambda} I(i) + I(j) \\ I(i) \xrightarrow{\mu} R(i) \end{cases} \quad (1)$$

In interactive multimedia system, the node which gets interested in video segment c_i can be defined as infected node $S^{c_i}(h)$, the node which plays or caches the video segment c_i can be defined as $I^{c_i}(h)$, and the node which has already finished playing the video segment c_i can be defined as $R^{c_i}(i)$. Suppose at time t , the density for these three kinds of nodes are $s^{c_i}(t)$, $i^{c_i}(t)$, $r^{c_i}(t)$, we can get differential equations as in Eq. (2) :

$$\begin{cases} \frac{ds^{c_i}(t)}{dt} = -\lambda s^{c_i}(t) i^{c_i}(t) \\ \frac{di^{c_i}(t)}{dt} = \lambda s^{c_i}(t) i^{c_i}(t) - \mu i^{c_i}(t) \\ \frac{dr^{c_i}(t)}{dt} = \mu i^{c_i}(t) \end{cases} \quad (2)$$

where λ represents the access rate of the video segment, μ represents the recovered rate, and the constraint condition is $s^{c_i} + i^{c_i} + r^{c_i} = 1$. Through this model, a specific trend can be concluded about the scale of infected users, which play or cache video content during the video propagation process in interactive multimedia system. At first, infected users increase generally with more and more users get interested in the video content. However, if infected users finish playing video, they will transfer to recovered users. On the other hand, the susceptible users, who get interested in video content, will decrease as time goes by. Therefore, the infected users in system will tend to a constant value finally. Extend

Eq. (2) into Eq. (3) with initial conditions $s^{c_i}(0)$, $i^{c_i}(0)$ to describe the propagation rule in interactive multimedia system:

$$\begin{cases} \frac{ds^{c_i}(t)}{dt} = -\lambda s^{c_i}(t) i^{c_i}(t) \\ \frac{di^{c_i}(t)}{dt} = \lambda s^{c_i}(t) i^{c_i}(t) - \mu i^{c_i}(t) \\ \frac{dr^{c_i}(t)}{dt} = \mu i^{c_i}(t) \\ s^{c_i}(0) = s_{t_0}^{c_i}, i^{c_i}(0) = i_{t_0}^{c_i}, \end{cases} \quad (3)$$

where t_0 denotes the initial time, $s_{t_0}^{c_i}$ denotes the density for users get interested to video segment c_i , and $i_{t_0}^{c_i}$ denotes the density for users who play or cache video segment c_i . Since solving analytical solutions for $i^{c_i}(t)$ and $s^{c_i}(t)$ is very complicated, the usual method is to find numerical solutions [21] for Eq. (3). At time t , the relationship between density for users playing video segment c_i and users get interested to video segment c_i can be defined in Eq. (4):

$$i^{c_i}(t) = s_{t_0}^{c_i} + i_{t_0}^{c_i} - s^{c_i}(t) + \frac{\mu}{\lambda} \ln \frac{s^{c_i}(t)}{s_{t_0}^{c_i}} \quad (4)$$

According to eq. (4), we can obtain the $s^{c_i}(t)$ as follow:

$$s^{c_i}(t) = \frac{\mu W \left(\frac{\lambda}{\mu} s_{t_0}^{c_i} e^{\frac{\lambda i^{c_i}(t) - \lambda s_{t_0}^{c_i} - \lambda i_{t_0}^{c_i}}{\mu}} \right)}{-\lambda} \quad (5)$$

where W represents Lambert W Function [12]. Therefore, the density for users get interested to video segment c_i can be calculated by Eq. (5) based on the SIR model and the knowledge of initial situation for interactive multimedia system. Moreover, the number of cached video segments can be determined to achieve requirements for users.

3. PSIM DETAILS DESIGN

In this section, we present two practical algorithms to solve the above video dissemination problem in realistic environment: *Propagations-based Video Chunk Demands Estimation Algorithm* and *Stability-based Cooperative Carrier Selection Mechanism*. Due to the difficulties of obtaining parameters of Eq. (5) and gathering information in a mobile distribute environment, *Propagations-based Video Chunk Demands Estimation Algorithm* has been proposed to analyse the video demands in real time over the MANETs. And *Stability-based Cooperative Carrier Selection Mechanism* aims to determine the nodes to carry the corresponding video content, which ensures the network resource can be utilized more efficiently.

3.1 Propagations-based Video Chunk Demands Estimation Algorithm

Based on the video dissemination analysis above, we present a practical algorithm: *Propagations-based Video Chunk Demands Estimation Algorithm*. In PSIM, the media server not only provides the initial video content for mobile user, but also manages the users' query information of video chunks by using a list. Unlike the traditional peer-assisted video sharing system, each mobile node in PSIM maintains a query information table to record the request information they received, the query information of node U_i can be describe as

Algorithm 1 : Video Chunk Demands Estimation Algorithm

H_c : the list for maintaining the R_u ;
for each video chunk c in VoD
 if $(U_j, c_i, RT_i) \notin H_c$
 Media server collects the query information R_{U_k} into H_c
 for $U_j \in H_c$
 if $c_i == c$
 then $N_{v_i}^{c_i}(T_n) = N_{v_i}^{c_i}(T_n) + 1$
 end if
 if $C_{cache} = c$
 then $n_{v_i}^{c_i}(T_n) = n_{v_i}^{c_i}(T_n) + 1$
 end if
 end for
 end if
determine the λ_{c_i} according to $\frac{N_{v_i}^{c_i}(T_n)}{T_n}$
determine the μ_{c_i} according to $\mu_{c_i} = \frac{1}{CT_{c_i}}, C = 1, 2, \dots, m$
calculate the $E(S^{c_i}(t_i))$ according to eq. (6);
 if $B_{c_i} E(S^{c_i}(t_i)) > B_{c_i} \cdot \sum_{j=1}^c n_{v_j}^{c_i}(t_i)$
 calculate the demand of chunk c according to eq. (7);
 end if
end for

following 4-tuple: $R_{U_k} = (U_j, c_i, RT_i, C_{cache})$, where U_j represents the request user ID, c_i represents the request video chunk, RT_i represents the request time, and C_{cache} represents the current video chunk that U_i cache. For every time interval T , the mobile nodes upload the received query information to media server, where $T = nT_c$, $n = 1, 2, \dots, n$, and T_c is the playback time of video chunk. In order to predict the future demands of video chunk k , we use $n_{v_i}^{c_i}(T_n)$ denotes the number of users which cache video chunk c_i in current period T_n , and $n_{v_i}^{c_i}(T_n)$ can be calculate by the R_{U_k} . In practical environment, the λ, μ in eq. (5) are hard to obtain the accurate values, in order to implement the algorithm in real world, the media server use $\frac{N_{v_i}^{c_i}(T_n)}{T_n}$ to approximate the access rate λ in this paper, where $N_R^{c_i}(T_n)$ represents the number of requests of video chunk c_i in time interval T_n . $N_R^{c_i}(T_n)$ can be calculate according to query information that media server gathered. As the same reason, the recovered rate is set to: $\mu_{c_i} = \frac{1}{CT_{c_i}}, C = 1, 2, \dots, m$, where C denotes the size of the cache of the node, which should be the integral multiple of the size of video segment. Based on the defined diffusion rate, recovered rate and Eq. (5), the number of users who get interested in video segment c_i at time $T_n + 1$ can be defined as

$$E(S^{c_i}(T_{n+1})) = \frac{N_{vod} \mu_{c_i} W \left(\frac{\lambda_{c_i}}{\mu_{c_i}} E(S_{t_0}^{c_i}) e^{f(T_n)} \right)}{-\lambda_{c_i}} \quad (6)$$

where $f(T_n) = \frac{1}{\mu_{c_i}} \{ \lambda_{c_i} (n_{v_i}^{c_i}(T_n) + N_{v_i}^{c_i}(T_n) - n_{v_i}^{c_i}(T_n) \mu_{c_i}) - \lambda_{c_i} E(S^{c_i}(t_0)) - \lambda_{c_i} N_{v_i}^{c_i}(T_0) \}$, N_{vod} represents the total number of users in the VoD system. Suppose the bit rate is B_{c_i} , the bandwidth for the demand for video segment c_i at time

t_i is $B_{c_i}E(s^{c_i}(t_i))$. The current system can provide bandwidth $B_{c_i}N_{v_i}^{c_i}(T_n)$. If $B_{c_i}E(s^{c_i}(t_i)) > B_{c_i}N_{v_i}^{c_i}(T_n)$, more cache backups are needed. The demand video chunk number $n_r^{c_i}$ can be expressed as

$$n_r^{c_i} = \frac{B_{c_i}E(s^{c_i}(t_i)) - B_{c_i} \cdot \sum_{j=1}^c n_{v_j}^{c_i}(t_i)}{B_{upload}} \quad (7)$$

where B_{upload} denotes the upload bandwidth. Therefore, media server should choose $n_r^{c_i}$ nodes which cache the video chunk c_i according to Eq. (7). The details algorithm is described as **Algorithm 1**.

As the algorithm discussed, the media server maintains a list H_c to gather the query information R_U , and the end user uploads the R_U periodically. The media server leverages the upload R_U to calculate the λ_{c_i} and μ_{c_i} according to $\lambda_{c_i} = \frac{N_{v_i}^{c_i}(T_n)}{T_n}$ and $\mu_{c_i} = \frac{1}{CT_{c_i}}$. After the approximate value of λ_{c_i} and μ_{c_i} obtained, the media server estimates the demand of each video chunk according to Eq. (7). Therefore, we can obtain the video demands in a large scale distribution environment through this algorithm.

3.2 Stability-based Cooperative Carrier Selection Mechanism

In PSIM, a number of mobile nodes called carriers are selected. For carrier nodes, the buffer can be divided into two part: playback buffer and cooperative buffer. The playback buffer caches the current playback video chunks of users, which is the same as ordinary nodes. While the cooperative buffer aims to cache the popularity video chunks according to Eq. (7). In order to make full use of users' free storages and to guarantee the smooth playback for users, the system should choose the stable nodes to act as carriers, we first define the stability of nodes j as follows:

$$st_j = \frac{t_j}{p_v} \quad (8)$$

where t_j is the joint time of nodes and t is the playback time of video. The media server records the stability of nodes as $ST = (st_1, st_2, \dots, st_n)$ in descend order. For each video chunk c_i , the number of required carriers is $n_r^{c_i}$. For the chunk c_i which has the largest $n_r^{c_i}$ value chooses the first $n_r^{c_i}$ of ST nodes as carriers. The rest video chunks can be done follow the same method. This is because the more popular chunks should be cached by more stable carriers, which can guarantee the request success rate of popular video chunks. The detailed algorithm is described as **Algorithm 2**.

As the algorithm described, the aim of *Stability-based Cooperative Carrier Selection Mechanism* is to choose the relatively stable mobile nodes in the system to cache video contents with high demand. The media server maintains lists JT and C_p . JT is to record the join time of mobile node and C_p is to record the demand of video content. The media server sorts the video content demands in descend order and calculates the number of carrier nodes required for each chunk, choose the highest stability nodes in ST as the carrier of corresponding video chunk, and send messages to

Algorithm 2 : Cooperative Carrier Selection Mechanism

JT: the list for maintaining the join time of mobile node;
Cp: the list for maintaining the video chunk demand in descend order;
 $ST = \phi$, $JT = \phi$;
for each mobile node n_j joins the PSIM
 record the join time t_j of n_j ;
 add the t_j into JT ;
end for
for each mobile node n_j in PSIM
 calculate the nodes stability st_j by eq. (8);
 $ST[0]=st_j$;
 while($ST[0]>ST[n]$)
 $ST[n+1]=ST[n]$;
 $ST[n]=ST[0]$;
 end while
end for
while ($C_p[n] \neq 0$)
 choose $n_r^{c_i}$ of nodes as carrier of $C_p[n]$ in ST ;
 delete the chosen nodes from ST ;
end while

these mobile nodes to cache the video content.

4. PERFORMANCE EVALUATION

We compare the performance of the proposed solution PSIM with the popularity-based balanced chunk distribution algorithm of PMCV [7]. Both systems are deployed in a VANET-based environment by making use of the Network Simulator (NS2). We choose a 10 minutes long video clip and evenly divided it into 20 chunks, namely the length of each chunk is 30 s, the detailed simulation settings and performance comparison results are described as follows.

4.1 Testing Topology and Scenarios

Table 1 lists some important NS2 simulation parameters of the VANET. There are 1000 mobile nodes in VANET. The nodes are deployed in a square area of $x=2000$ m by $y=2000$ m. An urban topology, which consists of five horizontal and five vertical streets is considered. Every street has two lanes in each direction. The vehicular movement behavior follows the Manhattan mobility model[22]. In Manhattan mobility model, vehicles are moving along the street. When a vehicle reaches the specified destination, it is assigned a random residence time and restarts its movement with a new assigned speed and destination. Both solutions use the IEEE 802.11p WAVE network interface which only supports wireless communications between vehicle nodes for the exchange of control and state information and the transmission of video data, and the bandwidth of end user is set to 27 Mbps. We also create 20,000 synthetic user viewing log entries based on the interactive actions, measurements and statistics from[23]. The mobile nodes which finish the playback of the whole video will quit the system. The bandwidth at the media server side is set to 10 Mb/s. The n of $T = nT_c$ is set to 3 according to the repeated test results.

Table 1: Simulator Parameter Setting

Parameters	Value
Area	$2000 \times 2000m^2$
Channel	Channel/Wireless Channel
Network Interface	Phy /WirelessPhyExt
MAC Interface	Mac/802.11
bandwidth	27 Mbps
Frequency	5.9 GHz
Multiple Access	OFDM
Transmission Power	33 dBm
Wireless Transmission Range	250 m
Interface Queue Type	Queue/DropTail/PriQueue
Interface Queue Length	50 packets
Antenna Type	Antenna/OmniAntenna
Routing Protocol	DSR
Min mobile speed	0m/s
Max mobile speed	30m/s
Network layer protocol	IP protocol
Transport layer protocol	TCP

The cache size of mobile node is set to 4.

4.2 Performance Evaluation

The performance of PSIM is compared with that of PMCV in terms of average chunk seek delay (ACSD), average lookup success rate (ALSR), server stress and control overhead, respectively. Besides, in order to estimate the quality of experience (QoE) metric of PSIM, we compare the peak signal-to-noise ratio (PSNR) of PSIM with PMCV.

Average Chunk Seek Delay (ACSD): The mean difference between the time when the node receives the video data and the time when the node sends the request message indicate the average chunk seek delay. Fig. 3 plots the comparison results of PSIM and PMCV with the increased number of mobile nodes. PMCV's ACSD curve reaches the lowest value of 0.792 s, after which increases to roughly 1.2 s. This is because the increased mobile nodes reduce the cross community video chunk requests, therefore, the PMCV's ACSD decrease before 140. However, with the system scale keeps growing, the network congestion level goes up, the whole system suffers a long delivery latency and high packet loss rate, thus the ACSD increases rapidly. The PSIM follows the same trends, but unlike the popularity-based balanced chunk distribution algorithm (PMCV), PSIM analyses the evolution pattern of user playback behavior, which estimates the demand of each video chunk, and proposes a carrier selection mechanism which chooses the stable mobile nodes to cache video chunk with big demand. Therefore, the PSIM outperforms PMCV.

Average lookup success rate (ALSR): A node receives the data of requested chunk from other nodes after it sends first request message. The ratio between the number of successful lookup times and the number of total lookup times is considered as ALSR. Fig. 4 plots the ALSR comparison results of PSIM and PMCV with the increased number of mobile nodes. As figure shows, with the mobile nodes number increases, both PSIM and PMCV increase the ALSR rapidly. Since PSIM analyses the video chunk demand

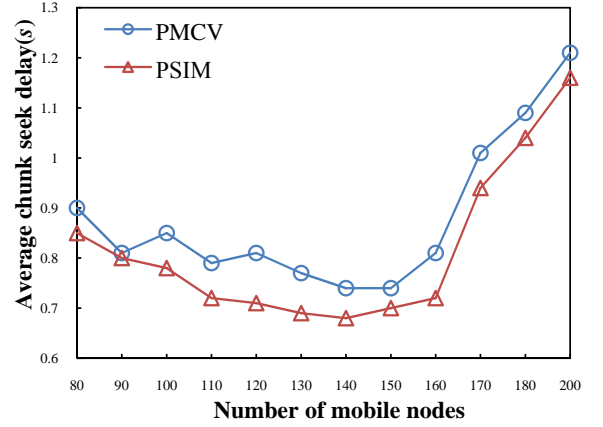


Figure 3: Average seek delay versus mobile nodes number

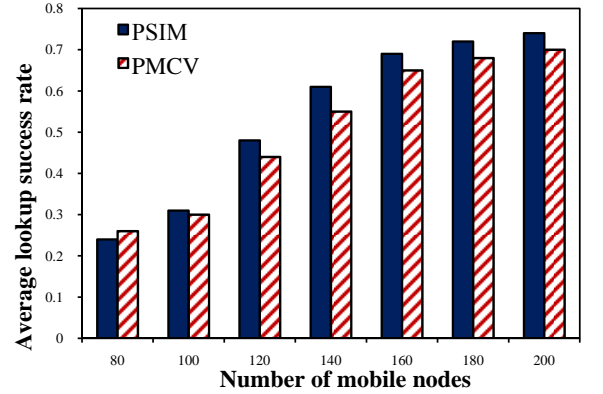


Figure 4: ALSR versus mobile nodes number

by building a SIR based model, and proposes a mechanism which ensures the popular video contents will be cached in relatively stable nodes, the resource distribution is more efficient and can better suit the dynamic network situation. Therefore, the PSIM can obtain the high level ALSR.

Server Stress: The ratio between the current number of streams serving mobile nodes at the media server side and the maximum number of streams supported by the server is defined as the server stress. Fig. 5 plots the server stress comparison results of PSIM and PMCV with the increased number of mobile nodes. Due to the system scale is small at the beginning, most of the users' requests are responded by the media server. Then with the increase of mobile nodes number, the probability of video chunk cache in mobile nodes also increases, therefore the server stress decreases rapidly. PMCV's popularity-based balanced chunk distribution algorithm only focuses on current video demand, ignores user request behavior with time varying. PSIM efficiently estimates the video chunk demand and considers the carrier stability, which ensures accurate pre-fetching of video chunks in mobile environment, thus the PSIM obtains the lower server stress than PMCV.

Control overhead: The bandwidth which is used for control message exchange per second is defined as control over-

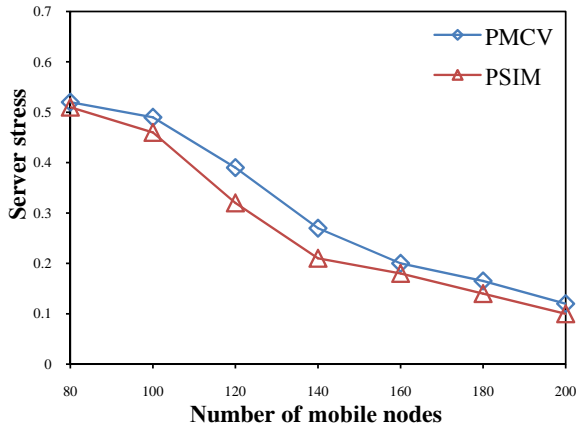


Figure 5: Server stress versus mobile nodes number

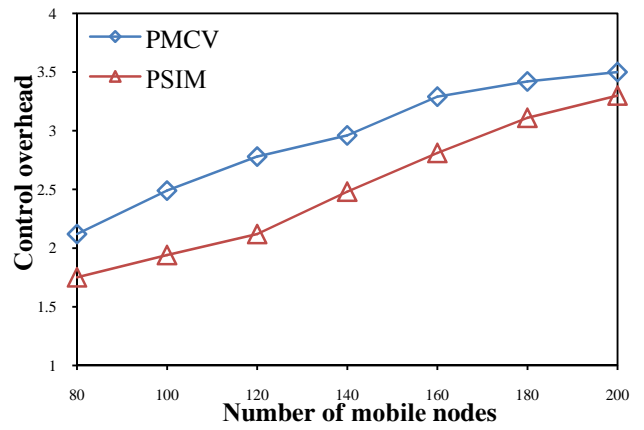


Figure 6: Control overhead versus mobile nodes number

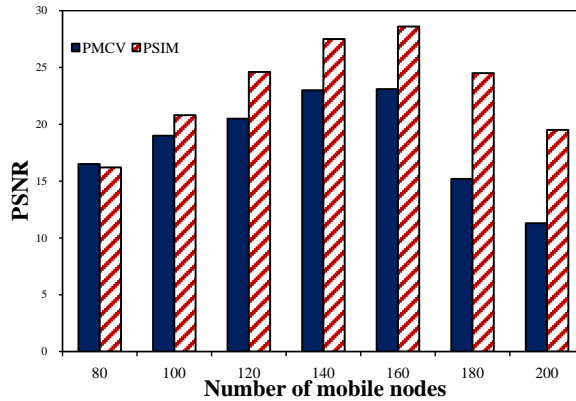


Figure 7: PSNR versus mobile nodes number

head. Fig. 6 shows the control overhead comparison results with the increase in the number of vehicles from 80 to 200. Due to the system scale increase, the curve corresponding to both solutions maintains a fast increasing trend with increasing number of system members. The curve of PMCV shows a faster rise trend than PSIM. When the number of mobile nodes reaches 120, the deviation between two solutions reaches the peak value as 0.66kb/s. The content caching mechanism in PMCV depends on user playback pattern, with the video play, the playback of user is varying, thus to ensure the accurate, the nodes should exchange the playback pattern frequently. In PSIM, mobile nodes upload the query information to media server every time interval T . Consequently, the control overhead of PSIM is lower than PMCV.

Peak Signal-to-Noise Ratio (PSNR): In this paper, in order to estimate the received video quality of end user, we use the peak signal-to-noise ratio (PSNR) as the video quality metric. The PSNR estimation rule is according to [7]. In this paper, we estimate the average PSNR of each mobile nodes in system. Fig. 7 shows the PSNR comparison results with the increase of the number of vehicles from 80 to 200. As it shows in the figure, both PMCV and PSIM experience an increasing trend before the number of mobile nodes reaches 160. However, with the system scale keeps expand-

ing, the PSNR of PMCV declines sharply. This is due to the congestion caused by the increase number of mobile nodes in mobile network, and which has obvious impact on QoE of end users. The PSIM declines from 160 to 200 with the same reason, but the curve of PSIM declines more smoothly. This is because PSIM employs a novel video chunk demands estimation algorithm based on video dissemination model to cache popular video content advanced. Moreover, PSIM utilizes the network resource more efficiently. Consequently, the PSNR of PSIM is better than PMCV.

5. CONCLUSIONS

This paper proposes a novel **Propagation-based Content Dissemination solution for Social Interactive Multimedia over MANETs (PSIM)**. PSIM formulates the video chunk dissemination as a SIR model. According to the SIR model, we obtain the interactive multimedia system's video demands evolution with time varying. Based on the problem formulation, we propose a *Propagations-based Video Chunk Demands Estimation Algorithm* to estimate the video demands in realistic environment, and introduce a *Stability-based Cooperative Carrier Selection Mechanism* to choose proper nodes to cache the video chunks. Simulation results show how PSIM outperform PMCV in terms of the average chunk seek delay, average lookup suc-

cess rate, server stress, control overhead, and peak signal-to-noise ratio, respectively.

6. ACKNOWLEDGMENTS

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