Video Ads Dissemination through WiFi-Cellular Hybrid Networks

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***Abstract*—In this paper, we propose a method for video ads dissemination through a hybrid network consisting of WiFi and cellular networks, in order to provide timely delivery of video ads with preferred content to users according to the users' contexts. In recent years, video download/streaming services for cellular phones have already become popular. Among various video delivery services, a service for disseminating video ads according to the users' contexts is expected to achieve high advertising effects. However, context-aware video ads dissemination will consume large bandwidth since the size of video ad is rather large and the same ad is required at different time from various users. We propose a new video ads dissemination method for mobile terminals which utilizes both WiFi and cellular networks. In the proposed method, a file of video ad is divided into pieces and each node exchanges the pieces with neighbor nodes using WiFi ad hoc communication so that the usage of cellular network is reduced. In order to make the method works effectively for a large number of nodes, we propose an algorithm where mobile nodes autonomously and probabilistically decide their actions without a central control. Through simulations, we confirmed that our method reduces cellular network usage by about 93% compared with a case that all nodes download video ads via cellular network, and works effectively in cases with a large number of nodes and high mobility.**

I. Introduction

Recently, cellular phones are capable of playing back videos, and accordingly watching digital TV and downloaded videos on cellular phones is becoming popular. In such a situation, video ads delivery services to cellular phones have attracted public attention. We can expect high advertising effect if users timely watch video ads with preferred contents on their cellular phones according to their contexts. The challenge in realizing such a video ads delivery service is that there may not be enough cellular network bandwidth to transfer various video ads so that users timely receive the video ads with preferred contents. We need a delivery method specialized to video ads dissemination which reduces usage of cellular network in an environment that many users require various video ads at different time.

Information exchange methods based on BitTorrent[1] are widely studied, and some methods such as a method in [6] enable file exchange among mobile terminals on mobile ad-hoc network. However, mobile ad-hoc network has some practical problems on data propagation ratio in wide area, due to limited communication range between terminals and mobility.

In this paper, we propose a method for delivering video ads for many users according to their contexts. Our method utilizes both cellular network and WiFi ad hoc communication between mobile terminals at the same time, aiming at reducing usage of cellular network while keeping high delivery ratio at user terminals. We assume an urban environment with many users. The users have mobile phones (terminals) capable of communication over cellular network and ad-hoc mode on WiFi. The terminals automatically choose some video ads, and set deadline of receiving each ad according to the context, which is the schedules of the user, life patterns, etc.

We propose a method to allow terminals to receive the requested contents until the deadline, while reducing usage of cellular network. In our method, a content, which is a file, is split into chunks and nodes exchange the chunks over WiFi communication in order to reduce usage of cellular network. In order to achieve high efficiency, scalability, and robustness, we propose a simple probabilistic distributed algorithm in which each terminal decides their own action autonomously without any central control.

In order to evaluate our proposed method, we conducted experiments by simulations supposing urban environment. The results showed that our method reduced the usage of cellular network by 93% while satisfying the deadline restriction, compared with the case that all terminals download video ads via cellular network. We also observed that higher terminal density results in greater reduction of cellular network usage.

II. Related Work

The straightforward way to disseminate video ads to mobile terminals according to the corresponding users' contexts is that each terminal downloads a video ad when the content of the ad is matched with its user's context. However, this method consumes considerable cellular network bandwidth and there is a scalability problem. Thus, we consider disseminating ads over both cellular network and WiFi network.

There are some studies which utilize IEEE 802.11 based ad-hoc network between mobile terminals to reduce cellular network cost and/or increase available bandwidth of cellular network.

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In [2], Wu, et al. proposed a hybrid system which utilizes both ad hoc network and cellular network so that a terminal in a overloaded cell can use a neighbor cell with less load through ad hoc network.

In [4], Luo, et al. proposed a method for 3G cellular network based on 1xEV-DO [3], which increases available bandwidth of an entire cell by integrating IEEE 802.11b-based ad-hoc network. In this method, packets sent to terminals with low communication quality (far from base station) are forwarded by terminals with good communication quality (near base station).

In [5], Kang, et al. proposed a technique to solve the anonymity problem (the information on who downloaded which contents is exposed) which occurs when utilizing 3G cellular network and ad hoc network at the same time. This method has a problem of extra overhead when a user downloads a content.

In [6], Rajagopalan, et al. proposed and implemented a method for realizing BitTorrent mechanism on ad hoc network. They evaluated the performance while varying the mobility and the size of a chunk. It is shown that their method is effective even in case of network partition. This method only uses ad hoc network, which means that the area size of data propagation range is practically limited.

In [7], [8], [9], Nandan, et al. proposed an ads dissemination system based on BitTorrent, where cars communicate with access points embedded at roadsides and with other cars through vehicular ad hoc network (VANET). This method targets cars as mobile nodes which move at high speed and realizes BitTorrent mechanism as is.

Our contribution in this paper and difference from the existing studies are as follows: First, our method targets pedestrians with mobile phones capable of communication using both cellular network and WiFi network at the same time. Second, our method disseminates video ads which are much larger than the data handled by existing studies. Third, our method is fully distributed and scalable to the number of nodes. Fourth, our method reduces cellular network usage as much as possible by utilizing ad hoc communication between mobile terminals via WiFi network.

III. Video Ads Dissemination Problem

In this section, we describe our assumptions for the video ads dissemination problem, and then formulate the problem.

A. Assumptions

1) Application Model: Let $U = \{u_1, u_2, \cdots, u_n\}$ denote the set of all terminals. We assume that each user has only one terminal, and thus, we use the term *user* and *user terminal*, interchangeably.

Let $C = \{c_1, c_2, \cdots, c_m\}$ denote the set of all video ads. Each content c_i consists of multiple chunks with the same size $Size$. We assume that each terminal u automatically decides a set of contents that the user u wants to receive and their deadlines for download according to u's context such as position, time, schedule, and other information. For example, if a user has a plan to go to a movie theater after work, the user terminal automatically selects some movie trailers, and sets the deadline to the time he/she leaves the office.

Let $u.Req = \{u.c_1, u.c_2, ...\} \subseteq C$ denote the contents the user u wants to download. Let $u.c_i.deadline$ denote the deadline for completing the download of the content $u.c_i$.

2) Communication Model: Each terminal u is capable of communicating over WiFi (e.g., IEEE 802.11 ad hoc mode) and cellular networks (e.g., CDMA) at the same time.

A geographical region called the *service area* is specified for video ads dissemination service. There are sufficient number of base stations of cellular network which cover the entire service area. We assume that 3G communication service such as HSDPA or CDMA2000 1x EV-DO[3] is available through cellular network. Let BW_c denote the cellular network bandwidth available for each user terminal, and CAP_c denote the maximum number of terminals which can connect to the base station to receive packets through the cellular network at the same time.

Let R_W denote the radio radius of WiFi. Each user terminal u can broadcast a packet in a circle with radius R_W centered at u through WiFi device, and the user terminals in u's radio range at time t denoted by $Ngh(u, t)$ will receive the packet according to Nakagami fading model [10], where terminal farther from the sender will successfully receive packets at smaller probability. We assume that CSMA/CA works when the terminals communicate through the WiFi network. Let BW_w denote the available bandwidth of the WiFi network within the same radio range. Here note that all terminals in the same radio range share bandwidth of BW_w.

There is a server s in the fixed network which each user terminal can access through cellular network. Each user terminal can download the specified chunk of any content stored in s through the cellular network. Each terminal can broadcast the downloaded chunk through the WiFi network.

B. Problem Definition

Let $c_{i,j}$ denote the j-th chunk of content c_i. Let T denote the latest deadline among all contents requested by users.

We formulate the problem which minimizes the sum of cellular network usage for all user terminals to download requested contents before their deadlines.

Let $d(u, ch, t)$, $b(u, ch, t)$, and $r(u, ch, t)$ denote the actions that the user terminal u downloads, broadcasts, and receives a chunk ch at time t, respectively. Let $Cell$, $Bcast$, and $Recv$ denote the sets of user's actions of "download", "broadcast", and "receive", respectively. The following constraints must be satisfied for these parameters.

First, for every chunk $u.c_{i,j}$ of contents that each user u requests, $u.c_{i,j}$ must be downloaded via cellular network or received via WiFi network. Thus, the following condition holds.

$$\forall u \in U, \forall u.c_i \in u.Req, \forall j, \exists t,$$
$$d(u, u.c_{i,j}, t) \in Cell \lor r(u, u.c_{i,j}, t) \in Recv \quad (1)$$

Each chunk in actions $Cell$ and $Recv$ must be obtained within its deadline, and each download takes $Size/BW_c$ units of time. Thus, the following condition holds.

$$\forall d(u, ch, t) \in Cell, t + Size/BW_c \leq ch.deadline \\ \wedge \forall r(u, ch, t) \in Recv, t \leq ch.deadline \quad (2)$$

Next, if a terminal u receives a chunk ch, the chunk ch must have been broadcasted by another terminal in u's radio range. We assume that the time that a sender terminal finishes sending a packet is equal to the time that a receiver terminal receives the packet. Thus, the following condition holds.

$$\forall r(u, ch, t) \in Recv, \exists b(u', ch, t') \in Bcast, \\ t = t' + Size/BW_w \wedge u' \in Ngh(u, t') \quad (3)$$

The number of terminals which use cellular network at the same time is limited. The time duration to download a chunk is $Size/BW_c$. Thus, the following condition holds.

$$\forall d(u, ch, t) \in Cell, \\ |\{u' \mid d(u', ch, t') \in Cell, u \neq u', |t - t'| \leq Size/BW_c\}| \\ \leq CAP_c \quad (4)$$

If a terminal broadcasts a chunk, the terminal must have downloaded the chunk via cellular network or received via WiFi network. Thus, the following condition holds.

$$\forall b(u, ch, t) \in Bcast \\ (\exists d(u, ch, t') \in Cell, t' + Size/W_c < t \\ \vee \exists r(u, ch, t'') \in Recv, t'' < t) \quad (5)$$

In WiFi network, only a terminal in its radio range can broadcast a chunk at one time. Thus, the following condition holds.

$$\forall b(u, ch, t) \in Bcast, \\ \neg \exists b(u', ch', t') \in Bcast, u \neq u' \wedge |t - t'| < Size/BW_w \quad (6)$$

We would like to obtain action sets $Cell$, $Bcast$, and $Recv$ which satisfy the above constraints and minimize the cellular network usage. Thus, the objective function of the target problem is defined by the following function.

$$\textbf{minimize } |Cell| \quad (7) \\ \textbf{subject to } (1) - (6)$$

We can solve the above problem by using a theorem prover, if the neighbor relationship among nodes are always known. However, in an actual environment, such a relationship is unknown due to dynamic behavior of nodes and the centralized control of solving a complex theorem at one place impedes scalability to the number of nodes. Therefore, in the next section, we propose a simple distributed heuristic algorithm to solve the above problem.

IV. Video Ads Dissemination Protocol

In this section, we briefly state our basic ideas to solve the problem defined in the previous section, and then go into the details of the proposed video ads dissemination protocol.

A. Basic Ideas

Our basic ideas are as follows:

(1) divide each content into multiple chunks of the same size like BitTorrent so that all terminals can contribute to the transmission of video ads contents
(2) let terminals exchange as many chunks as possible through WiFi network so that the cellular network usage is minimized
(3) let terminals autonomously decide their actions among downloading, broadcasting, or receiving a chunk based only on local information

Multiple nearby terminals downloading the same chunk via the cellular network is not efficient in terms of cellular network usage. In order to avoid this situation, it is desirable that only one terminal which knows the demand of a chunk in its proximity (e.g., one-hop neighbor) downloads the chunk and distributes it to the terminals in its proximity.

We propose a protocol consisting of two phases: (i) *demand exchange phase* where terminals in a WiFi radio range exchange the information on what chunks each terminal already retains and want to download in the future; and (ii) *action decision phase* where each terminal decides which action (download a chunk from cellular network, broadcast a chunk it already retains, or wait to receive a chunk broadcasted by other terminal) to take.

In the demand exchange phase, each terminal u periodically broadcasts a *hello message* which tells which chunks u wants to receive and which chunks it already retains. Each terminal creates and maintains a table called *neighbor table* from the received hello messages and probabilistically decides its action based on the neighbor table. Each terminal takes one of the following actions: (1) download a chunk (which no neighbor terminals have) via cellular network; and (2) broadcast a chunk via WiFi network for neighbor terminals.

In the action decision phase, each terminal autonomously decides its action based on the neighbor table. For efficient usage of cellular network, it takes an action for downloading a chunk via cellular network at the probability inversely proportional to the number of terminals which want to receive the chunk.

Similarly, for efficient exchange of chunks via WiFi network, each terminal broadcasts a chunk that it already retains at the probability inversely proportional to the number of terminals which have the same chunk.

B. Video Ads Dissemination Protocol

We give the detailed protocol description below.

Demand Exchange Phase: Before a terminal decides its action, it requires (1) *demand information* and (2) *possession information*, for each chunk of content.

Each terminal u informs other terminals of u's demand and possession information by periodically broadcasting a hello message as shown in Fig. 1.

Each hello message consists of demand information and possession information of its sender terminal, where demand information and possession information are represented by a content ID and a sequence of bits indicating whether the corresponding chunk is already retained or not, respectively.

Each terminal creates and maintains a neighbor table from received hello messages as shown in Fig. 2, where each row consists of a sender id and its hello message. This table is updated each time when a terminal receives a hello message. When a terminal does not receive hello messages for several times from a sender in the table, it removes the row of the sender.

Each terminal knows which chunks are not retained by any nearby terminals by scanning the neighbor table.

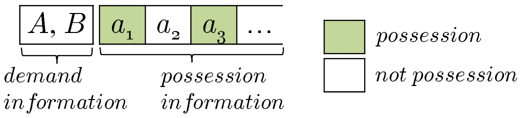

Fig. 1. Hello Message

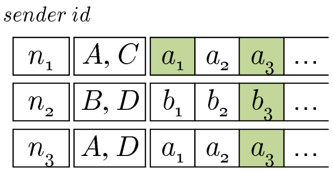

Fig. 2. Neighbor Table

Action Decision Phase: In this phase, we control terminals so that only a couple of terminals in each WiFi radio range downloads a chunk via cellular network and broadcasts another chunk via WiFi network, respectively.

Let $N_w(ch)$ denote the number of terminals which want a chunk ch in a WiFi radio range. We define the importance degree for a terminal in the WiFi radio range to download the chunk ch via cellular network by equation (8).

$$w_c(s) = \frac{1}{N_w(s)} \tag{8}$$

Here, the importance degree assigned to an action represents how importantly the terminal takes this action.

Each terminal broadcasts a chunk for its sharing if other terminals want the chunk. We regulate the probability of broadcast by each terminal so that multiple terminals do not broadcast the same chunk at the same time. Let $N_h(ch)$ denote the number of terminals which already retain a chunk ch. We define the importance degree for a terminal to broadcast the chunk ch via WiFi network by equation (9).

$$w_b(s) = \frac{1}{N_h(s)} \tag{9}$$

At each action, each terminal must decide what chunk is downloaded or broadcasted. We adopt a *roulette selection* based on the importance degree for decision. In roulette selection, the probability p_{ch} that a terminal selects a chunk ch with importance degree w_i is defined by the equation (10).

$$p_{ch} = \frac{w_i}{\sum_{k=1}^{N} w_k} \tag{10}$$

Flow of each phase: The demand exchange phase and the action decision phase are executed in parallel.

In the demand exchange phase, each terminal waits to receive hello messages from other terminals while it periodically sends a hello message. If the terminal receives a hello message, the terminal updates its neighbor table.

In the action decision phase, each terminal waits to receive messages from other terminals while other terminals broadcast chunks via WiFi network. If the terminal is not using cellular network, it selects a chunk from cellular network roulette based on equation (8) and (10) and starts downloading the chunk.

When the terminal is not using the WiFi network, it selects a chunk from broadcast roulette based on (9) and (10) and broadcasts a chunk via WiFi network at probability β. Here, β is a coefficient for avoiding collision by simultaneous packet transmission from multiple terminals.

V. Experimental Evaluation

In order to evaluate to what extent the proposed method suppresses the amount of cellular network usage when downloading video ads satisfying the deadline constraint, we evaluated our method by simulations reproducing usage in urban environments.

A. Configurations of simulation

For the evaluation, we developed a network simulator which simulates events at 1ms resolution. We recorded the following observed values every second.

- Elapsed time in simulation
- average time when all terminals obtain all requested chunks
- Average ratio of chunks downloaded via cellular network to all requested chunks

The ratio of using cellular network cr is defined as the ratio of the number of chunks N_d which are downloaded via cellular network to the number of chunks N_s as follows.

$$cr = \frac{N_d}{N_s} \times 100 \tag{11}$$

The number of contents is 4, and the size of each content is 1.5MB. Each content is divided into 1000 chunks, so the size of each chunk is 1.5kB. Each terminal randomly selects two contents and starts downloading when simulation starts. Deadline is set uniformly to 30 minutes after the start of simulation.

In order to simulate the bandwidth limitation of cellular network, we set the limitation so that each base station of cellular network can connect up to 64 terminals simultaneously. We set bandwidth for cellular network to be 1.2Mbps as follows, thus each chunk needs 10ms to be downloaded via cellular network.

$$\frac{1000}{10} \times 1.5kB \times 8bit = 1.2Mbps \tag{12}$$

The radio radius for WiFi is set to 200m, and we used Nakagami Distribution [10] as the probability of successful packet transmission over WiFi. The probability P_R of successful transmission is defined by (13) when the distance d between the transmitter and the receiver is less than 139m($= CR$), and (14) when d is more than CR. The probability distribution is also shown in Fig.3.

$$P_R = e^{-3(\frac{4d}{CR})^2}(1 + 3(\frac{4d}{CR})^2 + \frac{9}{2}(\frac{4d}{CR})^4) \quad (13)$$

$$P_R = e^{-3\gamma(\frac{(4d)^2}{CR})^2}(1 + 3\gamma(\frac{(4d)^2}{CR})^2 + \frac{9}{2}\gamma^2(\frac{(4d)^2}{CR})^4) \quad (14)$$

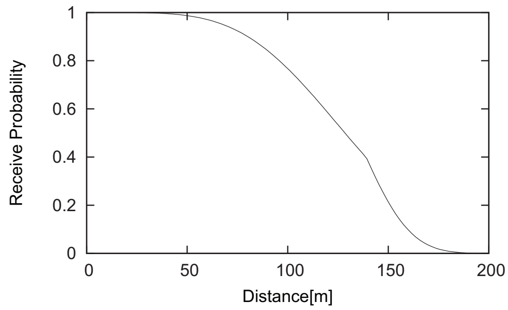

Fig. 3. Probability of successful packet transmission vs distance

In the simulations, we assume that broadcasting a packet in WiFi ad-hoc mode takes 7ms, and accordingly, the bandwidth is set to 1.7Mbps as shown in (15), according to the simulation parameters for IEEE 802.11 in QualNet[11]

$$\frac{1000}{7} \times 1.5kB \times 8bit \cong 1.7Mbps \quad (15)$$

When broadcasting a packet in WiFi ad-hoc mode, if another terminal simultaneously transmits a packet within the radio range, a packet collision occurs. In order to simulate this situation, we configured our simulator so that when a terminal receives two or more packets simultaneously, all packets are received as error packets. Each terminal uses CSMA/CA when transmitting a packet, so if a terminal hears another terminal sending a packet when starting transmitting a packet, the terminal does not start transmitting the packet. Since we are simulating broadcasting in ad-hoc mode, there is no exponential backoff.

B. Experiment method

We compared the case when only the cellular network is used and the case when WiFi and cellular networks are used together for parameters shown in Table I.

C. Result

In case of using only the cellular network, it took 155 seconds for all terminals to complete downloading. If WiFi ad-hoc communication is used together, the download took about 10 minutes, but the usage of cellular network was reduced to about 7% by adjusting parameters.

TABLE I
PARAMETERS FOR EXPERIMENT

Collision avoidance coefficient (β)	0.0005–0.005 by 0.0005 step
Hello message interval	5, 10, 30, 60 sec
Field size	500x500 m, 1000x1000m
Mobility	Fixed (0Km/h), Random Way Point(4km/h)
Number of terminals	500

a) Adjusting collision avoidance coefficient and interval of sending hello messages: Figs. 4 and 5 show the ratio of cellular network usage and the time to download all ads, respectively, in the field of 500×500m square with no mobility of nodes, while varying collision avoidance coefficient β and time interval h of sending hello messages.

The figures show that the ratio of cellular network usage gradually decreases as β decreases. This is because the frequency of packet collision is reduced, and thus success ratio of transmitting chunks and hello messages improves. The figures also show that if we increase the frequency of sending hello messages, the ratio of cellular network usage greatly decreases, and the minimum ratio reaches about 7%. This is because terminals are able to know which chunks are possessed by neighboring terminals, and thus the number of redundant downloading of chunks via cellular network is reduced.

The figures show that if we set β to 0.001 to 0.0025, the time to complete downloading is reduced. This is because if β is too large, too many collisions occur, while if β is too small, too small number of packets are exchanged via WiFi. If we reduce the frequency of sending hello messages, the time to download all ads is decreased. This is because many chunks are downloaded from the cellular network.

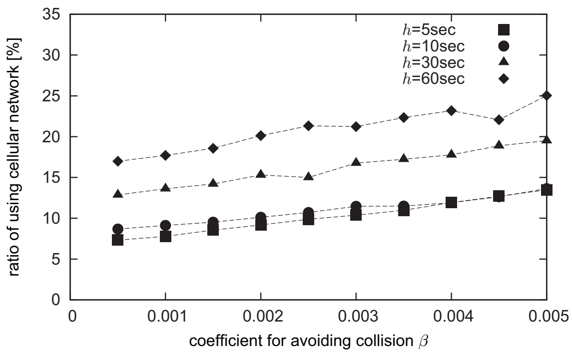

Fig. 4. Ratio of using cellular network in 500x500m field (no mobility)

b) Varying size of field: We compared the ratio of cellular network usage on the field of 500×500m square and 1000×1000m square. The result is shown in Fig. 6. The ratio is lower when the size of field is smaller, and when the field size is larger, some terminals could not finish downloading before deadline. This is because more terminals can receive a hello message transmitted by a terminal and more chunks can be received via WiFi, in denser node case.

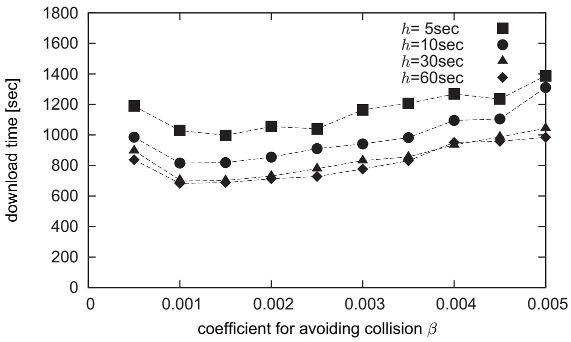

Fig. 5. Completion time of download in 500x500m field (no mobility)

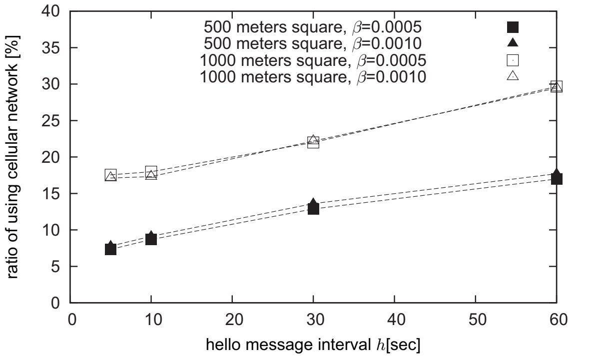

Fig. 6. Ratio of cellular network usage vs varied field size (no mobility)

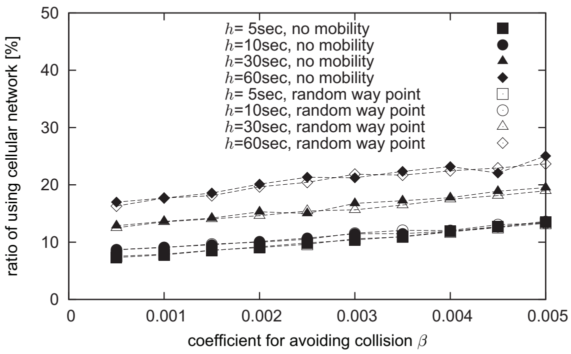

Fig. 7. Ratio of cellular network usage vs mobility

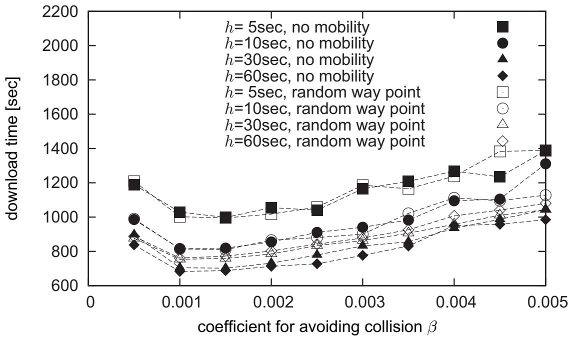

Fig. 8. Time needed to download vs mobility

c) Mobility: We introduced terminal mobility and observed the ratio of cellular network usage and the time to download all ads on the field of 500×500m square. The result is shown in Figs. 7 and 8. We see that no significant difference between the two cases. The reason is that in our method each terminal u uses only one-hop neighbor information and even when u's neighbor node goes out of a u's radio range, there is no significant influence of u's action decision. Thus, it is considered that our method is robust enough against node mobility.

VI. Conclusion

In this paper, we proposed a method for video ads dissemination for many users with various preferences and timeliness according to their contents. Our method makes use of both cellular network and the ad-hoc mode of WiFi, aiming at reducing cellular network usage. We evaluated our proposed method by simulations. We confirmed that our method satisfies the deadline constraints while reducing 93% of cellular network usage.

As part of future work, we will evaluate our method under more practical conditions in terms of user behavior model and contexts. We are also planning to develop a method based on multi-hop communication in WiFi network to further improve efficiency of our method.

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