Energy-Aware Cooperative Download Method among Bluetooth-Ready Mobile Phone Users

Yu Takamatsu, Weihua Sun, Yukiko Yamauchi, Keiichi Yasumoto, and Minoru Ito

Nara Institute of Science and Technology, 8916-5 Takayama, Ikoma, Nara 630-0192, Japan
`{yu-ta,sunweihua,y-yamauchi,yasumoto,ito}@is.naist.jp`

Abstract. In this paper, we propose a cooperative download method to save cellular network bandwidth when mobile phone users download large-size files. Our method allows users who want to acquire the same file to exchange part of the file called *chunks* when coming closer, while suppressing the power consumption by Bluetooth as much as possible. Moreover, our method lets each user actively use cellular network so as to acquire the whole file by the specified deadline.

Keywords: Cooperative Download, Energy-Awareness, Bluetooth, DTN.

1 Introduction

Recently, mobile phone users who download large-size contents from the cellular network are increasing as smartphone users increase and video sharing services such as YouTube become popular. However, if many users download large-size contents at the same time, quality of other communication services such as e-mail and web may be significantly deteriorated. In this paper, we propose a cooperative download method by which users exchange fragments of a content called *chunks* through Bluetooth with neighboring users while moving.

As a cooperative download method to reduce the load of network, BitTorrent has been used. However, BitTorrent is designed for the wired network and we cannot expect the good performance in mobile network. There are some cooperative download methods for mobile users. In [1], Conti, et al. studied how the MANET factors affect performance and overhead when implementing Gnutella in MANET and applied the cross-layer optimization to it. In [2], Rajagopalan, et al. designed and implemented the architecture of BitTorrent for MANET. In [3], McNamara et al. proposed a method where a user terminal identifies a specific terminal that is likely to have useful files while using public transportation. In [4], a cooperative download method for Bluetooth-ready terminals was proposed. However, these existing methods neither guarantee the acquisition of the whole file by the deadline nor consider efficiency in acquiring large-size files. As a cooperative download method that guarantees the acquisition of the whole file by the specified deadline, Hanano, et al. proposed a method utilizing both cellular and WiFi communications [5]. However, this method always turns on WiFi device and consumes a lot of power for WiFi communication.

We think that cooperative download methods for mobile phones should consider the following factors: (i) reducing cellular network load, (ii) suppressing power consumption, and (iii) acquiring contents by the specified deadline.

P. Sénac, M. Ott, and A. Seneviratne (Eds.): MobiQuitous 2010, LNICST 73, pp. 324–329, 2012.

Our method computes a schedule of communication actions for each user in order to reduce the cellular network load and to make users receive as many chunks as possible. Based on the schedule, user terminals (called *node*, hereafter) download some chunks and exchange them with encountered nodes. Our basic idea is that each user node retrieves a *contact table* specifying the probability and time to encounter other nodes from a server and determines a schedule of communication actions to exchange chunks based on it. Moreover, to reduce power consumed by Bluetooth device, we control each node's Bluetooth state and turn off the device during unnecessary time.

2 Problem Definition

In this section, we define the problem of the cooperative download utilizing both cellular and Bluetooth communication.

Communication Model. Each user terminal[1] u can communicate with other terminals which are in its communication range through Bluetooth. We do not consider the constraint of the number of sessions in the common radio range.

System Model. Each file that users want to acquire is called a *content*. Each content consists of multiple chunks of the same size. The deadline of each chunk is equal to the deadline of each content desired by user. There is a server in the Internet that stores the set of contents. Each terminal can download any chunk of any content stored in the server through cellular network regardless of present location and time.

Mobility Model. The field where users move is represented by a weighted graph $G = (V, E, w)$. The set of vertices V consists of intersections and spots (stations and malls, etc.) where users enter and leave spots but just pass through intersections. The set of edges E is the set of roads on which users move. The weight of each link $(v, v') \in E$ is the distance between vertices v and v' and denoted by $L(v, v')$. Each user appears at a spot (called *departure spot*) and moves to a destination spot selected by the user. A path (*route*) from the departure spot to the destination is decided when the user departs. However, a terminal does not know which route its user has selected. Each user moves on the beeline between the vertices and does not return to the edge the user has passed.

Terminals. Each terminal can utilize cellular and Bluetooth communications at the same time. We assume that the version of Bluetooth is 2.0+EDR. A terminal has information about the field G and knows which edge and location its user is currently moving by its built-in GPS device.

Server. A server has information about the field G. The server does not know the moving route of each user, but it statistically knows the probability that a user at an intersection v moves to an adjacent intersection v', denoted by $MP(v, v')$. In addition, the server knows the speed of each user.

Problem Definition. We consider the following constraints. First, each user must download every chunk through the cellular network or receive it through Bluetooth.

---

[1] Hereafter, we use the term *user*, *terminal*, and *node*, interchangeably.

Second, every chunk must be obtained by the deadline. Third, a terminal can send a chunk only to the terminals in its Bluetooth transmission range. Fourth, to send a chunk, a terminal must receive the chunk or download it in advance. Our target problem is to derive the set of actions (send or receive a chunk via Bluetooth or download a chunk via cellular network) of mobile terminals that satisfies the above constraints and minimizes the cellular network usage.

3 Cooperative Download Method Utilizing Bluetooth and Cellular

In our method, in order to allow each node to know the probability and the time of encountering other nodes, the server calculates a *contact table* for the node. Hereafter, we call the node under consideration (i.e., the owner of the contact table) *owner node*, and other nodes that will encounter the owner node *peer nodes*. Each entry of a contact table consists of the ID of a peer node, the meeting probability, the time when the owner node and the peer node will be in the communication range, and the set of chunks the peer node retains.

Our method consists of two phases, *contact table construction phase* and *action phase*. These two phases are executed repeatedly to update the contact table whenever a user registers its present location and retaining chunks with the server.

3.1 Contact Table Construction Phase

Contact table construction phase is executed by the following procedure.

(1) Information Registration to the Server. When a node u leaves intersection v_u at time T_u, u records v_u and T_u. Then, as soon as u recognizes the next intersection to reach[2], say v'_u, u informs the server of the following information: ID of u, v_u, T_u, v'_u, retaining chunks, and desired chunks. Whenever u passes through an intersection, u registers this information with the server. The size of this information is at most several KBs and overhead to register the information is sufficiently small.

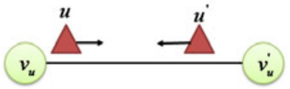
(2) Refining Encounter Candidate Node. To save cellular network usage, the server should be able to reduce the size of a contact table sent to each node.

A contact table should include the information that can identify the chunks with smaller opportunities to obtain them from peer nodes than other chunks. We call such a chunk with low acquisition opportunity *rare chunk*. In our method, the server selects entries of a contact table according to the following two conditions. First condition is whether the peer node u' of the entry will encounter the owner node u before u arrives at the next intersection. Second condition is whether the peer node u' retains some chunks that u wants to obtain. The server calculates and writes in the contact table the meeting time and probability of only the peer nodes that satisfy the above two conditions.

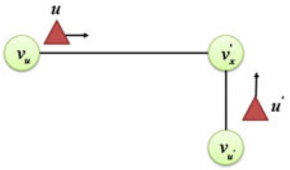
(3) Calculation of Meeting Time and Meeting Probability. The server calculates the time and probability that the owner node meets with the peer nodes. Meeting time

---

[2] We assume that each node can identify the next intersection from the position measured by GPS some time after passing the previous intersection.



(a) two nodes are approaching each other on the same edge



(b) two nodes are moving toward the same intersection

Fig. 1. Two Cases that Two Nodes May Encounter

Table 1. Parameter for Simulation

Number of chunks per content	100
Chunk size	150KB
Cellular network bandwidth per node	1.2Mbps
Bluetooth bandwidth per node	700Kbps
Bluetooth radio radius	10m
Number of desired contents per node	2 (Zipf distribution)
Node speed	1.0m/s
Number of chunks initially retained	0–50
Time length to deadline	8 min.
Simulation time	60 min.
Threshold α	0.25
Threshold β	100%
Number of contents	10, 20, 40, 100
Number of nodes	500

is calculated from length of road and speed of each node which the server knows in advance and the information which each node has registered with the server. There are the following two cases that two nodes u and u' encounter: **(case 1)** u and u' are moving on the same edge as shown in Fig. 1 (a); and **(case 2)** u and u' are moving on different edges but toward the same intersection as shown in Fig. 1 (b). Let v_u and v'_u denote the intersection that node u left and the next intersection toward which u is moving, respectively. If node u encounters node u', the sum of moving distance of u and u' will be equal to $L(v_u, v'_u)$ in (case 1) or the sum of $L(v_u, v'_u)$ and $L(v_{u'}, v'_{u'})$ in (case 2). Taking this into consideration, the server calculates the meeting time of node u with node u', denoted by $CT_u(u')$, by formula (1). Here, a is the speed of node, and T_u is the time when node u left the last intersection.

$$CT_u(u') = \begin{cases} \frac{1}{2}(\frac{L(v_u, v'_u)}{a} + T_u + T_{u'}), & \text{case 1} \\ \frac{1}{2}(\frac{L(v_u, v'_u) + L(v_{u'}, v'_{u'})}{a} + T_i + T_h), & \text{case 2} \end{cases} \qquad (1)$$

Meeting probability of node u with node u', denoted by $P_u(u')$, is 1 in (case 1) or $MP(v'_u, v_u)$ in (case 2).

The server constructs a contact table by calculating the meeting time and meeting probability of node u with possible peer nodes and sends the contact table to u.

It is possible to reduce cellular network load by including in the contact table only entries whose meeting probability is higher than a predefined threshold α.

3.2 Action Phase

Selection of Acquired Chunks. To exchange chunks efficiently among users, it is desirable that each node acquires rare chunks prior to others. The opportunity that node u receives chunk ch from node u' ($u \neq u'$), denoted by $w_u(u', ch)$, is calculated by formula (2). Here, $D_{u'}$ is the set of chunks which node u' retains.

$$w_u(u', ch) = \begin{cases} P_u(u'), & \text{if } ch \in D_{u'} \\ 0, & \text{otherwise} \end{cases} \qquad (2)$$

From the information of retaining chunks of all nodes registered in a contact table, the overall opportunity that node u receives chunk ch, denoted by $Wh_u(ch)$, is calculated by formula (3). Here, N_u is the set of peer nodes registered in node u's contact table and M_u is the set of chunks that node u wants to obtain.

$$Wh_u(ch) = \begin{cases} \sum_{u' \in N_u} w_u(u', ch), & \text{if } \; ch \in M_u \\ \infty, & \text{otherwise} \end{cases} \tag{3}$$

Since a chunk with small $Wh_u(ch)$ has small opportunity to be received, node u acquires such chunks prior to others.

Control of Bluetooth State. To establish Bluetooth connection between nodes, it is necessary to take synchronization between a terminal in inquiry state called *inquiry node* and a terminal in inquiry scan state called *inquiry scan node*. Total energy consumption for inquiry scan state is lower than inquiry state [4]. In our method, Bluetooth device is turned on only when the node encounters other nodes according to the meeting time in its contact table. In addition, each node searches with inquiry state peer nodes whose meeting probability is higher than a specified threshold β (e.g., 80%). For other peer nodes, each node waits inquiry packets with inquiry scan state.

Download Chunks through Cellular Network. There will be some chunks that cannot be received through Bluetooth by deadline. To meet the deadline, each node downloads chunks through the cellular network so as to keep the ratio of retaining chunks to be proportional to the ratio of the elapsed time to the time to deadline, as in [5].

4 Experimental Evaluation

In this section, we evaluate the proposed method with our own simulator that reproduces the Bluetooth session establishment behavior, inquiry and inquiry scan.

4.1 Simulation Settings

Parameters used in each experiment are shown in Table 1. The target field, moving routes of nodes, movement probabilities of nodes at intersections are shown in Fig. 2. The field is a $500m \times 500m$ square. We set four spots A–D on the center of some roads where nodes appear and disappear. Each node moves between spots. When a node finishes movement, it disappears from the field and a new node appears. Bluetooth session establishment time was set to 2 sec. according to [4].

We compared the performance of the proposed method with the following methods.

Always Activated Method (AAM). Nodes always turn on Bluetooth device. Bluetooth state is set to inquiry and inquiry scan alternately. When downloading and exchanging chunks, the node randomly selects some of the desired chunks.

Contact Oracle. Each node exactly knows when it meets each peer node by oracle. The node turns on Bluetooth device and starts communication only when peer nodes with desired chunks are in the Bluetooth communication range. The ways of selecting desired chunks are the same as the AAM.

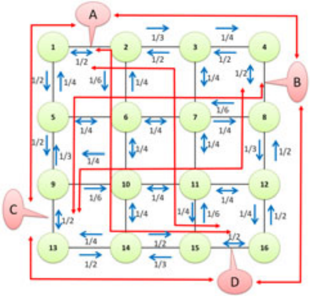


Fig. 2. Field, Moving Route and Moving Probability

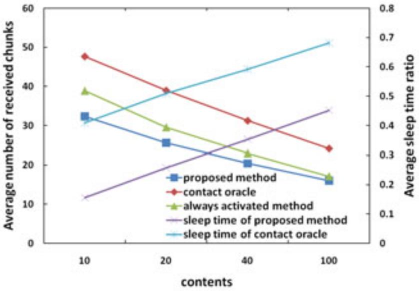


Fig. 3. Number of Received Chunks and Total Sleep Time vs. Number of Contents

In order to evaluate the reduction of the cellular network usage, we measured the average number of chunks that were received from peer nodes during simulation time. In addition, we measured the average ratio of the time during which node turned off the Bluetooth device.

4.2 Experimental Result

The experimental result is shown in Fig. 3. The number of received chunks and total sleep time ratio in our method are 70% and 50 – 70% of contact oracle, respectively. Our method achieved 15 – 45% total sleep time ratio, while the number of received chunks in our method gets closer to AMM as the number of contents increases.

5 Conclusion

In this paper, we proposed a cooperative download method, aiming to reduce usage of cellular network and save power consumption. In our method, user terminals utilize a contact table calculated by the server to make it turn on Bluetooth device only when they can exchange chunks. As part of future work, we will implement the proposed method on smartphones and evaluate the power consumption with real devices.

References

1. Conti, M., Gregori, E., Turi, G.: A cross-layer optimization of gnutella for mobile ad hoc networks. In: Proc. of ACM MobiHoc 2005, pp. 343–354 (2005)
2. Rajagopalan, S., Shen, C.-C.: A Cross-layer Decentralized BitTorrent for Mobile Ad hoc Networks. In: Proc. of Mobiquitous 2006, CD-ROM (2006)
3. McNamara, L., Mascolo, C., Capra, L.: Media Sharing based on Colocation Prediction in Urban Transport. In: Proc. of ACM MobiCom 2008, pp. 58–69 (2008)
4. Lee, U., Jung, S., Chang, A., Cho, D.-K., Gerla, M.: P2P Content Distribution to Mobile Bluetooth Users. IEEE Trans. on Vehicular Technology 59(1), 344–355 (2010)
5. Hanano, H., Murata, Y., Shibata, N., Yasumoto, K., Ito, M.: Video Ads Dissemination through WiFi-Cellular Hybrid Networks. In: Proc. of IEEE PerCom 2009, pp. 322–327 (2009)