

# Node selection in Peer-to-Peer content sharing service in mobile cellular networks with Reduction Bandwidth

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**Abstract:** The peer-to-peer service has entered the public limelight over the last few years. Several research projects are underway on peer-to-peer technologies, but no definitive conclusion is currently available. Comparing to traditional server-client technology on the internet, the P2P technology has capabilities to realize highly scalable, extensible and efficient distributed applications. At the same time mobile networks such as WAP, wireless LAN and Bluetooth have been developing at breakneck speed. Demand for using peer-to-peer applications over PDAs and cellular phones is increasing. The purpose of this study is to explore a mobile peer-to-peer network architecture where a variety of devices communications each other over a variety of networks. In this paper, we propose the architecture well-adapted to mobile devices and mobile network. In P2P file sharing systems over mobile cellular networks, the bottleneck of file transfer speed is usually the downlink bandwidth of the receiver rather than the uplink bandwidth of the senders. In this paper we consider the impact of downlink bandwidth limitation on file transfer speed and propose two novel peer selection algorithms named DBaT-B and DBaT-N, which are designed for two different cases of the requesting peer's demand respectively. Our algorithms take the requesting peer's downlink bandwidth as the target of the sum of the selected peers' uplink bandwidth. To ensure load balance on cells, they will first choose a cell with the lowest traffic load before choosing each peer.

**Keywords:** Network Security, P2P, Mobile Cellular Networks, Peer Selection, Load Balance, Reduction Bandwidth

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## 1. Introduction

In the cooperated network, the server-client technology has been used as the traditional way to handle network resources and provide Internet services. It has advantages to regulate Internet services by only maintain limited number of central servers. As a result, peer-to-peer technology has become popular and has been used in networks which manage vast amounts of data daily, and balance the load over a large number of servers.

At the same time, mobile Internet services have become very popular. In the past four years, the market of mobile Internet services has considerably grown successful in Japan where imode is the most famous example. The mobile environment is different from the fixed Internet in that it is an extremely constrained environment, in terms of both communication and terminal capabilities. This should be taken into account when developing systems which will work in

a mobile environment. Additionally, various wireless have been emerging of network environments such as IMT-2000 (International Mobile Telecommunications-2000, for example FOMA)[10], Wireless LAN and Bluetooth, and users can select them to satisfy their network demands. In the near future, an environment where many sensors, users and different kind of objects exist, move and communicate with one another, called "ubiquitous communication environment", will appear.

In this paper we study the problems of peer selection in P2P file sharing systems over mobile cellular networks with consideration of downlink bandwidth limitation. Our motivation is that, since the file transfer speed is limited by the requesting peer's downlink bandwidth, some other performance indicator such as load balance on cells should be focused on. So our goal is to achieve load balance on cells under the precondition that the requesting peer's demand is satisfied. In P2P file sharing systems the requesting peer's

demand can be divided into two cases, one is that the requesting peer demands a lower bound of the sum of the selected peers' uplink bandwidth (as in some P2P media sharing systems [5]), and the other is that the requesting peer demands a certain number of selected peers (denoted as *Numwant* in BitTorrent Tracker protocol [6]). We consider the two cases both and propose two algorithms for the two cases respectively. The first one is named DBaT-B (Downlink Bandwidth as Target, Bandwidth satisfied), and the second one is named DBaT-N (Downlink Bandwidth as Target, Number satisfied). Major features of our algorithms can be described as follows. First, they take the requesting peer's downlink bandwidth as the target of the sum of the selected peers' uplink bandwidth. Second, they choose a cell with the lowest traffic load before choosing each peer. Difference of the two algorithms lies in using different criteria in each peer selection round to satisfy the different demand. Moreover, we also provide a Fuzzy Cognitive Map (FCM) [7] that can be used in our algorithms to estimate peers' service ability according to multiple influential factors. Simulation results show that in respective cases DBaT-B and DBaT-N algorithms can both achieve favorable load balance on cells in mobile cellular networks while ensuring good file transfer speed, and compared with other two traditional peer selection algorithms our algorithms are nice improvements.

The principal goal of our work is thus to design a mobile peer-to-peer architecture and a general peer-to-peer platform that enhances communication capabilities for mobile clients, by utilizing network resources efficiently and supporting mobility in an integrated and practical way.

The rest of this paper is organized as follows. Section 2 gives an overview of our peer-to-peer architecture, describes each key element of our architecture and mobile device adaptation. Section 3 describes the Algorithm design. We introduce DBaT-B and DBaT-N algorithms in detail. Section 4 we present the FCM that can be used in our algorithms. In Section 5 we evaluate the performance of our algorithms through simulations. Finally we give out conclusions for this paper.

## 2. Architecture

### 2.1. Architecture Overview

The proposed mobile peer-to-peer architecture is shown in Fig. 1. All of the peer-to-peer communication entities that have a common set of interest and obey a common set of policies construct one peer-to-peer community. This architecture consists of the following basic components:

**Peer-to-peer node:** The peer-to-peer node is an independent communication entity in the peer-to-peer network.

**Mobile proxy:** Theoretically, all the mobile devices (e.g. WAP or i-mode terminals) can be independent nodes in the peer-to-peer architecture. However some of them are functionally limited and cannot act as autonomous nodes. The mobile proxy is a function in a node, which acts as a proxy

for the mobile devices with constrained capability, so that these mobile devices can join the peer-to-peer architecture.

**Pure peer-to-peer architecture:** There are only peer-to-peer nodes in the pure peer-to-peer architecture. The proposed pure peer-to-peer architecture is shown in Fig. 2 (a). The connection between peer-to-peer nodes is established on their mutual trust. Each peer-to-peer node is an independent entity and can participate in and leave the peer-to-peer network at its convenience. Messages are sent from a peer-to-peer node to another one directly or by passing them via some intermediary peer-to-peer nodes.

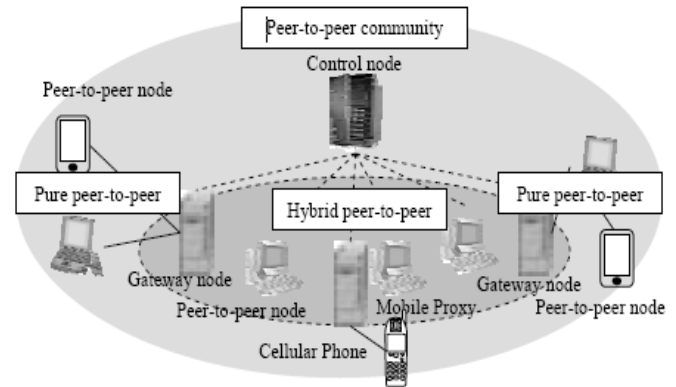


Fig 1. The mobile peer-to-peer architecture

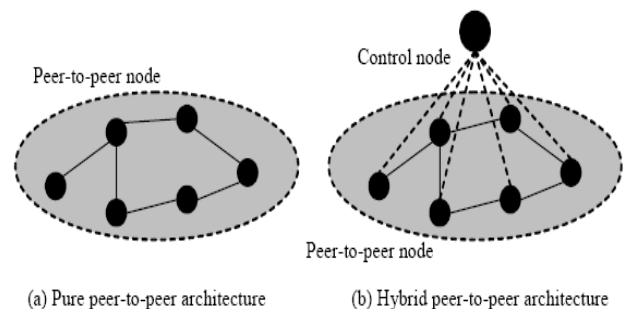


Fig 2. Pure peer-to-peer and hybrid peer-to-peer

**Hybrid peer-to-peer architecture:** The hybrid peer-to-peer architecture resolves the disadvantages of the pure peer-to-peer architecture such as inefficient routing, splits of network and lack of security, by introducing a control node. The proposed hybrid peer-to-peer architecture is shown Fig. 2 (b). In our architecture, the control node provides the functions for providing routing information to a destination node, discovering the first peer-to-peer node, recovering from the splitting of the peer-to-peer network, improving the network topology and security such as authentication, in order to improve the inefficiency of the pure peer-to-peer architecture. To realize the hybrid peer-to-peer architecture, the control node and the gateway node are defined.

**Control node:** Control node is an administrative entity which manages a peer-to-peer community in the peer-to-peer network. It provides several functions independent of particular applications such as name resolution, route information provision, the first peer-to-peer discovery, net-

work topology optimization, node authentication and multicast group management.

**Gateway node:** Gateway node is a connection entity linking between a pure peer-to-peer network and a hybrid peer-to-peer network. It provides for nodes in pure peer-to-peer network with several proxy functions such as routing information provision, node authentication, and multicast group management. A control node receives a request from a peer-to-peer node and provides it with routing information, topology optimization function and security function. A gateway node collects topology information on a pure peer-to-peer network and reports it to the control node.

## 2.2. Mobile Device Adaptation

Another distinct characteristic of this architecture is that it allows mobile devices to take part in the peer-to-peer network via a mobile proxy node. While a mobile device, such as a cellular phone, may have enough capabilities to act as an independent peer-to-peer node in the future, it still has the following limitations at this time:

- Limited storage
- Small runtime heap
- Modest processor performance
- Constrained electrical power

Thus, a current mobile device can't fully perform the role of a peer-to-peer node that offers services to other peer-to-peer nodes in a peer-to-peer network. In order to incorporate a mobile device into a peer-to-peer network, some functions must be done by other nodes on behalf of a mobile device. Through the cooperation of a mobile proxy, a mobile device can virtually act as a peer-to-peer node and can perform the necessary functions in the peer-to-peer architecture. From the point of view of the peer-to-peer architecture, mobile devices are modeled in the three ways.

In Fig.3(a), mobile devices share the same proxy node. From the point of view of the network, the mobile proxy acts as one peer-to-peer node. In Fig. 3(b), a mobile device has its own node name and acts as a separate peer-to-peer node in the peer-to-peer architecture.

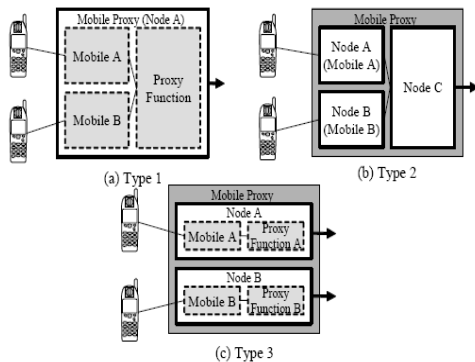


Fig 3. Mobile Device Adaptation

For realizing this type of mobile proxy, some proxy functions should be implemented on Node C such as transforming a message received from a mobile device into a

message of a peer-to-peer protocol. In Fig. 3(c), a pair of a mobile device and a proxy function constructs a peer-to-peer node in the peer-to-peer architecture. In this case, a mobile device has its own node name, and acts as a separate node through a mobile proxy. The mobile proxy does not act as an independent node. It will be decided by requirements of peer-to-peer applications, as to which type of mobile proxy model will be preferable.

## 3. Dbat Algorithms

In this section we depict the details about DBaT-B and DBaT-N algorithms, which can be denoted as DBaT algorithms as a whole. Due to the existence of downlink bandwidth limitation, it is unnecessary to always choose peers with high uplink bandwidth. So DBaT algorithms take the requesting peer's downlink bandwidth as the target of the sum of the selected peers' uplink bandwidth. Besides, to ensure load balance on cells, DBaT algorithms will first choose a cell with the lowest traffic load before choosing a peer.

In DBaT algorithms service ability is used as one of the criteria for peer selection. As we have mentioned before, in mobile environments estimation of peers' service ability is complicated since it is influenced by multiple factors. In this section we just focus on the details of DBaT algorithms. A method about how to estimate peers' service ability in P2P file sharing systems over mobile cellular networks will be provided in next section. Here we list the common notations used in this section and their meanings:

- $B_r$ : Upper bound of the requesting peer's downlink bandwidth.
- $L_{est}$ : Estimated traffic load on a cell after a peer in this cell is selected. Initial value of  $L_{est}$  is just the initial traffic load on this cell before peer selection.
- $B_{pa}$ : Available uplink bandwidth of a candidate peer.
- $B_{pe}$ : Estimated uplink bandwidth of a peer after it is selected.

The traffic load on a cell is defined as the ratio of the current used radio bandwidth over the total radio bandwidth of the base station in the cell. For example, assuming that the current used radio bandwidth of a 3G base station is 1.2Mbps, the traffic load on this cell is 0.6 since the maximum radio bandwidth provided by this 3G base station is 2Mbps. Obviously the value of traffic load on a cell ranges from 0 to 1.

### 3.1. Dbat-B Algorithm

DBaT-B algorithm is designed for the case that the requesting peer demands a lower bound (denoted as  $B_d$ ) of the sum of the selected peers' uplink bandwidth. The relationship between  $B_d$  and  $B_r$  can be discussed as follows.

On one hand, if  $Bd$  is higher than  $Br$ , it makes no sense due to the performance limitation imposed by  $Br$ . On the other hand, if  $Bd$  is lower than

$Br$ , we can easily take  $Bd$  as  $Br$  and DBaT-B algorithm still works. Here we list the notations used in this subsection and their meanings:

- $B_s$ : Sum of the estimated uplink bandwidth of the selected peers. Initial value of  $B_s$  is 0.
- $\Delta B$ : Difference between  $Br$  and  $B_s$ , more specifically,  $\Delta B = B_s - Br$ .

In more detail, DBaT-B algorithm works in the following steps:

- Step 1. Choose a cell:
  - 1-1. Sort the cells according to the traffic load;
  - 1-2. Choose a cell with the lowest traffic load, go to Step 2.
- Step 2. Check all the peers in this cell with  $Bpa$  and  $|\Delta B|$ :
  - 2-1. Compare the values of  $Bpa$  of all the candidate peers in this cell with  $|\Delta B|$ ;
  - 2-2. If there is no peer satisfying  $Bpa > |\Delta B|$ , go to Step 3, otherwise go to Step 4.
- Step 3. Choose a peer in this cell according to service ability:
  - 3-1. Choose a peer with the highest service ability in this cell;
  - 3-2. Calculate  $Lest$  for this cell according to (1), calculate  $Bpe$  according to (2);
  - 3-3. Recalculate  $B_s$  and  $\Delta B$ , go to Step 1.
- Step 4. Check all the peers in this cell with  $Bpe$  and  $|\Delta B|$ :
  - 4-1. Calculate the value of  $Lest$  and  $Bpe$  for each candidate peer that satisfies  $Bpa > |\Delta B|$  in this cell;
  - 4-2. Compare the values of  $Bpe$  of all the peers that satisfy  $Bpa > |\Delta B|$  in this cell with  $|\Delta B|$ ;
  - 4-3. If there is no peer satisfying  $Bpe > |\Delta B|$ , go to Step 3, otherwise go to Step 5.
- Step 5. Choose a peer in this cell according to service ability,  $Bpe$  and  $|\Delta B|$ :
  - 5-1. Choose a peer with the highest value of estimated service ability from the peers that satisfy  $Bpe > |\Delta B|$  in this cell;
  - 5-2. Recalculate  $B_s$  and  $\Delta B$ , end the peer selection process.

### 3.2. Dbat -N Algorithm

DBaT-N algorithm is designed for the case that the requesting peer demands a certain number of selected peers. In traditional fixed network environments, file transfer speed usually increases with more serving peers. However, in mobile cellular network environments, file transfer speed may not increase as the number of serving peers increases because it would be bottlenecked by the downlink bandwidth limitation. So the motivation of DBaT-N is to choose a certain number of selected peers whose sum of uplink bandwidth is fitly over  $Br$ . Here we list the notations used in this subsection and their meanings:

- $n$ : Number of selected peers demanded by the requesting peer.
- $Bref$ : Referenced value of uplink bandwidth for peer selection, more specifically,  $Bref = Br / n$
- $B'$ : Cumulative referenced value of uplink bandwidth for peer selection.
- $\Delta b$ : Difference value of uplink bandwidth for peer selection. Initial value of  $\Delta b$  is set to 0.
- $S$ : Number of candidate peers in a cell.
- $K$ : Number of peers in the candidate set in a cell.

In each peer selection round,  $Bref$  can be seen as a fixed target of the selected peer's uplink bandwidth,  $B'$  can be seen as the actually used target of the selected peer's uplink bandwidth since it represents the adjustment of  $Bref$  after last peer selection round, and  $\Delta b$  is used to record the value difference between  $B'$  and a candidate peer's estimated uplink bandwidth. So, the basic idea of DBaT-N can be described as follows. In each peer selection round DBaT-N chooses a peer with uplink bandwidth close to  $B'$ , and in the last round it chooses a peer that makes the sum of selected peers' uplink bandwidth fitly over  $Br$  according to  $\Delta b$ .

In more detail, DBaT-N algorithm works in the following steps:

- Step 1. Choose a cell:
  - 1-1. Sort the cells according to the traffic load;
  - 1-2. Choose a cell with the lowest traffic load, go to Step 2.
- Step 2. Calculate  $\Delta b$  for each peer in this cell:
  - 2-1. Calculate the value of  $Lest$  and  $Bpe$  for each candidate peer in this cell;
  - 2-2. Calculate  $B' = Bref - \Delta b$ , then calculate  $\Delta b = Bpe - B'$  for each candidate peer in this cell;
  - 2-3. Check the value of  $n$ , if  $n > 1$ , go to Step 3, if  $n = 1$ , go to Step 4.
- Step 3. Choose a peer according to service ability,  $K$ 
  - 3-1. Choose a peer with the highest estimated service ability from the  $K$  peers that have the lowest values of  $|\Delta b|$  in this cell;
  - 3-2. Record the value of  $Bpe$  and  $Lest$  for this peer, record the value of  $\Delta b$ , let  $n = n - 1$ , go to Step 1.
- Step 4. Choose a peer according to service ability,  $K$  and  $\Delta b$ :
  - 4-1. Choose a peer with the highest estimated service ability from the  $K$  peers that have the lowest values of  $\Delta b$  and satisfy  $\Delta b > 0$  in this cell;
  - 4-2. Record the value of  $Bpe$  and  $Lest$  for this peer, record the value of  $\Delta b$ , end the peer selection process.

In Step 4, it is possible that the number of peers satisfying  $\Delta b > 0$  (denoted as  $k$  here) is lower than  $K$ . In this case, the algorithm will take  $k$  as  $K$  in Step 4. Moreover, it is also possible that the value of  $k$  is 0.



## 4. Fcm for Estimation of Peers' Service Ability

Service ability in environments of mobile cellular networks:

- *Uplink Bandwidth*. A peer's uplink bandwidth has direct and great impact on its service ability.
- *Delay*. The delay between a peer and the requesting client will affect the peer's service ability to some extent.
- *Packet Loss Probability*. According to our simulations, Packet loss probability on the link between a peer and the requesting client impacts the peer's service ability greatly.
- *SINR*. SINR (Signal to Interference and Noise Ratio) value of a radio link can indicate the radio link quality which has a direct impact on the packet loss probability of the link.
- *Energy Level*. Since the battery energy is relatively limited on mobile hosts, the energy level has a direct impact on *peer churn probability* which greatly affects the peer's service ability. Moreover, a peer with higher energy level is expected to stay longer.
- *Lingering Time*. As in we assume that if a peer stays longer its *peer churn probability* is lower.
- *Moving Speed*. In mobile environments, a higher moving speed usually means a lower radio link quality, and thus means a higher packet loss probability. Moreover, a peer with higher moving speed often has higher *cell handover probability* which affects its service ability to some extent.

### 4.1. Simple P2P Protocol for Cellular Phones

We have designed the P2P protocol for cellular phones with a simple text format over HTTP, since they can only support HTTP and cannot process the protocol based on XML. The P2P protocol for cellular phones is provided by mobile proxy. Each mobile proxy acts as a virtual peer-to-peer node for a cellular phone and converts the XML based P2P protocol to the simple P2P protocol for the cellular phone. An example of a P2P message for cellular phone is shown in Figure 4. A message included in the HTTP body, is written in a simple text format and is composed of two parts. The first part of the message corresponds to the P2P core protocol, and the second part corresponds to the application protocol.

```
P2PFRM 92
Source: Node ID of source node
MulticastGroupID: ID of multicast group
ApplicationURI:
http://www.mml.yrp.nttdocomo.co.jp/ED/2003/03/p2p_instantmsg_app
InstantMessage
UserMessage: Hello All!
FRMEND
```

Fig. 4. A sample of P2P message for cellular Phone

## 5. Performance Evaluation

In this section we evaluate the performance of DBaT algorithms on our simulation platform built upon OMNet++. Network topology used in the simulations is shown. where there are 20 cells in total. As shown in Fig. 4, we adopt a BitTorrent-like [6] architecture for the P2P systems used in our simulations.

### 5.1. Simulation Settings

In our simulations, to simulate a relatively realistic and moderate initial status, the initial traffic load on each cell is randomly generated in the range of [0.25, 0.75]. The number of requesting peer is 10, and each requesting peer has 100 candidate peers. So there are totally 1000 candidate peers that are randomly distributed in 20 cells. Some parameters of each candidate peer are set as follows. The delay between a candidate peer and the requesting peer is randomly generated in the range from 0 to 500ms. The SINR value of a radio link is randomly generated in the range from 0 to 100dB. The energy level is randomly generated in the range from 0 to 5. The lingering time is generated by a random number in combination with the value of the energy level, and has a range from 0 to 5 hours. The packet loss probability of each radio link is generated by a random number in combination with the SINR value and the value of the moving speed, and has a range of [0.001, 0.01].

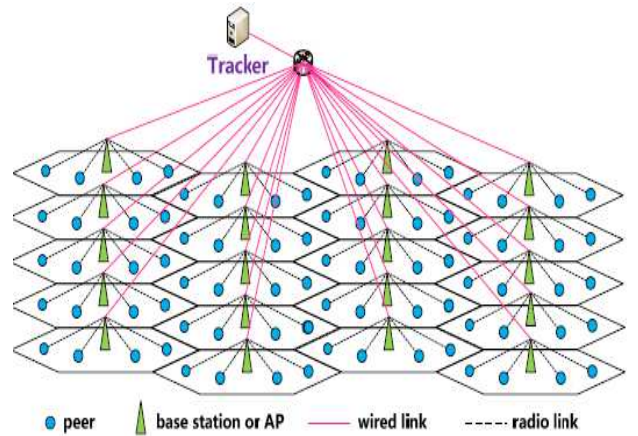


Fig 5. FCM for P2P systems over mobile cellular networks

Moreover, during the data transmission process, each serving peer has a probability of peer churn, which is generated by the value of the energy level in combination with the value of the lingering time. After a peer churn happens, the churned peer will leave the system, and the requesting peer will ask the tracker to return a new serving peer to get the remaining data.

Furthermore, each serving peer also has a probability of moving to a neighboring cell, which is called cell handover probability and is generated by the value of the moving speed in combination with a random number. After a serving peer move to a neighboring cell, its parameters including delay, SINR value and packet loss probability will be

regenerated. We evaluate the performance of DBaT algorithms using a BT-like file sharing process. First, the 10 requesting peers join in the system and send requests for files to the Tracker simultaneously. Second, the Tracker performs the same peer selection algorithm for the 10 requesting peers and returns them a peer list respectively. Finally, the 10 requesting peers receive a file from their own serving peers respectively. We record the average transfer time of the 10 files and the Standard Deviation (SD) of the traffic load on the 20 cells during the file sharing process.

### 5.2. Case I: A Lower Bound of the Sum of the Selected Peers' Uplink Bandwidth is Demanded

In this subsection we consider the case that the requesting peer demands a lower bound of the sum of the selected peers' uplink bandwidth. We compare the performance of DBaT-B algorithm with other two algorithms. One is called HSA-B Highest Service Ability, Bandwidth satisfied), and the other is called RS-B (Random Selection, Bandwidth satisfied). HSA-B is in fact the same with the peer selection algorithm that always chooses peers with the highest service ability [5], and RS-B is in fact the traditional peer selection algorithm used in BitTorrent that chooses peers randomly [6].

Fig. 6 shows the simulation results under the scenario of 3G networks when the downlink bandwidth of each requesting peer ranges from 200Kbps to 1Mbps. The results can be observed and analyzed as follows.

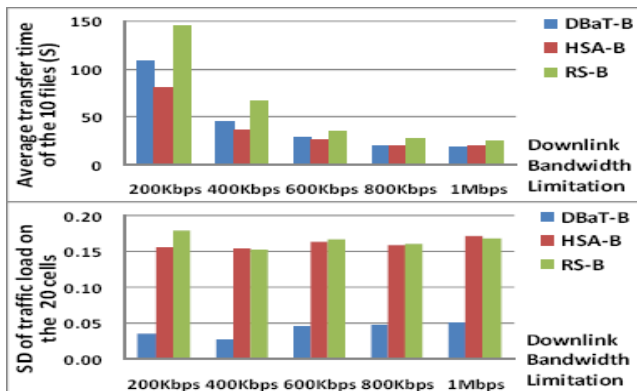


Fig 6. Simulation results under the 3G scenario in case I

First, with any value of the downlink bandwidth, the SD value of DBaT-B is much (at least 66%) lower than those of HSA-B and RS-B. This indicates that DBaT-B achieves much better load balance on the 20 cells than the other two algorithms. Second, with any value of the downlink bandwidth, the average file transfer time of RS-B is obviously (at least 33%) higher than that of DBaT-B or HSA-B. This indicates that the service ability of the serving peers chosen by RS-B is still lower than those chosen by DBaT-B or HSA-B, although the sum of their uplink bandwidth is over the downlink bandwidth of each requesting peer. Third, as the downlink bandwidth increases, the difference between

the average file transfer time of DBaT-B and that of HSA-B gets smaller. This can be explained as follows. When the downlink bandwidth is small, the number of serving peers in the system will not be great.

From the results and analysis in subsection 5.2 we can draw conclusions including:

- 1) Downlink bandwidth limitation has great impact on file transfer speed;
- 2) Our DBaT algorithms can achieve much better load balance on cells than traditional HSA and RS algorithms;
- 3) Our DBaT algorithms can achieve file transfer speed similar with that of HSA, especially when the traffic load on cells is relatively high.

## 6. Conclusion

In this paper we studied the problems of peer selection in P2P file sharing service over mobile cellular networks with consideration of downlink bandwidth limitation. Our major contribution was to propose two peer selection algorithms (named DBaT-B and DBaT-N) that can achieve load balance on cells under the precondition that the requesting peer's demand is satisfied. The two algorithms were designed for two different cases of the requesting peer's demand respectively. Our algorithms take the requesting peer's downlink bandwidth as the target of the sum of the selected peers' uplink bandwidth. Compared with the traditional HSA and RS algorithms, our DBaT algorithms can achieve much better load balance on cells, and they can also achieve file sharing speed better than that of RS, or similar with that of HSA, especially when the traffic load on cells is relatively high. So our algorithms can be seen as nice improvements. Peer-to-peer security will be an important issue for such an environment. We are considering the incorporation of peer-to-peer security into our mobile peer-to-peer architecture. Additionally, we continue to develop new mobile peer-to-peer applications and will evaluate efficiency and performance of our peer-to-peer protocols.

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