Incentive-driven Content Distribution in Wireless Multimedia Service Networks

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Abstract—With the multi-fold development in communication technology, there has been a rapid growth in consumption of multimedia services using mobile devices. In particular, lots of research has been done to provide multimedia services using a 3G/WLAN dual mode to mobile device users. All users download contents from content providers through cellular networks and can share their contents with their neighbors. However, we believe that selfish users (or users with limited resources) are not willing to cooperate or share their contents with other users.

In this paper, we propose an incentive scheme that gives the benefit of contents sharing to users in a 3G/WLAN dual mode supporting network. There are two types of users: premium users and ordinary users. Premium users can get high quality contents at the expense of spending their own money and resources of power and bandwidth, while ordinary users receive plain quality contents freely or with paying little amount of money. Our incentive mechanism designs the content provider to offer each premium user a discounted price for downloading high quality contents. Through our approach, each premium user will receive some incentive of a discounted price for receiving high quality contents in proportion to the contribution to the content provider. By doing so, the content provider can increase its total utility too. Our simulation results confirm that our proposed incentive scheme performs well.

I. INTRODUCTION

Existing multimedia services among mobile devices have been provided by downloading from content providers directly. With the development in mobile device technology, both cellular and secondary channels such as WLAN or Bluetooth can be used simultaneously. Using two different channels simultaneously is beneficial to both the content provider and users. The content provider can benefit from contents distribution among users in the aspect of the reduced server load. From each user’s point of view, he/she can reduce the cost for receiving contents by sharing with other users. Due to these reasons, lots of research has been done to provide multimedia services using a 3G/WLAN dual mode to mobile device users [1,3].

These works, however, use a primary assumption that users are not selfish but cooperative. Therefore, all users download contents from the content provider through a cellular network and share their contents with their neighbors. In other words, users effectively reduce the cost for receiving contents as they share these with others. However, we believe that many users do not cooperate and share the contents with other users because contents sharing requires them to consume their resources. Therefore, efficient use of a 3G/WLAN dual mode cannot be achieved.

In this paper, we propose an incentive scheme for multimedia services in a 3G/WLAN dual mode network. There are two types of users: premium users and ordinary users. We classify premium users as users who are willing to pay for the contents, while ordinary users are not. When premium users share their contents with ordinary users, they will receive high quality contents from the provider at a discounted price. The content provider compensates premium users for their sharing because they consume their resources for contents sharing. It can earn the benefits of saving the server’s resources and keeping the network use at a minimum. We design a utility function that gives the benefit to both the content provider and premium users. With the proposed utility function, we propose the content provider to use an algorithm in deciding each premium user’s paying price for receiving high quality contents to maximize its utility. As a result, the content provider can increase its utility by attracting more premium users through the proposed algorithm.

The rest of this paper is organized as follows. Section II provides the overview of the related work. The detail of an incentive scheme is described in Section III. Section IV presents simulation results. In Section V, we conclude with future work.

II. RELATED WORK

There has been a lot of research for multimedia services among mobile devices. In [1], Kang et al. proposed CHUM where one of the servers is designated as an active server that manages the network topology and membership information. With this information, all nodes can be scheduled for effective contents distribution. In [2], Yoon et al. proposed MOVi protocol for VoD (Video-on-Demand) service among mobile devices where mobile devices can receive streaming services from APs and other devices, using a P2P protocol. This process is determined by the MOVi server. In [1] and [2], their proposals are centralized schemes, so a particular server manages all information about the network status and devices.

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On the other hand, in [3], Leung et al. proposed the COSMOS protocol that is a distributed method for sharing multimedia contents among mobile devices. They assumed that all mobile devices should broadcast their contents to neighbors, and the contents received from the neighbors should be broadcasted again. Moreover, all mobile devices should download from cellular networks in turn in order to reduce the download cost. J. Kim et al. designed a protocol for live streaming in a P2P network [4]. They proposed to use super peers which service rates are determined by the server according to the number of leaf peers that each super peer can serve. They applied the second price auction to obtain each super peer’s service rate and tried to maximize the number of leaf peers that can be served using their proposed heuristic algorithm.

III. PROPOSED INCENTIVE SCHEME

A. Scenario

In [3], all users are assumed to share their contents with their neighbors by broadcasting. Therefore, they can get high quality of contents service with reduced cost. However, if we assume that they are selfish, they have no reasons to share their contents because they are required to consume their resources for contents sharing. Therefore, we consider a different scenario given in Fig. 1. When premium users who are willing to pay for high quality contents share a part of their contents with ordinary users who are not, they are given some discount for receiving high quality contents from the content provider as an incentive. If ordinary users are served by premium users, the content provider obtains improved advertising revenue by serving more ordinary users through the relaying support of premium users, thereby achieving higher utility. By doing so, the content provider is able to increase its utility and encourage more premium users to participate in broadcasting to ordinary users within the coverage.

B. Utility Function

Our proposed incentive scheme needs utility functions that can be used by the content provider and users to make decision. First, we consider the utility function for premium user \(i\), which is expressed as a function of the service rate, \(r_i\), and the number of ordinary users that premium user \(i\) can serve, \(N_i\), as follows:

\[
U_i(r_i, N_i) = \log(1 + \frac{r_i}{r_i,max}) - c_i(r_i, N_i)\sqrt{r_i} - c_b(N_i),
\]

where \(r_{i,min} \leq r_i \leq r_{i,max}\).

The benefit of a premium user is modeled as a log function of \(\frac{r_i}{r_i,max}\), which represents the relative rather than absolute benefit. The cost is modeled as a square root function of \(r_i\). When a premium user \(i\) enjoys the content with the service rate \(r_i\), the cost that the premium user should pay can be expressed as

\[
c_i(r_i, N_i) = d(N_i)k(r_i),
\]

where \(k(r_i)\) denotes an original price for the content with the service rate \(r_i\), and \(d(N_i)\) denotes a discount as an incentive when the premium user \(i\) is serving \(N_i\) ordinary users. \(N_i\) is assumed to be known to the content provider. This means that the content provider can manage the information about \(N_i\). When premium user \(i\) broadcasts to their neighbors, the amount of its consumed energy can be expressed as

\[
c_b(N_i) = \begin{cases} 
  c_{\text{broadcast}} & (N_i \geq 1), \\
  0 & \text{otherwise}.
\end{cases}
\]

According to the characteristics of the wireless channel, the amount of energy consumption of premium user \(i\) is independent of \(N_i\).

Each premium user joins the network when his/her utility is larger than 0. Therefore, the original price \(k(r_i)\) needs to be determined to make the utility of premium user \(i\) larger than 0 according to the following condition.

\[
\log(1 + \frac{r_i}{r_i,max}) - k(r_i)\sqrt{r_i} \geq 0.
\]

From (4), we obtain the original price \(k(r_i)\) as

\[
k(r_i) = \frac{\log(1 + \frac{r_i}{r_i,max})}{\sqrt{R_{\text{max}}}},
\]

where \(R_{\text{max}}\) represents the maximum feasible rate. Then we can express the utility function of user \(i\) as below

\[
U_i(r_i, N_i) = \log(1 + \frac{r_i}{r_i,max})(1 - \sqrt{\frac{r_i}{R_{\text{max}}}}d(N_i)) - c_b(N_i),
\]

where \(d(N_i)\) can be determined by the content provider.
We obtain the utility function of the content provider as

$$\Delta U_C = \sum_{i=1}^{m} \gamma(N_i) + c_i(r_i^*, N_i)\sqrt{r_i^*} - c(r_i,o)\sqrt{r_i,o},$$  

(7)

where $m$ denotes the number of premium users who want to join the network. $\gamma(N_i)$ stands for the revenue that the content provider can get when premium user $i$ is serving $N_i$ ordinary users. $c_i(r_i^*, N_i)\sqrt{r_i^*}$ is the revenue of the content provider when the content provider provides contents with the discounted price $c_i(r_i^*, N_i)$ to the premium user $i$, while $c(r_i,o)\sqrt{r_i,o}$ is the revenue of the content provider when the content provider offers contents at the original price. Obviously, premium users want to maximize their utilities. Therefore, $r_i,o$ is the service rate to maximize $U_i(r_i) = \log(1 + \frac{r_i}{r_i,o})(1 - \frac{r_i}{R_{\text{max}}})$. In the same manner, the premium users $i$ will select the service rate $r_i^*$ that maximizes $U_i(r_i, N_i) = \log(1 + \frac{r_i}{r_i,max})(1 - \frac{r_i}{R_{\text{max}}})d(N_i)) - c_b(N_i)$.

### C. Price Decision

Each premium user can get the utility of $U_{i,\text{before}} = \log(1 + \frac{r_{i,max}}{r_{i,\text{max}}})(1 - \frac{r_i}{R_{\text{max}}})$ even though he/she does not broadcast. Therefore, it is obvious for each premium user to broadcast only when his/her utility becomes larger by broadcasting. Therefore, the condition that a premium user $i$ serves his/her neighbors can be expressed as follows:

$$U_{i,\text{after}} = \log(1 + \frac{r_i}{R_{\text{max}}})(1 - \frac{r_i}{R_{\text{max}}})d(N_i)) - c_b > U_{i,\text{before}}.$$  

(8)

Then, we can get the minimum number of ordinary users and denote it as $P$. If there are at least $P$ ordinary users, each premium user is willing to serve those ordinary users because he/she can achieve higher utility. It can be easily derived that the larger $c_b$, the more ordinary users needed for each premium user to get high utility by broadcasting. Similarly, the larger $U_{i,\text{before}}$, the more ordinary users are needed.

The content provider gives an incentive to a premium user only when its utility becomes larger than 0. We assume that $\gamma(N_i)$ is given by the content provider. In this paper, we simply let $\gamma(N_i) = \alpha N_i$. Using $\gamma(N_i)$, we select $d(N_i) = \frac{1}{N_i + \epsilon}$ for simulations. We can get the minimum number of ordinary users that make the content provider’s utility larger than 0 by letting $\gamma(N_i) = \alpha N_i$ from the following condition.

$$\gamma(N_i) + c_i(r_i^*, N_i)\sqrt{r_i^*} - c(r_i,o)\sqrt{r_i,o} > 0.$$  

(9)

Assume that the minimum number of ordinary users which satisfies (9) is $Q$. If $P \leq Q$, it is obvious that only premium users who can support ordinary users greater than $Q$ in number, receive the multimedia service of high quality at a discounted price. However, if $P > Q$, the situation becomes different from the case of $P \leq Q$. For example, if $P = 7$ and $Q = 2$, the content provider can acquire a high utility by giving an additional incentive to a premium user of $N_i = 5$. There is no reason for the premium user to broadcast because $N_i$ is not larger than $P$. However, if the premium user shares his/her contents, the content provider can get a higher utility. Hence, the content provider wants such premium users to broadcast and makes giving them an additional discount possible. Needless to say, the content provider should lower the price as long as (8) and (10) are satisfied.

$$\gamma(N_i) + \epsilon c_i(r_i^*, N_i)\sqrt{r_i^*} - c(r_i,o)\sqrt{r_i,o} > 0,$$  

(10)

where $\epsilon$ means an additional discount. The procedures for the price decision are presented in Algorithm 1.

### Algorithm 1 Price Decision

1. Get premium user $i$’s $N_i$, $r_{i,min}$, and $r_{i,max}$
2. Calculate $P$
3. if $\gamma(N_i) + c_i(r_i^*, N_i)\sqrt{r_i^*} - c(r_i,o)\sqrt{r_i,o} > 0$ then
4. if $N_i \geq P$ then
5. $c_i = k(r_i)$
6. else if $\gamma(N_i) + \epsilon c_i(r_i^*, N_i)\sqrt{r_i^*} - c(r_i,o)\sqrt{r_i,o} > 0$ then
7. $c_i = \epsilon k(r_i)$
8. else
9. $c_i = k(r_i)$
10. end if
11. else
12. $c_i = k(r_i)$
13. end if

### D. Price Decision of a Premium User in a Dense Network

Each premium user decides his/her paying price to get high quality contents according to the number of ordinary users he/she can serve and the service rate he/she wants when there are no other premium users who can serve those ordinary users. In a dense network such as in trains and downtowns, however, there are several ordinary users within the transmission range of a premium user. Fig. 2 shows an example of a dense network where there are two premium users. In this case, the content provider creates the topology to maximize his/her utility. For example, when premium user 2 comes into the network, premium user 1 has already been serving four ordinary users. Premium user 2 informs the
content provider that the number of ordinary users he/she can serve is 7. Ordinary users A, B, and C want to be served with good channel conditions that depend on the distance from the source. Therefore, even though premium user 1 is broadcasting, they want premium user 2 to share his/her contents. After receiving the information about premium user 2, the content provider compares \( U_{C, before} \) with \( U_{C, after} \) to determine the price of premium users 1 and 2 according to Algorithm 2. \( U_{C, before} \) denotes the utility of the content provider before a new comer joins the network, while \( U_{C, after} \) denotes the utility after joining.

We assume that \( R_{\max} = 1000 \text{kbps} \), \( \gamma = 0.2 \), and \( c_{\text{broad}} = 0.3 \). If premium user 2 joins the network while premium user 1 has been being served, \( U_{C, before} \) is 0.449, and \( U_{C, after} \) is 0.930. Hence, the content provider will increase the price of premium user 1 because premium user 2 will serve ordinary users A, B, and C. By doing so, the content provider can increase his/her utility. Due to the joining of premium user 2, the utility of premium user 1 will decrease from 0.305 to 0.255. The procedures are given in Algorithm 2.

**Algorithm 2 Price Decision in a Dense Network**

1. Calculate \( U_{C, before} \)
2. \( S \) : Set of premium users within tx range of ordinary users that a new comer \( i \) can serve
3. \( N_s \) : Number of ordinary users within tx range of a premium user \( s \) (\( s \in S \))
4. do Algorithm 1 for the new comer \( i \)
5. if \( c_i \neq k(r_i) \) then
6. sort \( S \) in descending order with \( N_s \)
7. \( j \leftarrow 0 \), \( U_{C, after} \leftarrow c_i \sqrt{r_i} \)
8. while \( j \leq |S| \) do
9. do Algorithm 1 for \( j^{th} \) user in \( S \)
10. \( U_{C, after} \leftarrow U_{C, after} + \gamma(N_j) + c_j \sqrt{r_j} \)
11. \( j \leftarrow j + 1 \)
12. end while
13. if \( U_{C, after} < U_{C, before} + c(r_{i,o}) \sqrt{r_{i,o}} \) then
14. \( c_i = k(r_i) \)
15. end if
16. else
17. \( c_i = k(r_i) \)
18. end if

There are \( 2^{|S|+1} \) cases for calculating \( U_{C, after} \). Because our primary assumption is that the content provider can benefit from premium users serving ordinary users indirectly, \( S \) should be sorted in descending order with \( N_s \), which is the number of ordinary users near premium user \( s \).

**E. Managing the Number of Ordinary Users**

The most important thing for the price decision is the number of ordinary users that each premium user can serve. The content provider can gain the benefit by encouraging more premium users to serve more ordinary users. Therefore, the content provider needs to know correctly how many ordinary users each premium user can serve. To solve this problem, we assume that the symmetric key between each user and the content provider has already been negotiated. Each ordinary user must send a report message encrypted with his/her private key periodically to the serving premium user. Each premium user has to send an aggregated report message to the content provider periodically to prove the number of ordinary users he/she is serving. With this procedure, the content provider can get the correct information about the number of ordinary users served by each premium user.

**F. Policy for Service Rate Differentiation**

Premium users should be served with high quality contents than ordinary users because they pay for the contents, while ordinary users get plain quality contents for free. It is obvious that any users will not pay for the contents if quality is not differentiated. In this paper, Layered-Coding is used to provide differentiated quality of contents between premium users and ordinary users. Layered-Coding is used in some works related with P2P streaming services [6]. It divides each video content into \( M \) layers. If a user receives more number of layers among \( M \) layers, he/she will be able to enjoy higher quality of the content. Currently layer 1 through \( l-1 \) should be downloaded in advance to decode the video content of \( l \) layers. In this paper, we assume service differentiation is made by one layer difference between premium and ordinary users.

**IV. SIMULATION**

**A. Simulation Setup**

We develop a C++ based simulator. The topology that is considered in simulations is shown in Fig. 3. There are 40 users and among those 10 users are premium users. They are randomly placed in a 300m x 300m area. The transmission range of each user is fixed to 75m. Each user randomly joins the network. There are three types of premium users shown in Table II.

**B. Simulation Results**

Fig. 4 is the simulation results according to \( \alpha \). We set \( R_{\max} = 1000 \text{kbps} \) and \( c_{\text{broad}} = 0.35 \). Arrows indicate the join time of each premium user. The bottom line shows the
case that all the premium users download from the content provider only. Hence, the utility of the content provider increases when more premium users come into the network. On the other hand, the utility of the content provider increases when more premium users come into the network.

Fig. 4. The utility change of the content provider according to $\alpha$.

Fig. 5. Comparison of three different schemes

network. Our scheme is combined with an algorithm for price decision which tries to maximize the utilities of each user and the content provider in a dense network. Through simulations, we confirmed that our proposed incentive scheme successfully harmonizes the interests of users and the content provider.

We will consider the mobility of users in designing the utility function in future work where premium users predict their connectivity with his/her neighbors according to the measured channel quality.

V. CONCLUSION AND FUTURE WORK

In this paper, we proposed an incentive scheme that aims to provide multimedia services as many users as possible in a cost effective way in a 3G/WLAN dual mode supporting

### TABLE II

<table>
<thead>
<tr>
<th>Type</th>
<th>$r_{i,min}$ (kbps)</th>
<th>$r_{i,max}$ (kbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>700</td>
<td>1000</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>700</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>500</td>
</tr>
</tbody>
</table>

Fig. 6. Obtained Topology by our proposed incentive scheme for the topology of Fig. 3.

REFERENCES


