Distributed Resource Allocation in Cloud-Based Wireless Multimedia Social Networks

Guofang Nan, Zhifei Mao, Minqiang Li, Yan Zhang, Stein Gjessing, Honggang Wang, and Mohsen Guizani

Abstract

With the rapid penetration of mobile devices, more users prefer to watch multimedia live-streaming via their mobile terminals. Quality of service provision is normally a critical challenge in such multimedia sharing environments. In this article, we propose a new cloud-based WMSN to efficiently deal with multimedia sharing and distribution. We first motivate the use of cloud computing and social contexts in sharing live streaming. Then our WMSN architecture is presented with the description of the different components of the network. After that, we focus on distributed resource management and formulate the bandwidth allocation problem in a game-theoretical framework that is further implemented in a distributed manner. In addition, we note the potential selfish behavior of mobile users for resource competition and propose a cheat-proof mechanism to motivate mobile users to share bandwidth. Illustrative results demonstrate the best responses of different users in the game equilibrium as well as the effectiveness of the proposed cheating avoidance scheme.

With the growing penetration of wireless handheld devices and rapid development of communication technologies, wireless networks have shifted the world from fixed Internet access to ubiquitous wireless access. More people are using their mobile devices such as smartphones, personal digital assistants, laptops, and tablets to explore network resources, especially when watching video and listening to audio. The amount of video and audio has been growing at a remarkable rate as users are willing to share personal media with colleagues and friends [1, 2]. People may interact with each other to form a large-scale multimedia social network, which usually consists of content providers that provide live content and multiple users who watch live programs simultaneously [3].

Peer-to-peer (P2P) has been a traditional infrastructure for multimedia networks [4]. Such architectures are designed to improve the video quality and reduce delay. However, most mobile devices have not been designed to inherently support real-time multimedia applications. Normally, mobile devices have limited computation capabilities as well as limited storage space. The provision of high-quality multimedia services to mobile users thus becomes very challenging. The emerging cloud computing paradigm may be incorporated into multimedia social networks to tackle these challenges [5]. Such multimedia clouds are able to store, process, and distribute live streaming by sharing the computation and communication resources in a social network environment. Although a traditional cellular network can provide wireless access for mobile users to watch live programs, content providers have to pay for extra bandwidth when delivering their multimedia services to wireless users. In addition, wireless users have to pay for multimedia streaming downloading. The incurred cost may not be appreciated by either content providers or wireless users.

In this article, we present a cloud-based wireless multimedia social network (WMSN) to deal with multimedia sharing and distribution. By introducing cloud computing, it is possible to store, process, and distribute live streaming in a multimedia social network environment. Users are categorized on the basis of social contexts, available resources, preference for sharing resources, and device capabilities. The network allows one type of users to obtain live programs from the cloud and share their live streaming with socially related wireless users. Although the proposed architecture has several advantages with respect to cost reduction and performance improvement, sharing the radio resources among users should be carefully studied. We focus on distributed resource management in WMSNs when only local information is available. Considering the complicated interactions among users and their own evolution, we study the resource allocation within a Stackelberg game theoretical framework, where the users sharing resources are leaders in the game, while the

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users consuming the resources are followers in the game. Game theory has been shown to be a powerful tool to investigate P2P video streaming [6] and devices' cooperation [7]. In addition, we notice the potential cheating behavior of mobile users and propose a cheat-proof strategy based on a new punishment mechanism.

The remainder of the article is organized as follows. The following illustrates the network architecture, which comprises three key concepts: a multimedia cloud, user diversity, and social contexts. We then focus on the critical challenges of resource management and quality of service (QoS) provisioning. We formulate bandwidth allocation among different users in a game-theoretical framework and solve the problem in a distributed manner. Following that, we first analyze potential cheating behaviors and then propose a cheat-proof strategy to efficiently eliminate cheating. The conclusion is presented in the final section.

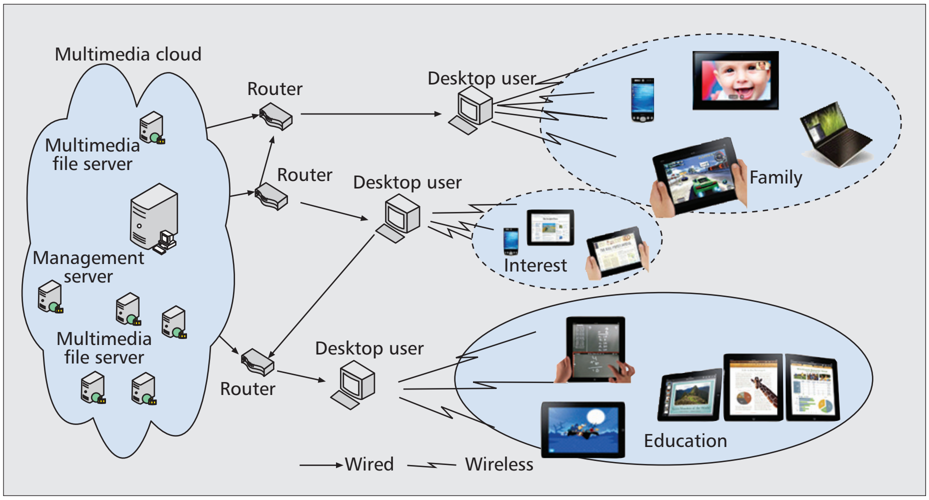

Figure 1. Proposed wireless multimedia social network architecture.

Proposed Architecture of Cloud-Based Wireless Multimedia Social Networks

Figure 1 shows our proposed architecture of a cloud-based wireless multimedia social network. A WMSN is essentially a heterogeneous network that has a multimedia cloud and different subnetworks. These subnetworks are established on the basis of various social contexts (e.g., location, family, personal interests, education).

The Multimedia Cloud

Since multimedia social networks are characterized by a very large number of large multimedia files, the storage of these files has been known to be a significant challenge. In a typical wireless live streaming network, multimedia files are usually stored in and provided to users by content providers' central servers. Since the number of users in the network can be very high, the response time may be slow for some user requests. Furthermore, such networks may be vulnerable to various security problems. For example, they may suffer from a denial of service (DoS) attack. These challenges can be tackled if we incorporate the *cloud* concept into the wireless multimedia social network.

In the principle of cloud computing, infrastructure as a service (IaaS) provides an on-demand computing infrastructure and a virtual computer infrastructure [8]. IaaS can be deployed through a private cloud or by a third-party through a public cloud. With virtualized resources, a content provider can establish a multimedia cloud. Regarding the cloud concept, our proposed architecture contains two main components: a multimedia file server and a management server. The multimedia file server provides storage for multimedia files for the content provider and delivers live streaming contents to the users in the network. Users can flexibly access the multimedia file system through a web interface that displays the hierarchy of files and folders. Since multimedia files are normally large, it may take some time for them to reach users. The management server works as a controller to efficiently distribute multimedia files and handle requests from users.

Content Providers

Content providers deliver high-resolution and high-bandwidth live programs to their subscribers, and they pay telecommunication operators for the communication services. Live streaming content providers can be entities that multicast live programs or deliver an ongoing university lecture to distance learners in remote locations. Hence, the content providers can distribute multimedia files to a number of servers that are placed in different locations. Users who request different programs can retrieve the corresponding files. Furthermore, the multimedia file of a program can be divided into a number of clips and distributed among several servers. In this way, the workload of the servers can be balanced. Still, their requests are first reported to the management server of the multimedia cloud. Then the requests are distributed to the correct server. Upon receiving the requests, the multimedia file server sends files to the users.

User Categories

Without loss of generality, users are categorized into two types: wireless users and desktop users. In this way, the streaming topology is organized in a tree-based topology. Then the service provider has a centralized control of the desktop users, while the desktop users have the privilege of scheduling mobile users who want to obtain live programs from them. The desktop users watch the live programs offered by live content providers. There are dedicated gateways to process contents, and communicate between live content providers and their desktop users. These desktop users form a multimedia social network and can also share their own resources with each other. Mobile users watch live programs by utilizing their desktop friends' resources without paying fees for wireless services to telecommunication operators. The term desktop users is introduced in contrast to mobile users. Compared to mobile users, desktop users have higher computation capability and more resources. In addition, they are willing to share resources with mobile users.

Social Contexts

A social context is the natural glue that is exploited when a local wireless multimedia network is organized for live program sharing, processing, and distribution. Such social contexts can be very diverse, including location, families, professions, interests, education, and hobbies. For instance, a home multimedia network can be organized for video sharing and distribution based on a family relationship. A multimedia news network can be opportunistically established if people share the same interests in daily news. A live streaming class network can be constructed in a lecture if students attend the same class physically or virtually through the Internet in remote locations.

Example Scenario: Home Multimedia Social Networks

The proposed architecture is very generic in the sense that it can be applied in many scenarios. We take home networks as an example. A typical home network might consist of a number of components:

- Mobile devices such as smartphones, laptops, and tablet PCs
- Relatively static equipment such as Internet-based HDTVs, media game devices, and PC desktops
- Network devices such as routers, switches, and cable modems

A home network can provide diverse features, and the capability to connect all home devices together and then make an Internet connection to the cloud. The exchanged media data in a home network can be uploaded to the cloud for storage and further processing. An example of sharing media via the cloud in a home network is to synchronize media among multiple home devices. For example, when a mobile user uses a smartphone to capture a large video file, other home devices such as desktops, tablets, and other Internet-based TV boxes will automatically synchronize with the captured video. The captured video is also stored in the cloud with the permission of its owners. Our proposed architecture is flexible in order to efficiently support this application. In the proposed architecture, a video captured by a smartphone will be compressed and uploaded to the media cloud and stored in multiple multimedia servers. A management server will monitor all the home devices, accept or deny all requests, and then multicast the video to the devices that should be synchronized. During the synchronization process, multiple mobile and desktop users could compete for network resources such as bandwidth to achieve their required QoS.

Resource Allocation Strategies: Challenges and Solutions

Resource Allocation Problem

The proposed cloud-based multimedia system architecture is able to provide high-quality live streaming. Desktop users would like to share multimedia programs with their nearby mobile friends. Moreover, this kind of a system architecture allows mobile users to obtain desired multimedia files directly from their neighboring desktop users via a wireless local network such as WiFi instead of a wide-area access network. Short-range communications will efficiently utilize the bandwidth from a content provider's perspective. It also saves the payoffs for mobile users, who will directly download multimedia streaming from the content provider. Although it is a substantial advantage to use any mobile device to share information at any time, wireless terminals may be very different with respect to communications and computation capabilities, and storage space such as various mobile devices including laptops, iPads, tablets, smartphones, traditional desktops, and wearable computers. There are two fundamental challenges due to device diversity:

- Devices that will compete for the limited resources in a desktop. Users normally request bandwidth based on the size of a multimedia file.
- Devices that have different bandwidth requirements when users watch live programs. For instance, the latest version of the iPad with a high-resolution retina display usually needs more bandwidth than a traditional mobile phone.

How to efficiently allocate the bandwidth of desktop users to mobile users and how to establish connections between these two kinds of users become critical challenges in our cloud-based multimedia system.

Resource Allocation Strategy: A Stackelberg Game Approach

We consider a WMSN consisting of both desktop users and mobile users. Let $\mathcal{M}$ and $\mathcal{N}$ denote the set of desktop users and the set of mobile users, respectively. We define $\mathcal{M} \equiv \{1, 2, \dots, M\}$ and $\mathcal{N} \equiv \{1, 2, \dots, N\}$. Considering the fact that some mobile users in the network may have common social properties (e.g., location, profession, family), we can group the mobile users according to their social contexts. We assume that these N mobile users are divided into a set of $\mathcal{G}$ groups, $\mathcal{G} \equiv \{1, 2, \dots, G\}$. Users in the same group are allowed to communicate with each other freely, and private information can be exchanged among them. Furthermore, members in the same group can connect to different desktop friends if available.

In this wireless multimedia social network, we establish a virtual market in which the desktop users are sellers and the mobile users are customers. The desktop users share portions of their bandwidth with mobile friends nearby for a certain price, while the mobile users buy a connection from one desktop friend. The payment can be replaced by credits, tokens, or other equivalents. Let b_i denote the size of the bandwidth that desktop user i is willing to share. Let p_i represent the price charged by desktop user i. The desktop users compete with each other, and make trade-offs between the size of the bandwidth they are willing to share and the price they will charge. The main objective of the desktop users is to maximize their own utility. For the mobile users, they make the decision about to which desktop user they will connect. Each desktop user has the right to decide the size of the bandwidth and the price for utility maximization. Each mobile user, who competes with other mobile users, needs to decide the specific desktop user to which it is willing to connect. Therefore, it is a typical two-stage leader-follower game that can be analyzed using a Stackelberg competition model. In this Stackelberg game, the desktop users are the game leaders who optimize their strategies based on knowledge about the impacts of their decisions on the behaviors of the mobile users.

A Distributed Algorithm for Mobile Users' Evolution

We first study the evolutionary behavior among the mobile users who will select desktop users for bandwidth sharing. In this case, multiple mobile users may connect to the same desktop user, which may reduce the desktop user's utility; hence, it will increase the price in order to achieve higher utility. As a consequence, these mobile users may change their connections and switch to a different desktop user. This process can repeat many times until all users in the same group achieve identical utility. As indicated, each mobile user behaves selfishly and chooses a desktop user according to its own utility maximization. However, there are many users in the network, and it is very difficult to get all users' information as well as network status. Such information is necessary for an optimal decision. In this sense, the mobile users are not fully rational when making their decisions. Therefore, the behavior of the mobile users may be analyzed by employing an evolutionary game framework, which is a powerful tool for analyzing interactions among players with bounded rationality.

We define the basic components of the evolutionary game for the mobile users as follows:

- *Players* represent mobile users in the network who are selfish and semi-rational players in the evolutionary game.
- *Population* refers to the group of users in the network, and each group forms an independent population.
- *Strategy* indicates the set of strategies the desktop users have available for the mobile user.
- *Utility* is defined as the satisfaction of allocated bandwidth minus its payment.

A mobile user is always willing to connect to a desktop user such that higher satisfaction is expected. Mobile users within a group can communicate with each other and exchange information about their strategies. If one user observes that another user, choosing a different desktop user, has a higher utility, he may learn the strategy of the observed user and gradually change its connection with the goal of achieving higher utility.

Mobile users in the same group can learn from each other's strategies. In other words, the strategy of one player in a population can be replicated by other players in the same population. These replications form the evolution in the population. Here, we introduce replicator dynamics to describe the evolution in the population. In replicator dynamics, the share of a strategy in the population grows at a rate equal to the difference between the utility of that strategy and the average utility of the population. In this case, we consider the set of strategies that the desktop user has available for the mobile users. For population (i.e., group) g, let $\mathbf{x}^g$ denote the vector of a population state whose ith element x_i^g is the population's share of strategy i. Let π_i^g denote the utility of a mobile user in group g connected to desktop user i.

In a wireless multimedia social network, mobile users may not receive up-to-date data about the population state due to potential transmission latency. Therefore, they have to make decisions based on historical information about the other users. We consider this time delay in the replicator dynamics. The utility of a mobile user at time t is a function of the population state at time $(t - \tau)$ where τ denotes the time delay. The replicator dynamics is given by

$$\dot{x}_i^g(t) = x_i^g(t)(\pi_i^g(t - \tau) - \bar{\pi}_i^g(t - \tau)) \tag{1}$$

This equation demonstrates that the share of a strategy with higher utility will increase over time. When the shares of all strategies do not change, the evolution is over. This shows the convergence to a stable state, that is, the evolutionary equilibrium.

We present an iterative algorithm for the mobile users to converge to the evolutionary equilibrium. Based on the replicator dynamics, each mobile user changes its strategy to maximize its own utility. In order to achieve the evolutionary equilibrium, an evolution protocol is presented for each mobile user. Since the users in the same group can exchange information, the current choice and utility of one mobile user is available to others, but not available to the users in different groups. A user changes its choice with some probability if he finds that another user in the same group has a higher utility. When all users in the same group have obtained equal utilities, the evolution is complete. This protocol is specified as follows:

1. Initially, each mobile user randomly connects to an available desktop user;
2. Each user computes its utility using the allocated bandwidth and the charged price by the connected desktop user. The allocated bandwidth is measured by this mobile user himself since the total number of mobile users connected to the same desktop user is unavailable;
3. After communicating with the other users in the same group, each user gets its data about choices and utilities, and then computes the average utility of the group.
4. If the average utility is greater than its own utility, the mobile user changes its connection to another desktop user who possibly offers higher utility. Otherwise, the user keeps the current connection.
5. Repeat steps 2 to 4.

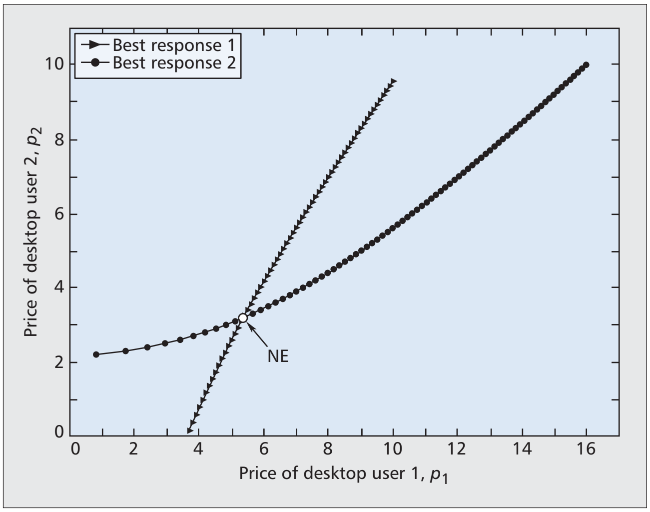

Figure 2. Best responses of desktop users when price is the strategy.

It is clear that all users in the same group can obtain equal utility at the equilibrium. Since the mobile users choosing the same desktop user can also receive equal utility regardless of the group to which they belong, the evolution can provide desirable fairness for the whole system if multiple groups are connected to each desktop user.

Competition among Desktop Users

Based on the result of the mobile users' evolution, the desktop users will compete with each other and update their strategies in order to maximize their own utilities. We model the competition among the desktop users as a non-cooperative game and consider the Nash Equilibrium (NE) as the solution to the game. In this non-cooperative game, players refer to desktop users. The strategies are the size of the bandwidth a player is willing to share and the price a player charges. The utility is defined as the difference between the total payment from the mobile users who connect to this desktop user and the cost for transmitting live streaming files. The NE is a commonly used concept in solving game-theoretic problems. In the NE, no user can improve its own utility by unilaterally changing its strategy. The NE can be computed by finding the fixed point of the best response functions of all players.

Illustrative Results

Figure 2 shows the best response of each desktop user. In this example, desktop user 1 and desktop user 2 have 50 units and 10 units of shared bandwidth, respectively. As we can see, the best responses of both desktop users are increasing. This observation demonstrates that their strategies are "strategic complements." The gradient of the best response of desktop user 1 is constantly smaller than 1, which is different from that of desktop user 2. This is because desktop user 1 allocates more bandwidth than desktop user 2 to the mobile users. Notice that there is only one intersection point of these two best responses. Hence, the NE is unique and given by (5.366, 3.188). To achieve higher utility, desktop user 2 may

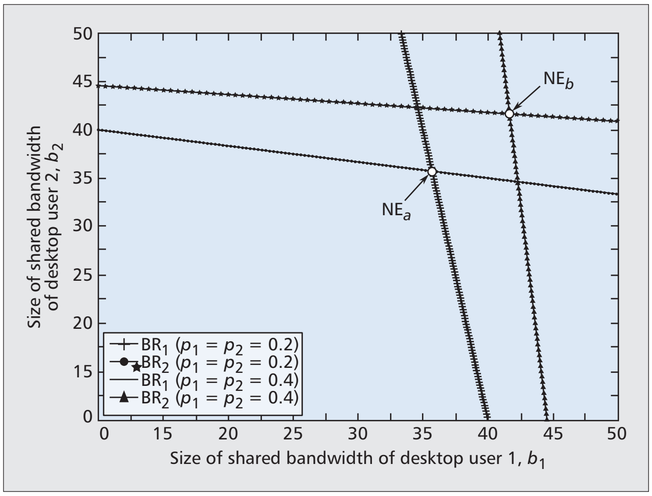

Figure 3. Best responses of the desktop users when the bandwidth and the price are strategies. NE_a is the Nash Equilibrium when $p1 = p2 = 0.2$, while NE_b is the Nash Equilibrium when $p_1 = p_2$=0.4.

have to increase the bandwidth it allocates to the mobile users.

We further consider the best responses of the desktop users when the size of the bandwidth and the price are variable. Figure 3 shows the best responses of two desktop users in terms of the size of the bandwidth. If one of the desktop users increases its shared bandwidth, more mobile users will switch from their rivals to this desktop user. Then the newly chosen desktop user will perform a different operation since it needs to raise the satisfaction and compensate for the loss from the mobile users who left it. However, when the prices of both desktop users increase, the shared bandwidth at the best response of each desktop user increases as well, since a higher price will lead to a greater utility. The NE of the competition between the two desktop users is represented by the intersection point in the figure, which is (b_1^*, b_2^*) = (35.714, 35.714) when the price (p_1, p_2) is (0.2, 0.2), and (b_1^*, b_2^*) = (41.667, 41.667) when the price (p_1, p_2) is (0.4, 0.4).

Cheat-Proof Resource Allocation Strategy

In the game interaction, mobile users may potentially tend to cheat if they believe that cheating can increase their payoffs through dishonestly reporting their private information to desktop users. We take a closer look at this issue by mainly focusing on the critical parameters during the interaction between mobile users and desktop users.

Cheating Analysis

In the game interaction, a mobile user intends to maximize its utility. Following this reasoning, if we consider a noncooperative behavior, each mobile user has three key activities:

- Wireless user i bids an amount w_i^r and reports its minimum bandwidth requirement b_i^{min} to a desktop user.
- The best response of each wireless user is determined by the desktop user.
- The desktop user computes the bandwidth allocation for each wireless user according to each wireless user's bid w_i^r.

Note that this process involves private information reported by each wireless user. Players may tend to cheat if they believe that cheating can increase their payoffs through dishonestly reporting their private information to the desktop users. One possible way of cheating is to dishonestly report their minimum bandwidth requirement b_i^{min}. This cheating activity can be detected by the desktop user by examining the types of wireless devices. Hence, we mainly concentrate on another cheating strategy of bidding a dishonest w_i^r to desktop users for more bandwidth.

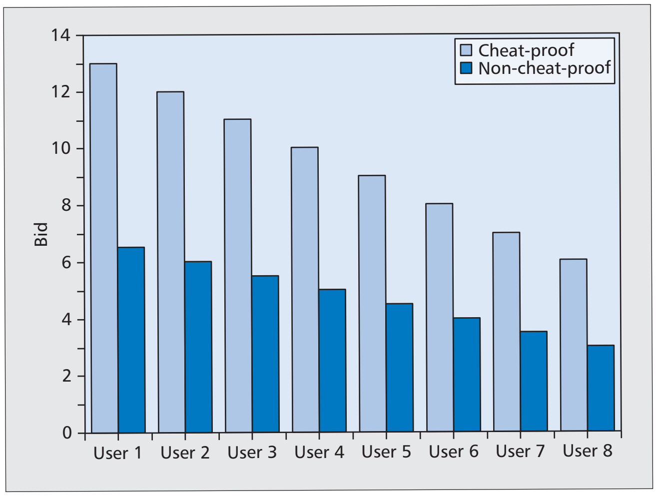

Figure 4. Bid amounts among mobile users.

We now take a close look at the utility of each player. The utility of each player is defined as the allocated bandwidth from the desktop user plus its residual bonus points. For the allocated bandwidth, a desktop user allocates its available bandwidth to different mobile users who connect to it in proportion to the mobile users' desired bandwidth requirements. Wireless users obtain the same amount of bandwidth if the ratio of their bid to their minimum bandwidth requirement is a positive constant λ. The residual bonus in the utility is decided by the amount of bonus points of wireless user i used to bid for bandwidth. A lower bid will lead to more residual bonus points. Consequently, wireless users can achieve the same amount of bandwidth and more residual bonus points with a very small bid (nearly zero) as long as the ratio of their bid to their minimum bandwidth requirement is a very small constant. In addition, with a smaller constant, wireless users will pay less while they still receive the real bandwidth they request. Accordingly, the cheating behavior will take place when all wireless users cooperate to keep the ratio of their bid to their minimum bandwidth requirement as a constant far less than 1. This cheating strategy is apparently unfair to desktop users, and we need a cheat-proof solution.

A Punishment Mechanism for Cheating Avoidance

As explained earlier, the reason cheating takes place is mainly due to the proportional allocation mechanism. In order to avoid wireless users' cooperation to require more bandwidth with lower bids by cheating, a punishment coefficient $(w_i^r)/(b_i^{min})$ is introduced to evaluate the bandwidth of wireless user i obtained from a desktop user. Specifically, we discuss the impact of a punishment coefficient on the utility of wireless users in three different cases: $(w_i^r)/(b_i^{min}) < 1$, $(w_i^r)/(b_i^{min}) = 1$, and $(w_i^r)/(b_i^{min}) > 1$. For each wireless user i:

- If $(w_i^r)/(b_i^{min}) < 1$, its bid is lower than its minimum bandwidth requirement. This shows that the obtained bandwidth of wireless user i from the desktop user will be reduced by punishment, and thereby makes the allocated bandwidth insufficient to watch live programs.
- If $(w_i^r)/(b_i^{min}) = 1$, its bid is equal to its minimum bandwidth requirement. This indicates that the mobile user is honest and will not suffer from punishment.

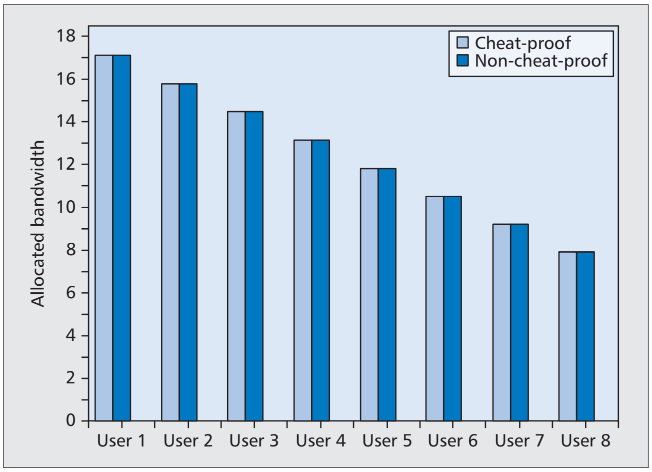

Figure 5. Allocated bandwidth among mobile users.

- If $(w_i^r)/(b_i^{min}) > 1$, its bid is larger than its minimum bandwidth requirement. As a consequence, wireless user i receives more bandwidth while losing some residual bonus points. Due to the fact that all wireless users are rational, they are usually reluctant to lower their payoffs by more bids.

Hence, the punishment mechanism is efficient for cheating avoidance.

Cheat-Proof Strategy Implementation

Bandwidth allocation is performed when desktop users detect that a new wireless user bids non-zero bonus points in a bandwidth request. If a wireless user bids zero bonus points to a desktop user, it will be ignored by the desktop user. In addition, the received bandwidth of wireless users will be decreased when more wireless users access the network successfully. When a desktop user finds that its available bandwidth has been successfully allocated and cannot satisfy the minimum bandwidth requirement of a connecting wireless user, it will not accept the new wireless user. The cheat-proof bandwidth allocation protocol is described as follows:

1. Initially, each wireless user detects the available desktop users, and sends a request to one of them.
2. The desktop user checks whether it can accept the new wireless user according to the network capacity and the minimum bandwidth requirement of the new wireless device. Then the desktop user responds to the request by answering “yes” or “no.”
3. If the response is “no,” the program goes to step 1 and selects a different desktop user. If the response is “yes,” the new wireless user will also receive a packet including information about the bids of the other wireless users who have already connected to the desktop user. Meanwhile, other wireless users will receive the bid information of the new user.
4. The wireless users compute their trade-off coefficient according to other wireless users’ bids, and obtain their best bids by computing their own utility. Then all wireless users send their bids to the desktop user.
5. The desktop user allocates bandwidth to the wireless users according to the predefined proportional allocation rule with a punishment mechanism.
6. After the wireless user finishes the process of watching multimedia files, he will send an “end” request to the desktop user. Then the desktop user responds to the request by ceasing the connection. The desktop user also informs other wireless users who are connecting to it that the connection has been canceled. Then go to step 4.

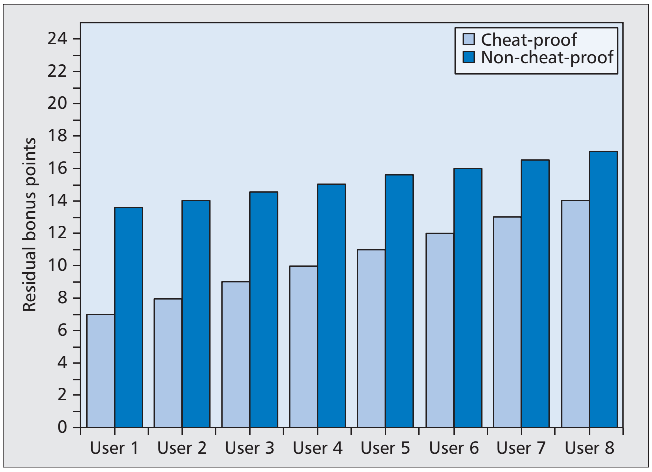

Figure 6. Residual bonus points among mobile users.

Illustrative Results

To evaluate the performance of the proposed algorithm, we set up a simulation scenario including one desktop user and 8 ($N = 8$) wireless users. The available bandwidth that the desktop user is willing to share is 100 units. Figures 4–6 show the performance of the proposed cheat-proof strategy compared to schemes without any cheat-proof strategy. We can see that our cheat-proof strategy is able to eliminate cheating in bandwidth allocation by comparing it with a non-cheat-proof method. Our cheat-proof strategy uses a punishment coefficient to avoid wireless users cheating bandwidth from the desktop user. In the non-cheat-proof method, cheating may happen when all wireless users keep the ratio of their bid to their minimum bandwidth requirement as a constant far less than 1. Figure 4 illustrates different bid strategies of our cheat-proof and non-cheat-proof methods for each wireless user to obtain an amount of bandwidth that is no less than its minimum bandwidth requirement. Figure 5 shows the result of bandwidth allocation by different bid strategies. In our cheat-proof strategy, each wireless user must honestly bid the amount that is equivalent to their minimum bandwidth requirement to obtain its desired amount of bandwidth from the desktop user. However, in the non-cheat-proof method, each wireless user can obtain the same amount of allocated bandwidth by bidding $\lambda\omega_i^r$ to the desktop user while keeping more residual bonus points (Fig. 6).

Conclusion

We have proposed a cloud-based wireless multimedia social network in which desktop users receive multimedia services from a multimedia cloud, and they can also share their live contents with mobile friends through wireless connections. This network architecture offers advantages of cost savings for network services and satisfying the increasing demand on bandwidth requirements. In this multimedia social network, we focus on a bandwidth allocation problem with the objective of sharing bandwidth efficiently between desktop users and mobile users. This problem has been solved by a game-theoretical approach. Illustrative results show the efficiency of the proposed scheme. An interesting future topic is related to distributed elaboration [9]. In cloud-based wireless multimedia social networks, the distributed collaboration and distributed resource allocation mechanisms can be studied jointly to achieve efficient multimedia sharing and transmission. Resource discovery mechanisms can also be incorporated in the framework of resource management [10].

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