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D2D Relay Incenting and Charging Modes That Are Commercially Compatible With B2D Services

QINGGUO SHEN[1,2], (Member, IEEE), WENJUAN SHAO[2,3], AND XIAO FU[1]
[1]National Mobile Communications Research Laboratory, Southeast University, Nanjing 210096, China
[2]College of Communications Engineering, Army Engineering University of PLA, Nanjing 210007, China
[3]Zijin College, Nanjing University of Science and Technology, Nanjing 210023, China

Corresponding authors: Xiao Fu (zhenling34@qq.com) and Wenjuan Shao (shaowj_nj@139.com)

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ABSTRACT Attractive monetary or other kinds of incentives are needed to motivate the relayers in device-to-device (D2D) communications. In this paper, little attention has been paid to D2D charge and incentive mechanisms that are also compatible with prevailing mobile service charging models. To help lay a foundation for commercial applications of the D2D, this paper studies the charge, reward, and penalty modes of D2D communication under operator control. The charge and reward mechanisms of D2D services are analyzed from the perspective of the commercial relationships between operators and end users participating in D2D links, deriving the incentive principles based on which a number of examples of practical reward/penalty and charging modes are presented. For unicast services, the user perception of charging and rewards in a D2D relay service is studied in detail for an end-to-end communication process and a reward and penalty metering method, compatible with a base-station-to-device (B2D) billing mode is analyzed. Specifically, in a typical congestion scenario, the probability of a relayer deliberately disconnecting the D2D is estimated and modeled, and the effect of reward and penalty policies on the reliability of D2D services is analyzed quantitatively. For a directional content multicast service, the process of establishing a D2D relay connection with reward status awareness is presented. Furthermore, the prevalence of free-riding can be reduced by measures such as giving users high reward credits with a higher priority in obtaining B2D and D2D services. Finally, following the derived principles, some segmented D2D application scenarios with commercial or social utility are identified as avenues to promote the commercial use of practical D2D relaying.

INDEX TERMS Charge, D2D relay, penalty, policy, reward, unicast, multicast.

I. INTRODUCTION

Traditional mobile communication is based on the link between a base station and a terminal in what is known as a B2D (Base-station-to-Device) communication. When the signal of the base station received at a terminal is weak, the terminal can be connected to the base station by relaying through another terminal in a D2D (Device-to-Device) relay service [1].

In [1], two types of D2D relay service are defined: Device relaying with operator controlled link establishment (DR-OC) and Device relaying with device controlled link establishment (DR-DC). In DR-OC, resource allocation and call setup are performed by the base station and interference between B2D and D2D can be alleviated near optimally. The merit of DR-OC is the effective management from a global view. Meanwhile, its de-merit lies in the congestion when the BS receives the intensive request from the D2D peers, which will induce D2D transmission delay and massive control overhead in the cellular network. In DR-DC, there is no base station or server to control the communication between devices so its design is more challenging than that of DR-OC. In this paper we mainly focus on DR-OC.

To provide a D2D relay service, the relaying devices use their own resources such as battery power and wireless bandwidth to forward data from other devices while

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money or other incentives may be offered as compensation. At present, incentives for D2D relaying is an active area of research but mostly focuses on reducing power consumption and interference, which are achieved by the terminals automatically bargaining with each other [2]–[5]. In these studies, little attention is paid to the practical mechanism of metering D2D charges and providing incentives that are compatible with current B2D charging models. However, instead of being a stand-alone communication system, D2D relaying is usually a supplement to an existing mobile communication network. Therefore, how to charge and reward D2D relaying is not only concerned with the incentives for D2D relay providers but is also related to the impact on the mobile operator's original business model. Especially for DR-OC services, if the charging and incenting mode is not appropriate, it will either lead to a loss of revenue for the mobile operator or discontent among D2D relayers, making it difficult to apply D2D relaying more widely. Whether an appropriate D2D charging model can be designed within the constraints of compatibility with B2D charging will have a decisive effect on its prospects for wider application [6].

Even if there are incentives, various physical and human factors may cause a D2D link to break unexpectedly. The physical factors include movement of the relaying terminal and battery exhaustion [7]. Human factors may arise from user concerns about the degradation of their own service due to relay traffic occupying too much bandwidth or high battery power consumption, e.g., half the battery power may be used in 30 minutes, which may cause the owner of the relaying terminal to manually break a D2D connection. The unreliability of D2D communication would then make users unwilling to use D2D services and so impact on the prospects for D2D application. Hence, the D2D charges should be low [6] and disincentives for the D2D relayers should be introduced to reduce the chances of disconnection. A well-designed incentive and penalty mechanism is needed to avoid the deliberate termination of D2D connections and to encourage the maintenance of D2D links through behavior e.g., the user proactively limiting their movement range or not starting unimportant power-consuming applications while providing a D2D relay service.

D2D relaying is in line with the principle of shared economy. However, the success of systems based on internet sharing concepts such as P2P content distribution may not automatically replicate in D2D relay applications because there is a critical difference between P2P and D2D: P2P is an end-to-end communication, which can strictly stipulate that each peer should provide upload services, while the D2D in DR-OC is only a segment in the end-to-end communication (complementary to B2D connection) and the intermediate node has the freedom of not providing relay services. Moreover, in all kinds of typical P2P file sharing systems, user free-riding without sharing any resources is popular, ignoring both the requirement and incentive for providing uploads [8]–[10]. This is because these users are concerned about affecting their own service data rate and increasing their power consumption, and the incentives provided are weak. This phenomenon can provide a reference for the operation of the D2D relay service that is partially dependent on reciprocity among users. Therefore, restraining free-riding behavior based on lessons from P2P systems should also be considered in the design of D2D reward and penalty mechanisms.

This paper studies the charge, reward, and penalties of D2D communication under operator control. By discussing the commercial factors of unicast and multicast D2D relaying services, the charge and reward models of D2D services are analyzed based on the commercial interests of each participant. For unicast services, the user perception of charging and rewarding is studied in detail, the reward and penalty metering method compatible with B2D billing is given and the effect of reward and penalty policies on D2D service reliability is analyzed. For directional content multicast services, the process of providing awareness of the rewards available in a D2D relay connection is presented. This paper summarizes the principles of charging and rewarding, and studies example D2D application scenarios in a commercial and social context to promote the application of D2D communication.

The main contributions of this paper are as follows:

1) We have identified, and discussed in detail, the obstacles in a commercial D2D implementation such as the operator's income loss, dissatisfaction among D2D relayers, and free-riding users who are not willing to contribute resources.
2) For both unicast and multicast D2D services, a policy where the D2D relay reward is mainly paid by clients and secondarily by operators is proposed to reduce commercial loopholes.
3) In the DR-OC connection process a D2D service status notification stage is set up for the client and relayer terminals, and the formulas for calculating rewards and penalties are obtained. This lays the foundation for improving the reliability of D2D relay services and implementing reward and penalty policies.
4) In an example scenario, the probability of a relayer deliberately disconnecting a D2D link is calculated and the effect of reward and penalty policies on balancing QoS (Quality of Service) between the relayer and client is investigated.

This paper is organized as follows: Section II presents related works. Section III analyzes unicast D2D charging models based on the commercial interests of each participant. Section IV describes the establishment of a D2D relay connection and evaluates the metering of reward/penalty arrangements for unicast services. Section V analyzes the reward models and connection establishment process for multicast D2D relays. Section VI considers D2D application scenarios in social and commercial environments. Finally, Section VII ends with conclusions and directions for future work.

II. RELATED WORKS

Although incentives for D2D relaying have been a popular topic for many years, most of the studies pay attention to reducing power consumption and interference. Only a few proposals for practical D2D charging and incentive mechanisms can be found in the literature.

In [6], the potential business models for mobile operator controlled D2D services were analyzed. The rationale for charging D2D users arises from providing identity checking, QoS and security, contextual information, and management, etc. The paper proposed to charge users based on how many minutes or how much bandwidth they use in fully controlled D2D communications and charge a certain amount per month irrespective of the actual D2D data flow in loosely controlled D2D communications, but no detailed price model was given in the paper.

Tehrani *et al.* [1] defined four main types of D2D communications: DR-OC, DC-OC (direct D2D communication under operator control), DR-DC and DC-DC. They discussed pricing issues for each of the D2D communication types and proposed solutions using tools from game and auction theories. It was noted that the main challenge in DR-OC is to provide sufficient incentives for relaying devices. Since the relaying devices use their own resources e.g., battery power and bandwidth, to forward the information of other devices, they need compensating to encourage participation. The authors proposed two options. One was that the operator can offer discounts on monthly bills based on the amount of data their devices have relayed. The authors thought that giving such discounts is reasonable from the operator's point of view because the operator benefits from providing a better service to devices. Another option was that the operator can offer users some free bandwidth or traffic quota in exchange for the amount of data their devices have relayed. However, the authors did not consider the problem of a loophole that users may deliberately block or interfere with the base station signal to obtain the D2D relay incentives.

Penda [11] proposed a joint relaying mode selection and power allocation scheme for relay-assisted D2D communication under Rician fading channels. Her algorithm minimizes the power consumption, with considerations of battery-life and cache status, while ensuring the required confidence in end-to-end communication. However, she did not analyze the impact on the host's service bandwidth when relaying node forwarding packets, nor did she consider the reward problem for relay nodes.

Mastronarde *et al.* [2] assumed that rational users would be incentivized to cooperate with each other using tokens which they exchange electronically to buy and sell downlink relay services. The authors endowed each participating device with the ability to learn its optimal cooperation strategy online in order to maximize its long-term utility in the dynamic network environment. Similarly, Li *et al.* [12] adopted a distributed approach with a fictional pricing mechanism for D2D radio resources, where the base stations optimize and transmit to the D2D users who then adopt a best but selfish response. Numerical results showed that their algorithms converge quickly, have low overhead, and achieve a significant gain in throughput. The policies of auto-bidding per communication in [2] and [12] are difficult to implement, and even unexerciseable under existing data plans for mobile networks. Various existing mobile network plan packages have fixed total fees, which are equivalent to charging by data usage rather than data rate. Thus, the rate-based pricing of [2] and [12] would cause problems such as that users would have to provide an extra payment in addition to the agreed plan fee.

Zhang *et al.* [4] assumed that there are N data rates for a D2D relay, and each rate has its own reward price. They designed N contracts according to these rates, and each price was optimized according to the distribution of user rates. In their scheme, the operators share part of their revenue with D2D relayers. The authors argued that this kind of concession adds to social welfare and that the operators would be prepared to bear the loss of income. However, the author's assumption is idealistic and does not consider the requirement of operators to maximize profits. Even if the cost is reduced, and the number of users is increased, if the overall profit of the operators decreases, the operators would still be deterred from adopting D2D technology.

Song *et al.* [13] proposed two incentive mechanisms: performance-based, and monetary incentives. In their performance-based incentive mechanism, the operator provides an increased data rate to the D2D relaying UE (User Equipment) that is proportional to the average sum-rate relayed by it. However, there is a problem for the mechanism that if the relaying UE does not transmit any data at this time, it cannot obtain the benefits from the rewards. In their monetary incentive mechanism, the operator pays back a portion of revenue to each D2D relaying UE based on its contribution. They proved that the additional revenue after the system gives the payback to all D2D relaying UEs is always nonnegative and the charge for each D2D relaying UE with the monetary incentive mechanism is always less than or equal to the value without the monetary incentive mechanism. Nevertheless, this can be only achieved in rate-based charging, while in fact operators normally charge by the total amount of data. When the total amount of data that a user can transmit is fixed, the total fee is fixed. Then, a considerable part of it is distributed to the D2D relaying UE, thus reducing the revenue of operators.

The works of the above papers directly related to D2D charging and incentive schemes are essentially technology oriented and not commercially feasible. Therefore we look to other research on the pricing issues of wireless networks and incenting in P2P systems that can also be relevant. In [5], an adaptation pricing scheme was proposed to improve cooperation in ad hoc networks, where a user charges other users for relaying data. The proposed model assumes that each subscriber sends traffic to a destination node along a single original path. A node $n \in N$ charges other users a price μ_n (per unit) for forwarding their traffic. When the total demand exceeds the node transmission capacity, the node can then increase the price in order to reduce the demand. By allowing users to make routing decisions according to the dynamic price of each node, the authors designed an automatic process control mechanism to maximize the effectiveness of information transmission throughout the network. However, their model is too complex to apply to D2D because the prices given by users for providing D2D relay services should be simply based on B2D prices rather than being priced according to the relationship between supply and demand.

Iosifidis *et al.* [14] considered a generalized network-assisted mobile service that allows for quota reimbursement for subscribers who act as mobile WiFi hotspots (MiFi) to serve nonsubscribers. A hybrid pricing scheme is leveraged to increase the revenue of the operator and the amount of data served by the hosts. The free quota reimbursement is effort-based, that is, it depends on the amount of data each host transfers. However, in their scheme, nonsubscribers do not have to pay any fees to the operators. The authors believed that by default nonsubscribers should pay the host but gave no analysis of how to calculate the fees.

Khalili *et al.* [15] considered a network where the operator encourages some of its subscribers to operate as mobile Wi-Fi hotspots (hosts), providing internet connectivity to other subscribers (clients). The operator charges its subscribers a usage-based price for data consumption and offers a free data quota to encourage a host to provide internet access for the clients. This quota is proportional to the total amount of data that the host forwards for its clients. The authors realized that there is a loophole where two nearby hosts may pretend to be clients and obtain internet access by connecting to each other. By doing so, both hosts gain free data quota by forwarding data for the other user while the operator does not gain any benefit. To prevent such an arbitrage, they assumed that the operator offers a price discount equal to the free data quota ratio δ for the data usage of each host, i.e., a host only pays a price of $p(1-\delta)$ for each unit of their own data. Nevertheless, this method cannot prevent collusion between client and host. A client could connect directly to the operator network, but deliberately transfer through a host to allow the host to gain free data quota.

As with D2D communication, a P2P content distribution system also requires user nodes to share communication resources, which is achieved with the help of reward and penalty mechanisms. A P2P system uses resources in a decentralized way and each node in the network is equivalent. However, there are many free-riding nodes in a P2P system that do not contribute due to a reluctance to consume resources and concern that their non-P2P services will be affected. For example, in an early P2P system known as Gnutella, about 70% of users did not share any files and nearly 50% of file queries were served by only 1% of Gnutella users [8]. BitTorrent was developed later and now is one of the most popular P2P file-sharing systems. BitTorrent uses a TFT (Tit-For-Tat) incentive mechanism to reward generous peers and penalize free-riders [9]. Based on TFT, each peer prefers a node that has provided it with uploaded data and has a high download rate. In addition, BitTorrent also adopts an Optimistic Unchoking strategy, which randomly selects one node every 30 seconds regardless of past contributions to uploads. This can not only find better nodes but also avoids starvation of new nodes. However, this strategy also hides fairness loopholes, resulting in 10% of BitTorrent system nodes free-riding [9]. To address the free-riding problem, Zghaibeh suggests that a peer that has just joined the ring should be immediately excluded and blacklisted if it refrains from forwarding a segment after receiving it [10].

To the best of our knowledge, there is no study on the differences between P2P and D2D incentives. P2P services are free. Nevertheless, D2D services can be partially monetized with low management fees while related B2D services have a fee. In P2P, the upload service of a single node can usually be replaced by other nodes and when a node disappears, the users it serves can limit the impact by using other nodes, which can be distributed across the network. However, in D2D, the alternative node must be geographically nearby. As these nodes may be rare or nonexistent, the sudden loss of a relay node may cause communication to be interrupted, which has a much greater impact.

Hence, the design of an incentive mechanism in a D2D system is more difficult than that in P2P. In the design of reward and penalty mechanisms for D2D, we need to consider other factors such as the relationship with operators and compatibility with the existing B2D charging model, in addition to preventing users from free-riding.

Overall, in the existing literature which is related to D2D incentives, little attention is paid to the practical mechanism of metering D2D charges and providing incentives that take full account of the constraints imposed by the existing B2D pricing structure. How to charge and reward D2D relaying is not only concerned with the incentives for D2D relay providers but is also related to the impact on the mobile operator's original business model. Therefore, this paper analyzes D2D charge and reward mechanisms in detail on the premise that they must be compatible with the existing mobile network B2D charging modes.

The comparison of existing literatures regarding to D2D charging and incentive schemas is summarized in TABLE 1.

III. ANALYSIS OF UNICAST D2D CHARGING MODES BASED ON THE COMMERCIAL INTERESTS OF EACH PARTICIPANT

Simply from the technical point of view, D2D relaying can improve the quality of mobile communication services and is also in line with the principle of shared economy, so operators, end users, and other participants should be keen to support D2D relay communication. However, from the point of view of the specific commercial interests of each stakeholder, their different objectives have a significant impact on the design of D2D relay charging modes. If a participant in a D2D relay scenario should be rewarded but no reasonable charging and rewarding model can be designed, the D2D relay scenario cannot be put into commercial use.

At present, in mobile networks, services such as voice and data are unicast services. As shown in Fig. 1, UE1 is the

TABLE 1. Comparison of the D2D charging and incentive mechanisms.

Related Works	Incenting policies	Pricing based on			Comment
		rate	bytes	duration	
Dx-xC [1][6]	free quota, discount	√	√	√	loophole
D2D with token/fictiona -l price [2][12]	autobidding	√			extra payment
D2D with contracts [4]	revenue sharing	√			Operator income loss
D2D with certain incentive mode [13]	higher rate; revenue sharing	√	√		wasting reward; Operator income loss
AdHoc net [5]	autobidding		√		too complex to apply
Wifi hotspot [14][15]	free quota, discount		√		[14]: not charge client; [15]: collusion risk
Bittorrent P2P with TFT [19]	higher downloadin g rate	√			free riding up to 10%
Ours: practical reward and charging	reward: free quota, credit; penalty policy		√	√	Addressing compatibilit y with B2D and free-riding problems

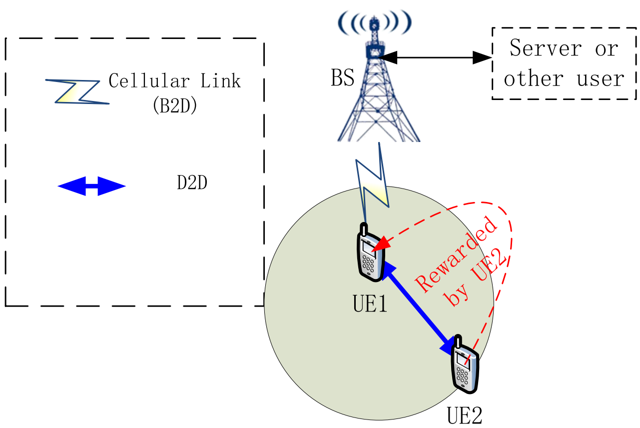

FIGURE 1. Communication between base station and UE2 is relayed by UE1.

provider of a D2D relay service and UE2 is the client. When UE2 utilizes the base station-UE1-UE2 connection for unicast services, UE1 should be rewarded. If rewarded by the operator, the reward should not be monetary or ordinary traffic quota but should be credits usable only for D2D services or idle time mobile services. This is because if monetary or ordinary traffic quota is rewarded, it may lead to commercial vulnerabilities such as the operator's internal staff or external unauthorized personnel deliberately not optimizing or shielding the base station signal to set up a relay terminal dedicated to earning D2D rewards. This would result in a loss of revenue for the operator. Thus, we come to Principle 1.

Principle 1 (Negativity of Operator Paying Reward): If the operator pays monetary or service credits convertible into money as a D2D relay service reward, this could lead to management loopholes resulting in a loss of operator revenue.

On the other hand, it would be more reasonable for UE2 to pay the reward because: 1) The overall business risk is controllable as the owner of UE2 can proactively observe the behavioral characteristics of UE1 and the loss due to unauthorized use could be limited. 2) Being used for paying a reward is the main purpose of a user earning D2D credits. Otherwise, its D2D credits will be valueless.

This could be implemented in a user-friendly way as follows: the D2D app displays on the screen of UE2 that a toll D2D relay can be provided by another UE to access the base station. Then the owner of UE2 can activate the D2D relay link after agreeing to pay the reward. In this way, in addition to paying the operator's fee, UE2 also pays UE1 the D2D reward credits.

From these observations, we come to Principle 2.

Principle 2 (D2D Reward Payment Policy): The reward for unicast service relaying should be mainly paid by the client and secondly paid by operators. The reward ought to be given in the form of a credit score with limited usage.

D2D credits can only be used to pay for D2D relay services and idle time traffic, or improve the user priority of B2D services, but cannot be used to exchange money or ordinary traffic quota. Considering the unbalanced time distribution of mobile internet traffic and the symmetry of D2D relay provider and client, we propose two optional exchange policies: 1) exchanging cellular traffic quota during idle time 2) exchanging traffic quota for a D2D relay service.

If UE2 needs D2D relays from multiple terminals to connect to the base station, the more relay hops there are, the more rewards it will need to pay and the greater the radio interference there will be to other terminals. Hence, the fewer hops there are, the better. As with the difficulty of charging a mobile terminal according to the distance from the base station, the radio power consumed by the base station, and how much interference is caused, the amount of rewards to be paid to various hops is difficult to calculate accurately and a practical solution would be to pay the same reward for each hop. So, we have Principle 3.

Principle 3 (Relationship Between Rewards and Hops): For a unicast D2D service with multiple hops, the reward for each hop is the same, and the total reward paid by the client UE is proportional to the number of D2D relay hops.

Although it is possible to reduce the total amount of rewards paid by the client UE each time using an automated bidding model similar to those in [2] and [3], the charging system would be far more complex. For example, the reward for each hop would be calculated by the QoS level of the relay service (bandwidth, packet loss rate, forwarding delay) and the level of interference. Thus, in order to reduce the D2D system complexity and interference to B2D, and provide clarity for users, the D2D path with the fewest hops should be chosen as far as possible, and a simple and transparent reward calculation scheme should be adopted.

Example 1 (Charging Mode): We consider such a D2D charging mode: one user pays a certain D2D package monthly fee (such as $1) to the operator, then they can transmit a certain amount of D2D traffic while being obliged to provide D2D relay services. When their D2D traffic quota is used up, any D2D credits earned by providing the D2D relay will be utilized for rewarding other relaying UE. When those credits are also used up, they will be charged by time or per K bytes.

Based on the above example, we come to Principle 4.

Principle 4 (Policy for Compatibility With B2D Billing): D2D communication prices should be significantly lower than B2D prices to avoid excessive additional charges beyond those of B2D. Charges should be based on traffic or time rather than on QoS and power consumption to be consistent with existing B2D metering practices.

Even if operators are able to charge a D2D service fee, it does not mean that they would be willing to support a D2D service. This is because D2D services may reduce the revenue of operators, for example, when users with the same base station communicate directly via single- or multi-hop D2D, the traffic originally transferred via B2D would be diverted, thus reducing the total revenue of the operator. If the proportion of shunting is large, the operator's B2D revenue will be greatly impacted.

Although UE can earn credits by providing a D2D relay service, this will lower its own quality of communication by reducing its battery life, residual communication time, and available bandwidth. Thus, its willingness to provide relay services may be reduced. Similar problems exist in the P2P file sharing system. For example, in the popular BitTorrent-based P2P system, although all user nodes are required to provide shared resources and are rewarded, 10% of the user nodes are free-riders sharing no resources [8], [9]. The reasons for this are: these users are concerned about affecting their own service data rate and increasing their power consumption; and it is difficult for the system to provide attractive incentives. As the services of a P2P system are free, the service providers do not charge users and their operations are often supported by advertising revenue. Therefore, the incentives provided are weak, and can only be used to pay for free download services (often in the form of instant reciprocity).

Therefore, each UE should give authorization to provide a D2D relay service to the base station only when its battery power is sufficient. When its battery power is insufficient, it should be able to revoke its authorization from the base station. However, while its D2D relay service is used by other terminals, the D2D connection cannot be freely disconnected. If it disconnects the D2D connection deliberately, it should incur a penalty. A specific penalty scheme will be studied in Section IV.

According to Principle 4, D2D relay nodes only receive relatively low rewards but this will increase the prevalence of free-riding, where users only want to enjoy D2D relay services rather than be D2D relay providers. This can be averted by increasing reward credit incentives, such as giving higher priority to users with higher credits to obtain B2D and D2D services, and higher communication bandwidth to compensate for their contribution.

IV. UNICAST D2D RELAY CONNECTION ESTABLISHMENT PROCESS AND REWARD/PENALTY METERING

A. RELAY CONNECTION ESTABLISHMENT PROCESS

From the above introduction, it can be seen that it is not a simple matter for operators to charge for D2D relay services due to the complex relationships among multiple participants, and we have derived some principles to guide the design of the reward and charging modes. Now, we analyze the process of establishing a DR-OC connection and explain the steps by which users of client and relay UEs are informed that D2D relaying will be activated if they agree.

We describe the process using Fig. 1 where UE2 accesses a base station by relaying through UE1. Assume that UE1 and UE2 have both subscribed to a D2D relay service with a charging mode similar to Example 1 in Section III.

1) UE1 and UE2 have detected strong and weak base station signals respectively and have discovered each other within range of a D2D link. Furthermore, the battery power of UE1 is above the D2D relay service threshold. They report their statuses to the base station.
2) After concluding that UE1 can link UE2 to it, the base station informs UE2 and UE2 displays the available icon of a D2D relay link on the screen.
3) The user of UE2 sees the icon and manually triggers the D2D relay connection request, which indicates that they are willing to pay UE1 a reward in addition to the original B2D fee (if they do not require a high data rate at this time, they may not activate the D2D link).
4) UE1 agrees to the request from UE2 (indicating that its user is aware that its own communication services may be affected) and establishes a D2D connection with UE2, creating a forwarding relationship between the D2D and B2D connections.
5) UE2 detects that the D2D-B2D path is established and sends a 'connection success' message to the base station. When the base station receives the message, charging begins.

B. REWARD CALCULATION

After UE2 is connected to the base station via D2D, it can use the mobile network services. The cost of the communication is the sum of its B2D and D2D expenses. The D2D expense paid to UE1 as the reward can be calculated according to the amount of traffic or the duration of the transmission.

For data services, if the reward is charged only by the quantity of bytes transferred, it will be insignificant when the number of bytes transferred by UE2 is small (e.g., only some housekeeping messages are transmitted). However, the relay connection may last a long time with UE1 consuming a large amount of administrative overhead and energy. This would be unfair to UE1. On the other hand, if the reward is charged by duration, then it would be unfair to UE2. Therefore, the reward should be charged by considering both duration and bytes transferred. For example, assume the price per unit time is A1, and the free traffic that can be transmitted per unit time is b bytes. The traffic in excess of b bytes is charged at A2 per byte. If the duration is t and the total traffic is d bytes, the reward to be paid to UE1 is:

$$AWARD_{data}(t, d) = \mathrm{A1} \cdot t + \mathrm{A2} \cdot max(0, d - t \cdot b) \quad (1)$$

where $\mathrm{A1} > b \cdot \mathrm{A2}$.

For a voice service it is appropriate to charge by duration t:

$$AWARD_{voice}(t, d) = t \cdot \mathrm{A1_V} \quad (2)$$

where $\mathrm{A1_V}$ is the reward per unit time. As the quality requirement for a voice service is higher than for data, $\mathrm{A1_V} > \mathrm{A1}$.

At present, most mobile network plan packages have fixed total fees for B2D data and voice services, providing quotas of free data traffic and voice time. When the free quotas are used up, data services and voice calls will be charged by traffic and duration respectively. For most of the time, the B2D free quotas are not fully consumed but mobile service users will pay extra fees if a D2D relay is used. Furthermore, there would be no package plan for D2D services because the relay UEs are not fixed and it is difficult to negotiate a wholesale price with a relay UE.

C. PENALTY FOR DELIBERATELY DISCONNECTING A D2D RELAY

Both physical and human factors can lead to a break in the D2D connection. Physical causes include the movement of the relay terminal itself and the depletion of battery power. These factors degrade the quality of B2D or D2D connections and lead to automatic disconnection. Human reasons include concerns that the relayed traffic affects the normal operation of the host device (for example, the relayed traffic occupies too much bandwidth, high battery power consumption affecting QoS), leading to manually terminating the D2D connection. Disconnection reduces the quality of the communication service so that minimizing the occurrence of manual disconnection is an important measure to improve QoS. Therefore, it is necessary to penalize the relayer for intentional disconnection.

In the situation that B2D and D2D signals and battery power are all above their useful thresholds, if the relay UE owner wishes to disconnect the D2D connection manually, the D2D app should first give a warning about the deduction from their reward credits. If they confirm the disconnection, the D2D credits will be deducted as a penalty. Determining a suitable penalty requires careful weighing of various factors but the basic principle is to set it higher than the unit time reward. Hence, we have:

$$penalty = C_p \cdot \mathrm{A1} \quad (3a)$$

where the coefficient $\mathrm{C_p} > 1$.

Principle 5 (Penalty Policy for Manual Disconnection of a D2D Relay): Manual disconnection of a D2D link due to personal reasons should be penalized with a penalty that is higher than the unit time reward.

In addition, it would be useful to assess the reliability of a relay UE by a *Trust* metric. Initialized with a positive value that would be updated as:

$$Trust = \begin{cases} Trust - 1, & \text{when D2D relay is manually disconnected} \\ Trust + 1, & \text{when D2D relay service finishs normally} \end{cases} \quad (3b)$$

When a UE's *Trust* reaches 0, it is forbidden to provide a D2D relay service for a fixed time (e.g., one week).

D. PROBABILITY ANALYSIS OF DELIBERATE DISCONNECTION OF D2D RELAY DUE TO CONGESTION

In this section, we analyze the problem of the manual disconnection of D2D relay services and study the effectiveness of different penalty policies on the probability of disconnection in a specific congestion scenario.

Scenario Description: Both Alice and Bob happen to be at a location some distance from a base station. Alice's UE has a moderate signal strength and is willing to provide a D2D relay service. Bob watches a video on the internet via his UE through Alice's D2D relay service and the video QoS priority level is high. We assume the download rate of Alice's UE B2D connection is proportional to the signal strength it receives and only one channel of video traffic can be handled. Later, Alice wishes to access a high-QoS feature, such as a video or e-commerce site that contains multimedia content. The remaining bandwidth of her UE's B2D connection is insufficient and the base station gives bandwidth priority to Bob's already connected video based on network service policies, making Alice's high-QoS service unavailable. At this point, Alice has two options. One is to give up or postpone accessing her service; in this case Bob's video can be completed normally. The other is to insist on accessing her service and manually disconnect Bob's D2D relay service, interrupting the video.

The probability of Alice interrupting Bob's video is calculated below: Assume that the duration of mobile video obeys a negative exponential distribution with an average value of $1/\mu$ and that the arrival processes of video and e-commerce services on each mobile phone follow a Poisson distribution with average arrival rates $\lambda 1$ and $\lambda 2$, respectively.

While Bob is watching the video, the probability that Alice has no high-QoS multimedia requirement is

$$\text{P\{no arrival of Alice high-QoS service\}} = \int_0^{\infty} e^{-(\lambda_1+\lambda_2)t} \mu e^{-\mu t} dt = \frac{\mu}{\lambda_1+\lambda_2+\mu} \tag{4}$$

The probability that Bob's video service will be interrupted by Alice is

$$P_{\text{xBob}} = \text{P\{Bob's video is interrupted by Alice\}} \leq 1 - P \times \text{\{no arrival of high-QoS service for Alice\}} = \frac{\lambda_1+\lambda_2}{\lambda_1+\lambda_2+\mu} \tag{5}$$

According to observed traffic characteristics for mobile internet [16], [17], we can assume that $\lambda 1 = 2$ per day, $\lambda 2 = 1$ per day, $1/\mu = 6.35$ min. In this way, P_{xBob} is less than 1.25%. That is, the probability of Bob's video service being interrupted by Alice is less than 1.25%. Of course, this would be less if disconnecting the D2D relay link incurred a penalty.

In order to avoid a high probability of interruption to Bob's video service, the base station needs to set up a scheduling policy to protect the bandwidth of the service that was allocated first when there are multiple high priority service requests and the remaining bandwidth is insufficient. In addition, penalties for disconnecting a D2D relay can also reduce the probability of Bob's video service outage caused by Alice.

For Alice's video session, we denote the probabilities of her giving up and persisting when she experiences x failed playing attempts as Pgvup (x), and Perst (x), which meet Pgvup (x) + Perst (x) = 1. According to the measured data in [18], we can assume a vector **Perst** = [Perst (x), x = 1, 2, ... 10] = [1 − Pgvup (x), x = 1, 2, ... 10] = [0.7, 0.5, 0.4, 0.32, 0.26, 0.21, 0.18, 0.15, 0.12, 0.10].

When Alice decides to view the video persistently, she will want to disconnect the D2D relay service if there is no penalty, resulting in Bob's video stream being interrupted. However, if there is a penalty (and an additional reward) for (not) manually disconnecting the D2D relay service, Alice may defer viewing the video. Assuming the reward is $awd = r_{\text{awd}} * \text{awd}_{\text{max}}$, $r_{\text{awd}} \in [0,1]$, then according to [19], the probability that Alice will defer playing is

$$\text{Defer}(r_{awd}, \tau) = \frac{r_{awd} * \text{awd}_{\text{max}}}{\text{C}(1+\tau)^2} = \frac{r_{awd}}{(\text{C}/\text{awd}_{\text{max}})(1+\tau)^2} \tag{6}$$

where τ is the duration of the postponement and C is a constant which is inversely proportional to the penalty. Next, we study setting up the reward ratio r_{awd} with the support of a specific D2D service policy.

Suppose the mobile operator uses the D2D service priority policy. When Alice attempts to disconnect the D2D relay service on the cell phone, the D2D app prompts Alice that Bob's video will end in about $1/\mu$, at which time, the app would give Alice a link idle prompt. If Alice waits until then, she will be given the reward *awd*. Otherwise, if she insists on disconnecting the D2D relay service, she will be penalized by a unit time penalty and by reducing the credit score *Trust*.

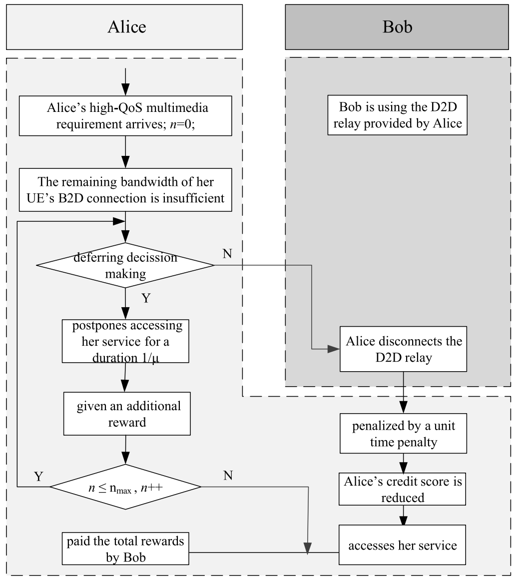

FIGURE 2. Alice deferring procedure due to congestion.

The algorithm flow chart of Alice deferring procedure due to congestion is illustrated in Fig.2.

Based on the experimental data in [19] and [20], we assume that the probability of a user being willing to defer for a time equivalent to the duration of a short video $1/\mu$ is 2/3 for a large enough reward (for example, equivalent to a short video traffic fee) and then we get $(\text{C}/\text{awd}_{max})(1+1/\mu)^2 = 1.5$. Thus, when the reward is $awd = r_{\text{awd}} * \text{awd}_{\text{max}}$, the probability that Alice is willing to defer for $1/\mu$ is:

$$Defer_1(r_{awd}) = r_{awd}/1.5 \tag{7}$$

After Alice has delayed by $1/\mu$, if Bob's video is still not finished, Alice will make a 2nd playback and deferral decision, with probabilities of Perst(2) and Perst(2) $*$ Defer_1, respectively, taking $1/\mu$ to cycle, repeatedly looping down until the nth cycle ($1 \leq \text{n} \leq \text{n}_{\text{max}} = 10$ in most circumstances).

At the beginning of the nth cycle, the probability that the Bob's video is still not finished is

$$\text{P}_{n,\text{ Bob}} = \int_{(n-1)/\mu}^{\infty} \mu e^{-\mu t} dt = e^{1-n} \tag{8}$$

The probability of Alice interrupting Bob's video with all the $\text{n}_{\text{max}} = 10$ cycles of playback/deferral decisions is:

$$P_{\text{brk}}(r_{awd}) = \sum_{j=1}^{10} \{[\prod_{i=1}^{j} \text{Perst}(i)]\text{Defer}_1^{j-1}(r_{awd}) (1 - \text{Defer}_1(r_{awd}))P_{j,\text{ Bob}}\} \tag{9}$$

For typical reward ratio values $\{r_{\text{awd}}\} = \{0.1, 0.3, 0.5, 0.7, 0.9, 1.0\}$, correspondingly we have $\{\mathbf{P_{brk}}(\text{r}_{\text{awd}})\} = \{0.661, 0.580, 0.496, 0.408, 0.313, 0.265\}$.

In the case of the D2D protection measures such as reward and penalty, by modifying (5) we have the probability of Bob's video interruption as

$$P_{xBob\_D2Dp} \leq \frac{P_{brk}(r_{awd})\lambda_1 + \lambda_2}{\lambda_1 + \lambda_2 + \mu} \tag{10}$$

The probability of Alice giving up the video playback is:

$$\begin{aligned} P_{xAlice} &= \sum_{j=1}^{10} \{[\prod_{i=1}^{j-1} Perst(j)]\mathrm{Defer}_1^{j-1}(r_{awd}) \\ &\quad \times (1 - Perst(j))P_{j,\mathrm{Bob}}\} \\ &= \sum_{j=1}^{10} \{(r_{awd}/1.5e)^{j-1}(1 - Perst(j)) \prod_{j\geq 2, i=1}^{j-1} Perst(j)\} \end{aligned} \tag{11}$$

The average deferral time for Alice to play the video successfully is, (12), as shown at the bottom of this page.

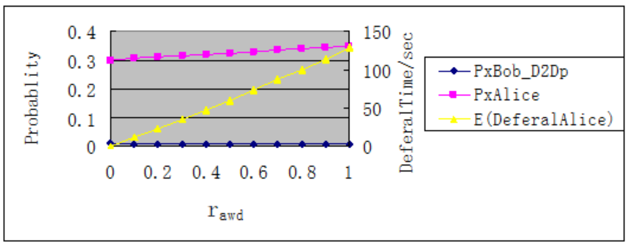

FIGURE 3. Video outage probabilities and playback deferral time change with reward.

From Fig. 3, we can see that P_{xBob} and P_{xAlice} are not sensitive to reward ratio r_{awd}, while Alice's deferral time is sensitive to r_{awd}. In order to achieve $P_{xBob} < 1\%$ and Alice's average deferral time is not more than 30 sec, it is appropriate to set the r_{awd} value to between 0.1 and 0.3.

Whether it is manually disconnected or automatically disconnected, D2D service clients are still required to provide rewards to the relay UEs by (1) or (2) for the time of communication that has been completed.

V. ANALYSIS OF MULTICAST D2D RELAY REWARD MODES AND CONNECTION ESTABLISHMENT PROCESS

A. ANALYSIS OF D2D RELAY CHARGING MODES IN MULTICAST SERVICES

Cellular networks can provide multicast services in Point-to-Multipoint mode. Although the cooperative transmission of adjacent base stations in a 4G/5G network can be used to improve the multicast signal reception quality at the edge of each cell, there are usually some locations with a bad signal (such as cells in rural districts, indoor environments blocked by high buildings etc.). Hence, in a cellular multicast service, D2D relays can be used to expand coverage. Intuitively, when a D2D relay is used to carry multicast traffic, its fees should be reduced. However, as cellular multicast services are not usually charged on the basis of traffic volume but by monthly fixed fees, or even free of charge, it is doubtful whether D2D clients would be willing to reward any relay service providers. Therefore, the issue of D2D multicast rewards can only be effectively studied after the cellular multicast charging mode is clearly understood.

In this section, we study the related charging problem under a specific content-oriented multicast OC-DR scenario where the relay topology is controlled by the operator or CSP (content service provider). As shown in Fig. 4, assuming a CSP provides free streaming multicast services sponsored by advertisers, the content of multicast can contain: commodity

$$\begin{aligned} E(Deferral_{Alice}) &= \frac{E(\text{Deferral with BobVideo Broken}) + E(\text{Deferral with Bob Vedio Finished})}{1 - P_{xAlice}} \\ &= \frac{1}{1 - P_{xAlice}} \left\{ \sum_{j=1}^{10} [(j-1)u^{-1} * \text{Prab(broken in the begin of } j\text{th Period)}] \right. \\ &\quad \left. + E(\text{Bob Video duration when finishing in the } j\text{th Period}) * \text{Prab(Alice defers } j \text{ times)} \right\} \\ &= \frac{1}{1 - P_{xAlice}} \left\{ \sum_{j=1}^{10} [(j-1)u^{-1} [\prod_{i=1}^{j} \text{Perst}(i)]\text{Defer}_1^{j-1}(r_{awd})(1 - \text{Defer}_1(r_{awd}))P_{j,\text{Bob}}] \right. \\ &\quad \left. + \sum_{j=1}^{10} [\int_{(j-1)/\mu}^{j/\mu} t\mu e^{-\mu t} dt * [\prod_{i=1}^{j} \text{Perst}(i)]\text{Defer}_1^{j}(rawd)] \right\} \\ &= \frac{u^{-1}}{1 - P_{xAlice}} \left\{ \sum_{j=1}^{10} [(j-1)(r_{awd}/1.5e)^{j-1}(1 - r_{awd}/1.5) \prod_{i=1}^{j} \text{Perst}(j)] \right. \\ &\quad \left. + \sum_{j=1}^{10} [(je - j - 1)(r_{awd}/1.5e)^{j} \prod_{i=1}^{j} \text{Perst}(j)] \right\} \end{aligned} \tag{12}$$

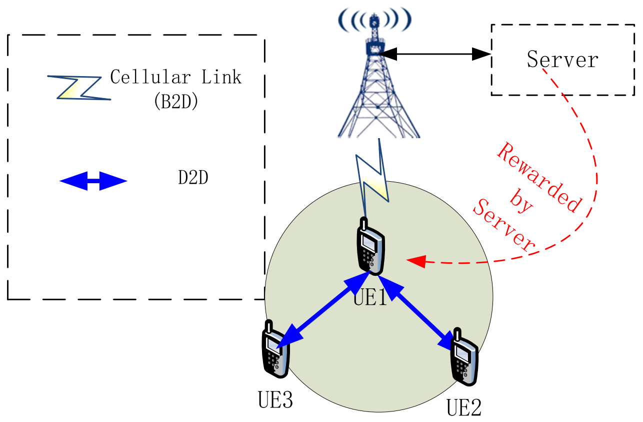

FIGURE 4. UE1 provides multicast relays for UE2 and UE3.

publicity, brand advertising, tourism services, etc. Thus, the CSP needs to setup a server on the network side to store the contents and then stream it to the mobile terminals in a specific area by renting the base station multicast channel from the mobile operators. Users who watch the streaming media do not pay for the services, and the related communication fees are paid by the CSP. When a user is at a location where the multicast signal is weak, the bit error rate of the multicast service may become high. Therefore, a multicast D2D relay would help to improve QoS.

Supposing UE2 and UE3 receive multicast messages with "Base-station-UE1-UE2/UE3" connection topology, they need to give UE1 reward credits. If UE1 is obliged to forward data in return for its free use of the multicast service, the owner of UE1 may abandon subscribing to the multicast service due to the acceleration of its battery consumption. Based on considerations similar to Principle 1 in Section III, if the reward is paid by the CSP in money, there would be a commercial loophole, so co-payment by UE2 and UE3 is an option. However, with this co-payment option, UE2 and UE3 might be less willing to watch the multicast. From the points of view of ability of providing D2D reward credits and improving the ratings of the multicast program, it is also an option for the CSP to provide rewards. In any case, the commercial risk is reduced after restricting D2D credits to be only used to pay for D2D relay services.

Principle 6 (Directional Multicast D2D Reward Payment Policy): Directional multicast D2D relay rewards should be paid primarily in credits by the client UEs and secondarily by the CSP.

Based on multicast's point-to-multipoint features, the rewards received by a relay UE should be independent of the number of client UEs it has, and should be calculated in a way similar to (1) and (2). These client UEs pay the reward equally in a shared manner, according to Principle 4. That is, when the number of client UEs is n, the proportion each UE client pays is 1/n. If a client UE is a relayer for other UEs in the topology, the net rewards it obtains will be non-negative. Edge UEs are the ultimate source of the rewards.

Example 2 (Multicast D2D Relay Charging Package): Whether or not there are cellular multicast service charges, mobile operators can provide multicast D2D relay management services. Users can have a certain amount of D2D relay time by ordering a D2D relay service at a lower monthly package fee (e.g., 1 dollar). At the same time, all multicast users (whether or not they subscribe to the relay service) are obliged to provide a D2D a relay service and they can earn credits when technological conditions permit. When the D2D relay time ordered by a user is exhausted, they can use the D2D reward credits earned previously to pay for the D2D relay. The payment between the D2D relay provider and the client is accomplished through the operator as intermediary.

Mobile operators should open their D2D service control and charging interfaces so that CSPs can manage the multicast D2D relay topologies based on their own reward policies and build optimized D2D relay networks.

B. CONNECTION ESTABLISHMENT PROCESS

From the previous introduction, it can be seen that the multicast OC-DR can be adopted in specific content-oriented multicast scenarios and the operators or CSPs can charge for D2D relay management services. In the following, we analyze the connection establishment process of multicast OC-DR and explain the steps by which users of client and relay UE are informed that the D2D link will be activated if they agree.

Referring to Fig. 4, UE3 accesses the multicast service of the base station relayed by UE1. Assume that UE1 and UE3 have ordered multicast D2D relay services according to the charging package in Example 2, Section V-A. Also suppose that when UE3 enters the base station service area, UE1 is already conducting a multicast relay service for UE2. The process then runs as follows:

1) UE3 detects that the base station signal is weak. Through negotiation with UE1 and UE2, it finds that multicast D2D relay links are available via UE1 or UE2 (and the battery power of UE1/UE2 are both above the minimum threshold). It reports these conditions to the base station.
2) After determining that UE1 is more suitable, the base station informs UE3 of this. Then UE3 displays the 'available' icon of a multicast D2D relay link on the screen.
3) The user of UE3 notices this icon and manually triggers a D2D relay connection request, which indicates that they are willing to pay UE1 a reward in addition to the original B2D fee.
4) UE1 agrees to UE3's D2D relay connection request, joins UE3 to the multicast D2D relay group and adjusts its forwarding power according to the change of relay group coverage.
5) UE3 detects that its multicast B2D-D2D path is established and sends a 'connection success' message to the base station. When the base station receives the message, the reward charging begins.

VI. CONCEIVING D2D APPLICATION SCENARIOS BASED ON SOCIAL OR COMMERCIAL RATIONALITIES

The previous analysis showed that it is not a simple matter to reward the D2D relay service. We think that D2D relay service will first be successfully applied in various segmented scenarios, gradually accumulate experience, and cultivate users for future large-scale routine applications. In the following, we give some typical segmented scenarios and carry out detailed analysis of their social or commercial rationalities.

A. D2D RELAY SERVICE SCENARIOS FREE OF REWARDS

When providing a D2D relay service, the relay terminal must bear the battery power loss and the QoS degradation. Although in normal cases the relay terminal needs to be rewarded based on a payment policy in accordance with Principle 2, situations where the relay host is willing to withstand these losses without requiring rewards can exist in scenarios such as: social groups, Internet of Things, police and emergency services. This is because these situations are essentially in the social/public interest where being free of rewards can save a lot of management overheads.

1) SOCIAL GROUPS

This D2D application mainly occurs within groups of members with a high degree of cohesion in the social network, such as groups of friends. For free D2D relay services between friends we can develop a friend's circle app with D2D relay capability where free D2D services can be provided to each other by default among circle members. We can use the contact rate between two nodes as the metric to determine social distance. The distributed k-clique algorithm is adopted to identify the social group [21]. If the contact rate is higher than certain threshold, the node will add the peer node into its familiar set, and through this way each node builds its local social group by merging its familiar set with other selected nodes which share at least $k-1$ common 'neighbors'. By supporting such applications, operators can improve the service success rate and quality, thereby providing an opportunity to increase their revenues.

A D2D relay service based on a circle of friends can be widely used in areas where cellular network signal coverage is poor, such as high-rise offices, suburban residential buildings and so on. For example, in suburban residential housing, the signals in some rooms can be weak, the telephone voice cannot be heard clearly, or the data download rates are very low. A user can effectively improve the communication QoS for the whole family by setting up a simple mobile phone with an external power supply to provide a D2D relay service.

2) POLICE SERVICES

When police operate in an area with a poor cellular network, they are unable to send messages via the base station directly. However, these messages can be forwarded to the base station by other police UEs through a D2D relay service that is reward free.

3) EMERGENCY SERVICES

A D2D relay can be applied in emergency situations such as earthquake, fire, and traffic accidents. For example, in traffic accidents, real-time alerts or traffic status can be delivered to rescuers and doctors through D2D relaying between vehicles nearby.

B. D2D RELAY SERVICE SCENARIOS REQUIRING REWARDS

1) UNICAST D2D RELAY APPLICATION SCENARIOS

In Section VI-A, we envisaged free D2D services based on circles of friends, in offices, and residential areas. When a user who is not a member of a group of friends enters such a place, they can also access the D2D relay service therein if they are willing to pay a reward based on payment and compatibility policies in accordance with Principle 2 and Principle 4.

In dense blocks, waiting halls, tunnels, underground garages, and other places where base station signals are not good, when one terminal finds that other terminals nearby are willing to provide a D2D relay, as long as it agrees to pay incentives, it should be able to use the D2D relay service. By supporting such D2D applications, operators can reduce the cost of network coverage, improve the number of service connections and service quality, and thus increase revenue.

2) DIRECTIONAL MULTICAST D2D RELAY APPLICATION SCENARIOS

Now, we describe a typical application scenario in which commercial organizers pay a fee for directional content multicast which can be applied at large venues or places where information sharing needs are intensive, such as business advertising campaigns, museums, and scenic site introductions.

In large venues, there may be requirements for performance video sharing, close-ups, playbacks and so on. Due to the large number of people and the huge demand for peak bandwidth, without the help of D2D communication, the existing wireless network technologies struggle to meet requirements. Thus, with the help of multicast and unicast D2D relays to improve the efficiency of distribution of live video and playback, the performance organizer can rent a base station multicast channel to send live video to mobile terminals, while using unicast download to provide features such as playback.

Users are not charged for viewing or downloading the content (the related communication costs are paid by the performance organizer) and the D2D reward credits are given to the users who have provided the D2D relay service based on a payment policy in accordance with Principle 6. No free-riding occurs because providing a D2D relay service is a mandatory requirement for all users. Wireless operators increase revenue by providing D2D support to CSPs, improving the wireless network QoS and raising rental prices.

VII. CONCLUSIONS AND FUTURE WORK

This paper has analyzed requirements and costs from the perspective of commercial relationships among operators and end users participating in D2D connections. Through the analysis, we have identified the obstacles in a commercial D2D implementation such as the mobile operator's income loss, dissatisfaction among D2D relayers, and free-riding users who are not willing to contribute resources, which have to be overcome via reasonable charge and incentive/penalty modes. Therefore, we have analyzed D2D charge and reward policies in detail on the premise that they are compatible with the existing mobile network B2D charging modes. Furthermore, we have derived some principles to follow in designing D2D commercial models and gave some examples of incentive, penalty, and charging modes that would be feasible in commercial operation. We also propose measures, such as giving users high reward credits with a higher priority in obtaining B2D and D2D services, to reduce the prevalence of free-riding. Table 2 summarizes the business interests of participants in D2D relaying and their underlying principles.

TABLE 2. D2D business interests of participants and related principles.

	Benefits	Costs	Related Principles
Operator	Increasing B2D traffic and gaining more revenue.	Paying reward credits with limited usage; D2D link management; potential risk of losing income due to service offload.	Principle 1: Negativity of Operator Paying Reward; Principle 2, 3 and 6: D2D Reward Payment Policies; Principle 4: Policy for Compatibility with B2D billing.
D2D relayer	Getting reward credits.	Consuming battery power, reducing the available bandwidth of its own service, and its QoS. Penalties if disconnecting the D2D link.	Principle 5: Penalty Policy for Manual Disconnection of a D2D Relay.
D2D client	Improved communication quality	Paying rewards	Principle 2, 3 and 6: D2D Reward Payment Policies.

For a unicast service, reward and penalty assessment methods that are compatible with current B2D billing modes are described. The influence of reward and penalty policies on the reliability of a D2D service is investigated and the user D2D connection, operation, and presentation of reward/penalty information prompts are carefully designed in an end-to-end communication process. For a directional content multicast service, a D2D relay connection establishment process with reward status perception is introduced. The work done in this paper will help to lay a foundation for the rational and orderly application of D2D communication.

In the future we will continue our work. First, the relationship of interests among the stakeholders in D2D communications will be further formalized and quantified. Furthermore, in additional scenarios, we will establish a model of user behavior of services to analyze the costs and benefits for each party and systematically evaluate the effectiveness of various reward and penalty models.

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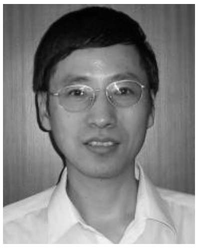
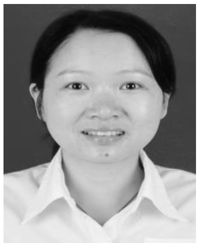
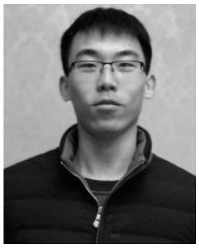


QINGGUO SHEN (M'00) received the Ph.D. degree from the PLA University of Science and Technology, Nanjing, China, in 1994. From 2001 to 2017, he was a Professor with the College of Communications Engineering, Army Engineering University of PLA, Nanjing. Since 2018, he has been a special-term Professor with the National Mobile Communications Research Laboratory, Southeast University, Nanjing. His research interests include next generation networks, M2M and wireless networks.



WENJUAN SHAO received the B.E. degree in computer communication from the Nanjing University of Posts and Telecommunications, Nanjing, China, and the M.S. degree in computer networks from the Beijing University of Posts and Telecommunications, Beijing, China, in 2001 and 2004, respectively. She is currently pursuing the Ph.D. degree with the College of Communications Engineering, Army Engineering University of PLA, Nanjing. She was an Engineer with China Mobile Communications Corporation, from 2004 to 2012. Since 2012, she has been a Senior Lecturer with Zijin College, Nanjing University of Science and Technology. Her research interests include D2D, social aware networks, and software-defined networks.



XIAO FU received the B.E. degree in communication engineering from the University of Electronic Science and Technology of China, Chengdu, China, in 2017. He is currently pursuing the Ph.D. degree with the National Mobile Communications Research Laboratory, Southeast University, China. His research interests include fifth generation networks and wireless networks.