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QoE-ensured Price Competition Model for Emerging Mobile Networks

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Abstract: The ubiquitous availability of devices such as smart phones, tablets, and other portable devices enables the collection of massive amounts of distributed data from the daily lives of citizens. These types of emerging mobile networks can provide new forms of valuable information that are currently not available on this scale via any traditional data collection methods. In such networks, price competition is the most important factor among the participants (mobile devices, Services Organizers and users) that highly affects their Quality-of-Experience (QoE). In this article, we first explain how a game theory model can depict social behavior, price competition and the evolutionary relationship among devices, Services Organizers (SOs) and users, and then we provide insights into understanding the price competition process of those participants in mobile networks. Finally, we outline several important open research directions.

1. Introduction

Mobile networks, which leverage the ubiquitous availability of devices such as smart phones, tablets, sensor nodes [1], and other easily portable devices, enable the continuous collection of a massive amount of distributed data, which can provide new forms of valuable information that are currently not available on this scale via any traditional data collection method [2]. In mobile networks, such devices are being manufactured with an increasing number of powerful embedded sensors in different categories (e.g., acoustic, sound, and magnetic vibration) [2]. Each device can sense and collect information directly from the surrounding environment and provide information services through mutual interaction, enabling a variety of new applications and services and playing a fundamental role in daily life. These devices, which directly sense information from the surrounding environment, are referred to as entities. Sensed information is a part of an information service called a simple service (SS). Because sometimes these simple services cannot be provided directly to a user (user), service organizers (SOs) are required to collect and organize these simple services (SS). SOs provide advanced services to users, such as VTrack [3], which provides omnipresent traffic information, and NoiseTube [4], which generates noise maps [4].

The organizers must pay for permission to collect and organize simple services, which the organizers can sell as an advanced service to users. In mobile networks, price competition is the core competition among entities, Service Organizers (SOs) and users. There are complex relationships in the price game. For SOs, the two main tasks are to collect simple services (SS) from entities and to organize SSs into more advanced services, thereby providing the user with a combination of high quality advanced services (AS). However, entities must pay (in time, energy, and storage space) for the perception and monitoring of the environment and for the collection of simple services. In general, SOs must pay entities to collect SSs from the entities, which incentivizes the entities to actively collect SSs to provide SOs with more simple services. The second task of SOs is to provide users with composite services (AS). After SOs gain access to collect and organize SSs, they can in turn profit by providing users with advanced services.

In this article, we argue that a game theory model can depict the social behavior of model Entities, Services Organizers and Users as well as price competition and evolutionary relationships between the participants. Moreover, we provide insight into understanding the price competition process of the participants of mobile networks. To illustrate this issue, we present different game methods and techniques to identify which game methods and techniques are suitable for those competition relationships. We find that a game theory model can depict different aspects of the behavior of the participants (including entities, SOs, users), and we discuss the technical challenges involved in developing and deploying such game methods.

2 Price competition in Mobile Networks

2.1. The composition of price competition in a mobile network

With the rapid development of technology and application requirements, smart phones play an increasingly key role in the daily lives of citizens. As typical representative mobile devices, such as iPhone and Android smart devices, smart phones have experienced rapid development in their hardware configurations and software performance capabilities. Moreover, smart phone mobile devices generally carry several types of sensors, including image, voice, GPS, acceleration, distance, direction, light, and temperature sensors, which allow users to share useful contextual data at any time and represent potential sources of information sensing on a global scale. Such systems have been called participatory sensing systems (PSSs) [2] or Crowd sensing networks (CSNs) [2]. Smart devices have greatly expanded the scope of human perception and have changed the way people perceive the world, opening up many new application fields in the process.

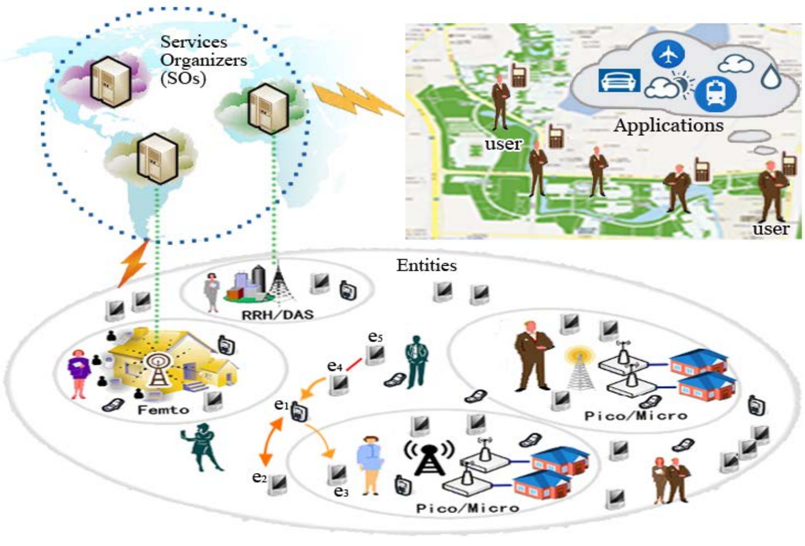

Figure 1. Illustration of the composition of a mobile network

Fig. 1 shows the structure of a mobile network, which consists of entities, Service Organizers (SOs) and users. Entities refer to the individuals in possession of the sensing device(s) in Fig. 1. Entities can sense information from the surrounding environment at any time and report the findings to SOs through wireless (cable) communication. Instagram [2] and Foursquare [2], for example, are useful for monitoring large-scale phenomena and require the active involvement of people who voluntarily share contextual information and/or make available their sensed data; other examples include VTrack [3], which provides omnipresent traffic information, and NoiseTube [4], which constructs noise maps [4]. Because collecting SSs requires the consumption of energy, time, storage and other costs, when an entity reports an SS to SOs, SOs pay the entity, which incentivizes the entity to collect more SSs. Although some entities provide SSs free of charge, free SSs are limited, which limits their usefulness to SOs.

2.2. The form of price competition in a mobile network

In a mobile network, there are three types of price competition: (1) price competition among entities; (2) price competition between entities and SOs; and (3) price competition between SOs and users. The new service system, based on a mobile network, has changed traditional price competition methods. In this new type of service system, entities are the source of the services and become the focus of the service system, i.e., an entity plays a key role in the system. At the same time, any entity can participate or withdraw from a service system at any time, which results in a degree of uncertainty in any given service. Because of these reasons, the price competition among Entities as well as between Entities and SOs are the most important of the three service system price competitions.

(1) Price competition among entities. Price competition among Entities is manifested in the following four forms: (1) price competition between Entities and SOs - Entities obtain SSs by directly perceiving the surrounding environment and are remunerated by reporting SSs to SOs. (2) Competition among Entities - The entity can buy SSs at prices lower than the price provided by SOs, which allows the entity to profit. For example, in the traffic information service system, entity A games with entity B; if they cooperate with each other in an interactive cooperation strategy, this interaction can be thought of as a cooperative game. Entities receive services by paying less than the service purchase price of the SOs and profit by reporting these services to SOs. However, the cooperator is paid for the service and does not profit in a cooperator-defector pair. Thus, in this new service mode, the situation among entities is very complicated and is characterized by a great deal of uncertainty. (3) Direct price competition among entities - In this type of price competition, an entity profits by providing another entity with services. (4) Price competition among entities through SOs - This type of price competition among entities refers to situations where some entities, such as entity A, requests a service from another entity through a platform that is provided by an SO. The service is not provided by SOs, but an entity that can provide such a service is noticed by SOs. Entity A games for services from those noticed entities. For example, in the mobile network, entity A requests another entity to complete a specific service to realize real-time ubiquitous pervasive computing. After SOs receive the request, they forward the service requests to entities that conform to the conditions. If the entity is willing to provide the corresponding service, price competition occurs among the entities through SOs.

(2) Price competition between SOs and entities. Each SO invests in collecting and organizing services and constantly seeks more services at a lower cost to improve the quality of the combined services for the users (or customers) and to maximize its profit. Generally, the more SS an SO collects, the better quality of service (QoS) of the combined services provided by the SO. For example, when VTrack collects traffic information services, incomplete traffic information will affect the QoS to the user. Thus, when an SO collects more information, the quality of service that can be provided by VTrack improves and the accuracy of the traffic information obtained by users increases. However, the collection of too much information by SOs can be detrimental because obtaining the information requires payment, and the additional information beyond a certain point may not sufficiently improve the QoS for the price. The number of services can be controlled by adjusting the service price dynamically. SOs raise the service price to incentivize entities to provide more services when the SO desires more collected services. In contrast, when the SO desires fewer collected services, SOs can reduce the price of the acquisition of the service. In general, because information collection costs the SO (sometimes in services), entities seek to sell their services at the highest price and buy services at the lowest price (such as λ). Based on these principles of supply and demand, a point of equilibrium can be reached for the service price between SOs and Entities.

(3) Price competition relationship between users and SOs. SOs profit by providing high-level services to users; thus, a price competition relationship exists between users and SOs. User usually refers to the person or organization that consumes a service. In the emerging mobile networks, user and entity may be the same mobile device, as a mobile device can collect services to report to SOs as an entity and can consume services from SOs as a user [10].

2.3. The key issue of the price competition in a mobile network

Researching the complexities of price competition can help SOs and entities choose the appropriate competition strategies and optimal prices to occupy the dominant position in the competition [7-9], [16]. For a long time, researchers have sought to establish a suitable model to depict the complex price competition system. The main problems for SOs include (a) the pricing problem of SOs. One part of the pricing problem is the pricing for entities. If the number of services SOs want to collect is ω, then for a given network, what price λ should be set by the SOs when users provide a service? If the price λ is too high, then the more services that are provided require more payments by the SOs, which could result in lower efficiency. Conversely, if the price is too low, then SOs may encounter difficulty in collecting sufficient services. Another part of the pricing problem is the pricing for users. Users order services that are provided by SOs, for which SOs charge a service price ζ to the user. The determination of price λ is not only influenced by price ζ but is also influenced by the user. Thus, the appropriate pricing of ζ is important for the survival of SOs. (b) Another problem for SOs is when the system becomes stable, how much is the total expected payment and payoff? (c) Furthermore, what is the number of services provided by entities with different strategies? When the SOs face a dynamic market, according to the different strategies, entities adopt effective pricing strategies that play an important role in price competition for SOs.

For entities, the key issue of concern is the pricing problem of entities. The price of an entity refers to the payment γ that they offer other entities that provide the service. SOs offer payment λ to an entity when an entity reports a service to an SO. The price λ stabilizes relatively quickly; the entity obtains little payoff if the service price γ of the entity is too high, which results in the demise of the entity. If the service price γ of the entity is too low, other entities have no incentive to interact with them, resulting in a disadvantage for the entity in pricing competition. Thus, setting a reasonable price is the first condition to ensure the survival of an entity.

3 Game theory-based price competition between SOs and user

3.1. Stackelberg Game Model for price competition between SOs and users

Price competition between sellers and buyers was previously studied by Walrand [10]. A similar price competition exists in mobile networks. SOs that provide services to users act as the sellers, whereas users who buy services are the buyers. Maximizing profit is the primary concern of SOs, which can be achieved by maintaining a high price level for users and a low amount of investment in the infrastructure. In contrast, users wish to maximize their utility by consuming high QoS at the lowest possible service price. The main price competition models are the

Cournot and Bertrand competition models [10]. In the Cournot model, SOs compete with each other to decide the extent of investment in their infrastructure. That is, SOs provide users with more comprehensive services mainly by buying more simple services (SS) and by investing in the infrastructure to allow the users to obtain faster and more convenient services. In the Bertrand model, SOs engage in price competition to attract more subscribers for a given infrastructure capacity.

Price competition exists between SOs and service users, and users will prefer to access SOs with better service quality and lower prices. Simultaneously, the SOs compete with each other to attract users. SOs seek a large enough customer base to pay for the cost of their investment. SOs must also consider the pricing strategies of their competitors when setting prices because users can choose a better service quality and price for an SO service request. Therefore, the characteristics of the interaction between SOs and users are a typical problem of the Stackelberg game [11]. For the analysis of the interaction behavior between a user and an SO, the Stackelberg game model can be used to depict the interaction behavior. There are two types of participants in the game: leaders and followers. An SO can be seen as a leader, who is the provider and owner of a service and a decider of the service price. The leader meets the service demand of the user by collecting simple services and influencing the service needs of the users through a price strategy to maximize its own utility. Each user is defined as a follower. SOs must pay to collect simple services from entities, and the quantity and quality of the collected service, as well as their investment in the infrastructure, will influence the service demand of the user. In other words, the correlation between the cost and profit of an SO can be represented by the utility function of the SO. For the user, the utility function of service demand quantity also exists.

3.2. Trust Game Strategy for price competition between SOs and users

A game mechanism based on credibility [12] is suitable for price competition between SOs and users. In the trust game model, SOs give a more preferential price to users with high credibility, which fosters “loyalty” from the user, to attract the user to achieve maximum profit. In a game based on trust, the following important issues need to be studied. (1) The credibility computation. In a price game based on credibility, the price is corrected based on the credibility function; thus, credibility computing reflects price changes. In a credibility game between SOs and users, the trust computation includes two aspects. One aspect is the SO-user trust computation, which influences the decision of the SO regarding which user with whom to play the game. The second is the user-SO trust computation, through which the user decides to choose which SO can service the request. (2) The choice of game strategy.

(**1) Evaluation of trust in users by SOs.** In the trust model, there is considerable variation in the concept of trust. Trust can have different definitions in the context of different applications. Trust generally occurs in a distributed environment; some game participants practice fraudulent behavior in the game, which is disadvantageous to the honest entity. Thus, trust is often defined as whether a game individual complies with an agreed upon strategy in advance in the process of a game, whereas trusted behavior is defined as the behavior of the game strategy to comply with a contract in advance; participants who practice other behaviors are considered untrustworthy. Trust can be defined by the ratio of the number of trusted behaviors to the overall behavior over a period of time. Obviously, SOs offer higher preferential prices to users with high credibility; thus, SOs attempt to retain entrusted users to improve their earnings. In a trust-based game, SOs offer the user a trust value measurement based on historical records of user interaction. SOs can adopt the method of grading to evaluate every interaction with users and their behaviors. SOs give users more positive trust values if they show a higher level of trust in the process of interaction with the SOs. In contrast, SOs will give negative evaluations of trust if users show fraudulent behavior over the course of their interactions. Because the interaction behavior between SOs and users at different periods of time do not have the same importance with respect to the evaluation trust value, in general, the closer to the current time of interaction, the more significance is attributed to the evaluation trust value. A forgetting factor is used by SOs to correct for the trust of a user based on time. The more distant an event is from the current time point, the smaller the forgetting factor will be. Likewise, greater weight will be placed on recent interactions to evaluate the credibility of the user.

(2) Evaluation of trust in SOs by users.

In price competition, some SOs may be dishonest, and quality products offered by reputable SOs are limited; thus, selecting the most profitable SOs as transaction partners is challenging, especially when users lack personal experience with SOs. The game model based on trust evaluation can help users evaluate the credibility of SOs and then choose which SOs will provide a better quality of experience (QoE). From the point of view of the user, evaluating the credibility of SOs is more complex and diverse because SOs offer users different prices and qualities of service (QoS). Moreover, different users may receive different QoE. In a mobile network, the traditional method can also be used to evaluate the credibility of the SOs. For example, to evaluate the credibility of SOs by using user feedback, a user can increase the credibility of an SO if the user expresses that the SO provides high quality services; this is an example of a single rating system.

Obviously, this trust evaluation method is also suitable for price competition between users and SOs. However, in this type of research, it is authentic to consider feedback information from the user. Notably, in real situations, a large amount of false feedback information exists. This trust evaluation method is also unsuitable for situations in which users do not report feedback. Dual reputation ratings systems can be used to evaluate the credibility of users and SOs. In this method, to report evaluations of transactions, both parties should submit ratings to the system after an interaction. If both parties are satisfied with the deal, the system will improve the credibility of the SOs. However, if the feedbacks are inconsistent with each other, indicating that at least one party could be lying, the system punishes both parties by reducing trust or prohibiting future interactions. The deficiencies in this type of feedback system include the fact that forcing both parties to submit ratings to the system is not feasible in actual mobile networks. Notably, the distributed mobile network has no credible rating system, and users and SOs have no obligation to submit ratings to the system. Moreover, in all systems that depend on feedback, the authenticity of the feedback information from the users and SOs cannot be ensured, facilitating cheating by collusion between malicious entities. These entities could enhance their own credibility by giving high mutual trust feedback values, which could not be recognized by the system.

(3) **The mechanism and strategy of trust games between SOs and users.**

Game models based on trust can also depict the price competition relationship between SOs and users, improving the QoE of the participants. In this model, each participant (SOs and users) is rational and hopes to maximize their own interests. Therefore, each participant will comprehensively consider various factors, such as the credibility of behavior, QoS, and overall QoE, thereby calculating the trust function of the game participants. For SOs, price λ in the matrix of a game is a value that is associated with the trust function, and SOs dynamically adjust the price λ as trust changes. For the user, the standards for choosing SOs may be the product of the provided price λ and the credibility of the SOs. Each participant chooses another participant according to their desire to maximize their own benefit, but they will adjust their gains matrix on the basis of the strategy of their opponent in subsequent games to achieve Nash equilibrium.

4 Game model insight into the price competition between SOs and entities

There is a price competition relationship between SOs and entities because simple services are provided by entities, SOs announce the acquisition price of simple services (SS), and entities obtain a payoff by reporting simple services to SOs. The price competition relationship between SOs and entities can be described by using the Bertrand price competition model [13]. The Bertrand model assumptions are as follows: (1) each SO competes by selecting a suitable acquisition price for an SS; (2) the produced advanced service is homogeneous; and (3) there is no formal or informal collusion behavior between the SOs. In price competition between SOs and entities, entities will report their simple services to the SO offering the highest purchasing price. The SO with the highest purchasing price will theoretically collect all of the SSs, whereas the other SOs would not receive any SSs. This would force the other SOs to increase their offered purchasing price for SSs to an extent that is limited by the marginal cost. After several rounds of the price game, the purchasing price of SOs tends to equal the marginal cost, which results in zero profit and is similar to competitive situations in real life.

The Bertrand price competition model is often used to depict price competition among enterprises. Generally speaking, the price competition among enterprises does not completely satisfy the premise of the Bertrand model. The Bertrand model assumes that the production capacity of an enterprise is not limited, i.e., the production capacity can fully supply the market. However, the production capacity of an enterprise is limited and cannot supply the entire market; thus, the price may not be limited by the marginal cost. In the new service model of mobile networks, the production ability of an SO is not limited. However, the price competition between SOs and entities is also limited by the Bertrand model; another consideration is that the produced advanced service is completely substituted. In practice, advanced services produced by different SOs are not identical. In general, the more SSs received by SOs, the higher the quality of the service provided by the SO, which results in a higher price charged to the user. Thus, the marginal cost of the SOs is the utility function associated with the received number of SSs. The marginal cost promotes a high-level quality of service, and each SO eventually reaches a balance by participating in the game on the basis of an appropriate price.

5 Game model - Understanding the price competition among entities

5.1. Game Models based on trust for price competition among entities

Trust-based price competition games among entities differ from the games between SOs and users. For example, in a Delay Tolerant Network (DTN), the DTN transports data depending on cooperation among the entities, thereby requiring cooperation among the entities and playing a significant role in the operation of the DTN. However, in such a system, an entity cannot always obtain direct benefits by helping another entity relay data, and the entity only obtains a payoff when the entity requires the system to relay data. The trust game mechanism is relevant to this type of system. The trust game mechanism provides that an entity can earn credits by cooperating with other entities or by helping others perform beneficial work. The entities use these credits in turn to obtain help from others.

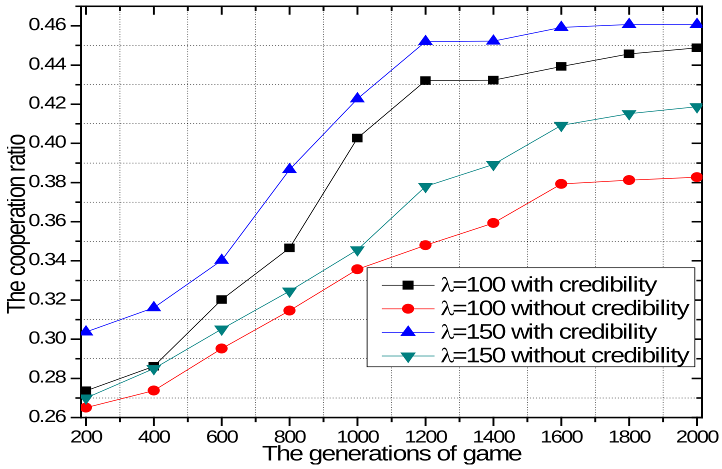

Figure 2. The cooperation ratio of entities with credibility

Fig. 2 shows that the cooperation ratio of entity games involving entities with high credibility can be improved. The credibility of an entity will be low if the entity always betrays their opponents in the game and does not pay other entities in exchange for SSs. Therefore, this game can inhibit the behavior of an entity with low credibility in the process of a game involving an entity with high credibility. In the trust-based game mechanism, an entity chooses an opponent based on trust from high to low, which increases the chances of the entity obtaining the biggest payoff. The cooperation ratio of this system can be improved (see Fig. 2).

5.2 Price competition based on auction by entities

Price competition among entities can be depicted by using the auction game mechanism [14]. When entity A in S_1 requests for S_2 via SOs, this situation is similar to an asset selling problems for entity A. Many entities can provide this service in S_2, arriving sequentially over discrete time slots (multiple entities can arrive in the same slot). These entities (offers) are independent and identically distributed (iid). As the offers arrive, each offer will provide their service price. Entity A has to decide whether to take an offer or wait for future offers. If entity A decides to accept the service at the current service price, the service price will be lower than later offers. Additionally, if entity A decides to wait for a future offer, then entity A pays a cost to consider the next offer. This cost includes time consumption and the value of important information, which is unknown due to the time delay. This cost can be represented as a growth function with respect to time loss. Therefore, the cost of entity A becomes larger in the process of waiting, which also increases the expectations by the entity for the following offer because previous offers cannot be recalled. The decision process ends with entity A either choosing an offer or not buying any service.

5.3. Incentive Game Models for price competition among entities

The incentive mechanism plays an important role in games among entities [15]. In mobile networks, due to limits in processing power, storage space, energy and other resources, an entity tends to be selfish, and selfish entities are usually not willing to cooperate with other entities, which will affect the function of the network. How to motivate selfish entities to improve the network performance is one of the major challenges for the current mobile network research field.

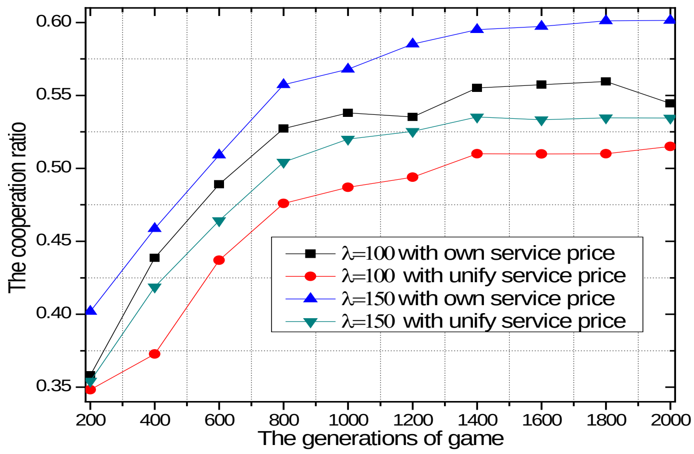

Figure 3. The cooperation ratio of entities with respect to service price

The result of the experiment for a price incentive game is shown in Fig. 3. In this game, each entity adjusts the service price according to the payoff. SOs also adjust the service price depending on the amount of the total obtained service in the game. To obtain more payoffs in the game, the entity increases the service price when the total payoffs increase and when the corresponding game number of the entity increases, which increases the willingness of the entity to game with other entities. Thus, the entity can obtain more payoff due to the incentive, resulting in increased cooperation and an increased cooperation ratio in the game.

Reputation systems can be used to depict the game among entities. Reputation can refer to the contribution of an entity to the network in the Delay Tolerant Network (DTN); the more data an entity relays, the better the reputation. Reputation can also represent the collaboration levels of the entities, whereby the cooperation ratio of a selfish entity would be low. Reputation can also represent other abilities of entities, such as the ability and the quality of sensory data. In the game model based on reputation, a system offers certain preferences to an entity on the basis of reputation, eventually involving the entity in a game and making the entity reluctant to deviate from the system game strategy; this results in the entity reaching the optimal equilibrium. The shortcomings of a reputation-based incentive mechanism are as follows: (1) this system works against a new entity that has just entered the system; (2) an entity could easily provide a good evaluation to another entity in collusion, which could increase the reputation of malicious entities; and (3) obtaining a fair evaluation is difficult using this system.

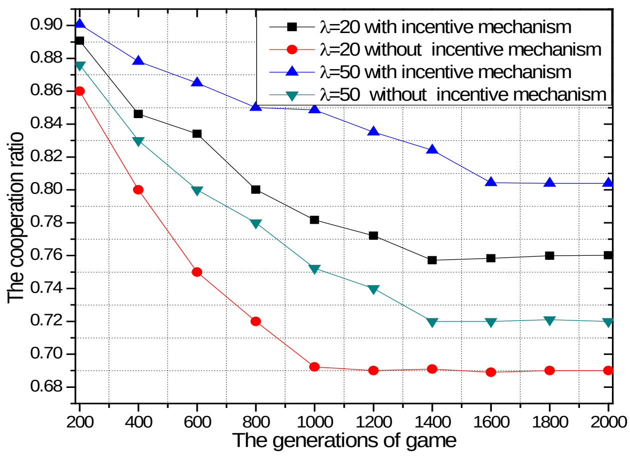

Figure 4. The cooperation ratio of the incentive mechanism

Fig. 4 shows that the incentive mechanism in games can improve the entity cooperation ratio. The total revenue of the entity increases due to the incentive mechanism, leading to an increase in the number of games and increasing the enthusiasm of the participants for the game. Thus, the entity becomes more willing to conduct the game. Additionally, the number of games decreases for entities whose total revenue decreases, which results in a decrease in the number of betrayals in subsequent games. This results in an increased cooperation ratio.

6 Potential research directions

6.1. Tolerate failure mechanism of game among participants

In the previous game mechanism, the participants either do or do not die to participate in the game when the total payoff of the participants involved in the game is 0. However, in practice, the death of the participants also tends to offer a certain probability to participate in a game and can often change the outcome of the game. For example, in real life, some entrepreneurs (SOs) may lose all of their investments but may take advantage of competition due to their own efforts and strategy adjustments. A similar situation can also occur between entities. As shown in Fig. 5, three lives can be given to an entity, i.e., three chances are given to an entity in a game in which the entity can “die”. The entity will be dead after using all three chances. When each entity is given three chances, the cooperation ratio significantly increased. This type of game strategy is in accordance with actual situations and is worthy of research. For example, how many resurrection opportunities should be provided to entities? What type of strategy should be amended to apply this observation to price competition in a mobile network?

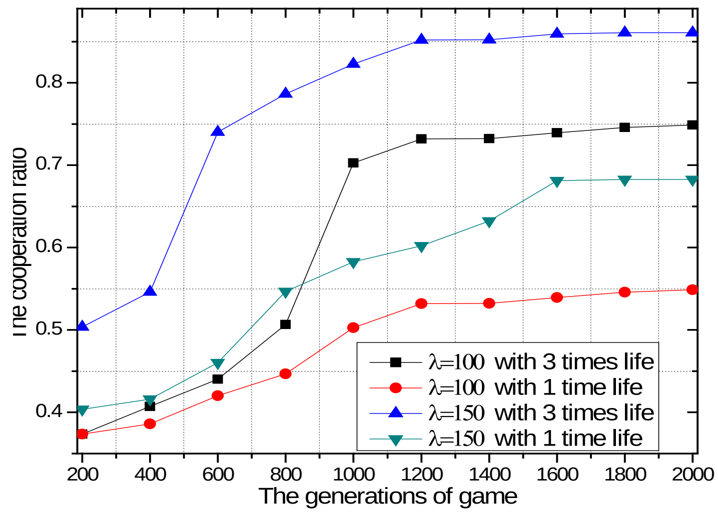

Figure 5. The cooperation ratio of an entity with 3 lives

6.2. The influence of network dynamics on the game

In the trust game, an incentive game is completed based on memory game history. In a mobile network, the influence of the movement of participants for a game is worthy of research. Vainstein et al. conducted a preliminary experiment on the movement of participants. In the experiment, they randomly placed an agent on a 2-D grid. A percentage of agents moved randomly to idle neighbors located in each generation. The agent system evolved into a game with their neighbors, whereby random moving produced the next generation. Interestingly, the study found that with the improvement of the mobile agent ratio, the system had a higher level of cooperation. The results of this research warrant further research of this concept in the context of a mobile network.

6 Conclusion

Mobile networks have gained tremendous momentum in recent years due to the widespread proliferation of mobile devices (entities). These entities perceive the surrounding environment and report their findings to Service Organizers (SOs), who compose simple services and provide users with ubiquitous availability of network services. These participants (including devices, SOs and users) tend to compete with each other through price to improve their QoE. Theoretically, these relationships reveal that price dynamics in mobile communication services are of vital significance.

Game theory has been used to model and analyze the price decision process of participants in a mobile network. Game theory models are useful for deciding on the price that will achieve maximum profit. In this article, we discussed different game models developed for price competition among SOs, entities and users. These models have been categorized based on objects in price competition. In these game models, the price competition between entities is the most complex. Trust-based games, incentive-based game mechanisms and auction-based game models are suitable for solving the price decision problems among entities. For the price competition between SOs and users, Stackelberg games and trust-based games can be used. The Bertrand competition model and improved game model can be used for price competition between SOs and entities. We also presented some experimental results to show the effectiveness of the game model. In this paper, we also outlined potential research directions to develop novel game theory models to solve price competition problems for mobile communication services.

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