Research on the Sharing Economy about Resource Sharing in Social Interactive Networks

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Supervisor: Georgios Iosifidis

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Declaration

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In the 21st century, the economic globalization has been facilitated a lot by the new scientific and technological revolution. Especially in the field of economic life, sharing economy and collaborative consumption are becoming trends in the society and they focus more on sharing and interactions among us. This thesis aims at finding out how the position of participants and the variance of resources affect the wealth of participants and the sharing level and the wealth inequality of the sharing networks. We invited 24 human players who were divided into 4 groups where there were already 6 AI players in each group to participate in WIFI sharing games where the human players needed to make their own sharing decisions and the AI players would follow a predefined sharing strategy. There were 20 WIFI sharing games totally where the variance of resources had 5 different values, all the participants were randomly embedded in networks with the same graph density. Our analysis showed that the wealth of a player was proportional to the degree of the player and if the variance was larger, the speed of the increase in wealth as the player having more neighbors would be slower. We also found out that as the variance increased from 10 to 50 Mbps, the path of the change of the Gini coefficient(representing the wealth inequality) was pretty like a letter 'W' while that of the sharing coefficient(representing the sharing level) was like a letter 'M', which indicated that if the variance was moderately smaller or larger than half of the base resource(60 Mbps), the sharing level of the whole network would reach a high position and more importantly, a higher sharing level would be beneficial to alleviate the wealth inequality of a society. We conclude that participants in a resource sharing network are supposed to maintain a good relationship with their neighbors by balancing the resources shared to different neighbors to assure that they will not be abandoned by any neighbor. In addition, for the network designers, they should control the resources to make it fluctuate in a reasonable range and provide the administrators with the right to adjust the variance by changing the logical structure of the network or updating the necessary supportive equipment so that the variance will arrive at an ideal value. In conclusion, all the research in my thesis is aimed at helping the members of a social network to gain more benefits from the network with a low level of wealth inequality so that the people in the network will enjoy a stronger sense of happiness.

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Chapter 1

Introduction

1.1 Background

In the 21st century, economic globalization has been deepened under the tide of the new scientific and technological revolution. With the rapid development of Internet, mobile devices and cloud computing technology, people are connected together far more easily and conveniently than before. Naturally, there is an increasing number of scenarios where sharing and cooperation act as the core concept among societies, associations and even ordinary people who are far away from each other.

Especially in the field of economic life, sharing economy and collaborative consumption are becoming trends in the society today and they focus more on sharing and interactions rather than traditional ownership-based modes[4, 5].

For example, bicycle sharing has been more and more popular all over the world especially in China which has hundreds of cities where people can easily get access to bicycles and even electric ones nearly anywhere and anytime in the urban area. All they need is making a order via their smartphones which will only take them less than 1 minute[6].

Another example is the sharing and borrowing service that provided by Alibaba in China. Everyone who have passed the credit assessment are free to borrow daily items ranging from smartphones, power banks to umbrellas and even game accounts which have been put online by others and the lenders will get reward depending on how long that item will be used by the borrower.

1.2 Target of Sharing Economy

The fundamental reason of researching on sharing economy is that it holds huge possibilities of improving the efficiency of idle resources in the society by reallocating them in the ways that there is nearly no cost to the owners but the receivers can benefit a lot from the shared resources. Essentially, sharing economy tries to explore and leverage the inequivalence between the demands for resources and redundant resources among all participants[7].

1.3 Sharing Models and Scenarios

In sharing economy models, the most prominent feature is that all the participants in it are both producers and consumers, which means they not only can offer their spare resources to others but also can receive and make use of resources provided by others. Furthermore, they are free to make decisions on whom to share with and how many resources they would like to share[8].

Evidently, the sharing economy has been successfully applied to many industries and there has been a great diversity of sharing models which encompasses an embedded network that imposes some restrictions on participants' sharing decisions. For instance, taxi sharing is constrained by the geographic locations and travel time, energy sharing like the electricity sharing highly depends on the grid networks that have already been planned and constructed and online peer-to-peer resource sharing counts on whether the needs matches the capability of each other. In summary, the sharing economy networks can be affected by spatial, temporal, technological and other possible kinds of constraints.

1.4 Significance and Prospects

Apparently, it is meaningful to do research on the sharing economy since efficient solutions with low-cost and sustainable strategies targeting practical problems will definitely boost the economy at a local or larger scale. In my dissertation, I have improved and conducted a series of simulated experiments to explore the rules under the participants' sharing decisions and tried to find what changes can we make to facilitate the sharing efficiency in general socio-technical networks[9].

In the ancient times, the development of human civilization cannot be so fast without the cooperation and sharing among our ancestors on food, residence and especially tools. Therefore, from my own perspective, the sharing network models we do research on today is also a kind of ways to explore the features of human nature and all the objective laws and solutions to this kind of problems we obtained during in this experiment will definitely help to deal with a great many basic and primary challenges in the whole human society.

1.5 WIFI Sharing Game

In this thesis, we will employ a resource sharing network model where all the participants are embedded in to share their spare resources. This model is constructed as a WIFI sharing game to simulate the practical applications in the sharing economy field and the virtual resource is the bandwidth of the WIFI.

In sharing economy models in real life, people are indeed making the sharing decisions about whether or not to cooperate with a certain neighbor and the number of resources that are supposed to a certain neighbor. Naturally, for the aim of designing a system structure about the sharing economy, it is necessary for designers to know what factors may impel people to make their sharing decisions and whether there is some patterns in it. Therefore, we need this kind of hypothetical sharing game to simulate the real sharing scenarios and we will try to extract the statistical model behind the experiment results so that the sharing system designer and the administrators of such systems will know what improvements are beneficial to decrease the wealth inequality of the whole network and increase the individual's wealth.

In this WIFI sharing game, all the participants will be in a cooperative relationship since the amount of wealth they own at the end of the game only depends on the number of resources they receive from their neighbors and in a competitive relationship as they have to fight with other players who have the common neighbors with them for the limited amount of resources owned by the common neighbors in the game.

The idea of WIFI sharing game is promoted by my supervisor Prof. George and his team in a paper which was published on Nature[10]. They mainly studied the effect of the connection range, graph density and degree assortativity on the wealth inequality of the whole network but in my dissertation, the research priority is totally different from theirs. I mainly focus on exploring the relationship between position and wealth and the relationship among variance, wealth inequality and the sharing level of the whole social network.

Chapter 2

Related Work and Background

It is no doubt that cooperation and sharing exist in nearly every aspect of human life so that there has been a lot of researches concerning these concepts in a great diversity of fields ranging from communication systems, peer-to-peer file sharing to solutions to renewable resource sharing. Some of them tried to explore a more efficient way to achieve the equilibrium in resource sharing and some of others made a series of experiments to test what kinds of factors would have an effect of the participants' benefits.

2.1 Public Goods Game

One of the most classical problem is the public goods games which represent a kind of social dynamic problems in the field of human cooperation. It is a well-known model for describing a situation where the participants (whether individuals or institutions) need to cooperate to achieve a state that most of the players can benefit from it[11].

There are three features of the resources in public goods games and they are jointly provided, non-excludable and non-rivalrous[12]. The first one means that the resources are generated and provided for all the members of a certain group. The next one means all the members of the group are able to enjoy the resources without being kicked out. The last one indicates that do not need to complete with other members for resources.

All the participants need to make decisions on the amount of resources that used to contribute to the generation of the public good and how much will be spent on personal use. The resources they shared out will work together to maintain the public good they are enjoying. However, due to the features outlined above, the players have incentives to free-ride on others since they will still be able to enjoy the public good even if they have made no contribution to the public good[13].

There has been numbers of papers and research articles discussing and introducing their experiments and analysis related to public good games in a great diversity of perspectives.

In [11], the authors designed a series of experiments which were targeted at the coevolving social network models. They mainly focused on explore whether the agents would benefit more if they could cut off the link with the group where their reward was low and establish a new relationship with a new group randomly. Based on the results gained from the experiments conducted in the laboratory, they found out that the link redirection showed to have a positive effect on the cooperation in public games not only in simulated experiments but also in experiments with real humans. The work in this paper is different from that in [14] because the social model network remained constant during the whole game which means the agents had no choice to quit the current assigned group and join in another one. From my point of view, the former one is more realistic and meaningful since, in our daily life, we are highly likely to change our social position owing to a good variety of reasons ranging from emotions, unforeseen accidents to the change of interpersonal relationship. So, the from Marco Tomassini and Alberto Antonioni has more practical significance to the companies whose social strategies is about this.

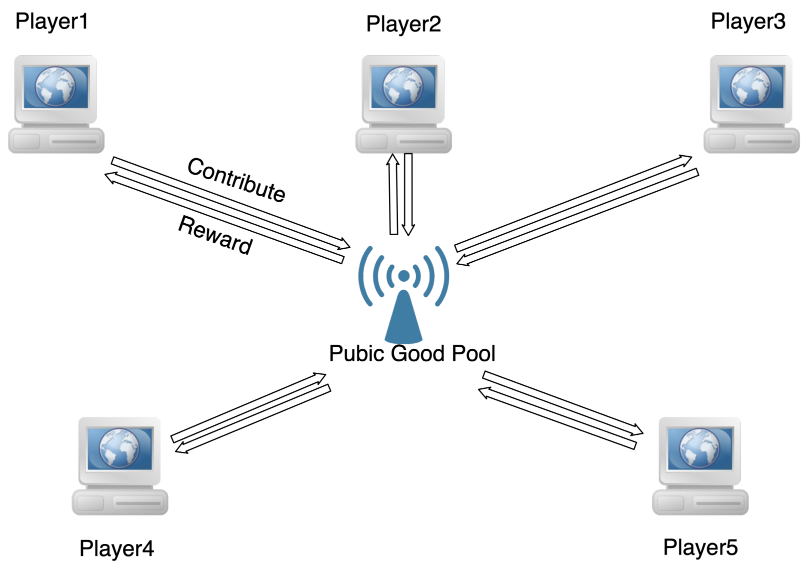


Figure 2.1: Classical Public Good Game Model

The Figure 2.1 illustrates the network structure of the classical public good game model. We can learn from it that there are many (usually more than 2) players participating in one group and all the participants that belong to one group connect to the same public good pool. Every one of them has the choices to choose whether contribute some resource to the public good pool or not and the amount of resource that they want to share. Besides, they will benefit from the public good pool evenly.[15]. However, in our WIFI sharing game, the players are connected in pairs and the decisions of sharing actions are pairwise as shown in Figure 2.2.The Player 1 represents each one of all the participants in the game. He may have more than one neighbors who connect with him and he can only share his resources (the WIFI bandwidth in this game) with their neighbors. This is one of the different parts of our cooperation and sharing model from the public good games model. In addition, the number of neighbors of every two players can be different like in Figure 2.2, player2 only have one neighbor that is player 4 but player 4 has 3 neighbors. So, Player 2 will compete with player 1 and player 3 for the resources that belong to player 4. This indicates that players have a competitive relationship with the neighbors of their neighbors in the WIFI sharing game.

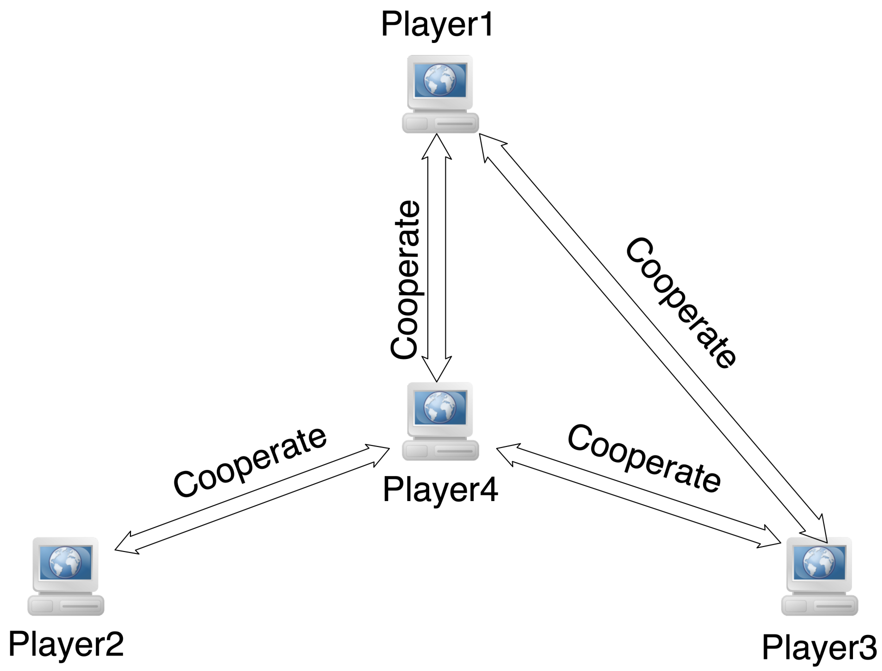


Figure 2.2: WIFI Sharing Game Model

2.2 Application Scenarios of Sharing Economy

Nowadays, it is no doubt that the research achievements in sharing economy business have been put into practice to a large extent in a wide variety of business sectors by taking advantage of the under-utilized resources. For example, when you are going to a place that is far away from your house for a long time, you definitely have the choice to rent your house out for some extra income. Another example is sharing idle private vehicles to others in need for some reward. This is definitely a big market as previous related studies how that private cars remain parked 95% of the time on average[16]. Consequently, here come a lot of companies with new technology like Uber and Airbnb to make profits in this business sector[17].

In [18], the authors focused on the Smart Grid and conducted a series of experiments to explore whether there are sharing economy opportunities in the electricity sector. In detail, they formulated the sharing investment decisions of the companies that share their electricity storage as a non-convex game. They found out that there exists a unique Nash equilibrium that improves the utilization rate of the under-utilized resources and supports the social welfare.

Another popular and interesting implementation is applying the sharing economy concept into the organic agriculture. As the population on the planet grows larger, there is an increasingly high demand on food[19]. However, the pesticides and fertilizers used in conventional agriculture have been leading to various kinds of environmental issues which ranges from the emission of harmful gas, potassium and phosphorus losses to deterioration of water quality, which has caused a lot of health problems on the humans[20]. Therefore, the organic agriculture as the ideal substitute of the traditional agriculture becomes more and more popular since it doesn't depend on any artificial chemicals which is harmful to the environment. Unfortunately, the organic farmers especially in developing countries are facing a significant loss owing to the fragmented structure of the organic food supply chains as there is no sufficient professional agricultural equipment and enough cold-storage facilities, which make the prices of organic food are always not that affordable to the majority of people especially in the developing countries[21, 22, 23]. At this time, the sharing economy model plays an important role in improving the present situation as it enables organic food producers across the whole supply chains to share and utilize a wide variety of tools, infrastructure and services more conveniently like operating online[24, 25]. Furthermore, Sobhan Asiana, Ashkan Hafezalkotob and Jubin Jacob John conducted experiments to explore whether it is meaningful to apply a sharing economy based agricultural cooperative model in a complex competitive organic food supply chains market. The results of their experiments indicated that the sharing economy based cooperative strategy indeed had a positive effect on making the whole organic food supply chains achieve a higher profit as increasing the utilization rate of all kinds of facilities and services in this market.

2.3 Previous Research on Sharing Models

In the engineering field of the cooperation and sharing economy, there has also been quite a lot papers done research on the user-provided network where the players are providers of resources like the Internet access and the uses of the corresponding resources in the meantime[26].

With the explosion and boom of the utilization of mobile devices, there is an increasing number of researchers who are interested in the sharing problems of the mobile user-provided networks. However, it is facing some challenges like having to rely on the real-time information feedback from other participants with respect to the different demands and available resources. In [27], the authors devised a new type of mobile user-provided networks system with controlling interventions in the cloud to apply data transmission strategies with adaptive flow-control and then they put the design into a real prototype to assess the performance of the service architecture.

In addition, the authors of [28] proposed two new kinds of incentive strategies targeting at the user-provided network services to evaluate their performance on encouraging the degree of participation in this kind of networks. However, these kind of paper emphasize more on the impact of the technical solutions for facilitating the sharing economy and rarely take the sharing decision strategies of real human players little consideration, which is different from our WIFI sharing game model.

Chapter 3

Experiment Platform

The WIFI sharing game in my thesis is designed on Breadboard from Yale University and all the participants interacted with each other through this platform.

3.1 Introduction to Breadboard

Breadboard is an online software platform developed by researchers in Yale University. It is built for researchers to devise simulation models and conduct related experiments online especially about human interactions with network structures. Apparently, it breaks the spatial barriers when conducting experiments since potential participants from all over the world are able to join in only if they have access to the Internet. In addition, breadboard is licensed free of charge for academic and non-profit use[1].

3.2 Technologies Used in Breadboard

Breadboard is developed using a great variety of technologies including[1]:

- The Play Framework
- Groovy
- TinkerPop's open source graph computing framework

- AngularJS
- D3.js
- TinyMCE
- CodeMirror
- Apache Commons
- jQuery
- Underscore
- Modernizr
- Bootstrap

3.3 Features of Breadboard[1]

- Experiment logic is designed and realized using a graph traversal DSL.
- Experiment content can be stored in a content management system and processed using a WYSIWYG editor.
- Real-time graph visualization is available throughout the processes of experiment design and deployment.
- High performance bi-directional client-server communication using Netty and WebSockets.
- An interactive script window allows the researchers to make changes to experiment setup easily.
- Recruit online participants from Amazon Mechanical Turk using the integrated module.

3.4 How to Use Breadboard

In fields as diverse as computational sociology, behavioral economics, and social psychology, researchers conduct experiments where the participants are embedded in networks of their own design, with rules of interactions of their own devising, in order to play repeated games where participants' actions affect others they are connected with[1].

Using breadboard, researchers can easily design new experiments using a flexible domain specific language. The experiment programs will be stored in the database and changes can be previewed and tested immediately without having to recompile and redeploy the whole project. The network is visualized in real-time which makes it easy for an administrator to see the global behaviors of the network as a whole[1].

Researchers are able to use breadboard to develop human interaction experiments (e.g. public goods games, coordination games), to conduct surveys, or to develop brand-new tasks to test their theories[1].

When an experiment is ready to conduct, the researchers can use breadboard to post a job to Amazon Mechanical Turk, an online crowd-sourcing marketplace and it will provide users immediate access to a diverse pool of participants from all over the world[1].

3.5 Previous Other Researches with Breadboard

Admittedly, there has been more and more researchers from all over the world that choose breadboard as the ideal platform for their experiments.

Studies show that people are willing to be treated equally when involved in a resource distribution scenario[29, 30, 31]. Thus, some researchers decided to design a series of experiments using breadboard to explore what is the potential determinant that has an effect on the inequality of distribution. They carried out a series of experiments involved more than one thousand players who are embedded in three social networks whose Gini coefficients are different from each other. The Gini coefficient represents the level of inequality on the income distribution of a group of people and there is less inequality when the Gini coefficient is more approaching to 0[32]. In each round of the game, all the participants need to choose between cooperating with their neighbors and defecting. If they choose to cooperate, their private wealth will be reduced by 50 units in order to increase all their neighbors' wealth by 100 units. If they choose to defect, there is no reduce on their own wealth and they will make no contribution to others. In addition to these basic setup, they manipulated the wealth visibility condition, which means they tested whether there was some change on resource distribution if the wealth information of their neighbors was unavailable to them. In the end, as shown in Figure 3.1 they found out that wealth invisibility led to adverse collective consequences and lower level of cooperation among all the participants[2].

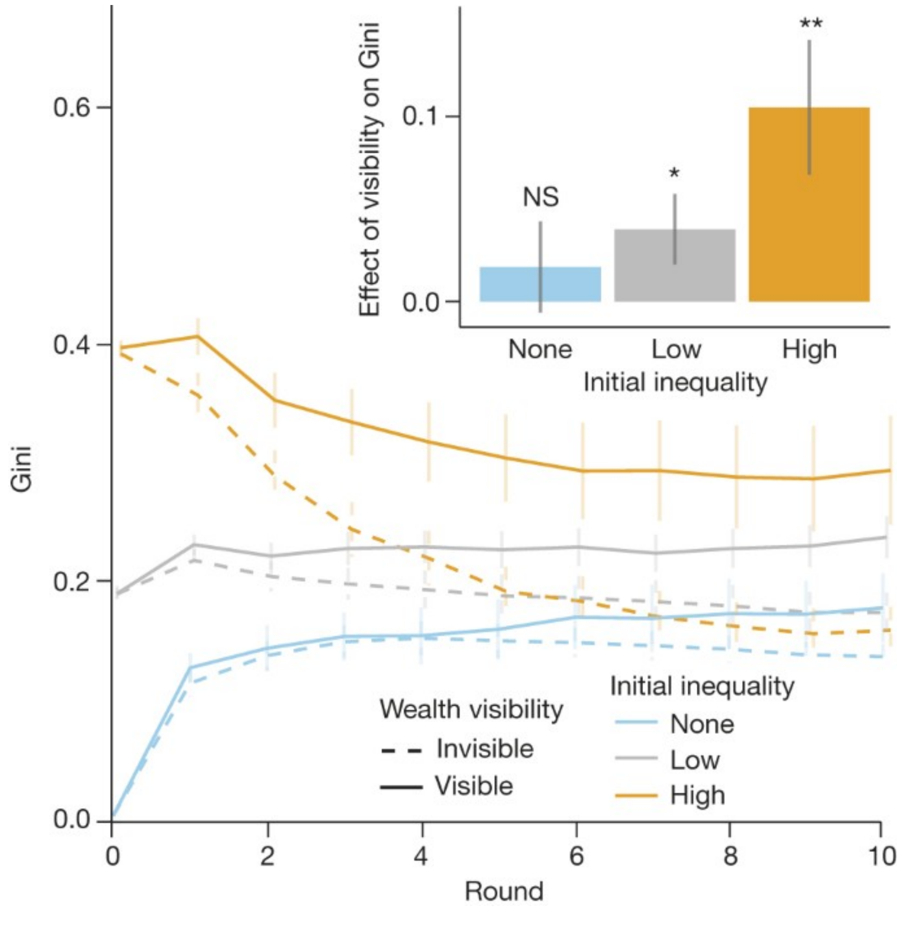


Figure 3.1: Wealth Visibility Affect[2]

In 2015, Akihiro and his teammates applied breadboard on explore whether the network fluidity would have an effect on the collective economic growth and the inequality of resource distribution. The term “network fluidity” is defined by themselves to represent the social behavior – breaking an already existing social tie and reforming a new one. They invited 1529 human subjects into their online experiments and designed 90 sessions game where there were 15 rounds in each session. In each round of the game, the participants would be given two choices. One of them is to cooperate with their network neighbors and the amount of resources they decided to interact with them. The other one is to enter a rewiring step where the players have the right to choose to break a tie with a certain neighbor or form a new connection with a new player who is not their neighbors yet. In the end, after a series of analysis on the results of the experiments, they found that the intermediate levels of the network fluidity were likely to help to generate the highest average wealth and have a positive effect on decreasing the Gini coefficient of the participants group. In addition, the results of their experiments and analysis also indicated the tendency that the networks with a higher level of the network fluidity always brought with a higher assortativity, which means that the wealthy participants were more willing to interact with other wealthy participants.interact with other wealthy participants[33].

Coordination problems are the root cause of a lot of issues in society. Imagine each actor is a player in a game, and must choose a strategy based on the information available to them. Coordination problems are basically ‘games’ with multiple outcomes, so they have to decide how to act[34, 35]. Several papers have examined that the coordination problems among a group are always stuck in a local sub-optimal result[36, 37, 38]. A lot of researchers worked a lot on it and held the belief that a certain level of noise was likely to have a positive effect on helping to lead this kind of problems to a global optimization[39, 40, 41].

Then, in 2017, Hirokazu and his colleagues tried to design an online experiment model with breadboard to capture the features of coordination problems and test the effect of randomness. They devised a networked color coordination game with 4000 subjects were involved and all the participants were divided into networks of 20 nodes with 3 robot nodes in it. The ideal collective target of the game in the end was that every player would have a color that was different from all the neighbors of them while all the participants were allowed to a color from green, orange and purple in each round. With respect to the optimization, the cost function of the game representing a coordination problem was devised as the number of conflicts on colors among the whole network. To test the effect of noise more convincingly, the authors conducted three kinds of games with different levels of the randomness. To put it specific, in the non-noise condition, the robot players behaved a greedy strategy where it choose the color that would make the number of color conflicts smaller. In the next two conditions, the robot players would randomly choose a color from those three available colors with a probability of 10% and 30% respectively. After a series of analysis on the outcomes of the experiment games, they found out that a slight noise existing in a coordination problem network indeed was beneficial to simplify the tasks of human players and would increase the collective benefits of the whole system[42].

Chapter 4

WIFI Sharing Game

4.1 Experiment Basic Setup

4.1.1 Participant

There are 24 human players invited to participant in this game and they are divided into 4 groups. Then, we add 6 AI players into each group. Therefore, there are 12 players in total in every group including 6 human players and 6 AI players.

Every human player is physically isolated with other players, which means that no one can share game information to other players like who are their neighbors in the current social network and how they make the sharing decisions.

After a player has been involved in a WIFI sharing game, the wealth of him is only depending on the resources he receive from all his neighbors. Hence, all the sharing decisions made by the player should be beneficial to let his neighbors share more resources to him so that he is more likely to be the wealthiest player in the current game.

4.1.2 Sharing Resource

In the WIFI sharing game, the resource used to simulate the resource that is shared in different scenarios in real life is the WIFI bandwidth and the unit for measuring it is Mbps(million bits per second).

The base of the WIFI bandwidth of each player in each sharing round is 60

Mbps. The base is used to simulate the average number of resources that the participants have in real life sharing networks. For example, it is reported that the average time that private car owners don't need their cars is 16 hours per day so the base of the WIFI bandwidth plays the role of simulating the 16 hours in this scenario.

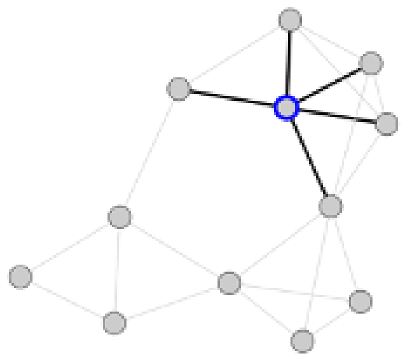
The variance of the WIFI bandwidth of each player in each sharing round can be 10, 20, 30, 40 or 50 Mbps. The variance is used to simulate the fluctuation range of the number of resources assigned to the players. In real life, the fluctuation may be caused by a great variety of reasons ranging from the individual aspect to the system aspect like the dynamic relation between supply and demand and whether the Internet in a certain day is under good condition or not. For example, a router in Tom's house broke down in the morning of a certain day, then, the number of Tom's idle WIFI bandwidth on that day will definitely be decreased to a certain degree. Another example is that if Mark decides to cancel one of the daily routines like driving to the seaside for photographing and just to go back home immediately after work one day, the amount of time when his car is available for others to borrow will be increased on that day. In a word, the function of variance is covering all the reasons that may result in any difference among the numbers of resources of all the participants in each sharing round.

At the beginning of every sharing round, every player will be assigned some idle resources and the number of resources will fluctuate from base minus variance to base plus variance.

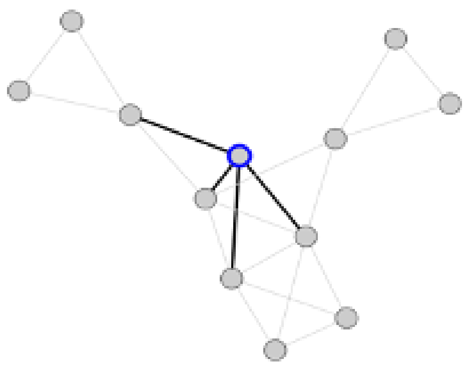
4.1.3 Social Network Structure

All the 12 participants in a WIFI sharing game will be randomly embedded in nodes of a network. The network is generated using a random geometric graph model which is capable of capturing the spatial deployment features of WIFI networks[43].

In Figure 4.1, there are two examples of such networks. As you can see, every one of them has at least one neighbor and the number of neighbors of different players can be different. For example, in the two instances, some players have 5 neighbors while some other players only have 2 neighbors. Although the two networks look different, their graph densities are the same, which can be set in breadboard. Since the research priorities in the thesis have no relationship with the graph density, so we just make it the same among all sharing games.



(a) Example 1



(b) Example 2

Figure 4.1: Two examples of random WIFI sharing social networks.

4.1.4 Experiment Structure

All the 4 groups were involved in 5 different games since the variance has 5 different values, so there are 20 games in total in my experiment. And in each game, there are 5 sharing rounds where the players need to make their sharing decisions.

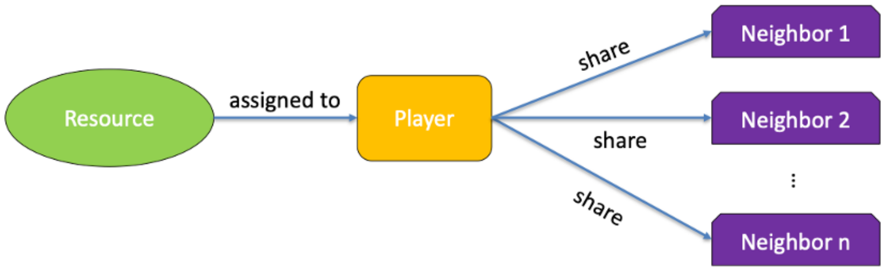


Figure 4.2: One Sharing Round for One player

4.1.5 Sharing Round

A sharing round consists of two parts – daytime part and nighttime part. As shown in Figure 4.2, at the beginning of each daytime part(the beginning of the sharing round as well), every player will be assigned some resources which play a role of simulating the resources shared in different scenarios in real life. Then, the player needs to make his own sharing decisions about whether or not to cooperate with a certain neighbor and the number of resources shared to a certain neighbor. After all the players submitting their sharing decisions, here comes the nighttime part. During the nighttime part, players will see how many resources have been shared to them by each of their neighbors in the daytime part of the current sharing round. Furthermore, players will not know the number of neighbors of their neighbors, the number of resources their neighbors have and how many resources have been shared to their other neighbors.

$$Resource = 60 + A * variance + B \tag{4.1}$$

The number of resources assigned at the beginning is calculated based on the Formula 4.1. Clearly, the base of the resource is 60 Mbps. Here, variable A is a random float number between -1 and 1 which is used to generate a value that lies in the fluctuation range of the resource(between base minus variance to base plus variance). The variable B is the number of resources left in last round by the player, which means that players are able to reserve some resources to share in the next round. Then, let's see the variance. As introduced above, it can be one of the 5 different values(10,20, 30, 40, 50) but it is constant in all the 5 rounds in each game. For example, in the first round of a game where the variance is 10, since there is no left resources in the first round, so the range of resources assigned to each player is between 50 to 70. If the player left 10 Mbps in the first round, then the range of resources that the player can share to his neighbors is between 60 to 80 since the 10 Mbps has been added in it.

4.1.6 Sharing Strategy of AI Players

In the first round of each game, AI players will distribute their resources evenly. The number of resources that will be shared to neighbor k of the AI player is calculated based on Formula 4.2. The 'Resource' in the formula represents the number of resources that the AI player have in the current round. The '$Distribute[neighbor_k]$' represents the number of resources that the AI player will share to his neighbor k.

$$Distribute[neighbor_k] = \frac{1}{the\ number\ of\ neighbors} * Resource \tag{4.2}$$

In the latter rounds, the number of resources that the AI player share with neighbor k is proportional to what percentage that the resource received from neighbor k accounts for in the resource that the AI player received in total in the last round and is calculated based on Formula 4.3. The '$Distribute[neighbor_k]$' represents the number of resources the AI player received from the neighbor k in last round. To put it simply, if you give more resources to an AI player, he will be more likely to give more resources back to you. But it is not always the case since other neighbors of the AI player may give him more or the AI player is assigned very little resources in that round.

$$Distribute[neighbor_k] = \frac{Receive[neighbor_k]}{\sum_{i=0}^{n} Receive[neighbor_i]} * Resource \tag{4.3}$$

The AI strategy is designed, updated and realized with a Java program and the code snippet has been presented in Appendix A.2.

4.2 Differences Compared with Previous Research

4.2.1 Making the Number of Resources Dynamic

In the previous research, all the players are assigned with the same number of resources in every sharing round. But in my dissertation, as introduced above, the number of resources assigned is calculated based on Formula 4.1 so it will fluctuate between a certain range. From my perspective, this design is more fit with the scenarios in real life. It is no doubt that, in real-world scenarios, the resources will be affected by a great variety of factors ranging from personal aspect to the whole network aspect and even will be affected by the change of external environment.

4.2.2 Reserving Some Resources to the Next Round

In the WIFI sharing game in the previous research, all the players need to distribute all their resources within every round otherwise the left resources will be neither carried over to the next round nor counted towards their wealth(hence, it will be abandoned resources). We made the decision to provide the choice of reserving some resources to the next round to players because there are indeed some kinds of resources that can be stored for a period of time in some ways in real life like the electricity. And sometimes, players really need more time to evaluate whether a neighbor is worth being shared more resources to. In addition, sometimes, in order to maintain or enhance their competitiveness in the next round, players are definitely able to reserve some resources in a round where they are assigned with quite a lot idle resources in case that they will be assigned with much less resources in the next round.

4.2.3 Different AI Players Strategy

In the previous research, all the participants are human players which means the sharing strategy will probably change as the players will think about the return on investment again when every round ends. In contrast, AI players will follow the same sharing strategy all the time. This design has a lot of real-world meaning since many Internet services provide the customization function where the users can set a preferred and fixed strategy that will be applied when they are busy or not available to make sharing decisions. This function will definitely be helpful for uses to continue the game without being kicked out. Previously, some researchers have tried to let the AI players share their idle resources randomly, which is definitely not the case in real life as nobody are willing to let their wealth merely rely on God's will without any logic behind it. Therefore, we change the strategy to sharing resources in proportion to the number of resources received from a certain neighbor, which agrees more with the preference of human beings and that is being willing to share more to a friend who gave more to ourselves before.

4.2.4 Different Research Priorities

The previous research studied the effect of the connection range, graph density and degree assortativity on the wealth inequality of the whole network but in my dissertation, the research priority is exploring the relationship between position and wealth and the relationship among variance, wealth inequality and the sharing level of the whole social network.

4.2.5 Keeping the Graph Density Unchanged

Since the research priorities are different, so we keep the graph density unchanged through all the 20 games to eliminate the effects that graph density may have on the experiment results.

4.2.6 Change the Extra Bonus to 0

In the previous study, the wealth of a player not only depends on the number of resources received from his neighbors but also the times of participating in WIFI sharing games which is called the extra bonus. In this thesis, we change it to 0 so that the wealth of a player will only be related to the number of resources received from his neighbors. This change will make the analysis of the relationship among the wealth, variance and position more straightforward and reliable.

4.3 WIFI Sharing Game Flow

4.3.1 Precautions

After a player signs in, he will see the precautions page(Figure 4.3) where the player get to know the basic steps of the WIFI sharing game - from tutorial part, test part to the real sharing game part.

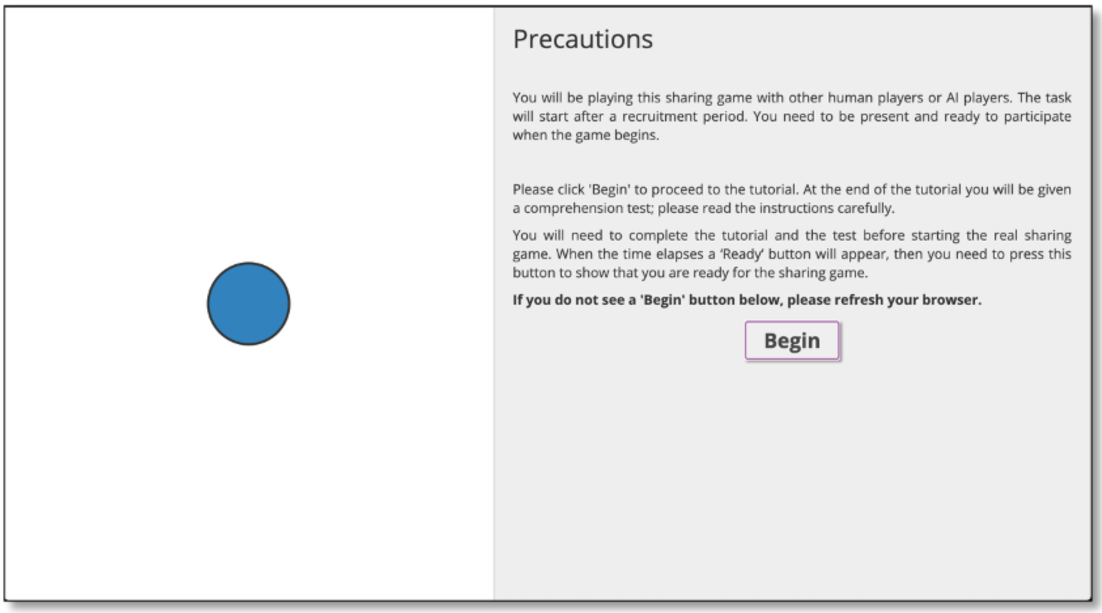


Figure 4.3: Precautions

4.3.2 Tutorial 1

From tutorial 1, the player will know that this sharing game simulates a WIFI sharing service and he can only interact with his neighbors who are in his WIFI area. The diagram on the right side of the page 4.4 helps the player to better understand the relationship between himself and the other members in the current social network.

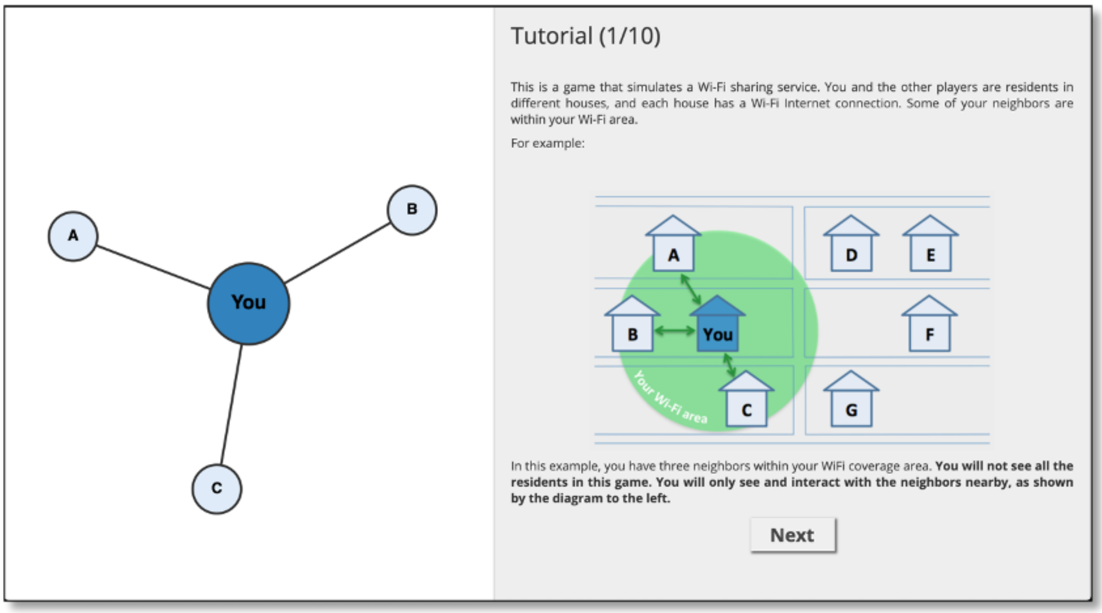


Figure 4.4: Tutorial 1

4.3.3 Tutorial 2

From tutorial 2(Figure 4.5), the player will learn that each one of this neighbors can be a neighbor of other network members at the same time and he will not know the number of resources that his neighbors have.

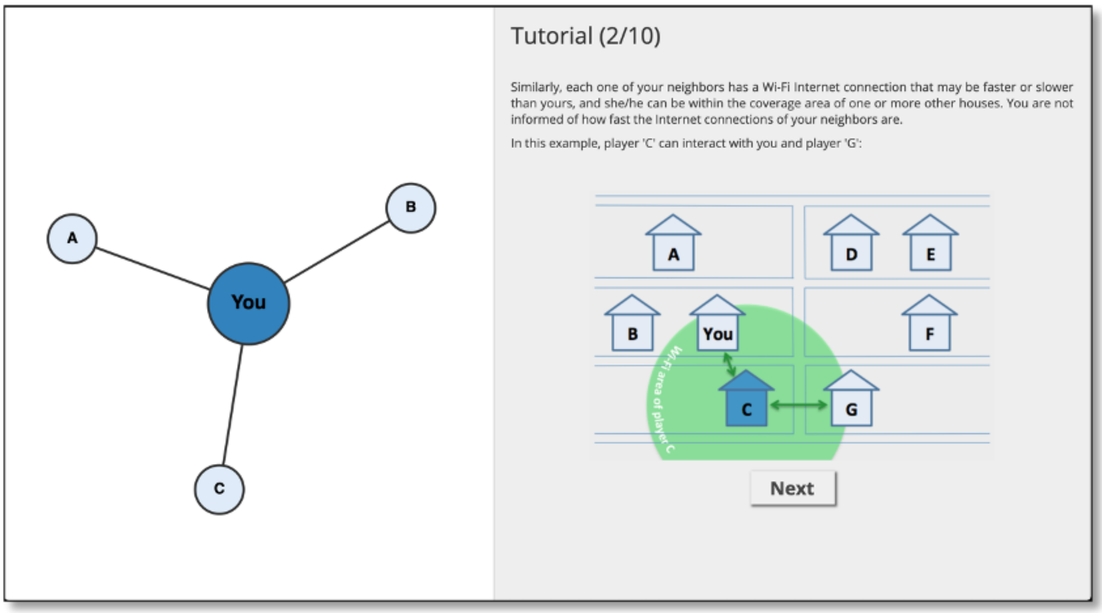


Figure 4.5: Tutorial 2

4.3.4 Tutorial 3

In tutorial 3(Figure 4.6), the player will learn that the reason why they need to share spare resources with their neighbors is that those resources are useless to them but they can benefit from them if they share the resources to their neighbors. Also, this tutorial also introduces the sharing rules of the game and the fluctuation range of the resources that each player has in each round. In addition, the ratio of wealth and resources in the WIFI sharing game and the wealth of a player is only related to the number of resources that the player received from his neighbors.

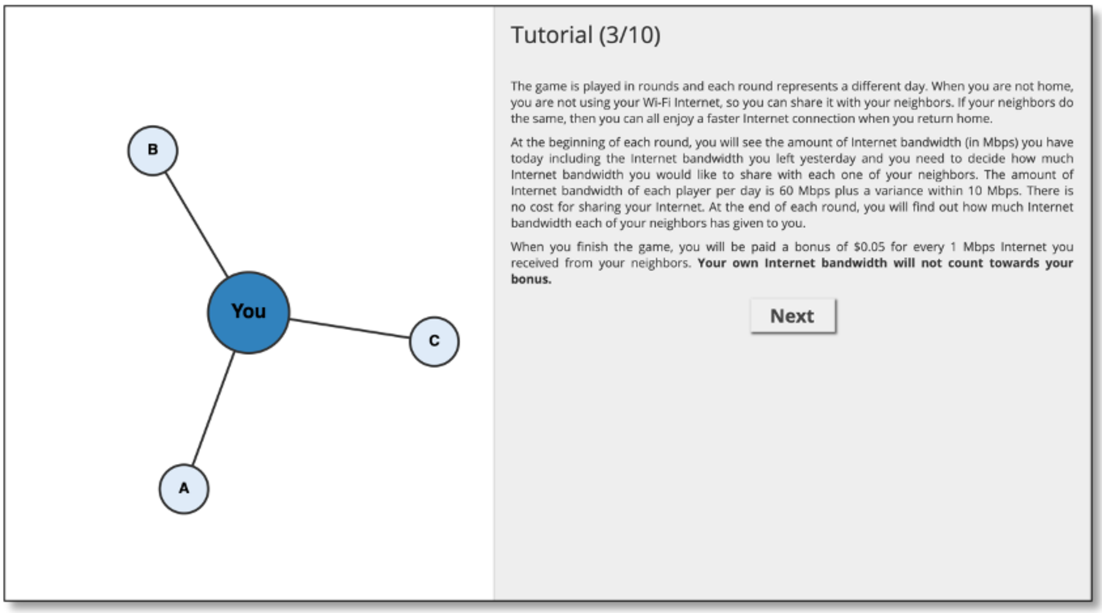


Figure 4.6: Tutorial 3

4.3.5 Tutorial 4

In tutorial 4(Figure 4.7), the player will know that the background of sharing WIFI bandwidth and what information will be displayed in the table in every sharing round. And it tells the player that in the next several tutorials he will try to practice some sharing rounds to get familiar with the WIFI sharing game.

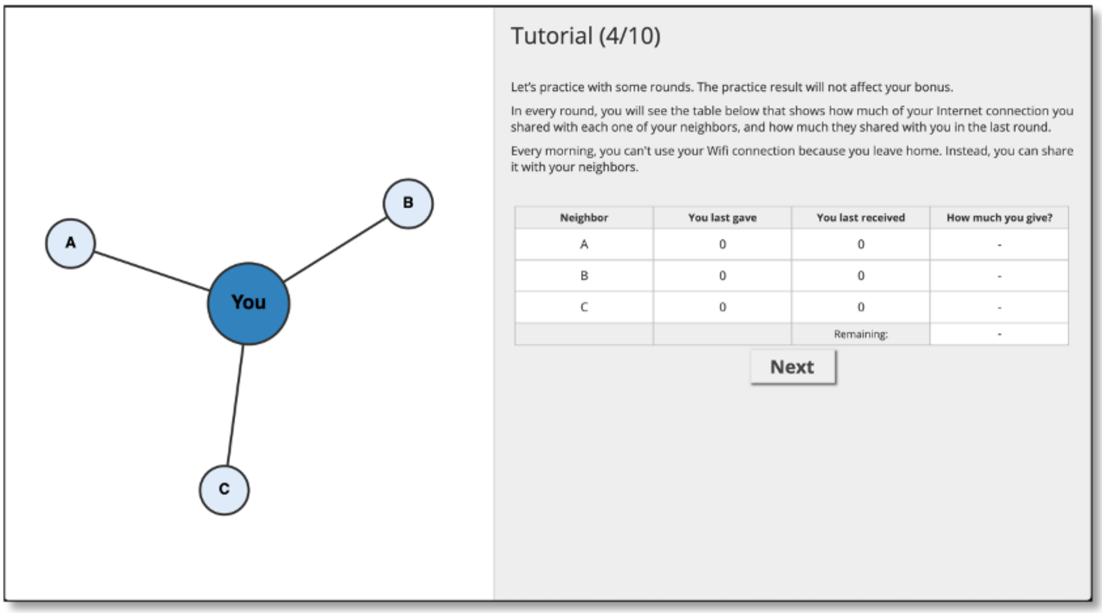


Figure 4.7: Tutorial 4

4.3.6 Tutorial 5

This is the daytime part of the round 1 of the practice game. As you can see, from the bottom right corner of the page of tutorial 5(Figure 4.8), the player can check how many resources he have in the current sharing round that he can share to his neighbors. If the player don't want to cooperate with a certain neighbor, he just needs to enter 0 into the box corresponding to that neighbor. And, it also reminds the player that the leftover resources will not help to increase the wealth of the player but can be reserved to the next day to share.

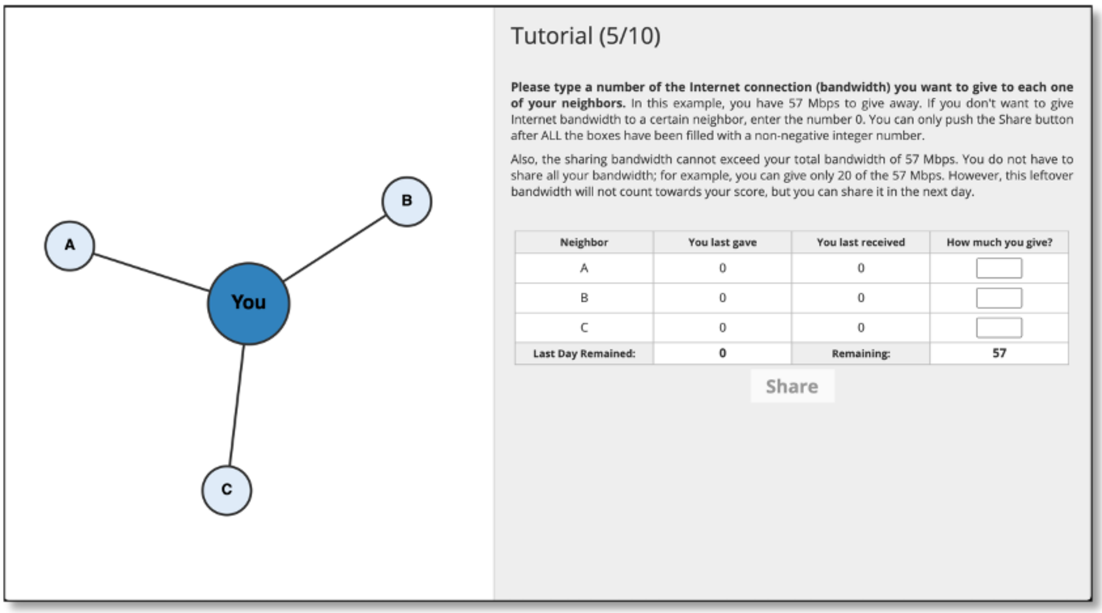


Figure 4.8: Tutorial 5

4.3.7 Tutorial 6

This is the nighttime part of the round 1 of the practice game. Here, from the table displayed at the center of the right side of the window(Figure 4.9), the player will see the number of resources that each neighbor shared with him in the first round. And, the number of accumulative resources received from his neighbors through all pasted sharing rounds is displayed above the table.

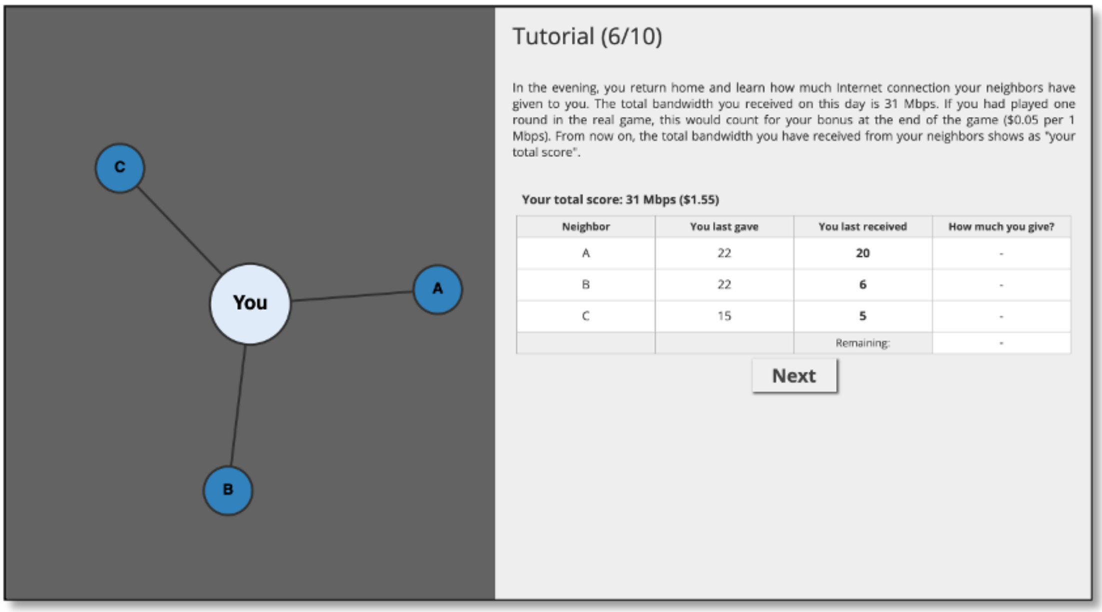


Figure 4.9: Tutorial 6

4.3.8 Tutorial 7 - 8

Tutorial 7 (Figure 4.10) shows the daytime part of the round 2 of the practice game. Similarly, the number of resources that can be shared to neighbors is at the bottom right corner. In the same time, at the bottom left corner, the player can see the number of resources that has been left in the last round and can be shared in this round. Tutorial 8 (Figure 4.11) demonstrate the nighttime part of the round 2 of the practice game.

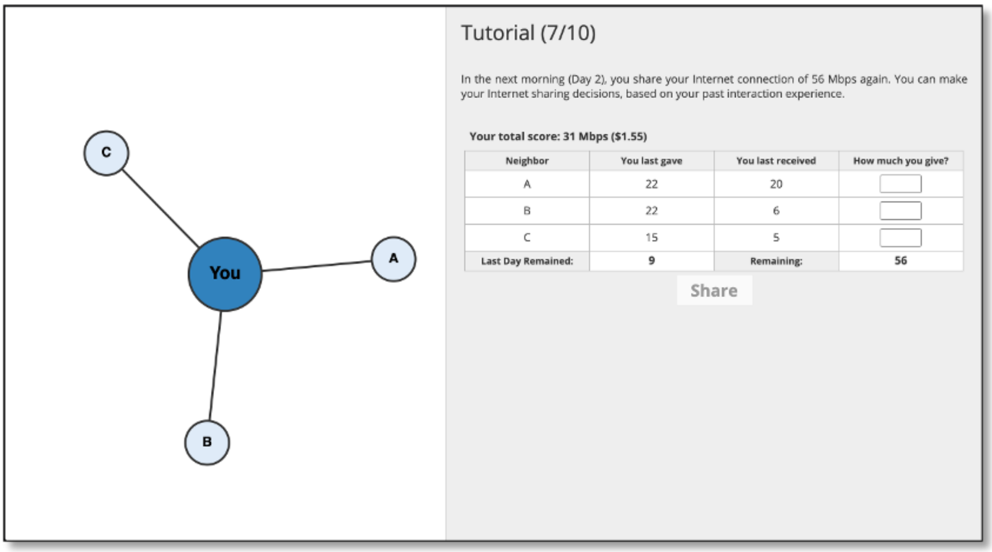


Figure 4.10: Tutorial 7

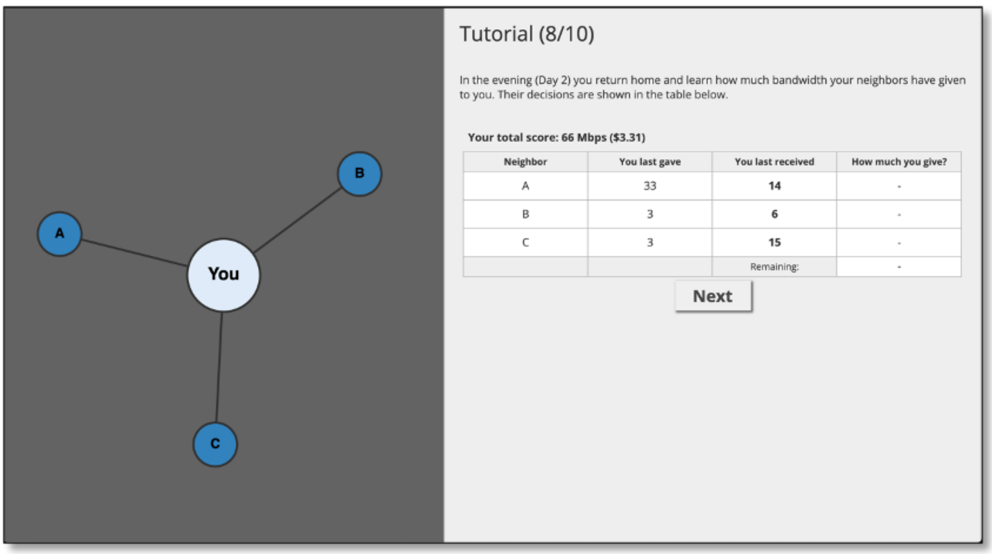


Figure 4.11: Tutorial 8

4.3.9 Tutorial 9

Tutorial 9 (Figure 4.12) mainly talks about the consequences of not finishing making sharing decisions within 90 seconds. If it happens, the player will be kicked out and the wealth of the player is only based on the resources that received from his neighbors in all sharing rounds that the player has been involved in.

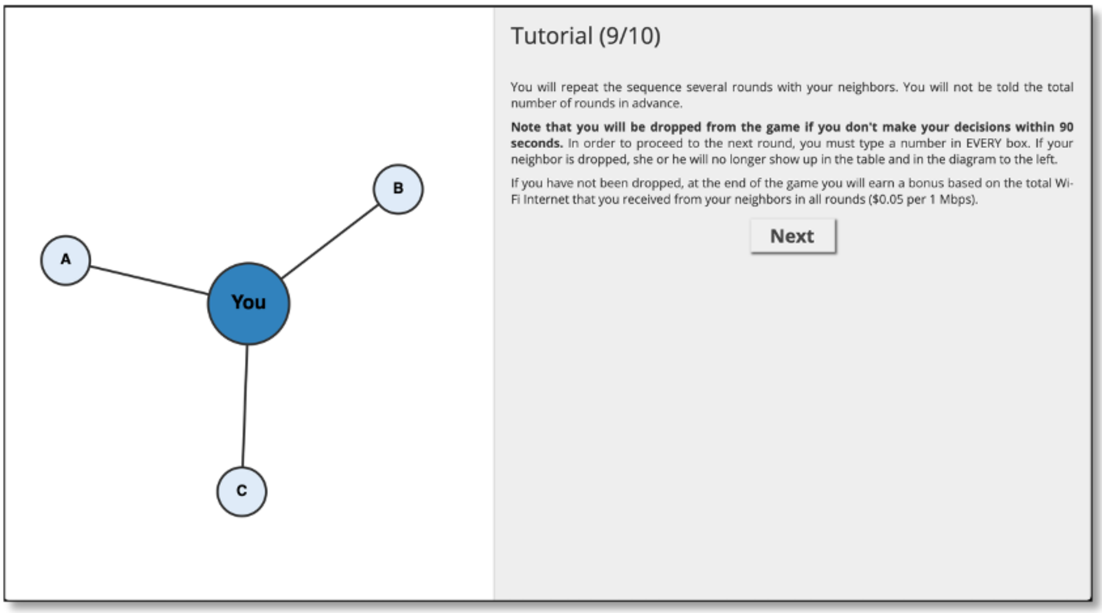


Figure 4.12: Tutorial 9

4.3.10 Tutorial 10

Tutorial 10 (Figure 4.13) is the end of the tutorial part and the player will enter the test part after this.

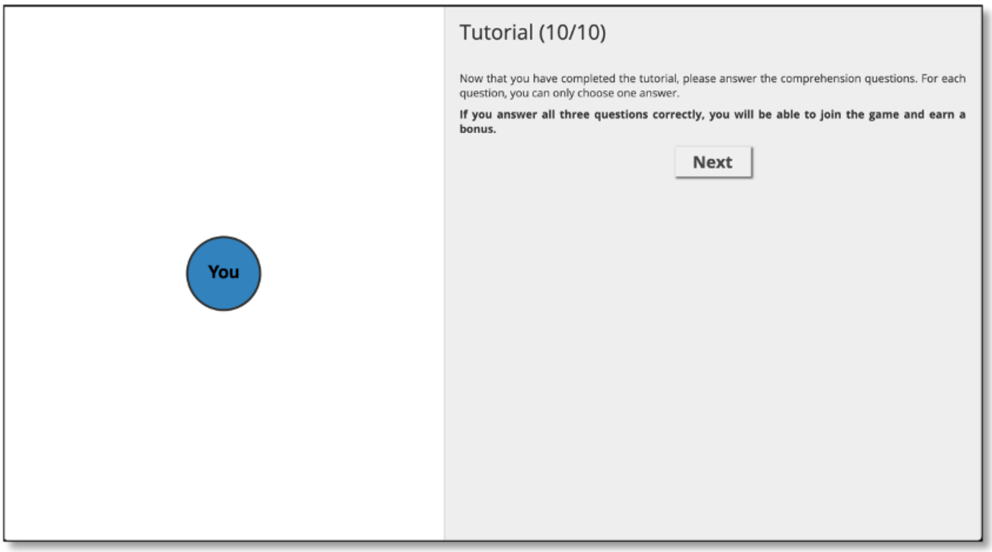


Figure 4.13: Tutorial 10

4.3.11 Test 1

Test 1 (Figure 4.14) is designed to check whether the player has correct understanding of what is the wealth of him.

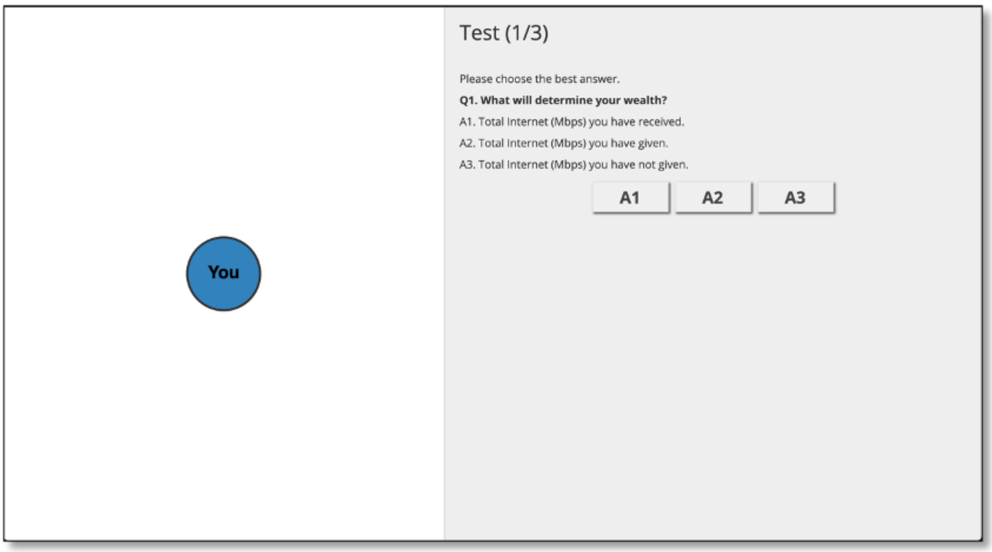


Figure 4.14: Test 1

4.3.12 Test 2

Test 2 (Figure 4.15) is designed to check whether the player has correct understanding of the background and rules of the WIFI sharing game.

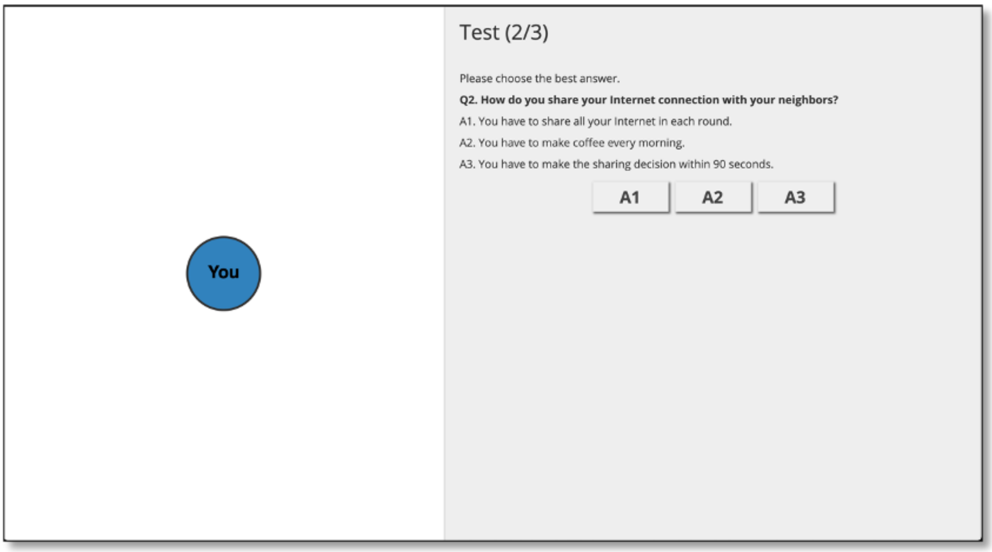


Figure 4.15: Test 2

4.3.13 Test 3

Test 3 (Figure 4.16) is designed to check whether the player has correct understanding of the structure of the WIFI sharing network and sharing rules.

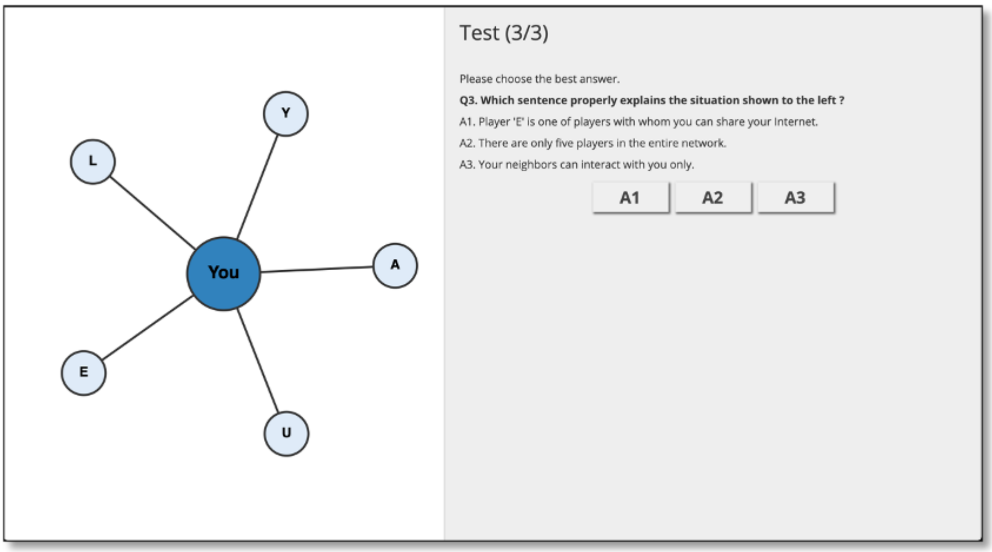


Figure 4.16: Test 3

4.3.14 Test End

After the player has passed the tutorial part and test part, he needs to press the 'Ready' button in the test end page (Figure 4.17) to show that he is ready for the real WIFI sharing game.

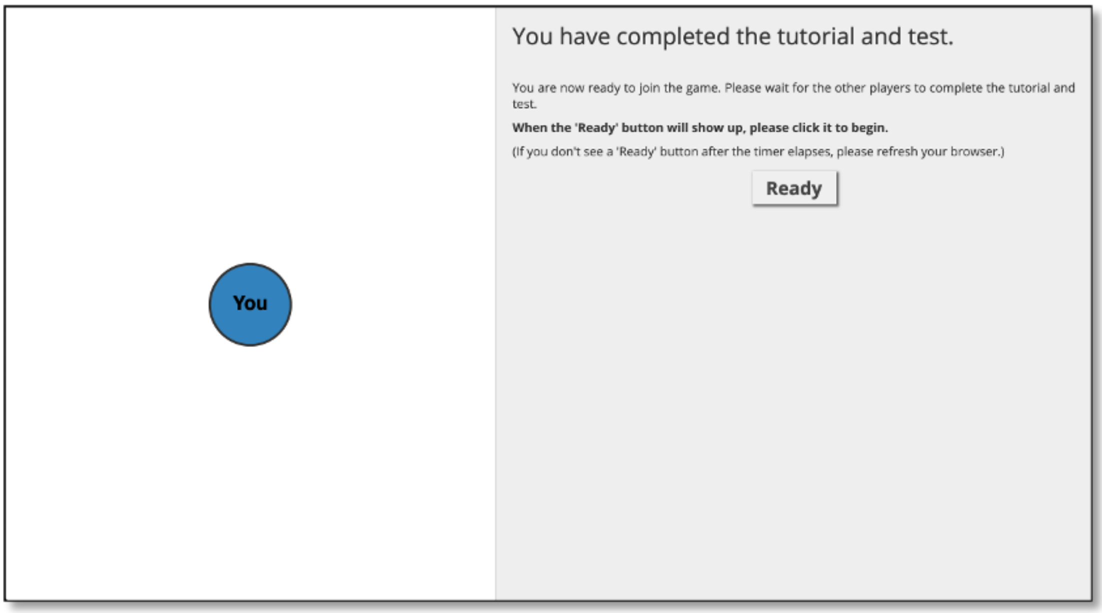


Figure 4.17: Test End

4.3.15 The First Round of The Real Game

After all the player press the 'Ready' button, the real WIFI sharing game will begin. All the players will be randomly embedded in a sharing network and here comes the daytime of the first sharing round as shown in Figure 4.18. Here, each player will see who are his neighbors and the number of resources he has in this sharing round and the player needs to make his own sharing decisions. After all the players submit their sharing decisions, here comes the nighttime of the first round where the player can check the number of resources received from each one of his neighbors as shown in Figure 4.19.

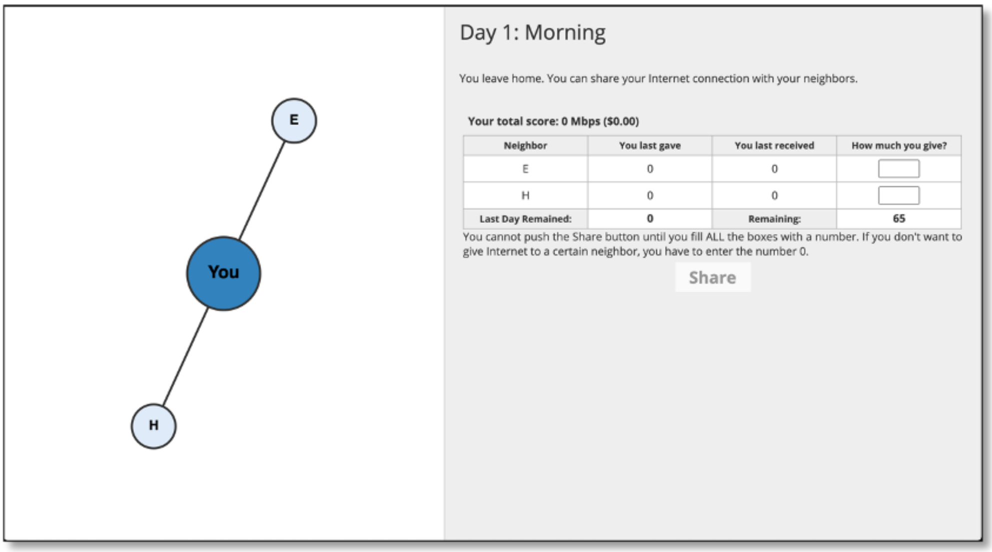


Figure 4.18: The daytime of round 1.

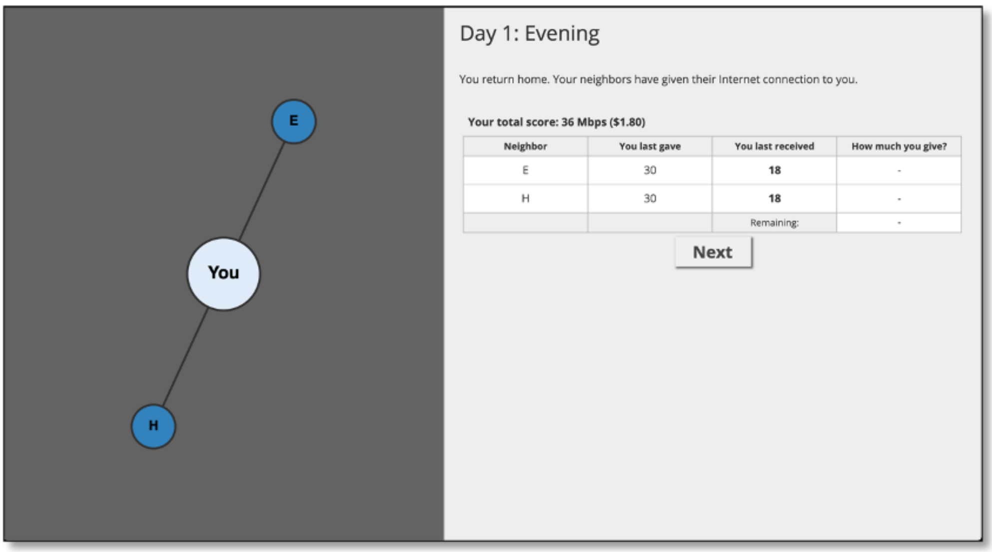


Figure 4.19: The nighttime of round 1.

4.3.16 The Second Round of the Real Game

As introduced in the tutorial part, the player will see the number of resources left in the last round and he can share these resources in this round.

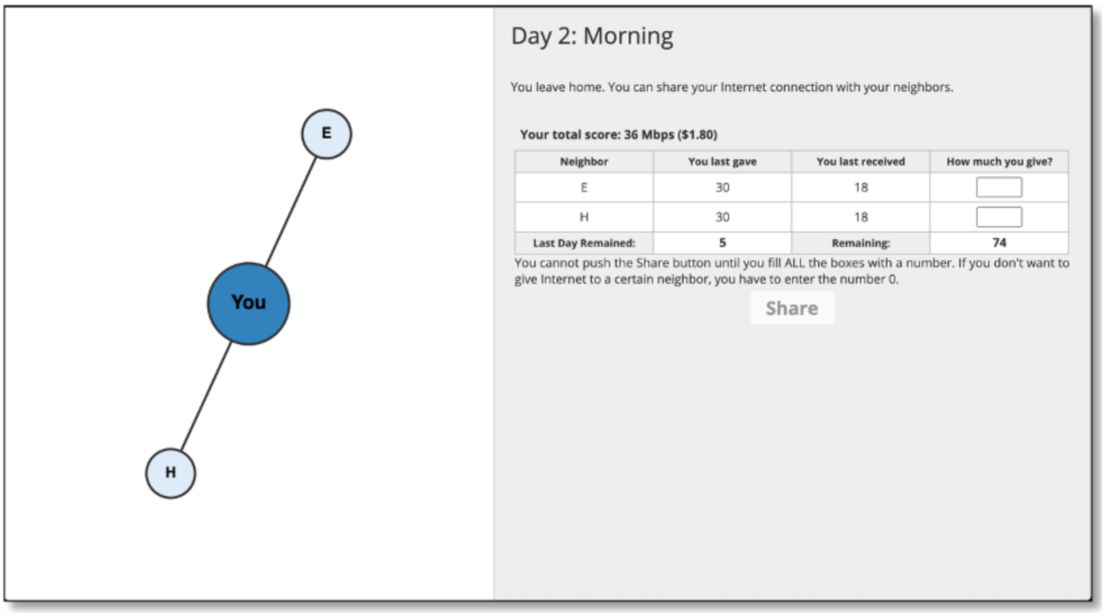


Figure 4.20: The daytime of round 2.

4.3.17 The End of the Real Game

After all the 5 sharing rounds, the player will arrive at the end of the current WIFI sharing game as shown in Figure 4.21. Here, the player will see the total wealth of him which is calculated based on the number of resources received from his neighbors through all the 5 sharing rounds and the ratio of wealth and resources.

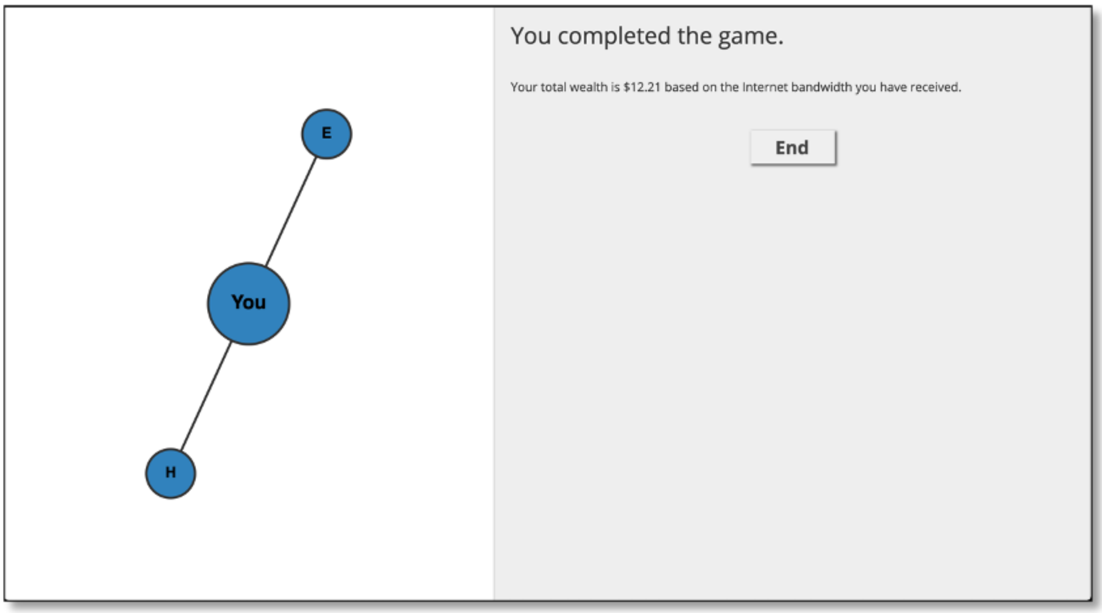


Figure 4.21: The end of one WIFI sharing game.

Chapter 5

Results and Analysis

After finishing all the 20 WIFI sharing games, we got 20 csv files which contain all the experiment data of each game including the participants information, the WIFI sharing network structure, the sharing details and so on. All the 20 csv files have been added in the zip file of the supplementary resources. In the first place, we wrote a program with Python to process the 20 csv files, which includes deleting the useless information, extracting data that is valuable to my research priorities and storing the data into structural variables(like List and Dictionary). Then, the analysis on the experiment results was conducted from the individual level and the network level. And all the calculation process, comparison operation and plotting work have been conducted by separate functions which are designed and realized in Python on my own. The code snippet for processing one WIFI sharing game has been presented in Appendix A.1.

5.1 Individual Level

5.1.1 Definitions

Position

The position of a player is represented by the degree of the node representing the player in the WIFI sharing network(i.e. the number of neighbors of the player).

Wealth

The wealth of a player is represented by the number of resources that the player received from all of his neighbors throughout the game.

5.1.2 Wealth and Degree

After all the 4 groups finished the games while the variance is 10, we got 4 csv files containing the experiment results of the 4 games. Based on these data, we first calculated the total wealth of each one of all the players in the 4 games(48 players in total) and divided them into different groups depending on their position (i.e. the number of their neighbors). Then, we drew a scatter plot to demonstrate these data as shown in Figure 5.1.

Apparently, the distribution situation of these points indicates that there seems to be a linear relationship between the wealth of the players and the position of them. Hence, we called the Linear Regression API from scikit-learn library to calculate the linear regression function. Then, we drew the regression straight line into the scatter plot as well.

Similarly, we did the same work to the experiment results with other 4 variance values and the results are as shown in Figure 5.2, Figure 5.3, Figure 5.4 and Figure 5.5 respectively. Clearly, we can learn from these figures that no matter the variance is large or small, players who have more neighbors are more likely to be wealthier (i.e. receive more resources) in the sharing networks. Although there are some players with a lower degree are wealthier than some players who have more neighbors, it is evident that the average wealth is increasing as the number of neighbors grows so the tendency is that the more neighbors you have, the wealthier you probably are.

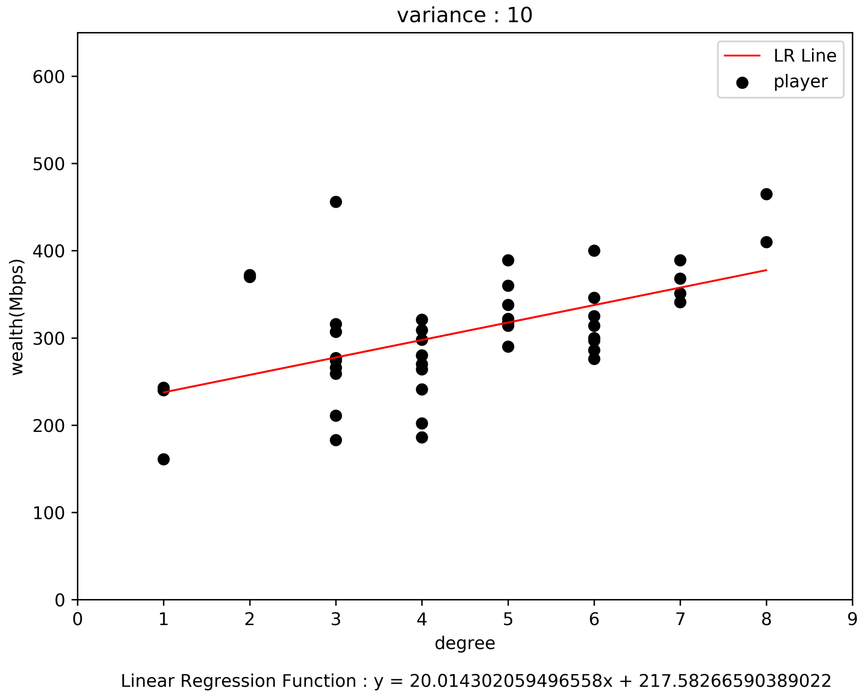


Figure 5.1: Wealth Distribution with 10 Mbps Variance

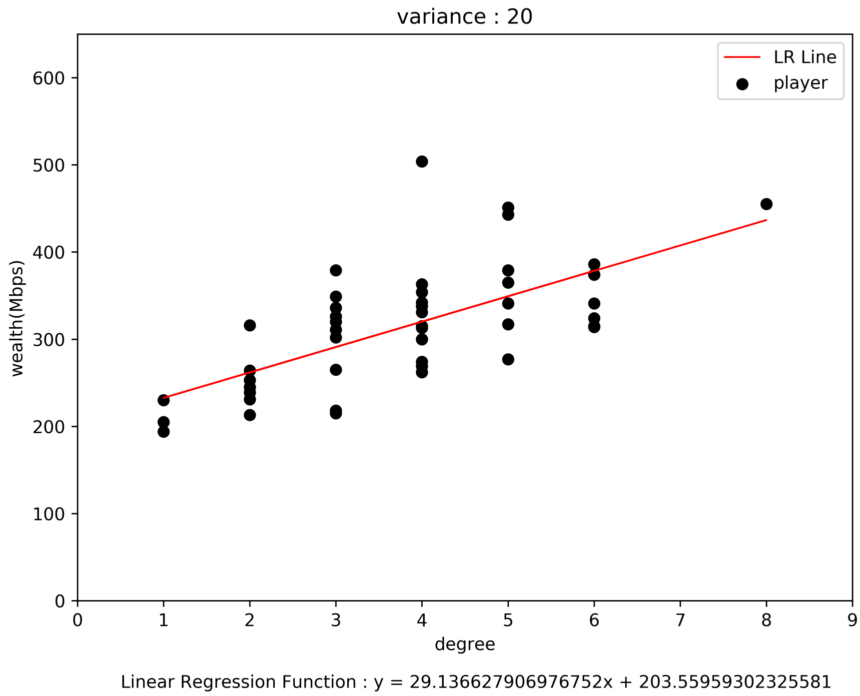


Figure 5.2: Wealth Distribution with 20 Mbps Variance

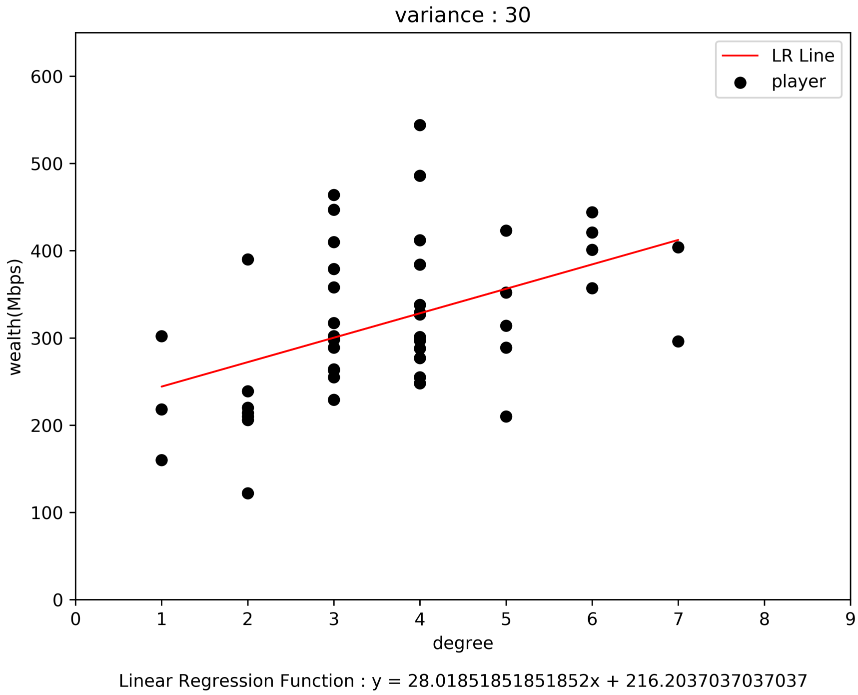


Figure 5.3: Wealth Distribution with 30 Mbps Variance

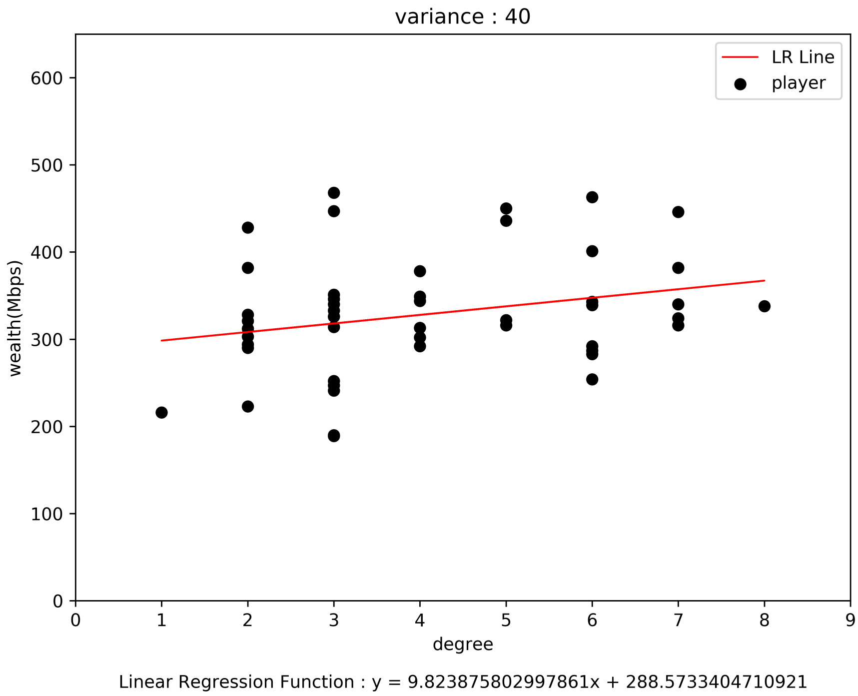


Figure 5.4: Wealth Distribution with 40 Mbps Variance

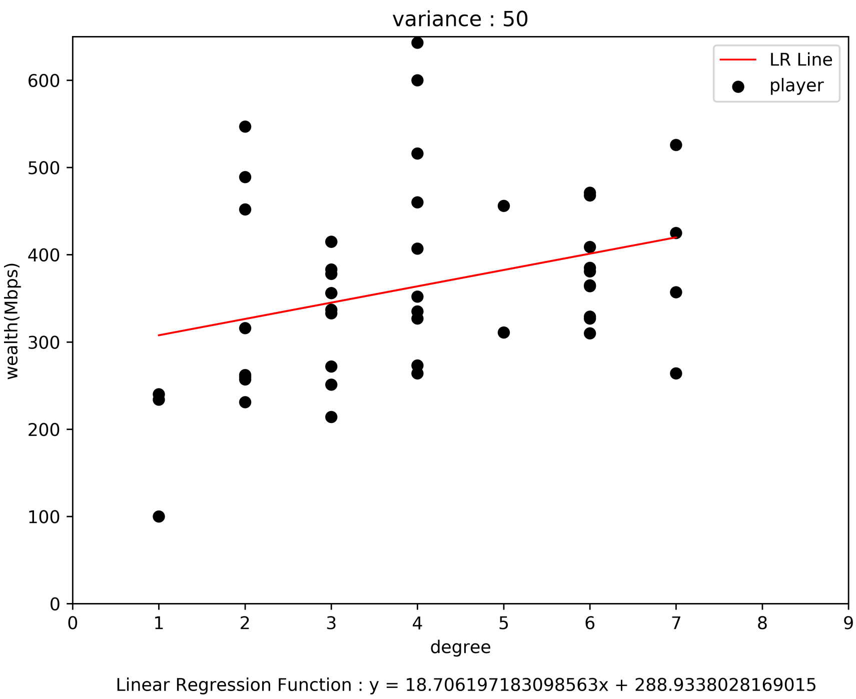


Figure 5.5: Wealth Distribution with 50 Mbps Variance

5.1.3 Wealth and Variance

And interestingly, although the wealth of the players is proportional to the degree of the players no matter how large is the variance, it is apparent that the slopes of the 5 linear regression lines are different, which means the speeds of the increase in wealth as having more neighbors are different if the values of variance are not the same. In addition, the intercepts are different as well and this indicates that the base of wealth changes as the variance varies. The data about the slopes and intercepts with different values of variance is shown in Table 5.1.

Variance	Slope	Intercept
10	20.0143	217.5827
20	29.1366	203.5596
30	28.0185	216.2037
40	9.8239	288.5733
50	18.7062	288.9338

Table 5.1: Slopes and Intercepts with Different Variance

To find the internal relations between the slopes and the variance and between the intercepts and the variance, we explored with the help of Pearson and Spearman Correlation Coefficients. The two are the most widely used correlation coefficients. Simply, we called the APIs provided in the library pandas to evaluate the degree of relevance between those factors. The results are listed in Table 5.2. Based on the definition of the Pearson and Spearman correlation coefficients, we can conclude that the slope of the linear regression line has a strong negative correlation with the variance. This means Additionally, the intercept of the linear regression line has a strong positive correlation with the variance, which means for players who have the same number of neighbors, if the variance of their network is higher, they are likely to receive more resources than those players from networks with lower variance.

Correlation Coefficient	Pearson	Spearman
Slope vs. Variance	-0.44	-0.60
Slope vs. Variance	0.85	0.7

Table 5.2: Correlation among Slope, Intercept and Variance

5.2 Network Level

5.2.1 Definitions

Wealth Equality

When assessing the wealth inequality, we use the Gini coefficient. It is most often used in economics to measure the degree of inequality in a distribution of a group, like the income distribution in a country. Gini coefficient is usually defined mathematically based on the Lorenz curve as shown in Figure 5.6, which plots the proportion of the total income of the population (y axis) that is cumulatively earned by the bottom x of the population. The line at 45 degrees thus represents perfect equality of incomes. The Gini coefficient can then be thought of the ratio about the two parts marked as A and B in the diagram. And the range of Gini coefficient is between 0 to 1, that is from complete equality to complete inequality. The Python function used to calculate the Gini coefficient is presented as follows(where the incoming parameter "wealths" is a list containing the wealth information of all the players in a game):

```
def gini_coef(wealths):
    cum_wealths = np.cumsum(sorted(np.append(wealths, 0)))
    sum_wealths = cum_wealths[-1]
    xarray = np.array(range(0, len(cum_wealths))) / np.float(len(cum_wealths)-1)
    yarray = cum_wealths / sum_wealths
    B = np.trapz(yarray, x=xarray)
    A = 0.5 - B
    return A / (A+B)
```

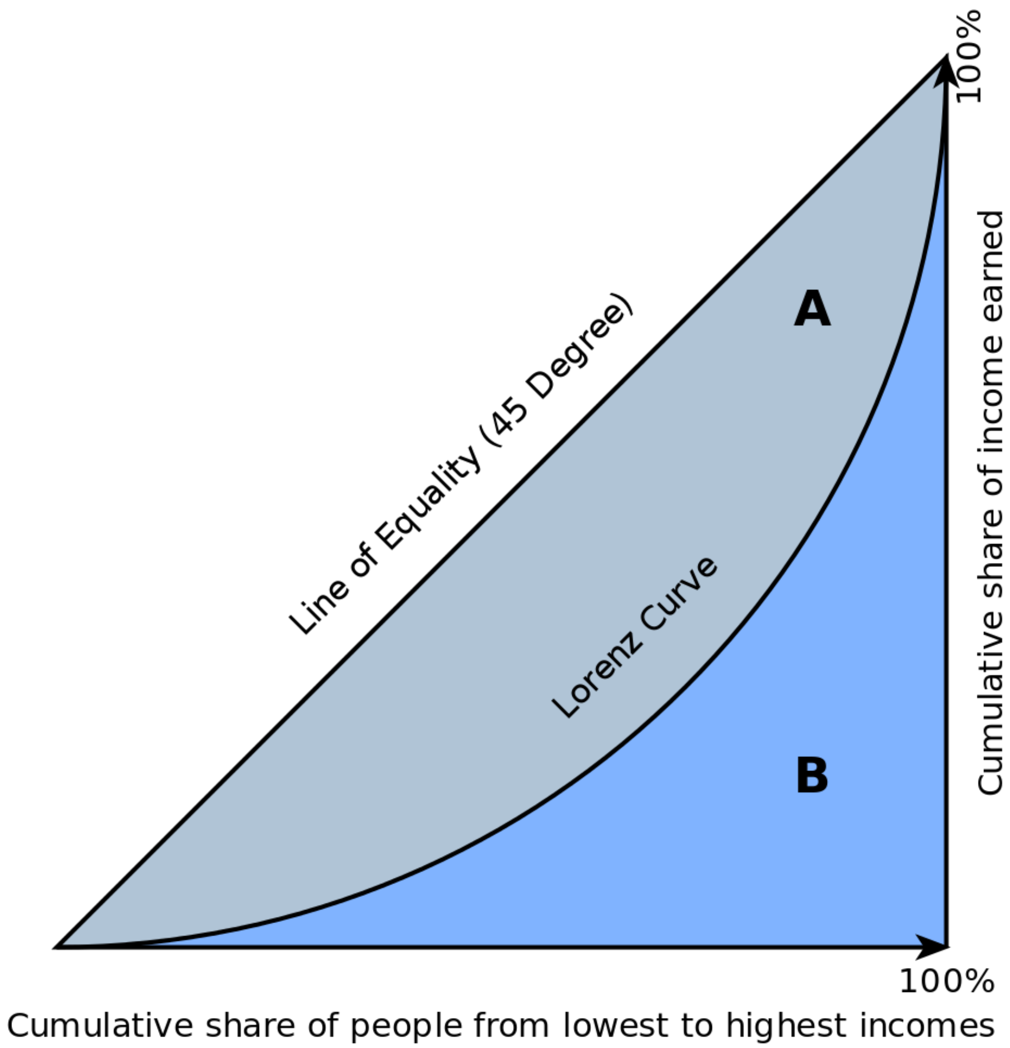


Figure 5.6: Lorenz Curve[3]

Sharing Coefficient(SC)

When assessing the sharing level of the network, we use the Sharing Coefficient, which is defined by myself. The Formula 5.1 is used to calculate the sharing coefficient of a player in a certain round, which has taken not only the number of shared resources but also the number of neighbors get benefits from the player into consideration. In Formula 5.1, the "$Neighbor_{snum}$" means the number of neighbors to whom the player gave resources in that round and the "$Neighbor_{tnum}$" means the number of neighbors of the player. The "$Distribute[neighbor_i]$" means the number of resources that the player gave to neighbor i and "$Resource$" means the number of resources the player have in that round. Then, the "SC_{pr}" on the left side of Formula 5.1 represents the sharing coefficient of player p in round r.

$$SC_{pr} = \frac{\sum_{i=1}^{n} Distribute[neighbor_i]}{\sum_{i=0}^{n} Receive[Resource} * 50\% + \frac{Neighbor_{snum}}{Neighbor_{tnum}} * 50\% \tag{5.1}$$

When calculating the sharing coefficient of a player in a game, we follow the equation in Formula 5.2. In this formula, the "SC_p" represents the sharing coefficient of player p in one game, which is the average sharing coefficient throughout the 5 sharing rounds in the game.

$$SC_p = \frac{\sum_{i=1}^{5} SC_{pi}}{5} \tag{5.2}$$

The equation in Formula 5.3 is designed to calculate the sharing coefficient of one game by calculating the average of the sharing coefficients of all the 12 players in the game.

$$SC_g = \frac{\sum_{i=1}^{12} SC_i}{12} \tag{5.3}$$

5.2.2 Variance and Wealth Inequality

According to the definition of Gini Coefficient, we calculated the Gini coefficients of all the 20 games.

The diagram in Figure 5.7 demonstrates how the Gini coefficient varies with the variance of all the 4 groups and the diagram in Figure 5.8 shows the average Gini coefficients of the 4 groups under the circumstances of 5 different variance values.

In Figure 5.7, we can easily find that all the 20 Gini coefficients fluctuate between 0.04 and 0.20 which is not a large range and this indicates that our experiment basic setups have helped to provide a stable environment for carrying on research about sharing economy. Additionally, it is evident that the Gini coefficient changes obviously as the variance increases. When the variance increases from 10 to 30, the Gini coefficients of 3 groups(Group 2, Group 3 and Group 4) fall off at first and then rise to relatively higher positions, however, there is only group 1 whose wealth inequality aggravates all the time(the Gini coefficient rises from below 0.05 to nearly 0.17). Then, as the variance keeps rising from 30 to 50, all the groups except group 4 experience a fall-rise on the wealth inequality while the Gini coefficient of group 4 descends all the way from above 0.14 to below 0.10.

In Figure 5.8, although the average of Gini coefficient when the variance is 10 is slightly smaller than the value when the variance is 20, we can regard it as a descending trend because the situation is mainly caused by the Gini coefficient of group 1 and as discussed in the last paragraph, group 1 acts quite oppositely so we can regard it as an outlier so that we can definitely neglect the effect of group 1 when the variance is 10.

Take both the two line charts into consideration, we can easily find that with the increase of variance, the path of the change of Gini coefficient is pretty like a letter ‘W’. As the base resource is 60 Mbps, so 20 Mbps accounts for 1 third and 40 accounts for 2 thirds. So, this tells us that if the variance is moderately smaller or larger than half of the base resource, the Gini Coefficient of the whole network is more likely to achieve a lower level, which means there is less wealth inequality in the network.

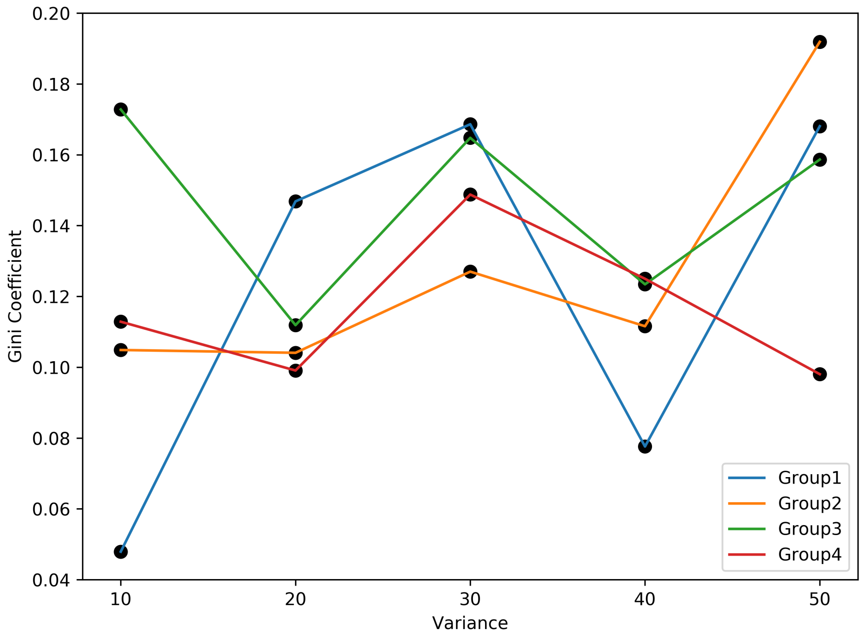


Figure 5.7: Wealth Inequality - Variance - 4 Groups

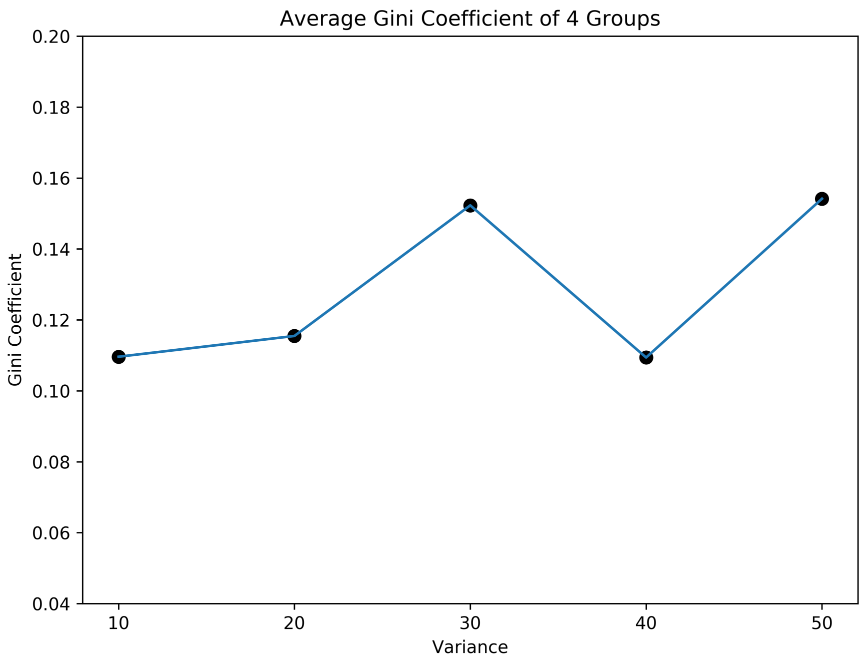


Figure 5.8: Wealth Inequality - Variance - Average

In addition, we also calculated the correlation coefficients between the variance and the Gini Coefficient. As shown in Table 5.3, the value of the two correlation coefficients are both between 0.3 to 0.5. Therefore, it indicates that they have a slightly strong positive correlation, which means, as a whole, the bigger variance is more possible to lead to a higher wealth inequality.

	Pearson	Spearman
Gini Coefficient vs. Variance	0.57	0.399

Table 5.3: Correlation between Variance and Wealth Inequality

5.2.3 Variance and Sharing Level

Based on the definition of Sharing Coefficient, I calculated the sharing coefficients of all the 20 games. The diagram in Figure 5.9 demonstrates how the sharing coefficient varies with the variance of all the 4 groups and the diagram in Figure 5.10 shows the average sharing coefficients of the 4 groups under circumstance of 5 different variance values.

In Figure 5.9, we can easily find that all the 20 sharing coefficients fluctuate between 0.92 and 0.98 which is not a large range and this also indicates that our experiment basic setups have helped to provide a stable environment for carrying on research about sharing economy. Furthermore, it is evident that the sharing coefficient changes obviously as the variance increases so that the variance is highly likely to have an effect on the sharing level of a sharing social network. Interestingly, the sharing coefficient of group 1 is the most special one since only it experienced a large decrease from over 0.96 to nearly 0.93 while the variance increased from 10 to 30 and experienced a huge increase from nearly 0.93 to over 0.97. However, the sharing coefficients of other 3 groups all experienced two rise-fall processes while the variance increased from 10 to 30 and from 30 to 50 respectively.

Take both the two line charts into consideration, we can easily see that the path of the change of Sharing coefficient is pretty like a letter 'M', which is nearly the opposite trend of the Gini Coefficient. As the base resource is 60 Mbps, so 20 Mbps accounts for 1 third and 40 accounts for 2 thirds. So, this tells us that if the variance is moderately smaller or larger than half of the base resource, the sharing level of the whole network is going to reach a high position. And more importantly, a higher sharing level will alleviate the wealth inequality of a society based on the analysis of wealth inequality in the last section.

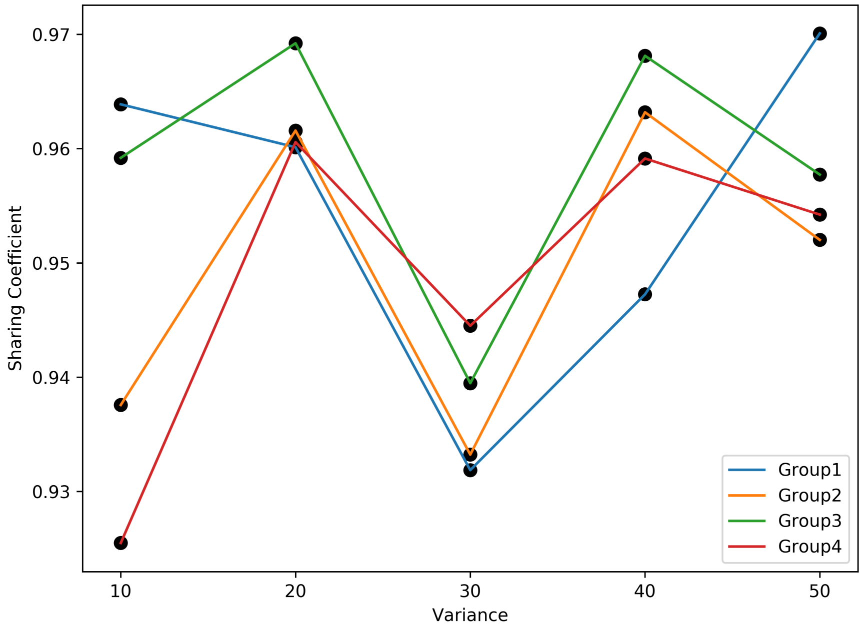


Figure 5.9: Sharing Level - Variance - 4 Groups

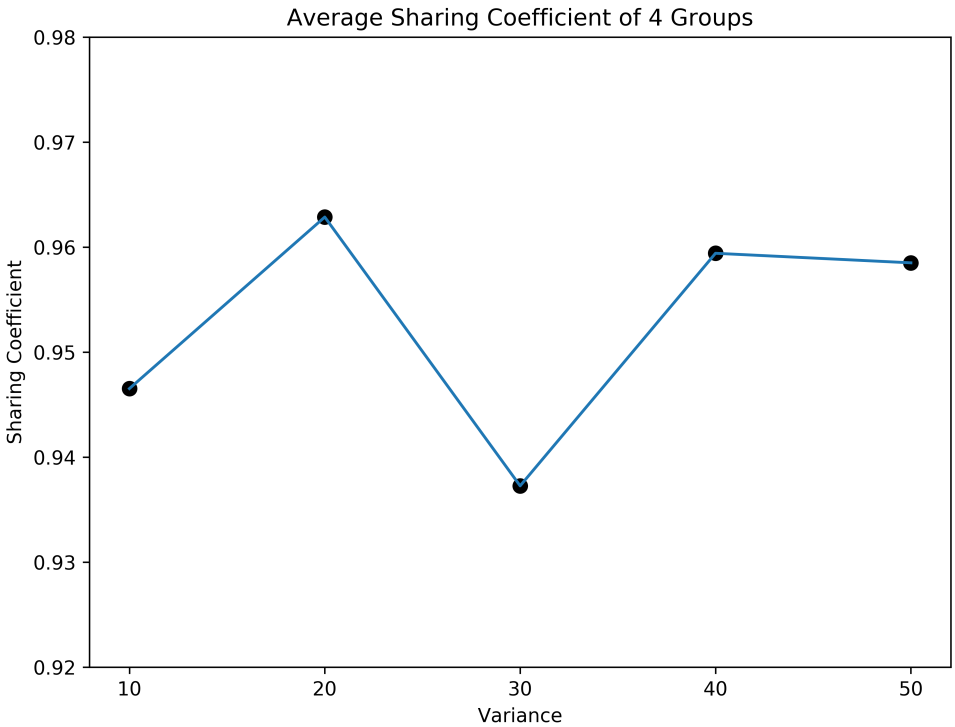


Figure 5.10: Sharing Level - Variance - Average

In addition, we also assessed the relevance between the variance and the sharing coefficient. As shown in Table 5.4, the value of the two correlation coefficients are both positive and nearly equal or smaller than 0.3. Therefore, it indicates that they have a weak positive correlation, which means, a bigger variance is possible to lead to a higher sharing level but not always.

	Pearson	Spearman
Sharing Coefficient vs. Variance	0.31	0.1

Table 5.4: Correlation between Variance and Sharing Level

Chapter 6

Conclusion

In this chapter, my contributions to the WIFI sharing game research will be presented and we will discuss the results. Finally, we detail possible future work.

6.1 My Contributions

Based on the research on the sharing economy using the WIFI sharing game in [10], there are a few researchers like Beiran Chen have been involved in the improvement work about it. The followed list contains the primary work finished by myself:

- Make the leftover resources in a certain sharing round still available in the next round. The reason why this is meaningful has been explained in Chapter 4. As in the WIFI sharing game project, the display part and the game logic part are separate so we need to deal with them respectively. The technologies used include HTML, JavaScript and Groovy.

- Make the number of resources assigned to each player fluctuates between different ranges. As introduced in Chapter 4, the practical significance is to simulate any possible factors that may have an effect on the idle resources in various scenarios.

- Design and test several kinds of sharing strategies for AI players and finally deciding on the current one where an AI player shares resources with a certain neighbor based on how many he received from the neighbor in the last round.

From my point of view, as discussed in Chapter 4, this strategy agrees more with the preference of human beings.

- Design the experiment structure and invite 24 human players from different places and arrange them to participate in 20 WIFI sharing games in total in order online.
- Design and put forward the Sharing Coefficient to evaluate the sharing level of a player and a sharing social network.
- Put forward my own research priority and it is exploring the relationships between position and wealth and the relationship among variance, wealth inequality and the sharing level of the whole social network and design the strategies of exploring the relations among them.
- Write python programs to process the 20 csv files containing the experiment data of the 20 WIFI sharing games. And based on the research priorities, do related calculations and comparisons like calculating the Gini Coefficient and Sharing Coefficient and visualize the analysis results with scatter plots, tables and line charts.
- Find and fix the program bugs inside the project. For example, during the process of tests, we found that if an AI player only have one neighbor and the neighbor share no resource to him, the game will get struck because at this time, the denominator and numerator in the AI sharing strategy are both 0, which is illegal in math. Therefore, we just let it be 1 Mbps if a player received no resource from a neighbor since 1 Mbps is negligible compared with the range of resources but can make the game continue smoothly.
- Update the tutorials and the display effect of the real sharing game to make them more fit with our own research priority.

6.2 Discussion

Based on the analysis of the experiment results from an individual's perspective in Chapter 5, we learn that no matter the variance is large or small, players who have more neighbors are more likely to be wealthier in the sharing networks as the slopes of all the 5 linear regression lines with 5 different variance values are all positive ranging from 9.82 to 29.14. Therefore, players are supposed to maintain a good relationship with their neighbors by balancing the resources shared to different neighbors to assure that they will not be abandoned by any one of their neighbors. If one of neighbors of a certain player is not satisfied with the number of resources received from the player, the neighbor may decide to not share any idle resources to the player in the following sharing rounds. Thus, the number of neighbors of the player will be decreased if this happens so that the player is highly likely to be poorer than he should be.

And according to the analysis of the sharing level and wealth inequality of the whole social network and the variance in Chapter 5, the trend of the Gini coefficient is nearly contrary to that of the sharing coefficient as the variance increases and the value of variance that is moderately smaller or larger than half of the base resource is helpful to help the whole network to achieve a state with less wealth inequality. Therefore, for those networks where there is an administrator like the collective heating network, the administrators can try to adjust the floating range of resources assigned to the participants to improve the sharing level so that the wealth inequality of the whole network will be decreased. Besides, as for the designers of the sharing social networks, they are supposed to control the resource to make it fluctuate among a reasonable range and provide the administrators with the right to adjust the variance by changing the logical structure of the network or updating the necessary supportive equipment.

In conclusion, all the research work in my dissertation is aimed at helping the members of a social network to gain more benefits from the network with a low level of wealth inequality so that the people in the network will enjoy a stronger sense of happiness.

6.3 Future Work

Firstly, as the wealth is proportional to the number of neighbors, so if players have the chance to build new relationship with other players, they can try to increase the number of neighbors. And in future research, we could try to provide this choice to players to test whether things will change.

Besides, the representation method of a player's position could be improved. In this thesis, the position of a player is merely dependent on the number of neighbors of him. Although this must be the most important factor that has a huge effect on the wealth of the player, the number of neighbors of the player's neighbors should be taken into consideration as well since they are the player's competitors and it is definite that the player will be wealthier easily if there are fewer competitors. Thus, we could try to find a better way to describe the position of a player.

In addition, in the WIFI sharing experiments in this thesis, there are only 5 different values for the variance of the resource and in the future, we could try to narrow the gap between two adjacent different values and increase the fluctuation range to test whether the laws found in Chapter 5 will change or not.

Last but not least, we are supposed to remain other factors unchanged but alter the number of players involved in a game or just the number of AI players in a game. If the laws found in Chapter 5 don't change while the number of players varies, we will draw a conclusion that all the findings in Chapter 5 could be applied to all the sharing social scenarios with different number of participants.

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Appendix A

Code Snippets

A.1 Process One Sharing Game

```
def processOneCsv(groupNum, variance, GiniList, SharingCoefficientList, avgWealthDegreeList20, totalWealthTupleList20):

    print("Group" + str(groupNum) + "-" + str(variance) + " : ")

    #read from csv file

    csvFile = open(generateFilePath(groupNum,variance))

    dataLines = csv.reader(csvFile)

    data = []
    roundNum = 0
    distributionDicList = []

    #csv['id', 'event', 'event_date', 'data_name', 'data_value']

    #store the content in the csv file into a list
    for line in dataLines:
        data.append(line)

    #delete records before assigning labels

```

```
    currentEvent = data[0][1]

    while currentEvent != "PlayerLabel":
        #get the number of rounds
        if data[0][3] == 'nRounds':
            roundNum = int(data[0][4])
        del data[0]
        currentEvent = data[0][1]

    #start making players list

    players = []
    onePlayer = []
    newLine = []

    while data[0][1] == 'PlayerLabel':

        #read 4 lines into onePlayer
        onePlayer = data[0:4]
        del data[0:4]


        #here comes a new player
        for i in range(len(onePlayer)):
            flag = onePlayer[i][3]
            if flag == "label":
                label = onePlayer[i][4]
            elif flag == "degree":
                degree = onePlayer[i][4]
            elif flag == "pid":
                pid = onePlayer[i][4]


        newPlayer = Player(pid, degree, label)
        players.append(newPlayer)


    #making a dictionary recording the numbers of degrees of all the players a
    ↪  dic for labels and a list for pids
    degreeDic = {}

```

```
    #making a dictionary for the labels of all the players
    labelDic = {}

    #making a list for pids of all the players
    pidList = []

    for i in range(len(players)):
        pid = players[i].pid
        degree = players[i].degree
        label = players[i].label
        degreeDic[pid] = degree
        labelDic[pid] = label
        pidList.append(players[i].pid)




    #start sharing


    for i in range(roundNum):

        #record the distribution in one round


        while(data[0][1] != "distributeBW"):

            del data[0]


        #iterate while in distribution round
        index = 0
        newLine = data[index]
        currentRoundDistributionDic = {}




        #enter the process of distribution
        while(newLine[1] == 'distributeBW'):

```

```
        #pendingLinesNum = 0
        #find the line with a pid
        while (newLine[3] != 'pid'):
            index += 1
            newLine = data[index]

            #record the number of pieces of distribution information that
            ↪  was created before printing pid
            #pendingLinesNum += 1

        #found the line with pid
        currentPid = newLine[4]
        currentPlayerLabel = labelDic[currentPid]
        currentPlayerDegree = int(degreeDic[currentPid])
        currentPlayerDistributionDic = {}


        for i in range(currentPlayerDegree + 3):
            dataName = data[i][3]
            currentDistributedResource = 0

            if dataName in pidList:
                #this line is a record that recods that the current player
                ↪  distributed his resource to a neighbour
                currentDistributedResource = int(data[i][4])
                currentPlayerDistributionDic[labelDic[dataName]] =
                ↪  currentDistributedResource
            elif dataName == 'resource':
                currentDistributedResource = int(data[i][4])
                currentPlayerDistributionDic[dataName] =
                ↪  currentDistributedResource

        #finish storing distribution information into dictionary then
        ↪  delete the lines belong to the current player
        currentRoundDistributionDic[currentPlayerLabel] =
        ↪  currentPlayerDistributionDic
        del data[0:currentPlayerDegree + 3]

        newLine = data[0]
        while (newLine[1] == "clientLogIn"):
            del data[0]
```

```
                newLine = data[0]
            index = 0


        #append the distribution dic of the current round to the distribution dic list
        distributionDicList.append(currentRoundDistributionDic)

        #remove result step records

        #delete "ResultStepStart" and "ResultStart"
        del data[0:2]

        while data[0][1] == 'ResultConfirmed':
            del data[0]



    #calculate the total wealth of each player

    totalWealthDic = {}

    #initiate the dic
    for label in labelDic.values():
        totalWealthDic[label] = 0

    for curRound in distributionDicList:

        for dic in curRound.values():

            for key, value in dic.items():

                if key in labelDic.values():

                    totalWealthDic[key] += value


    #convert the pair in totalWealthDic to tuple(degree, wealth)

    totalWealthTupleList = []

```

```
    for label, wealth in totalWealthDic.items():

        degree = int(degreeDic[list(labelDic.keys())[list(labelDic.values()).index(label)]])

        wealthTuple = (degree, wealth)

        totalWealthTupleList.append(wealthTuple)

    totalWealthTupleList20.append(totalWealthTupleList)



    #dic for average wealth of players with the same degree

    degreeMax = max(list(map(int, list(degreeDic.values()))))

    avgWealthDegreeList = [0 for i in range(degreeMax)]

    for label, wealth in totalWealthDic.items():

        degreeOfLabel = int(degreeDic[list(labelDic.keys())[list(labelDic.values()).index(label)]])

        avgWealthDegreeList[degreeOfLabel - 1] += wealth

    for i in range(len(avgWealthDegreeList)):

        if (avgWealthDegreeList[i] != 0):

            avgWealthDegreeList[i]  = avgWealthDegreeList[i] / float(list(map(int, degreeDic.values())).count(i + 1))

    avgWealthDegreeList20.append(avgWealthDegreeList)



    ###########################-----------------------------########################


    #calculate Gini coefficient
```

```
    GiniCoe = 0

    GiniCoe = gini_coef(np.array(list(totalWealthDic.values())))

    #append the gini into the GiniList
    GiniList.append(GiniCoe)

    print("Gini : ", GiniCoe)




    ↪ ###########################-----------------------------########################


    #calculate the sharing coefficient

    sharingCoefficientDic = {}

    #initiate the dic
    for label in labelDic.values():
        sharingCoefficientDic[label] = 0.0

    isFirstRound = 1

    for curRound in distributionDicList:


        for playerLabel, playerDisInCurRoundDic in curRound.items():

            #calculate for each player per round

            inResourceInCurRound = 0.0
            outResourceInCurRound = 0.0

            sharingNeighborNum = 0.0
            totalNeighborNum = 0.0

            sharingCoefficientInCurRound = 0.0
```

```python

            for neighborLabel, value in playerDisInCurRoundDic.items():


                if neighborLabel == "resource":
                    inResourceInCurRound = value
                else:

                    if value != 1:
                        sharingNeighborNum += 1

                    totalNeighborNum += 1
                    outResourceInCurRound += value

            sharingCoefficientInCurRound = outResourceInCurRound / inResourceInCurRound * 0.5 + sharingNeighborNum / totalNeighborNum * 0.5

            if (isFirstRound):
                sharingCoefficientDic[playerLabel] = sharingCoefficientInCurRound

            else:
                # update the way of calculating the avg of sharing coefficient

                #sharingCoefficientDic[playerLabel] = (sharingCoefficientDic[playerLabel] + sharingCoefficientInCurRound) / 2
                sharingCoefficientDic[playerLabel] += sharingCoefficientInCurRound

        isFirstRound = 0



    sc = 0

    sc = np.mean(np.array(list(sharingCoefficientDic.values())) / 5)

    #append the sharing coefficient into the SharingCoefficientList
    SharingCoefficientList.append(sc)
```

A.2 AI Strategy

```
g.addAI(a, nAi, { ai ->
  ai.active = true
  //ai.point = 0
  if (ai.getProperty("choices")) {
    def choices = ai.getProperty("choices")
    def choice = choices[r.nextInt(choices.size())]
    def params = [:]

    //==================

    k = Math.random()
    kk = (( k < 0.5) ? -1 : 1) * k//get a random -1~1 number


    ai.variance = variance * kk    //get a random variance value
    ai.resource = Math.round(resource + ai.variance-0.5)

    println("round " + curRound + "AIplayer" + ai.id + " variance resource:
    ↪  "+ ai.resource)


    //================== round 1

    if (curStep == "SharingStep" && curRound == 1) {  //distribute evenly in
    ↪  round 1

      def remainingBandwidth = ai.resource//resource.br: copy the AI resource
      ↪  to the remainingBandwidth variable
      //println('curRound > 1 ai resource:    ' + remainingBandwidth)


      //xu:initiate the record variable
      ai.remaining = ai.resource


```

```
        //xu:print the current assigned resources
        println("round " + curRound + "AIplayer" + ai.id + " total resource: "+ ai.resource)
        nn = 1 / ai.neighbors.count()
        allocation = remainingBandwidth * nn
               ai.neighbors.each { neighbor->
          params[neighbor.id] = Math.round(allocation - 0.5)
          //xu:decrease the remaining varible after each allocation
          //.remaining -= params[neighbor.id]
          //println('1 round:    ' + "neighbor:   "+ neighbor.id + "get:   " + params[neighbor.id])  //br:print out the allocation in first round to check
          //remainingBandwidth -= allocation
        }
        //xu:after the first round, print the remaining of resources
        //println('round 1 over, aiPlayer'+ai.id+' remained resources:'+ai.remaining)
      }
//==================round > 1
       if (curStep == "SharingStep" && curRound > 1) { // br: After first round AI allocate source acording to the percentage of previous day.
        def remainingBandwidth = resource
        def allocationResource = ai.resource//resource. br: same as the 1st round, just use different variable name to record the AI resource.
        //xu:update the total resource amount
```

```
        ai.resource += ai.remaining
        ai.remaining = ai.resource


        println("round " + curRound + "AIplayer" + ai.id + " total resource:
        ↪  " + ai.resource)


              ai.neighbors.each { neighbor->

         //println ('curStep == "SharingStep" && curRound > 1')
         ppid = ai.getId()

         nnid = neighbor.getId()

         // br: get the percentage from the list perList with the key combine
         ↪  with the information: which round which AI player paring which
         ↪  neighour.

         pper = perList[("round_" + (curRound-1) + "pid_" + ppid + "nid_" +
         ↪  nnid)]


         allocation = Math.round(allocationResource * pper - 0.5)

         //xu:prevent the distribution bug with 0 resource
         if (allocation < 1){
           allocation = 1
         }


         params[neighbor.id] = allocation  //br: out the allocation to
         remainingBandwidth -= allocation  // br: get the remaining bandwidth


         //xu:decrease the remaining varible after each allocation, this is
         ↪  not supposed to be here because in the SharingStep, we will do
         ↪  the same thing to every player including real players and AI
         ↪  players
         //ai.remaining -= allocation
       }
```

```
       }
//========================
      a.choose(choice.uid, params)
    }
  })
```

Appendix B

Github Link

The entire implementation code can be found on Github: `https://github.com/GeekDream-x/SharingEconomyResearch-MscDissertation-TCD.git`