WIRELESS ACCESS IN VEHICULAR ENVIRONMENTS USING BIT TORRENT AND BARGAINING

by

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A thesis

submitted in partial fulfillment

of the requirements for the degree of

Master of Science in Electrical and Computer Engineering

Boise State University

September 2008

The thesis presented by *Barsha Shrestha* entitled *Wireless Access in Vehicular Environments Using Bit Torrent and Bargaining* is hereby approved.

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Dedicated to my Mom, Dad and Family

ACKNOWLEDGEMENTS

I would like to thank Dr. Zhu Han (University of Houston, Texas) for providing me detailed reviews, guidance, and direction throughout my research. I would also like to thank Dr. Dusit Tao (Nangyang Technological University, Singapore) and Dr. Ekram Hossain (University of Manitoba, Canada) for their helpful suggestions and ideas for pursuing my research.

I am also very grateful to my other committee members, Dr. John Chiasson, Dr. R. Jacob Baker and Dr. Thad Welch for their help and support.

I also express my sincere appreciation towards the Department of Electrical and Computer Engineering at Boise State University for providing me with support.

ABSTRACT

Wireless Access in Vehicular Environment (WAVE) technology has emerged as a state-of-the-art solution to vehicular communications. The major challenges in WAVE arise due to the fast changing communication environment and short durations of communications due to the high mobility and speed of vehicles. As a result, it is difficult to broadcast a large amount of data in such a network for Vehicle-to-Roadside and/or Vehicle-to-Vehicle communications.

Considering channel adaptations and fairness in their achieved utility, the vehicles use different bargaining methods to exchange data. The bargaining solutions proposed include the Nash Bargaining Algorithm, the Kalai-Smorodinsky Bargaining Solution, and the Egalitarian Bargaining Solution. These three solutions are based on the fairness criteria. Nash Bargaining Solution will try to maximize the product of the gains of two vehicles sharing information. Kalai-Smorodinsky Bargaining Solution will try to keep the ratio of gain constant with their utilities and Egalitarian Bargaining Solution will try to make their gains equal. We propose a solution based on the idea of BitTorrent to distribute data from roadside unit to vehicles and bargaining to exchange information between vehicles. For RSUs, depending on the traffic pattern, distribution of packets to the OBUs is optimized considering the different priorities of the packets and the different traffic intensity at day and night time. During traffic hours, there are plenty of chances for the vehicles to exchange information, so the RSU would distribute different priorities of data evenly. On the other hand, during

late night when there is little traffic, RSU would distribute higher priority data first.

To study the theory that has been proposed, a two-lane highway traffic scenario was considered with two vehicles moving in opposite directions. Each vehicle is equipped with a transceiver. The maximum transmission range is 80 meters between the vehicles. The vehicle speed is uniformly random between 80-120 km/hr. The experiment was carried out using MATLAB. While the vehicles were in motion, the different solutions of the bargaining game (i.e., Nash, Kalai-Smorodinsky, and Egalitarian solutions) were applied in succession. Simulation results illustrate that the proposed methods can ensure fairness among the OBUs and adapt to different traffic scenarios with different vehicular traffic intensity.

Therefore, by using BitTorrent and Bargaining, we can solve the problem in WAVE regarding the inconsistency of complete data transfer due to the high mobility and speed of the vehicles.

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CHAPTER 1

INTRODUCTION

Traffic accidents have become a serious issue in the modern world. According to the World Health Organization (WHO), 1.2 million people lose their lives in road accidents annually. There are various causes for the accidents; the main one being the inability of the driver to take the correct step immediately. The number of accident and mishaps could be reduced by implementing a system where the vehicles can communicate, share information, and take preventative measures based on the information to avoid such incidents. A vehicular communication network was developed under Intelligence Transportation System (ITS). ITS is the combination of different types of technologies implemented in transportation to provide a secure and well-organized transportation system. Vehicular communication can be used for providing safety by sharing information regarding accidents, congestion, precautionary measures, etc. within vehicles. It can also be used for electronic payment for tolls, surfing the Internet, and downloading files, etc. The aim of vehicular communications that is being developed by the ITS is to supply safe traffic by providing security information such as traffic information, warnings, and congestion through Vehicle-to-Vehicle (V2V) and Vehicle-to-Roadside (V2R) communication.

V2V communication implements Dedicated Short Range Communication (DSRC) to transmit data from one vehicle to another vehicle through an On-Board Unit (OBU). In V2V communication, OBU sends information about its status to other vehicles within its range and also receives information from other OBUs. An OBU is a mobile device that supports information exchange, whereas Roadside Unit (RSU) is a device that operates at a fixed position located in traffic lights, signs, road crossings, etc. V2R communication uses Dedicated Short Range Communication (DSRC) to transmit data from one vehicle to a fixed infrastructure on the road. The vehicle transmits or receives messages through OBU whereas the infrastructure transmits and receives messages through RSU. Wireless Access in Vehicular Environments (WAVE) technology such as IEEE 802.11p is one of the solutions to the vehicular communications.

WAVE technology is getting very popular in the discipline of vehicular communications and it is expected to be implemented in near future. There are several topics that are being studied, including physical layers related to mobile channels, network configuration, security, Media Access Protocols (MAC), and congestion control system to name a few. The major application of WAVE is vehicle safety. Some of the examples of safety applications will be curve warning, emergency brake light, collision warning, and emergency braking. For these applications the vehicles need to communicate with each other and they need to analyze the data from RSU as well. Another application is infotainment.

Wireless Internet Access is used widely in almost all of the parts of the world. This service can be available in computer, notebooks, cell phone, Personal Digital

Assistant(PDA) and other devices. We can access the Internet using public hotspots. People carry these devices even when they are traveling but their use is complicated in a fast changing environments such as a moving car. In highways, the main problem is the discontinuous connectivity with the Internet which prevents a user from downloading files or doing any activity related to Internet. WAVE can be used to deal with the problem and increse effective Internet use.

In V2V communication and in V2R communication, the time period for data exchange should be very low considering the fast changing conditions in highways. The vehicles travel at high speed and they come in contact with each other for very short duration. The circumstances were studied and 100ms latency was estimated [4]. The size of data packets to maintain V2V communication is less than 100 bytes and 430 bytes for V2R communication [4]. The implementation of wireless communication for V2V and V2R provides the prospect for supporting safety application. Dedicated Short Range Communications (DSRC) can support the wireless communication between vehicles, and vehicle and Infrastructure at low latency.

DSRC is a short to medium range wireless communication employed in vehicular communication in transportation systems. The range of spectrum assigned to DSRC is between 5.850 to 5.925 GHz bands with bandwidth of 75 MHz based on line of sight of 1km with maximum speed of 140km/hr. DSRC provides high rate for data transfer and is useful in situations where low delay is important. Wireless Access for the Vehicular Environment (WAVE) is the wireless communication component of DSRC and together, they provide architecture for vehicular networks.

The major challenges to WAVE arise due to the fact that the communication environment varies rapidly and duration of communications between the communicating nodes can be short. Also, the data (especially multimedia data) that needs to be transmitted might be large and could not be delivered to all users with limited transmission time and bandwidth. Another issue in V2V and V2R communication is the method of exchange of information. Next issue is regarding security, the system should make sure that the data is genuine to avoid incorrect information. There are diverse kinds of data that can be transmitted by RSUs and OBUs. Prioritizing which data would be transmitted first needs to be addressed. Also, we need to figure out a method to find the address of the other nodes and information distribution. For example, if an accident occurs, how will the information be distributed to vehicles not in the range?

To tackle these problems, we propose to use the concept of BitTorrent to distribute data among vehicles and employ bargaining among vehicles to exchange data with different fairness criteria. Based on the BitTorrent and sequential bargain, we formulate the V2R problem and V2V problem. The V2R problem is to decide how to distribute different parts of data to the vehicles according to the traffic pattern and the average transmission time between OBU and RSU. The V2V problem is to optimize the communication between the vehicles according to the channel variations, so that the maximal mutual benefits (i.e. the exchange of data) can be achieved. To solve the above two problems, we propose two algorithms in OBU and RSU, respectively.

We propose a solution based on the idea of BitTorrent used for Peer-to-Peer networking, and the concept of bargaining used in game theory. Similar to the allocation of data in BitTorrent, the RSUs randomly distribute data to the passing vehicles.

Considering channel adaptations and fairness in their achieved utility, the On-Board units (OBUs) in the vehicles with different portions of the data will then exchange the information among each other using bargaining. We formulate two optimization problems - one for the RSUs and another for the OBUs. For OBUs, the bargaining solutions are proposed based on three fairness criteria. They are Nash Bargaining Solution, Kalai-Smorodinsky Solution (KSS) and the Egalitarian Solution (ES). For RSUs, depending on the traffic pattern, distribution of packets to the OBUs is optimized considering the different priorities of the packets so that the overall utilities of the OBUs are maximized. Simulation results show that the proposed schemes can ensure fairness among the OBUs, and adapt to different traffic scenarios with different vehicular traffic intensity.

For future work, performance analysis will be carried out from an application-centric point of view. Analytical models will be developed to determine the average time duration to complete data exchange and the probability of completion of data exchange for each vehicle. The analytical models would be useful for system performance optimization.

CHAPTER 2

PEER-TO-PEER NETWORKING AND BITTORRENT

Peer-to-Peer (P2P) networking is a type of computer network which reduces the number of servers or even eliminates them to allow the computers to share files with each other. Unlike client-server network systems, files can be distributed from any of the computers in the P2P network. P2P networking has a wide range of applications like voice IP and sharing files. One of the popular P2P application is BitTorrent which was introduced by Bram Cohen and was first implemented on July 2001.

In Section 2.1, we will discuss about P2P networking, its architecture, and different types of P2P networks. In Section 2.2, we will talk about BitTorrent, and explain the working principle of the BitTorrent followed by its advantages and disadvantages.

2.1 Peer-to-Peer Networking

P2P networking is prevalent among people today. It started getting popular when millions of users started downloading songs using Napster. In this section, we will be studying more details about the P2P networking.

2.1.1 Definition

P2P networking is a system in which computers are connected to each other wired or wirelessly. The computers in such a network communicate with each other directly. The system does not have separate servers and clients and the networked computers in the system behave as servers and as clients. Each node or user has equivalent capabilities. The main application of P2P networking is in sharing files. In a few years, file sharing and downloading big multimedia files has become very popular. Incorporation of P2P networking in such sharing systems have made the process more efficient. The other application of P2P can be to access a hard drive space from a remote computer, which can be used for backing up or storing data. P2P networking also allows a networked computer to access printers, scanners, and other peripherals that are connected to other peer computers. The P2P network structure is given in Fig 2.1.

P2P networking can also be used in distributed computing to utilize hard drive space and CPU processing power from an idle computer. In P2P networking, all the nodes/computers in the network provide computing resources, which increases the bandwidth. P2P networks perform better if more nodes join the system. Another advantage of P2P is the distributed nature of the network. Due to this property, if one of the computer/node fails or leaves the network, the entire system will not be affected because there is no central server and each node can act as a unique server/client.

P2P networks are overlay networks. Overlay networks are those networks which

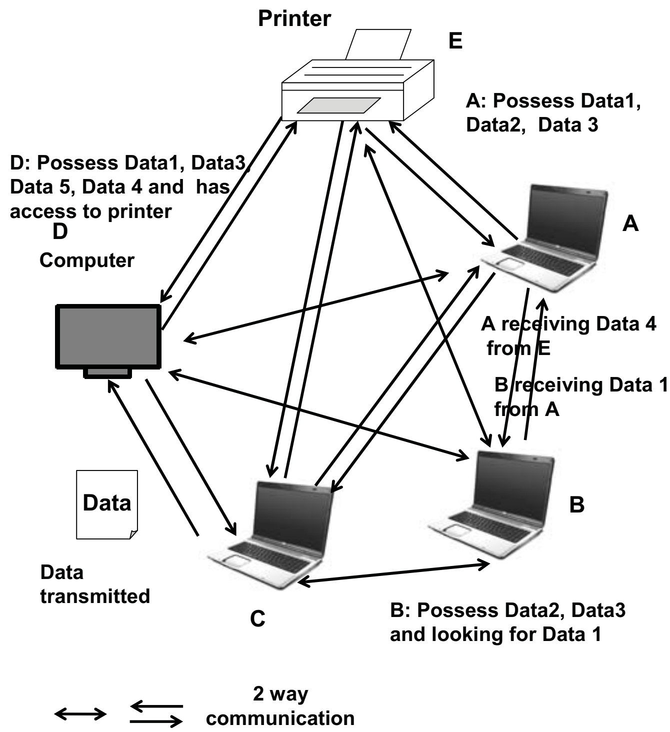

Figure 2.1: P2P Network

run on the top of other types of networks. P2P is built over the Internet. Based on the arrangement of the nodes on overlay networks, P2P can be both a Structured Network and an Unstructured Network.

1. Structured P2P Network

   Structured P2P network is a type of network where a node can find out other nodes in the network that has its file of interest. It is used to locate a node by mapping its key. So, this system is self organizing, robust, and does not require a server. There is a ID number (or key) that can be stored for a value or node and that value can be accessed if the ID number (or key) is known. Its drawback is that it is not good at performing file location searches. Distributed Hash Table (DHTs) is a structured P2P Network which uses consistent hashing for assigning the file to a particular node. Some of the examples of Structured P2P system are CHORD [10], Kademlia, Bamboo, TAPESTRY [11], Pastry [12], and CAN [13].

Let us consider the PASTRY system as shown in Fig 2.2. Each node has node ID and PASTRY consists of a key which is 128 bit. Pastry sends the message to the node with node ID nearest to the 128 bit key. Each one updates itself with the information about neighboring nodes. Each one has a routing table which consists of the IP address of the nodes whose prefix numbers of their ID is same as the current node. A node will always send the message to the node in routing table with common prefix of node ID. If such node do not exist, then it will send the message to its neighboring node.

2. Unstructured P2P Network

Unstructured P2P Network is a type of network formed by a new peer that joins the network. These new peers may or may not follow the rule as given in [9]. The Unstructured P2P network is represented in Fig. 2.3. Since a new peer connects to one or more peers in the system in a arbitrary manner, information is not uniformly distributed. Hence, all the neighboring nodes should be queried to find a file it is searching. One of the query methods is flooding which will search within a certain distance. It is not guaranteed that the data will be obtained. These types of networks have poor performance because of the nature of the

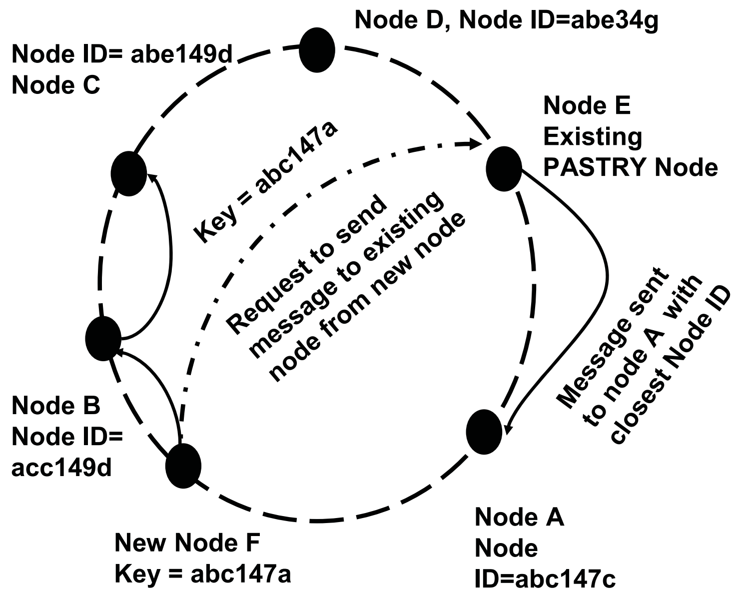

Figure 2.2: Structured P2P Network [14]

query. Its main application is in file sharing and content distribution. Gnutella is an example of a decentralized unstructured P2P network.

2.1.2 History

P2P network was developed in the 1990s. They were designed so that a group of nodes or users who have the same networking program could link to each other to access and share files and data easily [7]. Some examples of earlier networking programs are Napster and Gnutella.

The discussion of P2P remains incomplete if we do not mention the popular music sharing program, Napster. Napster comes under the first generation of P2P programs. Napster was developed by Shawn Fanning in September 1999. Napster is a centralized

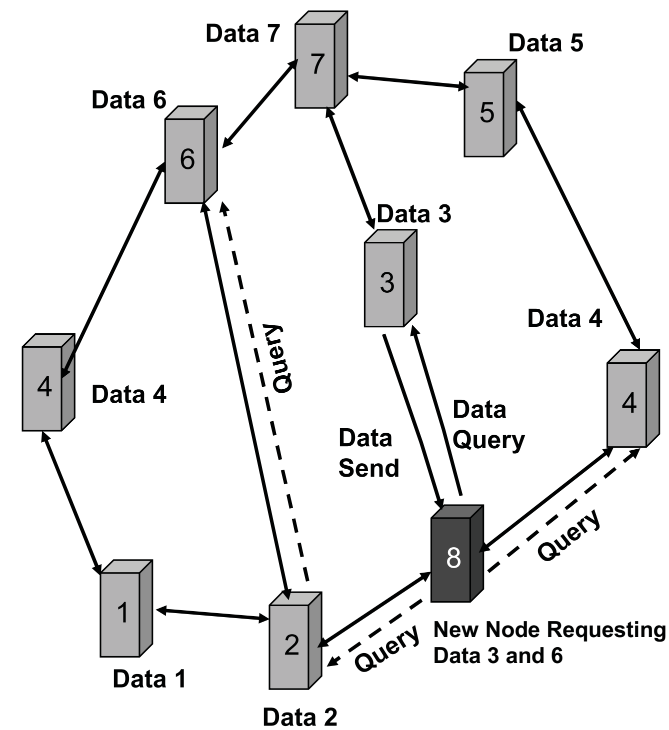

Figure 2.3: Unstructured P2P Network

P2P network because the server stores all the information and does the searches. When an individual user requests a file, the server scans the computers in the network and provides information of the address of the other users who have that file [5]. Fig 2.4 represents the Napster P2P Network. Napster was an efficient P2P program and became very popular. The Recording Industry Association of America (RIAA) sued Napster in December 1999 followed by the band Metallica for violating copyright laws [6]. Napster shut down in July 2001.

The second generation programs like Gnutella evolved in 2000 [7]. Unlike Napster, these systems do not have central servers and are decentralized in nature as shown in Fig 2.5. A user requests for a file to all the other users/nodes it is connected to.

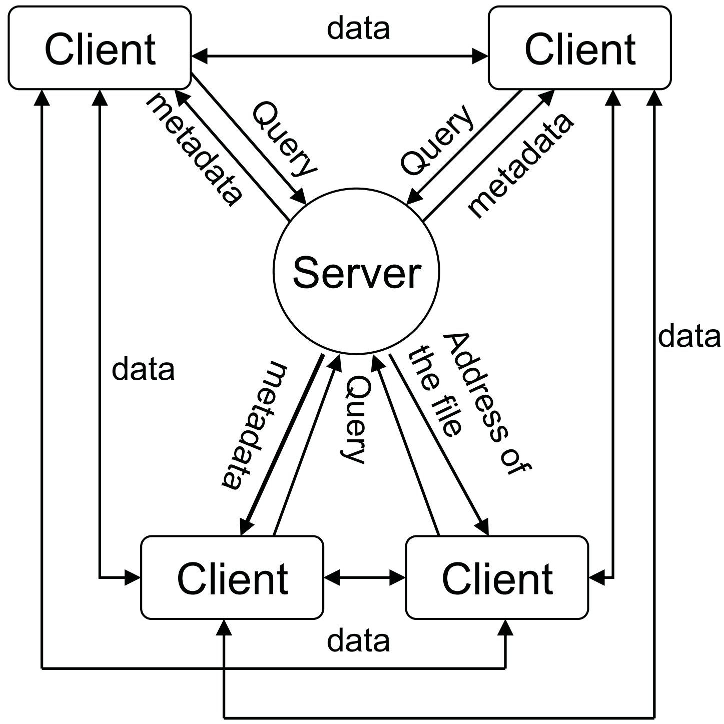

Figure 2.4: Napster Network

Those nodes will pass that request to other nodes they are connected to and also check if they have the file. However, this kind of search is very slow.

Fasttrack network is the third generation program and is represented in Fig 2.6 and some of the clients that connect to this network are Kazaa, and Grokster. Fasttrack is the most popular P2P network and it has features of super-nodes and high speed downloads [5]. Kazaa was introduced in March 2001 [7]. Currently, we have BitTorrent which is gaining it popularity as the download speed is very fast. It was introduced in July 2, 2001 [7]. It has a central server known as a tracker which is not required any more because of the use of Distributed Hash Tables (DHTs) in the BitTorrent protocol.

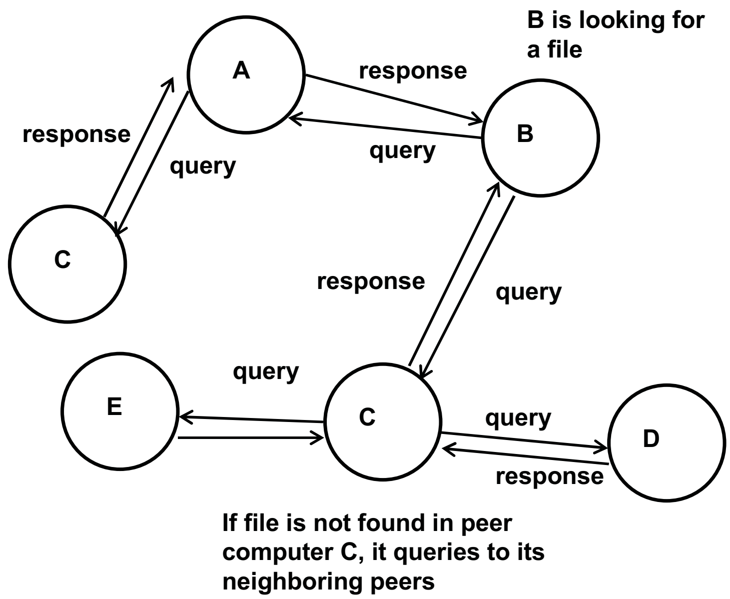

Figure 2.5: Gnutella Network

2.1.3 Architecture of P2P Network

P2P networks use different methods to keep track of the shared files and its distribution. Based on these various methods, there are three types of P2P architecture: Centralized, Decentralized and Structured, and Decentralized and Unstructured.

1. Centralized

   Centralized P2P network consists of a central server and clients as shown in Fig. 2.7. A node or the user will query for the data to the server and the server will provide that node with the list of other nodes or peer computers which have that data. Then, the querying node will try to connect with those nodes to download the particular file. The central server will help in setting up the connection and downloading. Since server is responsible for the existence

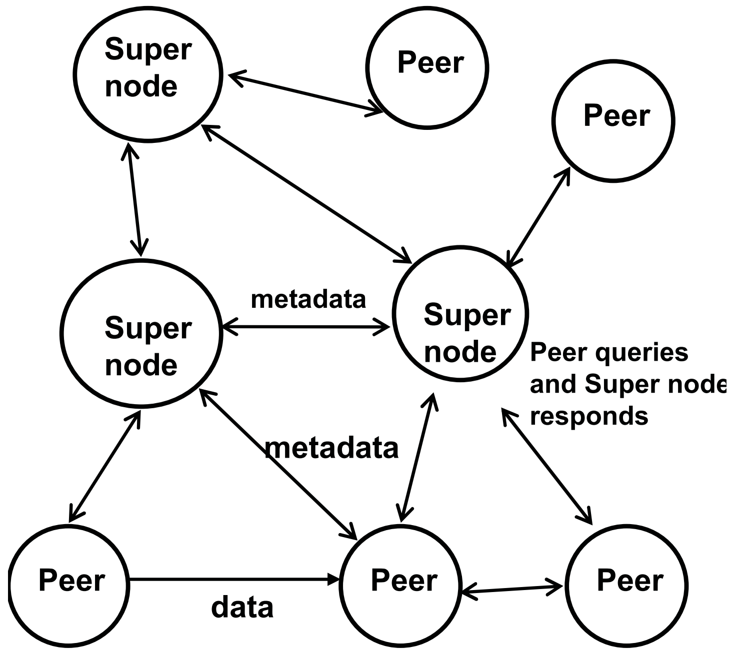

Figure 2.6: Fasttrack Network

of such a system, if the server fails, the whole network will fail. Napster is an example for Centralized P2P network.

2. Decentralized and Structured

   This type of network does not have a central server, which allows it to sustain even if one or more of the nodes fail. It is represented in Fig 2.8. The data or file shared has a unique identification and that identification can be used to trace the user or node which owns that file/data. It is very efficient in comparison to other types of networks. The P2P topology in this system is strictly controlled as the files are located in defined locations and are easily retrievable [3]. Freenet P2P is an example for Decentralized and Structured network.

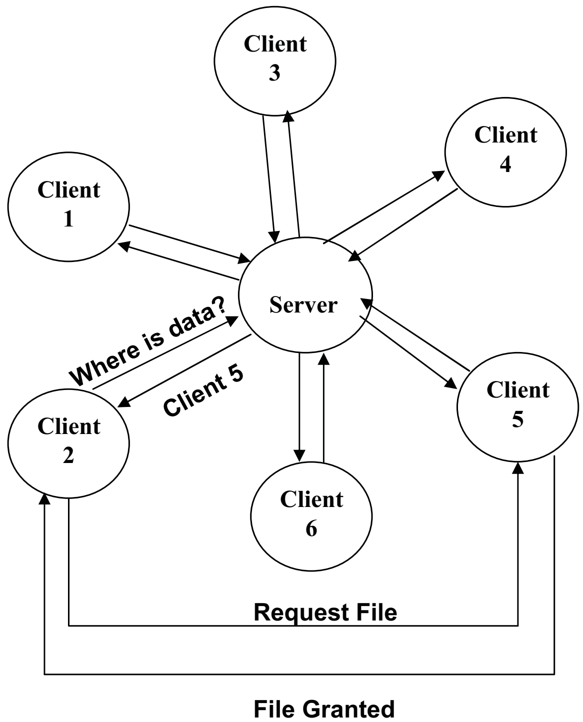

Figure 2.7: Centralized P2P Network

3. Decentralized and Unstructured

   This type of architecture also lacks a central server but may have multiple servers where the nodes or the users are arranged in a random way (i.e the topology is not structured). Flooding method is used for querying and the search is not efficient as the retrieval of the data is not guaranteed. It consumes high network bandwidth which is a drawback of such architecture. Fasttrack is an example for Decentralized and Unstructured P2P network.

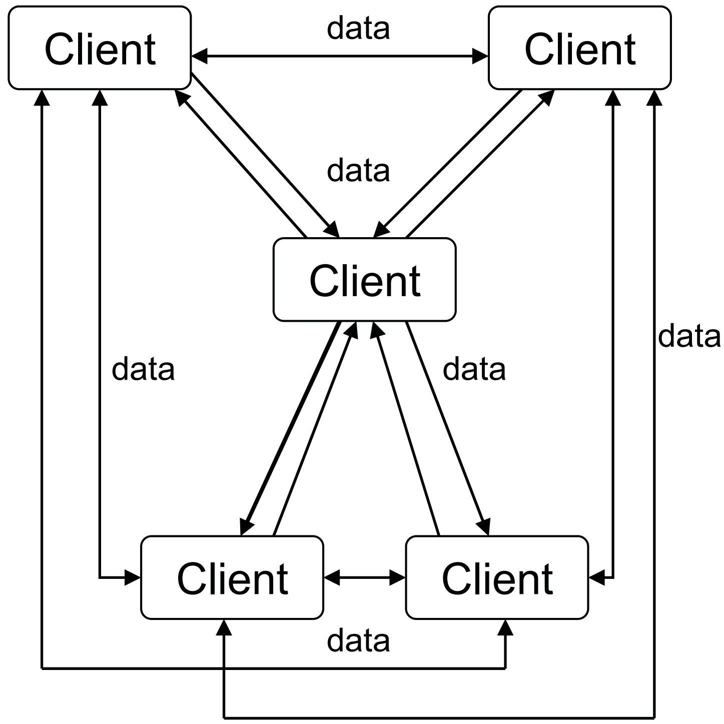

Figure 2.8: Decentralized P2P Network

2.1.4 Working Principle of P2P Network

In P2P networking, the P2P software should be installed in the user computer or the node. The examples of the P2P software are DirectConnect, Gnutellanet, KaZaA, eDonkey, iMesh, and Grokster. After installing the software, the program is launched. When the user searches for a file it wants to download, one or more IP addresses which are sharing the particular file are displayed. The user should then enter the IP address of the node or user in the same network it wants to connect to and when user with that IP is online, the connection is established [8]. The user can also connect to multiple users in the network. Hence, the file sharing allows the content of a computer in the network to other computers/nodes in the network. Another procedure could be that the P2P software will provide the user with a possibility to search for the file the user wants. The request is placed and the system attempts to discover other users who own the file and the results will be displayed. If the connection is established, file sharing process is possible.

2.1.5 Types of P2P Network

There are three types of P2P network based on the nature of the peer computers in the network; Pure P2P, Hybrid P2P and Mixed P2P.

1. Pure P2P

   Pure P2P networks do not have separate clients and server computers, but all the peers in the network act as clients and as server.

2. Hybrid P2P

   Hybrid P2P will have a central server. The information on peers will be stored in the server computer but it will not store the file. The peer computers should volunteer and provide that information about the files they want to share and download to the server computer.

3. Mixed P2P

   It consists of both the behaviors of Pure P2P and Hybrid P2P.

2.1.6 Advantages and Disadvantages

P2P network is used with different settings at home and at offices as well. For example, if some computers are connected and they share a printer, then it implements P2P networks. Similarly, people can access computers at work from home using P2P networking. If the number of computers in the network increases, bandwidth of the network increases. Hence, the network will have more storage space with more power. So, unlike client-server based network architecture, P2P system performance increases with an increase in the number of users in the network. In client server based networks, if the server fails then the system fails to function. But, the P2P system is robust as the failure of any node will not affect the whole network and the failed node can again get back into the network and access the data. Such networks have faster performance and are simple to set up. They are not expensive to maintain and a separate server computer is not required. It is simple to use and can be easily implemented by anyone.

One of the main fears of using P2P programs is security. In the process of sharing files, viruses and other harmful programs could be transferred to the users. Since the system is generally decentralized, it is hard to keep track of such files. Copyrighted materials might also be shared using P2P networks, which is illegal and also not secure. Searches should be done very carefully based on file names and the signatures. Since this system is not centralized, it is hard to keep track of the data and its owner node. Also, passwords are not required to share files, so the network link is not secure as server-client network.

2.1.7 Applications

P2P networks can be used in different fields. One interesting use is in Bioinformatics. They can be used to run large programs and analyze bulky data sets. There are also P2P search engines available for academic research such as Sciencenet. Application of P2P networks in sharing files and data is also getting very popular. One of the future applications can be search engines based on P2P. It can also be used in accessing remote resources like printers, scanners, modems and other accessories. Business can use P2P networking for distributing internal content and sharing data, which will lead to better performance and improved efficiency. P2Ps have also been applied in telecommunication network over the internet. Skype is an example of such a P2P application. BitTorrent is another example of P2P file sharing protocol over the internet and has gained huge popularity among users.

2.2 BitTorrent

BitTorrent is a file sharing protocol which is used for transferring or downloading files. It is a free software based on P2P network model. In this section, we will be discussing BitTorrent in greater detail.

2.2.1 Description

BitTorrent [30] is an unstructured centralized P2P file distribution communications protocol where the load is distributed among the users. A file can be downloaded by multiple users simultaneously from the internet using the BitTorrent sharing program.

Even if a user has an incomplete piece of a file it can be shared with other users, who can download different components of the entire file from different peers or sources. At the same time, they can share/upload the component of the file to other users in the network. In that fashion, all the users get the file from each other by contributing a piece of the file they have and taking the rest of the file they need from other users. Thus, BitTorrent helps for faster download of files without crashing the server when many users try to access a particular file at once. Such procedure of data distribution protocol applies to BitTorrent, where each recipient provides pieces of the data or information to newer peers, reducing the cost and burden on any given individual source. This provides redundancy against system complexity, and diminishes reliance on the original distributor.

2.2.2 Working Principle

Downloading files in the past was more problematic because files are centrally located in most of the network. If many people try to download a file simultaneously, servers will be overloaded and there is a high chance that the server will crash. As a result, no one will be able to access the file.

BitTorrent solves this problem by breaking the file into equal parts and randomly distributing it to the users in the network. BitTorrent is a very popular P2P file sharing protocol which is used for downloading files such as music, videos and software. For example, if there are users who want to download a book, BitTorrent will break the file or book into equal parts equivalent to a chapter and will distribute different chapters to different users in the network. In BitTorrent, when the users are downloading a file, they also upload pieces of the file to each other. All the users will have different piece of file or different chapters and they will exchange with each other to get the remaining parts of the file.

The decision to use BitTorrent is made by the publisher of a file. A file with the extension .torrent is placed on the web server. A .torrent file contains information about the file, its name, length, and the url of the tracker. Tracker has information about the peers who possess different parts of the file and it helps the downloader to find each other. The downloader sends information to the tracker about the file it is downloading, the port it is listening to, and the tracker replies with information about other downloaders who are downloading the same file. Downloaders use this information to connect with each other and exchange files or different chapters of the book.

The user (downloader) informs other peers in the networks about the pieces of the files he or she has. The peers in the network upload and download the files from other peers in the same network they are connected to. A user uploading and downloading a file who do not have a complete copy of the file is known as "Swarm." There are also peers who download files but do not upload files and are known as "Leechers." The download takes place in a tit-for-tat manner to ensure that the peers download and upload simultaneously. It increases the efficiency of the bandwidth, and the network system becomes better when the number of users increase.

The downloader tries to connect with the peers in the network by choking or unchoking. Choking is a signal that a Swarm peer is not intending to send the new user any data until the new user is unchoked. Data transfer takes place whenever one side is interested and the other side is not choking. Interested means that a swarm peer has data that a new user in the network does not have, and the new user wishes to acquire.

The interested downloader then connects to the other peers in the network using the information from the tracker and starts downloading. Once a peer completes downloading, all the components of the file (i.e. obtains all the chapters of a book), it possesses a complete copy of the file and it is known as a "Seed." Then, this file can be available to other peers. In this way, BitTorrent allows the user to download the file without overloading the server. Fig 2.9 below shows the P2P network implementing BitTorrent.

2.2.3 Algorithms

1. Choking Algorithm

   Choking algorithm is the strategy used to select peers in a P2P network. The choking algorithm avoids free riders by making sure the peer which downloads the file also uploads the file and ensures two way traffic of data transfer.

2. Rarest first Algorithm

   Rarest first Algorithm is the strategy to select a rarest piece first. In this strategy, all the peers have information about the number of pieces in their peer set and hence determine the rarest piece. Whenever a piece is added or

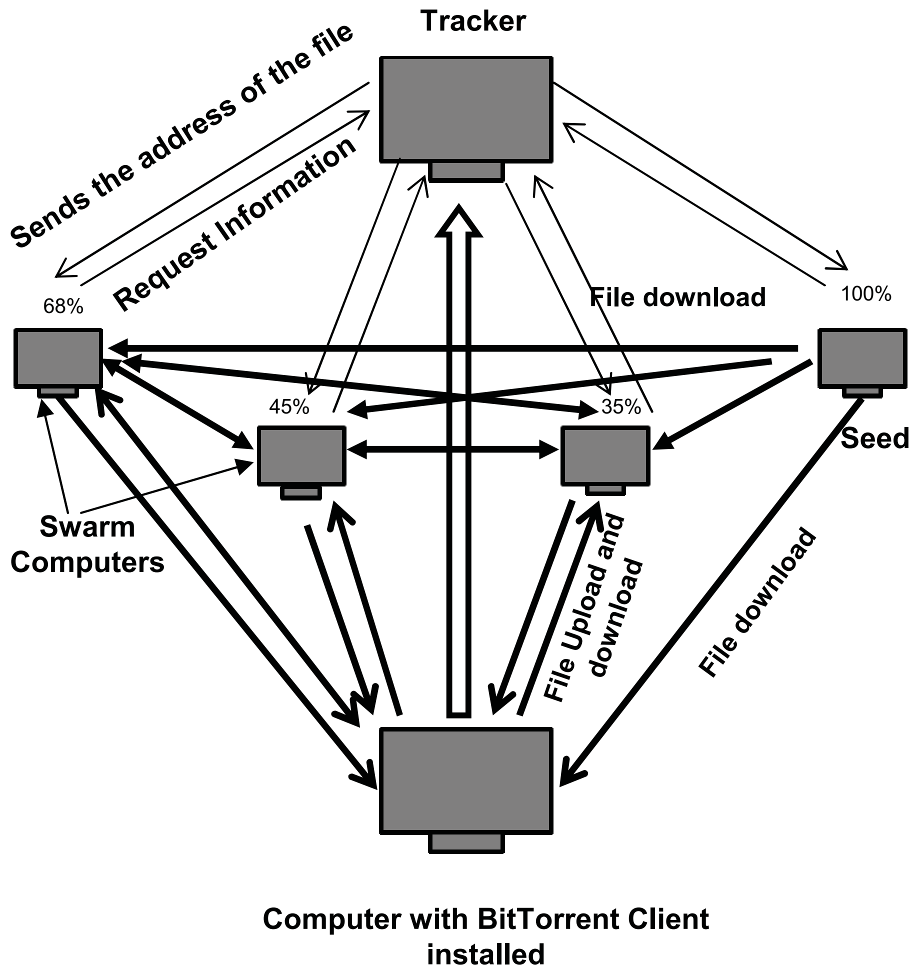

Figure 2.9: BitTorrent

removed from the peer set, rarest pieces set is updated. The steps are as thus [2]:

(a) First 4 pieces are chosen randomly.

(b) Then, it switches to rarest first algorithm.

(c) If a piece of a block has been downloaded then the remaining pieces will have high priority so that a piece is completely downloaded on time.

(d) After each block has been requested and the download has been completed, the requests to all the peers for that block are canceled.

2.2.4 Advantages and Disadvantages of BitTorrent

BitTorrent is getting very popular because of its following advantages:

1. It is free.
2. It has high speed for uploads and downloads.
3. It reduces the bandwidth burden on the distributor.
4. If the file is more popular, the download is faster.
5. A downloader is required to share/upload. One who does not share will not be able to download. This makes the system faster when there are many users in the network.

There are certain drawbacks to BitTorrent. Distributed nodes are greedy and they may not follow the protocol. The greedy peers might exploit fairness in different ways. Some of them can be retrieving the data from the seeds as seeds do not need any reciprocation. The presence of optimistic unchoke also allows greedy node to download from the fastest peers. They may also send fake pieces at a slow rate and receive valid piece [1]. This may also even lead to deadlock or starvation. So, we implement Game Theory along with BitTorrent.

CHAPTER 3

GAME THEORY AND BARGAINING

Game Theory was introduced by mathematician John Von Neumann. The interaction between two or more people or players where the decision of one affects the outcome of the other is termed as Game. Game Theory studies different actions that players use in a game producing different results depending on their decisions. Games can be cooperative and non-cooperative. In Cooperative games, players cooperate and communicate with each other by following a set of defined rules. Bargaining is an example of a cooperative game. But in non-cooperative games, players focus on achieving their own goals and do not communicate with each other.

In this Chapter, we will discuss Game Theory and Bargaining. Section 3.1 will focus on Game Theory including its definition, popular terms and the different types of Games. Section 3.2 discusses Bargaining and explains its types and solutions. Section 3.3 discusses Optimization.

3.1 Game Theory

3.1.1 Introduction

Game Theory developed in the latter half of the twentieth century. Game theory is a branch of applied mathematics and economics where two or more parties or agents are involved. These agents bargain using structured methods or strategies to maximize their utilities [17]. Utility is the satisfaction a consumer attains from the use or consumption of any economically beneficial good or service. The interaction between agents using their strategies results in different utility payoffs with varying action. This interaction is termed as "Game" and the agents involved are termed as "Players" [18].

The essential elements of a game are players, strategies, and payoffs. Other elements are actions, outcomes, information, and equilibrium. A player is a person who makes decisions and his objective is to maximize his utility by taking certain moves or actions. Action or move is an option that a player can choose. Strategy is an instruction which helps him to decide which action to take with information provided so that he can attain maximum benefit. Information can be the knowledge about the previous actions of the other player. Payoff is the utility that a player achieves after the game has ended. The outcome of the game is the set of payoffs.

Game Theory is used in many fields such as biology, business, gambling, artificial intelligence, and many more. It can be used to study the past behaviors of the players or the system and investigate the problem. For example, in business, a company producing different kinds of components of a computer can use Game Theory to forecast which of their product will be in high demand in the future using past records. If they find out that focusing on either "microprocessors" or on"memory" might be a lot more profitable, then they can set some strategy ahead of their competitors. However, these strategies require players to be very alert and careful throughout the game. In the field of artificial intelligence, robots are preprogrammed to carry out certain actions based on different situations. But, if it comes across a new condition, the robot cannot make decisions for such conditions. So, Game Theory can be used to create a program which will make decisions based on past events and make robots work on learning algorithm.

3.1.2 Terms Used in Game Theory

- Pareto Efficient

  The outcome of the game where no other way of rearranging actions will be better off without decreasing the utility of one of the players and making him or her worse off [19]. It is also known as Pareto Optimal. For example, if a player, say Microsoft, launched Internet Explorer and it is the only one used all over the world, then its outcome will be Pareto Efficient since it is impossible to make other players - say Firefox Mozilla - better off without taking away users of Internet Explorer and making Microsoft worse off.

- Dominant Strategy

  A strategy that a player chooses and it is its best move to any strategy that other players might pick (i.e whatever strategies the other players pick, his payoff is highest with the chosen strategy is known as dominant strategy). Prisoner's Dilemma is an example of Dominant Strategy, which arises in different situations like auction bidding or salesman trying to sell goods.

- Prisoner's Dilemma

  A popular yet simple game is the Prisoner's Dilemma which is the most studied example. It is a two person game. In such a game, the premise is that two conspirators, A and B, are arrested. We assume that there is no communication between the prisoners. They are interrogated separately, and told the outcome depending upon their actions. If both deny, then both will be sentenced to jail for one year. If one confesses and accuses the other for the crime, then the outcome for the person not confessing will be lower. So, the convict who collaborated with police will go free and the other will be sentenced to jail for 6 years. If A accuses B, and B doesn't confess then A will be freed while B will be sent to prison and vice versa. If each convict confesses the crime and accuses the other, then both will be sent to prison for three years. So, the strategies involved in this example are confessing and denying. Table 3.1 illustrates the outcome matrix for their actions and it is also known as payoff table. (A, B) represents the payoff of A followed by the payoff of B.

- Nash Equilibrium

  Named after John Nash. It is an equilibrium state when change in strategy by any one of the players would lead that player to be at a disadvantage than if

Table 3.1: Prisoner's Dilemma (Normal Form)

Prisoner B			
		Confess	Deny
Prisoner A	Confess	(A, B) (3years,3 years)	(A, B) (0 year ,6 years)
	Deny	(A,B) (6 years,0 year)	(A,B) (1 year,1 year)

the player remained in his/her current state. For prisoner's dilemma, if both players confess, it is the Nash equilibrium.

- Subgame Perfect Nash Equilibrium

  A subgame consists of branches that come from a point. Subgame Perfect Nash Equilibrium is an equilibrium state that comprises Nash Equilibrium for an entire game and for every subgame. Subgame is a game with a node that knows every past move of the players involved.

- Normal and Extensive Form

  A normal form is a representation of a game by using a table. For example, Prisoner's Dilemma has been represented in a table form in Table 3.1 with the payoffs for different strategies. An extensive form represents a game in a tree diagram. In a tree diagram, the game begins at some node and it passes through different states. The path followed depends on the decision of the players. When a player makes a decision, it is represented by a decision node. Each branch represents the decision point or decision node. As a player continues to choose paths depending on the decision, he reaches a point where the game ends which is known as terminal point. An example of the extensive form can be represented through competition between two mobile companies, "NTCP" and "UTLP". "NTCP" is an older company that has been in the city for a while whereas "UTLP" is a new company trying to compete with "NTCP". NTCP has two options. One is to lower its charge for its customers so that it will drive away UTLP; the other option is to reduce the number of phone lines and provide that their prices are constant. This provides some space for UTLP. For example, 10 is the maximum payoff. If UTLP launches and NTCP shares the market, the payoffs of NTCP will be 5 and of UTLP will be 3. If UTLP doesn't launch, the payoff of NTCP will be 10 and of UTLP will be 0. If UTLP launches and NTCP goes for price decrease, the payoff of NTCP will be 2 and of UTLP will be -5. Fig 3.1 represents this extensive form.

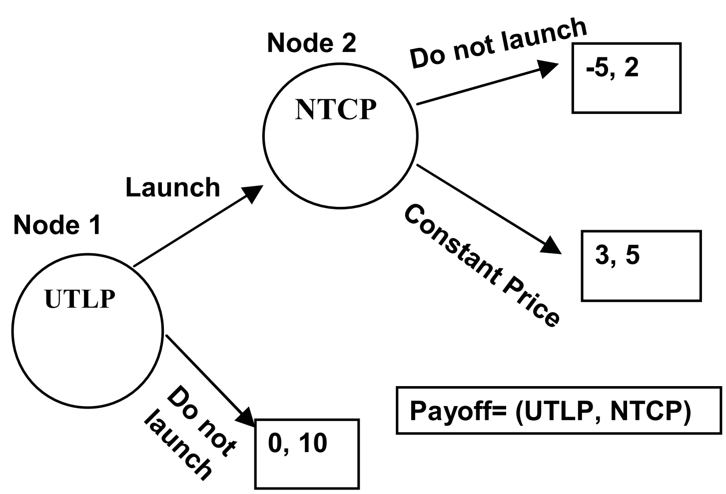

Figure 3.1: Extensive Form

3.1.3 Types of Games

Non-cooperative Game

A non-cooperative game is when the players do not cooperate with each other and are not allowed to communicate before the game starts. The players play for themselves with the sole purpose to achieve their personal goal. We cannot determine the best choice for strategies because there is no unique solution. A simple example of non cooperative game is a football match where both teams are focused on their own advantage.

Repeated Game

If the players play the same game multiple times, it is called a repeated game. Strategy depends on the outcomes of the games (i.e. a player's behavior will be noticed by opponents and considered while making decisions on the next round of the game). For example, there is customer "A" and a salon master "B." The customer can either have a haircut from B once a month or not have a haircut. The salon master B may give a nice haircut or mess it up. So, if A goes for a haircut and B messes it up, A will have a pay off of -1 and B will have a payoff of 3. If B gives a nice haircut, both have a payoff of 2. If A doesn't go for a haircut, the payoff of both is 0. The payoff of 0 is better than payoff of -1, so A will prefer not to have hair cut. The repeated game is represented in Fig 3.2.

If A will have a haircut assuming B will give a nice haircut, there is chance that A will have a haircut from B for several times - say 10 times - and see how B does

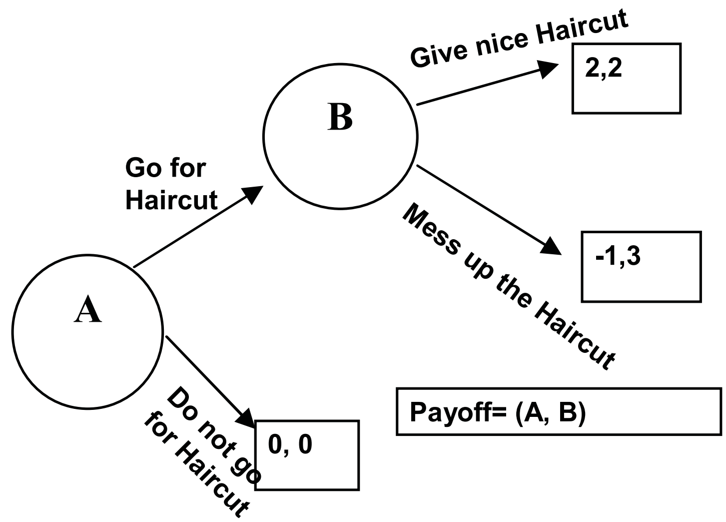

Figure 3.2: Repeated Game

his job. If B messes up a haircut, A will not go for haircut next month to punish him or suggest him to do the job properly before he goes for a haircut again. This is a repeated game.

Cooperative Game

Cooperative game is a game in which the players can communicate with each other to make binding agreements. These agreements can be either to coordinate with each other or to share the payoffs. An example of cooperative game is bargaining where the players can end up in either a complete or a partial agreement and both of them are satisfied with the end results.

Let's assume that there are two people named Kamala and Bimala. Kamala has a video game system but she wants to sell it for 150 dollars and Bimala has 200 dollars and wants a video game system. So, both of them will either keep what they have

	Kamala (has video game of value 150)	
Bimala (has cash $200)	Give	keep
Give	Bimala, Kamala 230,170	Bimala, Kamala 30,320
keep	Bimala, Kamala 400,0	Bimala ,Kamala 200,150

Figure 3.3: Cooperative Game

or give what they have and take what they need. If Kamala gives her video game to Bimala and Bimala gives her 170 dollars, then Kamala has 150 dollars and 20 dollars extra whereas Bimala has the video game system and 30 dollars. The payoff table is shown in Fig 3.3.

If both Kamala and Bimala keep what they have, then it is dominant strategy equilibrium. However, if both give what they have, they are better off and result in cooperative solution.

3.2 Bargaining

3.2.1 Definition

Bargaining is the negotiation of goods or services carried out between two or more players. These players can be buyers or sellers who try to come to an agreement for the distribution of the objects. One example of bargaining would be the negotiation of wages between the employees and the employer.

Let us consider an example. If “A” knows that “B” wants to sell a laptop for 600 dollars and B knows that A is willing to pay 800 dollars, then the bargaining would be to divide 200 dollars. So, the strategy of each player is important and the outcome depends on each player’s belief about what price his/her opponent will negotiate. If the transaction takes place at a price between 600 dollars and 800 dollars, then both players A and B are better off. Simultaneously, A will try to trade at a lower price while B will try to trade at a higher price; this conflicting situation in trade introduces bargaining. Most of the time, bargaining is time consuming as the players make offers and counteroffers.

For bargaining theory, appropriate solution depends extensively on available information and negotiation arrangements. If the solution is inappropriate, then the results will be misrepresented.

3.2.2 Bargaining Solution

Bargaining solution is the way in which the players divide the outcome. A Bargaining Solution is mathematically given as,

$$F : (X, d) \rightarrow S \tag{3.1}$$

where $X \subseteq R^2$ is a compact, convex set, and $S, d \in R^2$.

X is the set of possible utilities at different bargaining agreement points and d is the disagreement point.

3.2.3 Types of Bargaining Solutions

Nash Bargaining Solution

Nash Bargaining problem involves two players who will coordinate with each other for mutual benefit. An example of bargaining problem will be the negotiation of wages between employer and employee trying to come to an agreement or solution point. The solution is determining the amount of satisfaction each individual should achieve after negotiation.

In Nash Bargaining, players offer their prices and will try to negotiate on a certain amount. Player "A" will make an offer and player "B" may accept the offer or may make a counter-offer. If player "B" accepts the offer, the transaction takes place otherwise the game will continue with new offers until one of the players accepts the other player's offer [15].

For a two person game, we define a pair (a, S) where a is a point in the plane and S is a subset of the plane. And, $a = (a_1, a_2)$ where a_1 and a_2 are the pair of utilities that player 1 and 2 receive if they do not cooperate and $x = (x_1, x_2) \in S$ represents utility levels for players 1 and 2 when they cooperate. A solution to the bargaining problem is a function $f : U \to R^2$ such that $f(a, S) \in S$. For a pair $(a, S) \in U$, let bargaining pair $b(S) = (b_1(S), b_2(S))$ be defined as

$$b_1(S) = sup\{x \in R : for\ some\ y \in R\,(x, y) \in S\},$$

$$b_2(S) = sup\{y \in R : for\ some\ x \in R\,(x, y) \in S\}.$$

Let $g_s(x)$ be a function defined for $x \leq b_1(S)$ as

$$g_s(x) = \begin{cases} y \; if (x,y) \; is \; the \; Pareto \; of \; (a,S), \\ b_2(S) \; if \; there \; is \; no \; such \; y. \end{cases}$$

Nash Bargaining Solution should satisfy the following four axioms:

1. Pareto optimal: A Pareto Optimal solution is the one where a player cannot increase his/her payoff without decreasing the payoff of the other player(s).

2. Invariant to affine transformation: NB(S) is invariant even if the utility is multiplied by a positive constant. Affine transformation is $\tau_{AB} : R^2 \rightarrow R^2$ where A is a matrix and B is a vector of the form:

$$A = \begin{pmatrix} a_1 & 0 \\ 0 & a_2 \end{pmatrix}, B = \begin{pmatrix} b_1 \\ b_2 \end{pmatrix} \tag{3.2}$$

   The transformation can be defined as

$$\tau_{AB}(x) = Ax + B \tag{3.3}$$

   A bargaining solution is invariant to affine transformation iff $\forall A$ and B, if

$$F(X,d) = S \tag{3.4}$$

   then

$$F(\tau_{AB}(X), \tau_{AB}(d)) = \tau_{AB}(S) \tag{3.5}$$

3. Symmetry: The bargaining solution is symmetric if the utilities of the players ensure symmetric payoffs. Let x and y be the utilities for the players which satisfies the following conditions:

$$
\begin{aligned}
x + y &\geq 2, \\
x &\geq 0, \\
y &\geq 0, \\
d &= (0, 0) .
\end{aligned}
$$

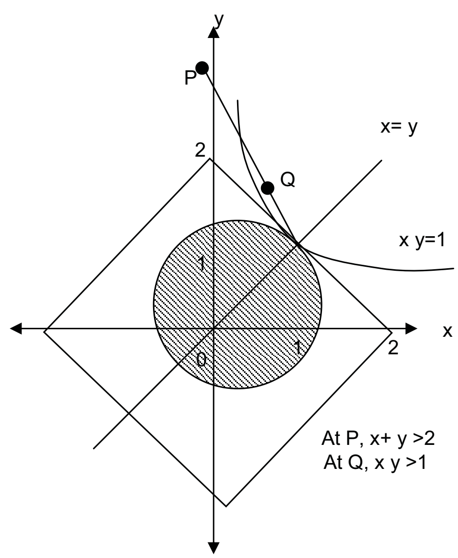

Figure 3.4: Symmetry [16]

Let us construct a square in region which is symmetric in line x=y as shown in

Fig. 3.4. So, the bargaining solution will be $(1, 1)$.

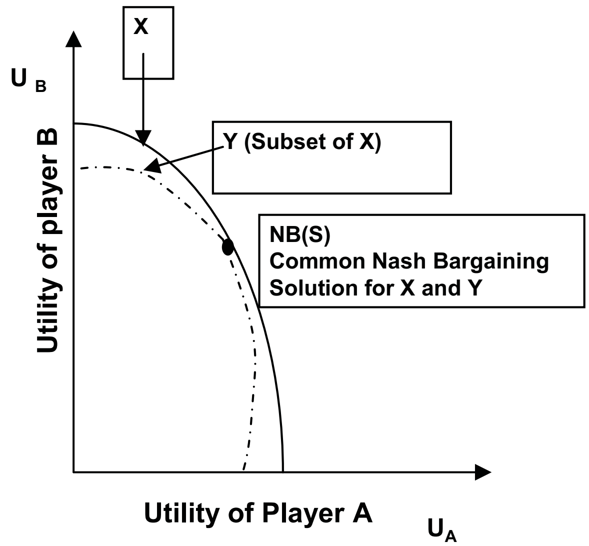

Figure 3.5: Independence of the Irrelevant Alternatives

4. Independence of the Irrelevant Alternatives: Let S be the Nash bargaining solution for bargaining set X, and Y be the subset of X that also contains S. S will be the Nash Bargaining Solution of Y as well. It is represented in Fig 3.5.

$$F(X, d) = S$$

$$Y \subset X$$

$$S \in Y, d \in Y,$$

$$then,\ F(Y, d) = S.$$

Kalai-Smorodinsky Bargaining Solution

Nash solved the two person bargaining problem. The result of Nash is that there exists a unique solution to the bargaining problem under certain axioms. He used the axiom "Independence of Irrelevant Alternatives" but it failed to consider important features of the bargaining sets. The fourth axiom of Nash bargaining solution is the main point of controversy because it is not always true [21]. Consider the two normalized pairs $(0, S_1)$ and $(0, S_2)$ as shown in fig 3.6 [21] where

$$S_1 = convexhull\left\{(0,1)\,,(1,0)\,,(0.75,0.75)\right\} and \tag{3.6}$$

$$S_2 = convexhull\left\{(0,1)\,,(1,0)\,,(1,0.7)\right\} \tag{3.7}$$

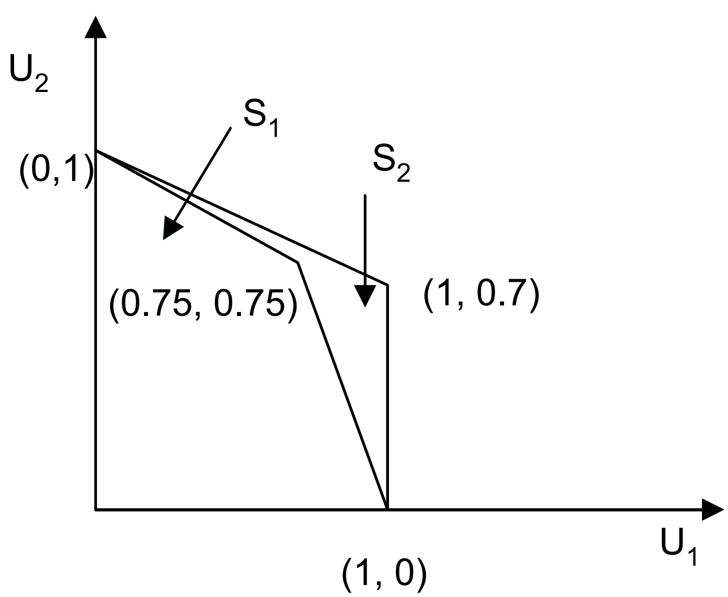

Figure 3.6: Nash Bargaining Solution [21]

Nash's solution of $(0, S_1)$ is $(0.75, 0.75)$ and of $(0, S_2)$ is $(1, 0.7)$ [21]. It doesn't satisfy player 2's demand. So, they suggested an alternate axiom, "Axiom of Monotonicity."

Axiom of Monotonicity

If (a, S_1) and (a, S_2) are bargaining pairs such that $b_1(S_1) = b_1(S_2)$ and $g_{s_1} \leq g_{s_2}$, then $f_2(a, S_1) \leq f_2(a, S_2)$ [21].

This axiom statement states that for every utility level that player 1 may demand, the maximum feasible utility level that player 2 can simultaneously reach is increased, then the utility level assigned to player 2 according to the solution should also be increased [21].

So, Kalai and Smorodinsky [21] modified the fourth axiom of Nash using monotonicity axiom [20]. If the set S is increased so that the maximum utilities of the players remain unchanged, then the players will not suffer from it.

Consider an ideal point I(S) where both players A and B will have maximum utilities. We can get the Kalai-Smorondinsky solution K(S) at the point where the line joining the ideal point I(S) and origin meets S as shown in Fig 3.7.

E. Kalai and M. Smorodinsky introduced an alternate solution by replacing Independence of Irrelevant Alternatives by the appropriate monotonicity condition. The solution they proposed maintains the ratios of maximum gains. If G_1 and G_2 be the maximum gains of players A and B, then the Kalai-Smorodinsky bargaining solution will result in point S such that

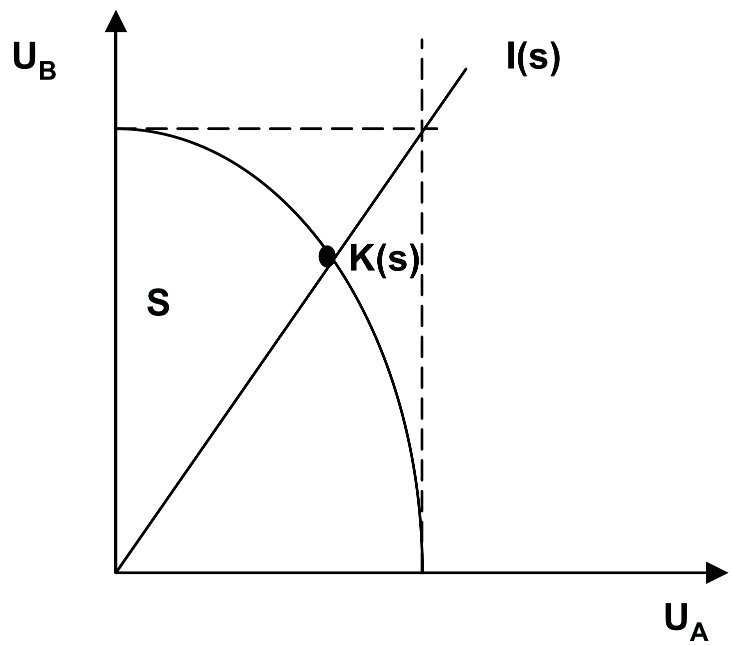

Figure 3.7: Kalai and Smorodinsky

$$\frac{S_1}{S_2} = \frac{G_1}{G_2} \tag{3.8}$$

If cooperative bargaining theory is related to the process on how agents bargain, then the axioms used by Kalai and Smorodinsky are more suitable than those by Nash.

Egalitarian Bargaining Solution

Egalitarian solution is a solution for cooperative games which was introduced by Dutta and Ray. They used Egalitarian solution to locate unique solution for a game. Egalitarian solution combines the concept of utility maximization and social goal of equality. For example, if there are x number of shareholders in a company ABC, surplus is shared among the shareholders after all the non labor costs are paid. Let y be the number of shareholders who left the company and started a new company where $y < x$. Since, the rule has already been made about dividing the surplus; y members will still get a certain portion of the surplus. So, the rule applies not only to the main company "ABC" but also to its deviating subsets of companies.

Egalitarian solution includes Independence or irrelevant alternatives and monotonicity and excludes scale invariance. This solution provides equal gain to both players [22].

3.3 Optimization

We know that in BitTorrent, there is high chance for the peer computers to exploit fairness. Bargaining, from Game Theory, introduces fairness in the game among the users resulting in different solutions depending on the strategy of the individual player. Using optimization, we can obtain the best solution.

Optimization is a process where the best solution (optimal solution) to a problem is calculated. Optimization problems arise in various disciplines. For example, a civil engineer constructing a bridge must choose materials and quantity for different components of the bridge so that the structure is safe and economic. The objective of the civil engineer will be to minimize the cost. But, he/she will also have to meet the standard requirements for safety which are his/her constraints. He/she will have to consider the design variables that affect his/her objective as well. The design variables can be the height and width of the bridge which affects safety requirement. To formulate an optimization problem, he/she needs to choose an objective function. He/she then needs to select the optimization variables, and finally identify the constraints.

We shall consider an example related to diet nutrients. Let us assume that the minimum daily diet is 8 units of Calcium, 19 units of Vitamins and 7 units of proteins. We define a diet to contain x units of asparagus and y units of apples. For a diet to satisfy minimum requirement, it must have

$$\begin{aligned} 3x + y &\geq 8, \\ 4x + 3y &\geq 19, \\ x + 3y &\geq 7, \\ x &\geq 0, \\ y &\geq 0. \end{aligned}$$

It represents the constraints. If the unit cost of asparagus is 5 and of apples is 2, then the cost of particular diet will be

$$C = 5x + 2y. \tag{3.9}$$

The diet which minimizes C is called optimal feasible diet and is the objective function where x and y are variables.

So, the standard form of optimization problem is given as

Minimize an objective function,

$$x_o = f(X) = f(x_1, x_2). \tag{3.10}$$

Subject to

$$g_1(x) \leq 0, \ \textit{inequality constraint}$$

$$h_1(x) = 0, \ \textit{equality constraint}$$

$$x_{iL} \leq x_i \leq x_{iU}, \ \textit{Bounds on optimization variables}$$

If the objective function is subject to constraints then it is known as constrained optimization problem. But, if an objective function is not subject to constraints, then it is known as unconstrained optimization.

3.3.1 Scope of Optimization

One of the important tools of optimization is linear programming. Linear programming problem is represented by a linear function which has to be optimized, i.e., either maximized or minimized and is subject to the constraints. These problems are solved using Simplex method.

Integer programming gives the solution of such optimization problems in which some of the variables are integer values. There are some problems which can be divided into different parts and we can optimize the decision processes. By optimizing the different parts, sometimes it might be possible to obtain an optimum for the original problem. This kind of decomposition process is very efficient, since it allows one to solve a series of smaller problems rather than one larger problem. Such process of solving larger problems use dynamic programming.

In many optimization problems, we cannot always assume linearity as there exists nonlinear problems as well. The technique used to solve these kinds of problems is known as nonlinear programming.

CHAPTER 4

WIRELESS ACCESS IN VEHICULAR ENVIRONMENTS TECHNOLOGY

4.1 Vehicular Communications

Wireless vehicular communication facilitate the exchange of information among vehicles and other support systems through internet wireless connection. It is an emerging technology which provides safety and efficiency in transportation systems. There are two types of devices involved in vehicular communication; Roadside Units (RSUs) and On-Board Units (OBUs).

An RSU is a device that operates at a fixed position whereas an OBU is a mobile device in vehicles that supports information exchange with RSUs and other OBUs. RSUs and OBUs communicate with each other. For example, traffic congestion, safety, and accidents are shared and transferred among different OBUs. Both types of these units are Dedicated Short Range Communications (DSRC) devices and operate at frequencies of 5.8/5.9 GHz.

Vehicular network, also known as Vehicular Ad hoc Network (VANET), is a Mobile adhoc network, which provides communication between the devices. One of the most common vehicular networks application exchanges information on accidents, warnings, traffic congestion, speed limits, etc to provide safety in traffic system. It can also be used for electronic toll and parking payment. Other applications include finding information about different services; gas station, rest areas, accessing maps, surfing web and sending emails. A vehicular communication network was developed under Intelligence Transportation System (ITS).

4.2 Intelligent Transportation System (ITS)

As traffic congestion increased, the number of fatal accidents have also increased. Most of these accidents are due to the carelessness of the driver. For example, the driver might be busy looking at their GPS without paying attention to a stop sign which creates higher chances of accidents. In order to reduce these accidents, ITS has been working on developing new services to improve safety. ITS is the combination of different types of technologies implemented in transportation to provide secure and well-organized transportation system. Some of the technologies implemented are wireless communications, programmable logic controllers, software applications, and sensing technologies. Currently, wireless communication using DSRC has been proposed for ITS and it is being promoted by the ITS.

4.3 Dedicated Short Range Communications (DSRC)

Dedicated Short Range Communications (DSRC) is a short to medium range wireless communication which operates between 5.850 to 5.925 GHz band. The bandwidth of DSRC is 75 MHz based on line of sight of 1km with maximum speed of 140km/hr. DSRC provides high rate of data transfer and is useful in situations where delay is not acceptable. For example, a person has an important meeting at his office. If there is an accident on his driving route then it be very likely that traffic congestion will be very high and he will not be able to attend the meeting. However, if he gets information on the accident beforehand, he would be able to take a diffferent route and get to the office on time. DSRC has many other applications. It can be implemented for safety purposes to reduce traffic accidents, to improve the traffic flow, and to provide internet access and file downloads. Wireless Access for the Vehicular Environment (WAVE) is the wireless communication component of DSRC and together, they provide architecture for vehicular networks. Fig 4.1 shows the DSRC Channel Allocation.

DSRC spectrum is divided into seven 10 MHz channels as shown in Fig 4.1. The data rate ranges from 6 to 27 Mbps per channel [23]. For the time being, channel 184 is planned for public safety and channel 172 for communications using High Availability and Low Latency (HALL). Table 4.1 provides information on FCC designated DSRC channels. Channels 172, 174, 176, 180, 182, 184 are service channels and channel 178 is the control channel. The control channel creates a connection between RSU and OBU. The control channel will also help connect OBUs with one another. RSU and

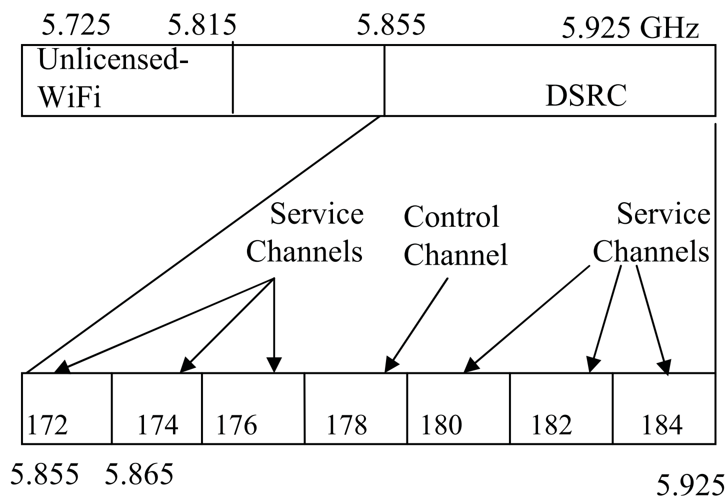

Figure 4.1: DSRC Channel Allocation [24]

OBU cannot transmit messages simultaneously, so DSRC is half-duplex. The RSU and OBU can send messages only when the channel is confirmed to be idle. If the channel is busy, RSU and OBU need to wait and if the channel is idle, then RSU or OBU will send the signal “Request to Send” to control channel. The control channel will allocate the channel on the basis of high priority first followed by low priority. The high priority messages are those messages related to public safety.

4.3.1 Elements in the Architecture

We will be discussing on the architecture of DSRC-WAVE, which is based on IEEE draft standards.

Table 4.1: FCC Designated DSRC Channels [25]

Channel Number	Channel Use	Frequency (MHz)
170	HALL Channel	5850-5855
172	Service Channel	5855-5865
174	Service Channel	5865-5875
175	Service Channel	5865-5885
176	Service Channel	5875-5895
178	Control Channel	5885-5895
180	Service Channel	5895-5905
181	Service Channel	5895-5915
182	Service Channel	5905-5915
184	Service Channel	5915-5925

On-Board Units (OBUs)

On-Board Units (OBUs) are located on the vehicles and act as a transmitter and a receiver. OBU is a part of On-Board Equipment (OBE) [26]. OBE consists of a processor, interface with vehicle services, human machine interface, GPS and the diagram is shown in Fig 4.2. OBU helps the vehicle to communicate with other vehicles or with RSU. The information is exchanged using communication links and DSRC is used as short distance communication technology. The OBU will collect data and store it in memory. It will then be sent to RSU. The rate at which the data is collected depends on the storage size of OBU and the size of communication link. In V2V communication, OBU will transmit data related to the status of the vehicle to other OBUs within its range at certain time intervals. Similarly, other OBUs will also send data to this OBU. The content of the data that the OBU sends has not been determined yet but it may contain ID, time, message type, and location.

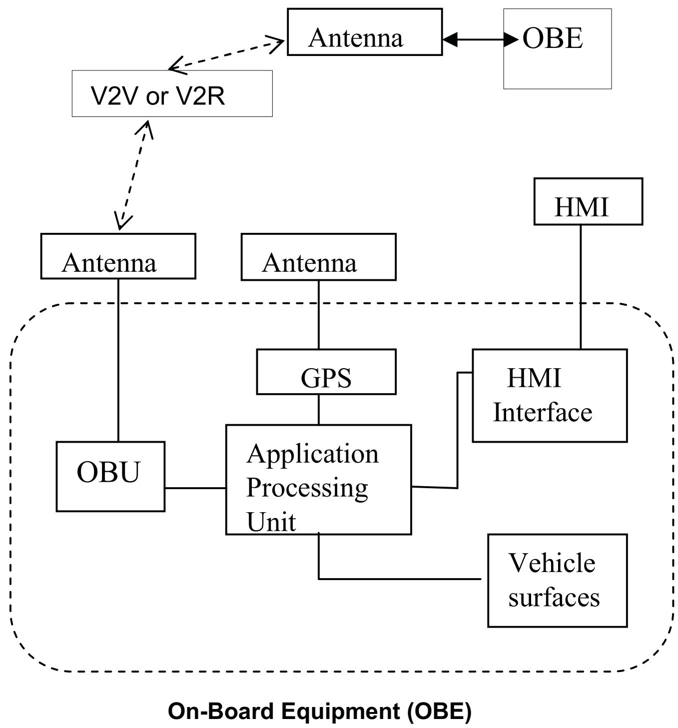

Figure 4.2: On-Board Equipment (OBE) [26]

Roadside Units (RSUs)

Roadside Units (RSUs) are usually stationary. They are distributed at different locations to collect data. They are usually located at intersection points with high risks of accidents, and other strategic locations. RSUs could be linked to the traffic system for sending warning messages to road side displays. An RSU sends and receives messages from the OBUs that are within its range. RSU transmits the Provider Service Table (PST) to OBU. The information on the application that RSU interacted with is contained in PST. These applications can be safety applications in highways or intersections. The safety application would warn the drivers about the condition of the road ahead such as if there is construction going on, if the road is slippery, or if there is an accident or emergency vehicle warning ahead. Fig 4.3 represents the communication between RSUs and OBUs.

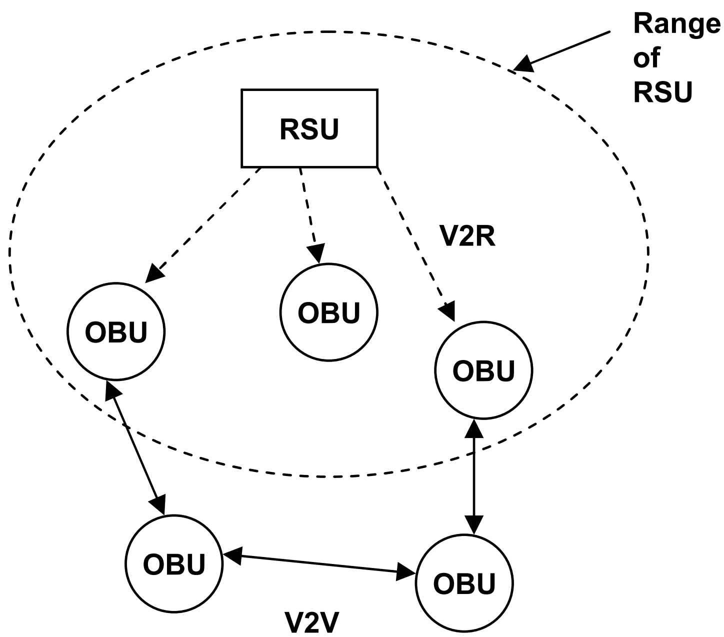

Figure 4.3: RSU and OBU Communication

Telecommunication Network

A switching circuit is used to distribute the load of data transfer to avoid data-overload.

4.3.2 Types of Vehicular Communication

Vehicle-to-Vehicle (V2V) Communication

V2V communication implements Dedicated Short Range Communication (DSRC) to transmit data from one vehicle to another vehicle through OBU. In V2V, communication, OBU should send information about its status to other vehicles within its range and OBU will also receive information about other OBUs. It also uses a GPS system, along with wireless technology, to provide warnings on potential dangers so that the operator can take caution.

An example for V2V communication would be an electronic brake application which sends an alert to the driver to slow down when another driver ahead brakes suddenly. Referring to the Fig 4.4, if vehicle 1 applies brakes to his car immediately, the vehicle behind it sees and can brake immediately. However, the vehicle behind 2 (vehilce 3) will not have information about the condition of the vehicle 1. Vehicle 3 will only react after vehicle 2 applies the brakes. Hence, there is a delay and there is high possibility of accident. V2V communication will allow a vehicle to send information to multiple vehicles. Here, vehicle 1 can send information to vehicle 2, 3 and 4 that brakes are suddenly being applied so that they can take action to prevent a possible accident.

Vehicle-to-Roadside (V2R) communication

Vehicle-to-Roadside (V2R) communication uses Dedicated Short Range Communication (DSRC) to transmit data from one vehicle to a fixed infrastructure on the road.

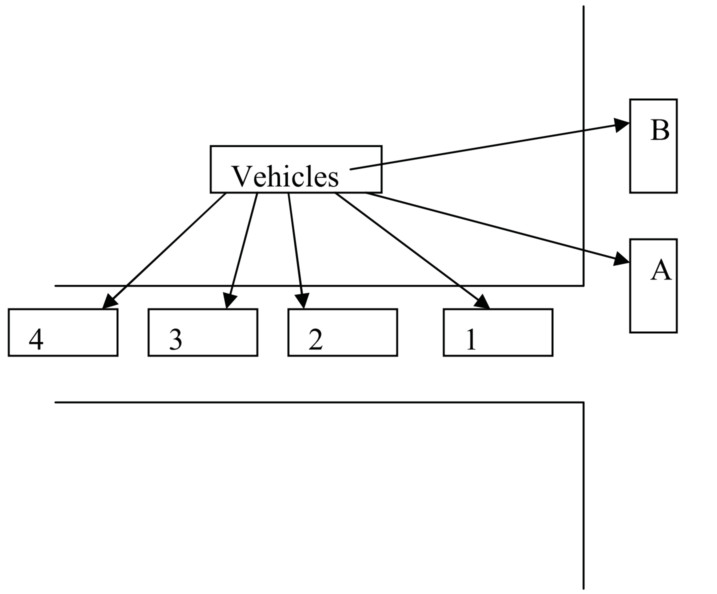

Figure 4.4: Electronic Brake Application

The vehicle transmits or receives messages through OBU whereas the infrastructure transmits and receives messages through RSU. It is primarily used for the security applications such as road bend warning, road conditions, etc.

An example of V2R communication would be a road bend warning as shown in Fig. 4.5. If there is an accident at the end of the curve, another passing vehicle cannot see it. But, with the application installed, the vehicle that was involved in the accident will send a message to an RSU in its range. This RSU will transmit information to a server nearby. The vehicle passing these RSUs prior to the curve gets information about this accident. It provides the driver with the opportunity to take necessary precaution.

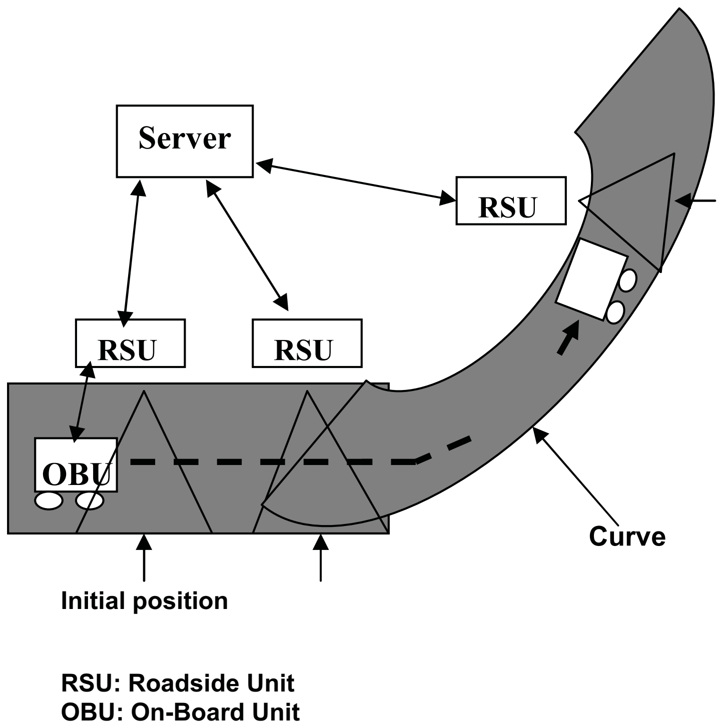

Figure 4.5: Curve Detection [25]

Communication between OBUs and RSUs

When an OBU on the vehicle detects any RSU within its range, it will exchange data with that RSU. In this way, RSU collects data from OBUs and RSU will forward the data to a switch. The switch works like a router, which will distribute the information throughout the network. This data can be stored and later accessed by other vehicles.

RSU will send messages using PST to all the OBUs in its range via DSRC channel 178. OBUs will send a reply back for some information on a particular application that it has. For example, if the "Sharp road turn detection" application is existing in an OBU, and RSU supports that application, RSU will connect to a security system which will find the necessary information. RSU will then transmit the data to an OBU on the vehicle and the driver receives the information about the curve beforehand.

4.4 Wireless Access for the Vehicular Environment (WAVE)

Wireless Access for the Vehicular Environment (WAVE) is a communication standard used in inter-vehicular communication. It is only a part of a group of standards of protocols for DSRC. There are teams working to control traffic congestion, avoid collision, provide weather, and temperature information. The vehicles can communicate with each other to exchange this information. The research work in 802.11 from IEEE working on these features is known as "Wireless Access for the Vehicular Environments." IEEE 802.11 is a set of standards defined for Wireless Local Area Network (WLAN) computer communication and WAVE technology will come under 802.11p. The main objective of WAVE is to provide connections with the applications in the vehicle and between the wireless devices in a quickly changing environment. The exchange of information must be completed in a very short time.

Wave uses a multiple channel concept. In the U.S and Europe, WAVE technology uses frequency of 5.8GHz/5.9 GHz with a guard band from 5.850-5.855 GHz. There are different mechanisms of communication between vehicles like Car-to-Infrastructure (C2I) communication and Car-to-Car (C2C) communication. Car-to-Car communication (C2C) is also known as Vehicle-to-Vehicle communication and Car-to-Infrastructure

(C2I) communication is known as Vehicle-to-Roadside communication, which we have already discussed in an earlier section.

4.4.1 Wave Architecture

The wave architecture is still in the process of development but the fundamental structure of the location of WAVE is given in Fig 4.6.

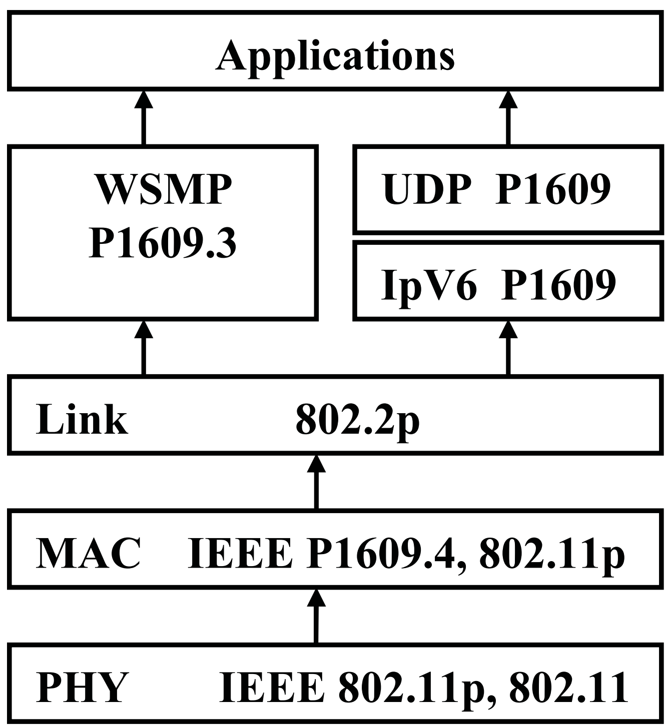

Figure 4.6: Structure and Location of Wave [24]

The physical (PHY) and Medium Access Control (MAC) layers employ IEEE 802.11p standard. MAC addresses are assigned a random value initially and when an OBU receives a message from another OBU or RSU, a new MAC address is assigned.

MAC layer also implements IEEE P1609.4, which is a Multi-Channel operation standard and it determines the behavior of MAC layer on the available control channel (CCH) and service channel (SCH). Control Channel is used for safety communication. Network Layer uses IEEE P1609.3 Networking Service Standard. The message may be transferred using Internet Protocol Version 6 (IPv6) or Wave Short Message Protocol (WSMP). WSMP employs non IP based application and uses high priority messages. The block which sends WSMP is known as a provider. The channels at the edges are reserved for future use to avoid accidents. Channel 178 is the control channel and the remaining ones are service channels.

4.4.2 Components in WAVE

WAVE consists of the following components:

1. IEEE 802.11p

   IEEE 802.11 is a set of standards defined for Wireless Local Area Network (WLAN) computer communication. The Institute of Electrical Engineers (IEEE) is working on an IEEE 802.11a wireless LAN to develop new standards for V2V communication and V2R communication known as IEEE 802.11p. It is the main technology of WAVE and is used for PHY/MAC layer. It will allow data exchange of within 100 milliseconds for vehicles in high speed. Hence, it will support communication between vehicles, and between vehicles and fixed units using Wireless Local Area Network (WLAN). Table 4.2 shows the difference between 802.11p and 802.11a. It shows that the bandwidth of 802.11p is half

Table 4.2: Comparison Table [25]

Name	IEEE 802.11p	IEEE 802.11a (USA)
Frequency	5.85-5.925	5.15 -5.35 GHz
Capacity	Max 27 Mbps	Max 54 Mbps
Modulation	OFDM	OFDM
Bandwidth	10 MHz	20 MHz
Number of Channel	7 CCH=1,SCH=6	12
Service Zone	10-300 m	5 -50 m
Transmission Power	28.8 dbm	28.8 dbm
Velocity	45 m/s (-160 km/hr)	6m/s (-20km/hr)

of 802.11a. It uses the ITS band between 5.85-5.925 GHz.

The objective of IEEE 802.11 MAC is to develop the communication system among the group of radios [24]. A group of stations with common access point implementing 802.11p, which communicates with each other over a wireless link known as Basic Service Set (BSS). The diagram of BSS is shown in Fig 4.7. The interconnected BSS can be combined into an External Service Set (ESS) using Distribution Services (DS). Service Set Identification (SSID) is the identification for the BSS and is equivalent to names of WiFi hotspots. Basic Service Set Identification (BSSID) is the identification number for the BBS for radios at MAC level. In 802.11p, the information can be exchanged between vehicles using BSSID and hence data can be exchanged in a short period.

2. IEEE P1609

IEEE P1609 set of standards stays above IEEE 802.11p and is used for higher levels and is shown in Fig 4.8. It describes the security, management, physical access in WAVE communication.

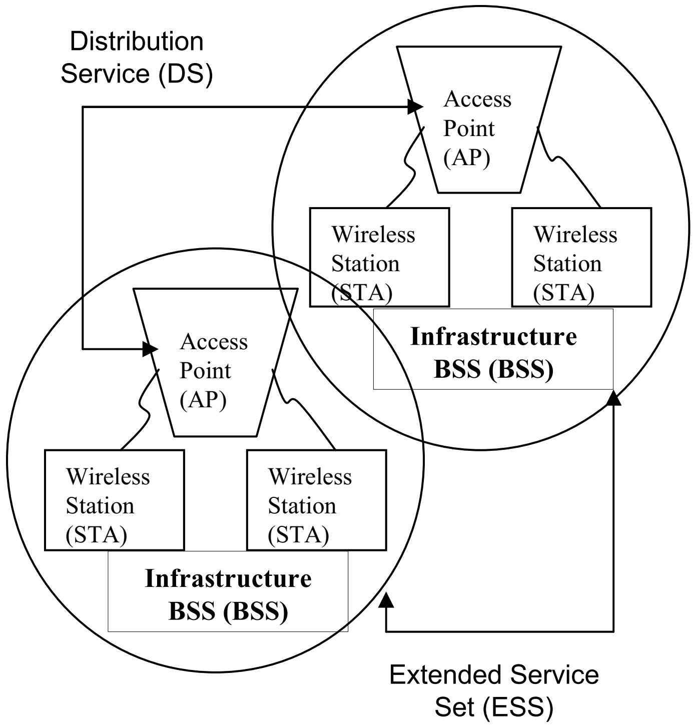

Figure 4.7: Basic Service Set (BSS) [24]

WAVE interface consists of four standards:

- IEEE P1609.1

  It represents the standard for Wireless Access in Vehicular Environments (WAVE) for resource manager. It defines how the data flow in the system, the format of the data and the types of devices that are supported by the OBU.

- IEEE P1609.2

  It represents the standard for Wireless Access in Vehicular Environments (WAVE) for security services and for applications and management of mes-

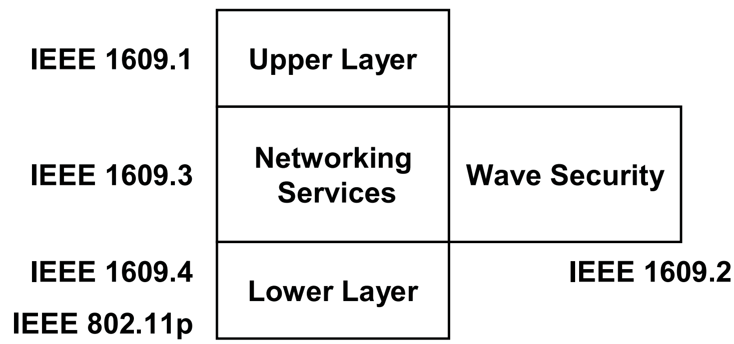

Figure 4.8: IEEE P1609 and WAVE

sages. It defines the message format and also the method of processing the messages.

- IEEE P1609.3

  It represents the standard for Wireless Access in Vehicular Environments (WAVE) for networking services. It defines the network level, the transport level, and Wave Short messages (WSM).

- IEEE P1609.4

  It represents the standard for Wireless Access in Vehicular Environments (WAVE) for multi-channel operations. It defines new features for IEEE 802.11 MAC layer.

4.4.3 Applications of WAVE

The following are possibilities for the application of WAVE:

- Vehicular Network Modeling

- Characterize the performance of the messaging protocol under various traffic conditions
- Make distributed routing decisions
- Ad Hoc Discovery of parking spaces
- Use of mesh networks of wireless parking meters operating jointly with mobile devices in automobiles using Internet or Google Maps
- Distributed Processing Control in a Dynamic Network
- High mobility rate and short connection
- Monitor congestion using sampling and in-network processing
- Imaging application in Vehicular Network
- Application of image recognition to determine vehicular flow on highways
- Capture pictures of streets for mapping purposes

CHAPTER 5

WAVE PROBLEMS AND PROPOSED SOLUTIONS

5.1 Introduction

In the previous chapters, we have discussed Wireless Access in Vehicular Environment (WAVE) technology. WAVE technology [27, 28, 29] has emerged as a state-of-the-art solution to vehicular communications in an Intelligent Transportation System (ITS). In WAVE, the communicating nodes are OBUs of vehicles and RSUs. The short range communication between these nodes can be achieved using IEEE 802.11p protocol in the Dedicated Short Range Communication (DSRC) band. For WAVE, the main challenges occur due to the fact that the communication environment varies rapidly and the duration of communication between the communicating nodes can be very short. On the other hand, the data (especially multimedia data) that needs to be transmitted might be huge and could not be delivered to all users with limited transmission time and bandwidth. To deal with this problem, we propose to use the idea behind BitTorrent to distribute the data among the vehicles and employ bargaining theory among them to exchange data using different fairness criteria. An example application of this WAVE and BitTorrent is the distribution of road-traffic information and a real-time online in-car entertainment system. With the ability of wireless communication, the driver and passenger can access multimedia data (e.g., image, video, and data files) efficiently.

BitTorrent [30, 31, 32, 33] is a P2P file sharing communications protocol. BitTorrent is a method of dispensing huge amounts of data widely without the original dispenser suffering from the total costs of the hardware, hosting, and bandwidth resources. When the data is distributed using the BitTorrent protocol, each receiver provides pieces of the data to newer recipients, reducing the cost and overhead on any given individual source. This also provides redundancy against system problems and reduces dependence on the original distributor. In WAVE, the RSU can distribute the different parts of data to different vehicles. The fairness and efficiency of the data exchange over the road can be achieved using bargaining game formulation. This bargaining game is a special type of cooperative game that can not only provide efficient share of mutual benefits via contract but also ensure fairness via interactions.

Based on the BitTorrent and bargaining, we formulate the V2R problem and V2V problem. The V2R problem is to decide how to distribute different parts of data to the vehicles according to the traffic pattern and the average transmission time between OBU and RSU. The V2V problem is to optimize the communication between the vehicles according to the channel variations, so that the maximum mutual benefits (i.e. the exchange of data) can be achieved. To solve the above two problems, we propose two algorithms in OBU and RSU, respectively.

The rest of the chapter is organized as follows: In Section 5.2, the WAVE system model in consideration is described. In Section 5.3, we formulate the V2R and the V2V problems and present the solution algorithms. Section 5.4 presents the simulation results.

5.2 WAVE System Model

For the channel model, we use the "2-ray ground reflection" model [34] for large-scale fading and "Rayleigh fading" for a small scale fading. The receiver signal-to-noise ratio (SNR) can be written as

$$\Gamma = \frac{P_t G_t G_r h_t^2 h_r^2}{\sigma^2 d^4} \tag{5.1}$$

where P_t is the transmit power, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, h_t is the transmitter antenna height, h_r is the receiver antenna height, d is the distance from the transmitter to the receiver, and σ^2 is the thermal noise level.

For WAVE, the radio channel varies rapidly and we need to ensure the required link quality. This can be achieved with the appropriate amount of channel coding to keep the bit error rate (BER) below some targeted BER threshold, which is assumed to be 10^{-5} in our system. In addition, joint consideration of adaptive modulation, adaptive channel coding, and power control can provide each user with the ability to adjust data transmission rate. A list of required SNRs to achieve different supported transmission rates under different BER requirement table can be found in the paper

[35].

Suppose we have L packets to distribute. Without loss of generality, we assume that all users want to receive all the packets, and all packets have the same length M. For packet k of OBU i, the priority value $w_i(k)$ is assigned. For kth and lth packets $(k, l \in \{1, 2, \ldots, L\})$ of OBU i, $w_i(k) \geq w_i(l)$, where $k < l$. The number of packets that can be transmitted within t_0 can be obtained from $n \leq R\frac{t_0}{M}$, where R is the transmission rate.

5.3 V2V and V2R Communications Problems and Solution Approaches Based on Bargaining and BitTorrent

We first formulate the V2V and the V2R communications problems for OBU and RSU, respectively. We then propose the bargaining algorithms for the V2V problem and data dissemination algorithm for V2R problem.

5.3.1 Problem Formulation

In Fig. 5.1, we show the WAVE scenario considered in this model. When the vehicles with OBUs pass by the RSUs which are located in places such as toll booths and gas stations, it is very unlikely that all L packets can be transmitted . This is because the communication duration for the OSUs and RSUs is usually limited. To overcome this problem, the RSUs randomly distribute the packets to the OBUs, and then allow

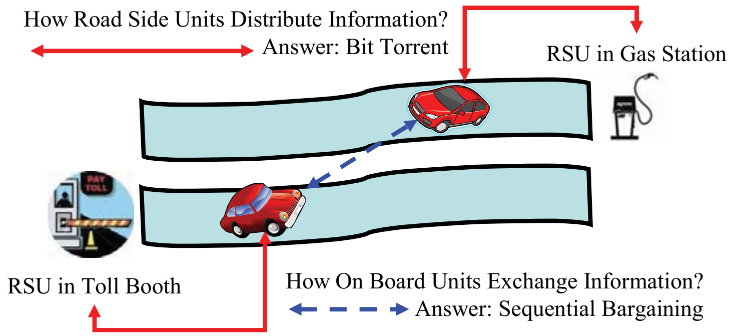

Figure 5.1: V2R and V2V Communications Model

the OBUs exchange information on the road.

1. *How do OBUs exchange information?*

   For each individual vehicle, we define the i^{th} vehicle's utility as the sum of weights for the set $\mathcal{I}_i$ of packets that it currently has, i.e.,

$$U_i = \sum_{k \in \mathcal{I}_i} w_i(k). \tag{5.2}$$

   This utility function corresponds to the user's satisfaction gained from an application-specific data packet.

   We only consider information exchange between two OBUs. For vehicle i and vehicle j, if each has some packets that the other does not have, they will exchange. In other words, the conditions for exchange are $\mathcal{I}_i \not\subset \mathcal{I}_j$ and $\mathcal{I}_j \not\subset \mathcal{I}_i$. For bargaining between two users, the problem formulation can be stated as follows:

$$\max \mathscr{F}(U_i, U_j) \tag{5.3}$$

$$\text{s.t.} \sum_{k \notin \mathcal{I}_i, k \in \mathcal{I}_j} 1 + \sum_{l \notin \mathcal{I}_j, l \in \mathcal{I}_i} 1 \leq n_{i,j}$$

where $n_{i,j}$ is the maximal number of packets that can be exchanged within the time period of t_0. $\mathscr{F}(\cdot, \cdot)$ is a function that represents the social welfare or how the bargaining can benefit both users.

2. *How do RSUs distribute information?*

   For RSUs, the objective is to maximize the overall utilities by changing the probability distribution function (pdf) for the distribution of the L different packets, i.e.,

$$\max_{P_r(l)} \sum_{i=1}^{K} U_i. \tag{5.4}$$

$$\text{s.t.} \sum_{l=1}^{L} P_r(l) = 1$$

   where $P_r(l)$ is the probability of packet l to be sent by RSU to OBU. The pdf is affected by the traffic pattern. For example, during midnight, it is very unlikely one vehicle will meet another vehicle. In this case, it is better to send the higher priority packet first. On the other hand, during a traffic jam, more uniform distribution might be preferred, since there are plenty of opportunities that an OBU can exchange all information with other OBUs.

5.3.2 Proposed Algorithms for Bargaining Between OBUs

In this subsection, we propose three fairness criteria for OSU bargaining. The algorithms for data exchange and those for bargaining solutions are then proposed.

First, we study the Nash Bargaining Solution (NBS) [36] for a two-player game. The definition of NBS is given below.

Definition 1 ***Nash Bargaining Solution****: Define $\mathcal{U}$ as the feasible region, $\boldsymbol{U}$ as the utility vector after users' bargaining, and $\boldsymbol{U}^0$ as the utility vector before the negotiation. $\phi(\mathcal{U}, \boldsymbol{U}^0)$ is the NBS that maximizes the product of utility from both players as follows:*

$$\phi(\mathcal{U}, \boldsymbol{U}^0) = \arg \max_{\boldsymbol{U} \geq \boldsymbol{U}^0, \boldsymbol{U} \in \mathcal{U}} \prod_{i=1}^{2} \left(U_i - U_i^0\right). \tag{5.5}$$

Under six general conditions shown in [36], the NBS has a unique solution.

Two other bargaining solutions have been proposed as alternatives to the NBS – the Kalai-Smorodinsky Solution (KSS) [36] and the Egalitarian Solution (ES). To define these solutions, we need to introduce the following definition:

Definition 2 *Restricted monotonicity: If $\mathcal{V} \subset \mathcal{U}$ and $H(\mathcal{U}, \boldsymbol{U}^0) = H(\mathcal{V}, \boldsymbol{U}^0)$ then $\phi(\mathcal{U}, \boldsymbol{U}^0) \geq \phi(\mathcal{V}, \boldsymbol{U}^0)$, where $H(\mathcal{U}, \boldsymbol{U}^0)$, called the* utopia point*, is defined as:*

$$H(\mathcal{U}, \boldsymbol{U}^0) = \left[\max_{\boldsymbol{U} > \boldsymbol{U}^0} U_1(\boldsymbol{U}) \quad \max_{\boldsymbol{U} > \boldsymbol{U}^0} U_2(\boldsymbol{U})\right]. \tag{5.6}$$

Definition 3 ***Kalai-Smorodinsky Solution****: Let $\boldsymbol{\Lambda}$ be a set of points on the line containing $\boldsymbol{U}^0$ and $H(\mathcal{U}, \boldsymbol{U}^0)$. $\phi(\mathcal{U}, \boldsymbol{U}^0)$ is the KSS which can be expressed as*

$$\phi(\mathcal{U}, \boldsymbol{U}^0) = \max\left\{ \boldsymbol{U} > \boldsymbol{U}^0 \,\middle|\, \frac{1}{\theta_1}(U_1 - U_1^0) = \frac{1}{\theta_2}(U_2 - U_2^0) \right\} \tag{5.7}$$

where $\theta_i = H_i(\mathcal{U}, \boldsymbol{U}^0) - U_i^0$. *The solution is in* $\boldsymbol{\Lambda}$.

Definition 4 ***Egalitarian Solution***. $\phi(\mathcal{U}, \boldsymbol{U}^0)$ *is the ES which can be expressed as:*

$$\phi(\mathcal{U}, \boldsymbol{U}^0) = \max\left\{\boldsymbol{U} > \boldsymbol{U}^0 | U_1 - U_1^0 = U_2 - U_2^0\right\}. \tag{5.8}$$

The KSS gives the bargaining solution as the point in the boundary of a feasible set that intersects the line connecting the disagreement point and the utopia point. The ES gives the bargaining solution as the point in the feasible set where all players achieve maximal equal increase in utility relative to the disagreement point. From the simulation results shown in the next section, we can see the differences among the fairness criteria.

Algorithm 1 Data Exchange Algorithm

repeat
    Neighbor Discovery: Investigate who has the best channel and most mutual benefited packets.
    Negotiation: OBUs exchange information of available data packets and their weights.
    Bargaining: The solution of bargaining game is obtained from Algorithm 2.
    Data Transmission: Exchange packets to the other OBU.
    Adaptation: Monitor the channels and adjust modulation and coding rate.
until Both OBUs have the same sets of packets or the channel becomes bad.

The algorithm for data exchanged between OBUs is shown in Algorithm 1. First, the OBU tries to find the neighboring OBUs within the communication range. Among all the reachable OBUs, the one that has best channel (e.g., channel quality is estimated using pilot signal) is paired. The expected number of transmitted packets $n_{i,j}$ between OBUs i and j is computed for a certain transmission duration t_0. After the OBUs are paired, the negotiation between OBUs is performed to exchange information about the available data packets and their weights. Without loss of generality, we assume that OBU i initiates the negotiation by sending a message containing information about its available packets to OBU j.

After receiving this information, OBU j checks whether it has data packets in OBU i or not. Then, OBU j replies with a message containing information about the needed packets from OBU i and their weights. Also, the information about the data packets available at OBU j is piggy-backed with this message and sent back to OBU i. Now, OBU i has complete information about data and their weights from OBU j. Therefore, OBU i executes Algorithm 2 to compute a solution of the bargaining game.

Given the solution n_i^*, n_j^* from Algorithm 2, the packets $1, \ldots, n_i^*$ and $1, \ldots, n_j^*$ are transmitted by OBUs i and j, respectively. In particular, the packets with the highest weights are transmitted. Note that in Algorithm 2, Kalai-Smorodinsky and Egalitarian solutions are approximated since the strategy space of OBUs is discrete (i.e., the number of the transmitted packets is an integer).

5.3.3 Proposed Algorithms for Data Dissemination by an RSU

To solve the RSU problem, the probability distribution $P_r(l)$ needs to be optimized. To reduce the search space, we assume that the weight of the packet is ordered (i.e., $w_i(k) > w_i(l)$ for $k < l$) and the probabilities corresponding to the different packets

Algorithm 2 Bargaining Algorithm

Input: Weight of available packet k from OBUs $i \in \{1, 2\}$ (i.e., $w_i(k) \in \mathcal{I}_i$), the number of transmitted packets $n_{i,j}$ between OBUs i and j, where $i \neq j$.

1: Sort packets according to their weights, i.e., $w_i(1) > \cdots > w_i(k) > \cdots > w_i(\langle \mathcal{I}_i \rangle)$, where $\langle \mathcal{I}_i \rangle$ gives the number of elements in set $\mathcal{I}_i$.

2: Define a set of number of transmitted packets by OBUs i and j as $\{(n_i, n_j) : n_i = \{0, \ldots, n_{i,j}\}, n_j = n_{ij} - n_i\}$. $U_i(n)$ can be obtained based on (5.2), i.e., $U_i(n) = \sum_{k=1}^{n} w_i(k)$.

3: **if** Nash solution **then**

4: Obtain solution in terms of $(n_i^*, n_j^*) = \arg\max_{(n_i,n_j)}(U_i(n_i) - U_i^0) \times (U_j(n_j) - U_j^0)$.

5: **else if** Kalai-Smorodinsky solution **then**

6: Define normalized utility $\hat{U}_i(n_i) = \frac{1}{\theta_i}(U_i(n_i) - U_i^0)$, where $\theta_i = \max_{n_i\{0,\ldots,n_{i,j}\}} U_i(n_i) - U_i^0$.

7: $(n_i^*, n_j^*) = \arg\min_{(n_i,n_j)} \left| \hat{U}_i(n_i) - \hat{U}_j(n_j) \right|$.

8: **else if** Egalitarian solution **then**

9: The solution is obtained from $(n_i^*, n_j^*) = \arg\min_{(n_i,n_j)} \left| (U_i(n_i) - U_i^0) - \big(U_j(n_j) - U_j^0\big) \right|$.

10: **end if**

11: $\phi(\mathcal{U}, \mathbf{U}^0) = (U_i(n_i^*), U_j(n_j^*))$

Output: The number of packets to be transmitted by OBUs i and j, i.e., (n_i^*, n_j^*), respectively.

have the following relation:

$$P_r(l+1) = \beta P_r(l), \; l = 1, \ldots, L-1 \tag{5.9}$$

where $0 < \beta \leq 1$. As a result, we have

$$P_r(l) = \begin{cases} \frac{1}{L}, & \beta = 1 \\ \beta^{l-1} \Big/ \frac{1-\beta^L}{1-\beta} & 0 < \beta < 1 \end{cases} \tag{5.10}$$

and the problem in (5.4) can be stated as

$$\max_{\beta} \sum_{i=1}^{K} U_i. \tag{5.11}$$

When β equals to 1, the uniform distribution is obtained, which models the situation that the OBUs have enough opportunities to exchange information with other OBUs. When traffic load is light, the value of β should be small. To maximize the utility, only the high priority packets should be transmitted, since the number of vehicles on the road will be few. The solution in (5.11) is suboptimal to the problem in (5.4). However, only one parameter needs to be trained and the solution can be much easier to obtain. In practice, under different traffic patterns, we can search for an optimal value of β based on the utilities that the vehicles obtain after exchanging data on the road.

5.4 Simulations and Discussions

5.4.1 Parameter Setting

We consider a two-lane highway traffic scenario. Each vehicle is equipped with a transceiver whose transmitted power is 0.4 watts, and the gains of both receiving and transmitting antennas are 1. The MAC PDU size is 2000 bytes, and the BitTorrent packet size is 20 MAC PDUs. The maximum transmission range is 80 meters. The vehicle speed is uniformly random between 80-120 km/hr. The vehicles enter highway with rate $\rho\lambda_1$ and $\rho\lambda_2$ (e.g., $\lambda_1 = \lambda_2 = 1.0$ (for symmetric case) and $\lambda_1 = 1.1, \lambda_2 = 0.9$ (for asymmetric case)) for lane 1 and 2, respectively, where ρ denotes the traffic intensity.

The total size of data to be exchanged between the vehicle in both lanes is 16

MB. There are three types of data, i.e., high priority (e.g., collision warning/highway traffic information), medium priority (e.g., infotainment data), and low priority (e.g., advertisement data). Each packet of these types of data have weights of 1.5, 1.2, and 1.0, respectively. Note that the vehicles in lane 1 have a larger size of high priority data to be transferred to the vehicles in lane 2 (i.e., 2000 and 1500 packets for the vehicles in lane 1 and 2, respectively). Therefore, if all data are exchanged, a vehicle in lane 2 will receive slightly higher utility than that of a vehicle in lane 1. For the probability distribution of the data, we assume $\beta = 1$.

5.4.2 Simulation Results

Fig. 5.2 shows the transmission rate (i.e., packets/second) between two vehicles. As two vehicles approach each other, the transmission rate becomes higher due to the closer distance and hence closer transmission range. As a result, the channel quality becomes better, and the transceiver can increase the transmission rate by changing modulation mode and coding rate. Note that the flat line on the top of the curve occurs when the highest transmission rate of IEEE 802.11p is used. The vehicles with slower speed have longer duration for data transmission. Specifically, transmission duration of the vehicles with a speed 70 km/h is longer than that of the vehicles with a speed of 100 km/h.

We then evaluate the different solutions of the bargaining game (i.e., Nash, Kalai-Smorodinsky, and Egalitarian solutions). Pareto optimality and three solutions under different transmission rates are shown in Fig. 5.3. The Pareto optimality is defined as

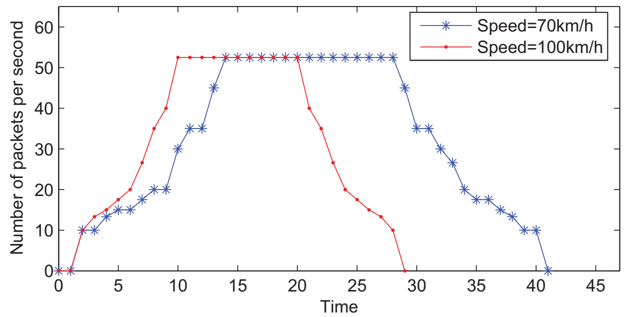

Figure 5.2: Transmission Rate Under Different Speeds

$(U_1(n_1), U_2(n_{1,2} - n_1))$, where $n_1 = \{0, 1, \ldots, n_{1,2}\}$. In this case, the Pareto optimality is concave. The Nash solution is located where $\max(U_1 \times U_2)/U_1$ intersects the Pareto optimality.

Next, the road traffic intensity ρ is varied. The utility of the vehicles under different solutions is shown in Fig. 5.4. Again, the utility from Nash solution is close to that from Egalitarian solution. In particular, utility of the vehicle in lane 1 is slightly higher than that in lane 2. However, the utility of the vehicle obtained through the Kalai-Smorodinsky solution is different.

The utility of the vehicle under Nash solution of the bargaining game is shown in Fig. 5.5. When the traffic intensity increases, there is a higher chance that the vehicles will exchange data. In particular, the vehicles in both lanes will pass each other more frequently. Therefore, the utility of all vehicles increases. However, at a certain traffic intensity level, this increase in utility becomes saturated since most of the data are transferred. Also, in the case of symmetric traffic intensity, the utility of the vehicle in lane 2 is slightly higher than that of the vehicle in lane 1, since the

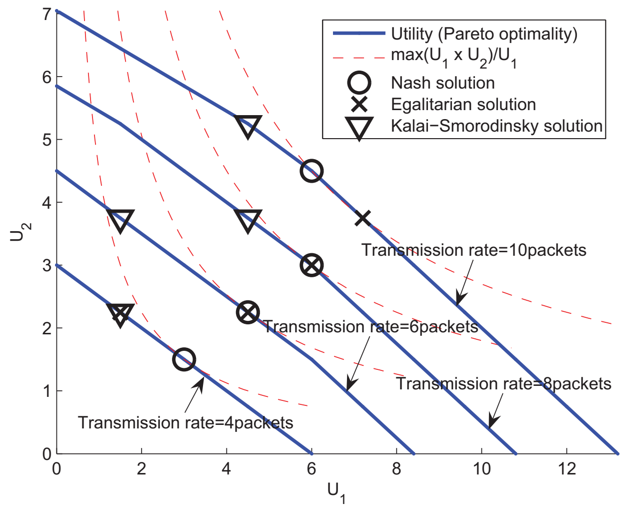

Figure 5.3: Utility, Pareto Optimality, and Bargaining Solutions

vehicle in lane 1 has larger amount of high priority data to send to the vehicle in lane 2. However, in an asymmetric case, the vehicle in lane 1 - which has larger traffic intensity (i.e., more number of vehicles on the highway) - achieves lower utility than that of the vehicle in lane 2, which has smaller traffic intensity. Since there are more vehicles in lane 1, the vehicle in lane 2 has a higher chance to receive the data from the vehicles in lane 1. Therefore, the utility is higher. Note that a similar effect is observed for Kalai-Smorodinsky and Egalitarian solutions.

We change the probability distribution of data with different priorities. The utility of the vehicle under different values of β is shown in Fig. 5.6. It is observed that there is an optimal value of β for the probability distribution so that the utility is maximized. When a value of β is large, only a small amount of high priority data are sent from RSU to OBU on a vehicle, and hence the utility is not maximized since

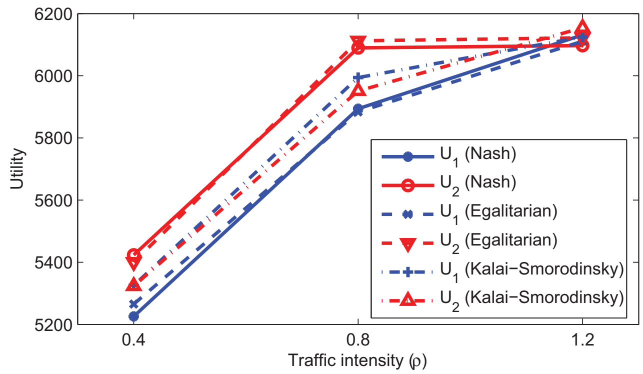

Figure 5.4: Utility of the Vehicle

most of the exchanged data have medium or low priority. However, if a value of β is small, only high priority data are sent to the vehicle. Therefore, medium and low priority data are not exchanged between the vehicles in two lanes, even though both vehicles have enough transmission resource. Note that we consider two cases. In case 1, only probability distribution for the data sent to the vehicle in lane 2 is varied according to β, while in case 2, the probability distributions for the data sent to the vehicle in both lane 1 and 2 are varied. When probability distribution of the data in lane 1 is varied in case 2, the utility of the vehicle in lane 2 is higher than that of the case 1 where the distribution of the vehicle is not changed.

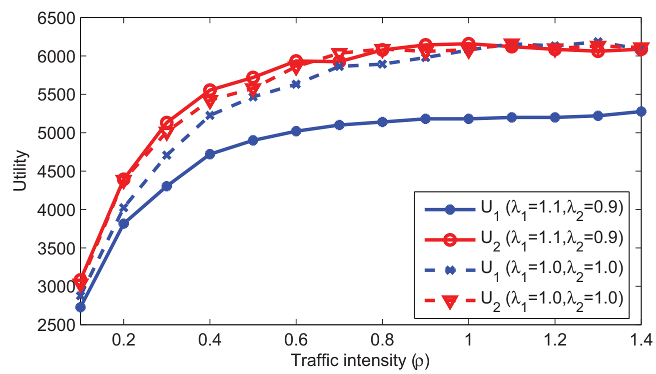

Figure 5.5: Utility of the Vehicles Under Different Traffic Intensity

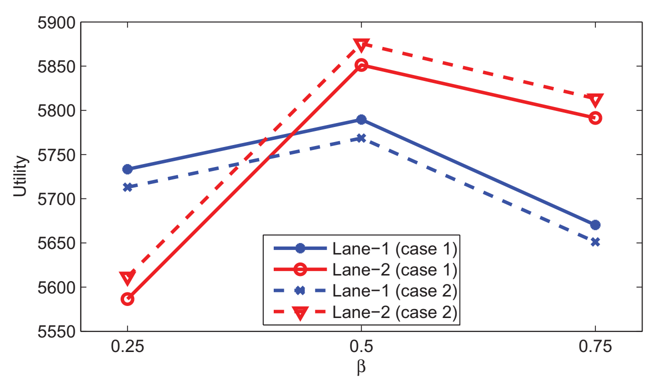

Figure 5.6: Utility of the Vehicles Under Different Data Distribution

CHAPTER 6

CONCLUSION AND FUTURE WORK

We have proposed a WAVE scheme to distribute a large amount of data over mobile vehicles using the concepts of BitTorrent and bargaining game. The key idea is to deliver different data to different OBUs and let the OBUs exchange the information on the road. Three fairness criteria are proposed for OBUs bargaining. A heuristic approach has been introduced for RSUs to distribute the packets with different priorities. From the simulation results, the proposed schemes can ensure the fairness among the OBUs, and adapt to different distributions according to different traffic intensity. We have studied the exchange of information between OBUs and how RSU distributes the information.

If a node has to acquire information on certain safety conditions and its RSU does not have this information then there are two possibilities. First, its RSU can query other RSU and get the information. For future work, how RSU communicates with other RSU will be studied. Second, current OBU can use multihopping to connect another OBU far way. In the future, we will consider the study of information exchange between two OBUs very far away within the range of two different RSUs using multihopping.

Another future study is the communication between the current OBU with multiple OBUs might be faster while querying for data compared to communication between two OBUs. During the multimedia download, in a fast changing environment, there are chances that an incomplete piece of file can be downloaded and the OBU may lose connection. To continue the connection, the next enhancement can be handing off the OBU to a neighboring OBU.

For future studies, performance analysis will also be carried out from an application centric point of view. Analytical models will be developed to determine the average time duration to complete data exchange and the probability of completion of data exchange for each vehicle. The analytical models would be useful for system performance optimization.

The application of the idea we have proposed is not only limited to vehicular communications but in diverse fields. One possible future application is in Biology. It is very difficult to study wild animals and their behaviors. However, if we install a device equivalent to OBU in a few animals - say polar bear - and set a few RSUs at locations where these animals roam around, then we can easily get information about their location, temperature, etc. depending on the features installed in the OBU. The animal in the range of RSU will transfer all the information to RSU and in case the animals with OBU meet by accident or they are in range, they can still exchange information about each other and RSU can get information of the animal even if it did not come in its range. It would make things easier for biologists. They would not have to watch them day and night, but can collect all the information staying at one convenient place.

Another application would be in file downloads from the web. BitTorrent is already in use, where a downloader is required to share/upload. Otherwise, one who does not share will not be able to download. This makes the system faster when there are many users in the network. However, at the same time, it has some loopholes. There is a high chance that greedy peers might exploit fairness in different ways. Some of them can be retrieving the data from the seeds as seeds do not need any reciprocation. Presence of optimistic unchoke allows greedy nodes to download from the fastest peers, send fake pieces at a slower rate and receive valid piece. However, if we implement BitTorrent along with bargaining, our proposal will resolve this issue as bargaining incorporates fairness in the system during downloads.

Another application would be in the field of Medical Care. Due to technology, even remote operation is possible and has been conducted. But, when a doctor has to diagnose a patient and study him, the patient will have to stay in hospital under supervision. This is not always convenient for the patient such as when he has other obligations. So, we can implement our concept, which would allow access of health information of their patient regardless of the location whether they are in hospital, on a vacation or attending important meetings. If the condition of a patient suddenly gets worse with no one to attend him, then a warning to the main operator could be sent so that necessary actions can be taken to avoid any mishaps. Similarly, if the patient is attending meeting, all the information can be obtained regarding his/her health status. In addition, if two patients from same hospital meet up, then the units can exchange information about the status of the health of the other person.

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