WIRELESS ACCESS IN VEHICULAR ENVIRONMENTS USING BIT TORRENT AND BARGAINING

by

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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 and Dad

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ABSTRACT

Wireless Access in Vehicular Environment (WAVE) technology such as IEEE 802.11p 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 mobility. In our context, when the vehicles with OBUs (On-board Units) pass by the RSUs (Road Side Units) which are located in places such as toll booth and gas station, since the communication duration for the OSUs and RSUs is usually limited, it is very unlikely that all the information can be transmitted. As a result, it is difficult to transmit a large amount of data in such a network for vehicle-to-roadside and/or vehicle-to-vehicle communications. To overcome this problem, we propose a solution based on the idea of BitTorrent used for peer-to-peer networking, and the concept of bargaining game used in game theory.

BitTorrent is an unstructured peer-to-peer (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. At the same time, they can share/upload the component of the file to other users in the network. BitTorrent helps for faster download of files without crashing the server when many users try to access a particular file at once. Bargaining is the negotiation of goods or services carried out between two or more players who can be buyer or seller and they try to come to an agreement for the distribution of the

objects. So, for bargaining theory, appropriate solution depends extensively on the available information and negotiation arrangements.

Similar to the distribution of data in BitTorrent, the roadside units (RSUs) randomly distribute the data to the passing vehicles. Then, the on board units (OBUs) on the vehicles with different data, exchange the information among each other using bargaining considering channel adaptations and fairness in their achieved utility. Two optimization problems - one for the RSUs and another for the OBUs have veen formulated.

For OBUs, the bargaining solutions are proposed which are based on three fairness criteria. They are Nash Bargaining Algorithm, Kalai-Smorodinsky Bargaining Solution and Egalitarian Bargaining Solution. 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.

A two-lane highway traffic scenario has been considered. Each vehicle is equipped with a transceiver. The maximum transmission range is 80 meters. The vehicle speed is uniformly random between 80-120 km/hr. Then, the different solutions of the bargaining game (i.e., Nash, Kalai-Smorodinsky, and Egalitarian solutions) are evaluated. Simulation results show that the proposed schemes can ensure fairness among the OBUs, and adapt to different traffic scenarios with different vehicular traffic intensity.

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Chapter 1

INTRODUCTION

Traffic accidents have become a serious issue in the modern world. According to World Health Organization (WHO), 1.2 million people lose their lives in road accidents annually. There are various causes for the accidents; one of the main reasons is the inability of the driver to take the correct step immediately, a lot can happen within the human reaction time. 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 secure and well-organized transportation system. There are multiple applications of vehicular communication. It 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 provide safe traffic by providing security information such as traffic information, warnings, congestion through Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication.

Vehicle-to-Vehicle communication implements Dedicated Short Range Communication (DSRC) to transmit data from one vehicle to other vehicle through 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 Road Side Unit (RSU) is a device that operates at a fixed position located in traffic lights, signs, road crossings, etc. Vehicle-to-Roadside 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 message through OBU whereas the infrastructure transmits and receives message through Road Side Unit (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 field of vehicular communications and it is expected to be confirmed in April, 2009. There are several topics that are being studied like physical layers related to mobile channels, network configuration, security, Media Access Protocols (MAC), congestion control system to name a few. The major application of WAVE is safety of vehicles. Some of the examples of safety application will be curve warning, emergency brake light, collision warning, and emergency braking. For these applications the vehicles have to communicate with each other and have to analyze the data from RSU as well. Another application is the 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, PDA (Personal Digital Assistant) and other devices. We can access Internet using public hotspots. People carry these devices even when they are travelling but their use is complicated in fast changing environment such as moving cars. In the highways, the main problem is the discontinuous connectivity with the Internet which prevents a user from downloading file or doing any activity related to Internet. WAVE can be used to address the problem and have effective Internet use.

In V2V communication and in V2I communication, the time period for data exchange should be very low considering the fast changing conditions in highways where 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 [12]. The size of data packets to maintain V2V communication is less than 100 bytes and 430 bytes for V2I communication [12]. The implementation of wireless communication for V2V and V2I 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 used in vehicular communication in transportation system. 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 very short. On the other hand, 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. Other issue in V2V and V2I communication is the method of exchange of information. Another issue is regarding security, the system should ensure that the data is valid and not fake providing incorrect information. There are different kinds of information and 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 the 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 vehicle-to-roadside (V2R) problem and vehicle-to-vehicle (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 distribution of data in BitTorrent, the roadside units (RSUs) randomly distribute data to the passing vehicles. Then, the on-board units (OBUs) on the vehicles with different portion of the data, exchange the information among each other using bargaining; considering channel adaptations and fairness in their achieved utility. 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 networking is a type of computer network which reduces the number of servers or even eliminates it and allows the computers to share files with each other. Unlike client-server network system, files can be distributed from any of the computer in the P2P network. P2P networking has wide range of applications like voice IP,sharing files. Files can be shared using BitTorrent. BitTorrent is a P2P file sharing application which was introduced by Bram Cohen and was first implemented on July 2001.

In this chapter, we will discuss Peer-to-Peer networking and BitTorrent. Peer-to-Peer networking is defined in section 2.1.1, section 2.1.2 will summarize its history, the architecture of P2P network is discussed in section 2.1.3, section 2.1.4 talks about the working principle of P2P network, section 2.1.5 will look at different types of P2P network, section 2.1.6 will examine its advantages and disadvantages and the applications of the Peer-to-Peer networking are discussed in section 2.1.7.

The next section 2.2.1, talks about BitTorrent, section 2.2.2 explains the working principle of the BitTorrent, section 2.2.3 points out the different types of algorithms implemented in BitTorrent, section 1.2.4 points out the advantages of BitTorrent and section 2.2.5 discusses about the drawbacks of BitTorrent.

2.1 Peer-to-Peer Networking

Peer-to-peer networking is prevalent among the 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 Peer-to-Peer networking.

2.1.1 Definition

Peer-to-peer networking abbreviated as P2P networking is a networking system in which the computers are connected to each other either through wire or wireless. The computers in such a network communicate with each other directly. The system does not have separate servers and clients, the networked computers in the system behave as servers and as clients. So, each node or user has equivalent capabilities. The main application of peer-to-peer networking is in sharing files. In a few years, file sharing and downloading big multimedia files has become very popular. Incorporation of peer-to-peer 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 back up or storing data. Peer-to-peer 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

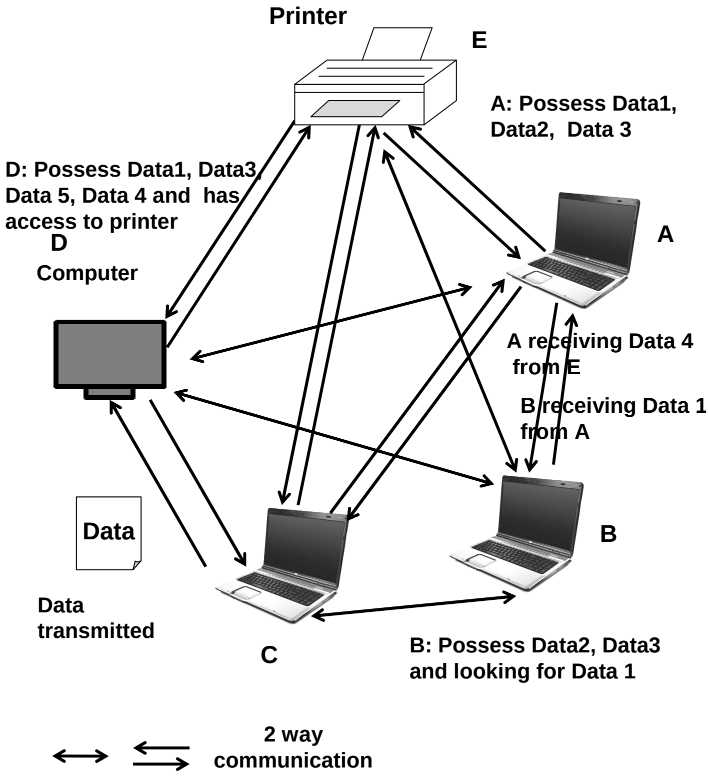

Figure 2.1. P2P Network

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

Peer-to-peer networks are overlay networks. Overlay networks are those networks which run on the top of other type of network and P2P is built on top of another network - the Internet. Based on the arrangement of the nodes on overlay networks, P2P can be both a Structured Network and also 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 key that can be stored for a value or node and that value can be accessed if the key is known. Its drawback is that it is not good at performing search. 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 [18], Kademlia, Bamboo, TAPESTRY [19], Pastry [20], CAN [21].

   Let us consider PASTRY sytem as shown in Fig 2.2. Each node has node ID and PASTRY consists of a key with is 128 bit. Pastry sends the message to the node whose node ID is closest to the 128 bit key. Each node updates itself with the information about neighboring nodes. Each node has a routing table which contains 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 message to its neighboring node.

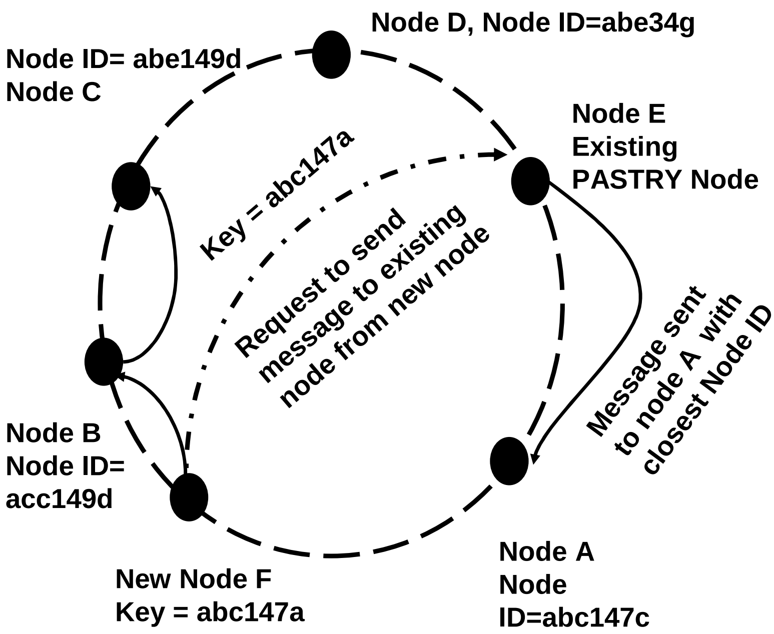

Figure 2.2. Structured P2P Network

2. Unstructured P2P Network

Unstructured P2P Network is a type of network formed by new peer that joins the network following the rules which may be as mentioned in [17] or they may not follow any rule as well. 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 random 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 query. Its main application is in file sharing and content distribution. Gnutella is an example of decentralized unstructured P2P network.

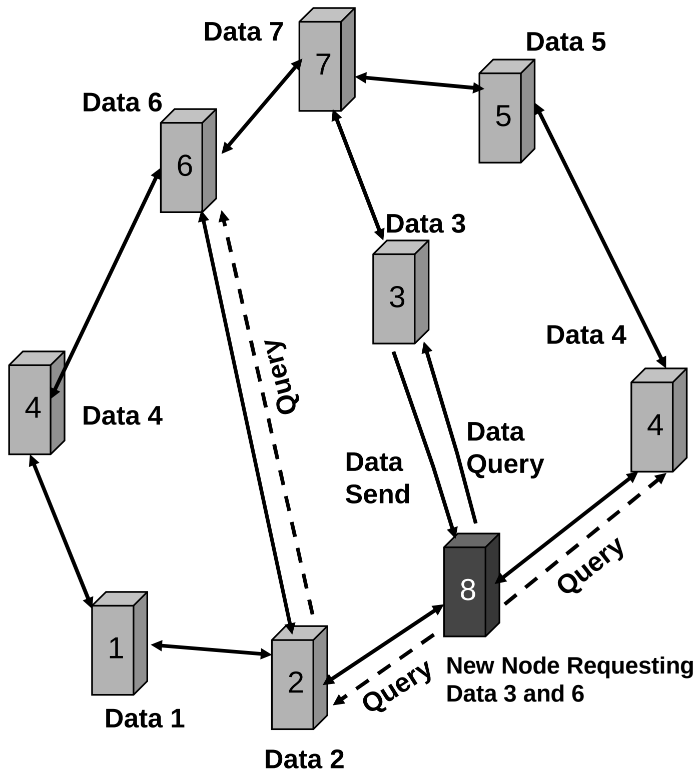

Figure 2.3. Unstructured P2P Network

2.1.2 History

Peer to peer network was developed in the nineties. They were designed such that if a group of nodes or users have same networking program to connect to each other, they can access and share files and data easily [15]. Some examples of the earlier networking program are Napster and Gnutella.

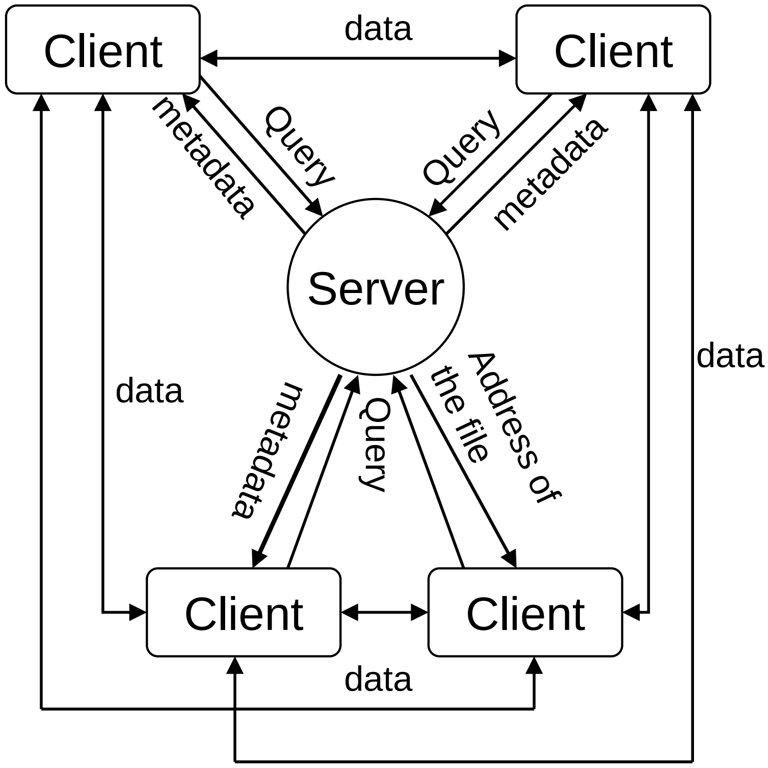

Figure 2.4. Napster Network

The discussion of P2P remains incomplete if we do not mention about the popular music sharing program- Napster. Napster was developed by Shawn Fanning in September 1999. Napster is a centralized P2P network as the server stores all the information and does the searches. When an individual user requests for a file, the server scans the computers in the network and provides information of the address of the other users who has that file [13].The Fig 2.4 represents the Napster P2P Network. Napster was an efficient P2P program and became very popular. The RIAA (Recording Industry Association of America) sued Napster in December 1999 followed by the band Metallica for violating copyright laws [14]. Napster shut down in July 2001. Napster comes under first generation P2P program.

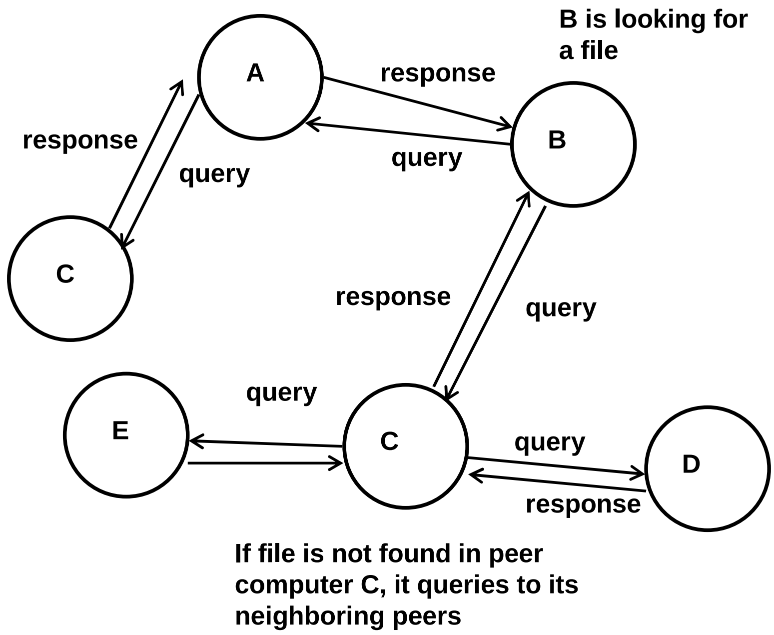

Figure 2.5. Gnutella Network

The second generation programs like Gnutella evolved in 2000 [15]. 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. Those nodes will pass that request to other nodes they are connected to and also check if they have the file. But, 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, Grokster. Fasttrack is the most popular P2P network and it has features of super-nodes and high speed

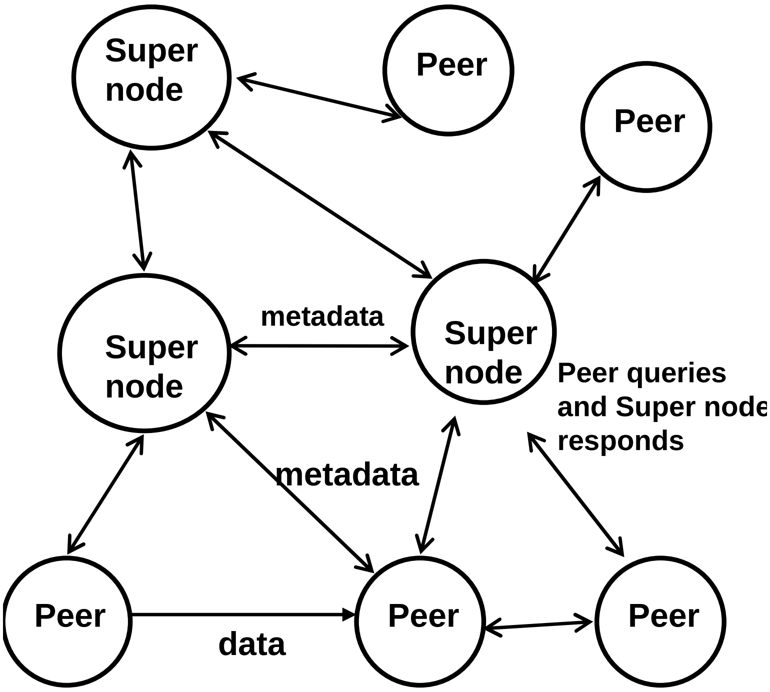

Figure 2.6. Fasttrack Network

downloads [13]. Kazaa was introduced in March 2001 [15]. Currently, we have BitTorrent which is gaining it popularity as the download speed is very fast. It was introduced in July 2, 2001 [15]. It has a central server known as tracker which is no longer required because of the use of Distributed Hash Tables (DHTs) in the BitTorrent protocol.

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

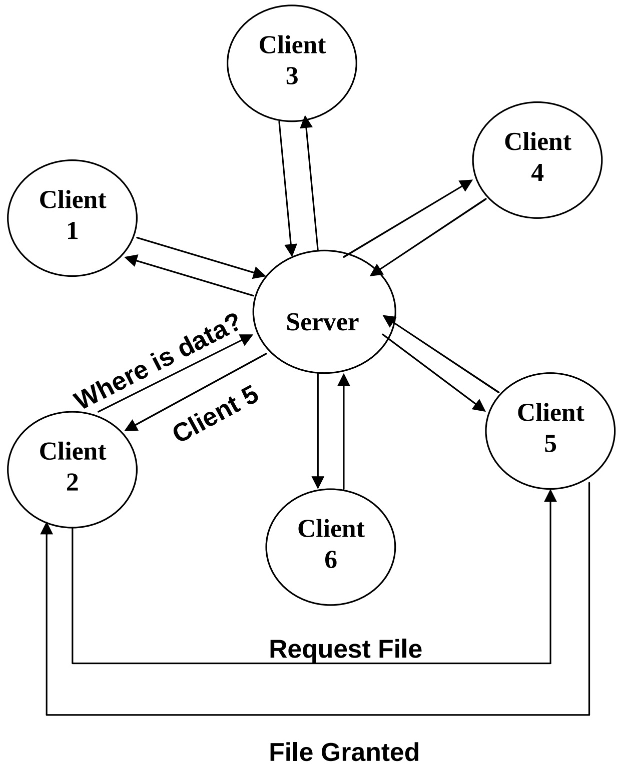

Figure 2.7. Centralized P2P Network

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 of such 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 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. So, 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 [11]. Freenet P2P is an example for Decentralized and Structured network.

3. Decentralized and Unstructured

   This type of architecture also lacks a central server but may have multiple servers and the nodes or the users are arranged in random way i.e the topology is not structured. Flooding method is used for querying and the search in 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.

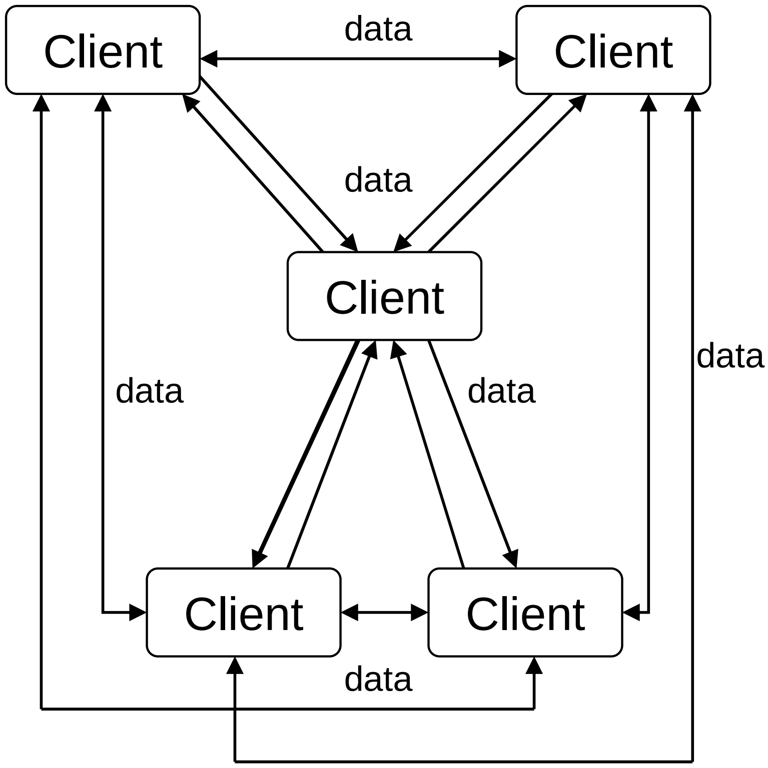

Figure 2.8. Decentralized P2P Network

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, 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[16]. The user can also connect to multiple users in the network. Hence, the file sharing allows sharing the contents of a computer in the network to the 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 tries to find out 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 network do not have separate client 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. So, 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

Peer-to-peer network is used with different settings at home and at office as well. For example, if some computers are connected and they share a printer, then it implements P2P networks. Similarly, people can access computer 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 network, if the server fails then the system fails to function. But, this 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 concerns 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. So, search should be done very carefully based on file name and the signature. Since this system is not centralized, it is hard to keep track of the data and its owner node. Also, password is not required to share files, so the network link is not secure as server-client network. The performance of network starts to degrade when the number of computers in the network reached ten. So, it is not a good option for large P2P network in big companies. It is designed for small group of people.

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 peer-to-peer search engines available for academic research such as Sciencenet. Application of peer-to-peer 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 P2P application. BitTorrent is another example of use 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 about BitTorrent in greater detail.

2.2.1 Description

BitTorrent[40] is an unstructured peer-to-peer (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 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 applied by BitTorrent, where each recipient supplies pieces of the data to newer recipients reduces the cost and burden on any given individual source. This provides redundancy against system problems, and reduces dependence on the original distributor.

2.2.2 Working Principle

In BitTorrent, the files are divided into multiple equal sized files. The user(downloader) informs other peers in the networks about the pieces of the files she has. The peers in the network upload and download the files from the peers they are connected to and the download takes place in tit-for-tat manner to ensure that the peers download and at the same time they should also upload. It increases the efficiency of the bandwidth and the network system becomes better when the number of users increase.

In this file distribution system, there is a server known as “Tracker” which manages the connection between the peers and the file transfer between them. There is a file called “.torrent” that directs the peers to the file they want to download. In this system, there is a computer that possesses a complete copy of a BitTorrent file and is known as Seed and a group of computers simultaneously sending (uploading) or receiving (downloading) the same file is known as “Swarm”. Those peers who download files but do not share files on their own computer with others are known as “Leeches”.

To download a file, a user goes to the torrent website and searches for a particular file she wants to download, which directs to a link. This link points to the meta-data .torrent file. The .torrent file contains information about the file and the IP address of the tracker. The meta-data files point to the tracker. The tracker contains information of all the Seeds and the Swarms in the network for the particular file. The downloader tries to connect with the peers in the network using handshaking and if successful proceed with the process of sharing.

Connections contain two bits of state on either end: choked or not, and interested or not. Choking is a signal that a Swarm peer is not intending to send new user any data, until the new user is unchoked. Interested means that swarm peer has data that a new user in the network does not have, and the new user wishes to acquire.

Therefore, the data transfer takes place whenever one side is interested and the other side is not choking. The interested downloader then connects to the other peers in the network using the information from the tracker and starts downloading. During the data transfer, the downloader keeps the file piece requests queued up at once in order to get good TCP (Transmission Control Protocol) performance. Requests for data transfer that can't be written out to the TCP buffer immediately are queued up in memory. If both sides don't send the same value in the TCP, they break the connection. In case of a successful file transfer takes place. Once a peer completes downloading all the components of the file, it possesses a complete copy of the file and behaves as a Seed.

Peer and piece selection are the two main strategies used for peer to peer file replication. The choke algorithm is the peer selection strategy used in BitTorrent. The algorithm is also called the tit-for-tat algorithm. The Rarest first Algorithm is the piece selection strategy used in BitTorrent.

2.2.3 Algorithms

1. Choking Algorithm

   Choking algorithm is the strategy used to select peers in a peer-to-peer network. The choking algorithm avoids free riders by making sure whether the peer which downloads the file also uploads and ensure two way traffic of data transfer. The choke algorithm changes from leecher state to seeder state.

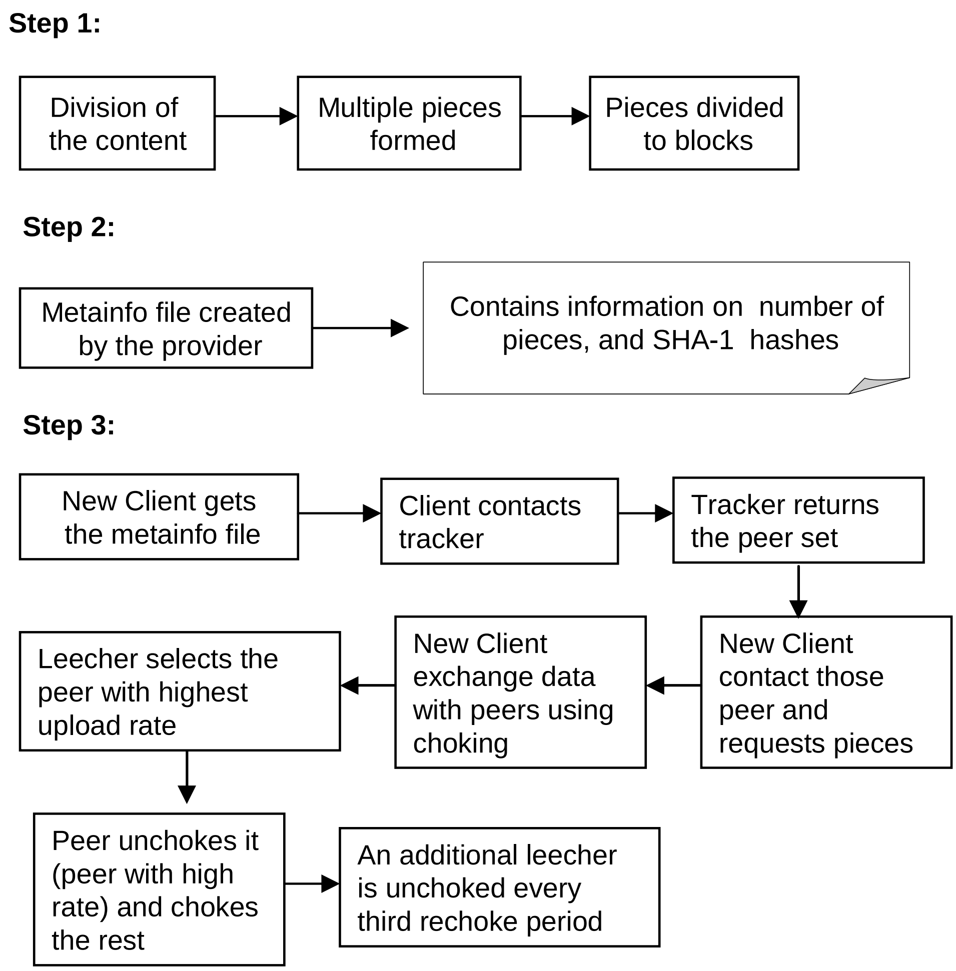

Figure 2.9. BitTorrent Working Principle

(a) Leecher State

In leecher state [10], four peers in the network can be unchoked and interested simultaneously. Peers can be unchoked as thus.

i. After every 10 seconds, depending upon the download rate, the peers are ordered and three peers with fastest download rate are unchoked.

ii. After every 30 seconds, another peer who is interested is randomly unchoked. It evaluates the download capacity of the new peers in the peer set and help new peer to start by giving them their first piece

(b) Seed State

In Seed state [10], four peers in the network can be unchoked and interested simultaneously. Peers can be unchoked as thus:

i. Every 10 seconds, the peers are ordered as recently unchoked peers first.

ii. For two 10 seconds period, the first three peers are kept unchoked and the fourth one which is choked and interested is unchoked.

iii. For the third 10 seconds period, the first four peers are kept unchoked.

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 removed from the peer set, rarest pieces set of a peer is updated. The steps are as thus [10]

(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.

Fig 2.10 below shows the peer-to-peer network implementing BitTorrent with one server, one tracker and many clients.

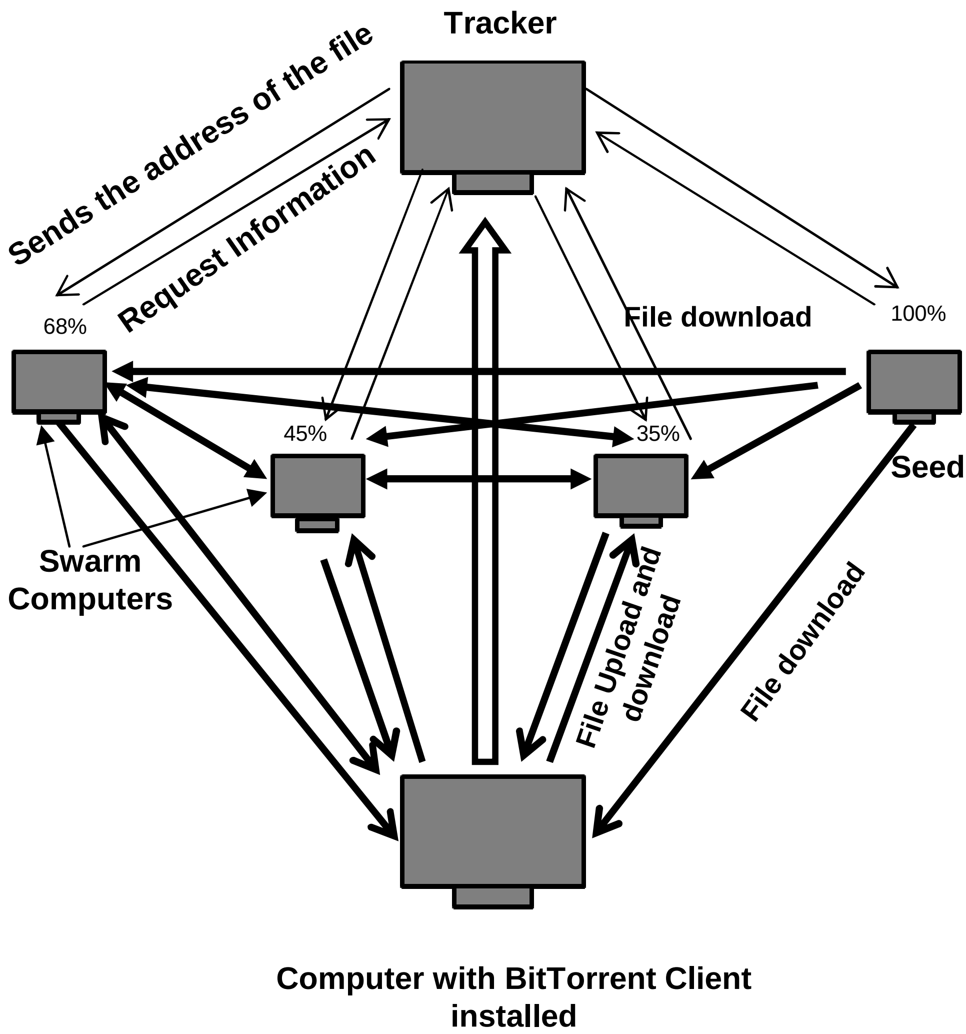

Figure 2.10. BitTorrent

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.

But, there are certain drawbacks of 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, presence of optimistic unchoke allows greedy node to download from the fastest peers, send fake pieces at slow rate and receive valid piece [6]. They may also even lead to deadlock or starvation. So, we implement Game Theory along with BitTorrent.

Chapter 3

OPTIMIZATION AND GAME THEORY

Optimization is a method of determining the best solution for a mathematical problem. It has its application in the branch of business, science and technology. It consists of study of optimality problem, deciding the algorithm to be used and computer simulations using those algorithms. For example an objective function to be optimized may be profit from the sale of any material. The variables will be cost price, sell price, buyer's price, seller's margin and these variables depends on some factors known as constraints. The price cannot be negative and the selling price depends on the bargaining between the seller and the buyer. This is constraint optimization. But, if an optimum value is found from an objective function without constraints, then it is known as unconstrained optimization.

Game Theory was introduced by mathematician John Von Neumann. Game Theory studies the different strategies that players play in a game producing outcomes depending on their utilities or preferences. All the players will try to maximize their utilities. A game can be co-operative game and non-cooperative game. Cooperative games are such games in which players cooperate with each other by following some set of defined rules. The players communicate with each other. But, non-cooperative games are such games where the players do not co-operate and they are focused to achieve their own goals. Players do not communicate in non-cooperative game.

In this section, we will discuss about Optimization and Game Theory. Section 3.1 provides brief information about Optimization and the general terms used in optimization. In section 3.2, we discuss on different types of programming. Section 3.3 talks about the Game Theory where section 3.3.1 will give the basic background about Game Theory, section 3.3.2 introduces different popular terms used in Game and section 3.3.3 will explain different types of Game.

The following section describes about Bargaining. Section 3.4.1 discusses about Bargaining, section 3.4.2 explains the different types of Bargaining. In next section 3.4.3, it talks about the bargaining solution and finally in section 3.4.4 discusses on types of Bargaining Solutions.

3.1 Optimization

Optimization is a method where the real function is either maximized or minimized using the real or integer values within the constraints. Optimization uses simulations and is implemented in various fields to control the systems and game theory is used to model those designs. Optimization makes a design better and efficient. It associates the objective function to agent. Optimization plays a vital role in economics, network analysis and various branches of science.

If a function $F : N \rightarrow R$ where N is a set to the real numbers R

Definition 1

Minimization, If x *is an element in set* N *such that* $F(x) \leq F\left(x^{'}\right)\ \forall x^{'} \in N$

Definition 2

Maximization, If x *is an element in set* N *such that* $F(x) \geq F\left(x^{'}\right)\ \forall x^{'} \in N$

This kind of formulation is known as Optimization problem. It has different parts: objective function, variables and set of constraints [22]. Objective function is a function which we want to minimize and maximize. Variables are the parameters in the objective function. Constraints in a function set the limit for the variables.

- Convex and Concave Function

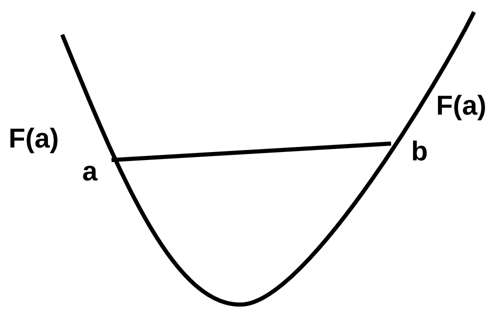

Figure 3.1. Convex Function

If a line is drawn joining two points $(a, F(a))$ and $(b, F(b))$ lies on or above the plot of function F, then the function is called convex function. The Fig 3.1 represents the convex function. Convex function considers a unique minimum value.Convex function considers a unique minimum value. A function F is concave if -F is convex.

- Convex and Concave Optimization Problems

  If the constraints are convex functions, and the objective function is a convex function when minimizing and concave function when maximizing, such problems are convex optimization problem.

- Non-linear Optimization

  The optimization problem where the objective function or the constraints are not linear is known as Non-linear optimization. Non-linear optimization is also known as Non-linear programming.

- Convex Set

  A pair of points from a set of vectors or points in an object when connected if lies in a same straight line then it is known as convex set. Any point lying inside a solid object will be a part of convex set but if a line passes through the space as in a crescent object, then the points on that line do not belong to convex set. It is represented in Fig 3.2.

- Convex Optimization

  A convex optimization problem is one of the form

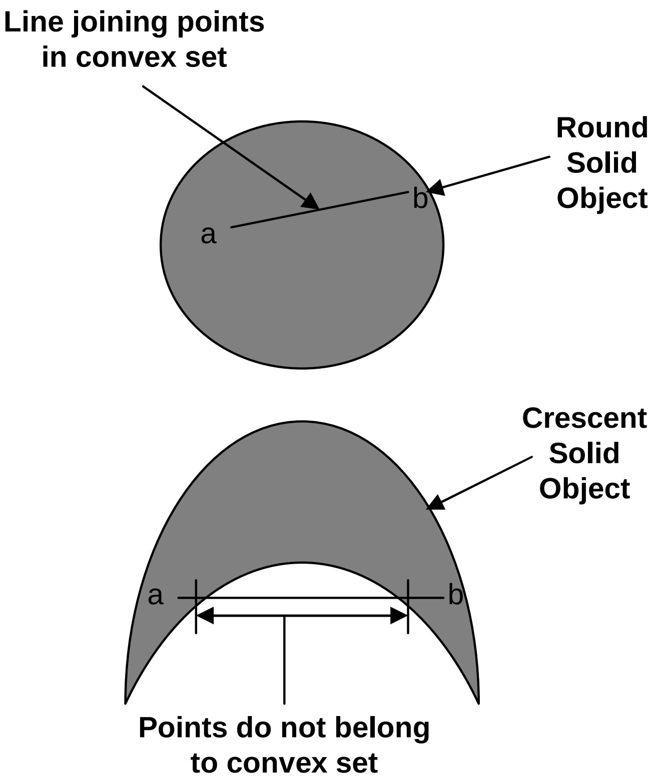

Figure 3.2. Convex Set

Minimize,

$$f_0\,(x) \tag{3.1}$$

subject to

$$f_i\,(x) \leq b_i \tag{3.2}$$

where $i = 1, ..., m$ and the functions $f0, ..., fm : X \rightarrow R$ are convex.

Convex optimization helps us to solve least squares and linear programming problems. Interior point method is one of the ways to solve Convex Optimization

Problems. The interior point methods for non-linear convex optimization is still under research.

In Convex Optimization, if $\aleph$ is a real vector space together with a convex, real-valued function

$$f : \chi \rightarrow \Re \tag{3.3}$$

where, χ is a convex subset of $\aleph$

We need to find the point x^* in χ for which the number $f(x)$ is smallest, i.e.

$$f(x^*) \leq f(x) \,\forall\, x \in \Re \tag{3.4}$$

3.1.1 Duality

Each linear program termed as Primal is associated to other linear program termed as Dual. Duality is used a lot in numerical programming to provide with alternate solution. The original problem is known as Primal and the transformed one is known as dual. So, the usual of the dual is primal.

Maximize

$$Z_x = c^T x \tag{3.5}$$

$$\text{subject to } Ax \leq b, x \geq 0$$

The corresponding dual problem is:

Minimize

$$Z_y = b^T y \tag{3.6}$$

$$\text{subject to } A^T y \geq c, y >= 0$$

where y is used instead of x as variable vector.

Duality theorem is related to convex programming as primal. If the primal is not convex, then the dual problem may not have solution from which the primal solution can be derived. Langranges method is a dual method. It is used to locate the extrema of a function with the variables subject to constraints. It is used in non-linear constrained optimization. .

3.2 Unconstrained Optimization

Unconstrained optimization is a method of finding out the optimum value of an objective function with multiple variables and no constraints. The main focus will be to find a local minimizer. In unconstrained optimization problem, the real-valued function $F(x)$ is minimized where x is a vector of n real variables

$$F(x') \leq F(x) \tag{3.7}$$

where x' and x values are very close.

There are different methods for Unconstrained Optimization. Gradient method is suitable for functions whose derivative is linear and Newton method is efficient when the second order information is easily calculated.

3.2.1 Gradient Descent Method

This method is used to find the local minima of a function. In it, steps are taken negative of the gradient of the function at that instant point. It is also known as Steepest Descent method and it is represented in Fig 3.3.

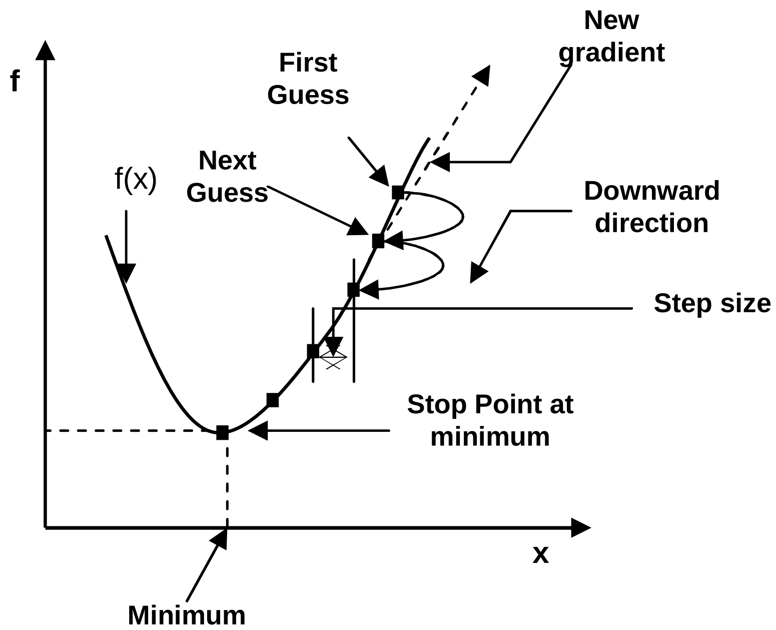

Figure 3.3. Gradient Descent Method

The algorithm for Gradient Descent is as follows:

1. Start with a point.

2. Select a direction.

3. Choose a step.

4. Update.

5. Repeat until stopping criteria is satisfied.

3.2.2 Newton Method

Newtons method is also known as Newton-Raphson method. It is an algorithm used for finding the roots of the complicated equation and it can also be used to find the local maxima or minima of the functions. It is represented in Fig 3.4.

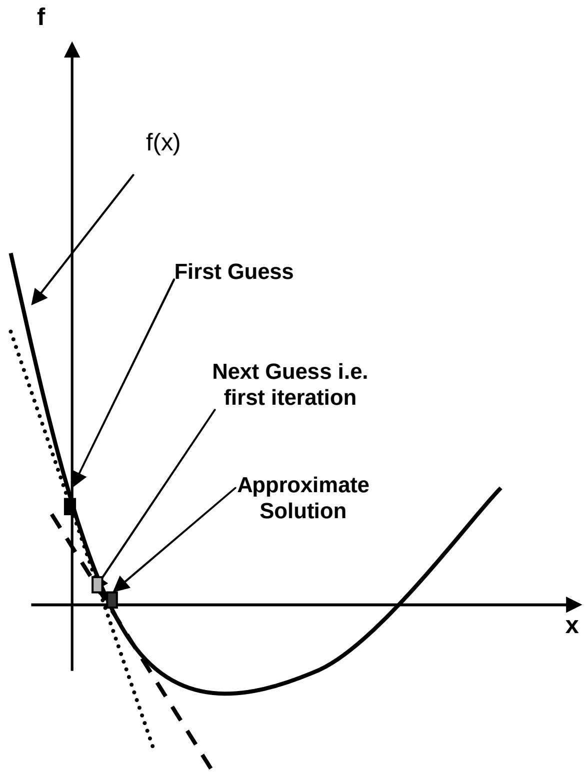

Figure 3.4. Newton's Method

Newton's algorithm

1. The equation is written in a form $f(x) = 0$.

2. The derivative f '(x) is evaluated.

3. An initial guess for the root of x is made, and a new value of x is computed as

$$x_{i+1} = (x_i - 1) - \frac{f(x_i - 1)}{f'(x_i - 1)}. \tag{3.8}$$

4. If the root exists, and $f'(x_i - 1)$ is not zero, each calculation solves for values of x_i which converges towards the roots of the equation.

5. It is continued until $(abs(x_{new} - x_{old})) \leq (limit)$ where limit can be value close to zero or if it doesn't converge, number of iterations can be set to a constant value.

3.3 Constrained Optimization

Constrained optimization problems are such problems in which function $F(x)$ is maximized or minimized and is subject to constraints. Constraints can be equality constraints or inequality constraints. The main objective of Constrained Optimization is to convert the problem to a simple problem such that it can be solved by iteration process. There are different methods for solving Constraint Optimization. Some of them are Substitution method, Langranges multiplier and Kuhn-Tucker Theorem.

3.3.1 Interior Point (IP) Method

Interior Point Method is also known as Barrier Method. It is used to solve both linear and non linear convex optimization problems. It has its impact on linear programming, quadratic programming, convex programming. Interior Point Method can be used to solve non linear problems either by implementing IP method directly or by implementing sequential linear programming or sequential quadratic programming. IPM can be classified into three classes. They are projective methods, affine scaling methods and prime dual methods.

3.4 Popular Types of Programming

There are different types of programming. In this section, we will discuss on Linear Programming, Quadratic Programming, Non-linear Programming, Convex Programming, Integer programming, Geometric Programming and Dynamic Programming.

3.4.1 Linear programming

Linear programming (LP) is minimizing or maximizing of the linear objective function. It determines the method to get the best outcome. It can be used in economics and in engineering applications. It is used in business to maximize income and minimize cost. It is a special kind of convex optimization. Linear problems are convex and linear programming problems are convex problems. The standard form of linear programming consists of a linear function, problem constraints and non-negative variables. The standard form is given as:

Linear function:

$$\min \ cx \tag{3.9}$$

Constraints: subject to

$$Ax = b \tag{3.10}$$

Non-negative variables:

$$x \geq 0 \tag{3.11}$$

where, x is the vector of variables , A is a matrix of known coefficients, and c and b are vectors of known coefficients.

As the number of variables and constraints increases, the number of extreme points also increases. The extreme points refer to feasible solution of the objective function. So, to provide systematic way to organize data, and remove the complexity due to large data, we use an algorithm known as Simplex Algorithm. It is an algorithm for finding out the solution for a linear programming model.

Simplex Algorithm

1. Compute initial BFS (Basic Feasible Solution) solution.

2. Test optimality.

3. If the optimality condition is verified, go to step 5 else go to step 4.

4. Identify adjacent BFS with better objective value and then go to step 2.

5. Stop.

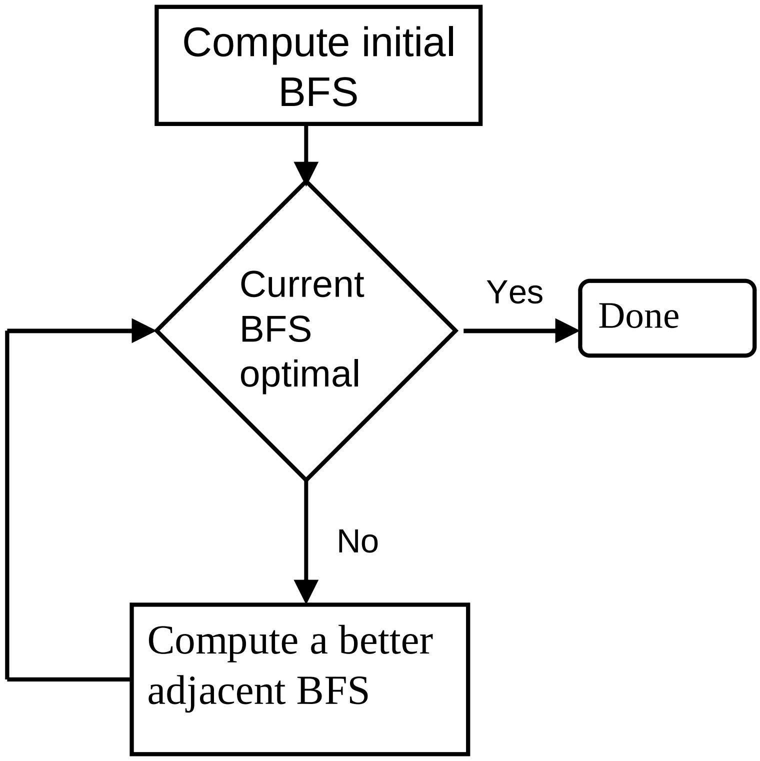

Figure 3.5. Simplex Algorithm

3.4.2 Quadratic Programming

In Quadratic programming, the objective function is quadratic and the constraints are linear.It is different from linear programming due to the possibility to have no inequality constraints in Quadratic programming. Mathematically, it is given as

Minimize,

$$q\left(x\right) = \frac{1}{2}\ x^TGx + g^Tx \tag{3.12}$$

subject to $A_ix = b_i$ (*equality constraint*)

where G is a symmetric matrix and $i = 1, 2, \ldots m_n$

subject to $A_ix \leq b_i$ (*inequality constraint*)

where $i = m_n + 1, \ldots, m$

3.4.3 Non-linear Programming

Non-linear programming (NLP) is a process of solving the constraints, maximizing or minimizing the objective function with set of unknown variables where the objective function or constraints are non-linear [25]. The programming which deals with solving of equalities and inequalities where the objective function or the constraint are non-linear is known as non-linear programming. It is implemented in data networks, production planning, and resource allocation. One of the problems in NLP is that some problems have local minima that do not satisfy the requirements of derivatives on functions. Local minima and maxima are shown in Fig 3.6.

The standard form is given as

$$\min\ F(x) \tag{3.13}$$

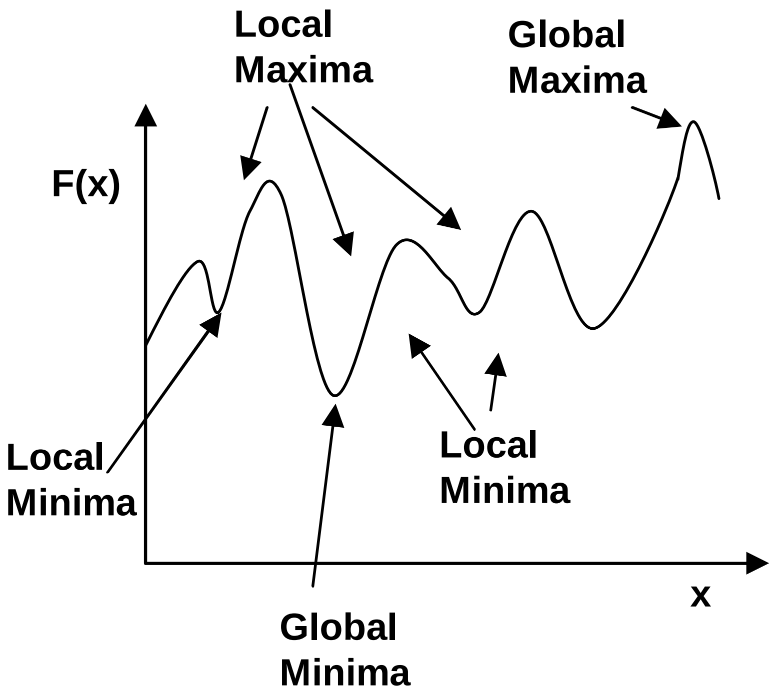

Figure 3.6. Demonstration of Local Minima and Global minimam

$$\text{subject to } g_i\left(x\right)=0$$

for $i=1,\ldots,m1$ where $m_1 \geq 0$

$$h_j\left(x\right)\geq 0$$

for $j=m_1+1,\ldots,m$ where $m\geq m_1$

Simulated Annealing

It is a method of optimizing a problem and locating a global optimum value of the given function. In this method, we have to define a starting point and then minimize in some direction and proceed. The problem it faces is that it can get trapped in local minima while a global minimum exists, as shown in figure above. The solution would be to select a different starting point. So, it is a slow method.

Convex Programming

Convex programming is a class of Non-linear programming. It is efficient and consists of strong numerical algorithms. It combines and simplifies least squares (LS), linear programming (LP) and Quadratic Programming (QP) [26]. It is getting more popular because of its high level of proficiency in performing convex analysis and numerical algorithms required to use it.Convex programming consists of a convex set $F \subseteq R'$ and a convex cost function $cf : F \rightarrow R$. The objective of convex programming is to find the point F which minimizes cf [27].

3.4.4 Integer Programming

Integer programming (IP) is the study of linear programs, where the unknown variables are all integers. If some variables can take integer and some can take floating point numbers, then it is called Mixed -integer programs. Integer programming is usually NP-hard i.e. nondeterministic polynomial-time hard.Usually when decisions are discrete like yes or no, integer programming is used. The standard form is given as

$$\min \ cx \tag{3.14}$$

subject to

$$Ax = b \tag{3.15}$$

$$x \geq 0 \tag{3.16}$$

3.4.5 Geometric Programming

Geometric Programming is a non linear non convex optimization problem but it can be transformed to convex optimization problem resulting in simplification. It has wide applications in non linear systems in science. Geometric programming can be represented in two forms. They are standard form which is implemented in network resource allocation problems and convex form applied in stochastic models.The standard form can be represented as

$$f : R^n + + \longrightarrow R :^1$$

$$f(x) = dx_1 a^{(1)} dx_2 a^{(2)} \ldots dx_n a^{(n)}$$

where $d \geq 0$ and the exponential constants $a(j) \in R, j = 1, 2, \ldots, n$

The convex form can be represented as

$$\min \ f_0(x) \tag{3.17}$$

subject to

$$f_i\left(x\right) \leq 1, i = 1, 2, \ldots, m$$

$$h_l\left(x\right) = 1, l = 1, 2, \ldots, M$$

3.4.6 Dynamic Programming

Dynamic programming is the method of solving such problems which can be broken down into sub-problems or such problems whose optimal solutions can be built from optimal solutions to its sub-problems. The objective of dynamic programming is to minimize cost function. The cost function is the mathematical expression for the undesirable outcome. Decisions are made in different stages and these decisions determine the state. Each decision results to a cost. Dynamic programming returns global minimum and it is an optimal method.

3.5 Game Theory

3.5.1 Introduction

Game theory is a branch of applied mathematics and economics where two or more parties are involved and they bargain using structured methods or strategies resulting in certain outcomes [29]. It developed in the latter half of the twentieth century.

These parties are also known agents. Each of these agents tries to maximize their utilities using some strategy. Utility is the satisfaction a consumer attains from the use or consumption of any economically beneficial good or service. If the value of utility is high, the outcome is more preferred. The interaction between these agents using their strategies results in different utility payoffs with varying action and this interaction is termed as "Game" and the agents involved are termed as "Players" [30].

In Game Theory, we make certain assumptions. First one is payoffs are known and are fixed, second one is all players behave rationally and the third one is rules of game are known to every player.

Game Theory has its application in wide range of fields like in biology, business, gambling. It can be used to study the past behaviors and investigate the problem and forecast in business and find out information on the price of the goods, profit and loss, and supply and demand. It will help in good management and planning. Military also use Game Theory to build up strategy for wars.

3.5.2 Terms in Game Theory

- Strategy

  It is a plan that the players implement for their benefit and it is the best option for them to attain maximum benefit for them under the rules of the game.

- Payoff

  Payoff in a game is the outcome or result of the game.

- Pareto Optimal

  Pareto Optimality measures the efficiency of the game. The outcome of a game will be pareto optimal if every player of the game is well off with at least one player in better off condition.

- Extensive Form

  Extensive form of games is governed by rules that control all possible moves in the state.

- 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 co-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 stay quiet and deny, then both will be sentenced to jail for one year. If one confesses and accuses other for the crime but the other does not confess, 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

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

TABLE 3.1 Prisoner's Dilemma (Normal Form)

and denying. The 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 payoff of B.

- Nash Equilibrium

It is named after John Nash. It is an equilibrium state when change in strategy by any one of them would lead that player to be at disadvantage than the player remained with the current state. In Nash equilibrium, for prisoner's dilemma, both players confess.

- Subgame Perfect Equilibrium

A subgame consists of braches that come from a point. Subgame Perfect Equilibrium is an equilibrium state in dynamic games which comprises of Nash Equilibrium for every subgame of the main game. Backward induction method is used to determine subgame perfect equilibrium.

- Pareto Efficient

The outcome of the game is Pareto Efficient if there is no other outcome or no other way of rearranging actions such that one player will be better off without reducing the utility of the other player and making her worse off [31]. It is also known as Pareto Optimal. For example, if player A has all the goods of brand XYZ then its outcome will be Pareto Efficient since it is impossible to make other players better off without taking away belongings of A and making her worse off.

- Normal and Extensive Form

  A game can be represented in tree diagram or in tabular form. If it is represented in tree diagram then it is known as extensive form and if it is represented in tabular form, it is known as normal form. The representation in tabular form as shown in Prisoner's Dilemma is the normal form. The game is represented in table with the payoffs for different strategies.

  In extensive form, the game begins at some node and it passes through different states and the path followed depends on the decision of the players. Each branch represents the decision point or decision node. The point where the game ends is known as terminal point.

  For example, if there is a mobile phone company "NTC" in city Kathimi and a new company "UTLP" is planning to launch its service in the same city. NTCP has two options. One is to lower its charge for its customers so that it will drive away UTLP. Next option is to reduce the supply of number of lines and keep the prices constant providing some space for UTLP. The figure below represents the extensive form.

Let 10 be 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. The Fig 3.7 represents the extensive form.

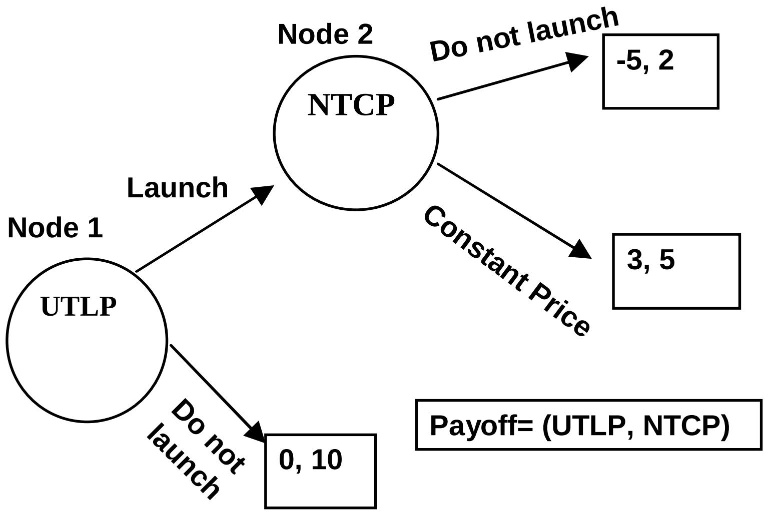

Figure 3.7. Extensive Form

3.5.3 Types of Games

Non cooperative game

Non-cooperative game is a game where the players are not allowed to communicate before the game starts. The players play for themselves with the sole purpose to achieve their goal. We cannot determine best choice for strategies because there is no unique solution. In this, the players are not able to make contracts. In it, players do not co-operate.

Repeated Game

If the players play the same game multiple times, it is called a repeated game. Strategy depends on the past games and the player's reputation will be affected, that is their 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 payoff of 2. The payoff of 0 is better than payoff of -1 ,so A will not have hair cut. The repeated game is represented in Fig 3.8.

But, if A will tend to 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 his job. If B messes up the 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.

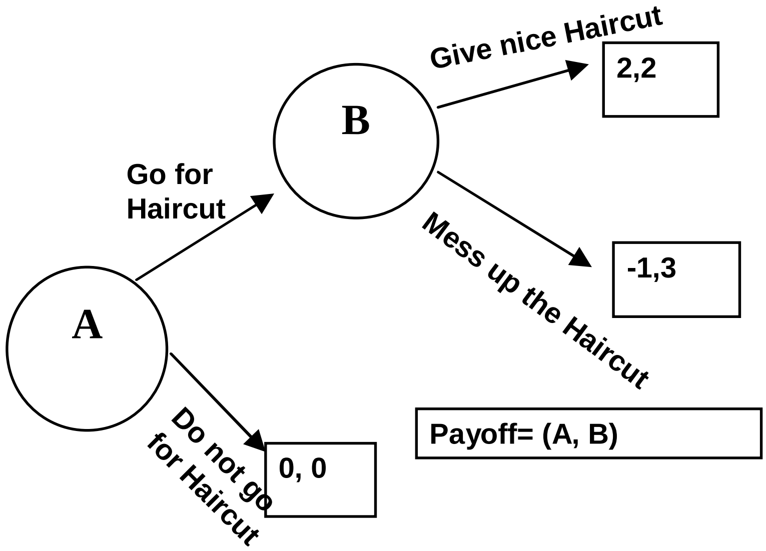

Figure 3.8. Repeated Game

Cooperative game

Cooperative game is a game in which the players can communicate with each other and make binding agreements. These agreements can be either to co-ordinate with each other or to share the payoffs. The agreement can be complete agreement or partial agreement.

Let us assume that there are two person named Kamala and Bimala. Kamala has a video game but she wants money 150 dollars and Bimala has 200 dollars and wants a video game. So, both of them will either keep what they have 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 video game and 30 dollars. The payoff table is shown in Fig 3.9.

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

Figure 3.9. Cooperative Game

So, if both of them keeps, then it is dominant strategy equilibrium. But, if both give, they are better off and result in co-operative solution.

3.6 Bargaining

3.6.1 Definition

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

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 at. If the transaction takes place at price between 600 dollars and 800 dollars, then both players A and B are better off. Simultaneously, A will try to trade at lower price while B will try to trade at higher price and this conflicting situation in trade introduces bargaining. Most of the time, bargaining is time consuming as the players make offers and counteroffers.

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

3.6.2 Types of Bargaining

Nash Bargaining

In 2-person bargaining problem, if X be the set of possible agreements and x will be the subset of X where x is the set agreed by both players.If $u1$ and $u2$ be the utility functions, then the bargaining problem is given by

$$(B, b') \tag{3.18}$$

where

$$B = (u_1(x), u_2(x)) : x \in X \tag{3.19}$$

and

$$b' \in B \tag{3.20}$$

b' is the parameter that maximizes the Nash product $(b1 - b1').(b2 - b2')$ [28].

Collective bargaining

Whenever multiple players or workers bargain collectively, then such process of bargaining is called collective bargaining. Workers come together and they negotiate with their employer or the opposite party as a group.

Cooperative bargaining

Cooperative bargaining is a bargaining game where multiple groups of players cooperate with each other. The players coordinate with each other and will try to get mutual gains.

3.6.3 Bargaining Solution

Bargaining solution is the way in which the players divide the outcome. Bargaining solution should be invariant to affine transformations, pareto optimal, independent from Irrelevant Alternatives and symmetric. A Bargaining Solution is mathematically given as,

$$F : (X, d) \in S \tag{3.21}$$

where $X \in R$ and $S, d \in R$

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

Any Bargaining Solution should satisfy following four axioms:

1. Pareto optimal: NB(S) should be a Pareto optimal solution point.

2. Invariant to affine transformation: NB(S) is invariant even if the utility is multiplied by a positive constant.

3. The transformation can be defined as

$$T(x) = Ax + b. \tag{3.22}$$

   A bargaining solution is independent of affine transformation If NB(S) =S' and NB (TAb (S)) = TAb (S').

4. Symmetry: The bargaining solution is symmetric if the utilities of the players are symmetric

$$\begin{aligned} NB(S) = x + y \leq 1, \\ x \geq 0, \\ y \geq 0, \\ d = (0,0) \\ . \end{aligned}$$

   So, the bargaining solution will be $(0.5, 0.5)$ and the plot will be as shown in Fig 3.10.

5. Independence of the irrelevant alternatives: If S is Nash bargaining solution

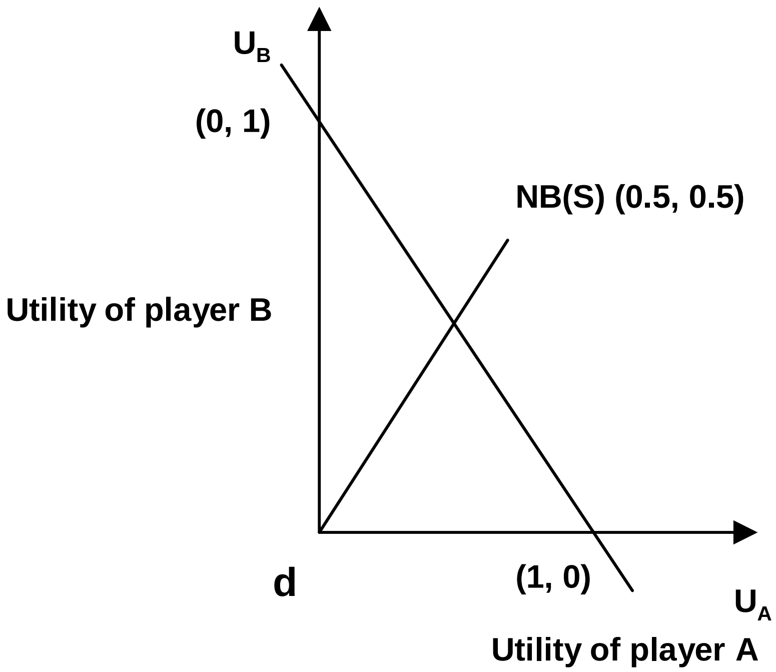

Figure 3.10. Symmetry

for set X, and if x is subset is X and contains NB(S), then S will be the Nash Bargaining Solution of x as well. It is represented in Fig 3.11.

3.6.4 Types of Bargaining Solution

Nash Bargaining Solution

In Nash Bargaining, players offer their prices and will try to negotiate on 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 continue with new offers until one of the players accept the offer

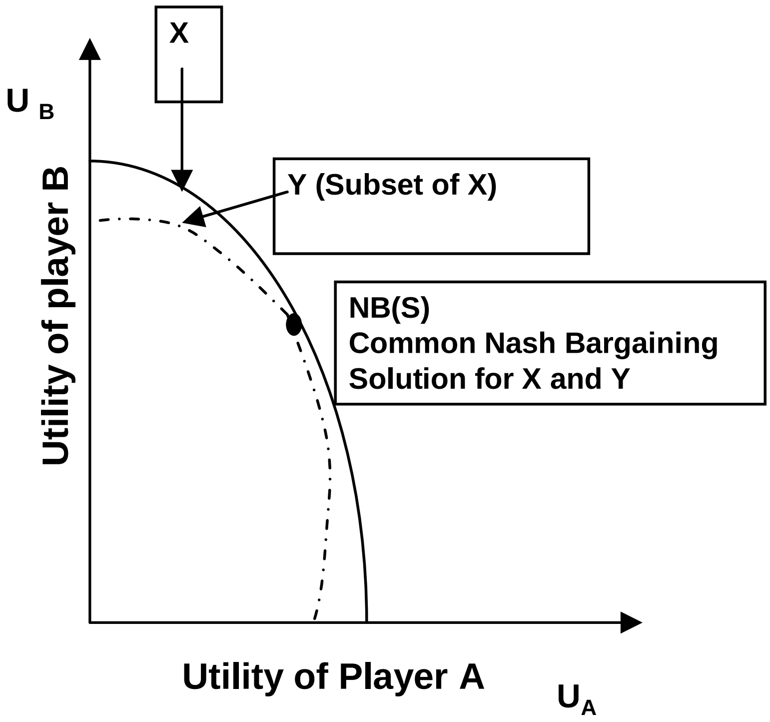

Figure 3.11. Independence of the Irrelevant Alternatives

[28].

Let $u_1(x)$ and $u_2(x)$ be the utility functions of the two players and x is a point of mutual agreement. If the players negotiate in time t at x', their payoff will be $(d_1u_1(x'), d_2u_2(x'))$. The Subgame Perfect Equilibrium for this game is defined by x' , y' such that

$$d_1u_1(x') = u_1(y')$$

$$d_2u_2(y') = u_2(x').$$

Player A offers x' and accepts any offer that is at least y'. Similarly, player B offers y' and accepts anything that is at least x'. If $d_1 = d_2 = d$, then this is a symmetric game.

Nash Bargaining Solution is similar to the solution of the symmetric game with alternating offers.Nash product is,

$$g(x) = (x_1 - d_1) * (x_2 - d_2) \tag{3.23}$$

where d_1 and d_2 are the utilities at the disagreement point when one of the player decides not to bargain with the other player.

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 [33]. For example, if we consider the following Fig 3.13, the utility of player A is maximum whereas of B is around 70 percentage, hence the payoffs are not equal.

So, Kalai and Smorodinsky (1975 modified the fourth axiom of Nash by monotonicity axiom [32] as if the set S is increased so that the maximum utilities of the players remain unchanged, then the players will not suffer from it.

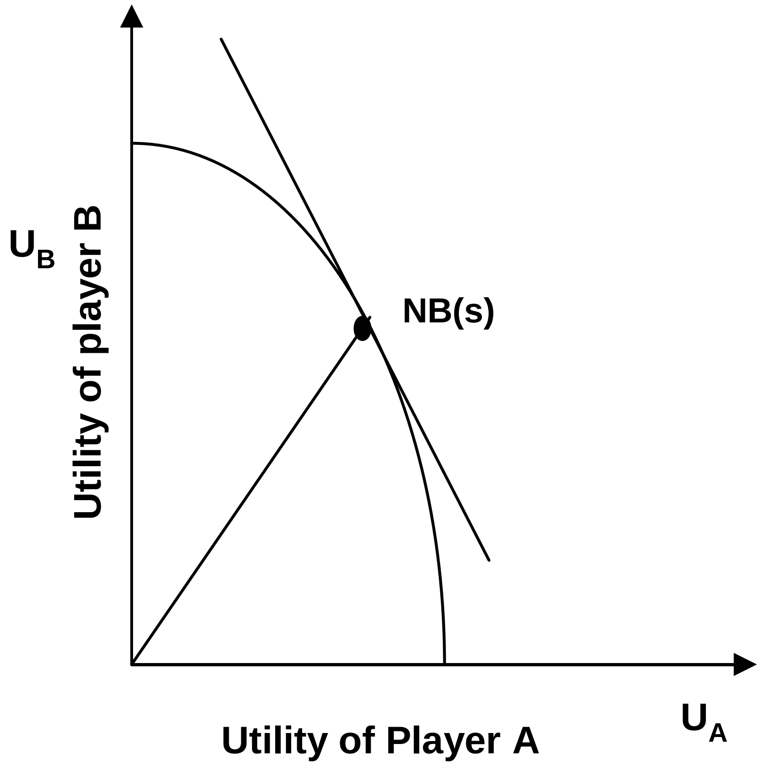

Figure 3.12. Nash Bargaining Solution

Monotonicity Condition

Monotonicity is the property of the monotonic function which conserves the current condition or state.

According to the axiom of monotonicity, if for every utility level that player 1 may demand, the minimum feasible utility level that player 2 can simultaneously reach is increased, and if the maximal utility level that player 1 may demand remains unchanged, the utility level assigned to player 2 in the arbitrated solution must also be increased.

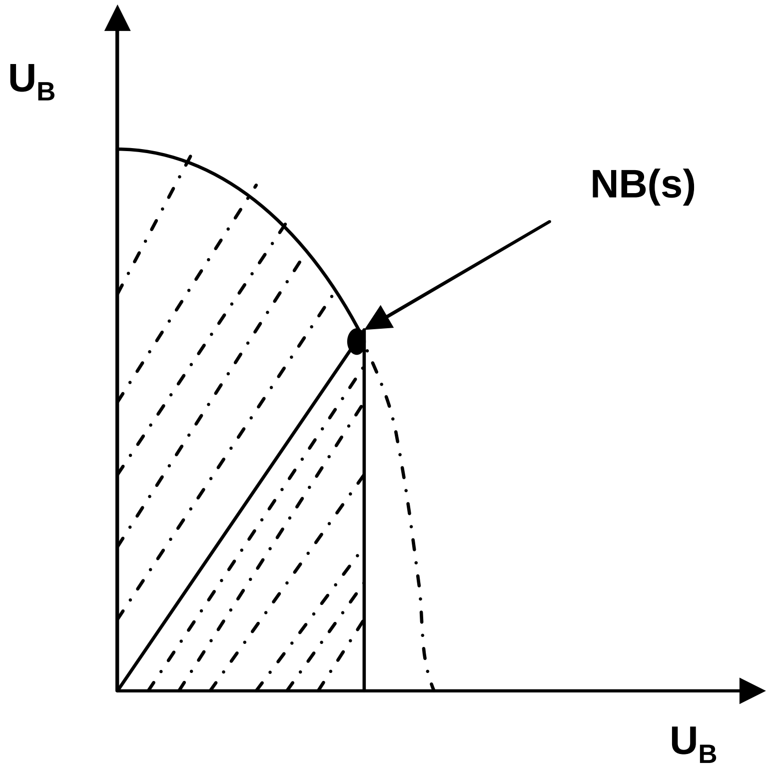

Figure 3.13. Unequal Utility

A solution Z is monotonic if an allocation A that is chosen at preference profile R is also chosen at a preference profile R' where A is considered (weakly) better by all agents.

Mathematically,

$$R' \in R,\ A \in W(R)$$

$$R' \in MT(R, A) \longrightarrow A \in W(R').$$

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 3.14.

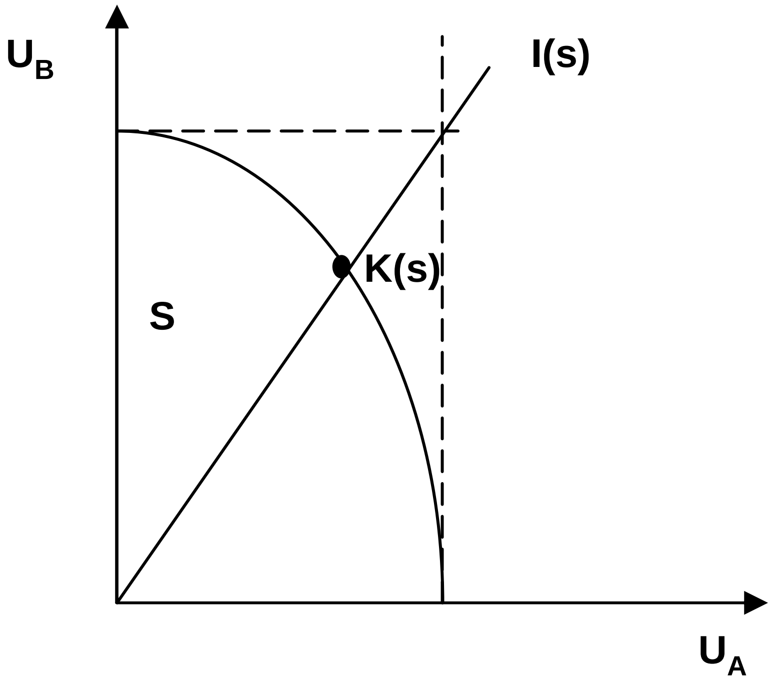

Figure 3.14. Kalai and Smorodinsky

E. Kalai and M. Smorodinsky introduced an alternate solution by replacing Independence of Irrelevant Alternatives by appropriate monotonicity condition. The solution they proposed maintains the ratios of maximum gains. If G1 and G2 be the maximum gains of players A and B, then the Kalai-Smorodinsky bargaining solution will result in point S such that

$$\frac{S_1}{S_2} = \frac{G_1}{G_2} \tag{3.24}$$

If co-operative 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 [**?**]. If a game is concave but not additive, then the

The egalitarian solution (Kalai (1977)) En is,

$$for\ each S \in X_n,$$

$$En\,(S) - \{X \in SIX_i = X_i\}$$

$$\forall i, j = 1, n\ and\ ay \in S$$

$$such\ that\ y >> x$$

Chapter 4

WIRELESS ACCESS IN VEHICULAR ENVIRONMENTS (WAVE) TECHNOLOGY

4.1 Vehicular Communications

Wireless vehicular communication implements internet so that there is wireless connection among vehicles and also other support systems to facilitate exchange of information. It is an emerging technology which provides safety and efficiency in transportation system. There are two types of devices involved in vehicular communication; Road Side 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. These units are also known as nodes. The communication takes place between vehicles and RSUs. Information about traffic congestion, safety, and accidents are shared and transferred among different nodes. Both types of these units are Dedicated Short Range Communications (DSRC) devices and operate at frequencies of 5.9 GHz. Vehicular network is also known as Vehicular Ad hoc Network (VANET). VANET is a Mobile adhoc network which provides communication between the devices.

Vehicular communication networks have various applications. One of the main applications is providing safety in the traffic system by exchanging information on accidents, warnings, traffic congestion, speed limits, etc. It can also be used for electronic toll and parking payment. Other applications of WAVE include finding information about different services; gas station, rest areas, maps, web surfing and sending emails. A vehicular communication network was developed under Intelligence Transportation System (ITS).

4.2 Intelligent Transportation System (ITS)

Over last few years, as traffic congestion increased, numbers of accidents have also increased resulting in massive human and economic loss. Most of these accidents are due to carelessness of the driver. Intelligent Transportation System (ITS) has been working on developing new services to improve safety. Intelligent Transportation System (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, 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 is a short to medium range wireless communication. 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 of 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. Fig 4.1 shows the DSRC Channel Allocation.

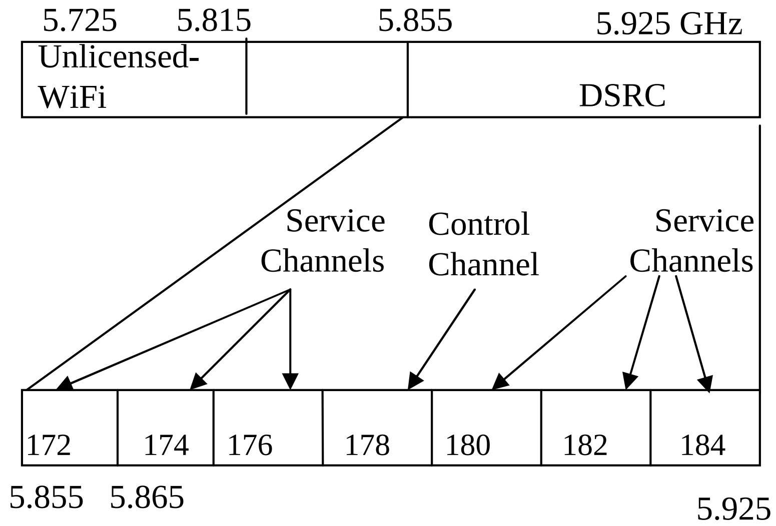

Figure 4.1. DSRC Channel Allocation

DSRC spectrum is divided into seven 10 MHz channels as shown in figure above. The data rate ranges from 6 to 27Mbps per channel [34]. For the time being, channel 184 has been planned for public safety and channel 172 for communications using

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

TABLE 4.1 FCC Designated DSRC Channels

High Availability and Low Latency (HALL). 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 and also between OBUs. RSU and OBU cannot transmit message simultaneously, so DSRC is half-duplex. The RSU and OBU can send message only when the channel is idle and will have to listen to the channel to confirm that the channel is not busy. 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. Internet protocol (IP) traffic data is not transmitted in control channel but in service channels. Table 4.1 provides information on FCC designated DSRC channels.

We will be discussing on the architecture of DSRC-WAVE, which is based on

IEEE draft standards. The vehicles consist of On Board Units (OBUs) and one vehicle can communicate with the other vehicle through OBUs using V2V (vehicle to vehicle) communication. These OBUs can communicate with Road Side Units (RSUs) located on the streets or highways through V2R (vehicle to roadside) communication. We will also discuss on V2V and V2R communication in next section.

DSRC has many applications. It can be implemented for safety purpose to reduce traffic accidents, to improve the traffic flow, internet access and downloads.

4.3.1 Elements in the architecture

On-Board Units (OBU)

On-Board Units (OBU) are located on the vehicles and act as both a transmitter and a receiver. The manufacturer of the OBU will be the license holder of OBU. 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. OBU is a part of On-board Equipment (OBE). OBE consists of processor, interface with vehicle services, human machine interface, GPS and the diagram is shown in Fig 4.2. The content of the data that the OBU sends has not been determined yet but it may contain ID, time, message type, location. 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 vehicle to vehicle 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.

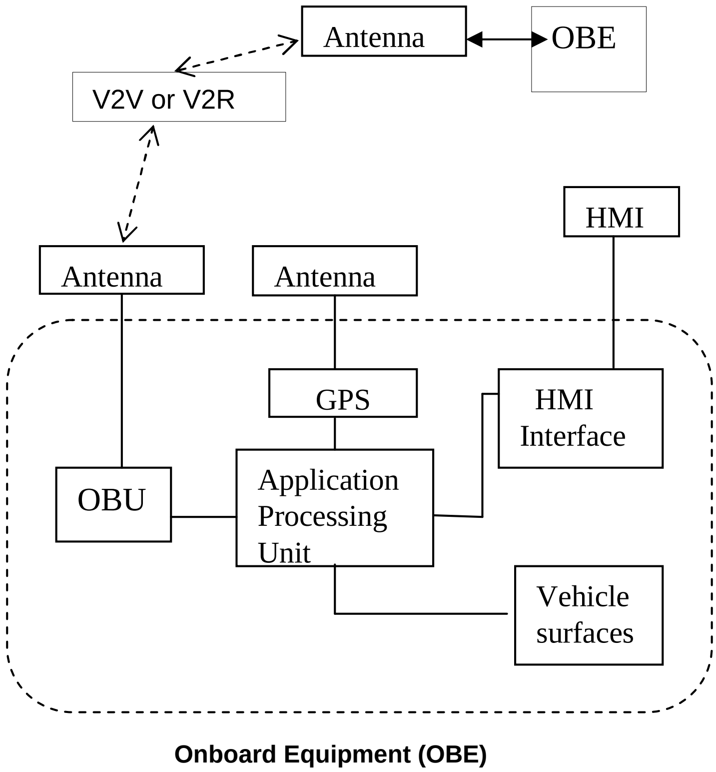

Figure 4.2. On-board Equipment (OBE)

Road-Side Units

Road-side Units (RSU) are usually stationary. They are distributed at different locations to collect data. They are usually located at points with high risk of accidents, intersections and other strategic locations. RSUs could be linked to the traffic system for sending warning signal on displays. An RSU sends and receives message from the OBUs that are within its range. RSU transmits Provider Service Table (PST) to

OBU and PST contains information on the applications in which RSU has interacted with. These applications can be safety applications in highways or intersections. The safety application would warn the drivers about condition of the road ahead, such as if there is construction going on, the road is slippery, there have been accidents ahead or emergency vehicle warning. These warning can be sent in the form of signs or through traffic detectors. Fig 4.3 represents the communication between RSUs and OBUs.

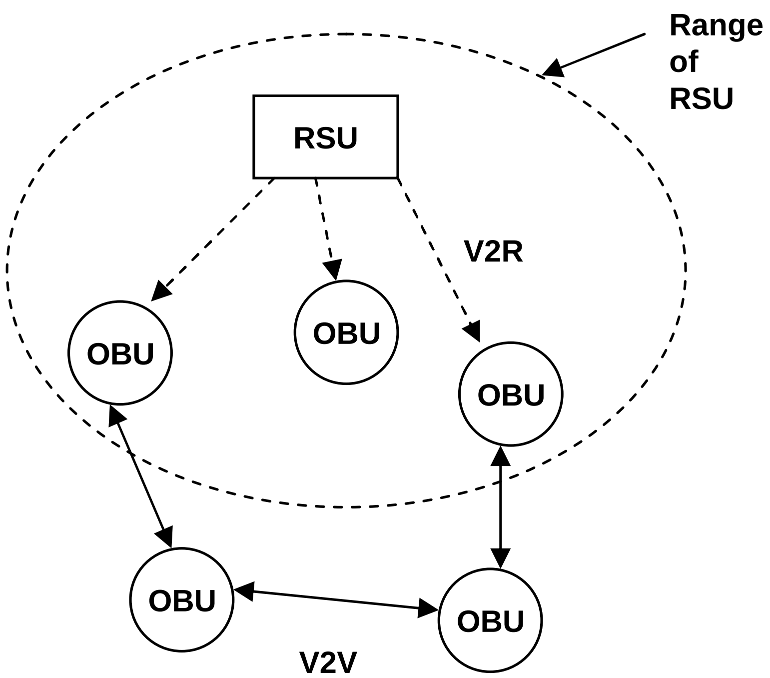

Figure 4.3. RSU and OBU Communication

Telecommunication Network

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

4.3.2 Types of Vehicular Communication

Vehicle to Vehicle (V2V) communication

Vehicle to vehicle communication implements Dedicated Short Range Communication (DSRC) to transmit data from one vehicle to other vehicle through OBU. In V2V, communication, OBU should send information about its status to other vehicle within its range and OBU will also receive information about other OBUs. It also uses GPS system along with wireless technology and provides warning on potential danger by asking the operator of a vehicle to take caution.

An example for V2V communication would be an electronic brake application which sends an alert to slow down to the driver when the driver ahead brakes suddenly. Referring to the Fig 4.4, in general case if vehicle 1 applies brakes to his car immediately, vehicle sees it and can take the necessary action immediately but vehicle 3 will not have information about the condition of the vehicle 1. So, vehicle 3 will only react after vehicle 2 applies the brakes. Hence, there is a delay and there is high possibility of accident. Vehicle to vehicle communication will allow a vehicle to send information to multiple other vehicles. In the example below, vehicle 1 can send information to vehicle 2, 3 and 4 that sudden brake is being applied so that they can take action to prevent possible hazard.

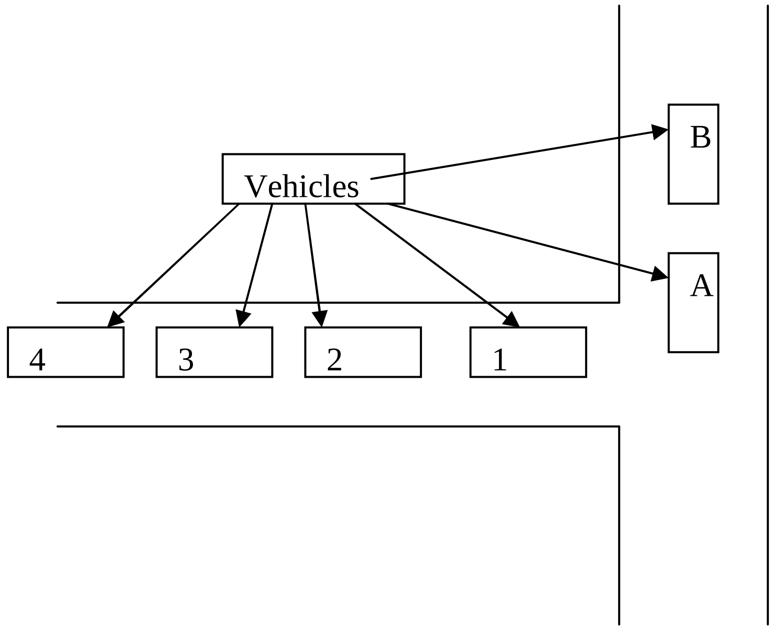

Figure 4.4. Electronic Brake Application

Vehicle to Roadside (V2R) communication

Vehicle to Roadside 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 message through OBU whereas the infrastructure transmits and receives message through RSU. It is primarily used for the application like toll collection. It uses TDMA (Time Division Multiple Access) architecture.

An example of V2I communication would be road bend warning like shown in Fig 4.5. If there is an accident at the end of the curve, and then another passing vehicle cannot see it. So, the vehicle that was involved in the accident will send a message to RSU in its range and The RSU will transmit information to another RSU which is in the passing vehicle's range. Then, this vehicle gets warning message about the coming curve and the accident and provides him with the opportunity to take necessary precaution.

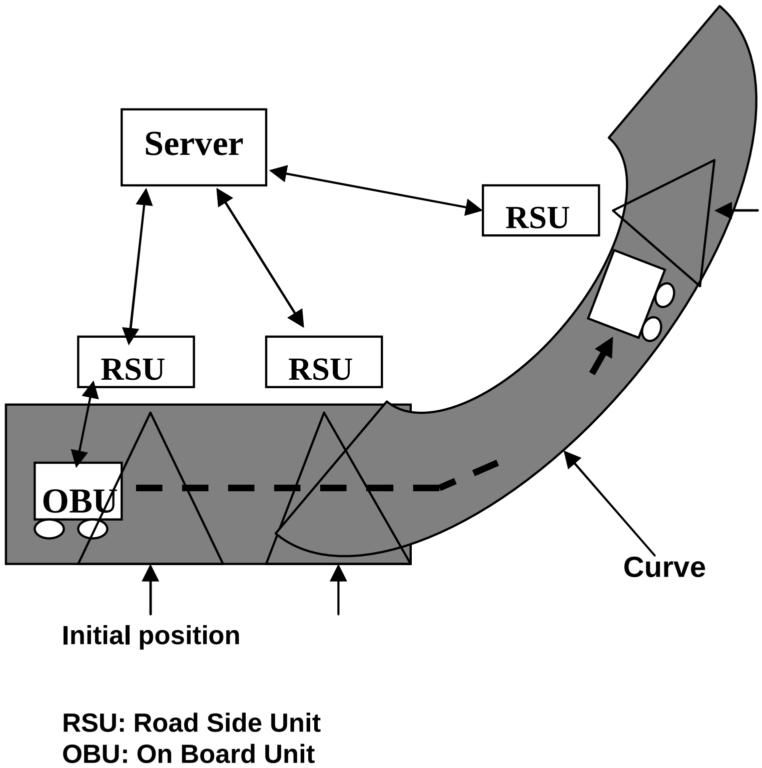

Figure 4.5. Curve Detection

Communication between OBUs and RSUs

The OBUs on the vehicles will collect data by exchanging information with other OBUs and when an OBU detects any RSU within its range, it will exchange data with RSU. In this way, RSU collects data from OBUs and RSU will forward the data to a switch. The switch like router will distribute the information in the network. If there is any danger on the way, then Traffic Controller department will send that information to the drivers. When a vehicle gets near to an RSU, all the information of the vehicle are transmitted to the RSU. These messages can be stored and later accessed by other vehicles.

RSU will send message using PST to all the OBUs in its range via DSRC channel 178 which indicates that RSU is available for different services. OBUs will send reply back for some information it wants to get on a particular application that it has. For example, if the "Sharp road turn detection" application is existing in an OBU, and RSU support that application, RSU will connect to security system which will find the information and send it to RSU.RSU will then transmit the message to OBU and the driver gets the information about the curve on the way.

4.4 Wireless Access for the vehicular Environment (WAVE)

WAVE stands for Wireless Access for the vehicular Environment. WAVE is a communication standard which will be used in inter-vehicular communication and is only a part of a group of standards of protocols for DSRC. There are teams working to control traffic congestion, avoid collision and provide weather, temperature information where 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 quickly changing environment and the exchange of information must be completed in very short time.

Wave uses multiple channels concept. In U.S and Europe, WAVE technology uses frequency of 5.8GHz/5.9GHz 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) communications is known as Vehicle to Roadside communication which we have already discussed in 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.

The physical (PHY) and Medium Access Control (MAC) layers employ IEEE 802.11p standard. MAC addresses are assigned 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 stan-

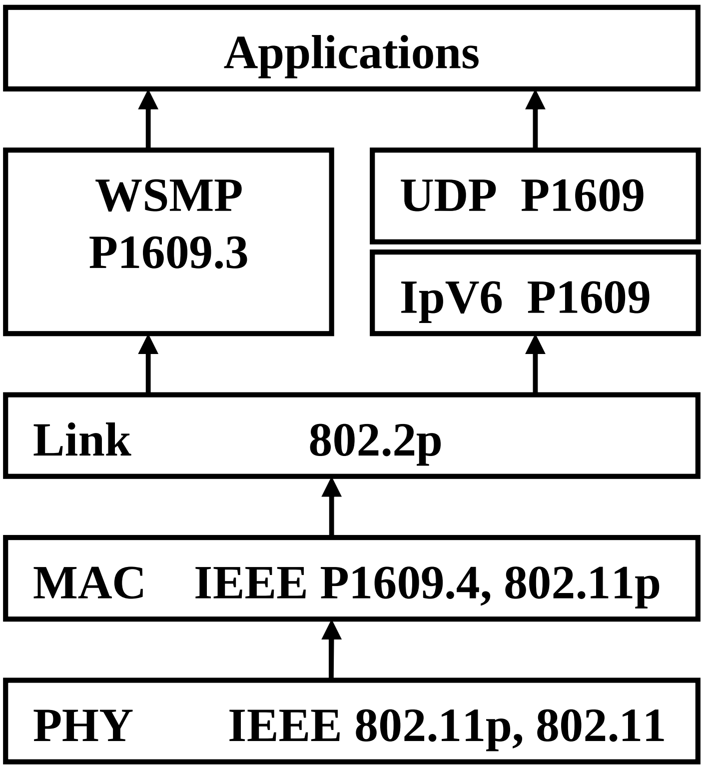

Figure 4.6. Structure and Location of Wave

dard and it determines the behavior of MAC layer on the available control channel (CCH) and service channel (SCH). Control Channels is used for safety communication. Network Layer uses IEEE P1609.3 Networking Service Standard. 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 message. The block which sends WSMP is known as provider. The channels at the edges are used reserved for future use for avoiding accidents. Channel 178 is the control channel and the remaining ones are service channels.

4.4.2 Components in WAVE

WAVE consists of following components:

1. IEEE802.11p

   IEEE 802.11 is a set of standards defined for wireless local area network (WLAN) computer communication. Institute of Electrical Engineers (IEEE) is working on an IEEE 802.11a wireless LAN to develop new standards for Vehicle to Vehicle communication and Vehicle to Infrastructure communication known as IEEE802.11p. 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). The Table 4.2 shows the difference between 802.11p and 802.11a. It shows that the bandwidth of 802.11p is half 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 [36]. A group of stations with common access point implementing 802.11p, which communicate with each other over 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 External Service Set (ESS) using Distribution Services (DS). Service Set Identification (SSID) is the identification

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)

TABLE 4.2 Comparison Table

for the BSS and is equivalent to WiFi hotspots names. 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 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.

WAVE interface consists of four standards:

- IEEE P1609.1

  It represents 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 is supported by the OBU

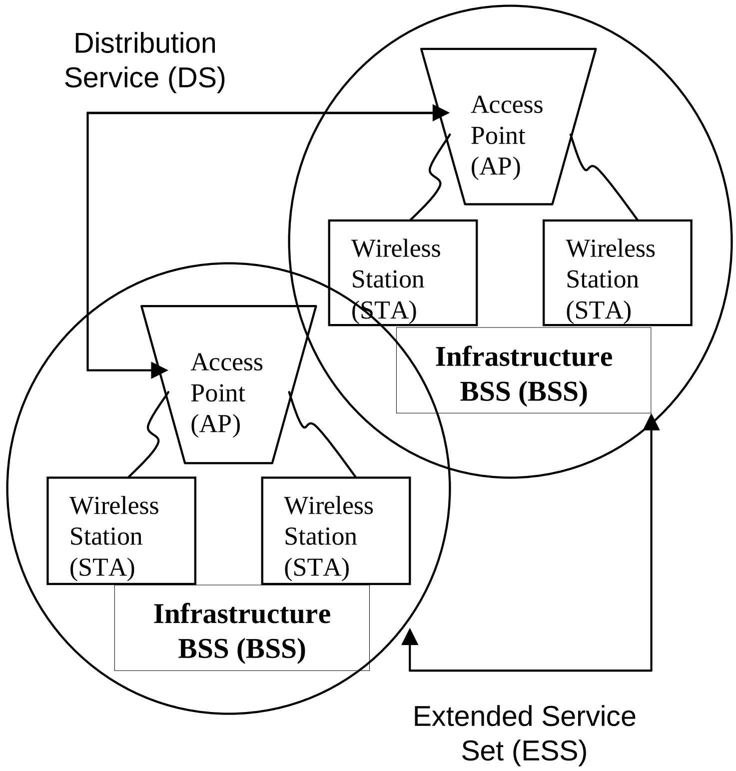

Figure 4.7. Basic Service Set (BSS)

- IEEE P1609.2

  It represents Standard for Wireless Access in Vehicular Environments (WAVE) for Security Services for Applications and Management Messages. It defines the message format and also the method of processing the messages.

- IEEE P1609.3

  It represents Standard for Wireless Access in Vehicular Environments (WAVE) for Networking Services. It defines network and transport level system, WSM (Wave Short messages).

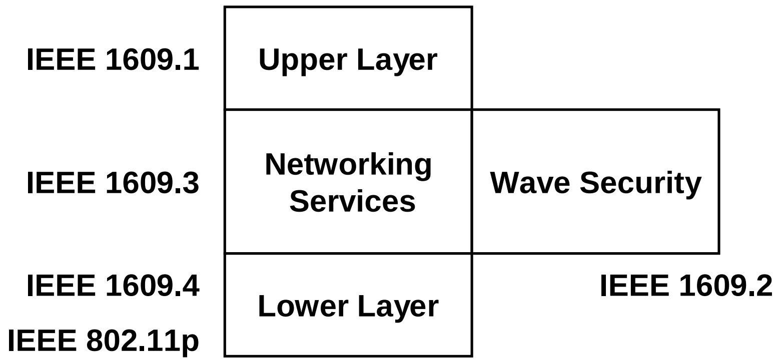

Figure 4.8. IEEE P1609 and WAVE

- IEEE P1609.4

  It represents 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 Application

- Vehicular Network Modeling
- Characterize the performance of the messaging protocol under various traffic conditions
- Makes distributed routing decision
- 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 map
- Distributed Processing Control in a Dynamic Network
- High mobility rate and short connection
- Monitors congestion using sampling and in-network processing
- Imaging application in Vehicular Network
- Application of image recognition to determine vehicular flow in highways
- Mapping companies such as Google and NAVTEQ have implemented projects that capture images of streets to provide a map-user a real perspective of the location

Chapter 5

PROBLEM AND PROPOSED SOLUTION FOR WAVE

5.1 Introduction

In the previous chapters, we have discussed about Wireless Access in Vehicular Environment (WAVE) technology. Wireless Access in Vehicular Environment (WAVE) technology [37, 38, 39] has emerged as a state-of-the-art solution to vehicular communications in an Intelligent Transportation System (ITS). In WAVE, the communicating nodes are between on-board-units (OBUs) of vehicles and roadside units (RSUs) and short range communication can be achieved using IEEE 802.11p protocol in the Dedicated Short Range Communication (DSRC) band. For WAVE, the major challenges arise due to the fact that the communication environment varies rapidly and duration of communications 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. So, to deal with this problem, we propose to use the idea behind BitTorrent to distribute the data among vehicles and employ bargaining among vehicles to exchange data with different fairness criteria. An example application of this

WAVE and BitTorrent is the distribution of road-traffic information and real-time online in-car entertainment system. With an ability of wireless communication, the driver and passenger can access multimedia data (e.g., image, video, and data files) efficiently.

BitTorrent [40, 41, 42, 43] is a peer-to-peer (P2P) file sharing communications protocol. BitTorrent is a method of distributing large amounts of data widely without the original distributor incurring the entire costs of hardware, hosting and bandwidth resources. When data is distributed using the BitTorrent protocol, each recipient supplies pieces of the data to newer recipients, reducing the cost and overhead on any given individual source, providing redundancy against system problems, and reducing dependence on the original distributor. In WAVE, the RSU can distribute the different parts of large amount of data to different vehicles whose 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 vehicle-to-roadside (V2R) problem and vehicle-to-vehicle (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.

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

5.2 WAVE System Model

For the channel model, we use the 2-ray ground reflection model [44] for large-scale fading and Rayleigh fading as 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 channels vary rapidly and we need to ensure the required link quality. This can be achieved with 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 and the adopted modulation with convolutional coding rates to achieve different supported transmission rates under different BER requirement can be found in [45].

Supposed we have a total of 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 ($k, l \in \{1, 2, \dots, L\}$) of OBU i, $w_i(k) \geq w_i(l)$, if $k < l$. 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. Then, we propose the bargaining algorithms for the V2V problem. Finally, we present the solutions for the 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 booth and gas station, since the communication duration for the OSUs and RSUs is usually limited,

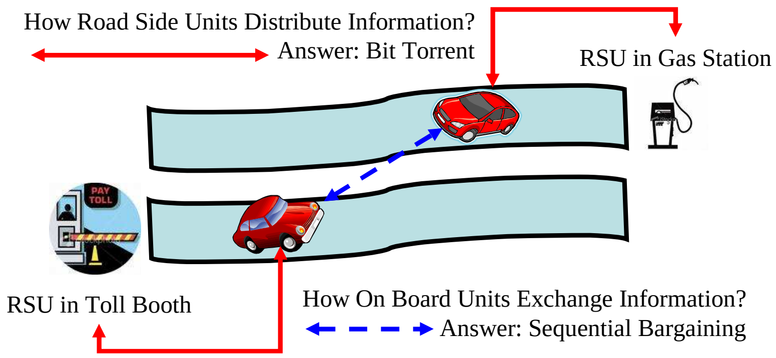

Figure 5.1. V2R and V2V communications model

it is very unlikely that all L packets can be transmitted. To overcome this problem, the RSUs randomly distribute the packets to the OBUs, and then let 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:

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

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

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. In other words, 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 distribution of the L different packets, i.e.,

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

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

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 other vehicles. In this case, it is better to send the higher priority packet first. On the other hand, during 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. Then, the algorithms for data exchange and those for bargaining solutions are proposed.

First, we study the Nash Bargaining Solution (NBS) [46] for a two-player game. The definition of NBS is given below.

Definition 3 ***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 [46], the NBS has a unique solution.

Two other bargaining solutions have been proposed as alternatives to the NBS – the Kalai-Smorodinsky Solution (KSS) [46] and the Egalitarian Solution (ES). To define these solutions, we need to introduce the following definition:

Definition 4 *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:*

$$H(\mathcal{U}, \boldsymbol{U}^0) = \begin{bmatrix} \max_{\boldsymbol{U} > \boldsymbol{U}^0} U_1(\boldsymbol{U}) & \max_{\boldsymbol{U} > \boldsymbol{U}^0} U_2(\boldsymbol{U}) \end{bmatrix}. \tag{5.6}$$

Definition 5 ***Kalai-Smorodinsky Solution***: *Let* $\mathbf{\Lambda}$ *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* $\mathbf{\Lambda}$.

Definition 6 ***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 different fairness criteria.

Algorithm 1 Data Exchange Algorithm

1: **repeat**
2: *Neighbor Discovery:* Investigate who has the best channel and most mutual benefited packets.
3: *Negotiation:* OBUs exchange information of available data packets and their weights.
4: *Bargaining:* The solution of bargaining game is obtained from Algorithm 2.
5: *Data Transmission:* Exchange packets to the other OBU.
6: *Adaptation:* Monitor the channels and adjust modulation and coding rate.
7: **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 piggybacked with this message and sent back to OBU i. From this information, 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 integer).

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 $i \neq j$.

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 $\mathcal{I}_i$.

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., $U_i(n) = \sum_{k=1}^{n} w_i(k)$.

if Nash solution **then**

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

else if Kalai-Smorodinsky solution **then**

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

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

else if Egalitarian solution **then**

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

end if

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

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

5.3.3 Proposed Algorithms for Data Dissemination by an RSU

To solve the problem in (5.4), 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 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. Since the number of vehicles on the road will be few, to maximize the utility, only the high priority packets should be transmitted. 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., $\lambda_1 = \lambda_2 = 1.0$ and $\lambda_1 = 1.1, \lambda_2 = 0.9$ for symmetric and asymmetric cases, respectively) 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 has weight 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 speed 70 km/h is longer than that of the vehicles with speed 100 km/h.

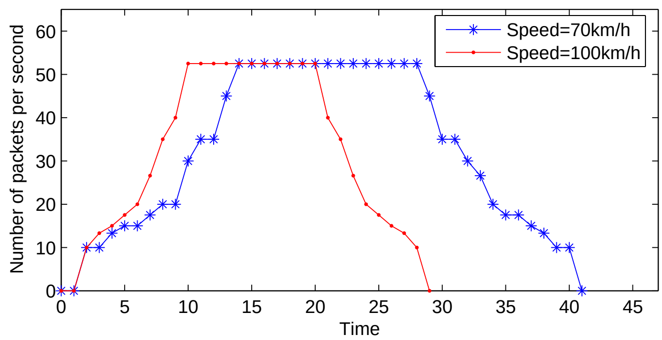

Figure 5.2. Transmission rate under different speeds

Then, we 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 $(U_1(n_1), U_2(n_{1,2} - n_1))$, 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.

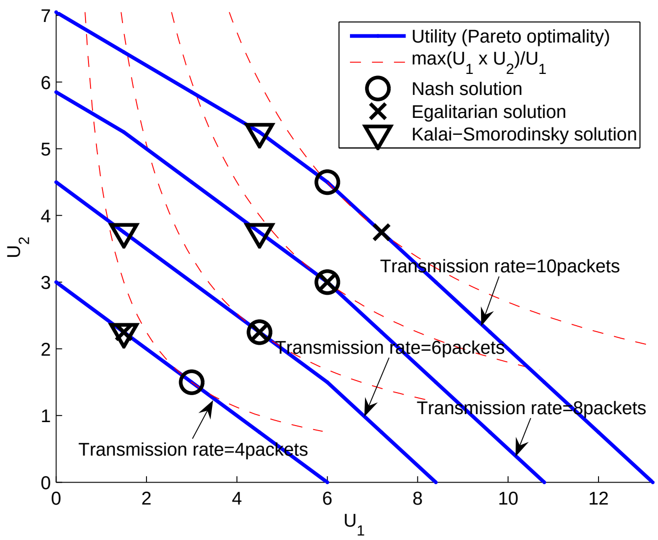

Figure 5.3. Utility, Pareto optimality, and bargaining solutions

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 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 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 vehicle in lane 1 has larger amount of high priority data to send to the vehicle in lane 2. However, in 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 number of vehicles in lane 1, the vehicle in lane 2 has higher chance to receive the data from the vehicles in lane 1. Therefore, the utility is higher. Note that similar effect is observed for Kalai-Smorodinsky and Egalitarian solutions.

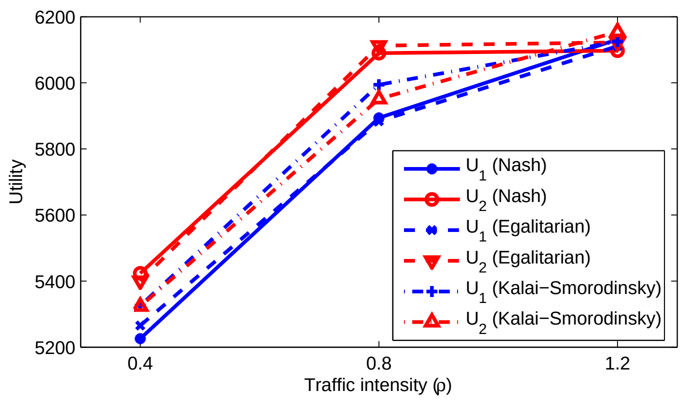

Figure 5.4. Utility of the vehicle

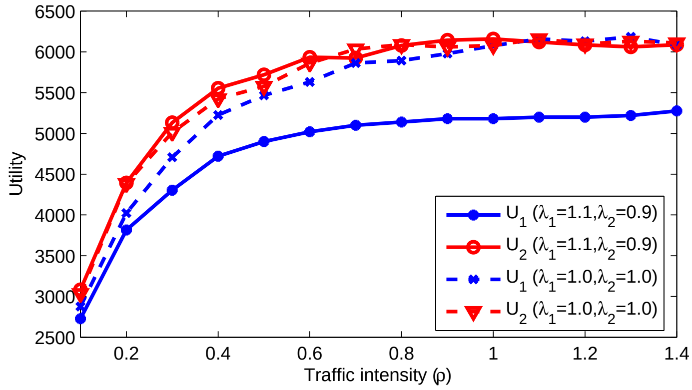

Figure 5.5. Utility of the vehicles under different traffic intensity

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 few of high priority data are sent from RSU to OBU on a vehicle, and hence the utility is not maximized since 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.

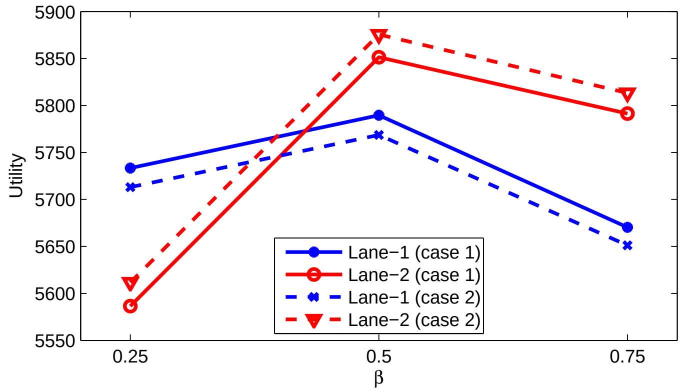

Figure 5.6. Utility of the vehicles under different data distribution

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 the method how RSU distributes the information.

If a node has to acquire information on certain safety condition and its RSU doesn't have this information then there are two possibilities. First one is that its RSU can query other RSU and get the information. For future work, how RSU communicates with other RSU will be studied. The next method can be that current OBU can use multihopping to connect to the certain OBU far way. In future, we will consider the study of information exchange between two OBUs very far away within the range of two different RSUs using multihopping.

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

Also, for the 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.

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. But, if we install a device equivalent to OBU in few animals say polar beer and set few RSU at location 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 didnt come in its range. It would make things easier for the Biologist. Now, they do not have to spy after them day and night but can collect all the information staying at their 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, one who does not share will not be able to download. This makes the system faster when there are many users in the network. But, at the same time, it has some loopholes. There is 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 node to download from the fastest peers, send fake pieces at slow rate and receive valid piece. But, if we implement BitTorrent along with bargaining, our proposal will resolve this issue as bargaining incorporates fairness in the system during downloads.

Next 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 location; whether they are in hospital, on a vacation or attending important meetings. If the condition of patient suddenly gets worse with no-one to attend him, then warning to the main operators OCE could be sent so that necessary action can be taken to avoid any mishaps. Similarly, if the patient is attending meeting, all the information can be obtained regarding the health status. In addition, if two patients from same hospital meet up then the units exchange information and some information about the status of the health of the other person can also be achieved.

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