CHAPTER I

INTRODUCTION

1.1 HISTORICAL EVOLUTION OF CELLULAR NETWORKS

Cellular technologies have evolved at an astounding rate over the past 10–15 years not only in terms of their deployment and usage but also in terms of their capabilities. A little over a decade ago 2G technologies such as global system for mobile communications (GSM) and Interim Standard 95 (CDMA) were the state of the art in cellular communications. As recently as 1992, GSM had not yet been deployed outside of Europe. Today, GSM spans the globe with more than 6 billion subscribers. A decade ago, most cellular networks provided data capabilities comparable to those of dial-up modems. The past decade has seen multiple generations of technology development, deployment, and adoption that have provided several orders of magnitude of improvement in data rates and general capabilities. Technologies such as universal mobile telecommunications system, wideband CDMA, high-speed packet access, CDMA2000, CDMA2000 evolution-data optimized, and long-term evolution (LTE) [1] have catapulted cellular networks into the forefront of the data revolution and sparked the rise of the wireless Internet. To put this all into perspective, over the course of a decade, cellular data networks have transformed from the equivalent of a dial-up modem to that of a fast Ethernet connection. Table 1.1 depicts the Historical evolution of Mobile Communication systems over the past 15 years.

The cellular industry was long marked by competing technologies that fragmented the global market into a CDMA world and a GSM world. A key takeaway from Figure 1.2 is that these two worlds are merging together into a single global technology path; all viable technology paths now lead to LTE. Over time, the entire global market will increasingly converge onto the same technology, which will likely enable an entirely new breed of global mobile devices. In fact, in the long-term view, the only differentiating factor between countries and markets may be frequency bands of operation. It should be noted that this discussion does ignore worldwide interoperability for microwave access (WiMAX) and its role in the commercial wireless landscape. WiMAX has been endorsed as a 4G technology. Although its future is uncertain, the authors believe that WiMAX is more likely to assume niche roles in the commercial wireless landscape, with LTE
remaining the dominant cellular technology of tomorrow. This will give LTE a significant advantage in the long term in terms of economies of scale and vendor diversity, which will make it, and its descendent technologies, an increasingly attractive option for the military community.

Table 1.1: Historical Evolution of Mobile Communication Systems

<table>
<thead>
<tr>
<th>Property</th>
<th>First Generation</th>
<th>Second Generation</th>
<th>Third Generation</th>
<th>Fourth Generation</th>
<th>Fifth Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representative Standard</td>
<td>AMPS</td>
<td>GSM</td>
<td>IMT – 2000</td>
<td>UWB</td>
<td></td>
</tr>
<tr>
<td>Radio Frequency (Hz)</td>
<td>400 M – 800 M</td>
<td>800 M – 900 M</td>
<td>1800 M – 2400 M</td>
<td>2 G – 8 G</td>
<td></td>
</tr>
<tr>
<td>Bandwidth (bps)</td>
<td>2.4 K – 3 K</td>
<td>9.6 K – 14.4 K</td>
<td>384 K – 2 M</td>
<td>20 M – 100 M</td>
<td>&gt;1Gbps</td>
</tr>
<tr>
<td>Multiple Access Techniques</td>
<td>FDMA</td>
<td>TDMA, CDMA</td>
<td>WCDMA</td>
<td>OFDM</td>
<td></td>
</tr>
<tr>
<td>Switching Basis</td>
<td>Circuit</td>
<td>Circuit</td>
<td>Circuit, Packet</td>
<td>All Packet</td>
<td>All Packet</td>
</tr>
<tr>
<td>Cellular Coverage</td>
<td>Large area</td>
<td>Medium area</td>
<td>Small area</td>
<td>Mini area</td>
<td></td>
</tr>
<tr>
<td>Service Type</td>
<td>Voice</td>
<td>Voice, Limited Data</td>
<td>Integrated HQ Audio, Video &amp; Data</td>
<td>Dynamic Info. Access, Wearable Devices</td>
<td></td>
</tr>
</tbody>
</table>

Many of the most important commercial wireless technologies share key technological similarities, as will likely future commercial wireless technologies. There are several key technology trends that are likely to affect the development of the next
generation of commercial wireless standards and, subsequently, future military solutions; these trends include MIMO, multi-carrier modulation, cognitive radio, and network coding. In table 1.2, we summarize the Historical evolution of Mobile Communication systems over the past few decades [158].

Simultaneous service to several terminals is possible due to segmentation of the resource into unit channels, or by imposing limits on the maximum time a terminal may continuously transmit. The two main classes of channel access protocols are random access protocols and contention free access protocols.

Random access protocols such as ALOHA or CSMA [115] stipulate rules for when a terminal may transmit, for how long, and what action to take when another simultaneous transmission is detected. Random access protocols are very useful when transmissions are unpredictable. Contention free access protocols, such as TDMA and CDMA, assign a unit channel to a specific communicating pair. It then has sole right to use this channel. If the required number of unit channels is too high, service is blocked for some terminals.

1.2 CELLULAR NETWORKS - CHALLENGES AND LIMITATIONS
Recently, Cisco has announced that, by 2017, mobile data traffic will grow to 1 billion gigabytes of data per month and by 2018 about two-third of the mobile data traffic will originate from video services [37]. This is the reason why wireless operators need to find a way to accommodate more users with large screen devices on their networks. The urgent needs of today's networks are clear. We need to find possible solutions to improve network performance and meet the growing demands of users. We cannot provide a solution unless we have a good understanding of the current limitations and bottlenecks of the networks [28]. In this section, we focus on these limitations, understand the nature of the wireless medium and briefly describe solutions and techniques that can be used to overcome the limitations.

1.2.1 Limited Bandwidth Resources
Bandwidth resource is globally considered as one of the most scarce resource on the planet. The total amount of frequency spectrum is limited. Of these limited frequency spectrum, only a portion can be used due to technology limitations and possible health effects of RF signals. The bandwidth resource is not only severely limited but it is also
shared by everyone and for different applications including cellular networks, sensor networks, WiFi, home appliances, etc. The frequency spectrum allocated for cellular communications is very limited, but user's interests require much higher data rate and better user experience. In table 1.2, we summarize the features and limitation of Cellular Networks over the past few decades. There are two solutions for overcoming this limitation:

Table 1.2: Features and Limitation of Cellular Networks

<table>
<thead>
<tr>
<th>Items</th>
<th>3G</th>
<th>4G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed</strong></td>
<td>Up to 2Mbps</td>
<td>100Mbps-1Gbps</td>
</tr>
<tr>
<td><strong>Services</strong></td>
<td>Difficulty of global roaming</td>
<td>Roaming Smoothly</td>
</tr>
<tr>
<td><strong>Core Networks</strong></td>
<td>Circuit and packet switching</td>
<td>IP based packet switching</td>
</tr>
<tr>
<td><strong>Technologies</strong></td>
<td>WCDM, CDMA2000, TD-SCDMA</td>
<td>OFDM, MC-CDMA, LAS-CDMA, Network-LMPS</td>
</tr>
<tr>
<td><strong>Features</strong></td>
<td>➢ Support Multimedia services ➢ Universal Access ➢ Portability ➢ Higher throughput and speed</td>
<td>➢ Support multiple wireless interface (Open Wireless Architecture OWA) ➢ IP based Network System ➢ Portability is increased ➢ Integration</td>
</tr>
<tr>
<td><strong>Limitation</strong></td>
<td>➢ Speed is slower when compared with 802.11 ➢ Cannot compete with the data rate of WLAN ➢ Infrastructure cost is high</td>
<td>➢ Need New Device ➢ Infrastructure cost is high</td>
</tr>
</tbody>
</table>

1.2.2 Additional Spectrum

The U.S. Federal Communications Commission has recently announce that they are trying to get an additional 500 MHz of spectrum for the next decade, including 300 MHz spectrum to be added to the available spectrum in the next five years [10].

1.2.3 Improving Bandwidth Efficiency

Adding more spectrum is a promising solution; however, it takes time and not all spectrum is of the same quality. For now we need to improve the bandwidth efficiency; we need to get more efficient in the way we use the network resources. To improve the bandwidth efficiency, better resource management and channel assignment schemes should be
designed. Most of the channel assignment schemes are based on the concept of frequency reuse. Frequency reuse is the practice of using the same frequencies and channels within a network more than once to improve the capacity and spectral efficiency; however, if two adjacent devices use the same frequency at the same time, they create interference which yields to poor user experience. To avoid any interference, wireless systems will isolate identical frequencies from each other. More information about channel assignment schemes is provided in the next section.

![Wireless Channel Diagram]

Figure 1.1: The Principles of Multi-User Access.

1.3 RECENT INNOVATIONS IN WIRELESS COMMUNICATION
Mobile and wireless networks have made tremendous growth in the last fifteen years. Nowadays many mobile phones have also a WLAN adapter. One may suppose that near soon many mobile phones will have WiMAX adapter too, besides their 3G, 2G, WLAN, Bluetooth etc. adapters. Today 3G mobile systems are on the ground providing IP connectivity for real-time and non-real-time services. On the other side, there are many wireless technologies that have proven to be important, with the most important ones being 802.11 Wireless Local Area Networks (WLAN) and 802.16 Wireless Metropolitan Area Networks (WMAN), as well as ad-hoc Wireless Personal Area Network (WPAN) and wireless networks for digital TV and radio broadcast [4]. Then, the concepts of 4G is already much discussed and it is almost certain that 4G will include several standards.
under a common umbrella, similarly to 3G, but with IEEE 802.xx wireless mobile networks included from the beginning. The main contribution of 5G mobile network concept, which is seen as user-centric concept instead of operator-centric as in 3G or service-centric concept as seen for 4G. In the proposed concept [33] the mobile user is on the top of all. The 5G terminals will have software defined radios and modulation scheme as well as new error-control schemes can be downloaded from the Internet on the run. The development is seen towards the user terminals as a focus of the 5G mobile networks. The terminals will have access to different wireless technologies at the same time and the terminal should be able to combine different flows from different technologies. Each network will be responsible for handling user-mobility, while the terminal will make the final choice among different wireless/mobile access network providers for a given service.

In January 2012 ITU approved the first release of the 4G global core standard (GCS). After the world radio communication conferences 2012 (WRC-12) [37], telecommunication industry began to discuss the visions and requirements of 5G. 5G is needed because of the explosive growth in video traffic, the acute shortage of spectrum, the growing need to minimize the energy requirements of web devices and network infrastructure and to cater to the insatiable desire for higher data speed rates.

For the customer, the difference between 4G and 5G technologies will be in higher speeds, lower battery consumption, better coverage, higher number of supported devices, lower infrastructure costs, higher versatility or higher reliability of communications [9].

Mobile communication systems have been playing an important role in our life for more than 20 years, and it will enter even more dimensions of the society due to technology improvement. In order to accommodate more users in the cell, we should define a mechanism so that multiple users can access the shared medium simultaneously. This is why multiple access techniques, with a global perspective of the system, are defined in Table 1.4. Multiple access techniques cope with two difficulties of the wireless systems; limited shared bandwidth and interference. If two or more users simultaneously transmit on the same or adjacent frequency bands, they may causes interference on each other and degrade the quality of service of all users. On the other hand, the allocated bandwidth to cellular network is limited and there cannot be a large space between allocated channels of users. Multiple access techniques intelligently divide the medium
and deploy smart modulation schemes so that more users can access the medium while causing no or small interference on each other.

Table 1.3: Multiple Access Techniques in different Wireless Communication Systems

<table>
<thead>
<tr>
<th>Advanced Mobile Phone Systems AMPS</th>
<th>FDMA/FDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global System for Mobile GSM</td>
<td>TDMA/FDD</td>
</tr>
<tr>
<td>U.S. Digital Cellular</td>
<td>TDMA/FDD</td>
</tr>
<tr>
<td>Japanese Digital Cellular</td>
<td>TDMA/FDD</td>
</tr>
<tr>
<td>CT2 Cordless Telephone</td>
<td>FDMA/TDD</td>
</tr>
<tr>
<td>Digital European Cordless Telephone</td>
<td>FDMA/TDD</td>
</tr>
<tr>
<td>U.S. Narrowband Spread Spectrum (IS-95):</td>
<td>CDMA/FDD</td>
</tr>
</tbody>
</table>

Depending on how the available bandwidth is allocated to the users these techniques can be classified as narrowband and wideband systems. The term narrowband is used to relate the bandwidth of the single channel to the expected coherence bandwidth of the channel. The available spectrum is divided into a large number of narrowband channels. The channels are operated using FDD. In narrow band FDMA [1], a user is assigned a particular channel which is not shared by other users in the vicinity and if FDD is used then the system is called FDMA/FDD. Narrow band TDMA allows users to use the same channel but allocated a unique time slot to each user on the channel, thus separating a small number of users in time on a single channel. For narrow band TDMA, there generally are a large number of channels allocated using either FDD or TDD, each channel is shared using TDMA. Such systems are called TDMA/FDD and TDMA/TDD access systems.

In wideband systems, the transmission bandwidth of a single channel is much larger than the coherence bandwidth of the channel. Thus, multipath fading doesn’t greatly affect the received signal within a wideband channel, and frequency selective fades occur only in a small fraction of the signal bandwidth.

1.4 RADIO RESOURCE ALLOCATION TECHNIQUES

Three main of channel allocation schemes are Fixed Channel Allocation (FCA), Dynamic Channel Allocation (DCA), Hybrid Channel Allocation (HCA). In a general wireless
communication network FCA means to allocate a fixed set of channels to a specific cell. All cells in the network have their own set of disjoint channels. There are two strategies to implement FCA scheme in the cellular network [37] [38]. One is to allocate a uniform set of disjoint channels to each cell in the network. This strategy works best under the condition that the traffic to all the cells in the network is also uniform. So each cell will have a uniform blocking probability. This strategy may be implemented in an area where traffic is not too high, may be rural areas. This strategy does not works best if the traffic conditions are not uniform e.g. in urban area with high population density. In such type of conditions the cells with high traffic density will suffer more blocking probability then the cells with low traffic density [37]. Second strategy is to allocate sets of disjoint channels, to each cell in the network, non-uniformly. This kind of strategy works more efficiently, as cells in high traffic density areas are allocated more channels then the cells in low traffic density areas, hence keeping the blocking probability in control. Also in real time scenarios we do not have uniform traffic conditions in the cellular network [38].

Basic concept of DCA is to allocate channels dynamically to the mobile users in the cellular network without allocating fixed sets of channels to the cells. FCA schemes are not much flexible in adapting change in traffic e.g. a cell allocated with set of channels to deal with high traffic intensity may have sometimes low traffic, in such a situation free channels available in the cell may never be used, hence wasting the resources. To overcome such type of issues DCA schemes have been introduced [37].

In DCA, a cell is not provided with fixed set of channels. Instead all channels are present inside a central pool mainly Mobile Switching Center (MSE) or are distributed among BSs in the network [38]. These channels are assigned to the calls when needed. Any channel can be used by any incoming or ongoing call in the whole network, keeping the CCI at a low level (channel reuse concept). Channels are assigned by the BS of the cell in which mobile user is present. Another strategy in DCA is also implemented for better performance, namely call borrowing strategy. In this strategy channels in the cell are allocated using FCA but when a call request is generated in the cell and there is no channel available to accommodate it in that cell, a channel is borrowed from a neighboring cell, keeping co-channel interference at its minimum. However, under high traffic, DCA schemes are not much efficient than FCA schemes [38].
HCA is the combination of FCA and DCA. Total channels in the cellular network are divided into two sets of disjoint channels. One set is allocated using FCA to all the cells in the network and second set is present in a central pool inside the cellular network. When all the allocated channels, using FCA, in the cell are busy then the channels allocated dynamically are used for the new call requests in that cell [38]. Here ratio of the channels allocated using FCA and channels allocated using DCA is very important. This ratio depends on the traffic conditions in the cellular network. In a cellular network, sometimes a cell may face an abnormal increase in traffic far beyond its capacity for a particular hour. Best example can be e.g. a cell covering a football stadium where a favorite match is going on. Such cell becomes a hot-spot in the network. For such type of conditions in [38] a HCA technique is proposed for the hot-spot cells.

Traffic Diversion Station TDS is the Mobile Phone’s access point to the network. TDS is responsible for carrying out radio communications between the network and the Mobile Phone. It handles speech encoding, encryption, multiplexing (Time Division Multiple Access), and modulation/demodulation of the radio signals. One TDS usually covers a single 120 degree sector of an area. Usually a tower with 3 TDSs will accommodate all 360 degrees around the tower. However, depending on geography and user demand of an area, a cell may be divided up into one or two sectors, or a cell may be serviced by several TDSs with redundant sector coverage. A TDS is assigned a Cell Identity. The cell identity denotes a particular Location Area, which provides details of the cell which the TDS is covering.

Multi-homing bandwidth allocation is considered to be a promising solution that can efficiently exploit the available resources in a heterogeneous wireless access medium to satisfy required bandwidth, reduce call blocking probability [10, 22], and allow for better mobility support. The main challenge in designing a multi-homing bandwidth allocation mechanism is how to coordinate the allocation from different networks so as to satisfy the user’s required bandwidth while making efficient utilization of available network resources.

One simple solution is to employ a central resource manager [5,7] with a global view over the available resources and the required bandwidth for different calls, which can perform the necessary coordination among different networks. However, this solution
is not practical in the case that those different networks are operated by different service providers. Hence, the question now is how to coordinate the resource allocation in different networks without a central resource manager. In addition, it is more practical that every network prioritizes bandwidth allocation to its own subscribers as compared to other users. Here we present a decentralized optimal bandwidth allocation mechanism that enables each MT to coordinate the allocation from different networks in order to satisfy its required bandwidth, and allows each network to give a higher priority in allocating its resources to its own subscribers. We consider only multi-homing calls in the system model. Also, we consider a static system model, without arrivals of new calls or departures of existing ones. Our main objective is to identify the role of each entity in the heterogeneous wireless access medium to support a decentralized multi-homing bandwidth allocation [3, 40].

In a dynamic environment, call arrivals and departures in different service areas [11] may trigger resource reallocations for all MTs in service. In a decentralized architecture, this is translated to a heavy signaling overhead between the MTs and different BSs/APs with every call arrival and/or departure in any service area. Hence, the main challenge is how to develop an efficient decentralized bandwidth allocation mechanism that reduces the associated signaling overhead with call arrivals and departures. In the future wireless communication network, it is envisioned that both single-network and multi-homing services will co-exist. Hence, it is required to develop radio resource allocation mechanisms that can support both service types. In this case, the radio resource allocation mechanism is to determine the optimal network assignment for MTs with single-network service and the corresponding bandwidth allocation for MTs with single-network and multi-homing services. Concepts of call traffic load prediction and Maximizing the network utility, are employed to enable effective optimal resource allocation for single-network calls and to satisfy multi-homing calls required bandwidth in such a decentralized network architecture.

One of the most important conclusions from the early tests of the new GSM technology was that the new standard should employ Time Division Multiple Access (TDMA) technology [11]. This ensured the support of major corporate players like Nokia, Ericsson, and Siemens, and the flexibility of having access to a broad range of suppliers.
and the potential to get product faster into the marketplace. GSM fulfills in the best way the user mobility requirement; at the same time its increasing worldwide presence provides high expectations for a future widely deployed application. Since its inception, GSM was destined to employ digital rather than analog technology and operate in the 900 MHz and 1.8 GHz frequency bands, except in North America where they operate in the 1.9 GHz band. The Uplink and Downlink frequencies allocated for GSM are 890-915 MHz, and 935-960 MHz [10]. GSM divides up the radio spectrum bandwidth by using a combination of Time- and Frequency Division Multiple Access (TDMA/FDMA) schemes on its 25 MHz wide frequency spectrum, dividing it into 124 carrier frequencies (spaced 200 KHz apart). Each carrier frequency divided into eight time slots using TDMA, and different carrier frequencies are assigned to each base station network infrastructure.

The space dimension is of particular significance as it allows the use of the same radio resource at the same time, frequency and with the same code at another physical location which is spatially separated in distance or angle. The magnitude of spatial separation depends on the required level of interference protection. This circumstance leads to the cellular concept which, in theory, enables a wireless system to completely cover an infinite area with a limited radio resource.

1.5 MOTIVATION OF THE STUDY
Although the deployment of third generation (3G) wireless communication networks has not been as successful as predicted during the 90’s, ubiquitous broadband communication is still actively pushed forward by the desire for multimedia communication. Wireless networks of third (3G) and future generations are different from second generation (2G) networks, e.g. the Global System for Mobile Communications (GSM), in several ways.

First, the bandwidth of the radio link is much larger than in second generation network. For example, the Wide-band Code Division Multiple Access (WCDMA) technology enables communication speeds of 2 Mbps compared to 14-64 Kbps in GSM. This enables besides voice communication, many other types of more advanced multimedia communications and data services. Second, using the packet-switched transmission paradigm means that network resources can be allocated and accounted with a much finer granularity, enabling the use of intelligent resource allocation algorithms.
A strong complement to cellular networks are wireless mobile ad hoc networks. Ad hoc networks are formed by wireless nodes that move freely and have no fixed infrastructure. Each node in the network may act as a router for other nodes, and flows follow a multi-hop path from a source to a destination. The flexibility that comes with lack of fixed infrastructure makes them ideal for novel scenarios, including cooperative environments, defense applications and disaster management. Both network types aim to provide a wide range of services in which soft real-time (multimedia), and high priority critical data seamlessly integrate.

Resource allocation problems with the aim of guaranteeing a certain level of service have been studied in the Internet community for many years. As a matter of fact, there are several differences which make the resource allocation problem more complicated. First, there is the nature of the wireless channel which entails the following:

- The limited spectrum available. Wireless networks share the same bandwidth and location-based interference can greatly reduce the communication capacity.
- Resource Management. Need for proper bandwidth management for supporting voice and multimedia services over wireless communication systems and also unpredictable traffic condition in real time multimedia applications. The resources in the wireless network is scarce
- User Satisfaction. In order to satisfy the large demand of mobile telephone services, channels need to be assigned efficiently with less cost and reused to minimize communication interference. An improper channel assignment may lead to network partition or link failure. In order to maximize throughput and minimize outage at the same time by seeking optimal channel allocation for a new call with the aim of minimizing interference to an existing call due to channel allocation for a new call

The favorable economics together with the ease of deployment and significant improvements in the Outdoor coverage for both voice and data services have resulted in an increasing popularity of this conception the recent years. Despite the clear understanding and requirement of user, the present network partially fulfil the user requirement. They do not provide a fundamental solution for a scalable architecture
which can organically grow and adapt to the short and long term changes in the network. The work in the present thesis has been conducted with such a vision.

1.6 PROBLEM DESCRIPTION

It is expected that the number of deployed wireless cellular networks will increase in the observable future to accommodate the plans for extending 4G/UTMS networks with IEEE802.11 cells, in the area of higher user density and relatively high mobility (e.g., airports, subways stations, campuses, city blocks, conventions, etc…). In recent years there is a rapid growth in the population of mobile users and in order to support the drastic increase in demand for resources, wireless networks need an advanced resource allocation schemes. However, Bandwidth allocation and management are crucial issues in sensitive cellular networks. Efficient bandwidth allocation strategy with simultaneous fulfillment of QoS requirement of a user in mobile communication is still critical and important practical issue.

To achieve the twin objective of providing high quality wireless connectivity and a seamless service to mobile terminals (MTs), next generation networks will turn out to be an integration of multiple wireless access networks, which would give rise to a heterogeneous wireless access system. Each and every one of these technologies is based on cellular networks. Cellular networks, which are comprised of cells, are allocated frequency channels from the available bandwidth. It is these frequency channels that have the responsibility of providing communication between mobile users. As the number of available channels in a cell is limited, whenever traffic in the cell is high, users could be faced with call terminations and as a result they could be blocked by the cell completely. As the demand for mobile communication has grown remarkably in the past few years, mobile communication networks (systems) should be able to utilize the limited resources in an efficient and a convenient manner. The radio frequency spectrum that is currently available is limited in nature and thus can no longer be counted on to support the ever increasing number of mobile users’ demand, and hence, the required Quality of Service (QoS) is no longer attainable until an optimum solution is obtained.

Quite a few of the schemes that have been proposed in prevailing literature tend to give priority to ongoing calls at the expense of blocking originating calls. One of the
challenges that they pose, is to allocate resource that would be in a position to support multiple traffic that include voice, video and data. Even though a lot of resource allocation schemes have been proposed, they mostly tend to focus on different ways to support multiple traffic in a single mode of network, or they concentrate on various schemes to support a single mode of traffic in an integrated heterogeneous wireless and mobile network. As a result, these various schemes that have been presented in related literature may not be the most suitable as far as being able to support multiplicity of traffic with respect to an integrated heterogeneous wireless and mobile network.

The problem described here is the result of the limitations of bandwidth, which lacks of incoming Calls, Bottleneck problem, increase Call dropping probability, system utility and less in QoS. This Knowledge is very necessary to prevent system underutilization i.e. waiting long time to be connected and critical call dropping probability. Therefore, a different approach that combines the acceptable efficiency of the above critical problems, the proposed scheme focus mainly of Network Performance and to satisfy users’ needs which reduces performance degradation.

1.7 RESEARCH METHODOLOGY
In Integrated Cellular Networks, if a Mobile Host (MH) in a hot cell is within the transmission range of a TDS, it can directly access to the TDS and makes a call by utilizing the bandwidth from a cell with enough free bandwidth through a relaying route. However, due to the limited number and transmission range of TDS’s, MH’s within the area uncovered by TDS’s are not able to directly divert their calling traffic through relaying routes. In this situation, the home BS chooses a pseudo source to release its occupied bandwidth for the use of the original source just after the quasi-source starts diverting traffic through a discovered relaying route.

1.7.1 Quasi-source selection
Quasi sources are those MH’s within the coverage of TDS’s. Whereas, the presence of more than one quasi sources requires that the home BS chooses only one quasi source to start a route discovery and divert its traffic, because many quasi-sources could cause a heavy routing overhead brought by the route discovery process. Hence, QCP (Quasi
Chosen Procedure) need to be applied to choose a reasonable quasi-source from lots of available pseudo sources. The goal of QCP is to decide quasi-sources to improve the overall performance of the system. In a congested cell, in order to allocate a bandwidth for the use of a MH uncovered by TDS’s, a Quasi-source is chosen by the home BS to release its occupied bandwidth without interrupting the present communication of the quasi-source. The QCP is implemented by the following methodology.

Initially QCP1 chooses source nodes with the most number of reachable TDSs, because these nodes have the most possibility of successfully discovering a relay route. DDR is the probability of a TDS failing to find a relaying route after broadcasting RREQs. Then, we could also choose a source node with the lowest DDR. One problem of the selection is that QCP1 could only choose MHs within a specific cross-area with most reachable TDSs. The result is that the bandwidth of TDSs covering the specific cross area is first consumed. Then, these TDSs could become congested but other TDSs still have lots of free bandwidth unused. Therefore, the developed QCP is modified to resolve the problem.

QCP2 tries to balance the bandwidth consumption among TDSs when choosing source nodes. To achieve the balance of TDS bandwidth consumption, QCP2 chooses Quasi-sources with maximum $B_{MHi}$. As a result, source nodes will consume the bandwidth of TDSs in average and avoid partially congesting. However, such a selection of source nodes may lead to a relatively higher DDR, because QCP2 is designed not to find a source node with a minimum DDR but to choose a source node with a maximum average bandwidth of reachable TDSs. Thus, compared with QCP1, QCP2 can avoid partially blocking TDSs by balancing the consumed bandwidth of TDSs, but the DDR in QCP2 could be higher due to the unpredictable number of reachable TDSs of source nodes.

QCP3 takes both the number and the average free bandwidth of reachable TDSs into consideration. Therefore QCP3 can achieve a balance of the bandwidth consumption of TDSs without highly increasing the DDR of the system during the selection of source nodes.

After applying QCP1, QCP2 or QCP3 to the selection of source nodes, a final source node still could not be specified because some MHs may have same value of weight during the calculation of QCP. Therefore after QCP1, QCP2 or QCP3, the mobility and
location information of MHs could be taken into consideration for the further selection of source node. The main idea of QCP-LA is to choose MHs with the most possibility of moving out of the home cell during call time, because MHs will automatically release its occupied bandwidth and use the bandwidth from the adjacent BSs as they move to the neighbor cells.

QCP algorithm is designed to execute in BSs to choose quasi-sources to divert their calling traffic. QCPs aim to choose source nodes that have the maximum possibility of successfully detecting relaying routes. Moreover, the source node selection in QCPs also tries to stabilize the bandwidth of TDSs, which is used for traffic diversion. Based on the quantity and bandwidth of TDSs, network planners can choose a reasonable QCP to achieve a relatively low call blocking rate. Alternatively, by estimating the amount of overloaded traffic, planners can choose a QCP to reduce the number of TDSs deployed in each cell. In some cases assigning too much bandwidth to single user, usage of Network is less and also the blocking probability rate is increased, when the arrival is high. These can be avoided with the help of Experimental Economic Method (EEM).

1.7.2 Maximizing Utility function
EEM technique has been designed to enhance the network performance by improving the utility functions. EEM has the ability to come up with fair resource allocations for various applications in different types of networks. Each network will be able to allocate a specific bandwidth to the different users, and will also be able to maximize a part of the utility function in a distributed fashion. It also reduces the blocking probability in a manner that is more efficient.

The Bandwidth Allocation using Game Theory (BAG) algorithm can be denoted by $G = [\mathcal{M}, \{\mathcal{B}^m\}, \{u_m\}]$. Users are allowed to calculate their own utility according to the bandwidth that has been allocated to them, and then select the network that maximizes its utility. By maximizing each network’s utility function, the game is played in a distributed fashion without any co-operation among networks.

Based on the above analysis, a distributed bandwidth allocation algorithm has been proposed, in which all the networks adjust their allocation results iteratively. We denote the time unit as $T$. The algorithm has been expressed follows: In first step, Initialize the value for $\varepsilon$ and reset the value of Network Utility function and the n increment the counter.
variable of $i$ by 1. Each network maximizes by adjusting its bandwidth allocation. In the next step maximize the Utility function until condition $(u_{m}^{i+1} - u_{m}^{i} < \varepsilon)$ is satisfied.

To discuss the blocking probability for different applications under different bandwidth allocation algorithms. When we observe that data applications have a higher blocking probability than voice applications, due to the fact that the bandwidth of voice applications is found to be lower than data applications. Moreover, as the proposed BAG algorithm pays more attention to utility, it offers a lower blocking probability, and as a result, voice applications outperform data applications. As stated before, it has been observed that voice applications have a higher priority over data applications, and thus it is only reasonable when we state that voice applications have a higher utility and lower blocking probability when compared to data applications. Finally, the convergence of the proposed BAG algorithm has also been studied.

Our approach has the ability to come up with fair resource allocations for various applications in different types of networks. Each network will be able to allocate a specific bandwidth to the different users, and will also be able to maximize a part of the utility function in a distributed fashion. It is able to optimize the utility of the various users, and also reduce the blocking probability in a manner that is more efficient. In above optimization done only for various application. It may be applicable among service providers. For optimizing Bandwidth among various service provider, a Two-level game Framework had been presented.

### 1.7.3 Optimizing Bandwidth allocation

A two-level game framework have been presented based on a differential game and an evolutionary game, in order to achieve optimal bandwidth allocation among service provider with respect to heterogeneous wireless networks (HWN). The dynamic service selection behavior of users has been modeled as an evolutionary game, and the strategy evolution process has been analyzed using replicator dynamics. The bandwidth allocation among different service classes considering users’ dynamic service selection has been formulated as a linear state differential game.

Without loss of generality, each access network is owned by each service provider. Service provider $i$ can provide $K_i$ service classes to users for satisfying different Quality
of Service requirements. Every user that is particularly registered to the same service class will share the available bandwidth in an equal manner. An underlying evolutionary game has been formulated that models the dynamic competition of service selection among users, which becomes the lower-level game in the two level game framework that has been proposed. Here, in this lower-level evolutionary game model, the players constitute the active users in the area \( a \) at any time \( t \). The players’ strategies constitute the choices of a particular service class from certain service providers.

Service providers can allocate bandwidth in an optimum fashion which would help in attaining maximum profit which is due to the users’ dynamic service selection behavior. On the other hand, the service provider’s overall profit reduces due to the limited capacity of the access network, which results in the reduction of bandwidth allocated to other services classes when the bandwidth allocated to one service class is increased. Here, a service provider’s differential game model with respect to bandwidth allocation has been formulated, and it constitutes the upper level game in the two-level game framework that has been proposed, by taking into account the users’ dynamic service selection.

The open-loop control strategy of service provider is taken into consideration due to the simplicity in its implementation thus suiting the loosely coupled heterogeneous wireless network. In the bandwidth allocation differential game, each and every service provider choose their bandwidth allocation control strategies simultaneously, thus being able to influence not only the evolution of the state of the differential game, but also the objective functions of both, their opponent and their own. For the open-loop Nash equilibrium to be achieved, it becomes essential that each service provider solves an optimal control problem. In this situation, the Pontryagin’s maximum principle can be used. First compute the Hamiltonian function of service provider and then find the corresponding maximized Hamiltonian function. In the next stage computing the adjoint equation and to obtain the derivative, Hamiltonian functions and the linear utility function are used.

The bandwidth allocation differential game is a linear state differential game possessing the property that the open-loop Nash equilibria are Markovian perfect. Based on the optimal control strategy, it can be easily observed that both of the service providers 1 and 2 allocate larger bandwidth to service class 1 due to the higher price offered, which
have resulted in more users selecting service class. By increasing the number of users in area $a$, the two access networks become congested, which can be controlled by the service providers by adjusting in a dynamic manner the proportion of bandwidth allocated to the service class that possesses a higher price. Here, it can be observed that the proportion of bandwidth allocated to service class 1 by service provider 1 is larger than that of service provider 2, as a result of the price differentiation of service classes of service provider 1 being on the higher side.

The two-level game framework have the potential to achieve optimal bandwidth allocation with respect to wireless networks that are of a heterogeneous nature, whereas analyzing the strategy evolution process has been achieved with the use of replicator dynamics. Moreover, allocating bandwidth among various service classes by considering the users’ dynamic service selection, has been formulated by utilizing the concepts of a linear state differential game. The solution that this differential game offers can be considered the open-loop Nash equilibrium. The fact that social welfare maximization can be achieved using the open-loop Nash equilibrium.

### 1.8 CONTRIBUTIONS

In the context of a general resource allocation framework for dynamic, open systems we have developed several algorithms aimed to optimize bandwidth allocation in wireless networks. We assume that acceptable quality levels for the different end-to-end connections are quantitatively specified using discrete resource dependent utility functions. We propose several allocation schemes that use these utility functions for allocating and reallocating bandwidth to connections, aiming to maximize the accumulated utility of the system. The contributions of the thesis are the following:

- **A Quasi Chosen Procedure (QCP) Approach is to avoid bottleneck problem, mobile traffic and to maximizing throughput and minimizing outage in Integrated Cellular Network.** QCP was designed to run in BSs to choose quasi-sources to divert their calling traffic. QCPs aim to choose source nodes that have the highest possibility of successfully discovering relaying routes. Moreover, the selection of source nodes in QCPs also tries to balance the bandwidth of TDSs, which is used for traffic diversion. According to the number
and bandwidth of TDSs, network planners can choose a reasonable QCP to achieve a relatively low call blocking rate. Alternatively, by estimating the amount of overloaded traffic, planners can choose a QCP to reduce the number of TDSs deployed in each cell. The design of QCPs is mainly driven by the need of reducing the Demand Denial Rate of a cellular network system. Although the QCPs are not designed specifically for data transmission, the principle adopted by the algorithms is equally applicable to data transmission. Considering the guarantee of data transmission, we need to specify the bandwidth required by the original source, and then the released bandwidth of quasi-sources (which could be more than one) should be able to satisfy the bandwidth requirement is presented in Chapter III.

- **Experimental Economic Method (EEM) approach is to avoid assigning too much bandwidth to single user, achieve high utility but also reduce low blocking probability.** With respect to the rapidly growing Fourth Generation (4G) wireless communication system, an outstanding feature is the heterogeneous wireless access. Despite the fact that this amazing feature allows users to connect to several wireless access networks simultaneously, various challenges with respect to bandwidth allocation (BA) among various heterogeneous networks also arise. A feasible and effective solution to tackle this problem has been proposed in chapter IV, which concerns a bandwidth allocation using game (BAG) algorithm with respect to heterogeneous wireless networks. Chapter IV proposes modeling a Resource allocation RA or Bandwidth Allocation problem as a game, and then formulating it to increase the total utility to a maximum of the dissimilar networks. The game model that has been proposed also establishes the existence of the Experimental Economic Method (EEM). In order to divert assigning too much Resource or bandwidth to a single user, utility functions have also been designed. Moreover, simulation results reveal that the scheme proposed only achieves a high utility, but also reduces blocking probability within a few iterations.

- **A Novel Framework is developed to achieve optimal bandwidth with respect to wireless networks.** Chapter V has attempted to present a two-level game
framework that was based on the concepts of a differential game and an evolutionary game, thus having the potential to achieve optimal bandwidth allocation with respect to wireless networks that are of a heterogeneous nature, wherein, the dynamic service selection behavior of the various users has were modeled on the basis of an evolutionary game, whereas analyzing the strategy evolution process has been achieved with the use of replicator dynamics. Moreover, allocating bandwidth among various service classes by considering the users’ dynamic service selection, has been formulated by utilizing the concepts of a linear state differential game. The solution that this differential game offers can be considered the open-loop Nash equilibrium. Here, co-operative bandwidth allocation of service providers which can assist in maximizing aggregated profit has also been considered. The fact that social welfare maximization can be achieved using the open-loop Nash equilibrium has also been demonstrated in Chapter V.

1.9 THESIS OUTLINE
The thesis is organized as follows. This chapter is a brief introduction into the principles of wireless communication. It highlights why the resource management is significant to cellular Communication Networks.

In Chapter II shows the background work on resource allocation in Wireless Communication Networks. It also shows the problems arising when using the total available bandwidth in every cell. The impact of bandwidth allocation in Wireless Communication networks are discussed.

Chapter III deal with new approach i.e., QCP. It is designed to execute in BSs to choose quasi-sources to divert their calling traffic and also tries to stabilize the bandwidth of TDSs, which is used for traffic diversion. Based on the quantity and bandwidth of TDSs, network planners can choose a reasonable QCP to achieve a relatively low call block rate. Alternatively, by estimating the amount of overloaded traffic, planners can choose a QCP to reduce the number of TDSs deployed in each cell.

Chapter IV describes a distributed game theory approach that can find use in adaptive bandwidth allocation with respect to heterogeneous wireless networks. EEM has the ability to come up with fair resource allocations for various applications in different
types of networks. Each network will be able to allocate a specific bandwidth to the different users, and will also be able to maximize a part of the utility function in a distributed fashion. It also reduces the blocking probability in a manner that is more efficient.

Chapter V describes a two-level game framework based on a differential game and an evolutionary game, in order to achieve optimal bandwidth allocation with respect to heterogeneous wireless networks. The dynamic service selection behavior of users has been modeled as an evolutionary game, and the strategy evolution process has been analyzed using replicator dynamics. The bandwidth allocation among different service classes considering users’ dynamic service selection has been formulated as a linear state differential game.

Chapter VI summarizes and concludes the work presented, highlights the limitations and points towards potential future work.