CHAPTER 1

1.1 INTRODUCTION

Historical Background

In 1838, Samuel Mores (1791-1872) demonstrated the first telegraph network. In 1844, Morse sent the first telegraph message successfully, from Washington D.C. to Baltimore, Maryland [1.1]. In 1895, Italian inventor and engineer Guglielmo Marconi (1874-1937) developed, demonstrated and advertised the first successful long-distance wireless telegraph [1.2].

Although the telegraph had collapsed out of common use by the start of the 21st century and it was substituted by the new technologies like telephone, fax machine. However, Telegraph set the groundwork for the communications revolution that led to later innovations like Wireless Communication, Satellite Communication, Infrared Communication, Broadcast Radio, Microwave Communication, Wi-Fi Communication, and Mobile Communication Systems [1.1].

The name wireless communication was first introduced in the 19th century and wireless communication technology has developed over the following decades. It is one of the most important methods of transmission of information from one device to other devices. In this technology, with the help of electromagnetic waves like Infrared Rays, Radio Frequencies, and Microwave Frequencies etc., the information is transmitted through the air without deploying any cable or wires or other electronic conductors.

Wireless technology is the most astonishing area in Communications and Networking. Emergence of a variety of standards for Wireless Communication Networks in culmination with advances in Radio Access Technologies offer better range, greater capacity, improved Quality of Service (QoS) and many more things. It also reduces energy consumption and deployment costs, paving the way for new applications and services in mobile broadband access.

In 1971, a pioneer of computer networking systems is ALOHAnet [1.4], popularly known as ALOHA, developed at the University of Hawaii. It provided the first demonstration of a wireless data network. ALOHA used investigational Ultra-High frequencies (UHF) frequencies to begin with; as frequency regulation or licensing for commercial applications
were not present in the 1970s. Further, ALOHA was used in cable (Ethernet based) and satellite applications.

In the early 1980s, frequencies for mobile networks became available, and in 1985 frequencies appropriate for Wi-Fi were assigned in US. These governing developments made the application of ALOHA possible both in Wi-Fi and in mobile telephone networks. Since then ALOHA has found many applications in wireline and wireless technologies.

While ALOHA has been a pioneer networking system, which spanned across wireline and wireless networks, the wireless technology itself has advanced over the past few years from using analog FM transmission for voice telephony to OFDM / OFDMA for mobile internet and video streaming applications in the recent years [1.5].

1.2 Evolution of Cellular Networks

All over the world, wireless communication networks have relished dramatic growth over the past 35 years. The first commercial cellular telephone system in the United States was deployed by Ameritech in the Chicago area in late 1983. It was an analog service called Advanced Mobile Phone Service (AMPS). Today, digital cellular telephone services are available throughout the world, and have well exceeded fixed-line telephone services both in terms of availability and number of users. According to survey, as of 2017 we have over 5.13 billion mobile subscribers in the world, which is more than double the number of fixed line subscribers and amounts to a higher than 69.4% penetration. The relative adoption of wireless versus fixed line is even more intense in the developing world. For example, in India, wireless penetration is more than four times that of fixed line [1.6].

Table 1.1 given bellow depicts the historical milestones in the development of cellular network to provide mobile broadband.

<table>
<thead>
<tr>
<th>Year</th>
<th>Important Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1892</td>
<td>Nikola Tesla found theoretical basis for radio communication and demonstrated radio transmission.</td>
</tr>
<tr>
<td>1897</td>
<td>Guglielmo Marconi demonstrated radio communications; awarded patent for it.</td>
</tr>
<tr>
<td>1902</td>
<td>First verifiable transatlantic radio transmission (telegraphy) made from</td>
</tr>
<tr>
<td>Year</td>
<td>Event Description</td>
</tr>
<tr>
<td>-------</td>
<td>-------------------</td>
</tr>
<tr>
<td>1906</td>
<td>Reginald Fessenden made first successful two-way transmission over North Atlantic and demonstrated voice transmission using amplitude modulation.</td>
</tr>
<tr>
<td>1915</td>
<td>First transatlantic radio transmission of voice from Arlington, Virginia to Paris, France.</td>
</tr>
<tr>
<td>1921</td>
<td>Short wave radio (HF radio: 2.3MHz to 25.82MHz) developed.</td>
</tr>
<tr>
<td>1934</td>
<td>AM radio systems used in 194 U.S. municipalities for public safety.</td>
</tr>
<tr>
<td>1935</td>
<td>Edwin Armstrong demonstrated FM.</td>
</tr>
<tr>
<td>1946</td>
<td>First mobile telephone service in St. Louis, Missouri introduced by AT&amp;T.</td>
</tr>
<tr>
<td>1948</td>
<td>Claude Shannon published his seminal theory on channel capacity: ( C=\log_2(1+SNR) ).</td>
</tr>
<tr>
<td>1956</td>
<td>Ericsson developed first automatic mobile phone called Mobile Telephone A (weighed 40kg).</td>
</tr>
<tr>
<td>1960–1970</td>
<td>Bell Labs developed cellular concept.</td>
</tr>
<tr>
<td>1971</td>
<td>AT&amp;T submits proposal for a cellular mobile system concept to FCC.</td>
</tr>
<tr>
<td>1979</td>
<td>First commercial cellular system deployed by NTT in Japan.</td>
</tr>
<tr>
<td>1983</td>
<td>FCC allocated 40MHz of spectrum in 800MHz for AMPS.</td>
</tr>
<tr>
<td>1983</td>
<td>Advanced Mobile Phone Service (AMPS) launched in Chicago.</td>
</tr>
<tr>
<td>1989</td>
<td>Qualcomm proposes CDMA as a more efficient, wireless voice technology.</td>
</tr>
<tr>
<td>1991</td>
<td>First commercial GSM deployment in Europe (Finland).</td>
</tr>
<tr>
<td>1995</td>
<td>First commercial launch of CDMA (IS-95) service by Hutchinson Telecom, Hong Kong.</td>
</tr>
<tr>
<td>1995</td>
<td>Personal Communication Services (PCS) license in the 1800/1900MHz band auctioned in the United States.</td>
</tr>
<tr>
<td>Year</td>
<td>Event</td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>2001</td>
<td>NTT DoCoMo launched first commercial 3G service using UMTS WCDMA.</td>
</tr>
<tr>
<td>2002</td>
<td>South Korea Telecom launches first CDMA2000 EV-DO network.</td>
</tr>
<tr>
<td>2005</td>
<td>UMTS/HSDPA launched in 16 major markets by AT&amp;T.</td>
</tr>
<tr>
<td>2005</td>
<td>IEEE 802.16e standard, the air-interface for Mobile WiMAX, completed and approved.</td>
</tr>
<tr>
<td>2006</td>
<td>WiBro (uses the IEEE 802.16e air-interface) commercial services launched in South Korea.</td>
</tr>
<tr>
<td>2007</td>
<td>Apple iPhone launched, driving dramatic growth in mobile data consumption.</td>
</tr>
<tr>
<td>2009</td>
<td>3GPP Release 8 LTE/SAE specifications completed.</td>
</tr>
</tbody>
</table>

**Table 1.1: Important Historical Landmarks toward the Development of Mobile Broadband [1.7]**

In the following paragraphs, the focus will be on the evolution and development of various generations of mobile wireless technology along with their significance and advantages of one over the other [1.8].

**1.2.1 The First Generation (1G): Analog Cellular Networks**

In 1979, the first commercially automatic cellular network (the 1G generations) was introduced in Japan by NTT. Bell Labs in 1984 developed present cellular technology, which employed several, base stations (cell sites) that are controlled centrally and each giving services to a small area (a cell). The cell sites are so installed that cells moderately coincided. In a cellular system, a moderate signal is required to reach between a base station (cell site) and a terminal (phone), so that the same channel can be used concurrently for different communication in different cells [1.9].

With the introduction of 1G phone, the mobile market showed annual growth rate of 30 to 50 per cent, mounting to nearly 20 million subscribers by 1990. 1G was an analog technology and the mobile phones normally had poor battery life. It provides great voice quality without much security, and would sometimes experience dropped calls. The maximum speed of 1G was 2.4 Kbps.
<table>
<thead>
<tr>
<th>NMT-450</th>
<th>NMT-900</th>
<th>AMPS</th>
<th>ETACS</th>
<th>NTACS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Bands</td>
<td>D/L: 869-894 MHz</td>
<td>D/L: 916-949 MHz</td>
<td>D/L: 860-870 MHz</td>
<td>NMT-450: 450-470 MHz</td>
</tr>
<tr>
<td></td>
<td>U/L: 824-849 MHz</td>
<td>U/L: 871-904 MHz</td>
<td>U/L: 915-925 MHz</td>
<td>NMT-900: 890-960 MHz</td>
</tr>
<tr>
<td>Channel Bandwidth</td>
<td>30 kHz</td>
<td>25 kHz</td>
<td>12.5 kHz</td>
<td>NMT-450: 25 kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NMT-900: 12.5 kHz</td>
</tr>
<tr>
<td>Multiple Access</td>
<td>FDMA</td>
<td>FDMA</td>
<td>FDMA</td>
<td>FDMA</td>
</tr>
<tr>
<td>Duplexing</td>
<td>FDD</td>
<td>FDD</td>
<td>FDD</td>
<td>FDD</td>
</tr>
<tr>
<td>Voice Modulation</td>
<td>FM</td>
<td>FM</td>
<td>FM</td>
<td>FM</td>
</tr>
<tr>
<td>Number of Channels</td>
<td>832</td>
<td>1240</td>
<td>400</td>
<td>NMT-450: 200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NMT-900: 1999</td>
</tr>
</tbody>
</table>

**Table 1.2: Major First Generation Cellular Systems [1.10]**

1.2.2 The Second Generation (2G): Digital Networks

In the 1990s, the 'Second Generation' (2G) mobile phone systems developed, principally using the GSM standard. These 2G phone systems use digital transmission instead of analog transmission. The rise in mobile phone usage as a result of 2G was explosive and this era also saw the beginning of prepaid mobile phones. The second generation introduced a new category to communication, as SMS text messaging became possible, firstly on GSM networks and finally on all digital networks. Quickly SMS became the communication technique of preference for the young generation. Today in many progressive markets the general public prefers sending text messages instead of voice calls.

Several benefits of 2G were digital signals requires less battery power for transmission, so it helps mobile batteries to last long. Digital coding improves the voice clarity and reduces noise in the transmission medium. Digital signals are considered environment friendly. Digital encryption has provided privacy and security to the data and voice calls. In 2G communication technology, proper working of mobile phones requires strong digital signals.
### Table 1.3: Second Generation (2G) Cellular Systems [1.10]

<table>
<thead>
<tr>
<th></th>
<th>GSM</th>
<th>IS-95</th>
<th>IS-54</th>
<th>IS-136</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year of Introduction</strong></td>
<td>1990</td>
<td>1993</td>
<td>1991</td>
<td></td>
</tr>
<tr>
<td><strong>Frequency Bands</strong></td>
<td>850/900MHz, 1.8/1.9GHz</td>
<td>850MHz/1.9GHz</td>
<td>850MHz/1.9GHz</td>
<td></td>
</tr>
<tr>
<td><strong>Channel Bandwidth</strong></td>
<td>200kHz</td>
<td>1.25MHz</td>
<td>30kHz</td>
<td></td>
</tr>
<tr>
<td><strong>Multiple Access</strong></td>
<td>TDMA/FDMA</td>
<td>CDMA</td>
<td>TDMA/FDMA</td>
<td></td>
</tr>
<tr>
<td><strong>Duplexing</strong></td>
<td>FDD</td>
<td>FDD</td>
<td>FDD</td>
<td></td>
</tr>
<tr>
<td><strong>Voice Modulation</strong></td>
<td>GMSK</td>
<td>DS-SS:BPSK, QPSK</td>
<td>π/4 QPSK</td>
<td></td>
</tr>
<tr>
<td><strong>Data Evolution</strong></td>
<td>GPRS, EDGE</td>
<td>IS-95-B</td>
<td>CDPD</td>
<td></td>
</tr>
<tr>
<td><strong>Peak Data Rate</strong></td>
<td>GPRS:107kbps; EDGE:384kbps</td>
<td>IS-95-B:115kbps</td>
<td>~12kbps</td>
<td></td>
</tr>
<tr>
<td><strong>Typical User Rate</strong></td>
<td>GPRS:20-40kbps; EDGE:80-120kbps</td>
<td>IS-95B: &lt;64kbps;</td>
<td>9.6kbps</td>
<td></td>
</tr>
<tr>
<td><strong>User Plane Latency</strong></td>
<td>600-700ms</td>
<td>&gt; 600ms</td>
<td>&gt; 600ms</td>
<td></td>
</tr>
</tbody>
</table>

“**2.5G**” using GPRS (General Packet Radio Service) technology is a cellular wireless technology developed in between its predecessor 2G and its successor 3G. GPRS can provide data rates from 56 Kbit/s upto 115 Kbit/s. It can be used for services such as Wireless Application Protocol (WAP) access, Multimedia Messaging Service (MMS), and for Internet communication services such as email and World Wide Web access.

“**2.75G**” – EDGE is an abbreviation for Enhanced Data rates for GSM Evolution. EDGE technology is an extended version of GSM. It permits the clear and fast transmission of data and information up to 384 Kbit/s speed.

#### 1.2.3 The Third Generation (3G): High speed IP data networks

The main technological difference that differentiates 3G technology from 2G technology is the application of packet switching instead of circuit switching for data transmission. The high connection speeds of 3G technology enabled a transformation in the
industry: for the first time, media streaming of radio and even television content on 3G handsets became possible.

In the mid-2000s an evolution of 3G technology begun to be implement, namely High-Speed Downlink Packet Access (HSDPA). It was an enhanced 3G mobile telephony communications protocol in the High-Speed Packet Access (HSPA) family, also coined 3.5G, 3G+ or turbo 3G, which allows networks based on Universal Mobile Telecommunications System (UMTS) to have higher data transfer speeds and capacity.

Current HSDPA deployments support down-link speeds of 1.8, 3.6, 7.2 and 14.0 Mbit/s. Further speed increases are available with HSPA+, which provides speeds of up to 42 Mbit/s downlink and 84 Mbit/s with Release 9 of the 3GPP standards.

Table 1.4, summarises various 3G technologies and gave there technical specifications.

<table>
<thead>
<tr>
<th>CDMA2000</th>
<th>1X</th>
<th>W-CDMA</th>
<th>EV-DO</th>
<th>HSPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>3GPP Release 99</td>
<td>3GPP2</td>
<td>3GPP2</td>
<td>3GPP Release 5/6</td>
</tr>
<tr>
<td>Frequency Bands</td>
<td>850/900MHz, 1.8/1.9/2.1GHz</td>
<td>450/850MHz, 1.7/1.9/2.1GHz</td>
<td>450/850MHz, 1.7/1.9/2.1GHz</td>
<td>850/900MHz, 1.8/1.9/2.1GHz</td>
</tr>
<tr>
<td>Channel Band width</td>
<td>5MHz</td>
<td>1.25MHz</td>
<td>1.25MHz</td>
<td>5MHz</td>
</tr>
<tr>
<td>Peak Data Rate</td>
<td>384–2048kbps</td>
<td>307kbps</td>
<td>DL:2.4–4.9Mbps UL:800–1800kbps</td>
<td>DL:3.6–14.4Mbps UL:2.3–5Mbps</td>
</tr>
<tr>
<td>Typical User Rate</td>
<td>150–300kbps</td>
<td>120–200kbps</td>
<td>400–600kbps</td>
<td>500–700kbps</td>
</tr>
<tr>
<td>User-Plane Latency</td>
<td>100–200ms</td>
<td>500–600ms</td>
<td>50–200ms</td>
<td>70–90ms</td>
</tr>
<tr>
<td>Multiple Access</td>
<td>CDMA</td>
<td>CDMA</td>
<td>CDMA/TDMA</td>
<td>CDMA/TDMA</td>
</tr>
<tr>
<td>Duplexing</td>
<td>FDD</td>
<td>FDD</td>
<td>FDD</td>
<td>FDD</td>
</tr>
<tr>
<td>Data Modulation</td>
<td>DS-SS: QPSK</td>
<td>DS-SS: BPSK, QPSK</td>
<td>DS-SS: QPSK, 8PSK, 16QAM</td>
<td>DS-SS: QPSK, 16QAM and 64QAM</td>
</tr>
</tbody>
</table>

Table 1.4: Summaries of Major 3G Standards [1.10]
1.2.4 The Fourth Generation (4G): Development of Mobile Broadband

Subsequently, the wireless community began looking to data-optimized 4th-generation technologies, with the possibilities of speed improvements up to 10-fold over existing 3G technologies. It was basically the addition in the Third Generation (3G) technology with added bandwidth and more services. The anticipation from the Fourth Generation (4G) technology was primarily the streaming of high quality audio/video over end-to-end Internet Protocol (IP). TeliaSonera in Scandinavia launched the first two commercially technologies the WiMAX standard and the LTE standard, portrayed as 4G technologies.

The main technological differences between 4G and 3G are the elimination of circuit switching and employing an all-IP network. Thus, 4G treats voice calls just like any other type of streaming audio media, utilizing packet switching over internet, LAN or WAN networks via VoIP.

4G LTE data transfer speed can provide peak download 100 Mbit/s, peak upload 50 Mbit/s, WiMAX offers peak data rates of 128 Mbit/s downlink and 56 Mbit/s uplink.

The table 1.1 summarizes the evolution of wireless generations over the past few decades [1.11].

<table>
<thead>
<tr>
<th>Generation</th>
<th>Period</th>
<th>Standards</th>
<th>Technology</th>
<th>SMS</th>
<th>Voice Switching</th>
<th>Data Switching</th>
<th>Data Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1G</td>
<td>1980’s</td>
<td>AMPS, TACS</td>
<td>Analog</td>
<td>No</td>
<td>Circuit</td>
<td>Circuit</td>
<td>2.4 Kbps</td>
</tr>
<tr>
<td>2G</td>
<td>1990’s</td>
<td>GSM, CDMA, EDGE, GPRS</td>
<td>Digital</td>
<td>Yes</td>
<td>Circuit</td>
<td>Circuit</td>
<td>50 Kbps or 1 Mbps</td>
</tr>
<tr>
<td>3G</td>
<td>2000+</td>
<td>UTMS, CDMA2000, HSDPA, EVDO</td>
<td>Digital</td>
<td>Yes</td>
<td>Circuit</td>
<td>Packet</td>
<td>21.6 Mbps</td>
</tr>
<tr>
<td>4G</td>
<td>2005+</td>
<td>LTE-A, IEEE 802.16 (WiMAX)</td>
<td>Digital</td>
<td>Yes</td>
<td>Packet</td>
<td>Packet</td>
<td>100 Mbps or 1 Gbps</td>
</tr>
</tbody>
</table>

Table 1.5: Summary of the evolution of Wireless Generations [1.11]
- AMPS – Advanced Mobile Phone System is an analog mobile phone system standard developed by Bell Labs, and officially introduced in the Americas on October 13, 1983, Israel in 1986, Australia in 1987, Singapore in 1988 and Pakistan in 1990.

- TACS – Total Access Communication System (TACS) and ETACS are mostly-obsolete variants of Advanced Mobile Phone System (AMPS), which were declared as the choice for the first two UK national cellular systems in Feb 1983.

- GSM – Global System for Mobile Communications, formerly Groupe Spécial Mobile is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation digital cellular networks used by mobile devices such as tablets, first deployed in Finland in December 1991 [1.9]. As of 2014, it became the global standard for mobile communications with over 90% market share, operating in over 193 countries and territories [1.12].

- CDMA – Code Division Multiple Access

- EDGE – Enhanced Data rates for GSM Evolution, it was deployed on GSM networks beginning in 2003 – initially by Cingular (now AT&T) in the United States [1.13].

- GPRS – General Packet Radio Service

- UTMS – Universal Mobile Telecommunications System

- HSDPA – High-Speed Downlink Packet Access

- EVDO – Evolution Data Only/Evolution Data Optimized

- LTE-A - Long-Term Evolution Advance

Following table gives a brief comparison between HSPA+, Mobile WiMAX and LTE:

<table>
<thead>
<tr>
<th></th>
<th>HSPA+</th>
<th>Mobile WiMAX</th>
<th>LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard</strong></td>
<td>3GPP Release 7 &amp; 8</td>
<td>IEEE 802.16e-2005</td>
<td>3GPP Release 8</td>
</tr>
<tr>
<td><strong>Frequency Bands</strong></td>
<td><strong>Early Deployments</strong></td>
<td><strong>Frequency Bands</strong></td>
<td><strong>Early Deployments</strong></td>
</tr>
<tr>
<td></td>
<td>850/900MHz, 1.8/1.9GHz,</td>
<td>2.3GHz, 2.6GHz, and 3.5GHz</td>
<td>700MHz, 1.7/2.1GHz, 2.6GHz, 1.5GHz</td>
</tr>
<tr>
<td><strong>Channel Bandwidth</strong></td>
<td>5MHz</td>
<td>5, 7, 8.75, and 10MHz</td>
<td>1.4, 3, 5, 10, 15, and 20MHz</td>
</tr>
<tr>
<td>Peak Downlink Data Rate</td>
<td>28–42Mbps</td>
<td>46Mbps (10MHz, 2 × 2 MIMO, 3:1 DL to UL ratio TDD); 32Mbps with 1:1</td>
<td>150Mbps (2 × 2 MIMO, 20MHz)</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------</td>
<td>---------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Peak Uplink Data Rate</td>
<td>11.5Mbps</td>
<td>7Mbps (10MHz, 3:1 DL to UL ratio TDD); 4Mbps with 1:1</td>
<td>75Mbps (10MHz)</td>
</tr>
<tr>
<td>User-Plane Latency</td>
<td>10–40ms</td>
<td>15–40ms</td>
<td>5–15ms</td>
</tr>
<tr>
<td>Frame Size</td>
<td>2ms frames</td>
<td>5ms frames</td>
<td>1ms sub-frames</td>
</tr>
<tr>
<td>Downlink Multiple Access</td>
<td>CDMA/TDMA</td>
<td>OFDMA</td>
<td>OFDMA</td>
</tr>
<tr>
<td>Uplink Multiple Access</td>
<td>CDMA/TDMA</td>
<td>OFDMA</td>
<td>SC-FDMA</td>
</tr>
<tr>
<td>Duplexing</td>
<td>FDD</td>
<td>TDD; FDD option planned</td>
<td>FDD and TDD</td>
</tr>
<tr>
<td>Data Modulation</td>
<td>DS-SS: QPSK, 16QAM, and 64QAM</td>
<td>OFDM: QPSK, 16QAM, and 64QAM</td>
<td>OFDM: QPSK, 16QAM, and 64QAM</td>
</tr>
<tr>
<td>Channel Coding</td>
<td>Turbo codes; rate 3/4, 1/2, 1/4</td>
<td>Convolutional, turbo RS codes, rate 1/2, 2/3, 3/4, 5/6</td>
<td>Convolutional and Turbo coding: rate 78/1024 to 948/1024</td>
</tr>
<tr>
<td>Hybrid-ARQ</td>
<td>Yes; incremental redundancy and chase combining</td>
<td>Yes, chase combining</td>
<td>Yes, various</td>
</tr>
<tr>
<td>MIMO</td>
<td>Tx diversity, spatial multiplexing, beamforming</td>
<td>Beamforming, open-loop Tx diversity, spatial multiplexing</td>
<td>Transmit Diversity, Spatial Multiplexing, 4 × 4 MIMO Uplink: Multi-user collaborative MIMO</td>
</tr>
<tr>
<td>Persistent Scheduling</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1.6: Summary Comparisons of HSPA+, WiMAX, and LTE [1.14]
1.3 Road Map for Higher Data Rate Capability

The first and second-generation cellular systems were principally designed for voice services and their data capabilities were inadequate. Wireless systems have since been developing to deliver broadband data rate capability as well.

GSM technology is moving forward to develop cutting-edge, customer-focused solutions to meet the challenges of the 21st century and 3G/4G mobile services. When GSM was first designed, no one could have anticipated the dramatic growth of the Internet and the escalating demand for multimedia services. These developments have brought about new challenges to the world of GSM. For GSM operators, the focus is now rapidly shifting from only activating and driving the development of technology to facilitating mobile data transmission to a new level of enhanced data rate, quality, simplicity, coverage range, and reliability.

People are increasingly looking to gain access to information and services anytime everywhere, GSM will provide that connectivity. The combination of Internet access, web browsing, and the whole range of mobile multimedia capability is the major driver for development of higher data speed technologies.

GSM operators have two non-exclusive options for developing their networks to 3G wide band multimedia services:

(a). The operator can use General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE) (also known as 2.5G) in the existing radio spectrum, and in small proportion of new spectrum; or

(b). The operator can use WCDMA/UMTS in the 2 GHz bands [1.15, 1.16, and 1.17]. Both approaches offer a high degree of liberty in investment because roll-out can progress in symmetry with market’s demand. Also, the existing network equipments and radio sites can be extensively reused.

Using High Speed Circuit Switched Data (HSCSD) is the first step to introduce high-speed circuit-switched data service in GSM. HSCSD is a feature that empowers the co-allocation of a number of full rate traffic channels (TCH/F) of GSM into an HSCSD configuration. The aim of HSCSD is to deliver a blend of services with different user data
rates by means of a single physical layer structure. HSCSD has a capacity several higher than that of TCH/F, leading to a significant enhancement in data transfer capability.

Ushering faster data rates into the mainstream is the new speed of 14.4 kbps per time slot and HSCSD protocols that approach wire-line access rates of up to 57.6 kbps by using multiple 14.4 kbps time slots. The use of a higher data rate is accomplished by increasing the current baseline 9.6 kbps to 14.4 kbps by reducing error-correction overhead of the GSM radio link protocol [1.18].

Evolution of short message service (SMS) is the next stage in the high speed road map. The examples of SMS are smart messaging and unstructured supplementary service data. The new GPRS, a packet data service using TCP/IP and X.25 that offers speed up to 115.2 kbps. GPRS has been standardized to optimally support numerous applications ranging from recurrent transmissions of average data rate to extreme data rate. Services of GPRS have been developed to decrease connection set-up time and permit an optimal usage of radio resources. GPRS provides a packet data service for GSM, over which data packets from numerous mobile stations can be multiplexed.

Digital Advanced Mobile Phone System (DAMPS IS-136) has been developed by adopting similar evolution strategy, it also includes GPRS. For operators planning to offer high bandwidth multimedia services, the move to GPRS packet-based data bearer service is significant. It is a reasonably small step compared to constructing a completely fresh 3G network. Use of the GPRS network architecture for IS-136 packet data service enables data subscription roaming with GSM networks around the globe. The IS-136 packet data service standard is also known as GPRS-136. GPRS-136 provides the similar competencies as GSM GPRS. The user can have the access of either X.25 or IP-based data networks.

GPRS offers a primary network platform for existing GSM operators to expand the wireless data market to offer 3G services; it also provides a platform on which UMTS frequencies can be built.

GPRS improves GSM data services considerably by providing end-to-end packet switched data connections. This is predominantly effective in Internet/intranet traffic, where short bursts of intense data communications aggressively are scattered with relatively long periods of idleness. Setting up a GPRS call is almost instantaneous and users can be continuously on-line, since there is no real end-to-end connection to be established. Users
have the extra benefits of paying for the definite amount of data transmitted, rather than for connection time.

GPRS uses only network resources and bandwidth when data is actually being transmitted, because it does not need any dedicated end-to-end connection. This means that a given amount of radio bandwidth can be utilized effectively among a number of users simultaneously.

The importance of EDGE for today’s GSM operators is that it can increase data rates up to 384 kbps and theoretically even higher in good quality radio environments that are using current GSM band and carrier configurations more efficiently. EDGE will both complement and be an alternative to new WCDMA coverage. EDGE will also have the influence of merging the GSM, DAMPS, and WCDMA services through the use of dual-mode terminals.

GSM operators who win licenses in 2 GHz bands will be able to introduce UMTS wideband coverage in areas where early demand is likely to be greatest. Dual-mode EDGE/UMTS mobile terminals will allow full roaming and handoff from one system to the other, with mapping of services between the two systems. EDGE will contribute to the commercial success of the 3G system in the vital early phases by ensuring that UMTS subscribers will be able to relish roaming and interworking globally.

While GPRS and EDGE require new functionality in the GSM network with new types of connections to external packet data networks, they are essentially extensions of GSM. Moving to a GSM/UMTS core network will likewise be a further extension of this network.

EDGE provides GSM operators whether or not they get a new 3G license with a commercially attractive solution for developing the market for wide band multimedia services. Using familiar interfaces such as the Internet, volume-based charging and a progressive increase in available user data rates will remove some of the barriers to large-scale take-up of wireless data services. The move to 3G services will be a staged evolution from today’s GSM data services using GPRS and EDGE.

Recently, several wireless broadband technologies have emerged to achieve high data rates and quality of service. Navini Networks developed a wireless broadband system based
on TD-SCDMA. The system, named Ripwave, uses beamforming to allow multiple subscribers in different parts of a sector to simultaneously use the majority of the spectrum bandwidth. Beamforming allows the spectrum to be effectively reused in dense environments without using excessive sectors [1.19].

The Ripwave system varies between QPSK, 16 and 64-QAM, which allows the system to burst up to 9.6 Mbps using a single 1.6 MHz TDD carrier. Due to TDD and 64-QAM modulation the Ripwave system is exceptionally spectrally efficient. Currently Ripwave is being used by several telecom operators in the United States. The Ripwave Customer Premise Equipment is about the size of a cable modem and has a self-contained antenna. Recently, PC cards for laptops are available allowing greater portability for the user.

Flarion Technologies is promoting their proprietary Flash-orthogonal frequency-division multiple (OFDM) as a high-speed wireless broadband solution. Flash-OFDM uses frequency hopping spread spectrum (FHSS) to limit interference and allows a reuse pattern of one in an OFDM access environment. Flarion’s Flash-OFDM system uses 1.25 MHz FDD carriers with QPSK and 16-QAM modulation. Peak speeds can burst up to 3.2 Mbps with continuous rates leveling off at 1.6 Mbps on the downlink. To further improve data rates Flarion has not implemented an antenna enhancement technology.

BeamReach is a wireless broadband technology based on OFDM and beamforming. It uses TDD duplexed 1.25 MHz paired carriers. Spread spectrum is used to reduce interference over the 2.5 MHz carriers allowing a frequency reuse of one. Individual users can expect downlink rates of 1.5, 1.2, and 0.8 Mbps using 32-QAM, 16-QAM, and 8-PSK modulation respectively. The aggregate network bandwidth is claimed to be 88 Mbps in 10 MHz of spectrum or 220 Mbps in 24 MHz of spectrum, which equates to a high spectral efficiency of 9 bps/Hz. It must be noted that the system uses either 4 or 6 sectors and these claims are based on those sectoring schemes. For any technology with a reuse number of 1 to achieve 9 bps/Hz per cell with 4 or 6 sectors, the efficiency in each sector would need to be a reasonable i.e. 2.3 or 1.5 bps/Hz, respectively [1.20].

IP Wireless is a broadband technology based upon UMTS. It uses either 5 or 10 MHz TDD carriers and QPSK modulation. For a deployment of 10 MHz deployment the theoretical peak transmission speeds is 6 Mbps downlink and 3 Mbps uplink respectively. The IP Wireless system only uses QPSK modulation and no advanced antenna technologies.
IP Wireless has significant prospective, when the advanced antenna technology and the High Speed Downlink Packet Access (HSDPA) are included together.

A SOMA network has also developed a wireless broadband technology based on UMTS. Like UMTS, SOMA’s technology uses 5 MHz FHSS carriers. Peak throughput is claimed to be as high as 12 Mbps, making SOMA one of the faster wireless broadband technologies.

The peak data rates of 3G systems are around 10 times more than 2G/2.5G systems. The fourth-generation systems may be likely to deliver a data rate 10 times higher than 3G systems. User data rates of 2 Mbps for vehicular and 20 Mbps for indoor applications are expected. The fourth-generation systems will also meet the requirements of next generation Internet through compliance with IPv6, Mobile IP, QoS control, and so on.

1.3.1 Evolution of 3GPP Standards

Thus a number of cellular wireless standards and systems have been covered, tracing the evolution from first generation analog voice systems to the development of LTE. Let’s now summarize the major enhancements and performance improvements that have been achieved at each step of this evolution. Since LTE was established by the 3GPP standards body, the focus will be only on 3GPP standards evolution [1.6].

The first version of a 3G standard by 3GPP was targeted for completion in 1999, and is commonly referred to as 3GPP Release 99, although the actual release occurred in 2000. Several UMTS networks globally are based on this standard. Subsequent releases are identified by a release number as opposed to year of release.

Each release provided enhancements in one or more of several aspects including

1. Radio performance improvements such as higher data rates, lower latency, and increased voice capacity,
2. Core network changes intended at decreasing its complexity and improving transport efficiency, and
3. Support for new applications such as push-to-talk, multimedia broadcast, and multicast services and IP Multimedia Services.

Table 1.7 summarizes the various 3GPP releases and the enhancements that each brought.
<table>
<thead>
<tr>
<th>3GPP Standards Release</th>
<th>Year Completed</th>
<th>Major Enhancements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release 99</td>
<td>2000</td>
<td>Specified the original UMTS 3G network using W-CDMA air-interface. Also included Enhancements to GSM data (EDGE).</td>
</tr>
<tr>
<td>Release 4</td>
<td>2001</td>
<td>Added multimedia messaging support and advanced toward using IP transport in core network.</td>
</tr>
<tr>
<td>Release 5</td>
<td>2002</td>
<td>Specified HSDPA with up to 1.8Mbps peak downlink data rate. Introduced IP Multimedia Services (IMS) architecture.</td>
</tr>
<tr>
<td>Release 6</td>
<td>2004</td>
<td>Specified HSUPA with up to 2Mbps uplink speed. Multimedia Broadcast/Multicast Services (MBMS). Added advanced receiver specifications, push-to-talk over cellular (PoC) and other IMS enhancements, WLAN inter working option, limited VoIP capability.</td>
</tr>
<tr>
<td>Release 7</td>
<td>2007</td>
<td>Specified HSPA+ with higher order modulation (64QAM downlink and 16QAM uplink) and downlink MIMO support offering up to 28Mbps downlink and 11.5Mbps uplink peak data rates. Reduced latency and improved QoS for VoIP.</td>
</tr>
<tr>
<td>Release 8</td>
<td>2009</td>
<td>Further evolution of HSPA+: combined use of 64QAM and MIMO; dual-carrier with 64QAM. Specifies new OFDMA-based LTE radio interface and a new all IP flat architecture with Evolved Packet Core (EPC).</td>
</tr>
<tr>
<td>Release 9</td>
<td>2010</td>
<td>Expected to include HSPA and LTE enhancements.</td>
</tr>
<tr>
<td>Release 10</td>
<td>2012</td>
<td>Expected to specify LTE-Advanced that meets the ITU IMT-Advanced Project requirements for 4G.</td>
</tr>
</tbody>
</table>

**Table 1.7: 3GPP Standards Evolution**

Table 1.8 summarizes the evolution of peak data rates and latency of wireless systems that evolved from GSM via 3GPP standards. Clearly, tremendous developments have been made over the past decade in both data rate and latency. Peak data rates in early GPRS systems were as low as 40kbps, as compared to LTE, that can provide up to 326Mbps which
is nearly a ten thousand fold increase. Typical end-user speeds raised from 10–20kbps with GPRS to 0.5–2Mbps with HSPA/HSPA+, and suppose to grow to 2–3Mbps or even more with LTE. Developments in technology have pushed us very close to realizing the Shannon limit for channel capacity, which makes achieving further gains in spectral efficiency quite challenging. Changes in protocols, frame sizes, and network architecture over the years have also resulted in dramatic reduction in latency. While GPRS and EDGE systems had user plane latencies around 350–700ms, HSPA systems bought it down to less than 100ms, and LTE systems will get it below 30ms. Lower latency improves the quality of experience of real-time applications such as VoIP, gaming, and other interactive applications [1.6].

<table>
<thead>
<tr>
<th>3GPP Release</th>
<th>Peak Down-link Speed</th>
<th>Peak Up-link Speed</th>
<th>Standard Speed</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPRS</td>
<td>Release 97/99</td>
<td>40–80kbps</td>
<td>40–80kbps</td>
<td>600–700ms</td>
</tr>
<tr>
<td>EDGE</td>
<td>Release 4</td>
<td>237–474kbps</td>
<td>237kbps</td>
<td>350–450ms</td>
</tr>
<tr>
<td>UMTS (WCDMA)</td>
<td>Release 4</td>
<td>384kbps</td>
<td>384kbps</td>
<td>&lt;200ms</td>
</tr>
<tr>
<td>HSDPA/UMTS</td>
<td>Release 5</td>
<td>1800kbps</td>
<td>384kbps</td>
<td>&lt;120ms</td>
</tr>
<tr>
<td>HSPA</td>
<td>Release 6</td>
<td>3600–7200kbps</td>
<td>2000kbps</td>
<td>&lt;100ms</td>
</tr>
<tr>
<td>HSPA+</td>
<td>Release 7 and 8</td>
<td>28–42Mbps</td>
<td>11.5Mbps</td>
<td>&lt;80ms</td>
</tr>
<tr>
<td>LTE</td>
<td>Release 8</td>
<td>173–326Mbps</td>
<td>86Mbps</td>
<td>&lt;30ms</td>
</tr>
</tbody>
</table>

**Table 1.8:** Performance Evolutions of 3GPP Standards

1.3.2 LTE Advanced: Heterogeneous Networks [1.21]

Developed by 3GPP, LTE is the leading OFDMA wireless mobile broadband technology. LTE delivers high spectral efficiency, low latency and high peak data rates. LTE influences the economy of 3G, as well as the worldwide ecosystem of infrastructure and device manufacturers, to offer the uppermost performance in a cost efficient manner [1.22].

The LTE standard was first presented in March of 2009 as part of the 3GPP Release 8 specifications. Comparing the performance of 3G and its evolution to LTE, LTE does not intend anything exceptional to improve spectral efficiency, i.e. bps/Hz. However, LTE
ominously increases system performance by spending wider bandwidths where spectrum is available.

To attain performance enhancements in LTE Advanced, the 3GPP has been working on numerous features of LTE comprising carrier aggregation (multiple component carriers), higher order MIMO (multiple antennas) and heterogeneous networks (picos, femtos and relays). Since enhancements in spectral efficiency per link are approaching hypothetical boundaries with 3G and LTE, the next generation of technology is all about increasing spectral efficiency per unit area.

In other words, LTE Advanced needs to deliver a persistent user experience to users everywhere inside a cell by altering the topology of traditional networks. The significant advantages of LTE Advanced in heterogeneous network deployments are explained briefly bellow [1.23].

1.3.3 Heterogeneous Networks

A. Traditional Network Deployment Approach

Existing wireless cellular networks are usually deployed as homogeneous networks using a macro-centric planning process. A homogeneous cellular system is a network of base stations in a calculated design and a assembly of user terminals, in which all the base stations have analogous transmission power levels, antenna patterns, receiver noise floors and related backhaul connectivity to the (packet) data network.

Moreover, all base stations deliver flawless access to user terminals in the network, and serve approximately the same amount of user terminals, all of which carry identical data flows with similar QoS requirements. The locations of the macro base stations are cautiously selected through network formation, and the base station settings are appropriately designed to maximize the coverage and control the interference between base stations. As the traffic demand grows and the RF environment deviations, the network relies on cell splitting or supplementary carriers to overcome capacity and link budget restrictions and sustain undeviating user experience. However, this deployment procedure is complex and iterative. Moreover, site procurement for macro base stations with towers becomes more challenging in compact metropolitan areas. A new flexible deployment model is desirable for operators to enhance broadband user experience in a universal and cost-effective way.
B. An Alternate Approach Using Heterogeneous Network

Wireless cellular systems have advanced to the point where a remote system (with just one base station) accomplishes near optimum performance, as determined by information hypothetical capacity limits. Future improvements of wireless networks will be achieved more from cutting-edge network topology, which will bring the network nearer to the mobile users. Heterogeneous networks, using a diverse set of base stations, can be installed to increase spectral efficiency per unit area. Consider the heterogeneous cellular system depicted in Figure 1.1. This cellular system consists of systematic (planned) placement of macro base stations that characteristically transmit at high power level (~5W - 40W), overlapped with numerous pico base stations, femto base stations and relay base stations, which transmit at significantly lower power levels (~100mW - 2W) and are normally deployed in a comparatively unplanned manner.

The low-power base stations can be installed to eliminate coverage holes in the macro-only system and increase capacity in hot spots. Although the placement of macro base stations in a cellular network is commonly based on vigilant network planning, the placement of pico/relay base stations may be more or less ad hoc, based on just rough information of coverage concerns and traffic density (e.g. hot spots) in the network. Due to their lower transmit power and smaller physical size, pico/femto/relay base stations can offer flexible site acquisitions. Relay base stations deliver added flexibility in backhaul where wireline backhaul is inaccessible or not economical [1.24].

![Diagram of Heterogeneous Network](image)

**Figure 1.1:** Heterogeneous Network utilizing mix of macro, pico, femto and relay base stations [1.25]
In a homogeneous network, each mobile terminal is served by the base stations with the strongest signal strength, while the undesirable signals received from other base stations are typically treated as interference. In a heterogeneous network, such principles can lead to significantly suboptimal performance. In such systems, smarter resource synchronization among base stations, better server selection schemes and more advanced procedures for efficient interference management can offer significant gains in throughput and user experience as compared to a conventional approach of installing cellular network infrastructure.

### 1.3.4 Different Types of Cells

There are different types of cell used for different applications. The traditional macro cells are still necessary to deliver overall coverage, and connectivity principally for those in remote areas or in fast moving in vehicles where numerous handovers are not anticipated. However, where high data rates are required in houses or urban areas, a range of small cell technologies can be used. These may use one of a range of backhaul technologies. However, the significant feature is that, these needs to appear as a sole network to the user, providing the same enhanced performance level.

A small cell is a minute form of the traditional macro cell. It compresses the characteristics of a cell tower like radio and antenna into a low power, portable and easy to install radio device. Small cells usually have a coverage ranging from 10 meters to a few hundred meters and are used by operators to either offload traffic from the macro network in a high density short range environment or to strengthen the range and efficiency of a mobile network.

Different types of cells and their characteristics are as under:

i. **Macro-cells** are the cell sites common for both the technologies i.e. HSPA+ and LTE. The coverage range of Macro-cells may vary from a few hundred meters (100mts) to a few kilometers. The maximum output power is of the order of tens of watts.

ii. **Micro-cells** normally cover smaller areas approximately up to a kilometer. The transmission power ranges from milliwatts to a few watts. Microcells are installed to provide temporary improved cellular coverage and capacity to
places like sports stadiums, convention centres etc. Sometimes, to improve bandwidth and reliability microcells may use distributed antenna systems (DAS).

iii. **Pico-cells** deliver capabilities and coverage areas, it can support up to 100 users above a coverage area of 250 yards only. Pico cells are normally installed indoors to increase poor wireless and cellular coverage inside a building, such as an office floor or retail space.

iv. **Femto-cells** are usually user installed to increase the coverage area inside closed vicinity, such as home, office or a dead zone within a building. Femtocells can be acquired through the service provider or bought from a reseller. Unlike picocells and microcells, femtocells are designed to support only a handful of users and are only capable of handling a few simultaneous calls. They are provided by the operator but can be self-installed by the consumer.

1.4 Overview and Motivation

Currently, Internet and mobile communications are converging to a new paradigm, the *Mobile Internet*. The ability to access information and services anytime, any from and anywhere has been shaping to new user profiles. This leads to the development of demands of new applications. With the popularization of the third generation (3G) and fourth generation (4G) technologies, mobile communication systems undergo embellishments of new services and functionalities. These advancements may results in some critical issues, such as interference, limited coverage, and restrictions on the use of triple play applications, etc.

In indoor conditions, channel quality between the cellular base station and the mobile node may be affected by walls and other hindrances. The wireless communication for indoor environment requires additional resources, including time, bandwidth, and transmission power so that they can guarantee the quality of service (QoS) required by consumers inside a building (office or home). However, in the absence of resources in wireless cellular networks will be critical, since more than 60% of the voice traffic and 70% of data traffic is produced in indoor environment.

Thus, it is required to examine access technologies to ensure acceptable levels of quality of service (QoS), considering the increasing demand for data services. Considering
the above facts, femtocells are an attractive alternative since they are cost-effective to considerably increase the user data rates of their wireless networks at the consumer premises. This rising demand for indoor wireless multimedia and latest trends of mobile convergence are flooring the way for the installing femtocells industries. Femtocells can be open access or closed access [1.26]. Open access permits a random number of users to use the femtocell, whereas in closed access, the use is limited to users that are exclusively permitted by the owner of the femtocells.

In this thesis the entire focus will be on the analysis of LTE & LTE-A femtocells. LTE (Long Term Evolution) is a technology for wireless broadband 4G (4th Generation) mobile networks for voice and data that ensures greater data speeds, better performance and more effective use of spectrum. In this context, LTE networks have gained much attention, mainly because this technology can be used to improve voice services where there is a limited local coverage [1.27].

LTE frequency provides high data rate, but limited by poor indoor coverage range in some regions. Therefore, LTE femtocell network can be a substitute to improve the indoor signal quality and offloading the macrocell. Factors related to LTE femtocell such as security, interference and management still need proper attention while analysis [1.28].

With recent growth in the use of mobile technology applications, the high demand in the use of voice and data services has created an incomparable increase for alternative solutions to mobile broadband services. There has been statistical increase in the use of mobile devices for surfing the internet (web trending applications and websites, for examples, Facebook, Twitter, WhatsApp, etc.), video streaming (YouTube, News Channels, Facebook Live broadcasts, etc.), Voice-Over Internet Protocol (VoIP) applications for internet calls (Mobile VoIP and Skype), medical applications running on real-time data loggings, video & voice calls and a number of new applications that has greater demands for high data traffic.

According to the Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, for 2016-2021, "Overall mobile data traffic is expected to grow to 49 Exabyte’s per month by 2021. Mobile data traffic will grow at a CAGR of 47 percent from 2016 to 2021, a 7-fold increase over 2016" as shown in figure 1.2.
Figure 1.2: Cisco Forecasts 49 Exabyte’s per Month of Mobile Data Traffic by 2021 [1.29]

Furthermore, it is predictable that from 2016 to 2021 for mobile data traffic there will be Compound Annual Growth Rate (CAGR) of 47% [1.29]. The tremendous effects of numerous connected devices that are becoming clustered in cloud computing and (the concept) of the Internet of Things (IoT) has led to this data rate upsurge. In Middle East and Africa the alarming increase in the growth of transferred data is shown in figure 1.2 [1.30].

Figure 1.3: Growth of transferred data around the World [1.29]
Femtocells have been introduced, to eliminate the relative installation cost and delivering a highly effective way to meet the high rate demands. The use of the femtocells in the offloading of traffic from macrocells has helped to free significant capacity and has created an enhanced user data experience [1.30].

Femtocells (also called as Femto Base Station, FBS) are considered as "inexpensive compact base station that delivers equal amount of radio access interface as compared to a common macro-cellular base station (MBS) for Use Equipments (UEs)" [1.31]; in other words, they are small, low cost base stations with considerable low transmitting power.

The FBS devices are installed independently by the subscribers as desired by them in their residential or organizational premises as plug and play devices. They are relatively smaller in dimension and can be unified in small casings or mountings on walls.

![Graph showing Cellular Traffic from Mobile Devices and Offload Traffic from Mobile Devices over years from 2016 to 2021.]

**Figure 1.4:** Offload pertains to traffic from dual-mode devices (excluding laptops) over Wi-Fi or small-cell networks [1.29]

One significant point is that the femtocell device is connected to the service provider core network over internet protocol via the customers own broadband connection; also the device is powered locally from the customer’s power supply [1.31], [1.32].

Nowadays, many service providers have started providing the femtocell services around the world. According to Wireless Federation [1.33], Chunghwa Telecom in Taiwan has offered free femtocells to users to offload the growing traffic, also, it has been reported
that Vodafone in Qatar and Telefonica in Spain have made deployments similarly, with reports giving evidence that the femtocells deployments has doubled [1.34].

Initially in the development of femtocells, great attention has been given to WCDMA (Wideband Code Division Multiple Access) but it is getting much attention in WiMAX and LTE solutions similarly. The femtocell is referred to as a Home Node B (HNB) - 3G femtocells, and Home eNode B (HeNB) - LTE femtocell in the third Generation Partnership Project (3GPP) [1.35].

1.5 Concept of Femtocell

1.5.1 Cellular Mobile Network

Mobile cellular network is a conception which appeared in 1960 as advancement of the fixed telecommunication network. Since that time the conception has developed and currently the mobile cellular network has become gigantic.

The cellular network infrastructure principally consists on different base stations installed through the entire service coverage area. Each base station (eNB, using 3GPP 1 notation), forms a coverage area known as cell. These cells are scattered in a non-overlapping arrangement in order to maximize the covered area.

The users geographically positioned inside a cell are served by the eNB which is forming that cell. Normally the cells formed by eNB are indicated as a hexagon and are named macrocells. Because of frequency reusing techniques, the same frequency slot is used by different macrocells which is feasible since the signal power will decrease as we are further moving away from the base station.

The techniques used in the mobile cellular network have evolved quite fast since their conception, nowadays the 4th generation (4G) has been starting to include every user around the world. This advancement started when shifting from analog to digital transmission from 1G to 2G. The change from 2G to 3G was the start of using spread-spectrum based communications, which enhanced the voice and data capacity. Many enhancements had been done on 3G technology to improve the data rate handling, but the improvement has not been considered as a new generation.

The shift from the 3G to 4G changed the techniques used for the transmission and the network deployment. Conventionally the deployment of the eNB is done by the service provider company’s engineers who configure the network and fixed the parameters for the
base stations. The new methodology introduce smaller cells which can be installed effortlessly and adjust its parameters to the network requirement. Femtocells are closely associated to micro-cells and pico-cells. The reduction in coverage area helps to handle the growing number of devices requesting for throughput, and to bring improvement in quality of service (QoS).

The 4th generation is also called as LTE and it is a intermediate step before LTE-A. These steps are essential because of a necessity of launching 4G effortlessly by steadily moving from 3G. Fundamentally LTE converge all the wireless technologies (GSM, HSPA, HSDPA, WiMAX & CDMA) in order to make the migration to next step easy.

- **LTE**: IP is the protocol used for the addressing. In existing IPv6 the network operator uses a more simple and scalable network.

  This network is composed of four parts:
  
  i) Radio Access Network (RAN),
  
  ii) Backhaul,
  
  iii) Core and
  
  iv) Backbone

  IP protocol permits interconnecting all the above parts. The Radio Access Network (RAN) uses OFDMA in downlink transmission, this technique allow the users to share and adjust the available bandwidth concerning to demands.

<table>
<thead>
<tr>
<th>Access Scheme</th>
<th>UL</th>
<th>DFTS-OFDM DL</th>
<th>OFDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>1.4, 3, 5, 10, 15, 20 MHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-Carrier Spacing</td>
<td>15 KHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum TTI</td>
<td>1ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM, 64QAM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.9**: LTE basic Parameters

In Table 1 few important parameters of the LTE are printed, another important fact is the spatial multiplexing introduced in the downlink (DL). The latency, system transmission delay, is reduced in LTE, and also the time to initialize is quite small.
• **LTE-A:** This technique adds some new features to the LTE. New frequency bands are used, TV bands for example. By channel aggregation the effective bandwidth can be increased up to 100 MHz.

All the generation migrations imply a high cost for the networks operators. Due to the high rates that these operators are paying for mounting new antennas (eNB) they were considering for an inexpensive solution.

### 1.5.2 Femtocells as a Solution

Since the spread spectrum techniques were introduced, users are expecting for more features and connection speed in their devices. Numerous users and devices are being added into the wireless network every day. Network operators have the accountability to provide improved throughput and bandwidth to the customers of the wireless network. The employment of femtocells into the network is also projected as a better solution. This technique is capable to reuse the frequency slots used by macro cell users in a specified range. It also transfers the data by means of the Internet to the Mobile Core Network (MCN), which results in attaining high bandwidth at low cost, pleasing the network users, by an inexpensive and low inversion for the network operators.

![Figure 1.5: Femtocell Scenario](image)

**Figure 1.5:** Femtocell Scenario [1.37]

A promising scenario showing these femtocells is shown in Figure 1.4. As can been seen the HeNB formed can be in a superimposing environment. HeNB requires interference mitigation techniques; it is true for femtocells also.
To construct the smallest of the mobile network cells a device is needed, these devices are called femtocells access points (FAP). This device in clubbed with plug and play technology that means no technical support is needed for the installation. The user needs to power on the device and connect it to a backhaul network; this backhaul connection is done through a high speed access network (xDSL) that connects the HeNB to the Internet. The network operator only requires handling the new connection to the network, which can be effortlessly done by appropriately configuring the gateway. This fact gives to the network scalability and also low installation cost.

FAPs (Femto Access Points) are designed for indoor deployments, since they are creating a cell of 20 meters range [1.38]. Generally the implementation is done by users who want to increase throughput inside office or home and by users who have low coverage in their buildings. The two different configurations proposed are suitable for these two scenarios, for home HeNB 5 users are allowed in to join the FAP in other hand up to 16 users can be managed in an office environment. Depending in the scenario that the HeNB are deployed also different joining policies for accepting join requests are used, these policies are described in Chapter 2.

Femtocells are not only introducing new feature in the network layer, also new application services appear by the deployment of femtocells. Since the HeNB is going to detect you when arriving home, some tasks can be automatized or notifications can be send [1.39].

1.5.3 Market Status

In 2007 Sprint launched the first consumer femtocell service, it was focused only in home deployment and it do not have a real impact in the market until the first standardization were done, and put in the market (2012). In 2013 many of the major mobile operators groups are offering femtocell services, most remarkable of them are: AT&T, China Mobile, France Telecom/Orange, Telefonica, T-Mobile/ Deutsche Telekom and Vodafone. Some of these mobile operators reported the statistics of their femtocell network, for example Sprint had deployed around one million units in US. Also in US estimations regarding the AT&T status give an approach of almost 1M units deployed by this operator. Other countries were femtocells are starting to be deployed have more moderate numbers, in UK Vodafone reported about hundreds of thousands of HeNB.

The most interesting to analyze is the potential growth that this market has. In femtocell forum presents a market status and an estimated forecast. The growth of the market is primarily credited to the small cells installed in the public areas, but the growth of private
cells is also quite fast. The forecast estimate a growth of 47% each year from 2016 to 2021. This growth is due to the LTE network which makes almost mandatory the use of these small cells. The prediction also talks about all-in-one devices which will include Wi-Fi access point and mobile network access point.

The expectations are that the small cell market represent a value over 20 billion US dollars, this represent an enormous amount of the market, this creates a fierce competition between the network operators to offer more services and more secure, which will allow them to get the maximum number of users.

Femtocells, also called home base-stations have short coverage area, low cost and low power access points (APs), deployed by the end-consumer for improved indoor voice and data reception. The user installed femtocell device is connected with the cellular network through a broadband connection such as Digital Subscriber Line (DSL), cable modem, or a distinct wireless backhaul channel (see Fig. 1.5).

Like microcells, DAs and relays, due to their small transmission distance, femtocells can significantly reduce the transmit power, can extend handset battery life and can accomplish a higher signal-to interference-plus-noise ratio (SINR). These translate into improved reception the so-called five-bar coverage and higher capacity. Because of the decreased interference, more users can be deployed into a given area in the same region of spectrum, thus improving the area spectral efficiency [1.40], or improving the total number of active users per Hz per unit area.

![Diagram](image)

**Figure 1.6:** The architecture in a microcell-aided cellular network [1.41]

The main benefits of femtocells are that there is very little altering cost to the service provider for increasing system capacity as compared to other techniques, such as distributed
antenna systems, microcells and relays. Further, they need fairly minimal coordination (involving negligible network overhead) with the macrocell BS [1.40]. Moreover, because femtocells are deployed by end-customer in their self-interest, they can be positioned at arbitrary positions in each cell-site; in contrast, other infrastructure such as fixed relays will need to be positioned by the service provider for realizing their benefits, implying increased network planning.

**Figure 1.7:** The fundamental architecture in a cellular system employing distributed antennas [1.42].

**Figure 1.8:** The Internal architecture of a multi-hop relayed cellular system [1.43]

Research on wireless usage shows that more than 50% of all voice calls and over 70% of data traffic originates, within indoor environments [1.40]. Voice networks are planned to tolerate low signal quality, since the necessary data rate for voice signals is very low, in the range of 10 Kbps or less. But on the other hand data networks involve much higher signal
quality in order to deliver the multi-Mbps data rates used by the mobile consumers. For indoor devices, mainly at the higher carrier frequencies likely to be installed in many wireless broadband systems, attenuation losses will make high signal quality and hence high data rates very difficult to accomplish. Poor indoor coverage is the cause behind customer dissatisfaction and it also encourages them to either change network operator or maintain a separate wired line when indoors.

![Diagram of femtocell-aided cellular network](image)

**Figure 1.9:** The fundamental architecture in a femtocell-aided cellular network [1.44].

This situation raises the clear question: why not encourage the end-user to deploy a short-range low-power connection in these sites? This is the principle of the win-win scenario for the femtocell methodology. The consumer is pleased with the higher data rates and reliability; the operator decreases the expanse on traffic on their costly macrocell network, and can redirect its resources to deliver better coverage precisely to mobile users. The improved home coverage delivered by femtocells will demotivate the indoor mobile users to switch carriers.

However, the coverage and capacity profits of femtocells are not achievable, without speaking about radio interference across tiers, i.e. between the primary tier 1 (cellular network) and the secondary tier 2 (femtocell networks). Interference in such a tiered cellular architecture arises as consumers in both tiers occupy the same region of spectrum, termed as *universal frequency reuse*.

Universal frequency reuse is desirable for reasons of economy and flexible deployment. With universal frequency reuse co-channel radio interference between cellular customers and femtocell consumers will expect to limit the performance of such tiered
cellular systems. Interference management in two-tier networks faces visible challenges from the absence of coordination between the macrocell base-station (BS) and femtocell APs due to reasons of scalability, security and narrow availability of backhaul bandwidth [1.40]. Subsequently, even though it may be easier to operate the macrocell and femtocells in a common spectrum from an infrastructure or spectrum availability perspective, at the same time, realistic explanations are necessary to reduce cross-tier interference. The motivation of this thesis is to provide decentralized radio interference management strategies in femtocell-aided cellular architectures.

1.6 Objective and Scope of Thesis

The Femtocell technology is considerably useful; there are doubts on how to increase the performance of femtocell technology over the developing technology releases of macrocell. More significantly, femtocells require to develop and make use of the opportunity the LTE development offers, to attain peak data rates and support for larger bandwidths.

The thesis has given an examination and investigation for the future use of femtocell as a solution to improve indoor coverage and off-load mobile data indoors on the macro cellular networks. Precisely, it deals with analyzing various parameters of femtocell performance in an indoor cellular network in relation to the macro cellular networks.

Also, the future of the femtocells is considered by comparing the performance parameters obtained from simulation and considering LTE-Advance, the technical challenges that need to be handled carefully. In addition, some of the key problems faced by the femtocell networks. Most commonly resource allocation, timing/synchronization and backhauling are major issues in Broadband femtocells. In Voice femtocells interference management in femtocells, access allowance to femtocells, handoffs, mobility and emergency services are the main issues. The network infrastructures of femtocells face concerns for security.

1.7 Research Methodology

There are considerable amount of literature is present; the focus has been given on uniqueness of presentation. Moreover, the 3GPP specifications have been the main idea for a major portion of the research work, Femto Forum (www.thinksma llecell.com) was regularly referred for the recent news and trend happening in Femtocell Technology.

Additionally, this thesis research was done by using the following methods:
1. Literature review and study of white papers, company (vendors, service providers and so on) perspective and journals

2. Literature review and study on the femtocell technology

3. Designing and Simulation of the Femtocell (FAP) in an indoor cellular network using OPNET Software.

4. Analyzing the performance of the femtocell by measuring various parameters.

5. Comparing femtocell network simulation results with the existing Macrocell parameters given by ITU.

1.8 Thesis Outline

The thesis is organized as follows:

Chapter 1 gives the review of the significance of the important theory and the importance of the chosen topic. It gives an overview from the basics of wireless cellular technologies to the need of femtocells.

Chapter 2 gives the critical review of the literature, relevant theory and the importance of the selected problem statement. It describes the general overview of the femtocells by considering the femtocells concept with general technology and system architecture and ample issues and challenges. It also gives a brief about the future of femtocells by considering some technological challenging factors like Security and backhaul, Self-Organizing Network (SON), enhanced MIMO, Interferences, Handover and other future issues.

Chapter 3 gives the general outline of the 3GPP LTE features and its emphasis is on the basic structure and features. Also it presents the LTE-Advanced technology components with examined view to make correlations with the major components of the technology.

Chapter 4 is used to describe the use of femtocell as a solution to improve indoor coverage and off-load mobile data indoors on the macro cellular networks. Precisely, the thesis deals with an investigation of femtocell performance in an indoor cellular network. This is accomplished by designing and modeling femtocell network in an indoor cellular network using OPNET modelling and simulation software. All the simulation results and the graphs are being shown in the chapter.

Chapter 5 is giving the summary and conclusion based on the study of femtocells, LTE and Simulation of femtocell network.
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