

# Long Term Evolution (LTE) & Ultra-Mobile Broadband (UMB) Technologies for Broadband Wireless Access

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## Abstract

The evolution of wireless telephone technologies can be discretely grouped into various generations based on the level of maturity of the underlying technology. The classification into generations is not standardized on any given metrics or parameters and as such does not represent a strict demarcation. However, it represents a perspective which is commonly agreed upon, both by industry and academia, and hence conceived to be an unwritten standard. At this time, there are two major efforts towards the development of the next generation - "4G" wireless access technology. The 3GPP or 3rd Generation Partnership project (brand named as Long Term Evolution) is the name of the 4G efforts being undertaken in Europe and the 3GPP2 or 3rd Generation Partnership project 2 (brand named as Ultra Mobile Broadband) is the 4G effort of North America and parts of Asia. This survey tries to present an evolutionary and objective sketch to the development efforts of these technologies that mark the future of wide area broadband wireless access technologies.

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## Keywords

Wireless telephone technology, wireless access, broadband, 1G, 2G, 3G, 4G, Long Term Evolution, Ultra-Mobile Broadband, Orthogonal Frequency Division Multiplexing, Multiple Input-Multiple Output, 3GPP, 3GPP2

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## 1. Introduction

The evolution of wireless telephone technologies [\[DNK98\]](#) can be discretely grouped into various generations based on the level of maturity of the underlying technology. The classification into generations is not standardized on any given metrics or parameters and as such does not represent a strict demarcation. However, it represents a perspective which is commonly agreed upon, both by industry and academia, and hence conceived to be an unwritten standard.

The first generation or 1G was represented by an analog wireless access system primarily for voice traffic. The AMPS (Advance Mobile Phone System) in United States and the TACS (Total Access Communication System) in most parts of Europe represented this generation. The analog channel was susceptible to static noise and did not provide any protection from eavesdropping on the shared media. However, AMPS laid the foundation to the "cellular" technology which pioneered the use of small hexagonal service areas and hence supported frequency re-use across the "cells" without interference.

The 1G technology was soon replaced by the second generation or 2G technologies which represented the replacement of the analog radio network with digital radio network. The digital technology was much superior than its analog counterpart in the sense that digitized data could be subjected to superior processing techniques making it less susceptible to noise. Also, digital technology is based on discreet bi-level signals as against continuous analog signals making it easier to calibrate and maintain and hence cheaper than analog devices. 2G technologies could be further classified into Time Division Multiple Access (TDMA) based and Code Division Multiple Access (CDMA) based. The TDMA based technology was adopted mostly in Europe and was called Global system for Mobile communications or GSM (originally Groupe Special Mobile) while USA adopted the CDMA based technology and it was called CDMAone or standardized as IS-95a. CDMA had the advantage of supporting more users than GSM due to the better usage of the spectrum. CDMA is a spread spectrum technology in which each user is allowed to transmit over the whole spectrum using a different orthogonal code. Plainly speaking, each user uses a distinct code of one's and zero's to represent a one and zero at the other end. All the codes are orthogonal to each other and hence don't interfere. Neighboring cells may reuse the same frequency band and not interfere as long as they use different code, thus allowing better use of the available spectrum. CDMAone supported digital data transfer rates varying between 4.8-14.4 kbps while CDMAtwo or IS-95b supported data rates of around 115.2 kbps.

The 2G technology led to an interim generation of 2.5G which represented 2G systems which implemented a packet switched domain in addition to the circuit switched domain. General Packet Radio Service (GPRS) was the 2.5G technology adopted by GSM. GPRS provides a packet switched service over GSM offering data speeds between 56-114 kbps. Enhanced Data Rates for GSM Evolution (EDGE) over GSM and CDMA2000 1xRTT over CDMA were touted as 2.75G technologies though they may well be called 3G technologies as they surpass data rates of 144kbps required to qualify as 3G technology because their data rates were far below the data rates of actual 3G technologies. EDGE provides data rates of 236.8 kbps [\[TIM03\]](#) while CDMA2000 deployments limit the data rates at 144kbps.

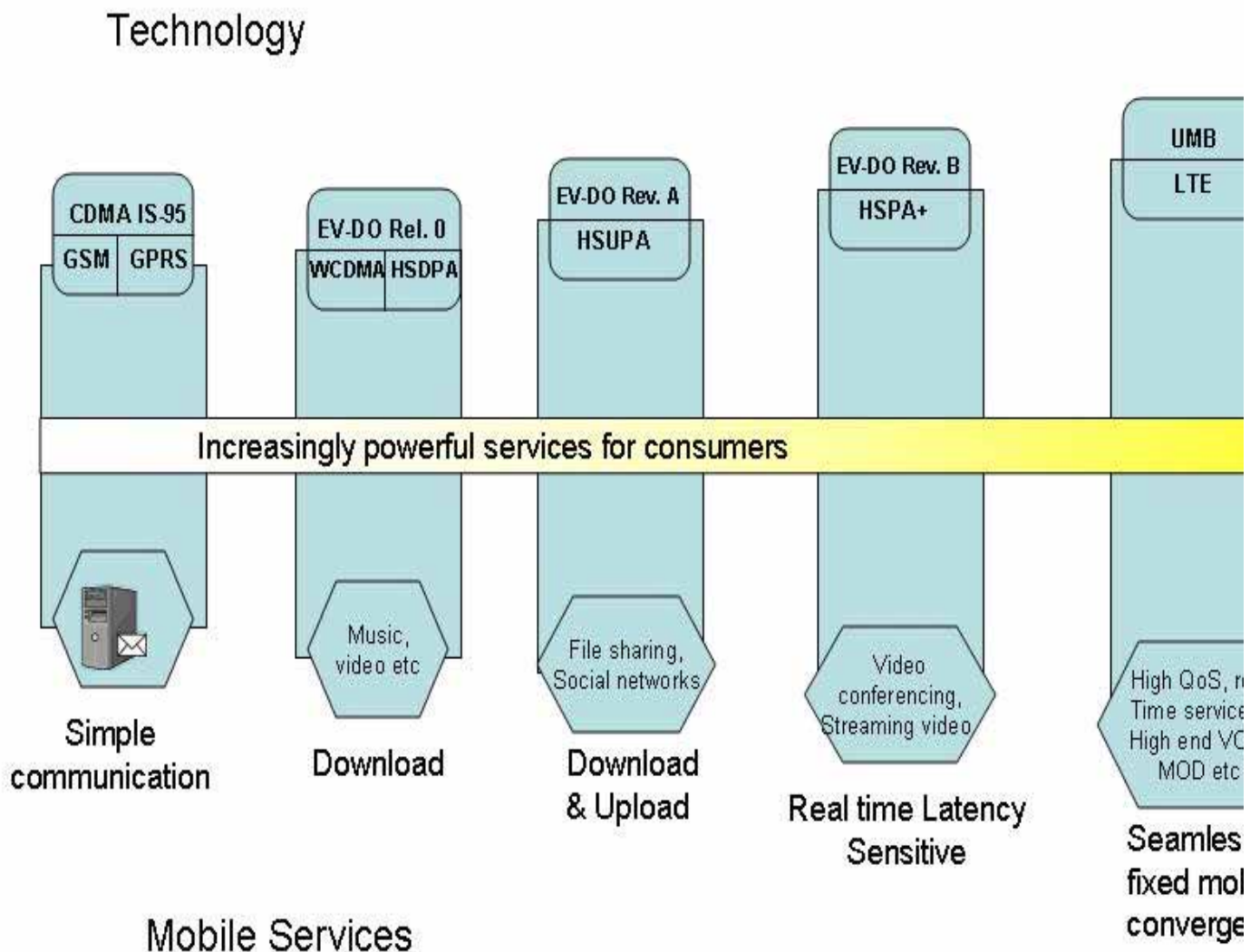
This interim period led to the evolution of the third Generation of Mobile technology, better known as 3G. The International Telecommunication Union (ITU) under the International Mobile Telecommunications Program fixed the minimum data rate of 144kbps for any technology to qualify to be a 3G technology. However, most technologies which fall under this category by far surpass this minimum limit and provide data rates typically between 5-10 Mbps. 3G Technologies attain better spectral efficiency (more bits/ Hertz) over wide area cellular telephone networks allowing for higher data rates and enhanced services. The first pre-commercial and commercial 3G technology was installed in Japan followed by South Korea. In Europe the Universal Mobile Telecommunication System (UMTS) is the adopted 3G technology using W-CDMA (Wideband Code Division Multiple Access) as the air interface. UMTS is sometimes called 3GSM to emphasize the fact that it is the 3rd generation technology succeeding GSM. The evolution of CDMA based technologies to 3G was through the CDMA2000 family of protocols, especially EV-DO (Evolution-Data Optimized) which uses multiplexing techniques including CDMA and TDMA to increase per user as well as system throughput.

UMTS based 3G technologies have raised themselves to 3.5G with HSDPA (High Speed Downlink Packet Access) allowing data rates up to 7.2Mbps. Also these networks are planning their progress into 4G through the 3GPP (3rd Generation Partnership Projects) where they aim to attain data rates in the order of 100Mbps downlink and 50 Mbps Uplink. Similarly, the North American counterpart is planning their 4th Generation through the 3GPP2 (3rd Generation Partnership Project 2) and aim at comparable data rates.

LTE or Long Term Evolution is the brand name given to the efforts of 3GPP 4th Generation technology development efforts mostly in Europe and UMB (Ultra-Mobile Broadband) is the brand name for similar efforts by 3GPP2 in North America.

Figure 1, presents a pictorial depiction of the discussion so far. Also, Figure 1 depicts the evolution of application and services in step with the evolution of the underlying wireless access technology.

Having presented some evolutionary details and a historical roadmap, our main aim in this survey is to study the two competing 4G technologies of LTE and UMB in more detail. In the rest of the survey, we shall provide a brief introduction into the LTE and UMB projects and look into the various technical challenges and the technologies adopted which shall go on to make these 4G efforts successful. We shall then look into the various services that shall be made possible as a result of these 4G technologies and finally try to present an objective comparison between the two 4G efforts and also between these 4G efforts and WIMAX(Wireless Interoperability for Microwave Access).



**Figure 1. Evolution of Wireless Telephone technologies and Services**

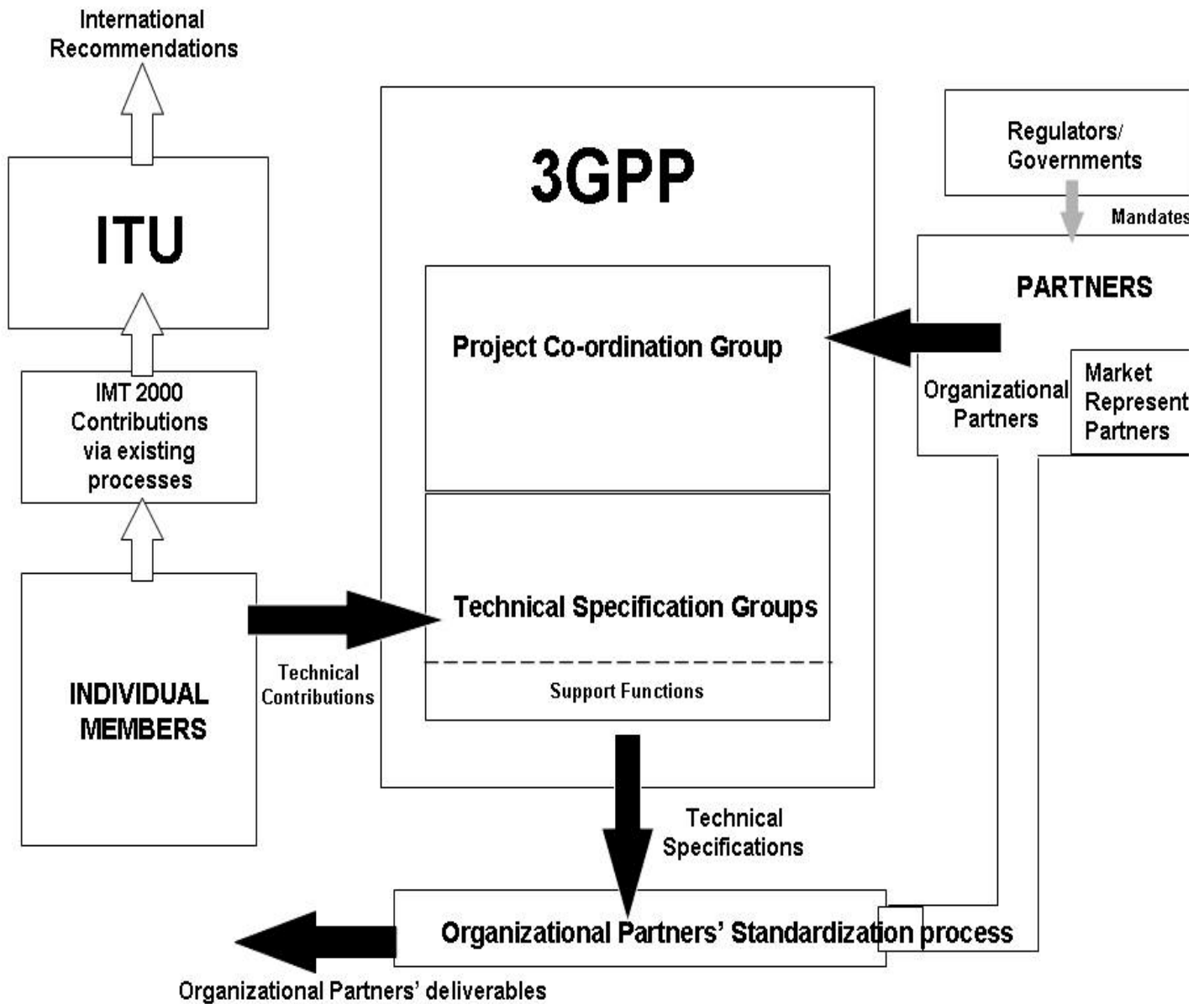
## 2. 4G wireless standards

The two competing bodies involved in churning out 4G wireless technologies [ADA07b] are the 3GPP in Europe and the 3GPP2 in North America. The 3GPP is marketed under the brand name of Long Time Evolution or LTE and is working on the 4G technology which is to succeed the 3G technology of UMTS. The 3GPP2 project is marketed under the brand name Ultra Mobile Broadband or UMB and their effort is to make transition to 4G from the existing CDMA2000 family of standards in North America.

*The High Level requirements for a 4G technology were identified as:*

1. Higher spectral Efficiency
2. Reduced cost per bit
3. Increased Service Provisioning by lowering the cost and increasing efficiency and experience
4. Open Interfaces as against closed technologies of the past
5. Power consumption efficiency
6. Scalable and flexible usage of frequency bands

The 3rd Generation Partnership project was established in December 1998, and is a collaborative agreement to bring together a number of Telecommunications standard bodies known as "Organizational Partners" [\[3GPP\]](#). The stated aim of the collaboration is to "co-operate for the production of a complete set of globally applicable Technical Specifications for a 3rd Generation Mobile System based on the evolved GSM core networks and the radio access technologies supported by 3GPP partners (i.e., UTRA both FDD and TDD modes)" . The 3GPP organization is based on a layered hierarchy with a "Technical specifications" Group working under the directions of a "Project Coordination" group to role out technical specifications as shown in Figure 2 (adapted from reference). The "Market Representation Partners" is an organization invited by the Organization Partners to advise them about market requirements and strategies. Individual members make technical contributions to the "Technical specifications Group". The "Organizational Partners" shall have joint ownership and copyright to the technical specifications churned out of the project.



**Figure 2. 3GPP Overview** [\[3GPP\]](#)

The technical specifications approved by 3GPP for the LTE project include the use of Orthogonal Frequency Division Multiplexing (OFDM) and advanced antenna technologies such as MIMO (Multiple Input Multiple Output). It specifies downlink peak speeds of 326Mbps and uplink peak speeds of 86Mbps, both in a 20 Mhz bandwidth. It also mandates the roundtrip latency between the base station and handsets to 10-milliseconds. The specification documents extend numerous documents and thousands of pages and the information provided above is just a summary of the final results.

The 3GPP2 [\[3GPP2\]](#)

is the Asian-North American effort for achieving similar capabilities for their CDMA2000 group of specifications and called by the brand-name of UMB. 3GPP2 organization is very similar to the 3GPP organization being a collaborative effort between 5 standards development organization from Asia(China, Japan, North Korea) and North America and multiple Market Representation Partners, providing market advice to the SDO's.

The technical specifications approved by 3GPP2 for UMB include and OFDMA based air interface with Frequency

Division Duplexing. The specifications specify downlink peak data rates of 275 Mhz and uplink peak data rates of 75 Mbps on a scalable bandwidth of 1.25-20 Mhz. It also supports the use of advanced antenna systems such as MIMO and Beamforming antennas.

It can be noticed that the technical specification of LTE and UMB are very similar to each other and are based on the same underlying technologies of OFDM and AAS(Advanced Antenna Systems). Both these standards represent a shift towards an All IP network and as such an All IP network has been specified as a part of the System Architecture Evolution (SAE), the core network architecture for LTE.

In the next section we shall discuss about the various technical challenges and discuss in detail the key technologies which make the transition from 3g to 4g possible.

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### 3. Technical Challenges and Technologies Adopted

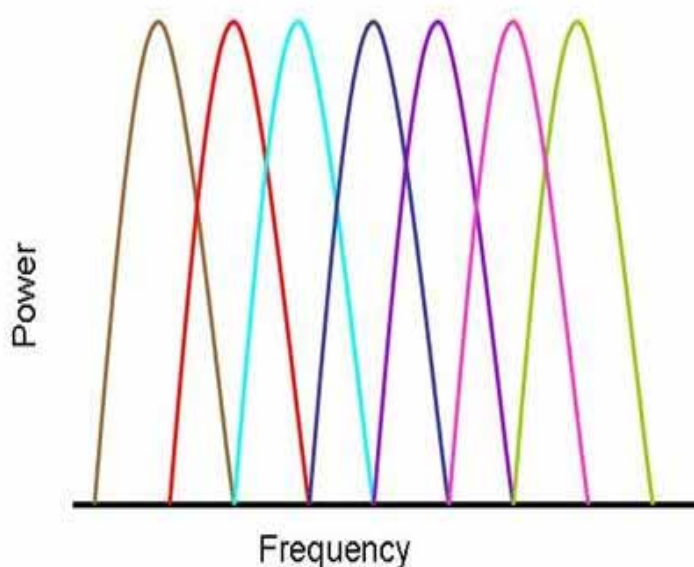
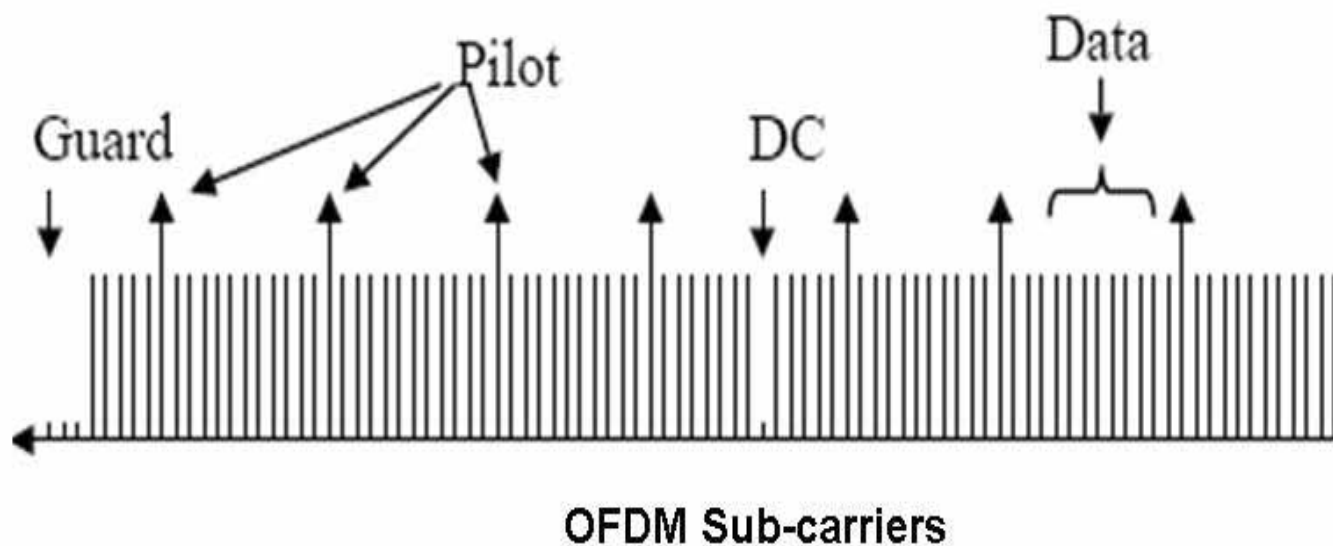
In this section, we first discuss the two generic technologies of OFDM and MIMO that are adopted by both standards (LTE and UMB) and then look into the details System Architecture Evolution- the proposed architectural framework proposed specifically for LTE.

#### 3.1 OFDM [\[PAN03\]](#):

Orthogonal Frequency Division Multiplexing is a superior air access method compared to its predecessor CDMA. Also OFDM is one of the key technologies which enable non-line of sight wireless services making it possible to extend wireless access system over wide-areas. It is a variant of the Frequency Division Multiplexing scheme in which the frequency channel is divided into multiple smaller sub-channels. In FDM, sub-channelization requires provisioning of guard bands between two sub-channels to avoid interference between them. OFDM (as shown in Figure 3) divides the frequency bandwidth in narrow orthogonal sub-parts called sub-carriers. A sub-channel is an aggregation of a number of these sub-carriers. The sub-carriers include data carriers, pilot carriers and a DC. The data carriers are used to carry data, the pilot carriers are used for channel sensing purposes and the DC mark the centre of the channel. Each subcarrier is modulated with conventional modulation scheme such as Quadrature Amplitude Modulation or Phase Shift Keying at a low symbol rate. Each user is provided with a integer number of sub-channels which is composed of a number of sub-carriers. User data is carried parallelly on each sub-carrier at a low rate. The combination of the parallel sub-carriers at the destination provide for the high data rates.

Since the sub-carriers carry data at a low rate and thus higher symbol time it is more resilient to multi-path effects, thus making it more suitable for wide-area non-line of Sight wireless access technology. Also, the use of overlapping orthogonal sub-carriers without guard bands make it more efficient than FDM scheme. OFDM resembles CDMA in that it is also a spread-spectrum technology in which energy generated at a particular bandwidth is spread across a wider bandwidth making it more resilient to interference and "jamming". However, unlike CDMA, OFDM allows adaptive assignment of sub-carriers to sub-channels based on channel conditions making it more robust and achieving higher spectral efficiency than CDMA.

The Multi-User version of OFDM is called OFDMA(Orthogonal Frequency Division Multiple Access).



**Orthogonal Frequency Division**

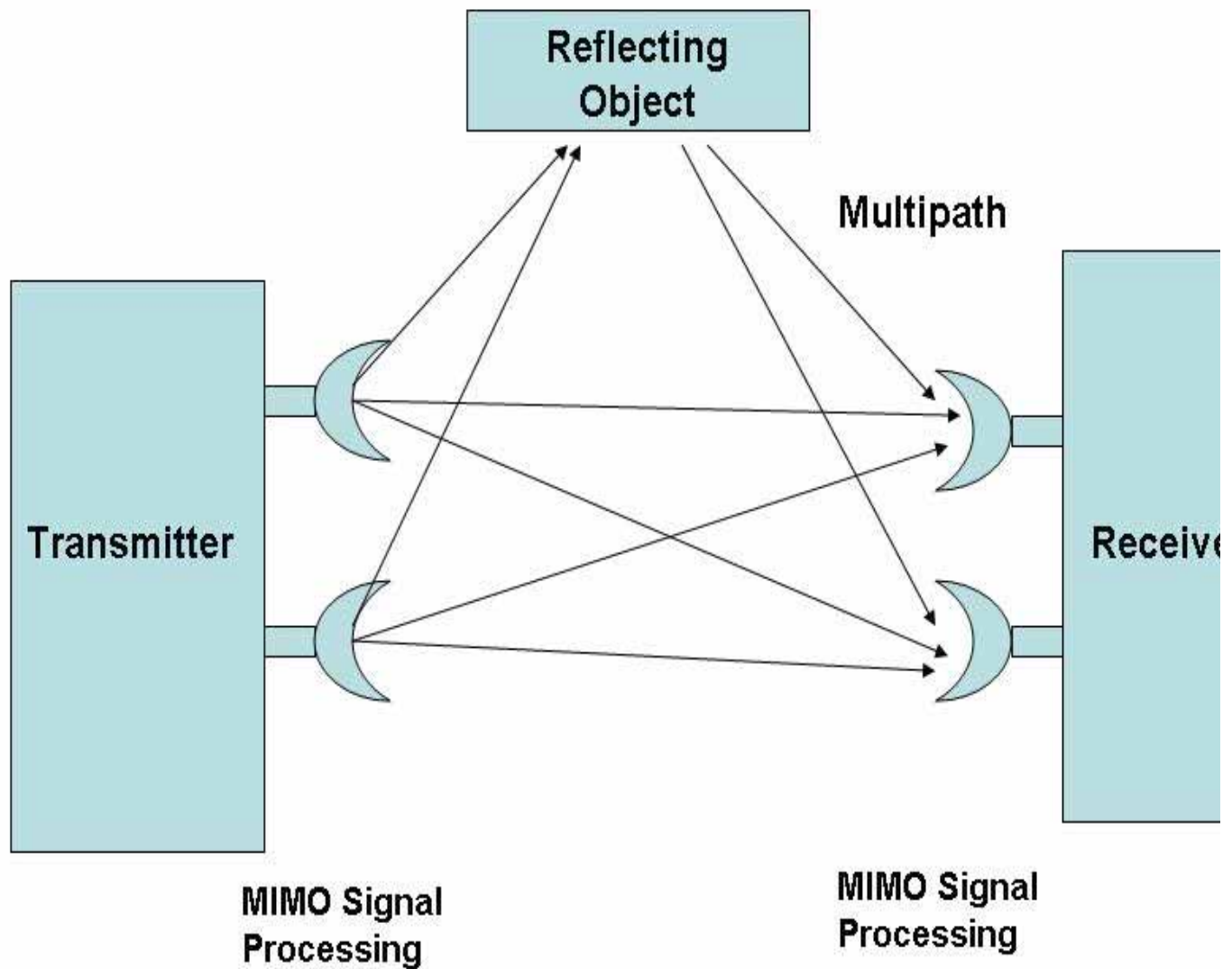
**Figure 3. OFDM**

### 3.2 MIMO [\[SAN04\]](#):

Multiple Input Multiple Output (MIMO) is one of the most popular Advanced Antenna Technologies which is supported both by LTE and UMB. The salient features of MIMO is that it offers higher throughput for a given bandwidth and higher link range for a given power value. A detailed discussion of the MIMO technology is beyond the scope of this survey and we provide a cursory glance at the key features of the technology. In MIMO the transmitter and receiver have multiple antennas giving MIMO multiple flavors based on the number of antennas present on each side. However, the key idea is that a transmitter sends multiple streams on multiple transmit antennas



and each transmitted stream goes through different paths to reach each receiver antenna as shown in Figure 3. The different paths taken by the same stream to reach multiple receivers allow canceling errors using superior signal processing techniques. MIMO also achieves spatial multiplexing to distinguish among different symbols on the same frequency. MIMO thus helps in achieving higher spectral efficiency and Link reliability.

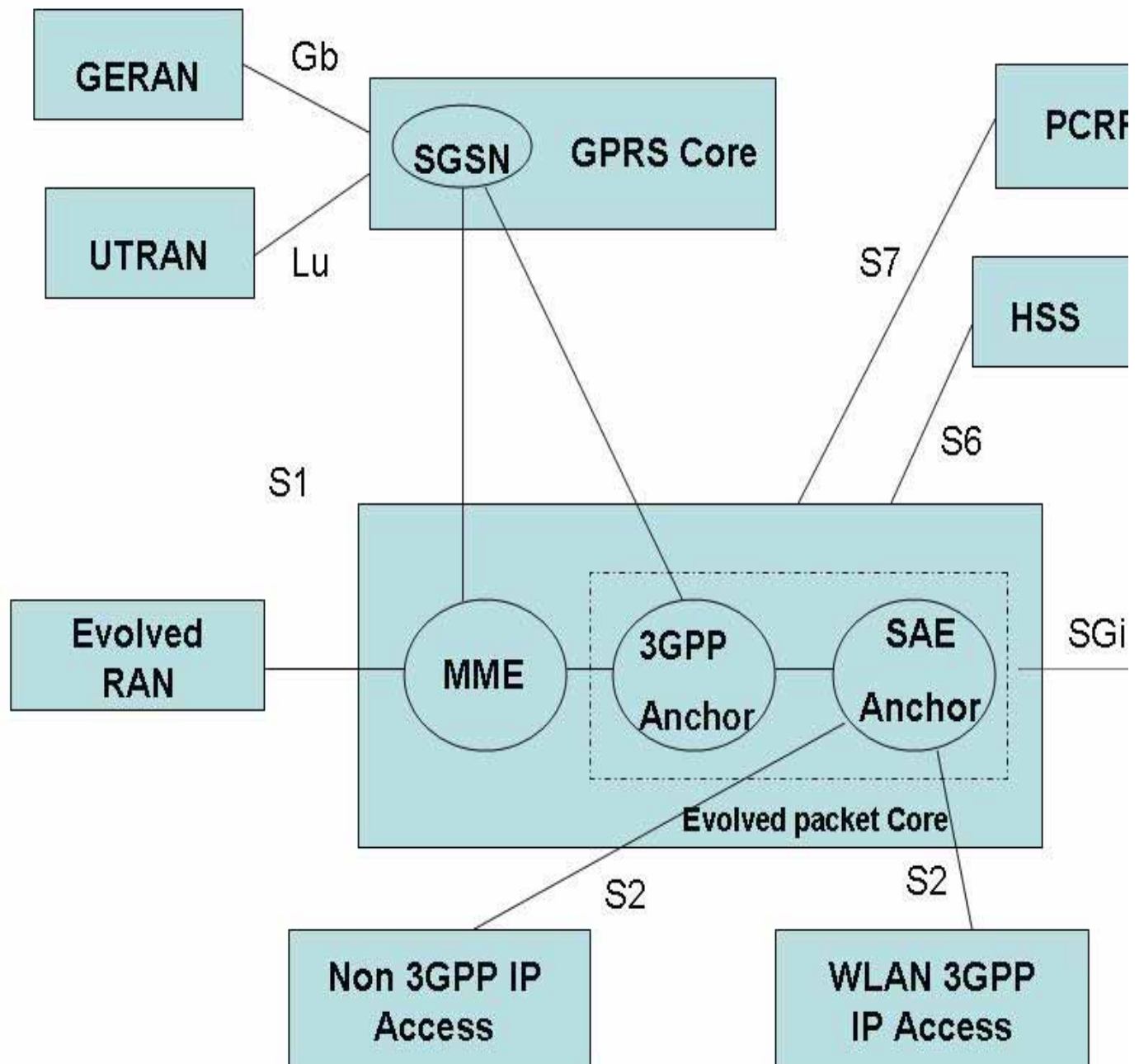


**Figure 4. MIMO**

### **3.3 SAE (System Architecture Evolution) [\[UNK06a\]](#):**

*The SAE defines the core network architecture for the LTE standard. The key features of SAE are:*

1. An all IP network - Evolution of the core network towards flat, packet only all IP based architecture
2. Higher throughput, Lower latency radio access technologies.
3. Interoperability across heterogeneous radio access technologies.
4. Vertical handover between multiple Radio Access Technologies.



**Figure 5. The SAE Architecture**

*The SAE architecture is composed of two node types:*

a. Base station or ENodeB (evolved NodeB)

b. AGW (Access Gateway)

As shown in Figure 5, The Mobility management entity (MME) is responsible for managing and maintaining user entity control plane context, authentication information, mobility management and generating temporary Identities. The 3GPP anchor is responsible for handling vertical handovers between 2G-3G and LTE. The SAE anchor is responsible for vertical handovers between 3GPP and non-3GPP such as WLAN etc. The link S3 in Figure 4 represents the user and bearer information exchange for inter-3GPP access System mobility. Link S6 represents the AAA interface for transfer of user access and authentication data for user access to the evolved system. Link S4 denote mobility support between GPRS core and inter AS support. S7 represent transfer of QoS(Quality of Service) policy and transfer rules. Link S2 represents mobility support between WLAN 3GPP IP access or non-3GPP IP access and Inter AS anchor.

### 3.4 Other Technical Aspects:

Some other technical aspects worth discussion are as follows:

#### 3.4.1 Quasi Orthogonal reverse Link [[QUA08b](#)]

UMB allows scheduling of end users over the same reverse link subcarriers and using multiple antennas at the base station to suppress the interference caused by multiple transmissions on the same resources. This method is called quasi-orthogonal reverse link in UMB and used to enhance the capacity of the reverse link

#### 3.4.2 Adaptive interference management Mechanisms [[QUA08B,QUA08a](#)]

There are some other techniques used by UMB to enhance and allow unplanned frequency. This requires several interference management techniques such as:

a. Fast Distributed Reverse Link Power Control: Each users reverse link power is shaped based on the interference it is causing to nearby other sectors.

b. Disjoint Link Support: A terminal is allowed to choose different forward link and reverse link sectors based on the signal strength on each sector on each of these links. This technique also minimizes the interference the terminal is causing to other sectors.

c. Fractional Frequency Reuse: In this technique, users at cell edge assigned to the strongest interfering sectors thus improving cell edge performance.

d. Flexband: In this method, all sub-carriers are used in all sectors using a power tiering mechanism wherein terminals close to the base station are assigned low power sub-carriers while those away from the base station are assigned higher power sub-carriers.

#### 3.4.3 Seamless Layer 1/Layer2 handoffs [[QUA08a,QUA08b](#)]

This is also an UMB feature that allows seamless handoffs so that delay sensitive applications are not effected due to serving sector changes. It uses active set management techniques to achieve seamless L1/L2 handovers in which the terminals maintain an active set of base stations and the base stations in the active set send RL pilot strength indications so that the terminal can decide on the strongest RL link. The handoff is initiated by the terminal by directly sending the handoff request to the target base station through physical layer signalling when it knows that the serving sector signal are not strong enough.

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## 4. Future services over 4G networks

The high data rates coupled with service centric approaches in ensuring high QoS awareness, fast handoff techniques, wide area mobility etc pave the way for multiple innovative and high end services over the wireless network infrastructure which were not possible before. Some of the services which were identified to be a true test of the success of these technologies can be listed as follows.

a. Laptops, PDA's and fixed broadband services: The most intuitive set of services that can be provided are related to all the fixed wired DSL internet services that we have today, except that they shall be provided wireless and shall support mobility. Also with the strong QoS support in these technologies, the operators shall be allowed to plan business strategies on various sectors based on the average throughputs of that sector.

b. Premium VOD(Video On Demand)/MOD(Music On Demand) Services: With High data rates and differentiated QoS services operators can provide premium multimedia based services such as video - on-demand and music-on-demand to subscribers who wish to avail of such services. The selling point of such services would be superior quality coupled with ease of mobility.

c. Multimedia Upload and Exchange services: The high uplink data rates of UMB and LTE allow for multimedia upload and exchange services such as file sharing, mobile blogging, social networking etc.

d. Consumer Electronics: The high data rates combined with mobility of UMB and LTE shall also spur a growth in development of newer and better consumer electronic goods leveraging these advantages. Better gaming consoles, vehicular entertainment systems, portable multimedia players, digital cameras with network capabilities and the likes of such shall be introduced which shall add value to the technology.

e. Business Applications for Vertical Markets: LTE and UMB shall allow operators to provide services to vertical business markets through business applications like Video conferencing to enterprise customers, video surveillance services to homes etc. The gamut of services that can be provided through LTE and UMB are only restricted by one's imagination. The above mentioned categories only represent the tip of the ice-berg. The limitless applications that can be supported through a truly mobile broadband infrastructure adds value to such technology and encouragement towards the efforts.

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## 5. UMB/LTE Vs WIMAX

WIMAX or Worldwide Interoperability for Microwave access can be seen as the biggest competition to UMB/LTE. It is a wireless broadband wide area network architecture defined in the IEEE standard 802.16. The standard 802.16d provides the standard for the fixed WIMAX while mobile WIMAX is defined in IEEE 802.16e. The stated peak data rate of WIMAX is around 74 Mbps covering a distance of 50 kms and allowing speed of 120 kmph. All these parameters are exclusive of each other meaning that each of them can be achieved only when the other factors are not extreme. The WIMAX forum is a group of around 300 companies who are involved in building workable profiles from the IEEE standards to ensure interoperability between devices manufactured by various vendors.

The competition between WIMAX and UMB/LTE is still on and only time shall tell as to which of these get wider acceptance in the market. However, compared technologically, UMB/LTE have certain advantages over WIMAX. They have about 2 times more data spectral efficiency over WIMAX. Also UMB provides much superior mobility service in terms of seamless handoffs, adaptive interference management and robust frequency re-use as compared to mobile-WIMAX. The UMB/LTE 4G technologies were developed grounds up keeping in mind the aspect of mobility. WIMAX on the contrary was developed for fixed wireless access and mobility was added much later to it. As of now, from technological comparisons, it seems that for mobile applications UMB/LTE pose a better solution than Mobile-WIMAX. Having said that, it is true that 4G technologies still don't exist. WIMAX on the other hand has already been installed on certain networks and working. This "time-table" advantage may mean a lot to any technology and contribute heavily towards its success or failure.

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## 6. Summary & Conclusion

Having discussed a great deal about the two main protagonists for the world's 4G efforts, it remains to be seen as to which technology gets to be successful. Our feeling is that UMB and LTE both represent the future and as such do not differ technologically from each other. We feel that the only difference is in market dynamics in different parts of the world. Also both define a different route for transition from 3G-4G and hence more likely to be accepted differentially in different parts of the world. However, these technologies are still in their infancy while another wide are wireless technology - WIMAX has already been developed and deployed in limited scale. Companies like "Sprint" are already marketing WIMAX as their 4G solution and it goes without saying that there is tough competition ahead. However, no matter which technology emerges from this technological race, the ultimate winner shall be the consumer who shall get to enjoy all the benefits of the superior technology and at the same time the competition shall make sure that the prices are affordable.

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## Acronyms

<b>AAS</b>	Advanced Antenna System
<b>AMPS</b>	Advanced Mobile Phone System
<b>CDMA</b>	Code Division Multiple Access

<b>EV-DO</b>	Evolution-Data Optimized
<b>FDMA</b>	Frequency Division Multiple Access
<b>GPRS</b>	General Packet Radio System
<b>GSM</b>	Groupe Special Mobile
<b>HSPA</b>	High Speed Packet Access
<b>HSDPA</b>	High Speed Downlink Packet Access
<b>LTE</b>	Long Term Evolution
<b>MIMO</b>	Multiple Input, Multiple Output
<b>OFDM</b>	Orthogonal Frequency division Multiplexing
<b>OFDMA</b>	Orthogonal Frequency division Multiple Access
<b>QoS</b>	Quality of Service
<b>SAE</b>	System Architecture evolution
<b>TACS</b>	Total Access Communication System
<b>TDMA</b>	Time Division Multiple Access
<b>UMB</b>	Ultra Mobile Broadband
<b>UMTS</b>	Universal Mobile Telecommunication System
<b>W-CDMA</b>	Wideband Code division Multiple Access
<b>WIMAX</b>	Worldwide Interoperability for Microwave Access
<b>2G</b>	2nd Generation
<b>3G</b>	3rd Generation
<b>3GPP</b>	3rd Generation Partnership Project
<b>3GPP2</b>	3rd Generation Partnership Project 2
<b>4G</b>	4th Generation

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