Overview of Wireless Data Network Standards and Their Implementation Issues

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***Abstract*—An overview and comparisons of existing broadband wireless networks are given with discussions on their implementation issues. The existing wireless standards are diverse and include those of 2.5G, 3G, Bluetooth, WirelessLAN and WiMAX. In the wide area network distance range, 2.5G and 3G Wireless converges voice and data to a broadband wireless data network to serve multimedia applications. In the local area network intermediate distance range, the lower cost WirelessLAN has been growing very fast all over the world. In the personal area network short distance range, the even lower cost Bluetooth network is enabling many more wireless applications. In the MAN distance range, WiMAX is growing rapidly. In moving to emerging or 4G wireless systems, it is not sufficient to only look at the technology, but one also need to learn from the experience in the implementations of existing networks.**

***Index Terms*—3G/4G Wireless Networks, CDMA, UMTS, WLAN.**

I. Introduction

MANY wireless network technologies have emerged and standards have been created in numerous standards organizations since the 1990's. Some standards have played a dominant role, but some were much less frequently implemented. Whether the standards are implemented into products are often not based on the technical merits of the technologies, so that it is not sufficient to consider only the technologies. It is also necessary to examine the implementation issues. We will examine some of the implementation issues together with the standards of wireless data network.

As voice and data in wireline networks are converging to the IP network, similar convergence is happening with wireless access networks. Many different wireless network standards have been developed or are under development for Metropolitan Area Network (MAN), Local Area Network (LAN), and Personal data network (PAN). Yet there are practical deployment issues. The discussion and understanding of these standards need to take these practical deployment issues into consideration.

The wireless access networks are diverse but the major standards may be classified as belong to either a group of public land mobile networks owned by cellular phone operators or to another group of wireless networks under the IEEE 802 family (Section II).

The cellular networks and systems themselves are diverse, and efforts to standardize them were the requirements of 3G Wireless in IMT-2000, which has qualified 3G Wireless standards (Section III).

The 3G standardization efforts did not result in one single 3G standard but rather a group of different 3G standards. Two major efforts were to converge these standards into 2 groups, under the 3GPP (Section IV) and 3GPP2 (Section V) program.

Technologies were not the only important points but there are many implementation issues for successful deployment of 3G Wireless (Section VI).

While the cellular networks started as voice networks moving to packet network, the opposite move from computer data network to incorporate the high qualify required in voice and other real-time applications are the wireless networks under the IEEE802 family (Section VII).

The importance of the IEEE 802 networks and the requirements in 4G Wireless towards much lower cost shares many goals in common. Convergence and interworking will be important in the next generation of wireless standards (Section VIII).

II. Different Wireless Access Networks

Different wireless access network systems have good technological reasons to exist. There are different power requirements, different distance ranges, different data rates, and different carrier frequencies. Different systems are therefore needed to optimize the performance and cost for the different requirements.

Let us first look at the proliferation of different wireless standards. We note that the most widely implemented wireless network standards may fall into two major groups. One group are the Public Land Mobile Network (PLMN) family of cellular networks. Another group of wireless networks are under the IEEE802 family of standards.

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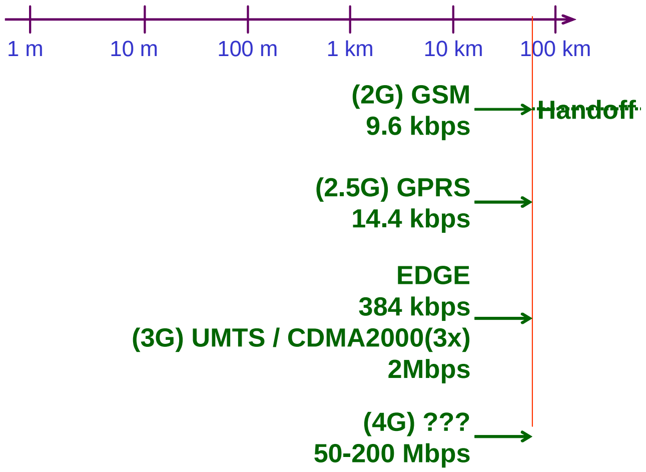

Figure 1. PLMN systems: data rates, distance range, and evolution.

A. Public Land Mobile Networks

The group of wireless systems under the PLMN family are primarily by the cellular telecom service providers and are shown in Figure 1.

The PLMN systems includes the existing GSM and IS-95 CDMA in the Second Generation (2G) Wireless, which evolves respectively to General Packet Radio Service (GPRS) and CDMA 1X to provide data service in 2.5G Wireless, and then evolves respectively to Universal Mobile Telecommunication System (UMTS) and CDMA2000 (or CDMA 3X) in the Third Generation (3G) Wireless. The supposedly high data rate of 2Mbps of shared capacity back in 2000 in the IMT2000 3G Wireless requirements is not high compared with a host of broadband access technologies such as DSL, cable, and fiber in the fixed access networks.

In order that the wireless systems can replace the wireline counterpart, the data rate for 4G will be in the range of 50-200Mbps. Yet, increasing the data rate is not the only primary issue. The complexity and the huge amount of functions in 3G systems are partly responsible for the high cost, which is an important obstacle for wider use of 3G Wireless systems. 4G systems will need to be at much lower cost to be competitive.

What is common in these PLMN systems is that each cell can be at least several km in radius. With handover between these cells, the distance range of service falls into that of the wide area network (WAN).

At still longer distance ranges but not belonging to the PLMN family are the broadcast network including Digital Audio Broadcasting (DAB) and Digital Video Broadcasting – TV (DVB-T) covering large geographical regions and the satellite network with coverage at the global level.

B. IEEE802 Wireless Networks

A important group of wireless networks are in the IEEE802 family of standards.

At the personal area network (PAN) distance ranges within 10 meters is the 802.15 Bluetooth standard. At the local area network (LAN) distance ranges within 100 meters are the 802.11 a/b/g WirelessLAN standards with shared data rates of 11 and 55 Mbps. At the metropolitan area network (MAN) distance ranges within 3-8km is also the 802.20 WiMobile standard to provide 1Mbps data rate per user. At WAN distance ranges within 30-50km are the 802.16 family of WiMAX standards providing shared data rates of up to 70Mbps. Figure 2 shows the data rates and distance ranges of these standards.

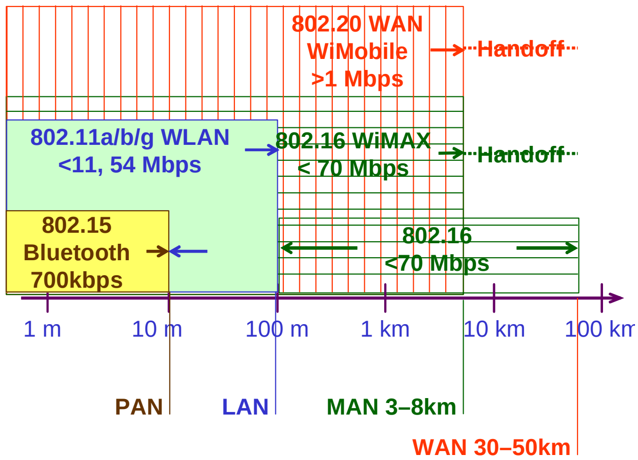

Figure 2. Wireless standards in the IEEE802 family: data rates and distance ranges.

The different wireless systems provide the said data rates to serve up to the said distance range. They are low cost systems providing the bare data transfer. Each standard is followed by many devices sharing the same set of user environment. Low cost is then possible with high volume production.

The proliferation of many different wireless systems may show that such a diverse number of wireless standards are indeed necessary. For example, WirelessLAN can provide relatively higher data rate but may only do so economically in a smaller geographical area of a hotspot. On the other hand, 2.5G or 3G network has a much larger coverage area but with relatively smaller data rate.

For the future Fourth Generation (4G) Wireless, it could be impractical to attain the same low cost with a one-size-fit-all solution. We can still share the same core network through a multiservice platform. Yet the different wireless access networks need to interwork seamlessly.

III. 3G Wireless Standards in the PLMN Networks

A. Goals of 3G Wireless Standards in IMT-2000

The 3G Wireless networks, which are the wireless access to global and metropolitan area data networks, are qualified according to the 3G Wireless requirements specified in International Mobile Telecommunications-2000 (IMT-2000). The IMT-2000 3G Wireless goals may be summarized in the following:

1) Enable Global roaming.

2) Use Standardized interfaces.
3) Support both packet data and circuit-switched services.
4) Support multimedia services.
5) Have minimum data rates of: 144 kbps in vehicular environment, 384 kbps in pedestrian environment, and 2 Mbps in indoor office environment.
6) Operate under multi-environment: Vehicular, Outdoor to indoor and pedestrian, Indoor office, and Satellite.
7) Operates in Virtual home environment with standardized capability sets.

B. 3G Wireless Standards

It may be tempting to have one single 3G standard globally. Indeed, in the 1997-1999 timeframe during the boom years of the telecom business when ITU was selecting candidate wireless technologies for 3G IMT-2000 standard(s), a single revolutionary CDMA based 3G IMT-2000 standard had been very strongly advocated. Yet creating a revolutionary system is expensive and not affordable to many service operators.

Another approach was to define a family of technologies including both some relatively inexpensive evolutionary technologies and some more revolutionary technologies. Different wireless service operators using different existing systems in different parts of the world have different deployment issues. The latter approach gives the wireless service operators more options to deploy advanced wireless technologies depending on various business considerations.

The radio access technologies in different 3G Wireless standards include combinations of different multiple access and different duplex methods, which are shown in Table I.

TABLE I
3G STANDARDS RADIO ACCESS TECHNOLOGIES

3G Standard	Access and Duplex Technologies	Radio Access Bandwidth (and chip rate)
EDGE	TDMA; FDD	200kHz; 1.6MHz
WCDMA/ UTRA-FDD	Direct Sequence (DS) CDMA; Freq. Division Duplex (FDD)	5MHz; 3.84Mcps
UTRA-TDD	DS-CDMA; Time Division Duplex (TDD)	5MHz;3.84Mcps 1.6MHz;1.28Mcps
Cdma2000	Multi-carrier (MC) CDMA; FDD	3 x 1.25MHz; 3.6864Mcps

Here, multiple accesses includes TDMA and code division multiple access (CMDA), which are of the types direct sequence (DS) and multiple carrier (MC) types. The frequency hoping (FH) type of CDMA is not used in PLMN but in Bluetooth. The duplex technologies include frequency division duplex (FDD) and time division duplex (TDD), whereas Code division duplex (CDD) is also not used in PLMN. Table I also shows the bandwidth and, for the case of CDMA, the chip rate. The inclusion of different multiplexing technologies in the 3G standards is an important provision for service operators in different countries towards implementation, as will be explained in a latter session.

IV. 3GPP PLMN NETWORKS

The dominating 2G system is GSM, which uses TDMA multiple access technology. As of 2005, the GSM users constitute two-thirds of all 2G mobile phone users in the world. The corresponding 3G standards that GSM can migrate to are the wideband CDMA (WCDMA), which is also known as Universal Mobile Telecommunication System (UMTS) Terrestrial Radio Access (UTRA) [1], and Enhanced Data-rate GSM Evolution (EDGE). Here the system of 3G ULTRA and network is known as UMTS.

The evolution path of the 2G GSM network starts at the 2.5 G GPRS and then towards the 3G EDGE and lastly UMTS. Table II summarized this evolution. These standards are under the Third Generation Partnership Program (3GPP) and will be discussed in the rest of this section.

TABLE II
EVOLUTION PATH OF GSM TO GPRS, EDGE, AND UMTS

	2G	2.5G	3G	
1.6MHz TDMA EDGE				UWC-136 (136HS) Indoor
200kHz TDMA EDGE	ANSI-136 TDMA (30 kHz)		UWC-136 (136-HS) Outdoor	
200kHz TDMA GSM/GPRS/EDGE	GSM	GPRS	Enhanced GPRS / EDGE	
5MHz WCDMA			UMTS	

A. 2.5G GRPS Standard

The wireless data networks in the PLMN family starts with the 2.5G Wireless Networks. In some regions, 3G may remain in the niche market for a few years after deployment. Its cost may only come down after the customer base has built up to support deployment in more areas. Meanwhile, some operators had already begun wireless data service in 2001

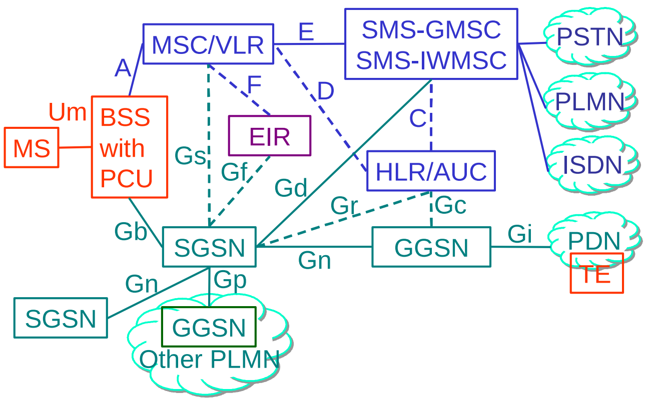

Figure 3. Architecture of 2.5G GPRS network as an evolution of the 2G GSM network.

using 2.5G technology.

The evolution of GSM to 2.5G is GPRS [1]. The architecture of GPRS as an evolution from the GSM network is shown in Figure 3.

The Mobile Station (MS) access the Base Station Subsystem (BSS) using Time Division Multiple Access (TDMA). The BSS in the circuit switching GSM network is added the capability to handle packets with the addition of packet control unit (PCU).

The routing of data packets inside the GPRS network is through the Serving GPRS Support Nodes (SGSN). The GPRS core network is then basically a network of SGSN, which is the counterpart of the Mobile Switching Center (MSC) in the GSM network and is analogous to the routers in an IP network. Both MSC and SGSN are supported by a database of user locations in the Visitor Location Register (VLR) to enable mobility functions and a database of MS in the Electronic Identification Register (EIR).

The GPRS network interconnects with other packet data networks (PDN) while the GSM network interconnects with other circuit switching telephony networks such as public switch telephone network (PSTN), Integrated Service Digital Network (ISDN), and other circuit switching PLMN networks.

The gateway to other packet networks is through the Gateway GPRS Support Node (GGSN), the counterpart of which in the GSM network is the Gateway MSC (GMSC) or Interworking MSC (IWMSC), which also provides the Short Message Service (SMS). They are supported by a database of subscribers of the home network in the Home Location Register (HLR) to enable roaming and also supported by an authentication center (AUC). Both AUC and EIR contribute to security functionalities.

GPRS maintains the features of the TDMA physical layer in GSM, but adds packet switching capability. The GPRS packet channels are time multiplexed with the GSM circuit channels to share the same 200kHz frequency band.

In GSM, each 200kHz frequency band may provide 8 TDMS channels to serve 8 GSM circuit switching connections, which may be doubled to 16 by using alternate time slots for each connection. These TDMA channels may be individually allocated to GSM or GPRS service according to the needs. At the early stages of deployment when the customer base for GPRS is not yet big enough, the operator may continue to use its existing GSM spectrum and allocate the unused channels to GPRS.

Such an evolution enables GSM and TDMA customers to quickly deploy wireless data service in conjunction with its existing GSM service without having to build a new system and especially without having to acquire new frequency band.

This wireless packet data service is similar to that of the 3G Wireless service except that the data rate is not as high as in 3G. It may remain an issue of whether this lower data rate in 2.5G is acceptable to wireless data system users.

GPRS automatically adjust the data rate according to the rf conditions by switching to different coding scheme. The different data rates per channel in different coding schemes are given in Table III. Up to 8 channels can be used together, enabling 144kbps data rate. Yet the GPRS mobile stations available up to 2002 are using fewer channels so that it can handle the increased power consumption over the GSM phone when these channels are operating simultaneously.

TABLE III
DATA RATES IN GPRS

Coding Scheme	data rate
CS-1	9.05kbps
CS-2	13.4kbps
CS-3	15.6kbps
CS-4	21.4kbps

These data rates are only a small improvement over a 56kbps phone line dialup modem. However, the data rate in 2G is typically only 9.6 kbps. The data rate in 2.5G is not catching up with the wireline broadband access technologies such as DSL and cable modem, which are over 1Mbps in their peak data rate. The value to the customer in moving from 2G to 2.5G may be more in terms of an “always on” packet data connection. That is, the 2.5G wireless access enables the customer at anytime and at anywhere to access services through the network.

Issues will differ among different regions of the World. In regions where potential customers are already subscribing to 2G, wireline phone, and Internet access, their affordability to subscribe to wireless data access needs to be determined. The advantage of 2.5G over 3G is the lower upfront cost and the flexibility to scale the business incrementally as new 2.5 customers are added.

B. 3G EDGE Standard

Higher data rate is possible with better signal to noise ratio. EDGE uses adjustable rate in which the data rate is dynamically maximized according to the channel conditions. Whereas the modulation scheme in GSM and in GPRS is fixed at Gaussian Minimum Shift Key (GMSK), EDGE increases the data rate by using 8PSK modulation. With a combination of convolution coding and puncturing, nine different modulation and coding schemes (MCS) with progressively increasing data rates are obtained and are summarized in Table IV.

TABLE IV
DATA RATES IN EDGE

Coding Scheme	data rate
MCS-1	8.8kbps
MCS-2	11.2kbps
MCS-3	14.8kbps
MCS-4	17.6kbps
MCS-5	22.4kbps
MCS-6	29.6kbps
MCS-7	44.8kbps
MCS-8	54.4kbps
MCS-9	59.2kbps

EDGE allows 3G data rate at the outdoor speed requirements by making minimal modifications in the radio interface of GPRS, using even the same 200 kHz bandwidth in GSM. The core network of GPRS is basically the same.

To reach the still higher 3G indoor data rate, EDGE will need to use the higher bandwidth of 1.6MHz.

EDGE does suffer the disadvantage that the data rate falls off faster as the users move away from the antennae in a cell. The requirement of good channel conditions implies the higher data rates are only achieved for mobiles close to the base stations. In order to achieve higher data rate for all mobile stations, the cell size will have to be reduced. The reduction in cell size implies the installation of many more cellular sites which is very expensive and had been the primary reasons of objection raised by proponents of WCDMA.

C. 3G UWC-136 Standard

Besides GSM, there are other TDMA systems, such as IS-136. Both GSM (200kHz band) and IS-136 (30kHz) can evolve into EDGE, which also uses TDMA. The 136HS Outdoor of UWC-136 uses 200kHz bandwidth for a peak datarate of 384kbps. The 136HS Indoor part of UWC-136 uses 1.6MHz to achieve 2Mbps [2]. A compact version of EDGE requires only 1MHz bandwidth, so that it becomes more scalable.

It is worth to note that as of year 2002, the deployment of TDMA type of systems with the inclusion of GSM and IS-136 has already covered almost all the service areas in the world.

D. 3G UMTS Standard

The network architecture of UMTS, shown in Figure 4, is largely taken from that of GPRS, although a lot of more features have been added, and transport channels have also been introduced.

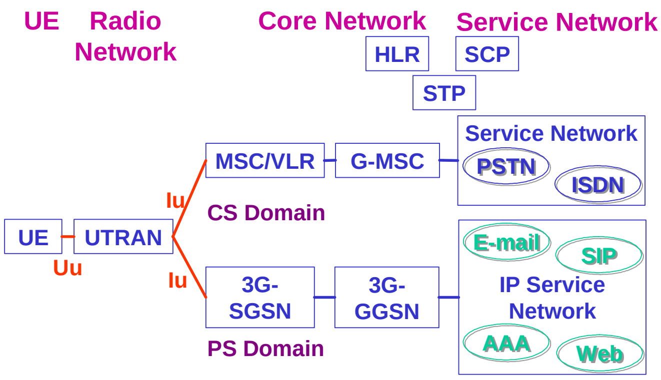

Figure 4. Architecture of 3G UMTS Network.

In essence, the bare UMTS core network is simply a network of SGSN upgraded to become 3G-SGSN, and with the GGSN gateways also upgraded to 3G-GGSN.

UMTS is intended to take advantage of the huge customer base of GSM by evolving GSM to UMTS. Extensive efforts have been put into the UMTS standards to inherit plenty of network features from GSM. Yet the multiple access methods are indeed different between WCDMA and GSM. Use of multi-mode mobile phone is needed to enable compatibility.

Later releases of UMTS move towards end-to-end all-IP network and add more features including interworking with WLAN.

The UMTS core network may be shared by different access networks.

E. 3G WCDMA Access Network Standard

The technology in UMTS Terrestrial Radio Access (UTRA) is called Wideband CDMA (WCDMA) using 5MHz bandwidth at chip rate of 3.84 Mcps. With the use of the wide bandwidth, it is technically more convenient to provide high data rate for users sharing this bandwidth.

The Frequency Division Duplex (FDD) system of WCDMA takes a 5 MHz bandwidth in each direction. Therefore the service operator needs to use at least 10 MHz of bandwidth. Multiples of these bandwidths may be needed depending on how the frequencies are reused in a cellular system. The high cost of the spectrum license will require a large enough customer base to offer the service. Yet it generally takes time for the number of its 3G customers to grow. Despite the technical merits of being broadband, it is more difficult to scale the business especially in the initial stage of deployment.

The Time Division Duplex (TDD) system of WCDMA in UMTS is more bandwidth efficient for asymmetric traffic, in addition to reducing by half the minimum bandwidth required to start the service. ULTRA-TDD is also known as Time-Division-Duplex - High Chip Rate (TDD-HCR).

F. 3G TD-SCDMA Standard

An alternative 3G Radio Access standard to WCDMA in UMTS is to take time division over code division, and is called Time Division – Synchronous Code Division Multiple Access (TD-SCDMA) [3].

While the different timeslots provide different TDMA channels to access the network, each of these timeslots may again provide different CDMA channels to allow different users to use the same timeslot by using different codes. It uses 1.6MHz frequency channels.

This alternate 3G standard uses the same UMTS core network as WCDMA, was proposed by China, was adopted in ITU as a 3G standard in 1999, and planned for deployment in 2006. As a member of the UMTS family, it is known as UMTS Terrestrial Radio Access - Narrowband Time Division Duplex (UTRA-NTDD) and also known as Time-Division-Duplex - Low Chip Rate (TDD-LCR).

V. 3GPP2 PLMN Networks

Unlike GSM which uses TDMA with 200kHz bandwidth, IS-95, which is a different important Cellular network standard, is already using CDMA in 2G Wireless with a larger bandwidth of 1.25MHz. The evolution towards 3G is then within the same CDMA radio access technology, and the standards are under the Third Generation Partnership Program 2 (3GPP2) [4].

The 2G IS-95 system was also named cdmaOne by its major service operator. The architecture of the IS-95 core network is similar to GSM, which is shown in the upper part of Figure 3. In fact, the core networks of all the 2G Wireless networks are similar, and support the PSTN type of signaling.

The radio interface of IS-95 is CDMA using 1.25MHz bandwidth in both uplink and downlink. In the uplink from the mobile stations to the base station, it uses long (64-bit) Codes to distinguish among the different mobile stations. In the downlink from a base station to the mobile stations, there are 64 orthogonal pseudorandom codes to distinguish the different channels, and these codes use different phases to distinguish the different base stations.

IS-95A has a data rate of 9.6kbps, whereas IS-95B has a data rate of 14.4kbps.

The evolution path the IS-95 cdmaOne network towards CDMA2000 may be in stages. These standards are summarized in Table V and briefed in the rest of this section.

TABLE V
EVOLUTION PATH OF IS-95 TOWARDS CDMA2000

	2G	2.5G	3G
1.25MHz CDMA / MC-CDMA	IS-95; IS-95A (9.6kbps); IS-95B (14.4kbps)	CDMA2000 1X (twice voice capacity, average data rate at 144 kbps)	CDMA2000 1xEV DO (2Mbps peak data rate, with separate carrier for data) CDMA2000 1xEV DV (2Mbps peak data rate, same carrier for voice and data) CDMA2000 3X

A. 2.5G CDMA2000 1X Standard

The CDMA2000 family of standards all use multiples of 1.25MHz bandwidth. Beginning with one times the 1.25MHz bandwidth is the CDMA2000 1X. With a bandwidth so much larger than that of GSM, these CDMA systems can evolve to higher data rate relatively much easier than the GSM system.

CDMA2000 1X can handle twice the voice capacity and have an average data rate at 144kbps.

The network, however, departs significantly from that of the legacy cellular networks. The core network is already moving towards a managed packet network, such as a managed IP network, supporting such functions like AAA.

B. 3G CDMA2000 1×EV and CDMA2000 3X Standards

The CDMA2000 1x EV is the evolution from CDMA2000 1X, and consists of CDMA2000 1xEV DO for data only and CDMA2000 1xEV DV for both data and voice.

The CDMA2000 1xEV DO system uses a separate carrier for data and has a maximum data rate of 2Mbps.

The CDMA2000 1xEV DV system combines both data and voice in a single carrier and may offer real-time packet data services.

The radio access technology in CDMA2000 3X is multi-carrier CDMA (MC-CDMA) using 3 of the 1.25 MHz bandwidth carriers.

Because CDMA2000 systems have already been moving towards an IP core network, the move towards “all IP” system can be achieved faster.

VI. 3G WIRELESS IMPLEMENTATION ISSUES

A. 3G Implementation Questions

Service operators throughout the world are already using different technologies. Cost, attractiveness to future customers, service to existing customers, and competitiveness with other technologies are some important issues for a service operator to run a business with 3G technology.

1) Customers’ willingness to pay: In countries where wireline broadband access network is already available, the 3G service is generally not competitive in cost to with the wireline services like DSL, cable modem or Ethernet LAN, which when available provides higher bandwidth at a lower cost.

One may observe that the customers’ willingness to pay has not increased much through the Information Age. For example back in the 1980’s, an average family may be paying a certain amount of money for telephone service which includes the basic monthly fee and long distance charges. Twenty years later in the 2000’s the total spending for an average family did not increase much. It may be paying approximately the same amount plus inflation. Yet they may now be getting long distance calling, wireless phone service, and Internet access for approximately the same amount that they paid twenty years ago for the much less services available at that time.

Many services initially started as a niche market for which the price is initially not affordable to the general public. As the price dropped in both wireline and wireless, its usage grew very fast. Now as 3G services begin to deploy, the consideration is whether it is able to target customers willing to spend more for the added service, or whether it can only grow along with accompanying price drop in other telecom and network services.

2) Who are the 3G Customers: If the customers are already existing users in broadband network services, the wireless technology needs to provide additional services that are not found in the wireline counterpart and for which the customers are willing to pay. These may be services taking advantage of mobility and location information. Then again the question is what amount matches with the customers’ willingness to pay for these additional services. For the service operator to implement 3G, realistic questions are:

How many potential wireless data service customers are already subscribers to wireline data service and 2G wireless service?

If the customers are already subscribing to a few services such as wireline telecom services, wireless service, Internet service, and broadband wireline network service, will they be willing to subscribe to a broadband wireless service in addition. If so, how much additional amount are they willing to pay?

If the customers are not currently subscribing to other broadband wireline services, then will these broadband wireline services become available in the near future and how will the 3G services compete with them.

3) What is the cost of Implementation: A major part of the cost in wireless service is the spectrum licensing fee. The licensing fees in 3G are expensive in many countries. The high price may only be feasible from 1980 to the early 90's when the price of wireless service was much higher.

It is expensive to deploy wireless service and wireless services are usually offered in smaller regions where there are sufficient customers to offset the equipment costs. More cells may only be added when the customer base grows. It then takes time for the customer base of any operator to grow. Yet the service operators often find themselves having to pay the licensing fees or the installments before the business has grown up sufficiently. So, even in 2G, some operators might still be unable to afford the licensing fee that some could become bankrupt.

The IMT-2000 spectrum after World Radio Conference (WRC-2000) along with the 3G spectrum in different regions of the World are shown in Fig. 5a and 5b.

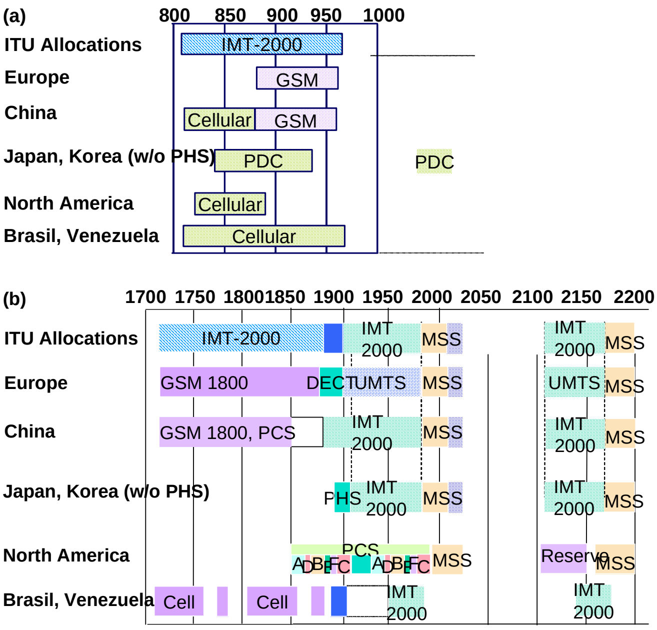

Figure 5. IMT-2000 Frequency Spectrum. (a) lower band; (b) upper band.

The intention was to adopt the same frequency spectrum globally so that a 3G mobile can be used in any part of the world. The 1.9-2GHz and the 2.1-2.2GHz were the original IMT-2000 frequency spectrum. The bands around 0.9GHz and around 2.6GHz were added in World Radio Conference 2000. It had taken many years since early 1990's for different countries to clear out other users in much of the original IMT-2000 frequency spectrum to prepare it for 3G usage. It is observed that as of 2002, most regions in the world where wireless service is offered, with the exception of the USA, have already cleared out some frequency in that 3G spectrum. Yet, the expensive licensing fee was partly responsible for the delays of 3G deployment in 2001. After bidding for the 3G spectrum at high prices, operators may find themselves difficult to afford the expensive 3G equipment.

In USA, part of the original 3G spectrum was already used for Personal Communication Service (PCS). This PCS spectrum was already licensed to service operators who were primarily using it to deploy 2G services.

The 3G frequencies may be licensed to service operators in different countries by different methods determined by the local government and administration. The schedule of the licensing, according to the data from UMTS Forum [5] in 2002, is plotted in Fig. 6.

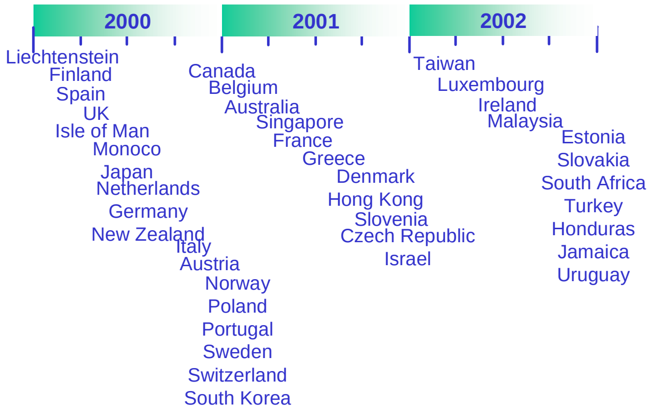

Figure 6. Licensing schedule of 3G Wireless spectrum.

4) New service operator versus existing service operator: An existing service operator, which is offering a 2G service, will already have the business with a customer base as it strides to offer wireless data service such as 3G. Yet, it is necessary to build on the existing 2G customer base. The question to implement 3G is how to switch existing customers to the new 3G service.

In a country such as Japan with a largely dominating service operator, the approach can be switching all customers to the new service. The operator also may already have already used up the existing spectrum.

In a consumer business environment where market is competitive among service operators, it may be more difficult to switch the customers. The question is what are the new applications or services to offer in the wireless data network that are not already offered in 2G, and whether these additional services are attractive enough to the customers that they will be willing to pay the added price so that the service operator can pay for the implementation of 3G system.

An entirely new 3G system which takes a revolutionary approach to the existing 2G service may not be practical in an open and competing market.

A new service operator may apparently need less consideration for compatibility with the existing 2G system. Yet, it does need to inter-network with other 3G networks. In addition, in the initial stage when its coverage area may be small, it will not be desirable if the mobile phones of the customers it is serving cannot use the phone when away from its network. There may be contractual agreements among operators to enable each other's customers to use their phones when traveling into the coverage area of another service provider's network. Such agreements help to expand the coverage areas to serve each other's customers. Then the 3G mobile station will still need to be compatible with the existing 2G systems.

It then becomes apparent that though it may be attractive to have one single 3G standard globally, it is difficult in terms of price and complexity for such a system to be adopted and implemented globally where the implementation issues may be different from one country to another.

5) Different regional needs in 3G: The alternative is to include a family of standards, to meet the regional needs of service operators.

The evolution path for service operators who are currently using GSM, IS-136 TDMA, and IS-95 CDMA respectively are shown in Tables II and V.

3G standards have incorporated years of work in technical design. The level of sophistication for such a network exceeds the LAN and PAN counterpart; so is the cost. Yet implementation issues including the high costs of 3G had slowed down its targeted deployment.

VII. Wireless Network Standards in the IEEE802 Family

A. *Wireless PAN 802.15 Standards and Issues*

The other extreme to a sophisticated global wireless network is a simple wireless network for short distance range. It is a wireless personal area network, such as the IEEE802.15 Bluetooth.

Bluetooth network has no network infrastructure other than the nodes. A Bluetooth network, called a piconet, consists one master node and up to 7 slave nodes within the radio frequency range of about 10 meters. Adjacent piconets may interconnect with each other through nodes in overlapping regions of the separate piconets to form a larger scatternet.

Bluetooth provides both symmetric circuit switching links and asymmetric packet switching links. The total data rate is within the 1Mbps range.

Bluetooth provides rapid ad hoc connections without cable, without requiring line-of-sight, using small form-factor, low power, and low cost devices. The use of low power enables longer battery life applications such as with a personal data assistant (PDA). Potential applications include phones and pagers, modems, LAN access devices, headsets, notebook, desktop and handheld PCs, digital camera and any appliance in the household. Table VI lists its major characteristics.

TABLE VI
IEEE802.15 Bluetooth System

Max output Power	Range	Data Rate	Spectrum	Air Interface
1, 2.5, 10 mW	10–100m	0.72 Mbps	2.4 GHz (ISM)	FH TDD GFSK

A wireless PAN is a low cost solution to serve the consumer market. The targeted users are the general public. The critical issues include therefore price competitiveness, ease of use, and the usefulness and attractiveness of the applications running over the wireless PAN.

Being much simpler in design than the LAN, WAN and PLMN counterparts, the entire set of Bluetooth functions can fit into a low-cost chip.

Bluetooth was initially anticipated to be ready for deployment in 2001. Production volume increase and price drop are needed for the growth. The anticipated growth in 2001 did not occur as the price of Bluetooth chip did not drop below the 5 US dollar line in 2001 but one year later in 2002. Yet the marketing conditions were already quite different in that year. It had taken longer for Bluetooth to gain high enough production volume to compete in the low cost consumer market.

The standards of Bluetooth had been adopted into 802.15 [6]. Merging into the IEEE802 family may give additional push to the deployment of this wireless PAN standard.

B. *Wireless LAN 802.11 Standards and Issues*

The delay and slow down in both 3G at the metropolitan and global distance range and Bluetooth at the short distance range had left a unique opportunity for the intermediate distance range wireless network technology.

Table VII lists 802.11 along with other wireless LAN standards.

TABLE VII
IEEE802.11 LAN Systems: Data Rate, Spectrum, and Air Interface Technologies

System	Data Rate	Spectrum	Air Interface
802.11 [7]	1 Mbps	2.4 GHz (ISM)	FHSS
802.11	2 Mbps	2.4 GHz (ISM)	DSSS
802.11b [8]	11 Mbps	2.4 GHz (ISM)	DSSS
802.11a [9]	54 Mbps	5 GHz (U-NII)	OFDM
802.11g [10]	54 Mbps	2.4 GHz (ISM)	OFDM
HiperLan1	23.5 Mbps	5 GHz (U-NII)	GMSK
HiperLan2	54 Mbps	5 GHz (U-NII)	OFDM
HomeRF	1.6 Mbps	2.4 GHz (ISM)	FHSS

The 802.11 [6] Wireless LAN network architecture consists of merely an access point (AP) to provide access to different WLAN users. The AP will itself connect to other networks to

provide connectivity to the WLAN users.

Even the AP is not essential. WLAN also provides the capability of peer-to-peer communications, so that the users may form an ad hoc network.

The 802.11b [8] WirelessLAN started growing very fast in year 2001, when the airline companies and the hotels began deploying wireless LANs in hotspots to convenience the business travelers, and coffeehouses also offered 802.11b to convenience the growing number of mobile users. While guests can access the Web, hosts can use the wireless network as a marketing tool in addition to serving their own networking needs.

Following the growth of 802.11b offering a shared maximum data rate of 11Mbps, the data rate has been extended to 54Mbps in 802.11g [10] which is backward compatible to 802.11b, and has also already started a fast growth.

Security is another issue that the standards have to address. The spreading codes for CDMA in 802.11 and the service set identifier (SSID) used as the primary security mechanism in 802.11, among others, are not highly secure. Subsequent standards for improved security are now in 802.11i [11].

The use of the free and unlicensed ISM radio band is partly responsible for the lower cost and faster implementation. The price is in interference with other devices. Bluetooth and IEEE802.11 both operate in the same 2.4 GHz unlicensed radio band, and both use frequency hopping. Yet frequency hopping in Bluetooth is 600 times faster than that of IEEE802.11. Therefore Bluetooth product is more likely to jam the operation of IEEE802.11 than the other way around.

C. Wireless MAN 802.16 Standards and Issues

Wireless networks do not only find widespread deployment in the user access networks at the distance scales of PAN and LAN, important applications are also found in the distance scale of MAN in many parts of the world.

The characteristics of these standards are summarized in Table VIII.

TABLE VIII
IEEE802.16 WiMAX

802.16 (2001)	802.16a/d (2004)	802.16e (2005)
2-5 km	2-6 km	1-3 km
LOS	LOS/NLOS	NLOS
10-66 GHz Licensed	2-11 GHz Licensed and Unlicensed	2-6 GHz Licensed and Unlicensed
Fixed	Fixed/Nomadic	Low speed Mobility
1.5-20 MHz	3.5-20 MHz	3.5-20 MHz w/ sub-channels
< 134 Mbps (28 MHz BW)	< 70 Mbps (20 MHz BW)	< 70 Mbps (20 MHz BW)
< 4.8 bps/Hz	< 3.5 bps/Hz	< 3.5 bps/Hz

In numerous developing countries, the communication infrastructure may be not yet available. In addition, it is often not practical if not impossible to install a wireline infrastructure in mountainous villages. It is then difficult to deploy local networks at those isolated locations when they are unable to join the national and international core networks.

Initially, wireless links with fixed antennas were used to connect remote locations. Such fixed wireless networks at the distance scale of MAN enable the connectivity of the local networks at those locations to the global networks. These local networks does not need to be wireless. They may be any Wireless PAN, WLAN, but may also be a wireline Ethernet, and may even be the cellular sites of the PLMN.

The fast growth in deployment of the IEEE802.16 networks especially in developing or mountainous countries have met with numerous improvements in subsequent versions of this standard. It has evolved from line-of-sight (LOS) to nearly line-of-sight (NLOS), and from fixed to nomadic and even low speed mobility in 802.16d (2004) and in 802.16e (2005).

D. Mobile Broadband Wireless Access (MBWA) 802.20 Standards and Issues

The goals of the emerging IEEE802.20 standards [12] are to provide 1Mbps individual access data rate, and to support mobility up to 250km/hour. The difference from 802.16e is that 802.20 uses licensed frequency spectrum. It is still controversial whether it will enjoy the same success as it wireless predecessor standards in the IEEE802 wireless family.

E. Wireless Regional Area Networks (WRAN) 802.22 Standards and Issues

The emerging WRAN 802.22 [13] is trying to make use of the unused TV channels. It is planned to operate on unused channels in the VHF/UHF TV bands between 54 and 862 MHz, and will be fixed, point-to-multipoint, wireless regional area networks.

VIII. 4G Wireless Standards

Having briefed the existing wireless systems and examined their implementation issues, we now give the views on the emerging 4G Wireless systems.

In terms of technologies, 4G Wireless include a higher data rate of 50-200Mbps, convergence with TV broadcast network, convergence with fixed wireless, and being end-to-end all IPv6 network. The core network also needs to merge with the wireline core IP network, which is moving towards the next generation network. In terms of services, it needs to provide more wireless services, which are seamless but are at low cost.

The existing wireless networks being so diverse because of their different applications in different environments, the 4G network should not be a one-size-fit-all wireless network. It needs to incorporate the diverse access networks that already exist.

Interworking [14] is expected to play a key role towards convergence of the PLMN family of networks and the wireless networks in the IEEE802 family. Let us look at what the combination of these existing networks can do. The convergence of both families of wireless networks will form a powerful combination to cover a broad range of distances (Figure 7).

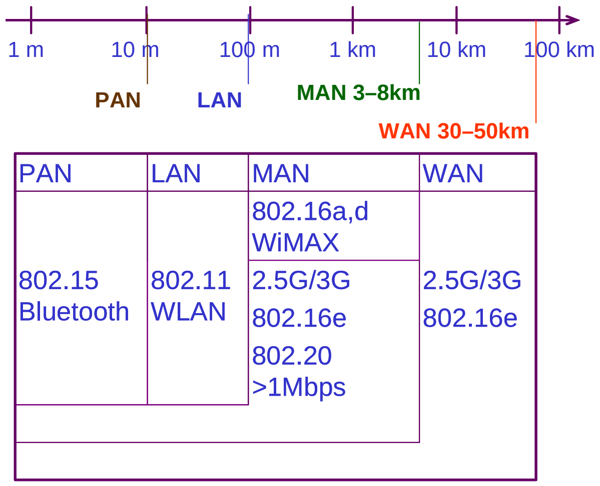

Figure 7. Convergence of PLMN and IEEE802 Wireless networks.

Interworking seamlessly with many different existing and important wireless networks and yet achieving a low-cost will be major challenges to successful deployment.

IX. Summary

Technologies for wireless data services are diverse. The standardization process may be tempted to pick the technology based on technical merit. Yet we have seen that many different standards have emerged, but only some of these standards have been deployed to a large extent.

For example in WAN, the high-performance technology such as 3G can be too expensive initially so that it will take longer time to grow. In PAN, the lower sophistication technology like Bluetooth was unable to meet the consumer price expectation in 2001 and was delayed. In LAN, while WAN and PAN were delayed, one of the 802.11 standard did take off fast in 2001.

What we observed were diverse wireless network standards which will be tested out for success in the competitive markets. The choices by the customers depend not only on the technology, but also implementation and other issues especially those related to the local region.

The PLMN family of wireless standards and the IEEE 802 standards has continued to be diverse. Interworking between different existing wireless networks will be a major requirement in 4G Wireless.

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