SIEMENS

3G Wireless Standards for Cellular Mobile Services

The Siemens View

Executive Summary

Wireless mobile is an attractive market; its appeal has sparked extensive development and seen the deployment of powerful standards for various mobile applications over the last decade. Particularly 2G cellular systems and, specifically, GSM have been a tremendous success.

We are now poised to introduce 3G systems in a bid to extend service offerings and, particularly, to embrace mobile data applications. Mobile operators are keen to learn how they can introduce new services to generate new revenues while containing costs.

The industry has defined and elaborated several 3G radio standards, all geared toward satisfying operators' needs. A closer look at their technical features and performance benchmarks reveals that no variant has major advantages or disadvantages over the others. Instead it would appear that there are other reasons for advocating the introduction of a specific standard:

- Availability of the 3G frequency spectrum and other salient regulatory requirements
- Availability and type of legacy systems, in particular with respect to smooth migration
- Worldwide acceptance and, hence, anticipated market penetration of standards and its impact on economies of scale
- Expected availability, features and cost of terminals

Taking into account all these issues, the GSM-to-UMTS migration path promises to be the best choice for the vast majority of operators.

Cellular standards clearly play a pivotal role on the wireless mobile market. Though the following sections focus chiefly on cellular standards, non-cellular standards such as Wireless LAN have also emerged. They constitute useful add-ons for rounding out operators' service ranges.

Motivation and Scope

Market demand and technological challenges have inspired the development of numerous wireless standards over the last couple of years. Due to the importance and size of the market, cellular standards have been the focus of international standardization committees' efforts.

In the quest to establish next generation (3G) cellular standards, a number of proposals have been submitted to ITU-R for evaluation and adoption within the IMT-2000 family. *Figure 1* points out the various technologies and their affiliation by categories. While today the 3GPP specifications group deals with W-CDMA, TD-CDMA, TD-SCDMA and EDGE, 3GPP2 handles cdma2000. The aforementioned technologies and standards are considered to be of greatest significance to 3G. The following section takes a closer look at these.

Non-cellular standards also emerged during the same period. Though these radio-based technologies provide communication and high data transmission rates at rather low prices, they have drawbacks such as lack of range and other limitations compared with GSM or UMTS.

This gives rise to questions regarding the positioning of all these wireless standards. It is essential to consider this issue, particularly in light of the fact that their application standards hinge exclusively upon technical criteria. Beyond that, even technical specifications do not allow for a clear preference. The technical grounds for this conclusion are discussed in this paper.

This paper presents Siemens' view on the position of the various wireless standards outlined below. For this purpose, related technologies are examined and compared in terms of their application areas and ability to bring maximum benefits to both operators and users. This assessment is not restricted to the radio interfaces' capabilities; it extends to the entire solution including the core network, radio access, and terminals, wherever applicable.

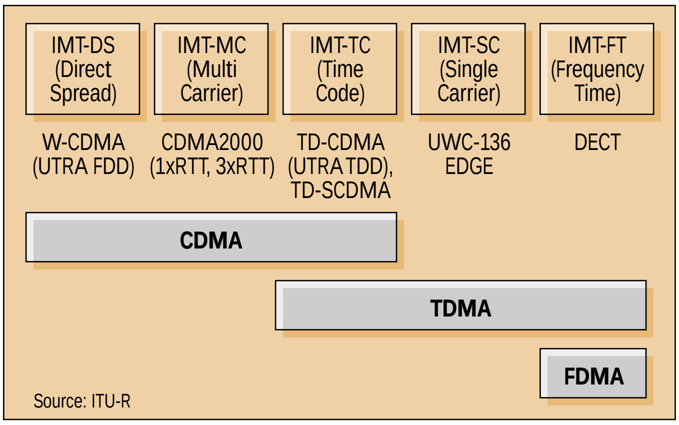

Figure 1: IMT-2000 terrestrial radio interfaces and categories

For purposes of examination in this document, wireless standards may be subdivided into cellular and non-celluar standards. Mobile operators are primarily interested in obtaining the best possible cellular system, so the standards that are most important to this brand of system are discussed in the following. Cellular systems are principally operated in the frequency range of 800 to 2200 MHz *(see also Figure 2)*.

For many years, 2G systems – GSM, that is - have been operated successfully all over the world. The anticipated demand for mobile data services providing high throughput, excellent quality of service (QoS) and improved system capacity has prompted operators to begin screening their options for the best choice in a 3G mobile system. A look at potential 3G candidates reveals that all have related 2G predecessors.

These can be classed in two major families: GSM/UMTS and IS-95/cdma2000. It is said that smooth evolution from 2G to 3G within each family is possible. A discussion of this follows – Today's market figures and the projections for 2005 *(see Figure 3)* illustrate the relative significance of these two families. The GSM/ UMTS family is expected to serve almost 75% of all future mobile subscribers.

The role of today's TDMA systems - in particular IS-136 - will only be discussed in terms of migration to 3G systems. It is fair to say that in many cases, the first migratory step would be to introduce GSM/GPRS as a prerequisite for subsequent steps towards 3G.

The GSM Standard

Since its commercial launch in 1992, the Global System for Mobile Communication (GSM) has conquered the world's cellular market. As of April 2002, more than 180 countries accessed GSM to provide service to more than 680 million customers. Nearly 50% of subscribers live outside Europe, more than 160 million in China alone. This accounts for more than 70% of the digital mobile phones used worldwide today.

Forecasts call for continued growth of the GSM/UMTS family's market share eventually leading to almost 75% of mobile subscribers worldwide soon. The multitudes of users have already engendered small, cheap devices offering many and diverse features, and they will continue to do. In fact, GSM handhelds are commodity products, and GSM/UMTS terminals are sure to follow suit.

Though the GSM system is commonly operated in 900 MHz and 1800 MHz bands 450 MHz, 850 MHz, and 1900 MHz bands are also used. It requires a paired spectrum and supports a carrier bandwidth granularity of 200 kHz.

The GSM radio interface uses a combination of FDMA and TDMA *(see Figure 4)*. The TDMA structure comprises eight timeslots (bursts) per TDMA frame on each carrier providing a gross bit rate of 22.8 kbps per timeslot or physical channel. Dedicated logical channels carry user data or signaling information, and they are mapped on timeslots of this TDMA frame structure on a given frequency carrier.

The basic GSM system supports voice bearers at 13 kbps (full rate codec, FR) or 6.5 kbps (half rate codec, HR) as well as circuit-switched (CS) data services at 300 bps up to 14.4 kbps. A suitable combination of FR and HR channels/codecs for voice can increase voice capacity by 50% over FR channels alone.

The majority of interference in a TDMA system is generated by the co-channels of neighboring cells. This mandates frequency planning to adequately address this issue,

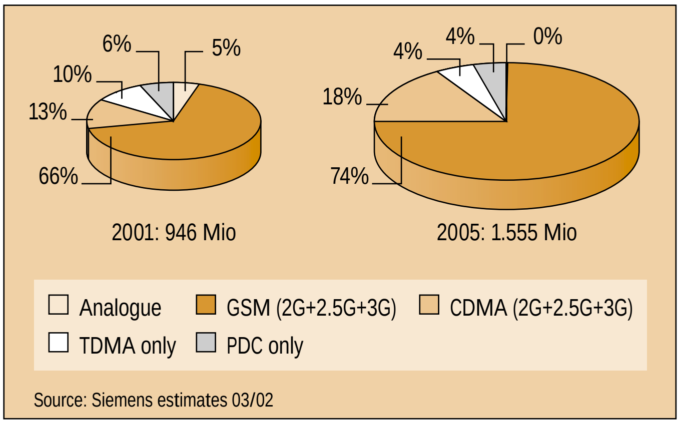

Figure 3: Cellular radio standards by subscriptions

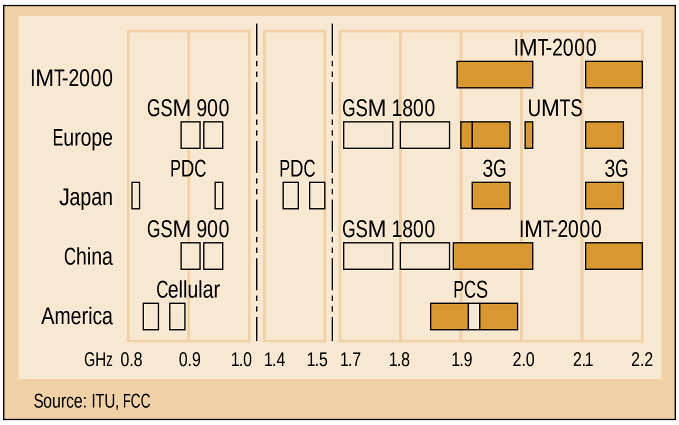

Figure 2: Cellular radio spectrum (800-2200 MHz)

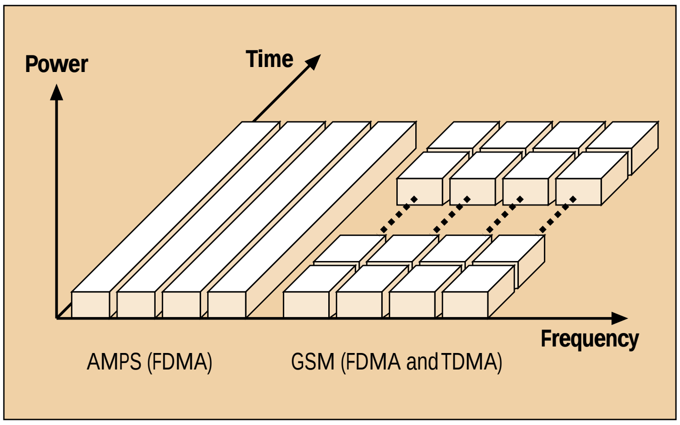

Figure 4: Frequency/Time Division Multiple Access

resulting in a frequency reuse factor or cluster size.

Voice and data is transported via multiple 16 kbps channels within the GSM Radio Access Network (RAN), – that is, between the network entities BTS and BSC of the Base Station Subsystem (BSS). Transport systems such as PCM30 or PCM24 are projected for the Abis interface.

The GSM Core Network *(see Figure 5)* provides circuit-switched bearers for voice and data at 64 kbps granularity. The GSM system uses the Mobile Application Part (MAP), which runs on signaling system No 7 (SS7 of ITU-T) to exchange mobility-related information between the core network entities.

General Packet Radio Service (GPRS)

The basic GSM system was designed largely to cope with voice and CS data with low bit rates. However, to support transmission of packet-oriented information while making efficient use of the air interface, the system must be able to accommodate flexible user rates for packet-oriented data transfer using timeslot assignment on demand rather than via permanent occupation. To this end, GPRS introduces packet data functions to the radio interface, the radio access network and the core network *(see also Figure 5)*:

- SGSN and GGSN network nodes are introduced into the core network to support GPRS also communicating with the HLR using a GSM MAP that has been extended with data-related functions. SGSN and GGSN are used exclusively for packet data transport and control. Packet information is conveyed between SGSN and GGSN via the GPRS Tunnelling Protocol (GTP) on top of an IP-based network.

- The basic frame structure of the radio interface remains unchanged, but one or more timeslots are allocated on demand to transmit one or more packets.

  Four new coding sets (CS1, CS4) [1] are introduced to adapt the radio interface to the given radio conditions and improve its performance. This provides maximum user data rates per timeslot as indicated in *Table 1*.

  A number of timeslots on a given carrier can be concatenated to a GPRS channel. This provides potential data rates up to 171.2 kbps (8 timeslots, CS4).

  In addition, the system supports a limited number of QoS characteristics (e.g. delay, throughput, packet loss/corruption).

- Fast resource allocation on demand (both in core and radio network) enables an "always-on" terminal status.

- GPRS services may be charged on the basis of transported data volume rather than channel occupation time.

Today GPRS networks have been deployed in many European countries (94 GPRS contracts had been awarded for commercial operation as of Nov. 2001). Once GPRS is rolled out, the entire GSM system supports voice and CS data as well as packet-oriented data services. This brand of integrated system includes subscriber management for all services and features.

Enhanced Data Rates for Global Evolution (EDGE)

EDGE offers advanced modulation (shifted 8-PSK in addition to GMSK) to achieve higher data rates. A combination of new coding sets and adaptive coding & modulation was introduced to enhance quality and compensate for the radio channel's fluctuating quality. Fundamental GSM radio interface benchmarks like frequency, bandwidth (200 kHz) and TDMA structure remain unchanged.

The following features employ EDGE:

- ECSD (Enhanced Circuit Switched Data) applies EDGE to HSCSD

- EGPRS (Enhanced General Packet Radio Services) apply EDGE to GPRS

The term EDGE is frequently used as a synonym of EGPRS. Today ECSD's role is marginal, so this paper does not discuss it further.

The higher-order modulation schemes ensure that one timeslot can transport more user data bits than can be transported with GMSK alone. EDGE conveys 348 bits per burst (0.577 ms). Nine modulation and coding schemes (MCS-1 to MCS-9) allow for net bit rates of 8.8 kbps to 59.2 kbps per timeslot [1]. In theory, the maximum possible

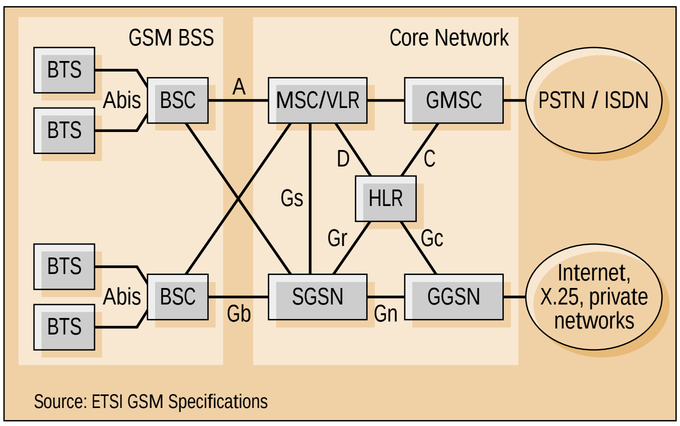

Figure 5: GSM network architecture

Standard	Coding Set	Modulation Scheme	Net Data Rate Per Timeslot
GPRS	CS-1	GMSK	9.05
	CS-2		13.4
	CS-3		15.6
	CS-4		21.4
EDGE	MCS-1		8.8
	MCS-2		11.2
	MCS-3		14.8
	MCS-4		17.6
	MCS-5	8-PSK	22.4
	MCS-6		29.4
	MCS-7		44.8
	MCS-8		54.4
	MCS-9		59.2

Table 1: GPRS & EDGE net user data rates

Class	Traffic Class	Class Description	Example	Relevant QoS Requirements
1	Conversational	preserves time relation between entities making up the stream conversational pattern based on human perception; real-time	voice video telephony video gaming video conferencing	low jitter low delay
2	Streaming	preserves time relation between entities making up the stream; real-time	multimedia video on demand webcast real-time video	low jitter
3	Interactive	bounded response time preserves the payload content	web browsing database retrieval	low round trip delay time low BER
4	Background	preserves the payload content	e-mail SMS file transfer	low BER

Table 2: UMTS QoS Classes

data is 473.6 kbps when all eight time slots are combined. In practice, though, user data throughput within the cell is actually determined by the number of allocated timeslots and applied MCS. Depending on actual radio noise, for example, owing to interference, MCS adaptation occurs automatically. Table 1 summarizes net data rates per slot contingent upon MCS.

By offering the data rates outlined above, EDGE enables a number of 3G data services to be supported. Although a 2.4-MHz spectrum is recommended for adequate performance, this spectrum needs not be contiguous. It can be subdivided in 200-kHz blocks for 12 carriers. This could be a relevant consideration in regions where the UMTS spectrum is initially unavailable (see also chapter "Regional Aspects").

It bears mentioning that EDGE is also expected to serve for voice transmission using the AMR codec at some point in the future to further increase system capacity.

In terms of implementation, EDGE is primarily a SW upgrade for the latest GSM base station systems.

GSM/EDGE Radio Access Network (GERAN)

The most recent development involving EDGE and GSM/GPRS are the efforts to define GERAN. GERAN standardization has two main objectives:

- to align GSM/GPRS/EDGE and UMTS packet services (mainly in terms of QoS)
- to interface with the UMTS core network (Iu interfaces both Iucs and Iupo)

In summary, GERAN constitutes a radio access network (RAN) featuring EDGE modulation and coding modes and interconnecting to an UMTS core network, which makes it a UMTS RAN that supports 3G services.

This definition has several consequences for packet data transmission:

- All QoS classes defined for UMTS [2] also apply to GERAN. Refer to Table 2 for a definition.
- QoS class definitions also enable GERAN to support wideband AMR codec. This allows voice capacity to be improved.
- "Seamless" service can be provided across both UTRAN and GERAN for CS and PO services.

In addition to its aforementioned capabilities, GERAN provides a backward-compatible architecture to GSM/GPRS via A and Gb interfaces. In this case, only QoS classes (3) and (4) can be supported across the Gb interface.

The UMTS Standard

Third Generation Partnership Project (3GPP) specification group defined the Universal Mobile Telecommunication System (UMTS) in recent years.

The first release of the specifications (Rel. '99) provides a new radio network architecture including W-CDMA (FDD) and TD-CDMA (TDD) radio technologies, GSM/GPRS/EDGE-enabled services both for the CS and PO domain, and interworking to GSM. The first networks slated to be rolled out in Japan and some European countries will be based on Rel. '99 specifications.

In March 2001, Rel. 4 specifications were frozen, including features like Virtual Home Environment (VHE) and Open Services Architecture (OSA) evolution, full support of Location Services (LCS) in CS and PO domains, an additional TDD mode (TD-SCDMA), and evolution of UTRAN transport (primarily IP support).

Scheduled for publication in March 2002, Rel. 5 will support advanced features such as multi-rate wideband voice codec, IP-based multimedia services (IMS), and high speed downlink packet access (HSDPA).

As for GSM, the UMTS network architecture defines a core network (CN) and a terrestrial radio access network (UTRAN) *(see Figure 6)*. The interface in between the two is named Iu. Notably, this interface is also projected to connect to GERAN *(see above)*.

This approach is evolutionary, so the UMTS core network may integrate into the GSM core network. This also applies to core network entities as well as to functions and protocols across the network, for instance, call processing (CP) and mobility management (MM). It applies specifically to the GSM/UMTS mobile application part (MAP), which is independent of the RAN.

The integrated GSM and UMTS core network entities facilitate development, provisioning of network entities and introduction of UMTS services. Multi-mode terminals for both GSM and UMTS allow for smooth migration from GSM to UMTS.

Based on CDMA technology, UTRAN has been designed specifically to satisfy the service requirements of 3G. CDMA's fundamental function *(see Figure 7)* is to spread actual user data signals over a broad frequency range fending off multi-path fading. For this purpose signals are multiplied with a unique bit sequence (spreading code) at a certain bit rate (called chip rate). In this way users and channels are separated on the same carrier.

In contrast to a TDMA system, in a CDMA system other users within the same cell generate most of the interference. This allows adjacent cells to use the same frequency, which they usually do, and obviates the need for frequency planning.

Time division principles may be used within a CDMA system much in the way of FDMA systems. This has its benefits, foremost that it allows time division duplexing to be used to separate uplink from downlink signals, creating radio transmission technology suited for use in unpaired frequency bands (see below).

The UTRAN system is designed to efficently handle voice and data as well as real-time and non-real-time services over the same air interface (i.e. on the same carrier), all at the same time and in any mix of data and voice. This variant is better suited for data transport than GSM, and it provides a powerful platform for voice traffic. A comprehensive channel structure was defined for the radio interface. It consists of:

- dedicated channels that may be assigned to one and only one mobile at any given time.
- common channels that may be used by all mobiles within this cell.
- shared channels that are like common channels, but may only be used by an assigned subset of mobiles at a given time. These channels are used for packet data transfer.

The UTRAN system calls for several radio interface modes. Essentially, the definition distinguishes between two modes of operation:

- frequency division duplexing (UTRAN FDD) for operation in paired frequency bands.
- time division duplexing (UTRAN TDD) for operation in unpaired frequency bands. This option allows for alternative chip rates and bandwidths to be implemented (see below).

Both FDD and TDD are harmonized, in particular in terms of how higher layers of the radio network protocols and the Iu interface are used. In practice, the various modes are hidden from the CN, meaning that the particulars of FDD and TDD are limited to the UTRAN and to terminals.

Both the operator and user benefit when FDD and TDD are available in the same network:

- Unique UMTS service may be offered to the end user irrespective of the radio access technology.
- The end user will enjoy the best possible coverage without giving a thought to technical implications.
- The UMTS network may be deployed in such a way as to drive down costs.

Wideband CDMA (W-CDMA)

The UTRAN FDD mode employs Wideband CDMA (W-CDMA). This radio access technology uses direct sequence CDMA with a chip rate of 3.84 Mcps on a 2x 5 MHz bandwidth carrier (uplink/downlink). Due to the nature of the system, it usually operates with a frequency reuse of one, meaning

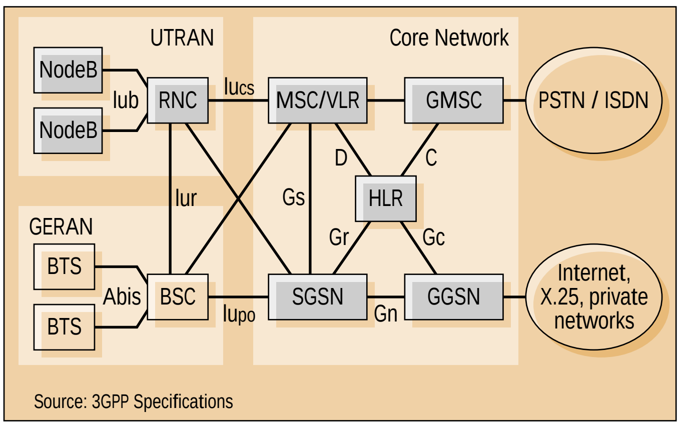

Figure 6: UMTS network architecture

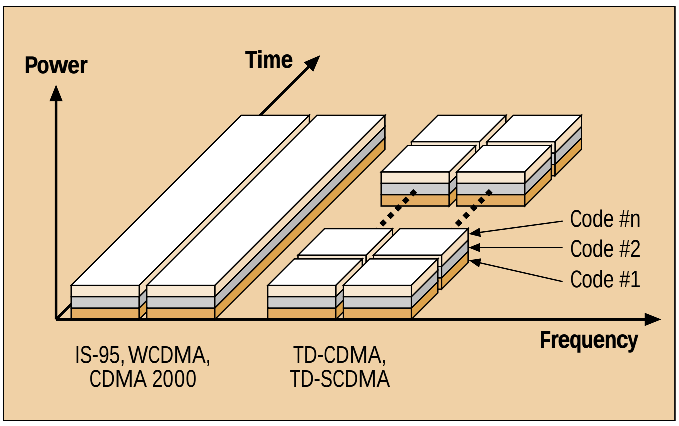

Figure 7: Time/code division multiple access

that all cells use the same carrier frequencies. As a consequence, the system provides a special process that mitigates intercell interference, especially at cell borders. Called soft handover (SHO), it is used for CS traffic. Rather than using SHO, PO traffic is switched in between two subsequent packets. In the course of an SHO, a mobile terminal is connected to more than just one NodeB, depending on actual radio conditions. The RNC multiplies and combines signals sent to and received from the terminal.

Though SHO is primarily a macro diversity feature, it also provides the basis for smooth and seamless inter-cell handover within the same frequency band. Softer HO is used between the sectors of one base station. This enhances efficiency, but it requires improved digital signal processing capabilities within the base station. Its effect is comparable to that of an SHO.

Again, other users within the same cell generate the majority of interference. This means that a CDMA system's cell size depends on the actual cell load; this effect is called cell breathing. To address this issue and ensure cell stability, CDMA networks should operate with a nominal cell load of some 50%, leaving margin for interference and allowing for some flexibility under peak load conditions.

More than one carrier may be used within a given cell or cell sector. Hard HO capability is provided to handover between these carriers. Separate carriers do not have common channels; they operate on their own. The radio network controller (RNC) coordinates all carriers within a given area, to include handling of admission control and the like.

W-CDMA can be used in all environments (vehicular, pedestrian and indoor) and for all kinds of traffic. However, by its very nature it is primarily suited for symmetric traffic using macro or micro cells in areas with medium population density.

Time Division CDMA (TD-CDMA)

The UTRAN TDD (time division duplex) employs time division CDMA (TD-CDMA) with a chip rate of 3.84 Mcps on a 5 MHz bandwidth carrier. This technology uses CDMA as well as TDMA to separate the various communication channels, which is why any given radio resource is denoted by timeslot and code. Timeslots can be allocated to carry either downlink or uplink channels, enabling this technology to operate within an unpaired band. In other words, a duplex frequency band is not required. That makes the minimum spectrum requirement just half the bandwidth of W-CDMA, that is, one 5 MHz block.

Moreover, TD-CDMA employs a joint detection algorithm. As its name suggests, it recognizes and decodes multiple channels jointly. This method eliminates intra-cell interference and helps boost system capacity. Due to the structure of TDMA and the fewer number of CDMA codes used within one timeslot, the joint detection algorithm can be implemented with an acceptable level of HW complexity and performance requirements. This algorithm may be extended in a future evolutionary stage to eliminate inter-cell interference.

The absence of intra-cell interference makes the system behave more like a TDMA system. It does not suffer from cell breathing, nor does it require SHO capability. That makes it particularly valuable in densely populated urban areas where indoor (pico environment) and outdoor (micro environment) solutions must cope with heavy data loads using the smallest cells. Moreover, since uplink and downlink timeslots may be assigned separately, TD-CDMA is well-suited for asymmetric traffic.

Time Division Synchronous CDMA (TD-SCDMA)

A technology similar to TD-CDMA, time division synchronous CDMA (TD-SCDMA) is different in that it uses special methods to maintain uplink synchronicity and avoid excessive guarding periods in the frame structure. It implements all the functions of TD-CDMA (in particular the joint detection algorithm), but it is based on a chip rate of 1.28 Mcps on a 1.6 MHz bandwidth carrier, which amounts to a third of the TD-CDMA chip rate and carrier *(see also Figure 8)*.

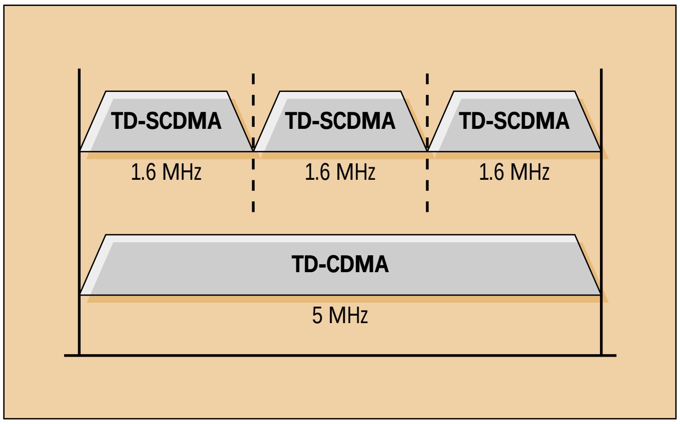

Figure 8: TD-CDMA/TD-SCDMA spectrum usage

This means three carriers may be used within the given spectrum's 5 MHz band. This affords operators greater flexibility. The system may be operated with frequency reuse of one, two or three. By the same token, the system could also be used in places where a contiguous 5 MHz block of the spectrum is unavailable. The basic TD-SCDMA parameters were selected specifically to enable deployment in all environments, including macro cell scenarios where mobility is high.

From its inception, the standard was designed with smart antennas in mind. Boosting system capacity tremendously, smart antennas have their advantages in macro and micro scenarios where user signals are concentrated rather than scattered.

TD-SCDMA technology is actually a component part of two different standards:

- The 3GPP UTRAN standard: Here the technology is UTRAN TDD's 1.28 Mcps option.

- The CWTS TSM standard: Here it is complemented with GSM radio procedures and embedded entirely in the GSM BSS and interworked into a GSM core network using GSM A and Gb interfaces.

TDD technology is expected to unroll from the Chinese market and extend into Europe for operation in unpaired 3G frequency bands. The size of the Chinese market (see "Regional Aspects") has the terminal volume required to attract operators and vendors to this technology.

High Speed Downlink Packet Access (HSDPA)

Designed to enhance the UTRAN system, high speed downlink packet access (HSDPA) endows the downlink with user data rates up to 10 Mbps. This feature is part of 3GPP standards Rel. 5 and may be applied to UTRAN FDD and TDD, i.e. to W-CDMA, TD-CDMA, and TD-SCDMA.

High user data rates are achieved by applying a higher-level modulation scheme (16QAM), including adapted coding rates with turbo codes. Since these modulation schemes require a better C/I ratio, the range of such a high-speed radio link will shrink, as will, by extension, cell size. This means HSDPA will primarily be used in scenarios with high traffic density or peak user data rates.

To achieve both high user data rates and excellent transmission quality, HSPDA defines a number of functions such as:

- Adaptive modulation and coding (AMC)
- Hybrid ARQ (H-ARQ)
- Fast cell selection (FCS); not part of Rel. 5
- Standalone downlink shared channel (S-DSCH); not part of Rel. 5

In principle, this concept is similar to the downlink shared channel (DSCH) available in UTRAN Rel '99. It allows the same physical channel to be shared by many mobile users on a statistical basis.

The S-DSCH feature calls for a configuration in which an entire 5 MHz downlink carrier is allocated to the DSCH and used exclusively for HSDPA. Typically this would be an amendment to a UTRAN FDD system.

From GSM to UMTS

UMTS networks are rolled out in steps. Deployment kicks off in urban areas where a specific demand for data services is anticipated. Next come suburban areas, and so on down line. In order to provide full coverage for service continuity from day one, networks and terminals are designed to enable roaming and handover between GSM/GPRS and UMTS.

In defining UMTS, all along the focus has been on a smooth migration path of the overall architecture and, in particular, the core network from GSM to UMTS. A look at the core migration issues follows:

- *Terminals:*

  Terminal manufacturers are committed to providing GSM/UMTS dual-mode terminals from day one. The projected market is huge and the manufacturers who have committed to GSM/UMTS *(see also Figure 3)* are many, so these terminals are bound to see worldwide use. Therefore the additional complexity imposed by the GSM part of dual-mode terminals is negligible; besides, the economy of scale will more than compensate. In fact, leading manufacturers expect cost benefits of some 30% compared with terminals featuring, for example, a cdma2000/GSM technology mix. This translates directly into real benefits: end users like the lower cost, making this venture a viable business proposition for operators.

- *Radio network:*

  UMTS technologies are designed specifically to use a bandwidth of 5 MHz (TD-SCDMA occupies 1.6 MHz only) of an unpaired or 2x 5 MHz of a paired spectrum to efficiently support high user rate data services in highly mobile environments. New radio spectrum was allocated for 3G, providing the basis for introducing new radio technologies without requiring spectrum to be re-farmed and legacy services and equipment to be replaced. The entire 3G spectrum is subdivided into 5 MHz bands.

  UTRAN *(see Figure 6)* is introduced alongside GSM RAN owing to its extended functionality and bandwidth.

- *Core network:*

  GSM and UMTS define the same core network architecture *(see also Figure 5 and Figure 6)*. GPRS is part of both GSM and UMTS. The implications for UMTS service introduction are clear: the legacy GSM core network can be upgraded to operate both GSM and UMTS within an integrated UMTS core network.

This means that operators can offer wide area coverage via GSM/GPRS and gradually build up their UMTS radio access infrastructure. At the same time, GPRS nodes and GSM MSCs may be upgraded to support UMTS services and interconnect the UMTS radio network via new Iu interface. All of this will reduce upfront investment and facilitate UMTS service introduction as well as subscriber and network management. And that, in a nutshell, is what smooth migration from GSM to UMTS is all about.

The IS-95 Standard (cdmaOne)

IS-95 is a 2G system operating in the 800 MHz cellular and 1900 MHz PCS bands. It was the first commercial CDMA mobile radio standard to use the direct sequence spread spectrum approach with a carrier bandwidth of 1.25 MHz and a chip rate of 1.2288 Mcps. Qualcomm was the driving force behind this standard. The first larger CDMA network based on IS-95 was introduced in Hong Kong in 1995.

The first version of the standard **(IS-95A)** [3] offers net bit rates of 8.6, 4.0, 2.0 or 0.8 kbps at 9.6, 4.8, 2.4 or 1.2 kbps gross bit rates. The bit rate is adapted for every frame (20 ms) in response to voice activity. This helps cut interference down to a minimum, thus boosting system capacity. On the forward[1] channel, each bit of the encoded bit-stream is repeated to achieve a constant coded bit rate of 19.2 kbps.

On the reverse channel, the same is done to achieve a constant coded bit rate 28.8 kbps. In consequence, low bit rate connections can be maintained at lower transmit power. IS-95 employs BPSK modulation and can theoretically allocate up to 63 traffic channels.

An early evolutionary advance of the IS-95 standard, **TSB74** increases the net bit rate to 13.35 kbps at 14.4 kbps gross bit rate. In effect, today every IS-95A network offers these user data rates.

In addition, **IS-95B** [4] features combinative channels: one primary channel may be combined with up to seven supplementary channels. In theory, IS-95B should support packet data services at speeds of up to 106.8 kbps. A more realistic assessment holds that a bit rate of 64 kbps is possible for packet data transmission.

IS-95 was primarily designed for voice traffic. Data transfer capabilities were added "artificially" [5] as an afterthought.

The upshot: significant error rates that are utterly unacceptable in data communication. A special RLP (radio link protocol, IS-99, IS-657 and IS-707) may be used to provide ARQ to compensate for transmission errors.

However, IS-95 has other drawbacks that degrade the system capacity projected in earlier phases of development:

- The slow power control update rate of 800 cycles per second degrades system performance and increases fading margin.
- The system has a bandwidth of 1.25 MHz. This engenders flat fading in certain environments, which diminishes rake receivers' efficiency.

Figure 9 shows IS-95's underlying network architecture. Signaling within the core network is carried out in the same way as in TDMA systems. ANSI-41 is used for purposes of mobility management. Based on the signaling system No 7 it serves to support communications between the network entities MSC, VLR, HLR, AC, MC and SME for purposes of authentication, registration, handoff, short message service, and so forth. [6].

However, ANSI-41 functions differ from those of GSM MAP in both name and content *(see Table 3)*.

IS-41 Revision D was the first ANSI publication (ANSI/EIA/TIA-41). Previous IS-41 revisions published by EIA/TIA merely supported regional roaming for voice services contingent upon on national agreements. Rev. E promises to provide global roaming and data service support.

The cdma2000 Standard

cdma2000 is another major 3G CDMA technology that has been submitted to ITU-R for IMT-2000 evaluation. An evolutionary approach based on IS-95, it is designed to increase legacy IS-95 networks' data transmission rates and voice capacity.

In contrast to W-CDMA, it includes a multi-carrier CDMA concept designed for 1.25 MHz carrier bandwidth with a chip rate of 1.2288 Mcps. A single 5 MHz band can accommodate three carriers *(see Figure 10)*.

3GPP2 specification group is the driving force behind cdma2000 standardization efforts. These may be subdivided into two phases:

- *cdma2000 Phase 1:*

  Providing a basic enhancement to IS-95, it is known by several names: IS-95C, IS-2000, MC-1X, IMT-CDMA or cdma2000 1xRTT (one-carrier radio transmission technology).

- *cdma2000 Phase 2:*

  Offering an improvement over the data rate of 1xRTT, it is also known as cdma2000 1xEV (one-carrier evolution).

[1] The terms "forward link" and "reverse link" are used synonymously within the IS-95/cdma2000 context to denote "downlink" and "uplink," respectively.

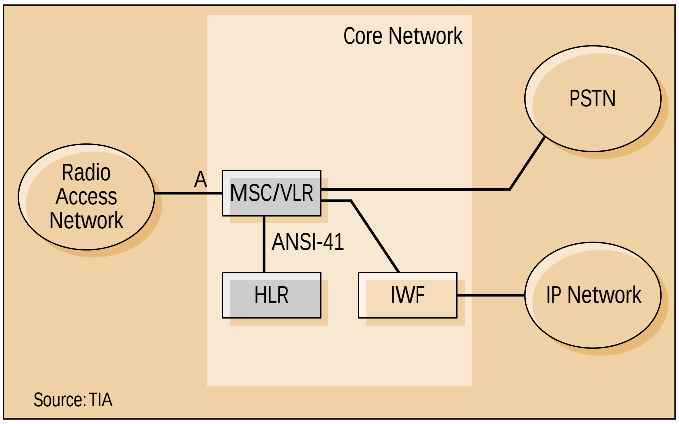

Figure 9: IS-95 Core network architecture

Function	GSM-MAP	IS-41/ANSI-41
SS7 signaling according to	ANSI or ITU	ANSI only
Supports data services	Yes	No
Supports SMS	Yes	Yes
Subscriber identification	GSM IMSI	IS-41 Rev 0, A, B, C: MIN (10 digit string) IS-41 Rev D: IMSI as an option
Terminal identification	GSM IMEI	ESN (32 bits binary)
For 3G	GSM-MAP according to 3GPP	IS-41 Rev E (≈ 2001): global roaming with IMSI, data services

Table 3: ANSI-41 versus GSM-MAP

Table 2: UMTS QoS Classes

Another cdma2000 option proposes a technology based on three times (3x) the carrier rate of 1xRTT. It is also known by several names: MC-3X, IMT-CDMA or cdma2000 3xRTT. This concept is unpromising. 1xEV technologies have made it obsolete, so this paper does not discuss it further.

The cdma2000 system architecture defines a radio access network (RAN) as well as a core network *(CN; see also Figure 11)*. However, the network architecture, interfaces and procedures differ somewhat from their UMTS counterparts. The core network comprises an ANSI-41 component, which is essentially the same as for IS-95 (see also above) and TDMA, as well as a new separate packet component based on IETF functions such as MobileIP for mobility support.

To at least support roaming between UMTS and cdma2000 for voice services, interworking functions are required both within the network and the terminal. These functions are about to be defined by the G-95, a sub-group of GGRF investigating roaming between GSM and CDMA systems similar to GSM-ANSI Interworking Team (GAIT). Albeit technically feasible, the economic viability of terminals offering cdma2000, GSM/GPRS and UMTS is questionable due to the interworking complexity and overhead involved. In view of the forecasts predicting a small market share for the standard, particularly in comparison to GSM/UMTS, it would appear that cdma2000's prospects are somewhat doubtful.

The following section outlines cdma2000's technological options. More detailed information is provided by another Siemens White Paper comparing cdma2000 to W-CDMA.

CDMA2000 1XRTT

The term 1xRTT in general denotes a one-carrier (1x) cdma2000 radio transmission technology. Compared with IS-95 voice services, 1xRTT networks will offer improved network capacity (more users; fewer dropped calls) and, in theory, better battery lifetime for terminals.

On paper the standard offers data transmission with a peak data rate of 625 kbps for data services. However, systems implemented to date only support a peak data rate of 307.2 kbps, while commercial 1x terminals allow a peak data rate of just 153.6 kbps. ISDN-like speeds (144 kbps) are expected to be obtained by mid-2003.

SK Telecom conducted trials with a cdma2000 1xRTT system south of Seoul, South Korea. The company reported an average data rate of 71 kbps across the cell area, which varied depending on both coverage – that is, the position of the mobile in relation to the base station - and environment (vehicular, pedestrian, and so forth). A peak user data rate of 153.6 kbps was measured close to the base station. Voice capacity increased by a factor of 1.5 to 2 over the 2G (IS-95) system.

It is fair to assume that efforts to standardize 1xRTT will require several phases. That poses serious problems for terminal vendors, particularly in regions where time to market is critical.

CDMA2000 1XEV

1xRTT technology is on the verge of being optimized for more efficient data services in particular and higher data rates in general. Much in the way of other radio technologies, the key improvement is a higher-level modulation scheme that allows for more data bits per frame. This standardization effort will require (at least) two steps as outlined below. The proposed technology is called **1xEV.**

In a first step, a technology was proposed for use on a separate carrier **(1xEV-DO)** for data only. For this purpose, 3GPP2 adopted an approach based on Qualcomm's HDR concept.

Conceptually, the downlink transmission process is **incompatible with 1xRTT.** It employs a downlink shared channel comprising the entire carrier and allowing multiple user multiplexing with a single user being served at a time. The base station transmits at its maximum TX power level so that each user can be served on the forward link at the optimal C/I. This approach promises a downlink peak data rate of up to 2.4 Mbps for packet data transmission, which is achieved by means of higher-level modulation (16QAM) and turbo encoding. Uplink data rates remain the same as for 1xRTT.

The idea of the 1xEV-DO proposal is to exploit radio overlay

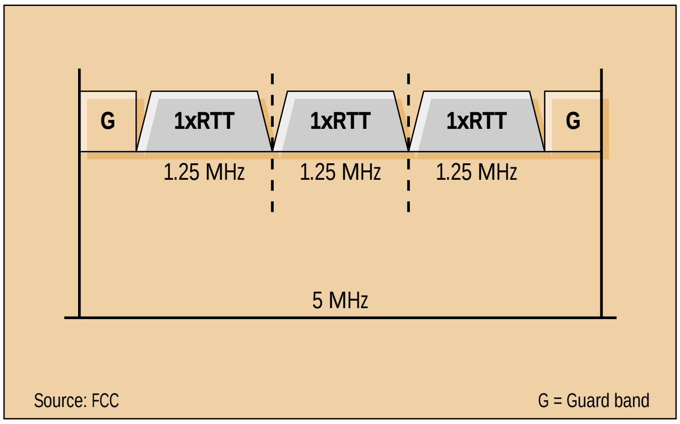

Figure 10: 1xRTT spectrum usage

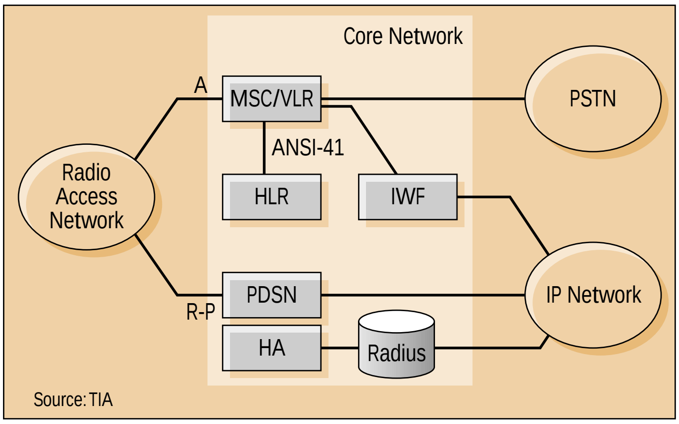

Figure 11: cdma2000 network architecture

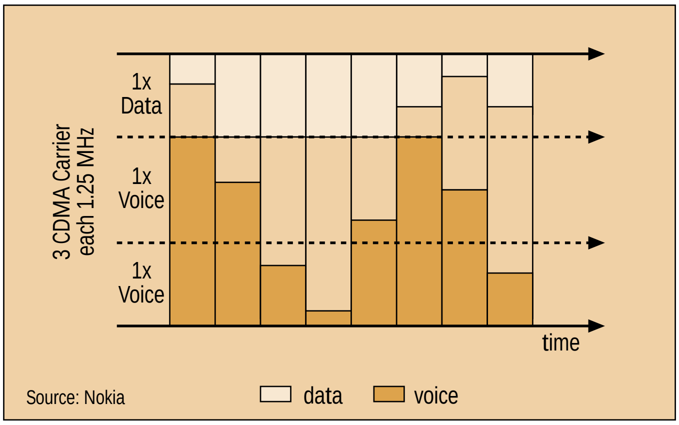

Figure 12: Voice and data traffic in an overlay network comprising 1xRTT and 1xEV-DO

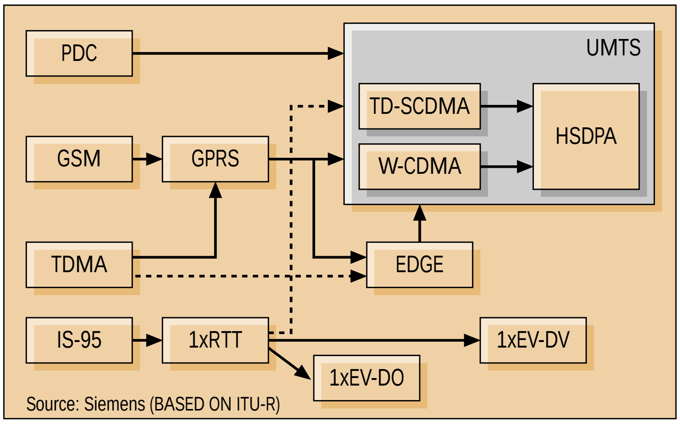

Figure 13: Migration of standards towards 3G

to facilitate this technology's introduction. However, a look at the entire system as illustrated in *Figure 12* shows that this wastes capacity. 1xEV-DO may be particularly interesting for best-effort data applications like web browsing that demand mobile wireless Internet access. It takes dual-mode 1xRTT and 1xEV-DO devices to place both voice and packet calls in this type of overlay structure.

According to reports, 1xEV-DO carriers have been installed to replace and run alongside 1xRTT carriers within legacy cdma2000 base stations without apparent limitations.

The next evolutionary step has already been envisaged. It will introduce an advanced technology **(1xEV-DV)** that is able to integrate voice and data transmission on the same carrier, avoiding the waste of capacity attributed to 1xEV-DO. It also retains backward compatibility to 1xRTT, but not to 1xEV-DO. This technology is expected to enable a downlink peak data rate of 3.1 Mbps for packet data transmission under ideal conditions.

Release C of cdma2000 specifications frozen end of May 2002, contains an initial version of 1xEV-DV.

From IS-95 to cdma2000

cdma2000 was designed to serve as IS-95's migration path. Several facts underscore this strategy:

- cdma2000 radio technology is based on IS-95. Chip rates and carrier bandwidths are identical. IS-95 terminals can be operated on 1xRTT base stations because 1xRTT is downward compatible to IS-95.
- The core network architecture and protocols for voice and CS data services are essentially the same as for IS-95 (see above).
- cdma2000's packet data infrastructure is based on IETF standards and may be added on to run in parallel to the legacy CS infrastructure. It is actually an overlay network.

In theory, migration from IS-95 to cdma2000 should not pose any problems. However, there are a few issues that deserve mentioning:

- ANSI-41 Rev. E makes MIN an optional parameter. Therefore compatibility with older IS-41 revisions and other new features and protocols may pose a problem. This applies particularly to roaming with other IS-41 networks.
- Although in principle it is downward compatible, new terminals must be introduced to truly benefit from cdma2000's improvements over IS-95 such as greater capacity and higher user data rates.

Migration of other cellular standards

As pointed out in the introduction to this paper, other cellular radio standards are discussed in terms of their migration options towards GSM/UMTS or cdma2000. This, in fact, is one of the hottest topics on the agenda today.

As outlined in the sections above, a plan for migration within the GSM/UMTS family as well as from IS-95 to cdma2000 was drawn up and proven in trials. The proposed migration paths shown in *Figure 13* reflect this. Note that this figure illustrates migration to UMTS as well as migration to any combination of the three options (e.g. W-CDMA, TD-CDMA or TD-SCDMA).

What will become of PDC?

Today PDC subscribers number 57m worldwide, with the majority being in Japan. The system has reached its limits, and Japan is the driving force in pushing for the introduction of 3G technology. In fact, NTT DoCoMo was the first operator to offer UMTS service. Most PDC subscribers will stick with the current networks as long as they require no additional services. At the same time, ever more subscribers will switch over to UMTS. This is sure to be a viable situation for both because the PDC and UMTS spectrums do not overlap and coverage is available for both systems.

How about migrating a TDMA network to GSM/GPRS?

As it stands today, this issue is chiefly a concern of North and South America operators simply because the majority of TDMA systems are operated in these regions. It bears mentioning that UWCC in its role as the TDMA operator interest group had recommended that its members migrate to GSM/UMTS rather than to the cdma2000 standard. This section merely looks at generalities; specific aspects of migration, particularly spectrum-related issues, are discussed in the appropriate sections of the chapter "Regional Aspects".

TDMA networks offer voice and low bit rate CS data services. An ANSI-41 core network is used to this (see also above). Providing packet data services would mandate CDPD technology. GSM/GPRS would be an excellent choice because it offers packet data services while also enabling voice service. In addition, the technology is cheaper in terms of factors such as cost per traffic density. Moreover, owing to the evolutionary scenarios towards EDGE and/or UMTS, it promises a broad range of services, opening a window of opportunity to future 3G.

A look at the core migration issues follows:

- Terminals:

  TDMA/GSM/GPRS/EDGE multi-mode GAIT terminals will be made available as required to allow for various migration scenarios.

  - If GSM/GPRS is operated in distinct areas only, multi-mode terminals will support both-way roaming and at least one-way handover – assuming that coverage is provided by the TDMA network.

  - If overall coverage of GSM/GPRS is envisaged, single mode TDMA and/or GSM/GPRS terminals are also acceptable. In this case, the operator may opt to gradually switch over from TDMA to GSM users.

- *Radio network:*

  In many cases, GSM/GPRS will be introduced as an overlay network.

  Though the technologies of TDMA and GSM radio networks and terminals differ, there are some similarities (for example, network planning) that allow operators to apply and benefit from skills they already have.

- *Core network:*

  The process of introducing GSM in an ANSI environment is comparable to the way PCS1900 core networks were introduced in the U.S. years ago. Here GSM-based network entities are operated together with a GSM MAP based on an ANSI SS7 protocol stack. Wherever necessary, GAIT functions will be used to some extent to interwork GSM and TDMA networks.

Some proposals suggest that it is easier to migrate TDMA to cdma2000 than to GSM/GPRS because the same core network infrastructure can be retained. And while it is true that no GAIT functions would be required for voice and CS data, this is only part of the story. cdma2000 also requires changes in the core network entities owing to modifications of the interfaces to the RAN and within ANSI-41.

The pivotal issue, however, is the availability and cost of

Table 4: Summary of cellular standards' benchmarks

	EDGE	GERAN	UMTS				CDMA2000		
			W-CDMA	TD-CDMA	TD-SCDMA	HSDPA	1xRTT	1xEV-DO	1xEV-DV
Carrier bandwidth [MHz]	0.2		5		1.6	According to base technology	1.25		
Min. spectrum required [MHz]	2x 2.4 (due to BCCH for 4/12)		2x 5	1x 5	1x 1.6		2x 1.25		
Multiple access principle	Time & frequency		code	code & time			code	UL: code DL: code & time	
Chip rate [Mcps]	Not applicable		3.84		1.28		1.2288		
Modulation	GMSK, 8-PSK		QPSK		QPSK, 8-PSK	QPSK, 16QAM	BPSK, QPSK	BPSK, QPSK, 8-PSK, 16QAM	
Peak user data rate [kbps] [1]	473		384 [2048 [2]]	2048	2048	10000 [3]	307 [625 [4]]	2400	3100
System asymmetry (UL:DL)	1:1		1:1	2:13-14:1	1:6-6:1	1:1-5:1	1:1	1:1-4:1	
QoS classes	3 & 4	1 … 4					None	3 classes of service only	
Transport network	PCM (CS), FR (PO)	PCM, FR, ATM	ATM for both CS and PO service domains				Sonet for CS domain, IP-network (PPP and SDLC) for PO domain		
Mobility support	MAP						IS-41, IP protocols for data		

[1] according to presently defined framing, coding and modulation schemes and assuming ideal radio conditions, [2] for pico cells
[3] present assumptions, [4] second phase

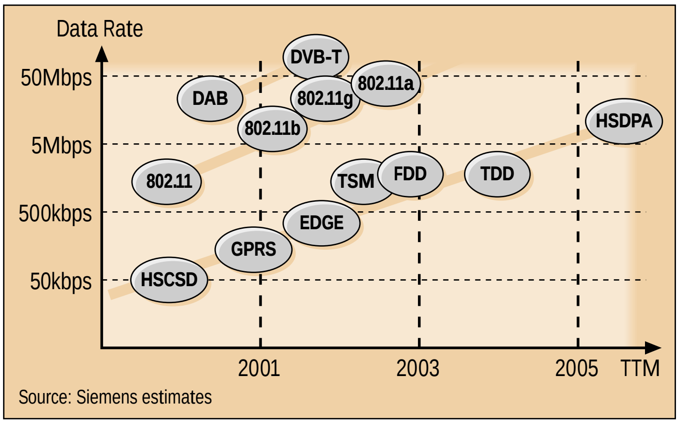

Figure 14: Migration of standards towards 3G

Note: The bullets representing the various standards indicate the given time to market rather than completion of the standards.

suitable multi-mode terminals. As it stands today, manufacturers have been reluctant to commit to offering TDMA/cdma2000 multi-mode terminals, and that is a prerequisite for this migration option.

Which approaches are suitable for migrating from IS-95 to GSM/UMTS?

According to market forecasts, over the long run cdma2000 users will remain a minority in the world market. That lends this question gravity. The fact is that this scenario is largely the same as for TDMA, except perhaps the terminals. As it stands today, not a single manufacturer has committed to IS-95/GSM/UMTS multi-mode terminals.

Summary

This section summarizes the key benchmarks of the cellular standards described above. As illustrated in *Figure 14*, standards evolve, especially in terms of user data rate performance. The figure also shows that wireless LAN and digital broadcast standards undergo similar developments (see also the related sections below).

Table 4 provides a summary of the key benchmarks of cellular standards discussed above. This table warrants a few comments:

- The figures shown here represent the standards and their features as it stands today. For example huge strides in EDGE's future development are unlikely *(see also Figure 14)*, while 3G standards such as UMTS W-CDMA still harbor considerable potential for further improvements in the coming years (case in point: HSDPA).

- The figures indicate values that apply to the standards as such as far as this is possible. Real-world scenarios may differ depending on which features have been implemented. For this reason, these figures may not be mapped onto product data sheets without further consultation.

Regional Aspects

The underlying conditions for the introduction of 3G systems are not the same all over the world. There are specific regional situations, mandating different approaches and perhaps different systems, all of which deserve a closer look. Moreover, these approaches may even differ for a given operator, depending on:

- availability of spectrum
- other regulatory aspects
- legacy systems
- availability of terminals

The following sections describe the situations in key geographical regions and discuss to which extent the given underlying conditions influence migration strategies.

Americas

Today cellular subscribers in **North America** number some 140m; just 9% of which use GSM terminals. That means the majority of cellular subscribers (AMPS 16%, TDMA 30%) will face a dilemma in the coming years because there are no direct evolutionary paths from AMPS or TDMA to 3G services and networks. Other technologies are vying for this market, particularly in view of the great potential that has been forecast for the period until 2005/2006.

Spectrum is allocated in North America without requiring a specific technology. As depicted in *Figure 2*, PCS systems, to include IS-95, and GSM1900, currently occupy IMT-2000 bands. This means that allocating 3G bands within the IMT-2000 spectrum *(Figure 2)* as recommended by WRC is impossible at this time. Whereas the PCS spectrum fully overlaps the UL band, the DL band is reserved for schools, healthcare and military services. The FCC is studying how other frequency bands, for example, 2520 to 2670 MHz, may be allocated. In the meanwhile, several operators try to agree on a 2x 5 MHz band for early UMTS introductions (by spectrum pooling).

The problem with the spectrum complicates matters for operators whose preferred 3G solution is UMTS: they have no way of introducing this system today. Instead they are likely to go for GPRS/EDGE in a bid to offer a suitable set of 3G services. In addition, operators may consider introducing GERAN if extended voice service capacity is of value to them.

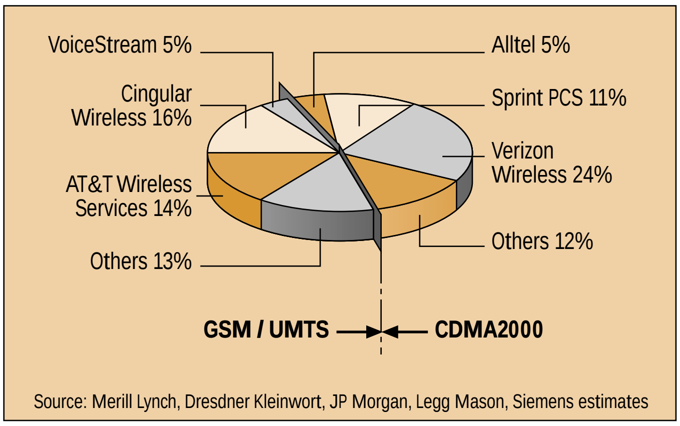

Figure 15: Cellular market in North America

The systems would have to share the same bands as the operators' legacy systems. Major operators such as Cingular, AT&T Wireless, VoiceStream *(refer to Figure 15)*, have already made decisions to take this route:

- Cingular opted to introduce GPRS and EDGE before the end of 2004.
- AT&T-Wireless committed in Nov. 2000 to build a GSM overlay network over TDMA. In May 2001, AT&T found that more than 15.3m TDMA subscribers are willing to switch to GSM within the next years.

As it stands today, Verizon, Sprint and a few others are likely to go for cdma2000.

It is expected that low-price multi-mode terminals (GSM/GPRS/EDGE and TDMA) will be offered during the transitional period and the door to future UMTS improvements will be kept open while waiting for spectrum problems to be solved. That will secure the investment in infrastructure made today for tomorrow. At the same time, all will benefit from economies of greatest scale, in particular in terms of terminals. Should this strategy succeed, GSM/EDGE is expected to gain a market share of some 35% within North America by 2005/2006.

At the end of 2001 there were some 85m subscribers in **South America**. *Figure 16* shows the distribution of subscribers among the various countries. TMDA systems are operated in most of these countries. At the end of 2001, just 5% of all subscribers used GSM, but about 40% are expected to switch over by the end of 2005 [7]. From July 2000 to December 2001, 16 licenses were granted in South America, half of them for GSM, the rest for TDMA and other digital standards [8]. As the AMPS market share (17%) diminishes, TDMA (58%) and GSM are on the rise.

Many countries in South America emulated the North American example in PCS spectrum allocation, and now operators in these countries are facing the same situation. Though IMT-2000 bands for 3G systems are available in some countries, UMTS is not on the agenda for the near future. Plans for its introduction may be made later.

It bears mentioning that in the wake of Cingular's and AT&T's landmark decisions, the majority of TDMA operators worldwide are considering migration to GSM. Research conducted by TDMA operators shows that more than one third of the world's 95m TDMA subscribers are today ready to move to GSM.

Many South American operators have committed to building a GSM/GPRS overlay network to augment TDMA, among them Personal in El Salvador and Argentina, Entel in Bolivia, and Telcel in Mexico. If this pace continues, the total number of GSM subscribers in South America is expected to rise to some 60m by the end of 2005 *(see also Figure 17)*.

China

Today China is the world's largest single-country GSM market. Just two operators serve more than 160m subscribers (see Figure 18). In addition, China Unicom operates a CDMA network serving about 1m subscribers. Investments in all mobile networks come to approximately 14" Euros. This is a critical consideration when planning to introduce 3G systems and terminals. Obviously, operators have a vested interest in securing as much of this investment as possible when migrating to 3G networks.

Like other regional standardization bodies, China's CWTS has forwarded a system proposal to ITU-R for IMT-2000 evaluation. Called TD-SCDMA (see Figure 1), after ITU-R adopted it and it was subsequently harmonized, this proposal was merged with UMTS and embraced in 3GPP Rel. 4. Now it is part of UTRA TDD mode's 1.28 Mcps option (see also chapter "Time Division Synchronous CDMA (TD-SCDMA)" for details).

In addition, TD-SCDMA is part of the TSM standard defined by CWTS. The goal of this standard is to combine the advantages of TD-SCDMA with the availability of the GSM system in order to enter the 3G market with early TD-SCDMA products. TSM is fully integrated into the GSM system, and it provides roaming and handover to GSM to benefit from existing GSM coverage. The Chinese commitment to TD-SCDMA provides considerable momentum for TDD not only in China, but also for the entire world market.

3G licenses have not been awarded nor has spectrum for 3G operation been allocated to date. This process is expected to ensue at the end of 2002 or beginning of 2003. Both paired and unpaired

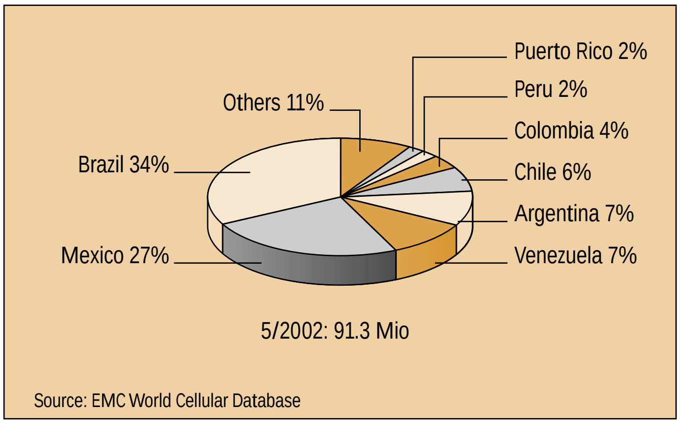

Figure 16: South American subscribers by country in March 2001

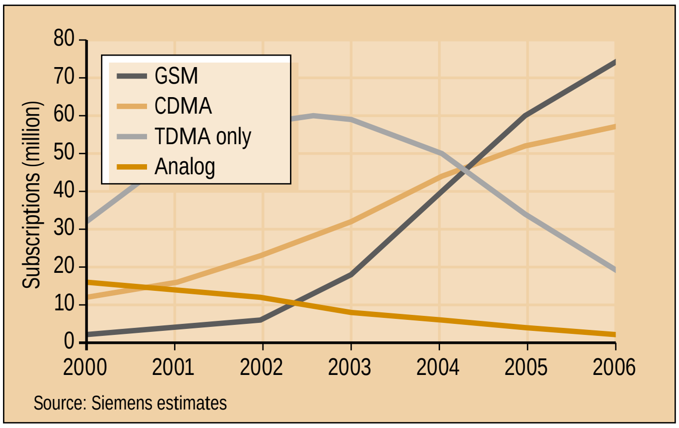

Figure 17: Technology forecast in South America

spectra will be allocated. Consequently, both W-CDMA and TD-SCDMA will be deployed as parts of a 3G network. In contrast to other parts of the world, China could benefit from an additional unpaired 2.3-to-2.4 GHz frequency spectrum for TDD. TD-SCDMA will be able to operate not only in pico and micro cells, but also in macro cells using smart antennas to enhance system capacity.

The majority of Chinese operators have already expressed their willingness to invest in W-CDMA as well as TD-SCDMA UMTS networks. Deployment of EDGE technology is not on the table at this time, but the issue may be raised (for example, for rural deployment) at a later date. EDGE is fully integrated into the GSM/GPRS architecture, and it is largely a SW-based feature, so this should be easily accomplished.

Figure 19 shows potential GSM migration options for China. Essentially, there are two choices. Operators may:

- introduce TSM (together with GPRS Core Network entities where there is demand for more than merely voice service), or
- introduce UTRA FDD (W-CDMA).

TSM migration will engender TD-SCDMA of UTRA TDD within an UMTS network. For the time being, the TD-CDMA option is not under consideration for China because interest in TD-SCDMA is far greater. This migration is facilitated by the facts outlined in the chapter "The UMTS Standard" above. This will ensure a smooth, investment-sparing path to 3G-service implementations.

Europe

With some 300m subscribers served by 128 networks as of the end of 2001, Europe has the largest GSM population in the world. Many operators have upgraded their networks to GPRS, but commercial EDGE service is currently unavailable mainly due to the lack of economically viable terminals. Investments are estimated to total some 40" Euros.

ETSI defined the GSM system with the active participation of European manufactures and operators. A stable and reliable system, it has proven a success. Not surprisingly, the European proposal to IMT-2000 regarding a future 3G system was UMTS, which of course is a clear evolution from the core network perspective. Consequently, most operators who were awarded 3G licenses and spectrum have committed to introduce UTRA FDD (W-CDMA) in the paired spectrum parts (2x 60 MHz).

Most licenses include allocation of unpaired spectrum (n x 5 MHz). For these cases, the UMTS standard defines the UTRA TDD mode. As outlined above, it is fully compatible with FDD in terms of architecture, interfaces, and services. In general, both TD-CDMA and TD-SCDMA may be considered for network capacity enhancements in pico, micro, and macro deployments – the latter using TD-SCDMA. The very nature of UTRA TDD makes it a particularly attractive option for accommodating asymmetric data traffic.

UTRA TDD deployments may prove sufficient for capacity enhancements in pico and micro cells up to 2007/2008. However, by that time it will take extra capacity in macro cells to cater to future UMTS extension bands. UTRA TDD is also useful in this context because it offers greater flexibility in terms of spectrum allocation options.

Alongside operators' commitment to the aforementioned cellular standards, the spotlight is turning to other radio standards that complement the service range of cellular mobile operators.

Three types of radio standards are expected to play a major role in the future, in particular in terms of next generation services:

- Bluetooth,
- wireless LAN and
- digital broadcast systems.

Cellular systems and other radio standards may be combined wherever warranted by market demand. The following chapters provide an overview of their technical benchmarks and the benefits that they bring to both operators and users.

Bluetooth

A wireless technology for personal area networks (PAN), Bluetooth transmits at low power levels of 1 mW (0 dBm) to 100 mW (20 dBm). It is an open standard for short-range digital voice and data transmission.

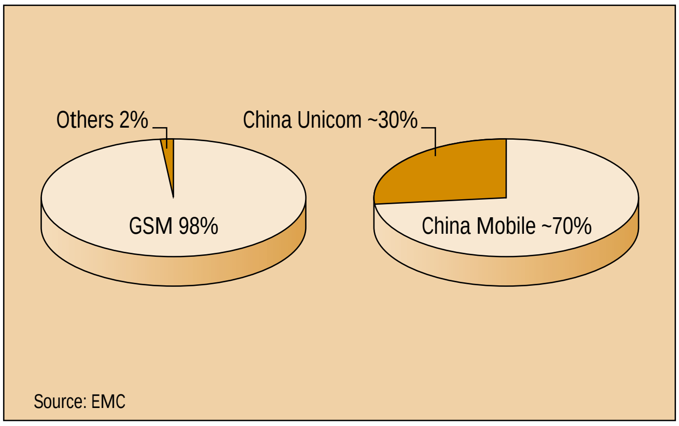

Figure 18: GSM market in China

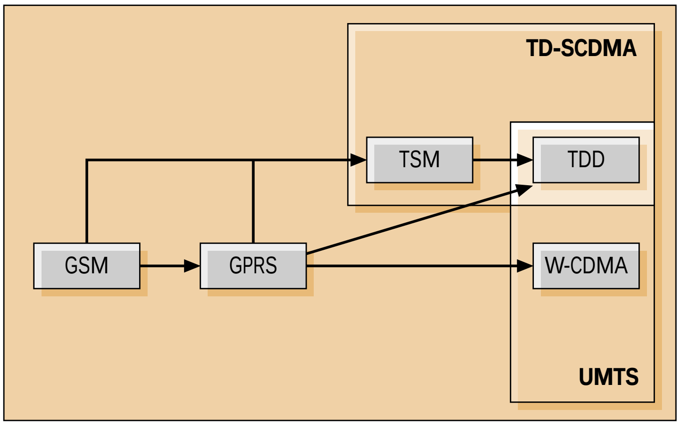

Figure 19: Migration options in China

Bluetooth is primarily designed to replace communication cables and infrared interfaces. Supported by the service discovery protocol (SDP), Bluetooth establishes connections between user devices such as mobile phones, PDAs, PCs, laptops, headsets as well as desktop computers, printers and the like. To this end, it supports both point-to-point and multipoint applications, but at the time of writing not handover procedures. A Bluetooth cluster may be composed of up to eight devices that communicate with each other.

Bluetooth provides data transfer rates of up to 720 kbps within a typical range of 10 meters, and up to 100 meters via a power boost unit. It operates in the unlicensed 2.4 GHz band (ISM band) using a frequency hopping spread spectrum process that changes frequency 1,600 times per second. Interference from other devices such as other Bluetooth-enabled appliances does not interrupt transmission, it merely diminishes the user data rate. The IEEE 802.15.2 Working Group is examining how Bluetooth can coexist with other standards operating in the ISM band, and it is developing guidelines for short distance personal area network standards. *Table 5* provides a summary of specifications.

Bluetooth chips are expected to be cost-efficient components in mature short-range systems. From the cost perspective, Bluetooth is likely to be added to virtually all future mobile user devices. In these scenarios, Bluetooth is an add-on technology serving the purpose of local communication, while wide area communication is performed via a suitable cellular standard.

Wireless LAN

The term wireless LAN (WLAN) can be a bit confusing. It is in fact used to describe two different applications:

- For one, it is a radio access technology compliant with IEEE 802.11 and subordinates operating in either the 2.4 GHz ISM band or in the 5 GHz band, both of which are unlicensed bands
- For the other, it describes and entire wireless local area network.

Figure 20 shows the frequency bands that these standards operate in.

A typical wireless LAN comprises the following components *(see also Figure 21)*:

- *Network interface cards (NICs):* These are part of the terminals, for example, PCMCIA card modules for laptop computers. Many new laptops ship with onboard WLAN modules.
- *Access point (AP):* This type of device is the wireless entry point to the network; it is generally connected to the hub of an Ethernet system, either via shared or switched line.
- *Network elements:* These include Ethernet cables (100 BaseT specification) serving to connect hubs, switches, bridges, etc.
- *Servers:* DHCP, DNS, and application servers.

Much like in a cellular system, "nomadic" users roaming between the various cells of the same access domain may be "handed over" from one access point to another.

Public network operators can benefit from their underlying cellular network infrastructure when offering services to WLAN customers. Several proposals have been forwarded for coupling WLAN with cellular networks, whereby "loose coupling" is considered on the best option. A look at the main premises of this approach follows:

- For purposes of data transport, for instance, for Web browsing, the LAN is connected to an Internet backbone via an access gateway offering access router functionality.
- The access gateway acknowledges visiting WLAN users and requests authentication from an authentication center such as HSS before it grants access to the outside world. On demand, it can also provide charging services for data communication.
- The WLAN is connected to central authentication and billing support systems such as micro payment systems. They are interfaced with the cellular network operator's billing system, ensuring trusted transfer of billing information.

Cellular operators could determine the depth of their com-

Application	Degree of symmetry up/downlink	Data rate	Key performance parameters and target values (BER, delay, others…)			Frequency band license status	Type of terminal
Voice	symmetric, directly linked to base band L2	16 kbps	target BER 10^{-3} voice, 10^{-6} data, depending on application & coding	typical 20 ms in the radio, core depending on network	service discovery protocol (SDP)	2400 MHz -2480 MHz	Mobile phone, printer, laptop, PDA, computer, consumer electronics
Data, email, WWW, ftp, OPEX	symmetric and asymmetric	16 kbps – 700 kbps (max bit rate for one user)					

Table 5: Bluetooth applications and benchmarks

mitment simply by choosing from among various business models. They can opt to:

- build full WLAN network infrastructures from the bottom up, including installing and operating radio equipment and cell site components
- work with WLAN brokers who interface with many operators.
- provide access to billing platforms only.

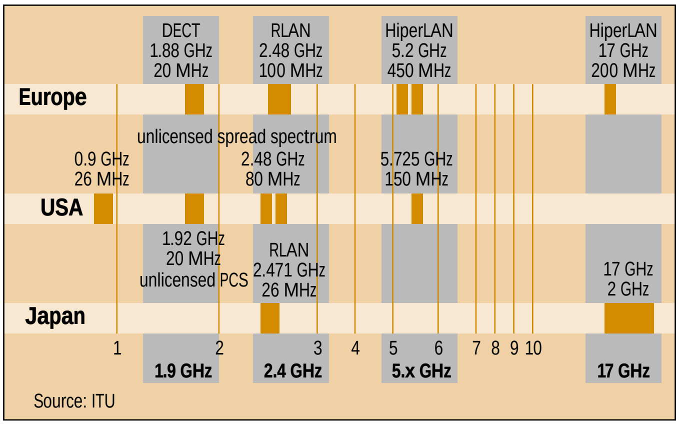

Figure 20: WLAN frequency spectrum

Note: The acronym RLAN is used generically by ITU-R to designate wireless LAN technologies

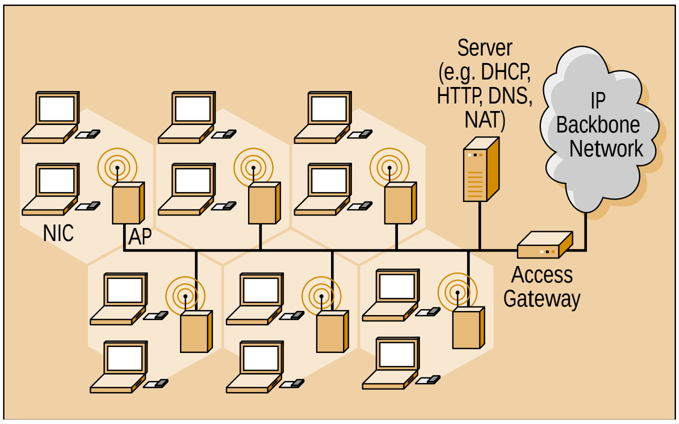

Figure 21: Wireless LAN network architecture

Today WLAN services are delivered by applications requiring no more than best-effort quality. However, (W)LAN standards already exist that call for some QoS, for instance, for advanced multimedia services. These standards may at some point foster solutions that are far more integrated with cellular approaches. At any rate, this of course mandates terminal equipment that supports this approach.

Trial systems have been implemented in a bid to resolve these issues.

Table 6 provides an overview of the various technologies and their radio interfaces' specifications. Wireless LAN systems' radio reach generally ranges from 50 to 100 meters. A contemporary WLAN offers user rates of 11 Mbps, and future systems will be able to transfer data at 54 Mbps. That makes them an interesting proposition for hotspots in corporate and public environments, which is why public cellular operators are so keen to learn more about WLAN capabilities and explore its business opportunities.

IEEE 802.11

Within the context of the local area network definition, the IEEE 802.11 standard specifies the two lowest network layers – the physical layer and data link layer of a WLAN. Layer one is the physical layer (PHY); it provides the underpinning for communication between network components.

The base standard IEEE 802.11 has many subordinates, all of which are compatible with the overall structure. *Table 6* provides an overview of the key subordinates.

Today IEEE 802.11 and its subordinates make up a global technology supported by PC, laptop and operating systems vendors. It is used worldwide and it will branch out into many areas – residential, business, and public.

HiperLAN2

HiperLAN2 is a broadband radio standard that was specified over the last years under the auspices of the ETSI BRAN project. It offers high-speed access to a variety of networks including Ethernet (IEEE 802.3), UMTS, ATM and IP-based networks. HiperLAN2 operates in

Technology	Multiple access technique	Modulation technique	User data rate	Key performance parameters and target values			Frequency band
				Typical BER	Typical delay	Connectivity	
IEEE 802.11	DSSS, FHSS	2GFDK, 4GFSK DBPSK, DQPSK	Up to 2 Mbps Typ 1 Mbps	~10^{-5}	10 ms-50 ms	Connection less	2.4 GHz unlicensed band (ISM band)
IEEE 802.11b	CCK-DSSS	DBPSK, DQPSK	Up to 11 Mbps Typ 5 Mbps				
IEEE 802.11g	CCK-DSSS, OFDM	DBPSK, DQPSK	Up to 54 Mbps				
IEEE 802.11a	OFDM	16-QAM, 64-QAM,	typ 25 Mbps				5 GHz unlicensed band (RLAN band)
ETSI HiperLAN2				Same as wired IP or ATM < $5x10^{-14}$	< 5ms	Connection less and connection oriented	

Table 6: Wireless LAN technical specifications

the 5 GHz frequency band. *Table 6* highlights this technology's key features. A synopsis follows:

- automatic dynamic frequency allocation & power control
- security support (authentication and encryption)
- mobility support
- network-application independent
- power saving

The HiperLAN2 Global Forum (H2GF) is a central body that supports and promotes HiperLAN2 for worldwide operation. As it stands today, the availability and cost of hardware are HiperLAN2's big drawbacks. In view of these shortcomings and the constraints of early 5 GHz technology, HiperLAN2 is unlikely to supplant or impede IEEE 802.11b for the time being.

Digital broadcast

Digital broadcasting will supersede analog broadcasting in the coming years. Two major systems are in use today:

- Digital Audio Broadcast (DAB) and
- Digital Video Broadcast (DVB)

Other digital broadcast systems include ISDB-T (Japan), ATSC (USA, CAN) and a variety of other digital satellite and cable systems.

DAB is geared primarily toward terrestrial reception, but it may also be used in cable and satellite systems. Though it has been deployed worldwide, the rate of spread is slow. The principal application is public radio and television broadcast services using cell sizes ranging up to some 60 km and typically designed for coverage greater than 95%.

DVB comes in terrestrial, cable and satellite versions and serves some 15 to 20% of European homes as of 2002, mostly via satellite. It is also used in many countries outside Europe. *Table 7* provides a summary of its benchmark features.

Its features, expected coverage, and support of high quality broadband services have sparked considerable discussion on proposals suggesting that DxB (in particular DVB-T as the terrestrial version of DVB) should be combined with cellular services. By providing a backward channel to interact with broadcast information, cellular services can benefit from DxB broadband capabilities. Both GPRS/EDGE and UMTS are under consideration as potential candidates.

Digital Audio Broadcast (DAB)

DAB is a standard of the International Telecommunication Union (ITU), European Telecommunication Standards Institute (ETSI), and European Broadcasting Union (EBU). Today DAB is received by some 276 million people worldwide [9], but it is spreading slowly.

Digital broadcasting was introduced chiefly to provide better spectrum efficiency, lower cost of transmission, enhanced mobile reception, higher sound quality and data transmission capability. DAB allows audio programs to be sent in CD quality. It can be operated in bandwidths up to 3 GHz for mobile reception with a spectral efficiency of some 1 bps/Hz.

The system is designed to provide reliable digital audio and data broadcasting for reception on mobile, portable and fixed receivers using non-directional antennas. DAB is transparent to any type of data transmission, so several different services can share the same trans-

Technology (terrestrial)	Application	Degree of symmetry up/downlink	Data rate	Key performance parameters and target values (BER, delay, others)			Frequency band license status	Type of terminal
DAB	Radio broadcast	Unidirectional (downlink only)	0.6.. 1.5 Mbps (net bit rate)	Depending on targeted coverage area. Typ. BER $<10^{-6}$ or better	Depending on the network size. (< 1 s)	Six levels of program coding	VHF band (Band III) L band	Car and home radio, PDA, PC card, mobile phone
	Data	Unidirectional (downlink only) Needs another system, if interactivity is required				Two levels of channel coding		
DVB-T	TV and radio broadcast	Unidirectional (downlink only)	15 to 32 Mbps (fixed) 5 to 15 Mbps (mobile)	Depending on targeted coverage area. Typ. BER $<10^{-8}$ or better		Trade-off protection data rate	Typical UHF band (Band IV and V)	Set top box, digital TV, PC, PDA
	Data	Unidirectional (downlink only), optionally with backward channel; For better interactive services, a telecom network is required						

Table 7: DAB and DVB-T Technical Characteristics

Conclusion

mission system. That means that alongside traditional radio broadcasting, it may blaze a new trail to emerging multimedia services comprising text, images or data.

Digital Video Broadcast for Terrestial usage (DVB-T)

The DVB-T standard is designed to enable high quality video broadcast services for reception at home or on mobile devices. The vision calls for these systems to replace legacy analog video distribution systems by around 2010. They are able to provide three to eight digital TV programs in a 6-to-8 MHz analog channel. Initially this application area was thought to be separate and independent of telecommunication, but there have been recent efforts to investigate the feasibility of hybrid systems consisting of combinations like DVB-T and GPRS or UMTS. These scenarios are expected to make multimedia services a more viable proposition, particularly in rural areas, than afforded by UMTS alone.

DVB-T operates in licensed frequency bands (130-160 MHz and 430-862 MHz) with a bandwidth of 8 MHz, typically using an OFDM modulation scheme. It offers spectral efficiency of about 1-to-4 bps/Hz [10]. This enables 5-to-30 Mbps effective throughput, contingent upon the given channel's properties (e.g. mobile or stationary reception). This could make it an interesting option for applications requiring high user rates such as general information provisioning, entertainment, or personalized information on demand.

In view of the points made above, for Siemens the ultimate goal in a 3G cellular system is UMTS. There are several good reasons for this choice:

- Forecasts call for GSM/UMTS to gain a market share as great as 77% by 2006, compared with just 18% for cdma2000. This potential is sure to attract various vendors, resulting in a rich feature set. By exploiting economies of scale, they will be able to offer terminals and network equipment at low cost. In fact, GSM/UMTS multi-mode terminals are expected to cost up to 30% less than those for any other technology. Furthermore, worldwide usage will facilitate global roaming.
- Full compatibility with GSM is given within the core network (architecture, protocols, network entities), enabling integrated core networks and services. Investments in GSM are secure, and smooth migration from GSM and overall coverage in dense urban, suburban, and rural areas is assured. In addition, an a-priori ability to add on GERAN is given.
- UMTS has the capacity for both paired and unpaired bands (either with 5 MHz or 1.6 MHz bandwidth) offering various spectrum allocation options. It can handle both symmetric and asymmetric traffic well.
- UMTS's performance and outlook are expected to top those of comparable systems, mainly due to its superior multi-path mitigation capabilities. This engenders excellent capacity and high user data rates (HSDPA).
- Siemens believes that TD-SCDMA, driven by the Chinese market, will become the technology of choice for unpaired bands worldwide.
- With overlay networks, there are no technical barriers to migration from TDMA and/or IS-95/1xRTT to GSM/UMTS.

EDGE is an important stepping stone down the path to this ultimate goal and a cornerstone of the overall strategy. For purposes of introducing UMTS, it benefits operators facing capacity or spectrum constraints as is the case in the Americas. EDGE technology delivers excellent voice performance (AMR) and supports competitive 3G user data services.

cdma2000 is the natural migration path for IS-95 networks. Though worldwide potential may run up a several million subscribers worldwide, ultimately it is not expected to play a significant role. Due to sparsely deployed networks and relatively few terminals, roaming will be difficult and expensive. This is why Siemens is not prepared to commit to it at this time.

Wireless LAN deployments are seen as useful add-ons and opportunities for cellular operators because the technology is cheap and mature. However, they may find it difficult to establish reasonable business cases.

Though it may take place in the coming years, an amalgamation of digital broadcast systems and mobile networks is neither a short-term challenge nor a long-term threat to UMTS. The technologies have different strengths and they complement each other. Digital broadcast systems will be able to provide some multimedia services more efficiently than cellular systems can, but these are the only solutions providing bidirectional, interactive communications services. They are, however, not competitive in terms of TV-like services.

These other wireless standards may be viewed as complements to cellular standards, add-ons that enhance the value of cellular services wherever feasible. *Figure 22* provides an overview of the positioning of all standards discussed herein.

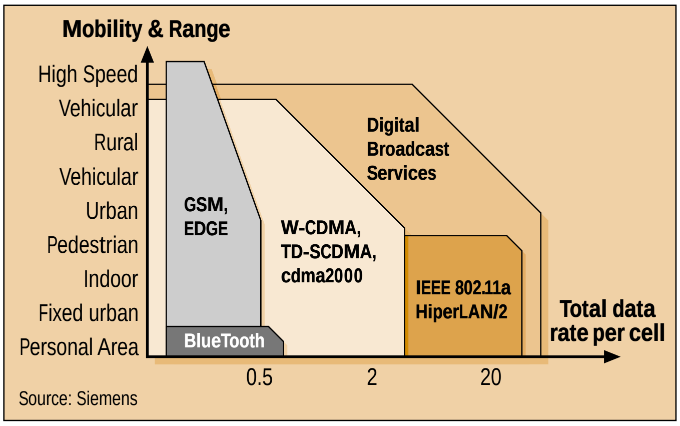

Figure 22: Positioning of wireless standards

Abbreviations and acronyms

2G	(communication system of the) 2nd Generation
3G	(communication system of the) 3rd Generation
3GPP	Third Generation Partnership Project (www.3gpp.org)
8-PSK	8 Phase Shift Keying
AMPS	Advanced Mobile Telephone System
AMR	Adaptive Multirate
ANSI	American National Standards Institute
ARQ	Automatic Repeat reQuest
ATM	Asynchronous Transfer Mode
PBCC	Packet Binary Convolutional Coding
BER	Bit Error Rate
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CAPEX	CAPital Expenditure
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CCK	Complementary Code Keying
CS	Circuit Switched
CSD	Circuit Switched Data
CWTS	China Wireless Telecommunication Standard group
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name Service
E1	2.048 Mbps plesiochronous or synchronous
EDGE	Enhanced Data Rates for Global Evolution (previously: Enhanced Data Rates for GSM Evolution)
ESN	Electronic Serial Number (IS-41)
FR	Full Rate
GAIT	GSM ANSI Interoperability Team
GERAN	GSM/EDGE Radio Access Network
GGRF	GSM Global Roaming Forum
GGSN	Gateway GPRS Support Node
GMSC	Gateway Mobile services Switching Centre
GMSK	Gaussian Minimum Shift Keying
GPS	Global Positioning System
GSM	Global System for Mobile communication
HLR	Home Location Register
H-ARQ	Hybrid ARQ
HR	Half Rate
HSCSD	High Speed Circuit Switched Data
HSDPA	High Speed Downlink Packet Access
HSS	Home Subscription Server
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
ITU	International Telecommunication Union
ITU-T	International Telecommunications Union - Telecommunication sector
IS-41	Interim Standard #41 for signaling
IS-95	Interim Standard #95 for an CDMA radio air interface
IS-136	Interim Standard #136 for an digital radio air interface
ISDN	Integrated Services Digital Network
LAN	Local Area Network
MAP	Mobile Application Part
MIN	Mobile station Identification Number (IS-41)
MSC	Mobile services Switching Centre
Node B	Base station for third generation network
O&M	Operation and Maintenance
OFDM	Orthogonal Frequency Division Multiplex
OPEX	OPeratioal Expenditure
OSI	Open Systems Interconnection (ISO/IEC 7498-4: 1989)
PCM	Pulse Code Modulation
PDH	Plesiochronous Digital Hierarchy
PO	Packet Oriented
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RLAN	Radio LAN
RNC	Third Generation Radio Network Controller
RRM	Radio Resource Management
SDH	Synchronous Digital Hierarchy
SGSN	Serving GPRS Support Node
SONET	Synchronous Optical NETwork
TDD	Time Division Duplex
TD-CDMA	Time DivisionCode Division Multiple Access
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
TSM	TD-SCDMA System for Mobile communication
UMTS	Universal Mobile Telecommunications System
UTRA	UMTS Terrestrial Radio Access
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitors Location Register
W-CDMA	Wideband Code Division Multiple Access

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