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Introduction to UMTS Networks

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Since their inception, mobile communications have become sophisticated and ubiquitous. However, as the popularity of mobile communications surged in the 1990s, Second Generation (2G) mobile cellular systems such as IS-95 and Global System for Mobile (GSM) were unable to meet the growing demand for more network capacity. At the same time, thanks to the Internet boom, users demanded better and faster data communications, which 2G technologies could not support.

Third Generation (3G) mobile systems have evolved and new services have been defined: mobile Internet browsing, e-mail, high-speed data transfer, video telephony, multimedia, video-on-demand, and audio-streaming. These data services had different Quality of Service (QoS) requirements and traffic characteristics in terms of burstiness and required bandwidth. More importantly, the projected traffic for these types of data services was expected to surpass voice traffic soon, marking a transition from the *voice paradigm* to the *data paradigm*. Existing cellular technology urgently needed a redesign to maximize the spectrum efficiency for the mixed traffic of both voice and data services. Another challenge was to provide global roaming and interoperability of different mobile communications across diverse mobile environments.

Toward these ends, the International Telecommunication Union (ITU), the European Telecommunications Standards Institute (ETSI), and other standardization organizations collaborated on the development of the Future Public Land Mobile Telecommunication Systems (FPLMTS). The project was later renamed International Mobile Telecommunications-2000 (IMT-2000). The goal of the project was to achieve convergence of the disparate competing technologies by encouraging collaborative work on one globally compatible system for wireless communications.

Set to operate at a 2 GHz carrier frequency band, the new 3G mobile cellular communication system needed to be backward-compatible with the 2G systems while improving system capacity and supporting both voice and data services. The system was expected

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to support both circuit switched (CS) and packet switched (PS) data services. For the PS domain, the supported data rates were specified for the various mobile environments:

- Indoor or stationary – 2 Mbps
- Urban outdoor and pedestrian – 384 kbps
- Wide area vehicular – 144 kbps

Of the various original proposals, the two that gained significant traction were based on Code Division Multiple Access (CDMA): CDMA2000 1X and Universal Mobile Telecommunication System (UMTS).

- CDMA2000 1X was built as an extension to cdmaOne (IS-95), with enhancements to achieve high data speed and support various 3G services. CDMA2000 1X further evolved to support even higher data rates with a data optimized version: CDMA2000 1xEV-DO [1].
- UMTS was based on the existing GSM communication core network (CN) but opted for a totally new radio access technology in the form of a wideband version of CDMA (Wideband CDMA: WCDMA). The Wideband Code Division Multiple Access (WCDMA) proposal offered two different modes of operation: Frequency Division Duplex (FDD), where Uplink (UL) and Downlink (DL) traffic are carried by different radio channels; and Time Division Duplex (TDD), where the same radio channel is used for UL and DL traffic but at different times. Evolution to support higher data rates was achieved with the recent introduction of High-Speed Downlink Packet Access (HSDPA) [2].

The goal of this book is to address the deployment aspects of the FDD version of the UMTS IMT-2000 proposal – namely WCDMA network planning and optimization. While it is accepted that deploying a WCDMA network requires a thorough knowledge of the standard, this book leaves that to other existing works such as Refs [3] and [4], and concentrates instead on the key aspects necessary to successfully deploy and operate a WCDMA network in a real-world scenario. For newcomers to this technology, however, this chapter describes the basic network topology and underlying concepts associated with the technology.

1.1 UMTS Network Topology

When deploying a WCDMA network, most operators already have an existing 2G network. WCDMA was intended as a technology to evolve GSM network toward 3G services. Paralleling that evolution, this chapter first discusses GSM networks, then highlights the changes that are necessary to migrate to Release 99 of the WCDMA specification. The discussion then moves on to Release 5 of the specification and the network changes needed to support HSDPA.

1.1.1 GSM Network Architecture

Figure 1.1 illustrates a GSM reference network [5], showing both the nodes and the interfaces to support operation in the CS and PS domains.

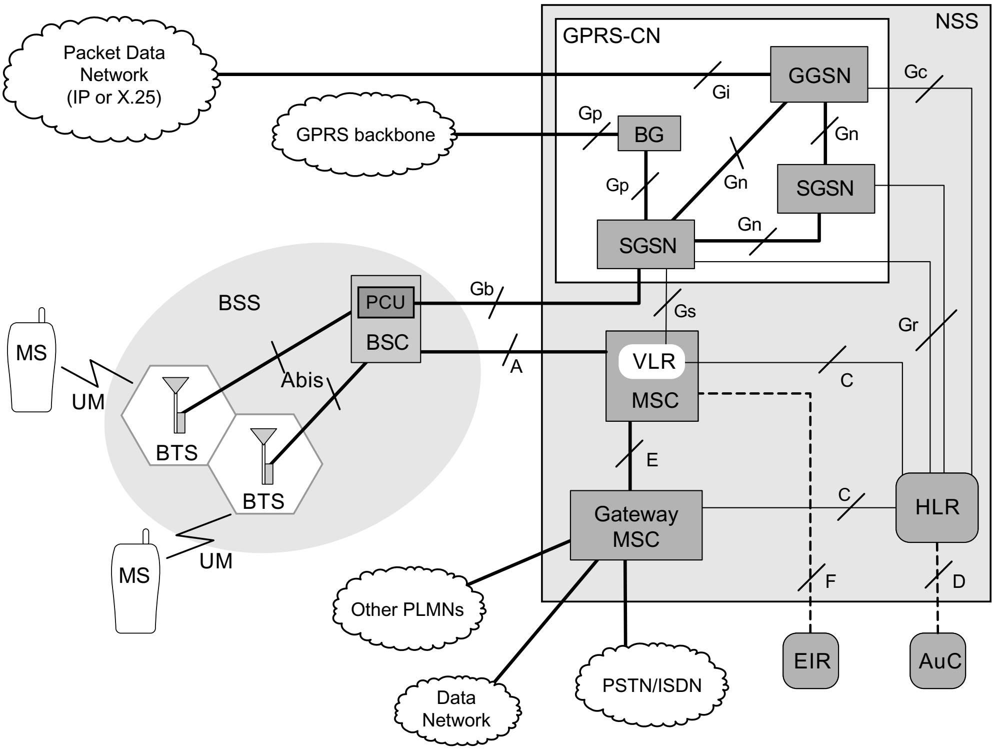

Figure 1.1 GSM reference network

In this reference network, three sub-networks [6] can be defined:

- **Base Station Sub-System (BSS) or GSM/Edge Radio Access Network (GERAN).** This sub-system is mainly composed of the Base Transceiver Station (BTS) and Base Station Controller (BSC), which together control the GSM radio interface – either from an individual link point of view for the BTS, or overall links, including the transfers between links (aka handovers), for the BSC. Although the interface connecting both nodes was intended to be standard, in real-world implementations the BTS–BSC links are closed to competition, particularly in terms of Operation and Maintenance (O&M). When data functionality was added to GSM with the deployment of General Packet Radio Service (GPRS), an additional node was added to the interface between the GPRS-CN and the radio interface, that is the Packet Control Unit (PCU). Interfaces toward the Network and Switching Sub-System (NSS) are limited to A for the CS domain and signaling, and Gb for the PS domain traffic. For simplicity, Figure 1.1 does not show the GSM/Edge Radio Access Network (GERAN). GERAN, a term that was introduced with UMTS, is the sum of all Base Station Sub-System (BSS) within the GSM Public Land Mobile Network (PLMN).
- **Network and Switching Sub-System (NSS).** This sub-system mainly consists of the Mobile Switching Center (MSC) that routes calls to and from the mobile. For management purposes, additional nodes are added to the MSC, either internally or externally.

Their main purpose is to keep track of the subscription data, along with associated rights and privileges, in the Home Location Register (HLR), or to keep track of the subscribers' mobility in the HLR and Visitor Location Register (VLR). Two other nodes manage security issues: the Equipment Identity Register (EIR) verifies the status of the mobile phone (i.e., the hardware), while the Authentication Center (AuC) manages the security associated with the Subscriber Identity Module (SIM). The last node listed in Figure 1.1 is the Gateway-MSC (GMSC). For all practical purposes, the MSC and GMSC are differentiated only by the presence of interfaces to other networks, the Public Switched Telephone Network (PSTN) in the GMSC case. Typically, the MSC and the GMSC are integrated. The interfaces listed (E, F, C, D) are not detailed here but mostly enable the communication between the different nodes as shown.

- **General Packet Radio Service, Core Network (GPRS-CN).** Within the NSS, two specific nodes are introduced for the GPRS operation: the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN). In the PS domain, the SGSN is comparable to the MSC used in the CS domain. Similarly, in the PS domain, the GGSN is comparable to the GMSC used in the CS domain. These nodes rely on existing BSS or NSS nodes, particularly the VLR and HLR, to manage mobility and subscriptions – hence the interfaces to the Gs and Gr interfaces (to the VLR and HLR respectively). Figure 1.1 also shows the Border Gateway (BG) that supports interconnection between different GPRS networks to permit roaming, and the PCU to manage and route GPRS traffic to the BSS.

1.1.2 UMTS Overlay, Release 99

As mentioned earlier, UMTS is based on the GSM reference network and thus shares most nodes of the NSS and General Packet Radio Service, Core Network (GPRS-CN) sub-systems. The BSS or GERAN is maintained in the UMTS reference network as a complement to the new Universal Terrestrial Radio Access Network (UTRAN), which is composed of multiple Radio Network Systems (RNS) as illustrated in Figure 1.2.

Compared to the GSM reference network, the only difference is the introduction of the Radio Network Controller (RNC) and Node Bs within the newly formed RNS. Essentially, these two nodes perform tasks equivalent to the BSC and BTS, respectively, in the GSM architecture. The main difference is that the interface Iu-PS to the PS-CN is now fully integrated within the RNC.

With the addition of these new nodes, a number of new interfaces are defined: Iub is equivalent to the Abis, Iu-CS is equivalent to the A, and Iu-PS is equivalent to the Gb. In addition, the Iur interface (not shown in the figure) is created to support soft handover (HO) between RNCs connecting multiple RNCs within the same UTRAN.

From a practical standpoint, the common nodes between GSM and UMTS would actually be duplicated, with the original nodes supporting the 2G traffic and the added nodes supporting the 3G traffic.

1.1.3 UMTS Network Architecture beyond Release 99

The initial deployments of WCDMA networks comply with Release 99 of the standard [7]. This standard, or family of standards, began to evolve even before being fully implemented, to address the limitations of the initial specifications as well as to include

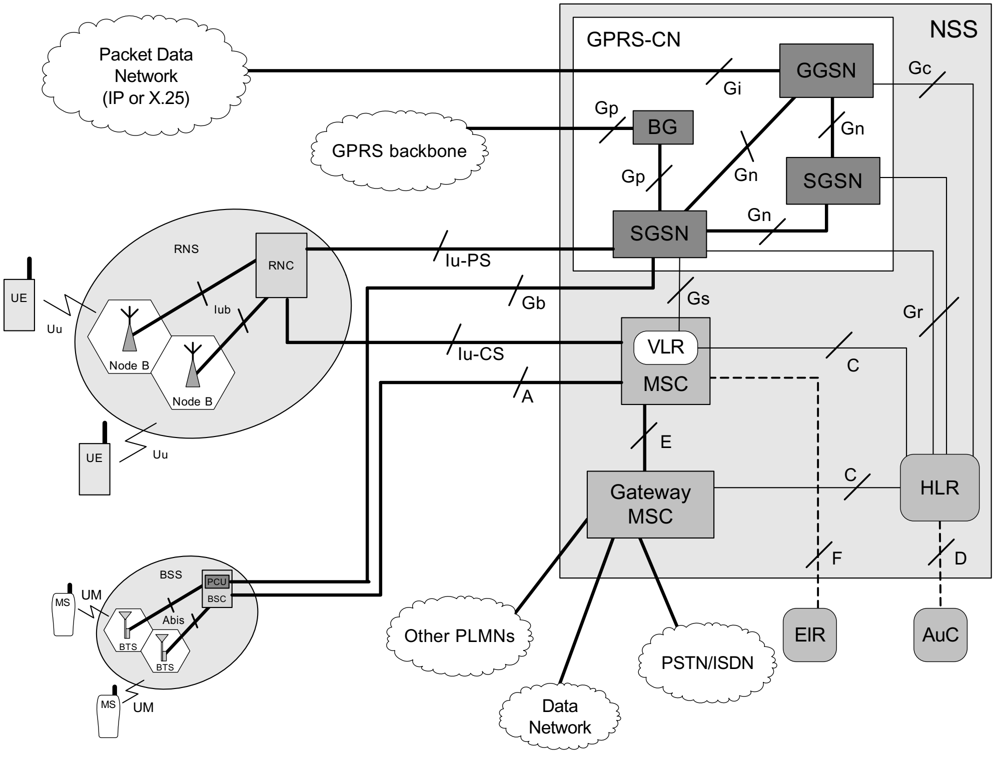

Figure 1.2 UMTS reference network

technical advancements. At a higher level, migrating from Release 99 to Releases 4, 5, and then 6 does not change the structure of the network. However, the details do differ: for example, the transport for the interfaces changes from Asynchronous Transfer Mode (ATM) in Release 99 to all Internet Protocol (IP) in Release 5. In addition, the layering changes in Release 5, to support HSDPA and Node B scheduling (see Section 1.2.2).

1.2 WCDMA Concepts

Figure 1.3 summarizes the physical aspects of the WCDMA air interface, where the flow of information at 3.84 Mega chips per second (Mcps) can be divided into 10 ms radio frames, each further divided into 15 slots of 2560 chips. Here the notion of chips is introduced instead of the more typical bits. Chips are the basic information units in WCDMA. Bits from the different channels are coded by representing each bit by a variable number of chips. What each chip represents depends on the channel.

This section discusses the most fundamental concepts used in WCDMA: channelization and scrambling, channel coding, power control, and handover. The section then defines how the different channels are managed (layers and signaling), and finally defines the channels at the different layers: logical, transport, and physical.

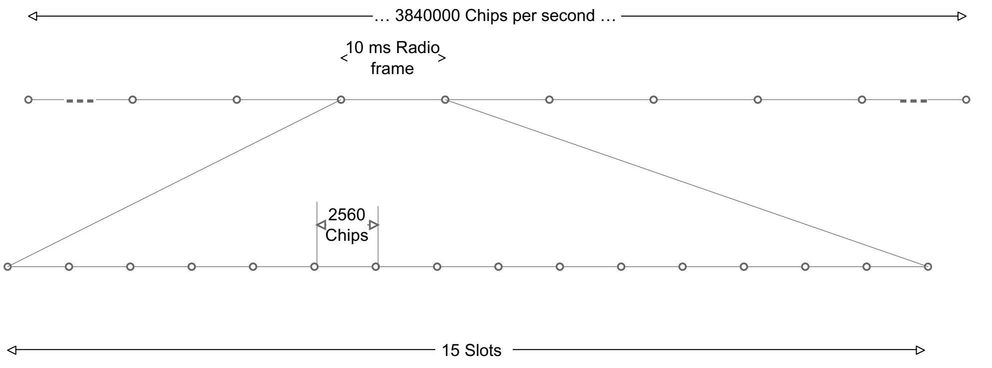

Figure 1.3 WCDMA air interface architecture

1.2.1 WCDMA Physical Layer Procedures

In the selection process for 3G standards, air interface efficiency – which translates to capacity – was one of the main criteria used to assess the different proposals. By that time, significant worldwide deployments of 2G CDMA-based networks had proven the technology's ability to deliver systems with high spectral efficiency. The concepts described in the following sections are vital in any CDMA technology.

1.2.1.1 Power Control

In CDMA technology, power control is critical. It ensures that just enough power is used to close the links, either DL, from the Base Station to the mobile device, or UL, from the mobile to the Base Station. Of the two links, the UL is probably more critical. The UL ensures that all instances of user equipment (UE) are detected at the same power by the cell; thus each UE contributes equally to the overall interference and no single UE will overpower and consequently desensitize the receiver. Without power control, a single UE transmitting at full power close to the Base Station would be the only one detected. All the others would be drowned out by the strong signal of the close user who creates a disproportionate amount of interference.

On the DL, power control serves a slightly different purpose, because the Node B's power must be shared among common channels and the dedicated channels for all active users. On the DL, all channels are orthogonal to each other (with the exception of the Synchronization Channel); thus the signal, or power, from any channel is not seen as interference. Ideally, the other channels do not affect the sensitivity. However, power control is still required to ensure that a given channel is using only the power that it needs. This increases the power available for other users, effectively increasing the capacity of the system.

Conceptually, two steps are required for power control:

- Estimate the minimum acceptable quality.
- Ensure that minimum power is used to maintain this quality.

Outer loop power control handles the first step; inner loop handles the second. Ideally, the outer loop should monitor the Block Error Rate (BLER) of any established channel and compare it to the selected target. If they differ, the quality target, estimated in terms of Signal-to-Interference Ratio (SIR), is adjusted. The closed loop power control can then compare, on a slot-by-slot basis, the measured and target SIR, and send power-up or power-down commands. Power control processes run independently in the UL and DL, each signaling to the other the required adjustment by means of Transmit Power Control (TPC) bits: the DL carries the TPC bits indicating the UL quality, while the UL carries the TPC bits indicating the DL quality.

On the basis of the frame and slot structure (10 ms radio frames consisting of 15 slots each), we can deduce that the TPC bits are sent at 1500 Hz, which is the rate of the inner loop. The outer loop, on the other hand, is not as strictly controlled by the standard and is thus implementation-dependent: neither its rate nor the step sizes are signaled to the other end. Moreover, although the purpose of the closed loop is to ensure that the BLER target is met, the implementation may be based on other measurements such as SIR, or passing or failing the Cyclic Redundancy Check (CRC).

1.2.1.2 Soft Handover

Soft handover refers to the process that allows a connection to be served simultaneously by several cells, adding and dropping them as needed. This feature is possible in WCDMA because all cells use the same frequency and are separated only by codes: a single receiver can detect the different cells solely by processing, with a single Radio Frequency (RF) chain. The need for soft handover in a WCDMA system is intertwined with the power control feature. Supporting soft handover ensures that a UE at the boundary among several cells uses the minimum transmit power on either link. On the UL, it is necessary to avoid overpowering the other UEs connected to the cell. On the DL, it is not as critical, but is a good practice because it maximizes capacity and increases link reliability. Once soft handover is enabled in a system, meaning that a UE must monitor and use the best possible link, additional benefits can ensue:

- On the DL, the UE can combine the different received signals to increase the reliability of demodulation. By combining the signals from different links, the effective SIR increases, which reduces the transmit power even when compared to the power required over the best link only. This is termed *soft combining gain*. In addition, the fact that the UE can be connected to multiple servers at once increases link reliability and thus provides a diversity gain, typically called *macro-diversity gain*.
- On the UL, if macro-diversity gain is observed, the same is not always true for the soft combining gain. If the cells in soft handover do not belong to the same Node B, it is not possible to combine the signals before they are demodulated. Instead, all the demodulated frames are sent to the RNC, which decides which one to use. This process still provides a gain compared to a single link, since it increases the probability of having at least one link without error. This is the selection gain, also a macro-diversity gain.

As we have seen, soft handover offers advantages: it increases the reliability of transmission and reduces the power requirement for each link used. Unfortunately, soft handover has drawbacks, too. Since information must be sent over multiple links, that repetition decreases the efficiency of resource utilization. As subsequent chapters (mainly Chapter 4) will show, balancing handover gains with resource utilization is a delicate process, controlled by multiple parameters. Clearly, the optimal balance is achieved only when the links that contribute significantly to the transmission quality are included in the Active Set.

1.2.1.3 Spreading, Scrambling, and Channelization

Soft handover is possible in a WCDMA system because all the cells of the Node Bs transmit using the same frequency. This universal frequency reuse – or 1 to 1 frequency reuse in Time Division Multiple Access (TDMA)/Frequency Division Multiple Access (FDMA) terminology – requires several codes to differentiate between cells and users. These codes must be introduced on both the UL and the DL, since the constraints on each link are different.

On the DL, the first requirement is to differentiate among different cells. In the TDMA/FDMA world, this is achieved by using a different frequency for each cell. In the WCDMA world, cells are discriminated by using Primary Scrambling Codes (PSCs). To understand how they work, imagine a coded message. When viewed, the coded message is perceived only as random letters – or *noise* in radio terminology. Only a reader using the proper ciphering key – or PSC in WCDMA terminology – can make words out of the random letters. These words can be further assembled into sentences, either on a single subject or on different topics. The topics can be compared to different channels for which proper rules must be defined: these rules would correspond to the different channeling codes that allow the decoded words to be assembled into sentences. Just as only a limited set of rules makes up a language to ensure that everybody understands it, only a limited number of channelization codes are used to simplify the implementation.

To extend the analogy, several words in a sentence typically express a single idea; this is the same principle as spreading, where several chips represent one bit. Just as in a language, where losing a single word does not prevent comprehending the idea, losing the exact value of a chip does not compromise the demodulation of the corresponding bit. In the WCDMA world, spreading, or conveying a single bit over multiple chips, is done at the channel level, before the PSC ciphers the entire message. Multiplying a signal with a PSC does not achieve spreading, it only randomizes the signal, as illustrated in Figure 1.4(a).

Within the cell, the different channels are separated by their own set of rules, the Orthogonal Variable Spreading Factor (OVSF). The OVSF handles the signal spreading, as illustrated in Figure 1.4(b). OVSF has two main characteristics: an orthogonality property, and the fact that the orthogonality is conserved between OVSFs of variable lengths.

- The OVSF orthogonality property ensures that different users of the same cell do not interfere with each other. If a signal coded with a given OVSF is decoded with a different OVSF, the resulting signal gives an equal number of 1s (-1) and 0s ($+1$). The result is an average null signal.
- The variable aspect of OVSF supports different data rates from the same code tree: low data rates can be coded with long OVSFs, while high data rates are coded with

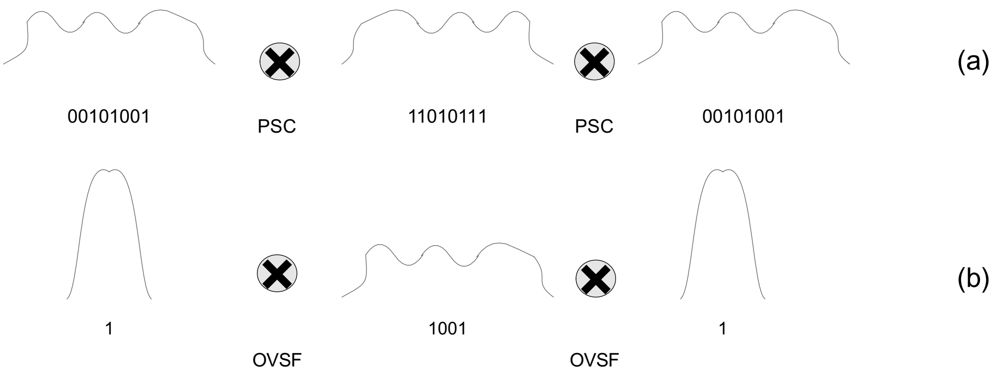

Figure 1.4 PSC and OVSF

short OVSFs. The length of the OVSF refers to the number of chips for a single input bit: a bit coded with OVSF length 256 would be represented by 256 chips, while a bit coded with OVSF length 4 would be represented by four chips. Using a long OVSF has the advantage of adding redundancy to the transmitted information. The impact of this redundancy is seen in the spreading gain, that is, the ratio of user bits to transmitted chips.

In combination, and with only a limited number of codes, PSC and OVSF can distinguish between cells and users. Without the PSC, the receiver cannot reconstruct the words sent by the different cells. Once the words are reconstructed, the same set of rules OVSF can be reused to understand (demodulate) the messages.

1.2.1.4 Channel Coding

The Physical Layer procedures described in Section 1.2.1.1 through Section 1.2.1.3 are required for efficient implementation of WCDMA. In addition to these mandatory procedures, channel coding further protects against transmission errors caused by repeating information multiple times, and spreading the retransmissions over time.

For channel coding, either convolutional or turbo coders can be used. Convolutional coders primarily apply to delay-sensitive information, since the resulting delay is relatively short and affected by the code rate and constraint length. Turbo coders, on the other hand, must consider a block of data before outputting the block. For turbo coding to be efficient, the block should contain a large amount of data, usually more than 320 symbols, thus causing significant delay in the coding and decoding processes.

1.2.2 UMTS Signaling Concepts

To understand signaling – or more generally the exchange of data – in WCDMA, it is important to understand layering and its relationship to the various nodes, for both the control plane (signaling) and the user plane (user data). As will be demonstrated in the following sections, WCDMA offers a highly structured protocol stack with clear delineation between the functions of each entity.

1.2.2.1 Layering Concepts

From an overall network point of view, the first distinction that can be made is between the radio access functions (Access Stratum, or AS) and the CN functions (Non-Access Stratum, or NAS). For WCDMA and GSM the Non-Access Stratum (NAS) is similar, so we will not discuss it further. The second distinction is between the control or signaling plane (control data) and the user plane (user data). For the control plane, all layers terminate at the operators' controlled nodes; for the user plane, the top layer ensures the user-to-user connection. Figure 1.5 illustrates these concepts as they apply to the CS domain.

WCDMA-specific processing occurs at the Access Stratum (AS) on the three lower layers, which are similar in both planes:

- **Radio Link Control (RLC).** Sets up the delivery mechanism ensuring that the data sent is received at the distant end.
- **Medium Access Control (MAC).** Permits multiple information flows to be sent over a single physical channel.
- **Physical Layer (Layer 1).** Transmits the combined information flow over the WCDMA air interface (Uu).

For each layer, different channels are defined and mapped onto one another: logical channels are associated with Radio Link Control (RLC), transport channels with Medium Access Control (MAC), and physical channels with Physical Layers.

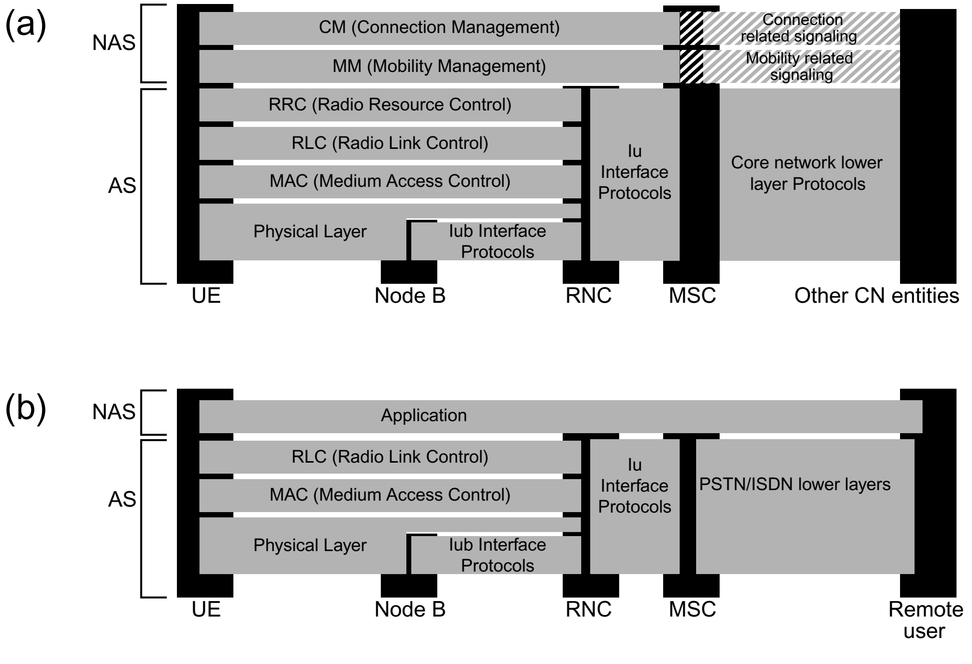

Figure 1.5 Control plane (a) and user plane (b) layering in the CS domain

In Figure 1.5, note that the AS Physical Layer is not entirely contained within the Node B. Outer loop power control and frame selection occur at the RNC, even though they are Physical Layer processes. This shows that in the UTRAN, the RNC is a critical node. In addition to some of the Physical Layer processing, the RNC is responsible for link supervision (RLC) and any multiplexing/assembly (MAC) for the channels.

At the RLC level, the link supervision is done in one of three modes: Transparent Mode (TM), Acknowledged Mode (AM), or Unacknowledged Mode (UM). The appropriate mode depends on the time constraints and error tolerance of the information:

- **TM.** Typically used for the user payload for speech services. For speech, delivery of vocoder packets at a constant rate is more important than error-free transmission; the vocoder can conceal errors if they are below a few percent, typically 1 or 2%. In TM, RLC does not verify the packets only passes them to the higher layers. In the worst case, retransmission can be achieved at the application layer when the user requests "can you repeat please."
- **AM.** Used when information must be sent error-free. Each packet is given a sequence number to be individually acknowledged and delivered in sequence to higher layers. A typical application is e-mail messages, where the content is more important than any latency in delivery.
- **UM.** Used for applications that must receive packets in order, but are neither delay- nor error-constrained. Examples are media streaming and some types of signaling. UM is appropriate for packets that may be processed at the RLC layer, but for which no retransmission is requested if errors are detected. For UM packets, processing is usually limited to reordering, ciphering, or segmentation/concatenation.

In the PS domain the structure is similar for the control plane with the exception of the terminating nodes, as shown in Figure 1.6.

The PS user plane (Figure 1.6(b)) shows more pronounced differences from the CS user plane, with an added layer in both the AS and NAS. The Packet Data Convergence Protocol (PDCP) on the AS is mainly used for header compression, to transfer TCP/IP packets more efficiently over-the-air interface. The Packet Data Protocol (PDP) on the NAS creates and manages the associated variables for the packet data sessions. For example, when an IP session is required, the IP addresses that identify the UE for a session are assigned at that layer.

As systems evolve and incorporate HSDPA, the PS domain layering will change, as shown in Figure 1.7. To speed up Physical Layer processing, the entire Layer 1 terminates at the Node B. The drawback is that the MAC layer must extend to the Node B, with the introduction of a specific MAC entity dedicated to high speed data; the MAC-hs.

Note that Figure 1.7 does not show the control plane; this is because HSDPA supports the user plane only. The control plane is maintained in the PS domain, Release 99 architecture.

In addition to the three basic layers used in all domains (packet/PS or circuit/CS) and all planes (user data/user plane or signaling data/control plane), a layer is defined in the control plane that defines the messages exchanged between the RNC and the UE: the Radio Resource Control (RRC). The RRC defines the messages exchanged between the RNC and the UE, which initiate connection set-up, tear down, or reconfiguration.

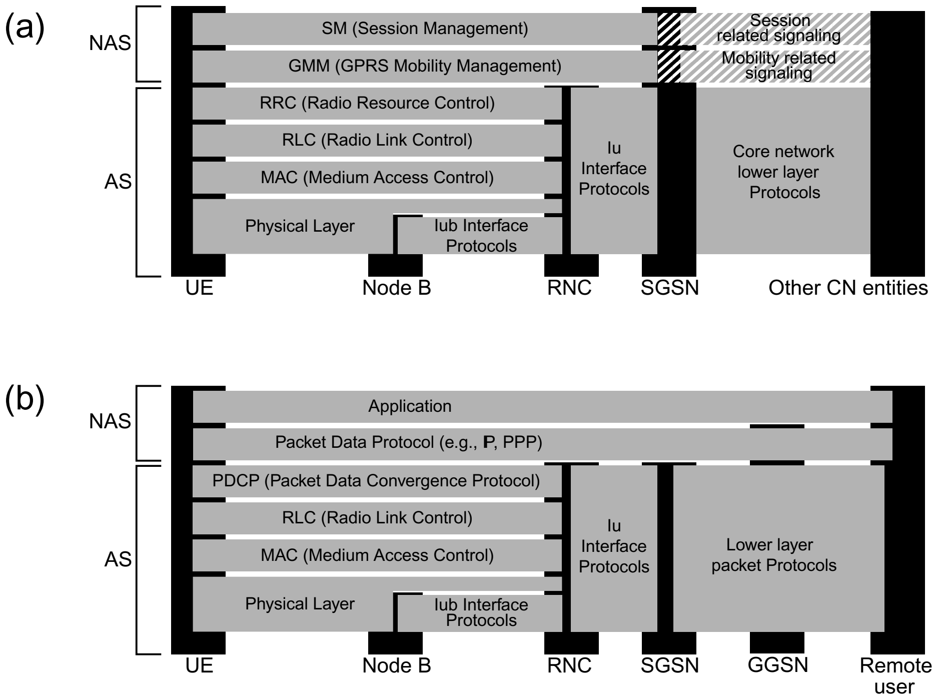

Figure 1.6 Control plane (a) and user plane (b) layering in the PS domain

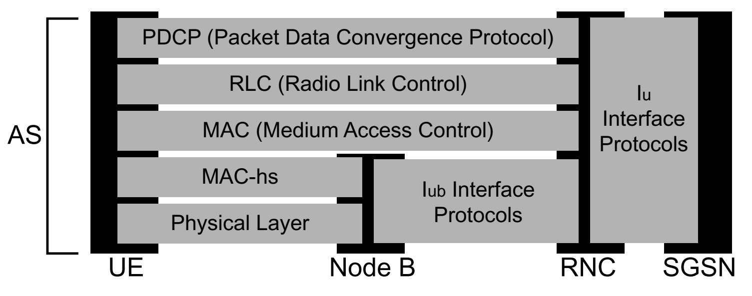

Figure 1.7 User plane layering in the PS domain, HSDPA architecture

All the call flow examples in later chapters (Chapters 5 and 6) of this book are based on RRC messaging [8], which is exchanged between the UE and the RNC over the Signaling Radio Bearers (SRB).

Prior to any message exchanges, the SRBs must be established during the RRC connection setup procedure. Depending on vendor implementation, three or four SRBs are established and mapped onto a single Dedicated Channel (DCH) by MAC.

1.2.3 Physical, Logical, and Transport Channels

Section 1.2.2 introduced the concept of mapping logical channels onto physical channels. Figure 1.8 shows the different channels for Release 99 and HSDPA operation, along with

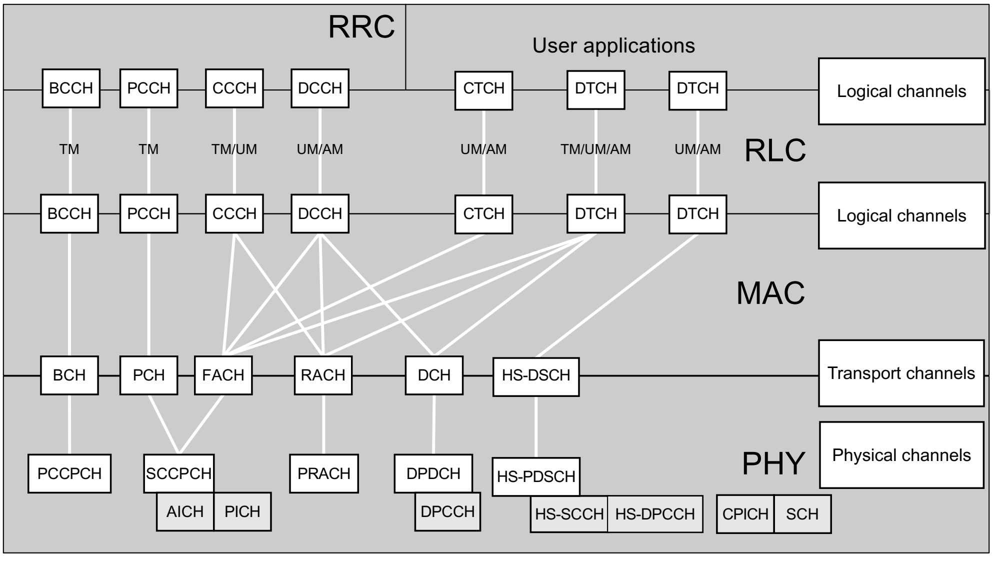

Figure 1.8 Physical and transport channels with their relation to the ISO model

how they map between different layers. At the Physical Layer, some of the channels, for example Synchronization Channel (SCH) and Common Pilot Channel (CPICH), are not mapped onto any transport channels. This is because these channels only support Physical Layer procedures; no actual data from higher layers is transmitted over them.

During optimization, it is important to understand which processes are associated with each type of channel. Physical channels are associated with all the coding and closed loop power control processes. Transport channels are associated with some of the critical channel measurements, such as BLER or SIR targets, since these values are set per transport channel.

Other physical channels are used for physical procedures or scheduling but do not directly map onto transport channels; however, they do carry information related to these physical procedures. Channels in this group include the Acquisition Indicator Channel (AICH), Paging Indicator Channel (PICH), Dedicated Physical Control Channel (DPCCH), High-Speed Shared Control Channel (HS-SCCH), and High-Speed Dedicated Physical Control Channel (HS-DPCCH). For example, the DPCCH is a channel that does not carry any user or signaling information but contains information to help the receiver decode the information carried by the Dedicated Physical Data Channel (DPDCH). Complete function details for all of these channels can be found in Ref [9] and [3].

Table 1.1 lists the channels shown in Figure 1.8, along with their main uses.

In addition to showing the logical, transport, and physical channels, Figure 1.8 also shows the mappings between them, along with the RLC mode typically used for these channels. Instead of describing all possible mappings, the following discussion analyzes one example, where signaling and user speech payload are transmitted over a single DL physical channel. Figure 1.9 illustrates the example.

In this example, a single physical channel carries seven logical channels: four for signaling and three for voice [10]. The information, coding, and transport block sizes are

Table 1.1 List of WCDMA channels

	Channel name	Description
BCCH	Broadcast Control Channel	*Logical channel* that sends System Information Block (SIB)
BCH	Broadcast Channel	*Transport channel* carrying the BCCH
PCCPCH	Primary Common Control Physical Channel	*Physical channel* carrying the BCH
PCCH	Paging Control Channel	*Logical channel* carrying the pages to the UE
PCH	Paging Channel	*Transport channel* carrying the PCCH
CCCH	Common Control Channel	*Logical channel* carrying the common signaling, e.g., RRC Connection Setup message
FACH	Forward Access Channel	*Transport channel* carrying common and dedicated control channel as well as user payload in certain connected states (Cell_FACH)
SCCPCH	Secondary Common Control Physical Channel	*Physical channel* carrying the PCH and FACH channels
AICH	Acquisition Indicator Channel	*Physical channel* used by the cell to ACK the reception of RACH preambles
PICH	Paging Indicator Channel	*Physical channel* used by the cell to inform a group of UEs that a page message can be addressed to them
DCCH	Dedicated Control Channel	*Logical channel* used to carry dedicated Layer 3 (RRC) signaling to the UE
RACH	Random Access Channel	*Transport channel* used by the UE to carry signaling or user payload
PRACH	Physical RACH	*Physical channel* used to carry the RACH
CTCH	Common Traffic Channel	*Logical channel* used to carry common payload, e.g., broadcast or multicast services
DTCH	Dedicated Traffic Channel	*Logical channel* used to carry user payload
DCH	Dedicated Channel	*Transport channel* used to carry dedicated signaling (DCCH) or payload (DTCH)
DPDCH	Dedicated Physical Data Channel	*Physical channel* used to carry the DCH
DPCCH	Dedicated Physical Control Channel	*Physical channel* used for carrying information related to physical layer operation, e.g., dedicated pilot or power control bits
HS-DSCH	High-Speed Downlink Shared Channel	*Transport channel* used for carrying user payload. Unlike the DCH, only user payload is carried over the HS-DSCH; no signaling (DCCH) is carried by HS-DSCH
HS-PDSCH	High-Speed Physical Downlink Shared Channel	*Physical channel* used for carrying the HS-DSCH

Table 1.1 (*continued*)

	Channel name	Description
HS-SCCH	High-Speed Shared Control Channel	*Physical channel* used for carrying HS specific control information, e.g., modulation, Transport Block Size (TBS), or HARQ related information
HS-DPCCH	High-Speed Dedicated Physical Control Channel	*Physical Uplink channel* used by the UE to carry Channel Quality Indicator (CQI) and Acknowledgment information
CPICH	Common Pilot Channel	*Physical channel* used for cell identification and channel estimation
SCH	Synchronization Channel	*Physical channel* used by the UE to detect the presence of WCDMA carrier (Primary SCH: P-SCH) and synchronize with radio frame boundary (Secondary SCH: S-SCH)

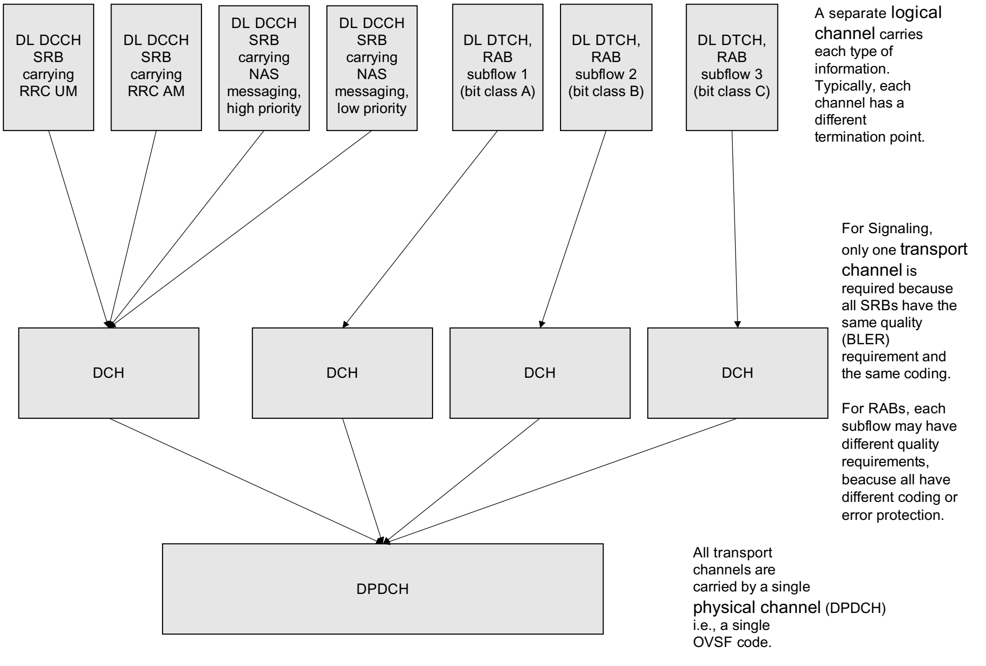

Figure 1.9 Mapping of logical to transport to physical channels for speech and signaling

all uniquely defined [10] and summarized in Table 1.2. The different SRBs and Radio Access Bearers (RABs) are each associated with an RLC entity. RLC also defines the size of the packet exchanged with the higher layer's Packet Data Unit (PDU). Headers can be added to the information if any multiplexing will be performed at the MAC level, or to verify the delivery of the packet. For speech, the user payload does not include

Table 1.2 Main channel characteristics for Speech + SRB example

Higher layer		RAB subflow #1	RAB subflow #2	RAB subflow #3	SRB #1 RRC	SRB #2 RRC	SRB #3 NAS	SRB #4 NAS
RLC	Logical channel type	DTCH			DCCH			
	RLC mode	TM	TM	TM	UM	AM	AM	AM
	Payload sizes, bit	39, 81	103	60	136	128	128	128
	Max data rate, bps	12200			3400	3200	3200	3200
	TrD PDU header, bit	0			8	16	16	16
MAC	MAC header, bit	0			4	4	4	4
	MAC multiplexing	N/A			Four logical channel multiplexing			
Layer 1	TrCH type	DCH	DCH	DCH	DCH			
	TB sizes, bit	39, 81	103	60	148			
	TFS TF0, bits	0 × 81	0 × 103	0 × 60	0 × 148			
	TF1, bits	1 × 39	1 × 103	1 × 60	1 × 148			
	TF2, bits	1 × 81	N/A	N/A	N/A			
	TTI, ms	20	20	20	40			
	Coding type	CC 1/3	CC 1/3	CC 1/2	CC 1/3			
	CRC, bit	12	N/A	N/A	16			
	Max number of bits/TTI after channel coding	303	333	136	516			
	RM attribute	180–220	170–210	215–256	155–230			
TFCS	TFCS size	6						
	TFCS	(RAB subflow #1, RAB subflow #2, RAB subflow #3, DCCH) = (TF0, TF0, TF0, TF0), (TF1, TF0, TF0, TF0), (TF2, TF1, TF1, TF0), (TF0, TF0, TF0, TF1), (TF1, TF0, TF0, TF01), (TF2, TF1, TF1, TF1)						
DPCH Downlink	Spreading Factor	128						
	Format	8 [9]						

Bits/slot	DPDCH Bits/slot		DPCCH Bits/slot			Transmitted slots per radio frame N_{Tr}
	Ndata1	Ndata2	Ntpc	NTFCI	Npilot	
40	6	28	2	0	4	15

such headers because TM is used and no MAC multiplexing is performed, although it is necessary for the signaling aspects.

At the Transport Channel level, the payload plus any necessary headers are put into transport blocks for which both a size and a Transmission Time Interval (TTI) are defined. For all the voice subflows, the TTI is 20 ms, or two radio frames, consistent with the frequency at which the vocoder generates packets. Alternatively for the SRBs, the payload is spread over four radio frames, with a TTI of 40 ms. For higher-speed data rate RAB, the basic payload size is at the most 320 bits (in Release 99), while the TTI is usually 10 to 20 ms and multiple blocks (RLC PDU) are transferred during each TTI.

The number of channels in this example and the fact that their multiplexing does not follow a predetermined pattern leads us to the concept of the Transport Format Combination Set (TFCS). The TFCS determines how the blocks corresponding to the different DCH channels are combined on the Physical Channel. In this example, not all combinations are allowed; only six are permitted, as per the standard. During the setup of the radio bearer (i.e., the Physical Channel) the possible TFCSs are signaled to the UE as a table. Within each radio frame, the Transport Format Combination Indicator (TFCI) signals an index pointing to that table. From this, the UE can reconstruct the DCH channels received. In the example (as compared to Table 1.2), slot format 8 does not reserve any bits for TFCI. In this case, the UE guesses which format was used, using a process called *blind detection* [11].

1.3 WCDMA Network Deployment Options

GSM networks boast an advanced network architecture, where macrocells, microcells, and indoor cells all interact. This flexibility is enhanced by the many available GSM network products, from a macro BTS handling a dozen transceiver modules (TRXs) per sector, to a pico BTS handling only a few TRX over a single sector.

Similarly, since WCDMA was designed to interact closely with the deployed GSM network, it will follow the GSM trend in terms of ubiquity and deployment options. From practical and economic points of view, WCDMA deployments are not initially justified outside the high-traffic areas, typically the city centers. This section discusses the main WCDMA deployment options and presents their relative advantages and shortcomings. All of the options assume that at least two carriers are available for deployment. If this is not the case, then deploying multiple layers – micro, macro, or indoor – greatly affects capacity, as Chapter 3 illustrates.

1.3.1 1 : 1 Overlay with GSM, Macro Network

A 1 : 1 overlay of WCDMA onto a GSM network has so far been one of the most popular deployment options, although not necessarily the best one. The main advantage that explains its popularity is that this approach largely simplifies the site acquisition process; the only acquisition needed is an additional antenna position within the existing structure. This option is sometimes further simplified, from a site acquisition point of view, by replacing the existing antenna with a multiband or wideband antenna. In this case, the design and optimization options for the WCDMA network are quite limited, thus leading to suboptimal performance.

This situation applies to any site reuse between GSM and WCDMA. From a network-planning standpoint, technical differences in the air interface between the two networks make it difficult to share sites. Key differences include coverage, mainly due to WCDMAs higher frequency band, and capacity, mainly because of WCDMAs improved spectral efficiency. Furthermore, the universal frequency reuse in WCDMA makes it difficult to deploy Hierarchical Cell Structure (HCS) in WCDMA networks, whereas it is widely used in GSM.

In GSM, using HCS is beneficial because large cells (with tall antennas) can provide coverage, while small cells (with low or medium height antennas) can provide capacity. With the 1 : 1 frequency reuse of WCDMA, deploying HCS would allow a UE to reselect the most appropriate layer; however, in Connected Mode, the UE would be in constant handover between the layers, or, if parameters are set to prevent handover, the resulting intercell interference would decrease the capacity advantage. Chapter 3 explores this in greater detail.

As a result, a WCDMA overlay onto a GSM network is usually not 1 : 1, but would exclude the tallest sites of the network as well as the microcells, at least initially. Also, initially the overlay is not made over the entire GSM coverage area but only where the capacity requirements are the highest. Two issues usually determine this choice: economics and coverage. These may be linked to some extent. From a coverage perspective, the initial WCDMA deployment occurs at 2100 MHz (1900 MHz in North America) while GSM is widely deployed at 900 MHz (850 MHz in North America). This gives GSM a 10 to 15 dB Link Budget advantage in terms of RF propagation. This can translate to a site count for WCDMA, for coverage only, of four to seven times the GSM site count. This offsets any economic justification for deploying WCDMA in rural areas, where coverage requirements are high but capacity needs are low. Because of this limitation, planners may rely on GSM coverage outside of urban centers. Unfortunately, the mechanism for inter-system transition, even if simple in principle, requires careful planning and optimization. To facilitate that, Chapter 6 discusses inter-system transitions in detail.

1.3.2 1 : 1 Overlay with GSM, Macro, Micro, and In-Building

The preceding discussion about applying a WCDMA overlay to a macro network could easily apply to all layers, if micro and pico Node Bs are available. In the early years of WCDMA growth, only macro Node Bs were available but that situation is rapidly changing.

To introduce a micro or indoor layer, it is necessary to have multiple carriers available. In this case, the macro layer operates on one carrier, while the micro and indoor layers operate on a separate one. This better isolates the layers, providing significant advantages in terms of resource utilization. The drawback, of course, is that managing mobility between layers – via cell reselection or handover – becomes more complex (see Chapter 6).

Not only is mobility management more complex but a 1 : 1 overlay with GSM may also use the available capacity inefficiently. In GSM, the spectrum – and hence the capacity – can be allocated in 200 KHz increments. But in WCDMA, increments are fixed at 5 MHz, which for most operators represents 33 to 50% of the available spectrum. For this reason, operators might decide to deploy the micro or indoor layers on the same carrier. However, they must then consider the spatial isolation between layers, which could affect capacity. Chapter 3 explores this issue.

1.3.3 WCDMA-Specific Network Plan

Another option for overcoming the limitations found in GSM overlay deployments is to create a network plan specifically for WCDMA. Here, one does not rely on GSM site locations but only on the expected WCDMA traffic and coverage requirements. As long as coverage and capacity issues (see Chapters 2 and 3, respectively) and indoor issues (see Chapter 8) are properly handled, a WCDMA-specific deployment results in a network that is easier to optimize. Unfortunately, because of the ever-greater obstacles to site acquisition, this option is only partially achievable. One possible solution is to start with a WCDMA-specific plan, then select the sites from an existing GSM site portfolio when they fulfill the coverage and capacity objectives for the WCDMA network.

1.4 The Effects of Vendor Implementation

In any WCDMA deployment scenario, vendor-specific implementation plays an important role, especially during network optimization. In spite of its 28 volumes containing hundreds of specifications, the Release 99 standard [12] does not cover every detail. As a result, vendors have a great deal of freedom to implement these details differently, to differentiate themselves from competitors.

Vendor implementation affects several areas of network deployments:

- **Node availability.** As mentioned earlier, micro, pico, or other flexible coverage solutions are only beginning to become available in the market. Eventually, all vendors will offer multiple Node Bs for different applications, but today the choice is limited. Vendor-specific implementations of RNC scalability are important for consideration. For example, an RNC with limited backhaul connectivity should have ample Iur connectivity and capacity to ensure that soft handovers can be supported across the RNCs.
- **Hardware architecture.** This is another area that will continue to evolve in the next few years. From a deployment point of view, the architecture itself is not critical but network planners should evaluate the performance associated with the architecture, as well as its expandability. The expandability should be considered as a two-dimensional space, where features and supported nodes are the axes. The importance of feature expandability is already an issue with High-Speed DL Packet Access (HSDPA; see Chapter 7), and High-Speed UL Packet Access, which is being finalized and deployed while Release 99 networks are still being rolled out. This continuous rollout – together with the standardization of WCDMA in different frequency bands, and node availability – also emphasizes the importance of expandability.
- **Performance.** This is only guaranteed by the standard to a limited extent. The standard mainly defines RF performance; however, there are other performance aspects to be considered. From a user's point of view, processing speed performance is at least as critical as RF performance. Even in lightly loaded networks, the processing speed for signaling can affect user performance. An example is how Measurement Report Messages (MRMs) are processed: an architecture that queues the MRMs instead of processing them in parallel is likely to retain obsolete members in the Active Set. When setting up parameters (see Chapter 4), optimization engineers must weigh such performance issues and their trade-offs.
- **Parameter settings.** This also is limited to a large extent by the architecture performance. To simplify initial implementation, most parameters can be set only at the RNC level, even if cell-level or area-level setting might eventually be required. But eventually, as in other maturing systems, such as GSM or CDMA2000 1X, the whole range

of standard parameters will be set at the Node B or cell level. This affects the workload of optimization engineers, since the number of parameters must then be multiplied by the number of possible permutations. Understanding the parameters in detail is so important that this book devotes an entire chapter to that subject; see Chapter 4.

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