2

CDMA AIR INTERFACE OVERVIEW

2.1 Cellular Wireless Communications

Objectives - The cellular wireless communications emerged as an answer to a need for a fully mobile telephone service. The service objectives are *mobility*, *full duplex voice*, *ubiquity* – service everywhere and all the time, and *capacity* - multiple independent sessions within the same area. *Grade of service* (GoS) is measured by the availability of call access and uninterrupted session continuation, and *quality of service* (QoS) – by the quality of the voice, where comparison is made to the voice quality of the line telephone.

Architecture - The cellular wireless is composed of multiple *star networks*, each covering a limited area ("cell") where communication is conducted between users within that area and the hub ("base station"). The latter administers the sessions ("calls") and interconnects calls to users in other cells or in the wired telephone system via backhaul conduits and switching centers. The part of the base station incorporating the transmission is called *BTS – Base Transceiver Substation*. The *BSC, Base Station Controller*, handles the call administration. One BSC may control several BSCs.

Deployment - The coverage area of each cell is measured by the sufficiency of the link budget between the base station and the user, and its dominance over interference from other users in the same cell and in other cells. The process of detaching the link from one base station and establishing the link with another ("handoff") when a user moves from the coverage of one cell to another is automatic and transparent to the ongoing call.

Spectral band and efficiency - The wireless cellular architecture was conceived over 50 years ago but its first commercial deployment took place in the early 80s, with the availability of the enabling technologies. Relevant frequency range for this service, aiming at Non Line Of Sight (NLOS) coverage, but at the same time limited range to allow for reuse of the same frequency band in adjacent cells, ranges from decimeter wavelength (450 to 1000 MHz) for open areas, to centimeter wavelength (1000 to 2500 MHz) for urban and indoors environments. Regulatory limitations on the frequency bandwidth allocated to the service, mainly based on priority allocation to other services (TV, military), has been a major challenge in the evolution of the wireless cellular technology. Spectral efficiency is a key parameter in the economy and scope of the service.

Duplex - FDD (Frequency-division duplex) is used in the cellular systems: transmissions from the base station to the user (*forward link* – FL, or *down link*) are separated from those from the user to the base station (*reverse link* – RL, or *uplink*) by a preassigned gap (45 MHz in the 850 MHz bands and the 900 MHz bands, 80 MHz in the 1800 and 1900 MHz bands, 90 MHz in Korean bands).

Multiple access - The first generation was based on analog modulation and filtering FDMA (Frequency-division multiple access) whereby calls in each cell were separated by frequency allocations of channels – 30 KHz in the US system AMPS. A guard zone is required beyond the coverage to avoid interference to other cells, which leads to reuse of the same channels only once in every 12 cells. The split of the circular (omnidirectional) cell to 3 directional sectors, by use of directional antennas, increases the isolation between cells thus achieving a reuse of 1/7.

The second generation, introduced in the early 90s, leverages on digital modulation and processing to increase the spectral efficiency and introduce new data services. The US TDMA (Time-division multiple Access) triples the capacity by time multiplexing 3 calls in each channel. It is an evolutionary standard into the same 30 KHz allocations. GSM, which has been allocated a virgin frequency band in Europe, opts for 8 time slots in a channel of 200 KHz, with respective reuse of 1/4. Frequency hopping techniques further increase the reuse.

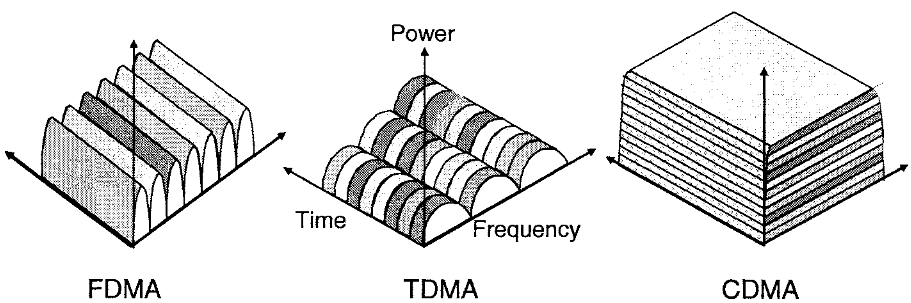


Figure 2-1. Multiple access schemes

CDMA (Code-division multiple access) was first proposed to the cellular service in 1989, and commercially introduced in the mid 90s. The system utilizes direct sequence spread spectrum technology to differentiate the user's channels by codes rather than by frequency filtering and time gating, thereby allowing for multiple access on the same channel throughout the network, with a reuse of 1. The channel bandwidth 1.25 MHz was chosen for multiple reasons: a) taking an evolutional strategy into the AMPS frequency allocation in the US, where 1.25 MHz captures 10% of the band allocated to each operator while doubling its capacity; b) technology maturity of digitizers and processors; and c) optimizing the time resolution (and then the number of delay-searching correlators – "fingers") to the main clusters of delayed multipath observed in the outdoors environment [1].

The ITU program IMT2000 standardized the third generation (3G). These are geared for a variety of mobile data services, including interactive multimedia and high data rate, in addition to voice. Two major standards emerged: UMTS (WCDMA) is a 4.5 MHz per channel CDMA, and CDMA2000 (1x and 1x-EV) – a 1.25 MHz per channel CDMA. In addition, two short-range TDD (Time-division duplex) standards have been approved: UTRA TDD and TD-SCDMA. The diversified requirements entail introduction of new techniques and resource management schemes: packet switching, scheduling, code and time multiplexing. The two standards' paths evolved around different perceptions of the transmission efficiency of the aggregate of services: CDMA2000 opted for dedicating a full channel for data optimized communications, which materialized as 1xEV-DO, separate from voice and low latency multimedia services in CDMA2000, while UMTS turned to combine all services in the 4.5 MHz channel.

2.2 CDMA IS 95 Air Interface Overview

2.2.1 System Concept

Spread Spectrum is a technology whereby the signal transmission is spread over a broad band. The spreading scheme is known only to authorized users, while for unauthorized ones the signal is embedded in noise and undetectable. This technology found wide usage in the defense applications as a Low Probability of Intercept (LPI) communications and anti-jamming method. This technology is applied to cellular communications in IS 95. The spectrum is spread by modulating the carrier by BPSK (QPSK in later versions) in the FL, and OQPSK in the RL, at a rate of 1.2288 MHz. The modulating sequence has a periodicity of 2^{41}-1 (the *long code*). The correlator integrates over 128 "chips", 0.8μs each, to form a signal bit at a rate of 9600 bps, thus achieving a processing gain of 21 dB to the desired signal over uncorrelated signals.

Reverse link – random code and power control. The long code is used on the reverse link to provide the link to the individual user. The transmission of other users is not coherently integrated by the per-user correlator in the BTS receiver, and appears as noise, well randomized by the long code. Same cell users and other cells' users are thus interfering to the desired signal. A power control scheme controls the transmission power of all in-cell users to be received at the BTS receiver with the same power level. Each user then contributes noise that is 21 dB lower than the desired signal. The contribution of all users piles up. Capacity limit is reached when the aggregate interference reaches the limit set by the modem detectability, *Eb/It* (energy per bit over the spectral density of noise plus interference). About 2/3 of the interference is generated by in-cell users; the rest comes from users in adjacent cells. The interference from the latter is bound by the Soft Handoff (SHO) process that applies the power control to users in the adjacent cells whose transmission exceeds the set threshold.

Forward link – the signal is spread by direct sequence spreading over the same bandwidth as the reverse link. The code structure is however different. The transmission from the BTS is one-to-many. Signal transmission to all users is synchronized, and each is identified by an orthogonal code. 64 length Walsh code is used, allowing for 55 to 61 user codes, and 1 to 7 paging codes, one synchronization code and one pilot code. A short spreading sequence of 2^{15} (the *short code*) multiplies the BTS transmission and identifies the BTS. The orthogonality of the Walsh codes eliminates any interference from other in-cell users, except for delayed multipath which adds noise. The *channel orthogonality factor*, indicating the fraction of the BTS transmission that is fully synchronized, is a channel quality measure for each user link. Interference from adjacent BTSs is significant only toward the cell edge.

Channel code and diversity – the modem threshold *Eb/It* (equivalent to *C/I* in analog systems), which sets the limit to the capacity, depends on the nature of the interference. *Error-correction codes* are applied to enhance detectability and reduce the required *Eb/It* . These codes add bits to the signal stream, that help in identifying the signal out of the interference by seeking an order in the signal corrupted by random noise. The powerful codes that are applied in the system are *convolutional codes*, which avoid excess delay in the decoding. This is an important factor in the service of full duplex voice, that allows for a delay not exceeding 40 ms. The spreading and transmission bandwidth (1.25 MHz) is larger than the coherent bandwidth of the propagation channel in open environments, thereby suppressing fading by its frequency diversity. The *rake receiver* incorporates a number of correlators ("fingers") that search for delayed replicas of the signal and optimally combines them. Further suppression of fading in more densely packed environments - dense urban and indoors where the coherent bandwidth exceeds the system bandwidth, is provided by the fast *power control*, which compensates for the missing power through deep fades. This is effective for slow moving users, commensurate with the power control response time. Faster fading is mitigated by the *coder-interleaver*, that spreads the transmitted signal bits over a period of 20 ms such that errors are randomized over the code symbols to enable error correction. The bits are then reordered by the *deinterleaver-decoder* at the receiver. Antenna diversity is also applied at the BTS receiver, space or polarization diversity. Transmit diversity option is built into the CDMA2000 standard. However, add-on transmit diversity is an option for IS 95 also.

The IS 95 air interface is summarized in Fig. 2-2. 9600 bps data (block a) is coming out of the vocoder, encoded, interleaved and then spread and upconverted, and transmitted as a 1.23 MHz spread signal (block b). This is picked up at the receiver, along with its self-thermal noise (block e), other narrow band interference (block f), other users' transmissions in the cell (block g) and those of users in adjacent cells (block h). The rake receiver, comprised of down-converter, A/D, despreading correlators and deinterleaver-decoder, despreads the desired signal from the input (block c) while spreading the narrow band interference (block d).

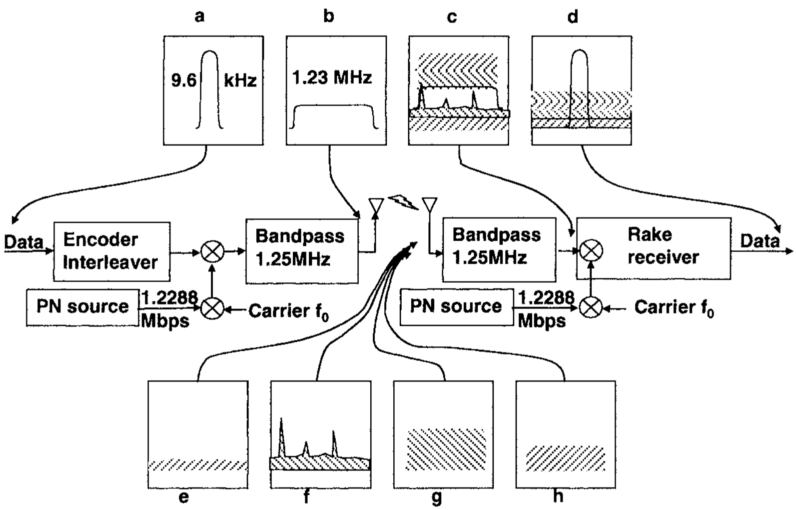


Figure 2-2. The IS 95 air interface concept

2.2.2 Logical and Physical Channels

2.2.2.1 Reverse Link

The reverse link of IS 95 has two logical transmit channels: *Reverse Traffic Channel* (RTCh) and *Reverse Access Channel* (RACh). RACh is used by the ST to establish a call or to respond to the system. RTCh is used only during a call, after the access has been established. Both are organized into 20 ms frames.

Reverse Traffic Channel has a variable data rate. RS1 (Rate Set 1) may use 1200, 2400, 4800 or 9600 bps data rate. RS2 may use 1800, 3600, 7200, or 14,400 bps data rate. These are built for use with a variable rate vocoder that automatically chooses the rate according to voice quality measures. The RS2 configuration employs a 1/2 rate convolutional encoder, while RS1 – a 1/3 rate encoder. The weaker protection for RS2 results in a higher *Eb/It* threshold and lower capacity than that of the RS1 configuration.

The ST transmission saves power in lower data rates by transmitting in bursts. The 20 ms frame is divided into 16 *power control groups* (PCG), 1.25 ms each. Full rate (9600 or 14400 respectively) transmission is continuous. 8 PCGs are masked out in half rate, 12 – in 1/4 rate and 14 in 1/8 rate. The masks are randomized within each frame.

Voice and data can be multiplexed on the same traffic channel. *Blank and burst* blanks out a full voice frame for data transmission. *Dim and burst* uses the blanked PCGs, this time in a continuous group in each frame, for data or signaling transmission.

Reverse access channels – are used by the ST when initiating a call, when performing an autonomous registration, and when responding to a paging message while being in an *idle state*. *Access probe* is a short transmission burst, timed randomly in order to avoid collision with *access probes* of other STs using the same RACh. An *access probe sequence* consists of a sequence of *access probes*, their transmission power increasing sequentially. A max of 16 access probes is transmitted in a sequence, and a max of 15 sequences can be transmitted.

The reverse link is Walsh code modulated, spread by the long code and then modulated OQPSK (Offset QPSK). The Q channel is offset by half a chip in order to smooth the transmission envelope and to allow higher efficiency ST amplifier operation.

2.2.2.2 Forward Link

The forward link of IS 95 has four types of channels: *Forward Pilot Channel* (FPiCh), *Forward Sync Channel* (FSyncCh), *Forward Paging Channel* (FPCh) (up to 7 channels) and *Forward Traffic Channel* (FTCh) (55 to 61 channels). Each channel is multiplexed and spread by Walsh codes. The pilot channel is designated W_0 (Walsh code 0), the Sync – W_{32}, and the paging channels W_1 to W_7. The traffic channels are randomly designated. Each channel is then individually amplified. The channel gains are determined by transmission considerations, including the pilot power allocation and the power control to the traffic channels. Once amplified, each channel is split to quadrature (I and Q) channels, and each arm is PN modulated by a *short code, common to all channels in the same sector.* All channels are then added up voltage wise, to form the base-band mask, which is shaped by a digital filter for minimum spectral spill off, upconverted and QPSK modulated for transmission. The information in the I and Q channels is the same, and the efficiency is that of BPSK. The quadrature modulation is applied in order to smooth the transmission envelope.

Half rate convolutional encoders are used in the FSyncCh, FPCh and FTCh. The transmissions are organized in 20 ms frames.

Pilot channel is a PN modulated carrier. It is always spread by Walsh code W_0, and then by a unique PN offset code that identifies the cell/ sector. The pilot is a reference time signal that allows the ST to acquire the system, provides phase reference for coherent detection, and provides the ST with signal strength measurement for *Soft Handoff* (SHO) window gates. The pilot strength is a network tuning parameter. All BTSs are time-synchronized, aided by GPS. The codes of the pilots throughout the system are identical short code, with different PN offset (delay) that is used for identification.

Forward synchronization channel transmits synchronization information to the STs at the *initialization state* to allow them to synchronize the codes they generate to the network. FSyncCh is transmitted at a 1/8 rate (1200 and 1800 in RS1, RS2, respectively) organized in an 80 ms super-frame.

Forward paging channels transmit system parameter information specific messages to STs paged. There is at least one, and max 7, PChs per sector. The transmission rate is 1/2 or full rate, organized in an 80 ms super-frame. The choice is communicated in the FSyncCh. STs are uniformly distributed among the FPChs by a hashing algorithm.

Forward traffic channels have a variable data rate: 1/8, 1/4, 1/2 and full rate – 9600 and 14,400 for RS1 and RS2 respectively. The output of the variable rate vocoder is fed to a half-rate convolutional encoder, followed by bit repetition for the lower voice rates to keep a constant bit rate transmission.

Power Control Subchannel (PCSCh) performs power control over the reverse link. It consists of one bit per control period. The 20 ms frame is composed of 16 *Power Control Groups* (PCG), 1.25 ms each. Within that period the BTS estimates the signal level received from each ST on the RTCh. A power control command bit is transmitted two PCGs later (2.5 ms later), consisting of a single bit. It is transmitted by puncturing the coded traffic symbol, and replaces two consecutive bits in the FTCh. The location of the power control bit within the PCG is randomized.

2.2.3 Power Control

2.2.3.1 Reverse Link Power Control

The capacity of the CDMA cellular system is interference limited by transmissions of other users in the cell and others in adjacent cells. The transmission power of each ST is controlled to minimize this interference and maximize the capacity. The control parameter is the error rate in the link, measured per frame in the CDMA system (FER – *Frame Error Rate*) that has to be kept under a level commensurate with the service. The allowed FER for voice is 1%. The FER is mostly influenced by the received E_b/I_t, which depends on the level of transmitted power. The power control system thus consists of 3 layers: *open loop power control*, where the ST estimates its transmission power level based on measurement of total received power and preacquired BTS parameters, *closed loop power control* that corrects the ST estimates by measurements of the received signal at the BTS, and *outer loop power control* that adjusts the ST power to suit the required FER.

Open loop power control is an autonomous operation of the ST. It operates during the access phase, when acquiring the connection to the network, and while in the traffic state. The ST estimates the transmission gain to the BTS by measurement of the average total power received (S_{Tm}), which does not require any prior knowledge of timing and BTS ID. The transmit power P_{RACh} is then computed from S_{Tm} and BTS transmitted parameters including *Power Offset-K*. This parameter is obtained by equating the reverse link to the forward link

$$K \equiv \frac{(C/I)_{Set} \cdot N_0 W \cdot F_{BS} \cdot P_{BS}\left(1 + \varsigma_N + \varsigma_{OC}\right)}{1-\eta} \tag{2-1}$$

where C/I_{set} is the required level at the BTS receiver, $N_0 W$ is the thermal noise, F_{BS} is the BTS noise factor, P_{BS} is the BTS transmit power, ζ_N, ζ_{OC} are the ratio of the thermal noise and of interference from adjacent BTSs to the BTS power, respectively, and η is the load level in the BTS. The nominal level set for RS1 is at -73 [dBmWatt^2] for 850 MHz band and -76 [dBmWatt^2] for the PCS band, representing a 50% loaded cell, 7 dB set E_b/I_t, 5 dB noise figure and 43 dBm BTS power. The power of the access probe is then

$$P_{RACh}[dB] = -S_{Tm} + K + \sum C_i \tag{2-2}$$

where C_i are ascending and correction terms defined for the access sequence. There are a maximum of 16 ascending probes in a probe sequence. The same equation holds while in the traffic state. The ST continues to measure S_{Tm} and add up correction terms, to account for changes in the BTS power, load and interference.

The *open loop power control* acts as an inverse AGC. Its dynamic range is 80 dB – to cover the range of path-loss within a typical cell. Because the fading on the forward and on the reverse links are not correlated, its estimate of the reverse link is accurate only to within 4 to 8 dB. The time constant is a trade-off between the need for a very fast response to a fast fade, and becoming a major source of interference to the network, and is set to about 30 ms, which allows it to compensate for fading only to slow moving STs.

Closed loop power control is when in the traffic mode, the BTS measures the received E_b/I_t from each ST and issues a power control bit every 1.25 ms, which commands the ST to increase or decrease its power by one increment of 1 dB. Its dynamic range is 48 dB. The accuracy of the closed loop power control in matching the desired signal level at the BTS receiver is about 1.5 dB. The BTS counts the consecutive "down" commands, and if that exceeds a specified threshold value the BTS interprets it as a malfunction of the ST and sends a "lock" command that disables the ST.

In *outer loop power control* FER is mostly determined by the E_b/I_t, but also by other parameters, including ST speed and multipath environment. The *outer loop power control* is set to maintain the required FER. The FER is assessed per every frame at the BSC. If the FER target is not met, it instructs the BSC to raise the target E_b/I_t ("set point") by 3 to 5 dB. The BTS then decreases the *set point* by 0.3 dB after every consecutive frame until a new "up" message arrives from the BSC. This individual setting of E_b/I_t per ST increases the variability of E_b/I_t by up to 2.5 dB, thereby reducing the capacity respectively.

2.2.3.2 Forward Link Power Control

The *forward link power control* (FLPC) applies to the FTCh only. Its purpose is to guarantee a set FER level while reducing the total power transmitted by the BTS to the minimum. The latter is important for reducing interference to other cells, reducing in-cell interference due to multipath (non-orthogonality) and increasing the FWD link capacity when it is limited by the BTS power. The overall variation allowed is ± 3 dB to ± 4 dB. The power control is applied to the *digital gain* (DG) of each traffic channel. A preset DG is assigned to each channel based on assessment of the signal received from that ST (*open loop power control*). The digital gain is then reduced by 0.25 dB every predetermined period (up to 80 frames). The ST counts the frames received in error, and if their percentage (FER) exceeds a predetermined level per required service, or the number of consecutive frames received in error exceeds a threshold, it issues a message (PMRM – power measurement report message). Upon receipt of the message, the digital gain is kicked up, typically 2 dB, and the process continues again.

2.2.4 Soft Handoff

2.2.4.1 Introduction

The *handoff* is a process whereby the communication of a ST to its party transitions from being relayed through one BTS to another BTS in a transparent way without interruption of the session. CDMA supports *Soft Handoff* (SHO) whereby the ST communicates with two or more BTSs simultaneously. This process is maintained as long as the communication with all the participating BTSs is satisfactory, and typically occurs over an area on the boundary of the coverage between these cells. *Softer Handoff* applies similarly between sectors belonging to the same BTS (and thus allowing for a coherent processing of all signals). The objective of the SHO is to guarantee a smooth handoff between cells. At the same time, the SHO serves to balance the transmission level of the STs across the network, reduce excessive interference between adjacent cells and balance the load between them. It also provides macro diversity for the ST, thus further reducing its transmission power. All participating BTSs transmit simultaneously during SHO. Their forward link power control compensates only partially for the excess transmission power from the participating BTSs.

2.2.4.2 Soft Handoff Process

The ST continuously scans the pilot code map for pilots that are strong enough to be considered for SHO. The rake receiver consists of 3 correlators ("fingers") for despreading the desired traffic and its delayed multipath replicas, and one pilot search correlator that performs the scan. The efficiency of this serial search requires a hierarchical structure in order to prioritize the search. This is built from the network planning and measurements and provided to the ST by the BTS. The pilots are divided into four groups:

Active set – Pilots associated with FTChs that are assigned to the ST and participate in the SHO. Also pilots associated with FPChs or FCCChs (in later versions of the standard) that are being monitored by the ST while in an idle state. The maximum number of pilots in the *active set* is 3. There are versions of STs with 6.

Candidate set – Pilots that are not currently in the *active set* but have been received by the ST with enough strength to indicate that the associated FTCh could be successfully demodulated. The maximum number is 10.

Neighbor set – Pilots that are not currently in the *active set* nor in the *candidate set*, but are likely candidates for handoff. The maximum number is 40.

Remaining set – The set of all possible pilots in the current system (SID) on the current CDMA frequency assignment, excluding the pilots in the *neighbor set*, the *candidate set* and the *active set*.

The SHO process is initiated by the ST. It is summarized in Fig. 2-3.When a pilot strength exceeds T_{ADD} (a level set by the system) it sends a *pilot strength measurement message* (PSMM) and transfers the pilot to the *candidate set* (1). The BTS responds by a *handoff direction message* (2), allowing the ST to transfer the pilot to the *active set*.

The ST performs and responds by a *handoff completion message* (3). When the pilot strength drops below T_{DROP} the ST starts the *handoff drop* timer (4). Once expired the ST sends a PSMM (5), the BTS sends a *handoff direction message* (6) and the ST removes the pilot from the *active set* to the *neighbor set* and sends a *handoff completion message* (7).

In case there are already 3 pilots in the active set, and a pilot in the candidate set exceeds any of them by T_{COMP} they interchange locations; the weaker goes to the candidate set and the new stronger goes to the active set.

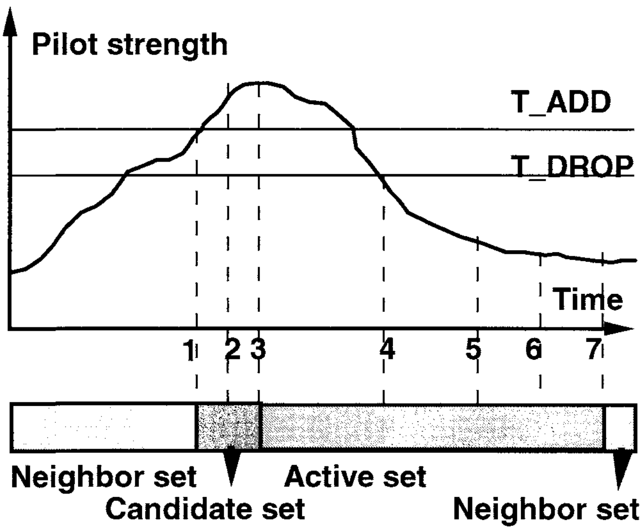


Figure 2-3. Soft Handoff sequence

2.3 Third Generation - 3G

2.3.1 The Motivation

The motivations for the third generation cellular are two-fold: technology drive and business push. The enormous success of the cellular service created a momentum for additional services, both by the technology leaders and manufacturers envisioning market saturation for the voice services, and by operators envisioning reduced profitability with increasing competition.

The efficiency of the cellular telephone transmission is limited by the nature of the service, requiring full duplex voice with low latency, and full mobility. High order modulation constellation is too sensitive to interference to sustain the multipath fading and the reuse requirements for high capacity.

Reaching to data services opens a new regime for both technology and business. Revenue is made of the information value of the bit, not the sheer air time. Latency, full duplex and full mobility are relaxed in lieu of higher data rates. A wide range of transmission modes, trading off SNIR, signal duration and spreading rate, is then open to suit the various needs of data and multimedia. Fig. 2-4 exemplifies the fact that the "volume" of transmission of a bit is fairly fixed, and its cost is optimized by service and environment-adaptive choice of its shape.

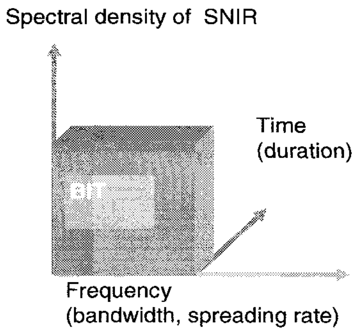


Figure 2-4. The cost of bit transmission

2.3.2 The Standardization

The ITU initiated a global standardization for 3G in a program named IMT2000 (International Mobile Telephone). The race of two major groups led to the creation of two main standards: 3GPP (3^{rd} generation partnership project) produced the WCDMA – UMTS standard, seeking an evolutionary process from the GSM and its infrastructure, while 3GPP2 produced the CDMA2000 standard, a fully evolutionary standard from IS 95. Both standards are based on CDMA technology and have similar structure and processes. The main differences are summarized in Table 2-2. The rationale for the choice of parameters in CDMA2000 is full backward compatibility with IS 95 and a simple upgrade of existing networks. UMTS opts for a wide band, having been given a virgin spectral allocation. The rationale for non synchronized BTSs is difficulties envisioned in GPS-based synchronization for micro and indoor BTSs.

2.3.3 The Features and Techniques

3G service objective is multimedia communications. Four traffic classes have been defined, each with its measure of Quality of Service (QoS), according to transmission constraints, and mainly the tolerance to latency:

Conversational – low end-to-end delay, symmetric traffic. Mainly circuit-switched voice services, and (circuit or packet-switched) video telephony. The QoS is strictly human perception.

Streaming – Transmission of data that can be processed as a steady continuous stream. Asymmetric, latency-tolerant. Typical services are web broadcast and video on demand.

Interactive – Request response pattern. Short round-trip delay. Typical applications are web browsing, video games, location-based services.

Background – Applications that do not require immediate attention. Starting from SMS, email services and to files transfer.

The techniques applied in response to these needs include:

Packet switching – the traditional circuit-switched allocation of a duplex channel continuously for the duration of a call is extremely inefficient for asymmetric data transfer and multiple data services. The data is packaged in addressed packets, dynamically allocated to users controlled by various scheduling preferences. Packet switching opens the infrastructure to a connectionless regime.

Variable spreading rate – high data rate uses lower spreading and applies protection by ARQ and longer codes (including turbo codes)/ longer frames.

Fast, complex channel control – with fast channel measurement and feedback.

Adaptive modulation and coding (AMC) – adapting the modulation and coding to the channel state and service.

Hybrid ARQ (HARQ) – (Hybrid Automatic Repeat Request) advanced message acknowledgement that expedites the transmission and verification.

Fast scheduling – scheduling transmissions according to channel conditions and "fairness criterion".

Fast FL power control – improvement of the FL channel and mitigation of multipath.

FL transmission diversity – (optional). Improvement of the FL.

Time multiplexing – Full power transmission to a channel-favorable designated user per each time slot ("water filling").

2.4 CDMA2000

2.4.1 Introduction

CDMA2000 is an extension of IS 95, designed for providing the service requirements of 3G. It supports both circuit-switched and packet data, and multiple supplementary and dedicated channels optimized for different multimedia applications. CDMA2000 is backward compatible with IS 95B, including most of the infrastructure, and its deployment constitutes a simple upgrade to IS 95 network. It requires CDMA2000-compatible ST.

CDMA2000 standard supports two spreading rates (SR):
SR1 spreads 1.2288 Mchips/s over 1.25 MHz band (CDMA2000-1x).

There are two versions of SR3: in SR3 DS (direct sequence), 3.6964 Mchip/s are spread over 3.75 MHz bandwidth, and SR3 MC (multicarrier) incorporates 3 1.25 MHz FL channels and one 3.75 MHz RL. SR3 has not yet been implemented commercially.

2.4.2 Forward Link

Six forward link *Radio Configurations* (RC) are defined for 1x, listed in Table 2-1. RC10 – EV-DV is discussed in section 2.9.

The main differences from IS 95 include:

- Different length Walsh codes, from 4 to 128 chips, to suit the application.
- QPSK modulation (and higher constellations in RC10 EV-DV).
- Turbo codes enhance the convolutional FEC codes in some configurations.
- Fast FL power control (800Hz) that assists in mitigating fading. There are 1, 0.5 and 0.25 dB steps that allow for a tighter control and reduce the ripple.
- Transmit diversity (OTD – orthogonal TD and/or STTD (Space Time TD).
- Additional channels to accommodate a variety of applications.
- Frame lengths – 20 ms for signaling and user information, 5 ms for control information.
- Forward Common Auxiliary Pilot Channel (FCAPiCh), and Forward.
- Dedicated Auxiliary Pilot Channel (FDAPiCh) to support smart antenna transmission.

Table 2-1. Forward link radio configurations for CDMA2000-1x

RC	Data rate (Kbps)	FEC Encoder rate	Modulation	TD
1	1.2; 2.4; 4.8; 9.6	1/2	BPSK	
2	1.8; 3.6; 7.2; 14.4	1/2	BPSK	
3	1.2; 1.35; 1.5; 2.4; 2.7; 4.8; 9.6; 19.2; 38.4; 76.8; 153.6	1/4	QPSK	+
4	1.2; 1.35; 1.5; 2.4; 2.7; 4.8; 9.6; 19.2; 38.4; 76.8; 153.6; 307.2	1/2	QPSK	+
5	1.8; 3.6; 7.2; 14.4; 28.8; 57.6; 115.2; 230.4	1/4	QPSK	+
10	81.6; 158.4; 163.2; 312.0; 316.8; 326.4; 465.6; 619.2; 624.0; 633.6; 772.8; 931.2; 1238.4; 1248.0; 1545.6; 1862.4; 2476.8; 3091.2	1/5	QPSK, 8-PSK, 16 QAM	

2.4.3 Reverse Link

The main differences from IS 95 include:

- Separate channels for different applications.
- Coherent reverse link with a continuous pilot per user.
- Continuous (not bursty) transmission.
- Forward power control information is time multiplexed with the pilot.
- Independent fundamental and supplemental channels.
- Frame lengths - 20 ms for signaling and user information, 5 ms for control information.
- Adaptive threshold Soft Handoff that reduces the SHO zone. Referring to Fig. 2-3 – once a pilot is reported crossing above T_{ADD} and being transferred to the *candidate set*, it is being measured and reported frequently, creating a pattern of its increase slope relative to the total energy detected and coherently combined from all pilots in the *active set*. It is transferred to the active set once it satisfies a criterion of ratio of powers and trend. Frequent power measurements of each pilot in the active set and in the candidate set establish the trends. When a pilot crosses down a ratio and trend criterion a timer is initiated, and upon its expiration it is moved to the *candidate set* or the *neighbor set* if it is above or below T_{DROP}. This process reduces the SHO zone, and the "ping pong" of pilots in and out of the SHO.

2.5 WCDMA UMTS

WCDMA for UMTS (Universal Mobile Telecommunication System) was released by 3GPP in December 1999. It is a standard responding to the requirements of IMT2000 for 3G cellular service.

Table 2-2. Major differences between WCDMA and CDMA2000 1x

	WCDMA	CDMA2000
Carrier spacing	5 MHz	1.25 MHz
Chip rate	3.84 Mcps	1.2288 Mcps
Power control frequency	1500 Hz	800 Hz
Base station synchronization	No	Yes
Frame length	10 ms	20 ms

2.6 CDMA Timeline

July 1993 *IS 95* - the first cellular CDMA standard, was published.

May 1995 IS 95A revision published.

Frequency-division duplex (FDD) system with 1.25 MHz channels. Primarily designed for voice services, but also provides circuit- switched data services at speed up to 14.4 Kbps. Fast power control (800 Hz) on RL, and slow power allocation on the FL (50 Hz). Supports soft handoff between base stations and softer handoff between sectors in the same base station.

1996 First commercial deployment in Hong Kong.

June 1997 IS 95B standard approved. Offers 64 Kbps packet switched data. FSCChs (*Forward Supplemental Code Channels*) are introduced, using Walsh codes from the traffic pool. Up to 7 FSCChs and one FTCh may be assigned to one user, reaching data rate of 115.2 Kbps. First commercial deployment in 1999.

July 1999 CDMA2000 (1x RTT) is approved. (1x stands for use of single 1.25 MHz channel. RTT – *Radio Transmission Technology*). First commercial deployment in Oct. 2000. Includes IS 95B as a subset. Voice capacity is increased on both FL and RL by 60% to 100%. Fast FL power control. QPSK modulation. Transmit diversity (optional) on FL. Coherent RL. Quick paging channel for increased standby time. Supplemental channels for packet data services at rates up to 153.6 Kbps on FL and RL.

December 1999 3GPP releases WCDMA-UMTS.

CDMA2000 Release A. New FL common channels to improve paging channel efficiency. Supports concurrent services (e. g. voice, packet data, circuit-switched data). Supplemental channel data rate increased to 307.2 Kbps.

CDMA2000 Release B. Rescue channel to reduce call drops.

CDMA2000 Release C (1xEV- DV FL). Time shared packet data channel on the FL. Time-division multiplexed. Fast scheduling with rate adaptation based on channel state feedback from the mobile. Hybrid ARQ. Forward link data rates up to 3.1 Mbps.

CDMA2000 Release D (1xEV- DV RL). Packet data channel on the reverse link. Autonomous rate adaptation by mobiles. Hybrid ARQ. RL rates up to 1.8 Mbps. Broadcast channel on the FL.

1xEV-DO. The different releases of CDMA2000 1x support circuit switched voice and data services on the same carrier. 1xEV- DO (1x EVolution –Data Optimized) is optimized for packet data services on a separate 1.25 MHz carrier.

October 2000 1xEV-DO Rev 0 standard approved. Commercial deployment in Korea, January 2002.

April 2004 1xEV-DO Rev A standard approved. 3.1 Mbps on forward link (2.45 Mbps in 1xEV-DO Release 0), 1.8 Mbps on reverse link (153.6 Kbps in 1xEV-DO Release 0).

2.7 Forward Link Time Multiplexing

The multipath channel conditions, and the respective SINR, vary across the coverage area and vary with time from one ST to another through their motion. While diversity techniques used in the CDMA regime smooth and "even out" the fluctuating channel, resources are sacrificed to serve the disadvantaged users via the power control on behalf of the total throughput of the BTS. Data applications that are not sensitive to latency can take advantage of slotted sequential transmissions to the users at times they enjoy the most favorable channel conditions. Full power transmission, "riding the crests of the multipath", as described in Fig. 2-5, renders much higher BTS throughput. Time slots are allocated by the *scheduler* to the Access Points (AP, an equivalent terminology to ST) according to their momentary channel conditions. A *fairness criterion* compromises between the maximum BTS throughput possible and a fair distribution of the service between APs. Mobility, that changes the multipath conditions differently to each AP, is expected to provide a fair statistical distribution of the channel conditions among them. Many users' activity offers more opportunities for signal peaks to the scheduler and increases the throughput.

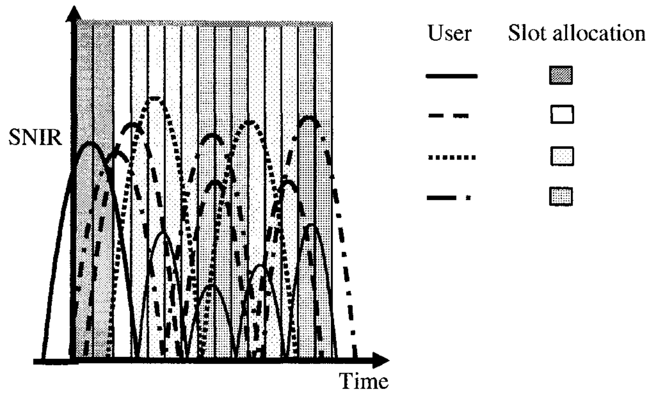


Figure 2-5. Multi-user diversity

This is "*user diversity*". Fading can actually improve the throughput with this scheme, and diversity techniques to "smooth" the channel are not employed, nor power control.

Each AP monitors all the accessible BTSs all the time, and reports an advisory with the desired data rate to the one with the best link, based on the measured SINR. These timely reports are processed by the scheduler to allocate the time slots. This time multiplexing scheme has been adopted by 1xEV-DO, 1xEV-DV and HSDPA for transmission of asymmetric high data rate.

2.8 1xEV-DO

1xEV-DO is an air interface optimized for packet data. It uses dedicated 1.25 MHz frequency allocations within the CDMA2000 allocated band.

The *forward link* is time multiplexed. It uses 1.67 ms time slots, full power, as shown in Fig. 2-6. Its coverage conforms to the coverage of IS 95 and CDMA2000 cells. The highest throughput is obtained in smaller cells, however. Data rate can change from slot to slot, from 38.4 Kbps to 2.4576 Mbps, and up to 3.1 Mbps in Rev A. All data transmissions are at the same power. Transmission in each slot is directed to only one mobile. It does not have soft handoff, only hard handoff. Adaptive Modulation and Coding (AMC) is used, together with Hybrid ARQ, to enhance throughput.

The scheduler at the base station chooses which mobile to transmit to in each slot.

Mobiles continuously transmit Data Rate Control (DRC) channel that indicates data rate and sector from which they want to be served. The scheduler uses channel feedback from mobiles to decide who to transmit to, and implement some fairness criterion.

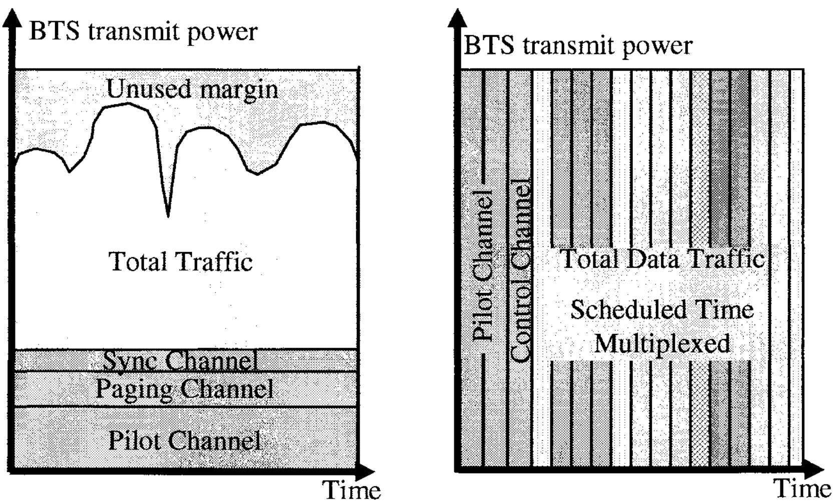
The *reverse link* is coherent CDMA with data rates from 9.6 Kbps to 153.6 Kbps and up to 1.8 Mbps in Rev A. The rate assignment is dynamic, decentralized.

Schedule-to-Tx-when-channel-is-above-average reduces the interference to other BSs statistically. Revision A incorporates Hybrid ARQ on reverse link also.

2.9 1xEV-DV

1xEV-DV is an extension of 1xRTT (CDMA2000), incorporating 1xEV-DO time multiplexing for high data rates. It is backward compatible with CDMA2000, including handoff. Packet data CDMA is scheduled for best transfer.

High data rate is time multiplexed and transmitted to the user with the best momentary channel, with all the power unused by the CDMA channels – a technique called "*water filling*". The forward link transmission resource used is described in Fig. 2-7. The main features and differences from HSDPA are summarized in Table 2-3.



a: IS 95 forward link structure

b: 1xEV-DO forward link structure

Figure 2-6. 1xEV-DO FL transmission

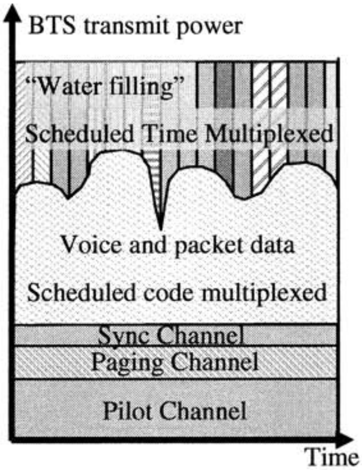


Figure 2-7. 1xEV-DV forward link transmission

2.10 HSDPA

HSDPA – *High Speed Downlink Packet Access,* is an extension of WCDMA and backward compatible with it. It is a downlink only multimedia optimized, transmitting up to 10.8 Mbps throughput (maximum specified by codes is 14.4 Mbps). It requires special ST. Its optimization rules are a bit different than those for UMTS. Table 2-3 summarizes the differences between HSDPA and 1xEV-DV .

Table 2-3. Main features and differences between HSDPA and 1xEV-DV

Feature	HSDPA	1xEV-DO
Forward Link Frame Size	2ms TTI (3 Slots)	1.25,2.5, 5, 10 ms Variable Frame Size (1.25 ms Slot Size)
Channel Feedback	Channel quality reported at 500 Hz rate (every 2 ms)	C/I feedback at 800 Hz (every 1.25 ms)
Data User Multiplexing	TDM/CDM	TDM/CDM (Variable frame)
Adaptive Modulation and Coding	QPSK & 16 QAM Mandatory	QPSK, 8 PSK & 16 QAM
Hybrid ARQ	Chase or incremental Redundancy (IR)	Async. Incremental Redundancy (IR)
Spreading Factor	SF=16 using UTRA OVSF Channelization Codes	Walsh Code Length 32
Control Channel Approach	Dedicated Channel pointing to Shared Channel	Common Control Channel

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