Course 330

Wireless Introduction Technologies & Development Overview

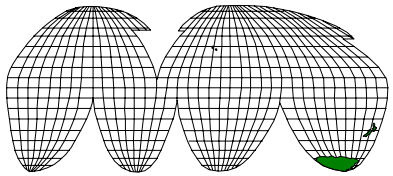
CDMA 330 Outline

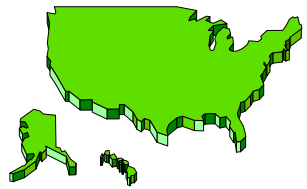
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Deployment Status of Wireless Technologies

Global and US Wireless Users by Technology

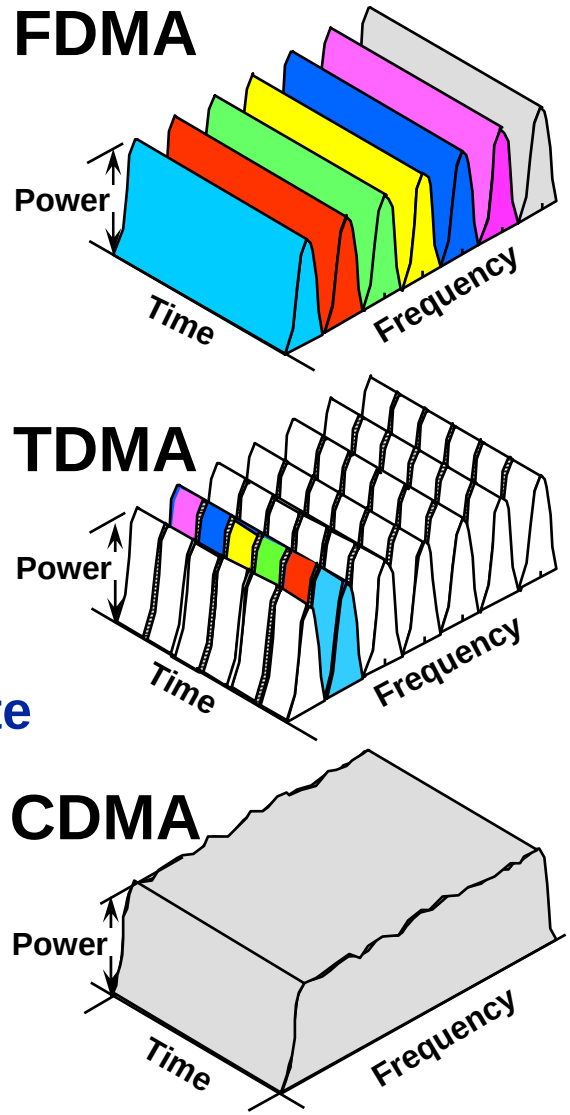




Course 330

Basic Technical Details of Wireless Technologies

Multiple Access Technologies



- FDMA **(example: AMPS)**

  Frequency Division Multiple Access

  - **each user has a private frequency**
- TDMA **(examples: IS-54/136, GSM)**

  Time Division Multiple Access

  - **each user has a private time on a private frequency**
- CDMA **(IS-95, J-Std. 008)**

  Code Division Multiple Access

  - **users co-mingle in time and frequency but each user has a private code**

Other Technologies: Avoiding Interference

- AMPS, TDMA and GSM depend on physical distance separation to keep interference at low levels
- Co-channel users are kept at a safe distance by careful frequency planning
- Nearby users and cells must use different frequencies to avoid interference

AMPS-TDMA-GSM

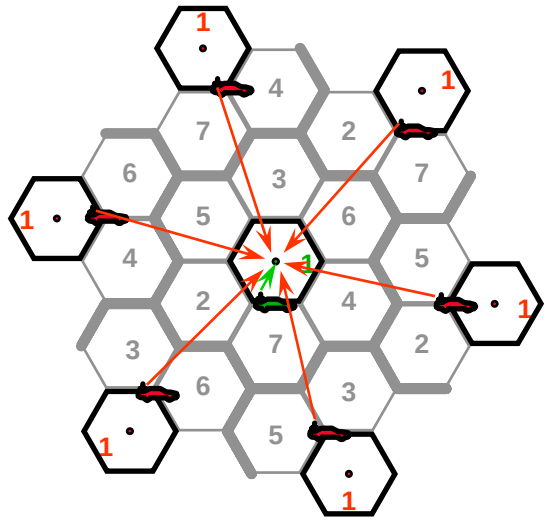


Figure of Merit: C/I
(carrier/interference ratio)
AMPS: +17 dB
TDMA: +14 to 17 dB
GSM: +7 to 9 dB.

CDMA: Using A New Dimension

- All CDMA users occupy the same frequency at the same time! Time and frequency are not used as discriminators
- CDMA interference comes mainly from nearby users
- CDMA operates by using CODING to discriminate between users
- Each user is a small voice in a roaring crowd -- but with a uniquely recoverable code

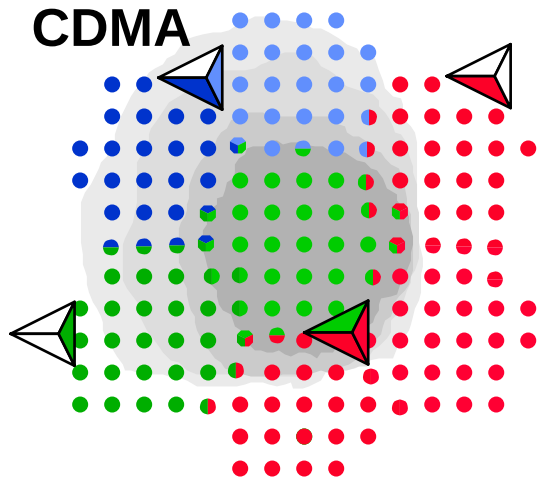


Figure of Merit: C/I
(carrier/interference ratio)
AMPS: +17 dB
TDMA: +14 to +17 dB
GSM: +7 to 9 dB.
CDMA: -10 to -17 dB.
CDMA: E_b/N_o ~+6 dB.

Generations of Wireless

- First generation wireless systems used Analog technologies to provide circuit-switched access for mobile voice telephony
  - AMPS (Advanced Mobile Phone System)
  - MTS, IMTS, NMT, TACS, ETACS, JTACS, others
- Second generation wireless systems use the earliest digital technologies to provide mainly circuit-switched access for mobile voice telephony
  - GSM (Global System for Mobile Communications) TDMA
  - IS-54, IS-136 TDMA
  - IS-95 CDMA
- Third generation wireless systems use improved digital technologies to provide packet-switched access for advanced voice and data applications
  - wider-bandwidth, higher-capacity, more features and applications
  - CDMA2000 1xRTT, 1xEV DO, DV, 3xRTT - migration path from IS-95
  - GPRS & UMTS - migration path from GSM and IS-136 TDMA
  - EDGE - migration path from TDMA, but will anybody use it?
- Fourth Generation technologies are erupting into the marketplace, a revolution that could topple (or be absorbed by) the established players

Migration Paths from 2G Technologies to 3G

The Path to 3G from IS-95 CDMA

The CDMA Technology Path to 3G

Generation	1G	
Technology	AMPS	
Signal Bandwidth, #Users	30 kHz. 1	
Data Capabilities	None, 2.4K by modem	
Features: Incremental Progress	First System, Capacity & Handoffs	

The CDMA Technology Path to 3G

		CDMAone	
Generation	**1G**	**2G**	
Technology	**AMPS**	IS-95A/J-Std008	
Signal Bandwidth, #Users	30 kHz. 1	1250 kHz. 20-35	
Data Capabilities	None, 2.4K by modem	14.4K	
Features: Incremental Progress	First System, Capacity & Handoffs	First CDMA, Capacity, Quality	

The CDMA Technology Path to 3G

		CDMAone	
Generation	**1G**	**2G**	**2G**
Technology	**AMPS**	IS-95A/J-Std008	**IS-95B**
Signal Bandwidth, #Users	30 kHz. 1	1250 kHz. 20-35	1250 kHz. 25-40
Data Capabilities	None, 2.4K by modem	14.4K	64K
Features: Incremental Progress	First System, Capacity & Handoffs	First CDMA, Capacity, Quality	•Improved Access •Smarter Handoffs

The CDMA Technology Path to 3G

		CDMAone		CDMA2000/IS-2000	
Generation	**1G**	**2G**	**2G**	**2.5G or 3?**	
Technology	**AMPS**	IS-95A/J-Std008	**IS-95B**	**IS-2000: 1xRTT**	
Signal Bandwidth, #Users	30 kHz. 1	1250 kHz. 20-35	1250 kHz. 25-40	1250 kHz. 50-80 voice and data	
Data Capabilities	None, 2.4K by modem	14.4K	64K	**153K 307K 230K**	
Features: Incremental Progress	First System, Capacity & Handoffs	First CDMA, Capacity, Quality	•Improved Access •Smarter Handoffs	•Enhanced Access •Channel Structure	

The CDMA Technology Path to 3G

		CDMAone		CDMA2000/IS-2000	
Generation	**1G**	**2G**	**2G**	**2.5G or 3?**	**3G**
Technology	**AMPS**	IS-95A/J-Std008	**IS-95B**	**IS-2000: 1xRTT**	**IS-2000: 3xRTT**
Signal Bandwidth, #Users	30 kHz. 1	1250 kHz. 20-35	1250 kHz. 25-40	1250 kHz. 50-80 voice and data	F: 3x 1250k R: 3687k 120-210 per 3 carriers
Data Capabilities	None, 2.4K by modem	14.4K	64K	**153K 307K 230K**	**1.0 Mb/s**
Features: Incremental Progress	First System, Capacity & Handoffs	First CDMA, Capacity, Quality	•Improved Access •Smarter Handoffs	•Enhanced Access •Channel Structure	Faster data rates on shared 3-carrier bundle

The CDMA Technology Path to 3G

		CDMAone		CDMA2000/IS-2000		
Generation	**1G**	**2G**	**2G**	**2.5G or 3?**	**3G**	**3G**
Technology	**AMPS**	IS-95A/J-Std008	**IS-95B**	**IS-2000: 1xRTT**	**IS-2000: 3xRTT**	**1xEV: HDR or 1Xtreme**
Signal Bandwidth, #Users	30 kHz. 1	1250 kHz. 20-35	1250 kHz. 25-40	1250 kHz. 50-80 voice and data	F: 3x 1250k R: 3687k 120-210 per 3 carriers	1250 kHz. Many packet users
Data Capabilities	None, 2.4K by modem	14.4K	64K	**153K 307K 230K**	**1.0 Mb/s**	**2.4 Mb/s** (HDR) **5 Mb/s** (1Xtreme)
Features: Incremental Progress	First System, Capacity & Handoffs	First CDMA, Capacity, Quality	•Improved Access •Smarter Handoffs	•Enhanced Access •Channel Structure	Faster data rates on shared 3-carrier bundle	Faster data rates on dedicated 1x RF data carrier

IS-95 to 3G:
The Radio Perspective

2G CDMA Beginnings: IS-95A and J-Std 008

- Original commercial CDMA systems in the 800 MHz. band complied with IS-95A, and 1900 MHz. Systems complied with the Joint Standard 008. Both had the following common features
- Signal structure:
  - 1.2288 MCPS spreading, signal ~1.25 MHz. Wide
  - BTS Sectors have short PN offsets, channels are Walsh codes
  - Mobiles have long PN offsets and transmit one channel only
- Traffic Channel Capabilities:
  - Rate Set 1: 9600-bps traffic channels for 8 kb/s vocoders
  - Rate Set 2: 14400-bps traffic channels for 13 kb/s vocoders and other 14400-max data applications

IS-95B: CDMA 2G Enhancements

- IS-95B is still considered Second Generation, but offers some needed enhancements to the original IS-95A and J-Std008
- Improved Access Methods
  - Mobiles originally could use only one sector during an access attempt
    - Multipath fading causes roughly 2% failed accesses!
  - IS-95B allows mobiles to use alternate sectors as “backup” during access in case the original sector fades
- Improved Handoff Methods
  - Original CDMA provided only fixed-threshold handoff triggers
    - Inflexible, can skip needed handoffs but waste unneeded ones
  - IS-95B uses slope and intercept-based thresholds to tailor handoff action to what is really needed for call survival
- Faster Data Services
  - Original CDMA allowed data only at the rate of a single traffic channel
  - IS-95B/IS-707 allows aggregation of traffic channels for faster data, but not at the rates provided by 3G cdma2000

RF Perspective:
3G Phase One: cdmaONE to cdma2000 1xRTT

- 1xRTT Keeps same chip rate and carrier bandwidth
- Splits I and Q phase planes, 2x cap!
- Keep existing IS-95-based channels for backwards compatibility with IS-95 mobiles
  - IS-95B enhancements retained
- Adds new radio configurations, adds new FWD and REV channels
  - New optional control channels
  - New fundamental traffic channels
  - New supplemental traffic channels for faster data
  - New codes and spreading techniques
- Operators can deploy 1xRTT with no additional spectrum and minor equipment upgrading

IS-95B Today



•Single Carrier 1.2288 MCPS
•Sectors different short PNs
•Mobiles different Long PNs
•9600, 14400 rate sets
•~35 max users/sector/carrier

Next: 1xRTT



•Single Carrier 1.2288 MCPS
•Sectors different short PNs
•Mobiles different Long PNs
•Backward compatible IS-95
•Independent Short PN I & Q
•~70 max users/sector/carrier
•More rates, modes, channels
•Better administration

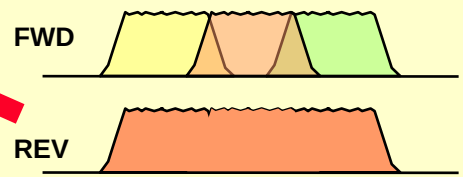
3G Phase Two: cdma2000 1xRTT to 3xRTT

- Forward link expanded to 3 carriers, each 1.2288 MCPS for 1.25 MHz. BW
  - Active walsh codes are not duplicated on the carriers so they maintain orthogonality and share capacity as traffic loading changes
- Reverse link expands to 3x current chip rate, 3.6864 MCPS, fits in 5 MHz.
- Adds new radio configurations and new supplemental channels faster than possible in 1xRTT
- Increased spreading rate requires new reverse short codes, other refinements

1xRTT



Next: 3xRTT



- **Forward Link 3 1x carriers**
- **Rev Link 1 3x carrier**
- **Sectors different short PNs**
- **Mobiles different Long PNs**
- **Independent Short PN I & Q**
- **~70 max users/sector/carrier**
- **More rates, modes, channels**
- **Better admin. & pwr. Ctrl**
- **New Features/enhancements**

LIKELY 3XRTT NEVER USED

3G Phase Two Alternatives: 1xEV

- 1x alternatives are available offering data rates just as fast as 3x!
  - 1xEV - 1x EVolution - is the term used to describe them
- Qualcomm's proprietary HDR (High Data Rates) technology dedicates a 1x carrier for fast data use only - no voice.
  - This is called 1xEV DO (Data Only)
- Motorola and Nokia have teamed up to develop and promote an alternative 1x technology under the trade name 1Xtreme
  - Uses more complex modulation techniques
  - offers up to 4.9 Mb/s data rates
  - backwards compatible with voice and data on same carrier
  - This is called 1xEV DV (Data and Voice)
- Both 1xEV DO and 1xEV DV use fragile modulation schemes
  - Maximum claimed rates will be available only under ideal conditions (near unloaded base stations)
  - 1xEV development is continuing - deployment probable in late 2002
- Despite drawbacks, 1xEV is still more attractive to operators than 3x
  - 3xRTT requires three physical carriers and substantially more BTS equipment than 1xEV!

The 3G Path from GSM: GPRS, WCDMA UMTS/UTRA

The GSM Technology Path to 3G

Generation	1G	
Technology	various analog	
Signal Bandwidth, #Users	various	
Data Capabilities	various	
Features: Incremental Progress	various	

The GSM Technology Path to 3G

Generation	1G	2G	
Technology	**various analog**	**GSM**	
Signal Bandwidth, #Users	various	200 kHz. 7.5 avg.	
Data Capabilities	various	none	
Features: Incremental Progress	various	Europe's first Digital wireless	

The GSM Technology Path to 3G

Generation	1G	2G	2.5G or 3?	
Technology	various analog	**GSM**	**GPRS**	
Signal Bandwidth, #Users	various	200 kHz. 7.5 avg.	200 kHz. Many Pkt. users	
Data Capabilities	various	none	9-160 Kb/s (conditions determine)	
Features: Incremental Progress	various	Europe's first Digital wireless	•Packet IP access •Multiple attached users	

The GSM Technology Path to 3G

Generation	1G	2G	2.5G or 3?	3G	
Technology	**various analog**	**GSM**	**GPRS**	**EDGE**	
Signal Bandwidth, #Users	various	200 kHz. 7.5 avg.	200 kHz. Many Pkt. users	200 kHz. fast data many users	
Data Capabilities	various	none	9-160 Kb/s (conditions determine)	384 Kb/s mobile user	
Features: Incremental Progress	various	Europe's first Digital wireless	•Packet IP access •Multiple attached users	Faster data rates on dedicated 200 kHz data carrier	

The GSM Technology Path to 3G

Generation	1G	2G	2.5G or 3?	3G	3G
Technology	**various analog**	**GSM**	**GPRS**	**EDGE**	**UMTS UTRA WCDMA**
Signal Bandwidth, #Users	various	200 kHz. 7.5 avg.	200 kHz. Many Pkt. users	200 kHz. fast data many users	3.84 MHz. up to 200+ voice users and data
Data Capabilities	various	none	9-160 Kb/s (conditions determine)	384 Kb/s mobile user	2Mb/s static user
Features: Incremental Progress	various	Europe's first Digital wireless	•Packet IP access •Multiple attached users	Faster data rates on dedicated 200 kHz data carrier	Integrated voice and data

GSM History

- The GSM network architecture was defined in work of the ETSI during the late 1980s
  - Switching and network architecture based on ISDN concepts
  - Roaming and location management derived from early Intelligent Networks concepts
- GSM has enjoyed large business success due to its non-proprietary open architecture and competitive vendors
  - Approximately 60% of global wireless subscribers use GSM

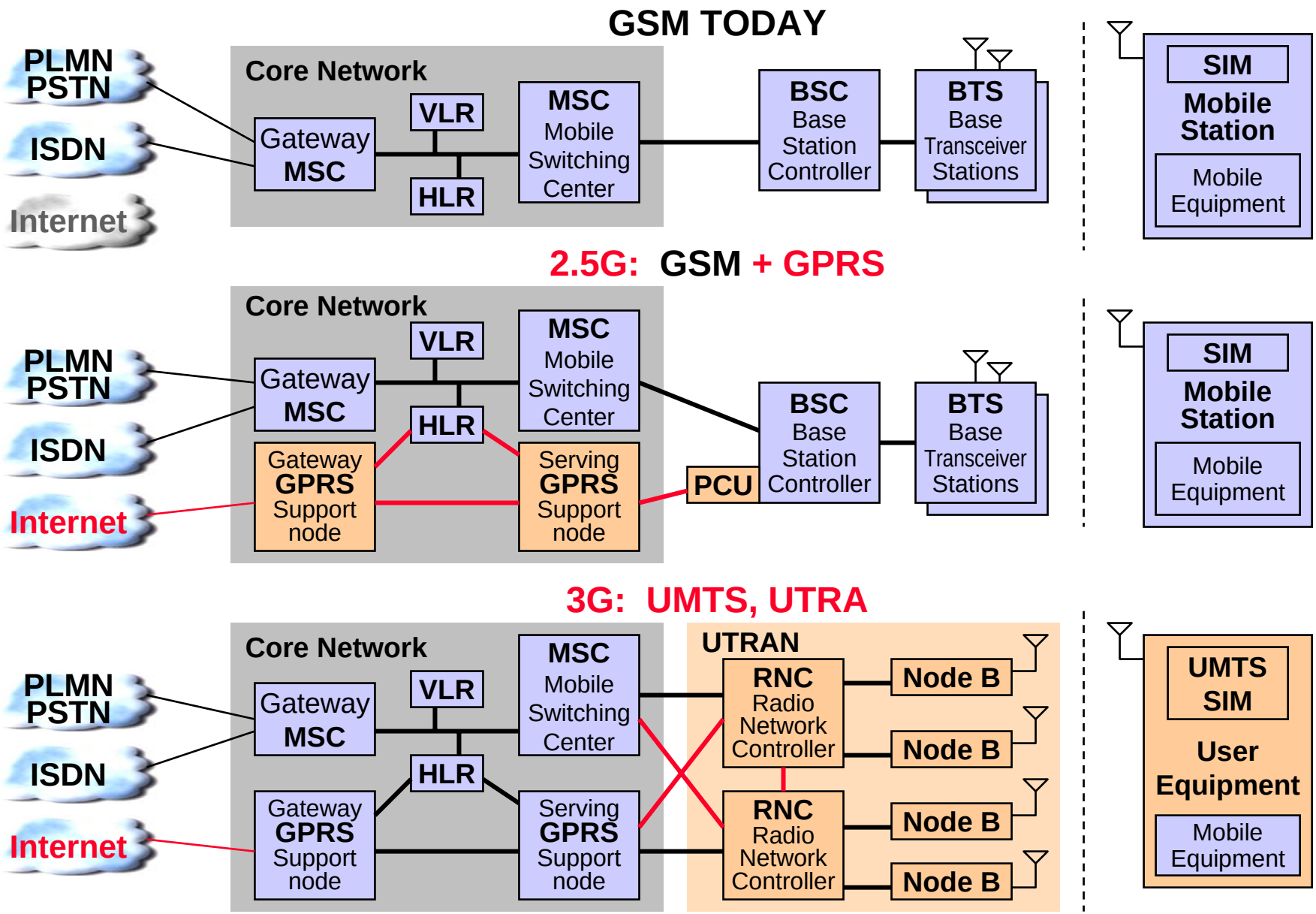
ETSI GSM Adopts W-CDMA!

- One of the most significant developments in the entire 3G evolution is the decision by the large GSM community to adopt a wideband CDMA technology as its 3G migration choice
- The 3G plane of capabilities is called the **U**niversal **M**obile **T**elecommunications **S**ervices (**UMTS**)
- The new WCDMA radio interface to support UMTS is called the **U**MTS **T**errestrial **R**adio **A**ccess (**UTRA**). There are two versions:
  - FDD Frequency Division Duplex: similar to CDMA2000, BTS transmission and mobile transmission in separate paired bands
  - TDD Time Division Duplex puts BTS and mobile on same frequencies taking turns transmitting bursts to each other
    - May be useful to operators without much spectrum
    - Large propagation delays can reduce capacity, so TDD is most effective in small-tier environments (indoors, etc.)
    - TDD can provide 2-Mb/s data rates in controlled fixed environments
- UMTS UTRA FDD is the primary high-tier mode intended to be used by most UTRA operators

GSM 3G Migration: Radio and Network

- The GSM community is making the transition to 3G in three distinct phases
  - Phase 1 adds a packet-switched radio network as an overlay on the existing physical structure
  - Phase 2 replaces base stations and controllers with the new UTRA sub-network
  - Phase 3 is completed by introducing UMTS handsets and their corresponding UMTS Subscriber Identity Modules (SIMs)
  - Core functionality of the existing network is maintained throughout the three phases of migration

3 Steps to 3G: The GSM Network Transition



Phase 1: GPRS General Packet Radio Service

- GPRS uses aggregated timeslots of existing GSM base stations to transmit packet data
  - IP routers (**SGSN** Serving GPRS Support Nodes and **GGSN** Gateway GPRS Support Nodes) forward IP packets to users
  - Users perceive a continuous connection using/browsing, even though packets are exchanged intermittently and no steady connection exists
  - GPRS supports 9.06, 13.4, 15.6, and 21.4 kb/s per GSM timeslot and total rates of 40-60 kb/s and more are possible as multiple timeslots are aggregated on demand
- Each BSC has a parallel PCU Packet Controller Unit which manages all packet streams
- GPRS provides IP capability in the near term, well in advance of the higher bandwidths possible on fully-implemented UMTS systems

The GPRS Air Interface

- General Packet Radio Service (GPRS)
- Same GMSK modulation as GSM
- 4 channel coding modes
- Packet-mode supporting up to about 144 kbps
- Flexible time slot allocation (1-8)
- Radio resources shared dynamically between speech and data services
- Independent uplink and downlink resource allocation

EDGE: Shortcut to Fast Data or Unneeded Detour on the Road to UMTS?

- **E**nhanced **D**ata rates for **G**SM **E**volution is a speed-enhancing modulation upgrade for data transmission and has variants for both GSM-GPRS systems and for US TDMA IS-136 systems.
  - EDGE uses Gaussian Minimum Shift Keying (GMSK) and 8-phase Phase Shift Keying (8-PSK) to allow 144kb/s bit rates for mobile users and 384kb/s for pedestrian users
- With unsynchronized base stations, a GSM network can be upgraded to EDGE in only 2.4 MHz. of spectrum
  - This can be lowered to 600 KHz. If the BTS are synchronized to prevent overtransmission during terminal assignment
- EDGE interest has fluctuated and many GSM and TDMA operators have chosen not to pursue it, believing it is more efficient to move directly to UMTS. This has led several manufacturers to stop their EDGE development activities

UTRA WCDMA Coding

- Like other deployed CDMA systems, UMTS UTRA WCDMA builds signals from individual channels, applying spreading in two steps
  - A channelization code is applied
    - This determines the bandwidth of the signal and the final spreading gain
  - A scrambling code is applied
    - This distinguishes different mobiles at the base station receiver, and different base stations at the mobile receiver
- UMTS channelization codes are variable length orthogonal codes, similar in function to the Walsh codes used in IS-95
- UMTS scrambling codes are different Gold sequences 2^{18} long
  - Each sector in a cluster has a different Gold code and all are transmitted synchronously
- UMTS frames are 10 ms. long and the longer codes are truncated to this length
- The use of a smaller set of known codes allows some fancy mathematical tricks in decoding, advanced receiver algorithms which can improve the reverse link quality

UMTS UTRA Compatibility with GSM

- In addition to using the GSM-MAP network architecture, UMTS systems have been carefully specified to ease the tasks of dual-mode GSM/WCDMA mobiles
- The superframe structures are compatible
  - Frame timing is 10 ms.
  - Dual-mode mobiles can conduct GSM MAHO measurements due to the comparable timing structures

The TDMA IS-136 Path to 3G: UWCS

The TDMA IS-136 Technology Path to 3G

Generation	1G	
Technology	AMPS	
Signal Bandwidth, #Users	30 kHz. 1	
Data Capabilities	None, 2.4K by modem	
Features: Incremental Progress	First System, Capacity & Handoffs	

The TDMA IS-136 Technology Path to 3G

Generation	1G	2G	
Technology	**AMPS**	**CDPD**	
Signal Bandwidth, #Users	30 kHz. 1	30 kHz. Many Pkt Usrs	
Data Capabilities	None, 2.4K by modem	19.2 kbps	
Features: Incremental Progress	First System, Capacity & Handoffs	US Packet Data Svc.	

The TDMA IS-136 Technology Path to 3G

Generation	1G	2G	2G	
Technology	**AMPS**	**CDPD**	**TDMA IS-54 IS-136**	
Signal Bandwidth, #Users	30 kHz. 1	30 kHz. Many Pkt Usrs	30 kHz. 3 users	
Data Capabilities	None, 2.4K by modem	19.2 kbps	none	
Features: Incremental Progress	First System, Capacity & Handoffs	US Packet Data Svc.	USA's first Digital wireless	

The TDMA IS-136 Technology Path to 3G

Generation	1G	2G	2G	2G	
Technology	**AMPS**	**CDPD**	**TDMA IS-54 IS-136**	**GSM**	
Signal Bandwidth, #Users	30 kHz. 1	30 kHz. Many Pkt Usrs	30 kHz. 3 users	200 kHz. 7.5 avg.	
Data Capabilities	None, 2.4K by modem	19.2 kbps	none	none	
Features: Incremental Progress	First System, Capacity & Handoffs	US Packet Data Svc.	USA's first Digital wireless	Europe's first Digital wireless	

The TDMA IS-136 Technology Path to 3G

Generation	1G	2G	2G	2G	2.5G or 3?	
Technology	**AMPS**	**CDPD**	**TDMA IS-54 IS-136**	**GSM**	**GPRS**	
Signal Bandwidth, #Users	30 kHz. 1	30 kHz. Many Pkt Usrs	30 kHz. 3 users	200 kHz. 7.5 avg.	200 kHz. Many Pkt. users	
Data Capabilities	None, 2.4K by modem	19.2 kbps	none	none	9-160 Kb/s (conditions determine)	
Features: Incremental Progress	First System, Capacity & Handoffs	US Packet Data Svc.	USA's first Digital wireless	Europe's first Digital wireless	•Packet IP access •Multiple attached users	

The TDMA IS-136 Technology Path to 3G

Generation	1G	2G	2G	2G	2.5G or 3?	3G	
Technology	**AMPS**	**CDPD**	**TDMA IS-54 IS-136**	**GSM**	**GPRS**	**EDGE**	
Signal Bandwidth, #Users	30 kHz. 1	30 kHz. Many Pkt Usrs	30 kHz. 3 users	200 kHz. 7.5 avg.	200 kHz. Many Pkt. users	200 kHz. fast data many users	
Data Capabilities	None, 2.4K by modem	19.2 kbps	none	none	9-160 Kb/s (conditions determine)	384 Kb/s mobile user	
Features: Incremental Progress	First System, Capacity & Handoffs	US Packet Data Svc.	USA's first Digital wireless	Europe's first Digital wireless	•Packet IP access •Multiple attached users	Faster data rates on dedicated 200 kHz data carrier	

The TDMA IS-136 Technology Path to 3G

Generation	1G	2G	2G	2G	2.5G or 3?	3G	3G
Technology	**AMPS**	**CDPD**	**TDMA IS-54 IS-136**	**GSM**	**GPRS**	**EDGE**	**UMTS UTRA WCDMA**
Signal Bandwidth, #Users	30 kHz. 1	30 kHz. Many Pkt Usrs	30 kHz. 3 users	200 kHz. 7.5 avg.	200 kHz. Many Pkt. users	200 kHz. fast data many users	3.84 MHz. up to 200+ voice users and data
Data Capabilities	None, 2.4K by modem	19.2 kbps	none	none	9-160 Kb/s (conditions determine)	384 Kb/s mobile user	2Mb/s static user
Features: Incremental Progress	First System, Capacity & Handoffs	US Packet Data Svc.	USA's first Digital wireless	Europe's first Digital wireless	•Packet IP access •Multiple attached users	Faster data rates on dedicated 200 kHz data carrier	Integrated voice and data

GPRS Networks

- consists of packet wireless access network and IP-based backbone
- shares mobility databases with circuit voice services and adds new packet switching nodes (SGSN & GGSN)
- will support GPRS, EDGE & WCDMA airlinks
- provides an access to packet data networks
  - Internet
  - X.25
- provides services to different mobile classes ranging from 1-slot to 8-slot capable
- radio resources shared dynamically between speech and data services

UWC-136: The TDMA Modes

- IS-54 and IS-136 operators have steadily refined and exploited narrowband TDMA technology for almost ten years
  - No spreading techniques are used!
  - However, the narrowband channel structure does not offer any simple ways to provide compatible high-bandwidth service
  - Several alternative modes have been investigated:
- 136HS Outdoor, also called EGPRS-136
  - Very similar to EDGE as deployed in GSM systems
  - Uses same network architecture as GPRS
- 136HS Indoor, sometimes called W-TDMA:
  - 1.6 MHz. Wideband carrier with adaptive modulation and rapid bursts
  - High data rates use bursts 1/16 the length of 4.615 ms frames
  - Medium data rates use bursts 1/64 the length of 4.615 ms frames

EDGE Technology

- EDGE: Enhanced Data-rates for Global Evolution
- Evolutionary path to 3G services for GSM and TDMA operators
- Builds on General Packet Radio Service (GPRS) air interface and networks
- Phase 1 (Release'99 & 2002 deployment) supports best effort packet data at speeds up to about 384 kbps
- Phase 2 (Release'2000 & 2003 deployment) will add Voice over IP capability

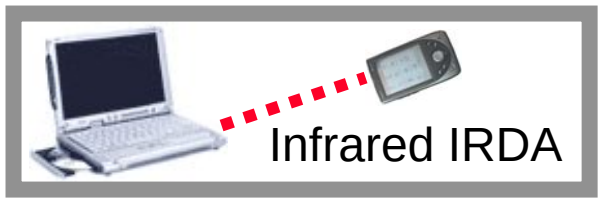
Edge Capabilities and Requirements

- Extends GPRS packet data with adaptive modulation/coding
- 2x spectral efficiency of GPRS for best effort data
- 8-PSK/GMSK at 271 ksps in 200 KHz RF channels supports 8.2 to 59.2 kbps per time slot
- Supports peak rates over 384 kbps
- Requires linear amplifiers with < 3 dB peak to average power ratio using linearized GMSK pulses
- Initial deployment with less than 2x 1 MHz using 1/3 reuse with EDGE Compact as a complementary data service

Wideband LAN (WiLAN) Technologies

Technology	Infrared IRDA	Bluetooth	802.11b	802.11a	HIPERLAN Type 1	HIPERLAN Type 2
Frequency Band	Optical	2.4 GHz	2.4 GHz	5 GHz	5 GHz	5 GHz
Access Method	Single User per Optical Carrier	various	DSSS	DSSS	OFDM	3.84 MHz.
Modulation Type	various	GFSK FH	CCK	BPSK, QPSK, 16QAM, or 64QAM	FSK or GMSK	BPSK, QPSK, 16QAM, or 64QAM
Max Raw Data Rate	4 Mb/s	1 Mb/s	11 Mb/s	54 Mb/s	23.5 Mb/s	54 Mb/s







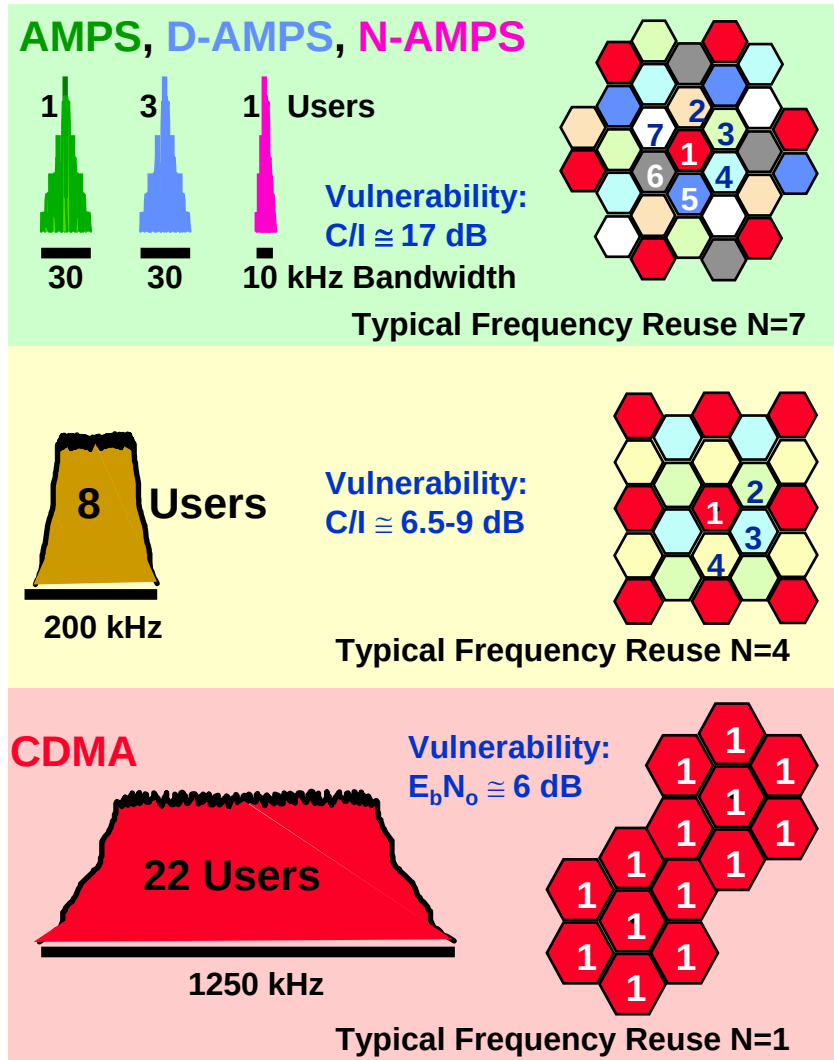
Course 330

Capacity Survey of Wireless Technologies

Wireless System Capacity

Each wireless technology (AMPS, NAMPS, D-AMPS, GSM, CDMA) uses a specific modulation type with its own unique signal characteristics

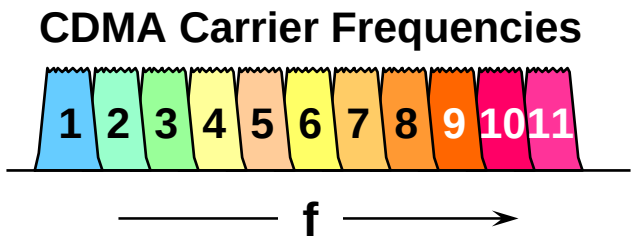
- Signal Bandwidth determines how many RF signals will "fit" in the operator's licensed spectrum
- **Robustness of RF signal determines tolerable level of interference and necessary physical separation of cochannel cells**
- Number of users per RF signal directly affects capacity
- In the following page, we will develop the number of users and traffic in erlangs per site for each of the popular wireless technologies



2G Wireless System Capacity Comparisons

	800 Cellular (A,B)			1900 PCS (A, B, C)			1900 PCS (D, E, F)		
Fwd/Rev Spectrum kHz.	12,500	12,500	12,500	15,000	15,000	15,000	5,000	5,000	5,000
Technology	AMPS	TDMA	CDMA	TDMA	GSM	CDMA	TDMA	GSM	CDMA
Req'd C/I or Eb/No, db	17	17	6	17	12	6	17	12	6
Freq Reuse Factor, N	7	7	1	7	4	1	7	4	1
RF Signal BW, kHz	30	30	1250	30	200	1250	30	200	1250
Total # RF Carriers	416	416	9	500	75	11	166	25	3
RF Sigs. per cell @N	59	59	9	71	18	11	23	6	3
# Sectors per cell	3	3	3	3	3	3	3	3	3
#CCH per sector	1	1	0	1	0	0	1	0	0
RF Signals per sector	18	18	9	22	6	11	6	2	3
Voicepaths/RF signal	1	3	22	3	8	22	3	8	22
SH average links used			1.66			1.66			1.66
Unique Voicepaths/carrier			13.253			13.253			13.253
Voicepaths/Sector	18	54	198	66	48	242	18	16	66
Unique Voicepaths/Sector	18	54	119	66	48	145	18	16	39
P.02 Erlangs per sector	11.5	44	105.5	55.3	38.4	130.9	11.5	9.83	30.1
P.02 Erlangs per site	34.5	132	316.5	165.9	115.2	392.7	34.5	29.49	90.3
Capacity vs. AMPS800	**1**	**3.8**	**9.2**	**4.8**	**3.3**	**11.4**	**1.0**	**0.9**	**2.6**

Multicarrier 2G CDMA Capacity



Fwd/Rev Spectrum kHz.	12,500	1,800	3,050	4,300	5,550	6,800	8,050	9,300	10,550	11,800	13,050	14,300
Technology	**AMPS**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**
Req'd C/I or Eb/No, db	17	6	6	6	6	6	6	6	6	6	6	6
Freq Reuse Factor, N	7	1	1	1	1	1	1	1	1	1	1	1
RF Signal BW, kHz	30	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
Total # RF Carriers	416	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RF Sigs. per cell @N	59	1	2	3	4	5	6	7	8	9	10	11
# Sectors per cell	3	3	3	3	3	3	3	3	3	3	3	3
#CCH per sector	1	0	0	0	0	0	0	0	0	0	0	0
RF Signals per sector	18	1	2	3	4	5	6	7	8	9	10	11
Voicepaths/RF signal	1	22	22	22	22	22	22	22	22	22	22	22
SH average links used	1	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66
Unique Voicepaths/carrier	1	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3
Voicepaths/Sector	18	22	44	66	88	110	132	154	176	198	220	242
Unique Voicepaths/Sector	18	13	26	39	53	66	79	92	106	119	132	145
P.02 Erlangs per sector	11.5	7.4	18.4	30.1	43.1	55.3	67.7	80.2	93.8	105.5	119.1	130.9
P.02 Erlangs per site	34.5	22.2	55.2	90.3	129.3	165.9	203.1	240.6	281.4	316.5	357.3	392.7
Capacity vs. AMPS800	**1**	**0.64**	**1.60**	**2.6**	**3.7**	**4.8**	**5.9**	**7.0**	**8.2**	**9.2**	**10.4**	**11.4**

Current CDMA Network Capacity Issues

- Today, CDMA networks for the most part are still single-carrier
  - this severely limits the capacity of one BTS to approximately 20 erlangs
  - implementing additional carriers brings logistical problems involving handoffs and system acquisition by mobiles
- Multiple-carrier operation is essential to achieve reasonable capacities
- Within networks, there are strategies for squeezing the most out of overloaded single-carrier BTSs. Some of the main points are:
  - reduce Pilot, Sync, and Paging levels as low as possible, thereby gaining precious additional energy for traffic channels
  - reduce BTS traffic channel DGU settings as low as possible without provoking forward link FER.

3G Information Resources
Bibliography - Articles - Web Links

Bibliography, 3G Air Interface Technologies

"3G Wireless Demystified" by Lawrence Harte, Richard Levine, and Roman Kitka 488pp. Paperback, 2001 McGraw Hill, ISSBN 0-07-136301-7 $50. For both non-technical and technical readers. An excellent starting point for understanding all the major technologies and the whole 3G movement. Comfortable plain-language explanations of all the 2G and 3G air interfaces, yet including very succinct, complete, and rigorously correct technical details. You will still want to read books at a deeper technical level in your chosen technology, and may sometimes turn to the applicable standards for finer details, but *this* book will give you what you won't find elsewhere -- how everything relates in the big picture, and probably everything you care to know about technologies other than your own.

"Wireless Network Evolution 2G to 3G" by Vijay K. Garg. 764pp. 2002 Prentice-Hall, Inc. ISBN 0-13-028077-1. $80. Excellent technical tutorial and reference. The most complete and comprehensive technical detail seen in a single text on all these technologies: IS-95 2G CDMA, CDMA2000 3G CDMA, UMTS/WCDMA, Bluetooth, WLAN standards (802.11a, b, WILAN). Includes good foundation information on CDMA air interface traffic capacity, CDMA system design and optimization, and wireless IP operations. Excellent level of operational detail for IS-95 systems operating today as well as thorough explanations of 2.5G and 3G enhancements.

"3G Wireless Networks" by Clint Smith and Daniel Collins. 622pp. Paperback. 2002 McGraw-Hill, ISBN 0-07-136381-5. $60. An excellent overview of all 3G technologies coupled with good detail of network architectures, channel structures, and general operational details. Good treatment of both CDMA2000 and UMTS/WCDMA systems.

"WCDMA: Towards IP Mobility and Mobile Internet" by Tero Ojanpera and Ramjee Prasad. 476pp. 2001 Artech House, ISSBN 1-58053-180-6. $100. The most complete and definitive work on UMTS (excellent CDMA2000, too!). CDMA principles, Mobile Internet, RF Environment & Design, Air Interface, WCDMA FDD standard, WCDMA TDD, CDMA2000, Performance, Heirarchical Cell Structures, Implementation, Network Planning, Basic IP Principles, Network Architectures, Standardization, Future Directions. This is a MUST HAVE for a one-book library!

More Bibliography, 3G Air Interface Technologies

"The UMTS Network and Radio Access Technology" by Dr. Jonathan P. Castro, 354 pp. 2001 John Wiley, ISBN 0 471 81375 3, $120. An excellent, well-organized, and understandable exploration of UMTS. Includes radio interface, channel explanations, link budgets, network architecture, service types, ip network considerations, a masterful tour de force through the entire subject area. Very readable, too!

"WCDMA for UMTS" by Harri Holma and Antti Toskala, 322 pp. 2000 Wiley, ISBN 0 471 72051 8, $60. Very good overall treatment of UMTS. Excellent introduction to 3G and summary of standardization activities, every level of UMTS/UTRA. Good overview of CDMA-2000, too!

"The GSM Network - GPRS Evolution: One Step Towards UMTS" 2nd Edition by Joachim Tisal, 227pp. paperback, 2001 Wiley, ISBN 0 471 49816 5, $60. Readable but not overwhelming introduction to GSM in all its aspects (140pp), DECT (11pp), GPRS (6pp), UMTS (7pp), WAP (25pp), EDGE (10pp).

Bibliography, The IP Aspect of 3G

"Mobile IP: Design, Principles and Practices" by Charles E. Perkins, 275 pp., 200, 1998 Addison-Wesley, ISBN 0-201-63469-4. $60. Comprehensive view of Mobile IP including home and foreign agents, advertisement, discovery, registration, datagrams, tunneling, encapsulation, route optimization, handoffs, firewalls, IPv6, DHCP. Tour-de-force of mobile IP techniques.

"Mobile IP Technology for M-Business" by Mark Norris, 291 pp., 2001 Artech House, ISSBN 1-58053-301-9. $67. GPRS overview and background, Mobile IP, Addressing, Routing, M-business, future prospects, IPv4, IPv6, Bluetooth & IrDA summaries.

"TCP/IP Illustrated, Volume 1, The Protocols" by W. Richard Stevens, 1994 Addison-Wesley, ISBN-0-201-63346-9, 576pp., $66. Comprehensive, definitive, and authoritative exposition of each protocol in modern networking – IP, ARP, RARP, ICMP, IP, dynamic routing, UDP, Broadcasting & multicasting, IGMP, DNS, TFTP, BOOTP, TCP including sections on connection establishment and termination, interactive data flow, bulk data flow, timeout and retransmission, all its parameters; SNMP, Telnet, FTP, SMTP, NFS, and much, much more. Very highly recommended.

"TCP/IP Explained" by Phillip Miller, 1997 Digital Press, ISBN 1-55558-166-8, 518pp. $50. In-depth understanding of the Internet protocol suite, network access and link layers, addressing, subnetting, name/address resolution, routing, error reporting/recovery, network management.

"Cisco Networking Academy Program: First-Year Companion Guide" edited by Vito Amato, 1999 Cisco Press, ISBN 1-57870-126-0, 438pp. Textbook supporting a year-long course on networking technologies for aspiring LAN/WAN (and 3G) technicians and engineers. It covers every popular networking technology (including all its elements and devices) in deep and practical detail. Excellent real-world understanding of TCP/IP, as well as the nuts-and-bolts of everything from physical components to protocols to actual devices such as routers, switches, etc. You might even want to take the evening courses at a local community college near you.

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"CDMA Systems Engineering Handbook" by Jhong Sam Lee and Leonard E. Miller, 1998 Artech House, ISBN 0-89006-990-5. Excellent treatment of CDMA basics and deeper theory, cell and system design principles, system performance optimization, capacity issues. Recommended.

"CDMA RF System Engineering" by Samuel C. Yang, 1998 Artech House, ISBN 0-89006-991-3. Good general treatment of CDMA capacity considerations from mathematical viewpoint.

"CDMA Internetworking: Deploying the Open A-Interface" by Low and Schneider. 616 pp. 2000 Prentice Hall, ISBN 0-13-088922-9, $75. A tour-de-force exposition of the networking between the CDMA BSC, BTS, and mobile, including messaging and protocols of IS-634. Chapters on SS7, Call Processing, Mobility Management, Supplementary Services, Authentication, Resource Management (both radio and terrestrial), 3G A-Interface details. One-of-a-kind work!

"CDMA: Principles of Spread Spectrum Communication" by Andrew J. **Viterbi**. 245 p. Addison-Wesley 1995. ISBN 0-201-63374-4, $65. Very deep CDMA Theory. Prestige collector's item.

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"Mobile and Personal Communication Services and Systems" by Raj Pandya, 334 pp. 2000 IEEE Press, $60. IEEE order #PC5395, ISBN 0-7803-4708-0. Good technical overview of AMPS, TACS< NMT, NTT, GSM, IS-136, PDC, IS-95, CT2, DECT, PACS, PHS, mobile data, wireless LANs, mobile IP, WATM, IMT2000 initiatives by region, global mobile satellite systems, UPT, numbers and identities, performance benchmarks.

"Wireless Telecom FAQs" by Clint Smith, 2001 McGraw Hill, ISBN 0-07-134102-1. Succint, lucid explanations of telecom terms in both wireless and landline technologies. Includes cellular architecture, AMPS, GSM, TDMA, iDEN, CDMA. Very thorough coverage; an excellent reference for new technical people or anyone wishing for clear explanations of wireless terms.

"Mobile Communications Engineering" 2nd. Edition by William C. Y. Lee. 689 pp. McGraw Hill 1998 $65. ISBN 0-07-037103-2 Lee's latest/greatest reference work on all of wireless; well done.

Web Links and Downloadable Resources

Scott Baxter: http://www.howcdmaworks.com
Latest versions of all courses are downloadable.
Category - Username - Password
Intro - (none required) - (none required)
RF/CDMA/Performance - shannon - hertz
3G - generation - third
Grayson - telecom - allen
Agilent - nitro - viper

Dr. Ernest Simo's Space2000: http://www.cdmaonline.com/ *and* http://www.3Gonline.com/

CDG: http://www.cdg.org (check out the digivents multimedia viewable sessions)
The IS-95 and IS-2000 CDMA trade marketing webside, CDMA cheerleaders.

GSM: http://www.gsmworld.com
The GSM Association website. Worldwide GSM marketing cheerleaders but also includes some excellent GSM and GPRS technical overview whitepapers and documents; latest user figures.

UWCC: http://www.uwcc.com
The IS-136 TDMA trade marketing website, TDMA cheerleaders.

RCR News: http://www.rcrnews.com
Wireless Industry trade publication - regulatory, technical, business, marketing news.
Subscribers can access text archives of past articles; very handy in researching events.

Wireless Week: http://www.wirelessweek.com
Wireless Industry trade publication - regulatory, technical, business, marketing news.

More Web Links

3GPP: http://www.3gpp.org/
The operators' harmonization group concerned mainly with ETSI-related standards

3GPP2: http://www.3gpp2.org/
The operators' harmonization group concerned mainly with IS-95-derived CDMA standards

ITU: http://www.itu.int/imt/

ETSI: http://www.etsi.fr/

UMTS forum: http://www.umts-forum.org/

GSM MoU: http://www.gsmworld.com/

TIA: http://www.tiaonline.org/

T1: http://www.t1.org/

ARIB: http://www.arib.or.jp/arib/english/index.html

TTC: http://www.ttc.or.jp/

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Sweet: Cell phones answer Internet's Call, IEEE Spectrum, August 2000 pp. 42-46. Broad summary of technologies, market and regulatory developments, industry direction for 3G.

Luediger, Zeisberg: User and Business Perspectives on an Open Mobile Access Standard, IEEE Communications Magazine, September 2000, pp. 160-163. Observations on a multistandard philosophy, open mobile access network, ultra wideband impulse technology.

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TCP Performance Issues over Wireless Links, IEEE Communications Magazine, April, 2001, pp. 52-58. Discussion of problems and considerations for internet access over wireless links.

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