

# 3G Cellular Systems

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## Second Generation Cellular Systems



- Motivation for 2G Digital Cellular:
  - Increase System Capacity
  - Add additional services/features (SMS, caller ID, etc..)
  - Reduce Cost
  - Improve Security
  - Interoperability among components/systems (GSM only)
- 2G Systems
  - North American TDMA (NA-TDMA)
  - Global System for Mobile (GSM)
  - IS-95 (cellular CDMA)
  - Pacific Digital Cellular (PDC)



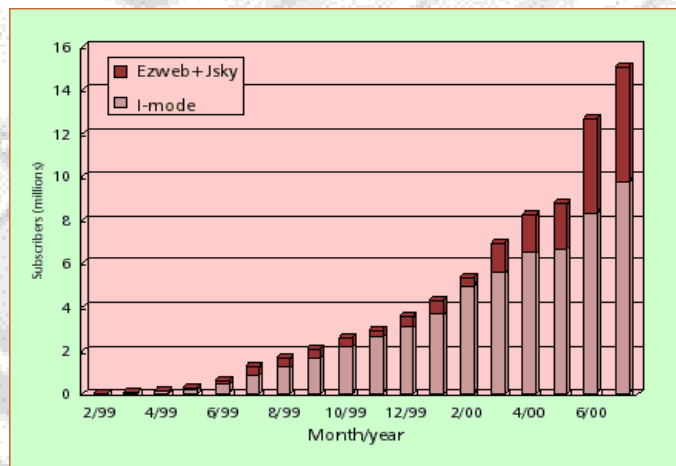
## 3G Driving Factors



- **Forecast 1 billion wireless subscribers by 2004,**
  - more than number of wired access lines!
- **Predicted explosion in *wireless Internet services***
  - more users than the wired Internet 2002 –2004
  - high-speed data/multimedia services from anywhere/any time – *mobile INTERNET*
  - email, web, m-commerce, location aware service,
  - Multimedia message service (MMS) etc.
  - data revenue (SMS) > voice revenue in parts of Europe
- **Converge different regional/national 2G systems => seamless coverage**

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## Wireless Web Access



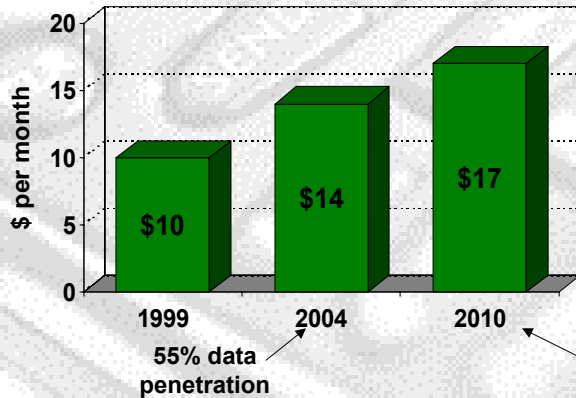
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Source: IEEE Communications Magazine, Dec 2000, pp.136

# Data ARPU Forecast

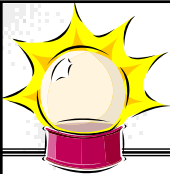


ARPU (per Data User) in W. Europe



ARPU trend impacted by:-

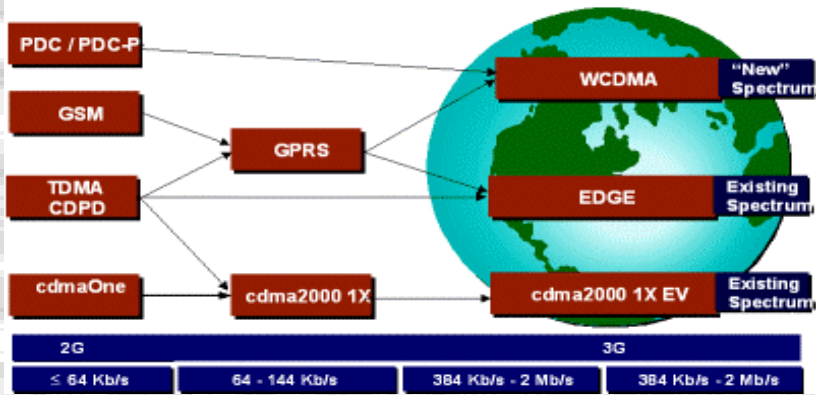
- downward pressure due to changing user mix (more consumers)
- increase due to availability of new applications



# Evolutionary Paths for 3G systems

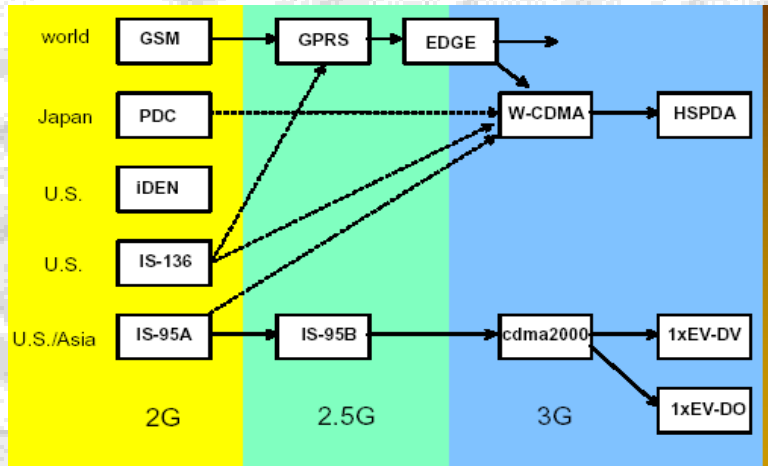


Evolution to 3G / IMT-2000





# Evolutionary Paths for 3G Systems



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## 2.5 G Systems



- 2G Systems provide slow speed data service
  - 9.6 Kbps – 14.4 Kbps
- 2.5G
  - Attempt to improve data services from 2G and build customer base for wireless data service
  - GPRS, HSCSD, *cdma 2000 1x*
  - *Mislabeled as 3G*
  - Basically overlay network of data service on 2G networks (voice still circuit switched)
  - Max data rate 57 Kbps – 150 Kbps
  - Typical data rates 33-56 Kbps – similar to dialup modem service



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# GPRS Network Entities



- GPRS Support Node (GSN): responsible for delivery and routing of data packets between the mobile station and external packet network
  1. Serving GPRS Support Node (SGSN)
    - supports the MS packet delivery (location, billing, security)
  2. Gateway GPRS Support Node (GGSN)
    - interworking unit between GPRS and PDN (Packet Data Network) : like HLR or Home Agent in Mobile IP
- GPRS Register (GR) co-located with the HLR
  - Stores routing information and maps IMSI to a PDN address
  - Signaling between SGSN, HLR, VLR, EIR is similar to GSM and extends only the GPRS related functionality
- Between the MS and SGSN, a GPRS mobility management and session management (GMM/SM) protocol is used

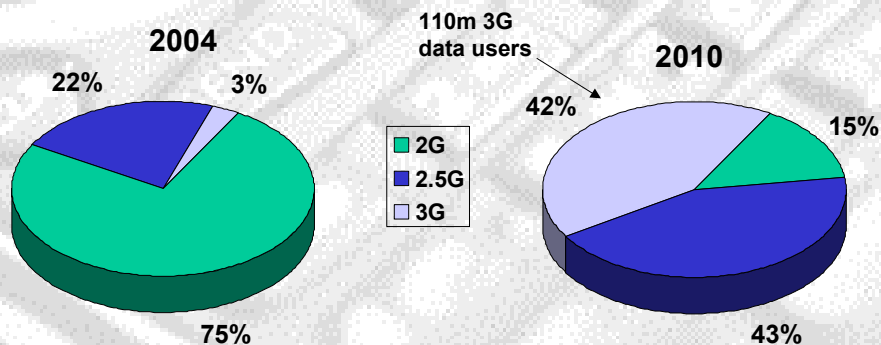
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# 2G to 2.5G to 3G Evolution



% of Cellular Data Users by Technology



- In 1999, almost 100% of data users are on 2G systems
- 2.5G includes HSCSD and GPRS/EDGE

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## Third Generation Cellular



- 1986 ITU-T began studies of 3G as:
  - Future Public Land Mobile Telecom. Systems (FPLMTS)
  - 1997 changed to IMT-2000 (International Mobile Telecom. in Year 2000)
  - ITU-R studying radio aspects, ITU-T studying network aspects (signaling, services, numbering, quality of service, security, operations)
  - *Intended* to evolve and converge 2nd generation systems into 1 global standard to support wireless multimedia
- Currently different competing standards

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## Third Generation Cellular



- IMT-2000 vision of 3G
  - Spectrum: 1885-2025 MHz and 2110-2200 MHz worldwide
  - Multiple radio environments (cellular, cordless, satellite, LANs)
  - Wide range of existing and new services - esp. data, Internet, multimedia - data rates up to 2 Mb/s
- Data rates
  - Vehicular: 144 kbps
  - Pedestrian: 384 kbps
  - Indoor office: 2.048 Mbps
- Support for packet switching and asymmetric data rates
- Devices always on!

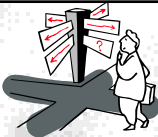
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## 3G Developments



- 1998 ITU-R guidelines for IMT-2000
  - EIA/TIA evaluated N. American proposals to evolve IS-95B CDMA and IS-136 TDMA
  - ETSI evaluated proposals to evolve GSM
  - Japan's ARIB (Assoc. for Radio Industry and Business) developed standards for wideband CDMA to evolve PDC - strongly pushed through ITU-T with support from Europe
- Several proposals with conflicting migration strategies
  - RTTs and Core Infrastructure

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## 3G Confusion



- Most proposals were based on CDMA, but the actual implementation and migration strategies were different
  - TDD or FDD?
  - Variable or fixed spreading?
  - Compatibility with legacy systems?
- Politics and economics played a big role in the standards selection
- ITU pushed for single spectrum worldwide as well as single standard – didn't happen

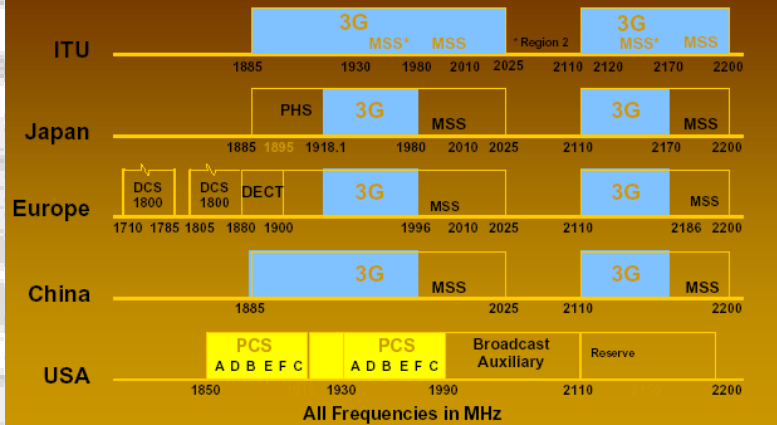
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# Spectrum



## 3G Spectrum Availability [2]



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## Third Generation Cellular



- Main 3rd generation standards:
  - W-CDMA (wideband CDMA) from ETSI and Japan
    - Dominant standard for CDMA outside of US and leading standard for 3G worldwide
    - Viewed by ITU-T as 3G migration path for TDMA systems
  - CDMA 2000
    - IS-95 CDMA is leading air interface for 2G systems in US offered by Verizon, Sprint PCS
    - cdma2000 1X: Qualcomm's pre-3G evolution of CDMA with data rates up to 307 kb/s - "2.5G"
    - cdma2000 2X and 3X: competes directly with W-CDMA up to 2 Mb/s in N. America
  - EDGE (Enhanced Data rates for Global Evolution)
    - TDMA standard with advanced modulation and combined timeslots
    - Provides unification of NA-TDMA and GSM
    - Basically 2.5 G standard – but meets some of 3G requirements

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## Current status of 3G



- Two partnership projects to harmonize and standardize ETSI, ARIB, ANSI etc.
  - 3GPP that deals with European WCDMA proposal
    - Chip rates of 3.84 Mcps
    - FDD and TDD mode
    - All IP backbone and air mode, QoS service classes
  - 3GPP2 that deals with the US cdma2000 proposal
    - Multicarrier CDMA
    - Chip rates of 3.686 Mcps, All IP backbone and QoS
  - Deployments slowly occurring
    - Service providers strapped for cash
    - Many carriers going with 2.5 G first



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## UMTS



- ETSI proposed GSM/TDMA evolution under name Universal Mobile Telecom. Services (UMTS)
- Most of 3G licenses in Europe **required** operator to deploy a UMTS system covering x% of population by a specific date y
  - Germany: 25% of population by 12/03, 50% by 12/05
  - Norway: 80% of population by 12/04
- WCDMA is the radio interface (UMTS Radio Access)
  - Two modes:
    - FDD: separate uplink/downlink frequency bands with constant frequency offset between them
    - TDD: uplink/downlink in same band but time-shares transmissions in each direction

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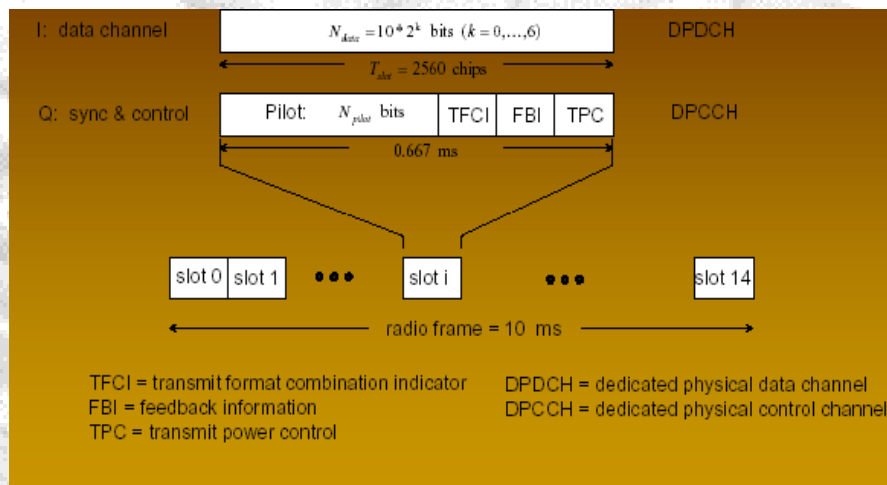
# WCDMA



- Wideband direct sequence spreading + variable orthogonal spreading for multiple access
- Spreading gains vary with user data rate and mode (FDD or TDD)
- QPSK modulation
- 5-MHz Channel (25 GSM channels)
  - Each service provider can deploy multiple 5MHz carriers
  - Each 5 MHz shared by multiple subscribers
  - Maximum chip rate = 3.84 megachips/sec
  - Standard advantages of CDMA
    - Soft handoff,
    - frequency reuse of 1,
    - Better quality in multipath environment, RAKE receiver, etc.

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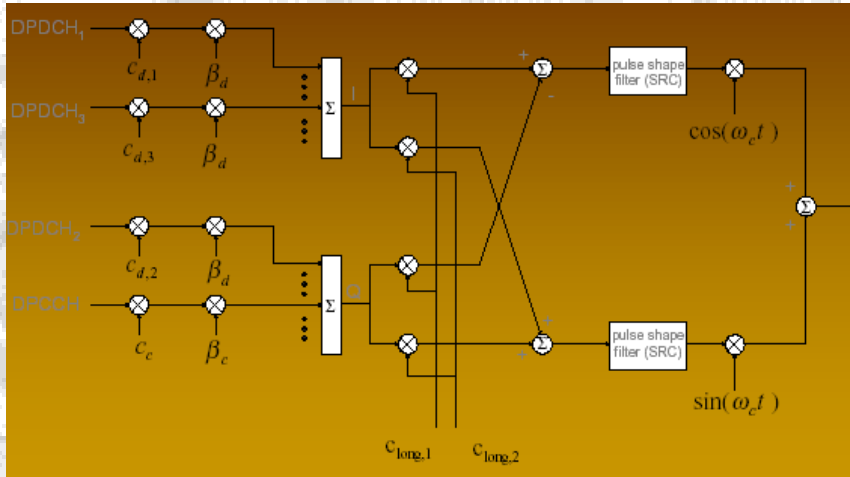
## WCDMA Uplink Frame Structure



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# WCDMA QPSK Modulator

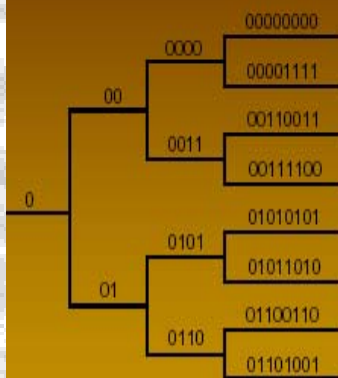


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# WCDMA Variable Spreading



$C_{d,i}$  selected from this tree



Notes:

- 1) For fixed chip rate, desired information rate determines length of spreading sequence and therefore processing gain.
- 2) When a specific code is used, no other code on the path from that code to the root and/or on the subtree beneath that code may be used.
- 3) All the codes at any depth into the tree are the set of Walsh Sequences.
- 4) Code phase is synchronous with information symbols.
- 5) FDD UL processing gain between 256 and 4  
FDD DL processing gain between 512 and 4  
TDD UL/DL processing gain between 16 and 1

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## WCDMA



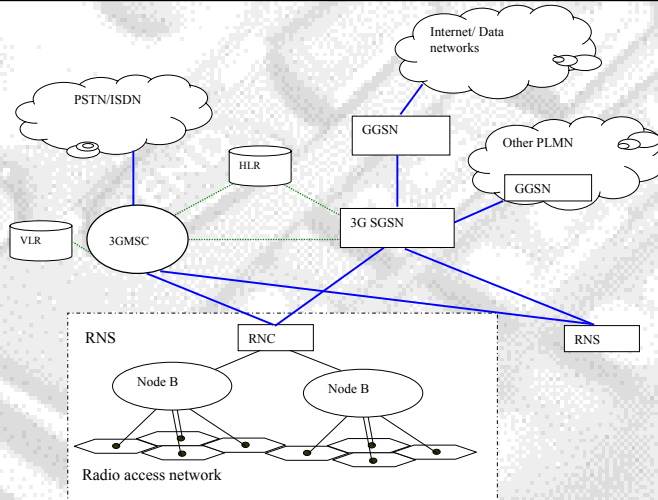
- Uses fixed rate 7.95Kbps speech coding with VAD/DTX also support AMR coding
- Forward Error Correction Coding
  - Convolutional Coding: for voice and control info
    - $\frac{1}{2}$  rate and  $\frac{1}{3}$  rate codes with constraint length 8
  - Block Interleave over 10, 20, 40, or 80 ms
  - Turbo Coding for data and some control info
    - Two parallel rate  $\frac{1}{3}$  convolutional codes constraint length 3 with interleaving – block length 320 – 5120 bits
    - Iterative decoding to improve BER in poor channel environments.
- Power control in forward and reverse links (1500 Hz)

## WCDMA (UMTS)



- UMTS has a complete system architecture
  - As in GSM emphasis on standardized interfaces
    - mix and match equipment from various vendors
  - Base stations are asynchronous from each other
  - Simple evolution from GPRS – allows one to reuse some of the GPRS backhaul equipment
  - Supports inter-mode handoff – FDD to TDD
  - Supports intersystem handoff
    - WCDMA to GPRS , or WCDMA to GSM
  - Wide range of data rate due to variable spreading, coding and modes

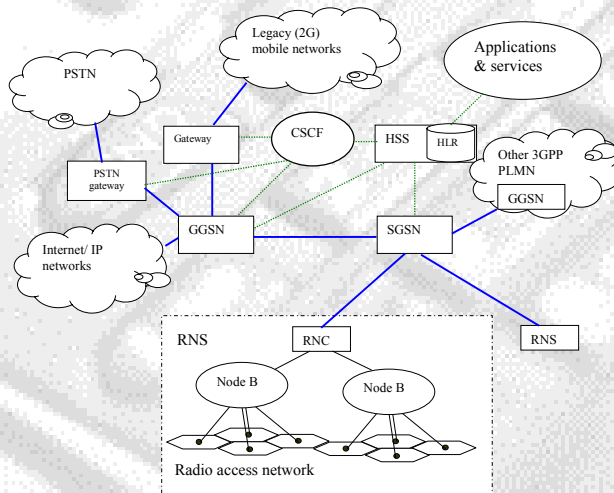
# UMTS System Architecture



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Figure 1.4 the UMTS system architecture [28, Figure 5.1]

# 3GPP IP Reference Architecture



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Figure 1.5 The 3GPP IP reference architecture



## EDGE



- W-CDMA is favored radio interface for 3G situations where increased bandwidth can be tolerated
  - Alternative (EDGE) is favored where wideband is not appropriate or possible
- UWC-136 IMT-2000 proposal is family of TDMA operating modes
  - Enhancements to existing TIA/EIA-136 30-kHz channels (designated IS-136+)
    - Change modulation from 2 bits/symbol (QPSK class) to 3 bits/symbol (8PSK class) → effective data rate 45-50 kb/s per 30-kHz channel
  - Additional wider 200 kHz TDMA-based carrier for vehicular/outdoor (called IS-136HS outdoor)
    - Includes GPRS, data rates up to 384 kb/s

## EDGE (Cont)



- TDMA frame is GSM based = 4.615 ms, 8 timeslots per frame
- 200-kHz carrier allows convergence of IS-136 TDMA and GSM
- This physical layer is referred to as EDGE
- Additional 1.6 MHz TDMA bandwidth for indoor (IS-136 HS indoor)
  - Data rates up to 2 Mb/s
  - TDMA frame = 4.615 ms, 64 or 16 timeslots per frame Basically GSM with higher level modulation+coding+ combined time slots and/or carriers to meet ITU data rates
- Uses GSM MAP signalling in wired network

# cdma2000

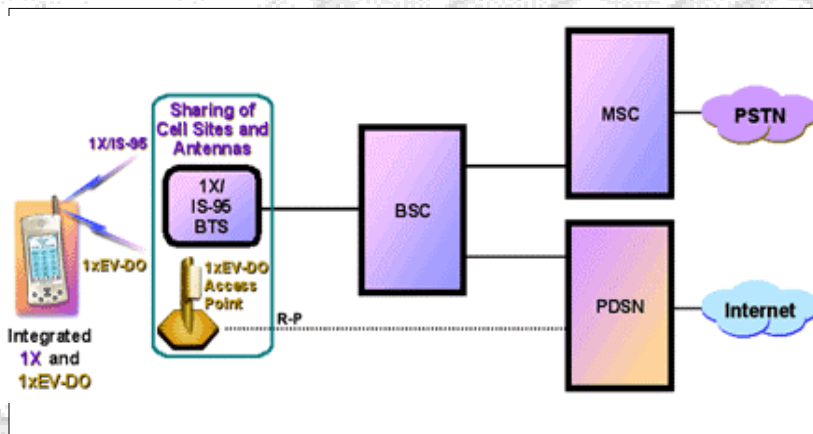


- cdma2000 is also called multi-carrier mode CDMA
  - Goal: provide 3G services over TIA/EIA-41 systems which include IS-95 CDMA
  - Evolutionary path
    - cdma2000-1xRTT uses multiple codes (4) on same carrier 2.5G to support packet data – up to 70 Kbps
    - cdma2000-1x-EVO – combines voice and data over common packet data infrastructure
    - cdma2000-2x changes air interface
  - CDMA 2000-2x and 3x
    - Extension of IS-95 – uses 3 x 1.25Mhz IS-95 channels
  - IS-41 signalling in core
  - Variable rate vocoder : error control treats every bit the same

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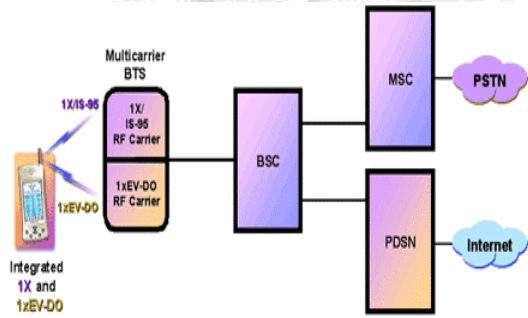
# cdma2000



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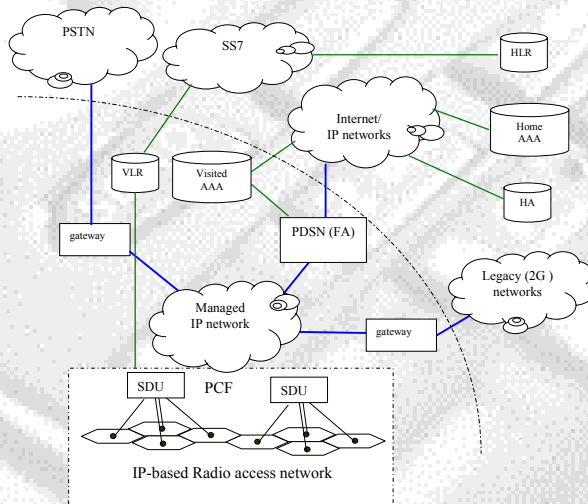


# cdma2000



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# 3GPP2 IP Architecture Model



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Wireless Access Provider Network

Figure 1.6 The 3GPP2 IP architecture model supporting mobile IP



## Systems Comparison



	CDMA 2000	WCDMA	GSM	IS-95
Physical Channel	1 to 3 1.25 MHz channels	5 MHz	200 kHz	1.23 MHz
Modulation	OQPSK	QPSK	GMSK	OQPSK
Channel rate	1.288 Mcps to 3.6864 Mcps	3.84 Mcps	270.833kbs	1,228.8kcps
Modulation Efficiency (b/s/Hz)	1	.768	1.4	1.0

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3G.co.uk



## Systems Comparison

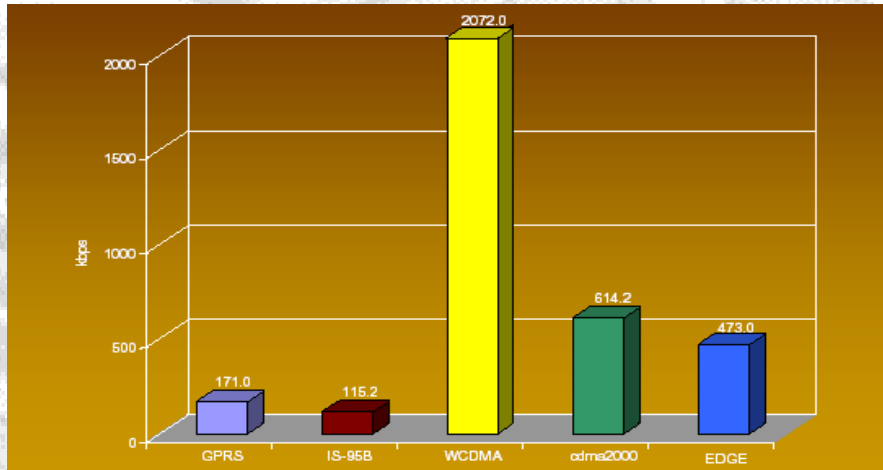


	CDMA 2000	WCDMA	GSM	IS-95
Power Control	800 Hz up and down link	1500 Hz up and down link	2Hz	800 Hz uplink
Base Station Synch	Yes using GPS	No	No	Yes, using GPS
Load Based Scheduling	Somewhat with coding and multiple carriers	Yes variable Spreading and coding, TDD mode	Voice only	Voice only
System standard	Air only	Complete System	Complete System	Air only

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# Peak Data Rates



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# Wireless Capacity



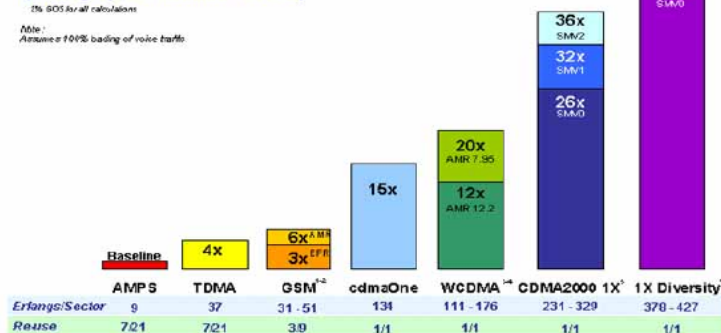
3GSM World Congress February 29, 2002

## Voice Capacity Comparison

(Erlangs per Sector in 10 MHz)

1% LOS for all calculations

Note: Assumes a 100% loading of voice traffic



1 Source: "The Rise of the 3G Era", Ericsson, Ericsson, Alex Brown, September 2001  
 2 Assumes 50% increase in voice capacity using a 1X with 39 reuse ("GSM AMR Capacity" - Qualcomm Internal analysis)  
 3 Source: "3GSM ULS for UETS" - Radio Access for Third Generation Mobile Communications, van Wely & Sim, KTD, copyright 2000  
 4 Source: "The Rise of the 3G Era", Ericsson, Ericsson, Alex Brown, December 2001  
 5 Source: "3G Capacity Forecasts" - Andy Shepard (Qualcomm), reference CDG-C-11-2000, 18/09/00, October 10, 2000, Assumes 8/16 + 3/24 and 20% power control gain  
 6 Source: "3G Capacity Improvements in CDMA Cellular Systems" - Qualcomm Inc. Robert Paterson (California Institute of Technology)

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Source: Qualcomm



# Trends



- 2.5G
  - More data services and usage than ever before
  - GPRS, HSCSD, EDGE, *cdma 2000 1x*
  - High speed WLANs
  - Bluetooth
- 3G
  - (UMTS) WCDMA, *CDMA 1xEV-DO*, *1xEV-DV*
  - IP in the backbone, All IP?
  - Higher data rates
- B3G/4G
  - Hybrid wireless data networks, cellular +WLAN

# Generations of mobile communications



Feature/ Decade	1980s	1990s	2000s	2010s	2020s
<b>Generation</b>	First	Second	2.5G	Third	Fourth/Fifth
<b>Keywords</b>	Analog	Digital Personal	Wireless Data	High speed wireless data	High Data rate, IP- based, high mobility
<b>Multiaccess</b>	FDMA	TDMA CDMA	<b>TDMA</b> <b>CDMA</b>	CDMA	Mixed
<b>Systems</b>	Analog Cellular	Digital Cellular	HSCSD, GPRS, Cdma 2000	EDGE, WCDMA, CDMA2000	4G-Cellular, Hybrid networks
	Analog Cordless	Digital Cordless	Max Data rate 150kbps	Minimum data rate 2-20 Mbps?	Minimum Data rate 2-20 Mbps?
		Mobile Data			
		Mobile Satellite			