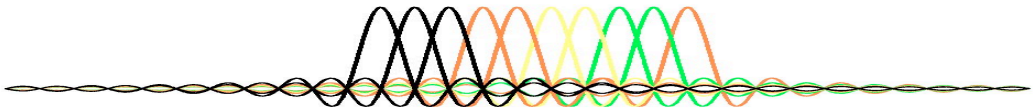


EHB 453, Introduction to Mobile Communications

Lecture 1: Introduction

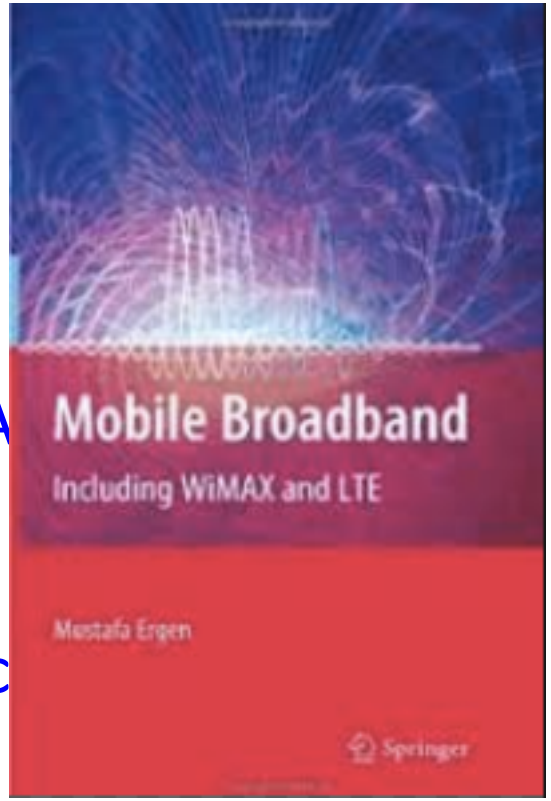
Prof. Mustafa Ergen

Course Basics

- Instructor: Mustafa Ergen,

- Lectures:
  - Tuesday, 9.30pm-12.20pm,

- Recommended Textbook:
  - Mobile Broadband – Including WiMA
- Class Homepage:
  - TBD
  - All handouts, lecture notes, announc posted to website



- Class Mailing List: TBD or WhatsApp – 0 554 7462813

Text Books

- *"Mobile Broadband – Including WiMAX and LTE," by Mustafa Ergen from Springer, 2009*
- *Andrea Goldsmith, Wireless Communications, Cambridge University Press, 2005.*
- *David Tse and Pramod Viswanath, Fundamentals of Wireless Communication, Cambridge University Press, 2005*
- *John Proakis, Digital Communications, Mc Graw Hill, 2001*
- *Ahmad R. S. Bahai, Burton R. Saltzberg, Mustafa Ergen, Multi-carrier Digital Communications: Theory and Applications of OFDM, Springer, 2004*

Course Information Policies

- Grading:
  - Midterm: %30
  - Homework: %20
  - Final Project: %30
  - 2 out of 5 Quizzes: %10
  - 3 out of 7 Attendance: %10

Outline

- The course will cover the upcoming mobile broadband technology and introduce basic building-blocks of today's communication and networking components.

- All-IP Networking brings tight interaction of wireless with IP communication. Hence, we'll see both sides of the story.

- The course will also talk about recent virtualization and AI trends in 5G mobile communication such as SDN, NFV.

Syllabus 1/12

- Introduction to Mobile Broadband
  - 4G and 5G
    - » 1G, 2G, 3G,
  - Mobile Market

Syllabus 2/12

- Wireless Communication Basics
  - Cellular Communication
  - Wireless Channel
  - Digital Communication
  - Rayleigh, Rician Channels
  - OFDM/OFDMA
  - Diversity
  - Duplexing

Syllabus 3/12

- All-IP Networking
  - IP
  - IP Routing
  - QoS
  - IP Security
  - AAA
  - EAP
  - Mobile IP
  - DHCP, NAT
  - SIP, IMS

Syllabus 4/12

- 3G and 4G Wireless Communication
  - WCDMA
  - OFDM
    - Coding
    - Synchronization
    - Channel Estimation
    - Equalization
    - PAPR

Syllabus 5/12

- Resource Allocation
  - Multiple Access
  - OFDMA
  - Frequency Reuse
  - Flash-OFDM

Syllabus 6/12

- MIMO
  - Spatial Diversity
  - MIMO Basics
  - SIMO/MISO/MIMO
  - Space Time Coding
  - BLAST
  - IEEE 802.11n

Syllabus 7/12

- UMTS
  - Networking
  - WCDMA
  - HSPA

Syllabus 8/12

- WiMAX
  - IEEE 802.16 OFDMA PHY/ IEEE 802.16m / IEEE 802.16j
    - Symbol
    - Frame
    - MIMO
    - Coding
    - Control
  - MAC
    - Header Suppression
    - ROHC
    - Sleep Mode
    - Handover
  - Network
    - Access Network
    - Reference Points
    - Accounting
    - Mobility
    - ROHC/MCBCS/LBS/ES/LI/USI/OTA

Syllabus 9/12

- LTE
  - EPS
  - E-UTRAN
  - LTE Networking
  - LTE MAC
  - LTE PHY
  - SC-FDMA

- 5G

Syllabus 10/12

- 5G Smallcells
    - Architecture
    - Interference Management
    - RRM
    - Handover
- 5G and Beyond

Syllabus 11/12

- Self Organizing Networks
- Artificial Intelligence

Syllabus 12/12

- Software Defined Networking
- Network Function Virtualization
- Network App Functions

Before Mobile Broadband

Paving the way towards 5G and beyond

Wireless Telegraph

Samuel Morse

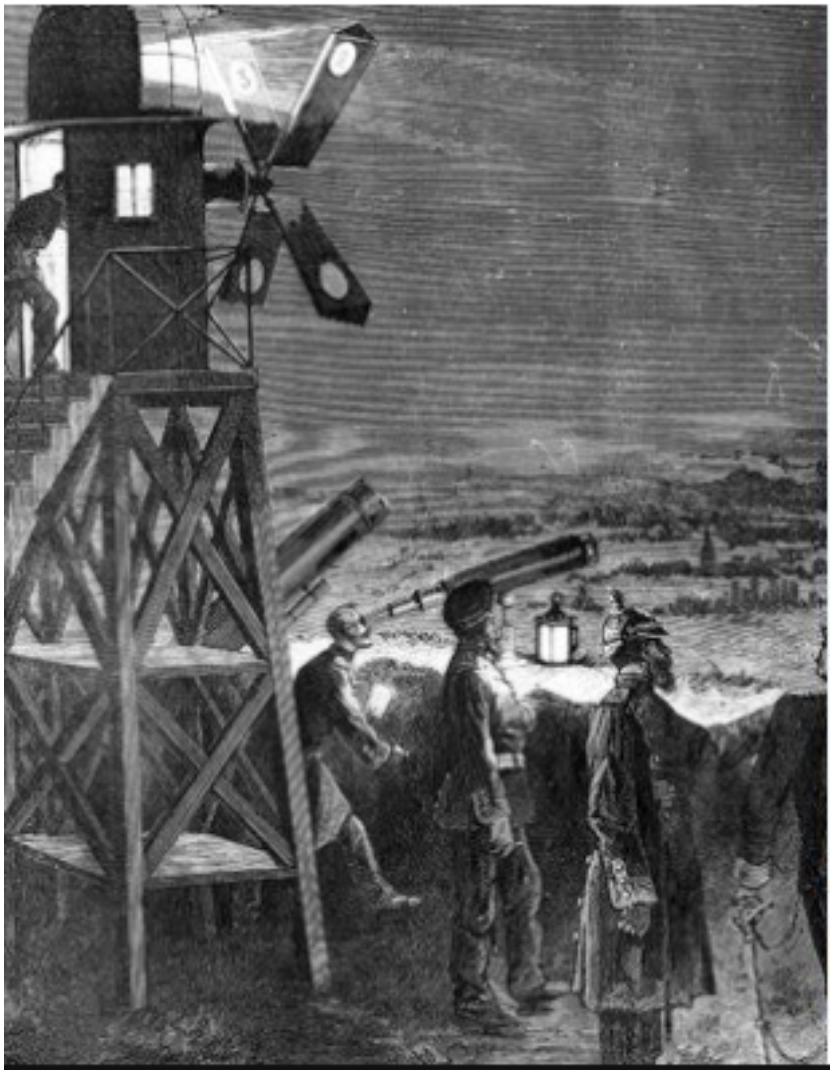
1842

1894 - Guglielmo Marconi

- **Tesla patents in 1892 but until 1942, Marconi's patent is valid.**

Telegraph by light - Semaphore

Napoleonic semaphore was the world's first telegraph network, carrying messages across 19h-Century France faster than ever before.



Wireless History

Very Very Early- Concept

One very highly-elevated antenna in a very large service area

One channel

Very very low bit rate !!!!

Pre-Cellular Concept

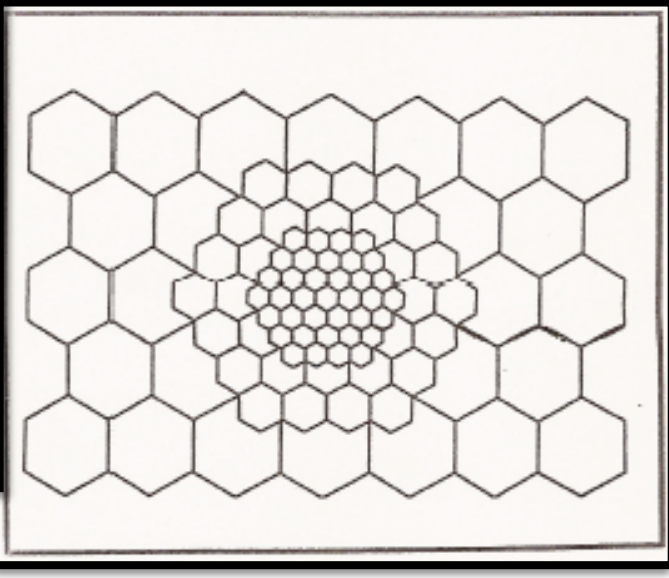
First Mobile Telephone Radio 1924

One highly-elevated antenna in a large
Service area

Small number of channel

Very low capacity

Cellular Concept



Frequency Reuse

Multiple Access

Proposed by Bell Laboratories in 1947

FCC Chairman Powell statement

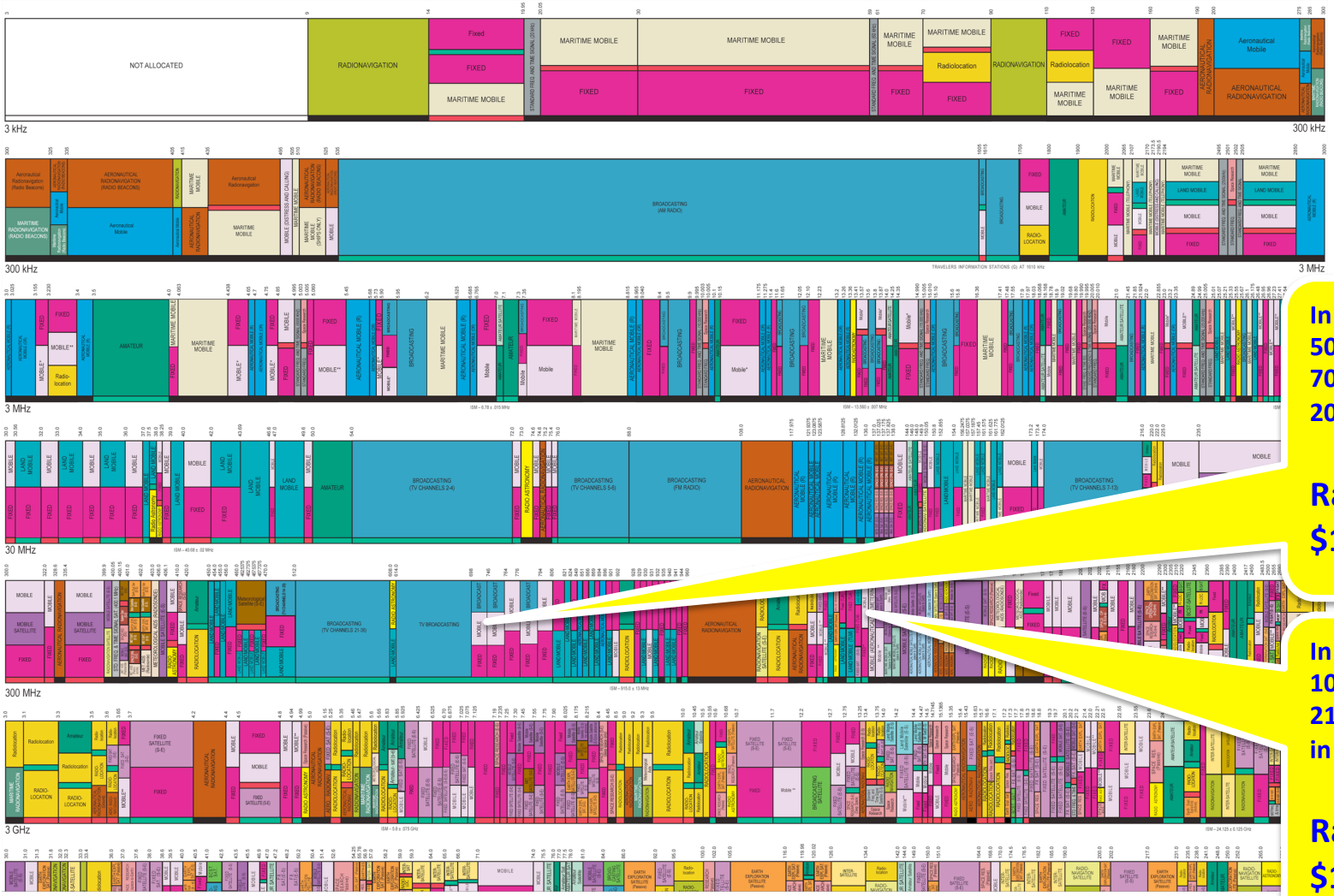
- We are still living under a spectrum "management" regime that is 90 years old. It needs a hard look, and in my opinion, a new direction.
- Historically, I believe there have been four core assumptions underlying spectrum policy:
- Unregulated radio interference will lead to chaos;
- Spectrum is scarce
- Government command and control of the scarce spectrum resource is the only way chaos can be avoided
- The public interest centers on government choosing the highest and best use of the spectrum.

Powell's statement (cont.)

- Today's environment has strained these assumptions to the breaking point.
- Modern technology has fundamentally changed the nature and extent of spectrum use. So the real question is, how do we fundamentally alter our spectrum policy to adapt to this reality?
- The good news is that while the proliferation of technology strains the old paradigm, it is also technology that will ultimately free spectrum from its former shackles.

What is our resource? Wireless Spectrum

- It is all about spectrum!!!



In USA 50MHz at 700MHz in 2008

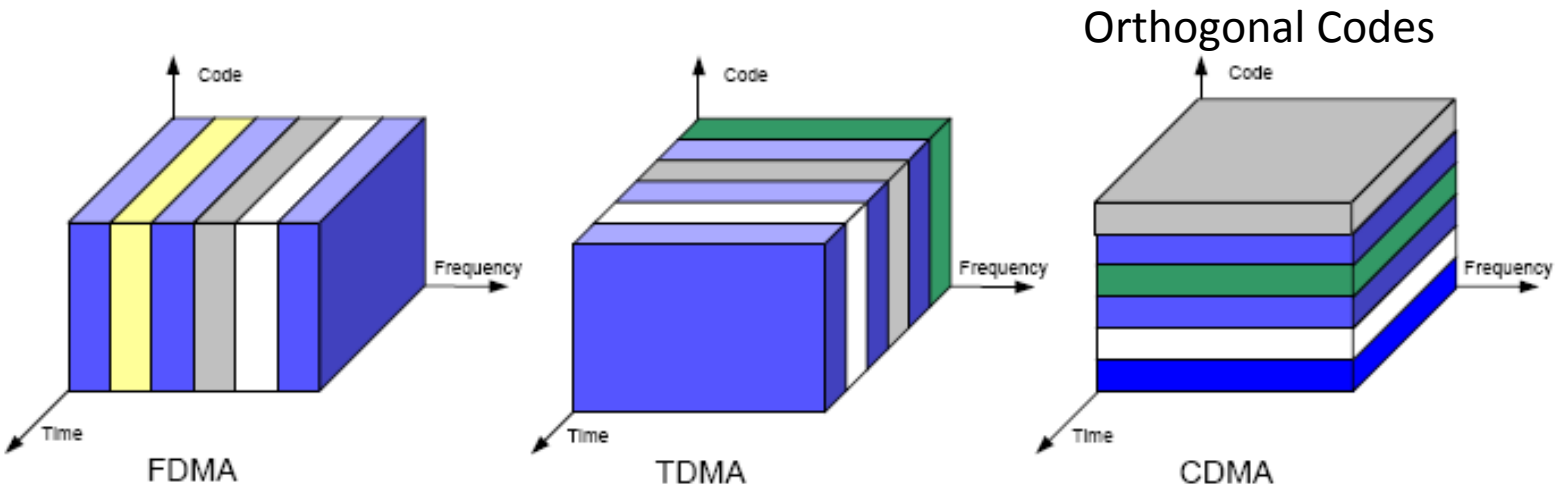
Raised $19B

In TR, 3G 105MHz at 2100MHz in 2008

Raised $1.3B

How we can achieve Multiple Access?

- By creating orthogonal resources



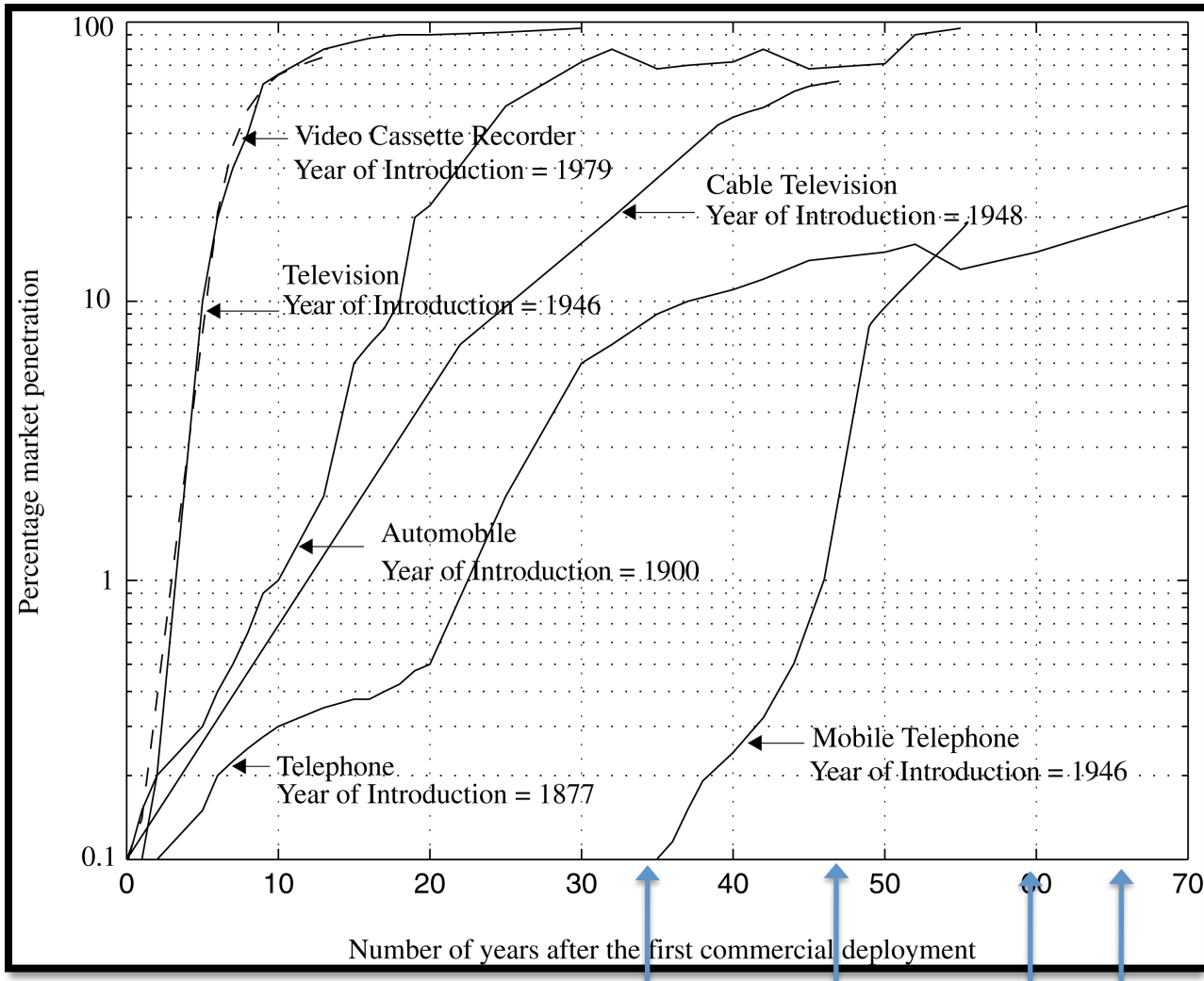
Frequency
Division
Multiple
Access

Time
Division
Multiple
Access

Code
Division
Multiple
Access

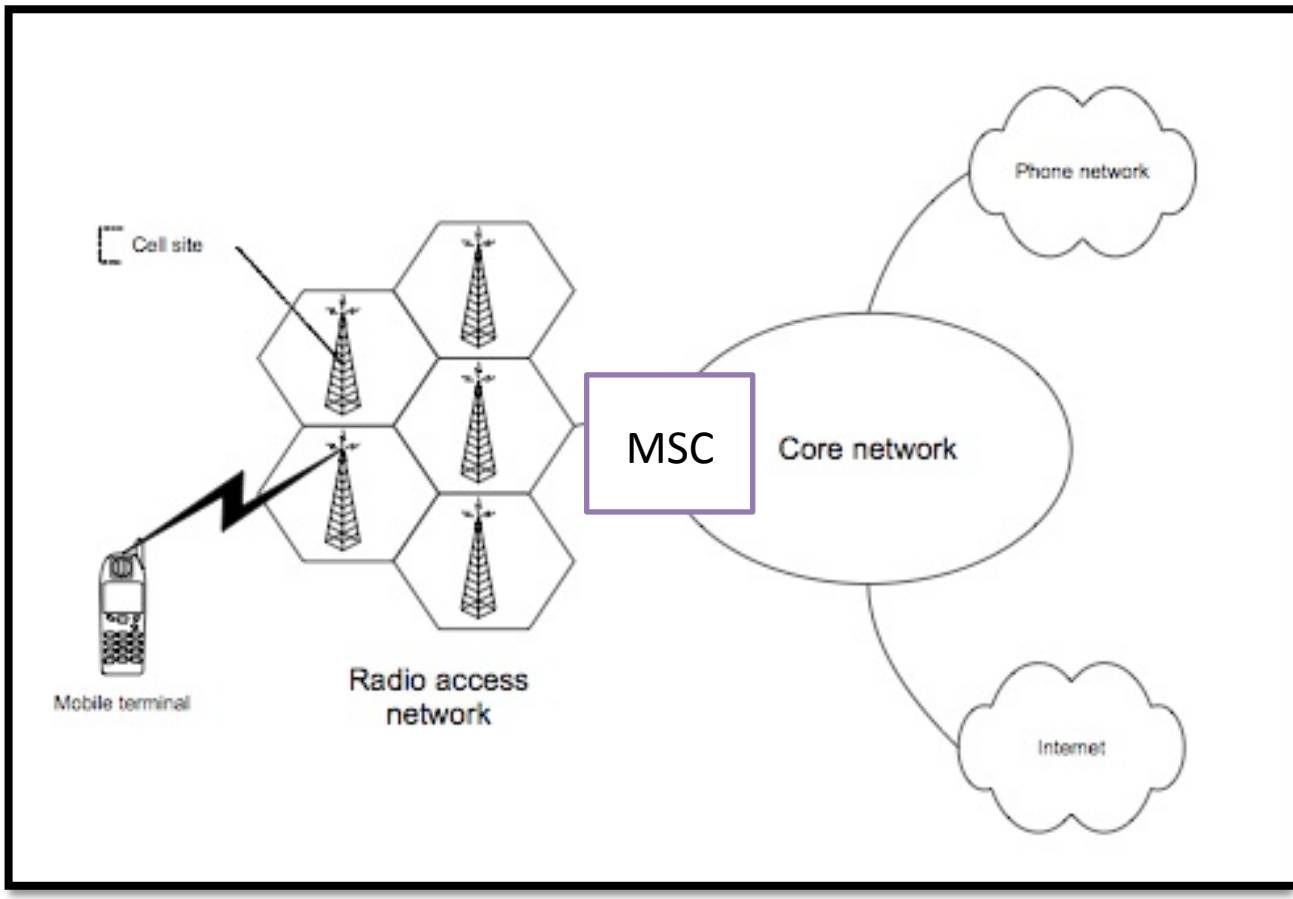
When it is started?

- 1G- Analog Voice
- AMPS - *FDMA*
  - Invented 1946
  - Deployed in 1980s
  - 30KHz FM
  - Lack of standardization

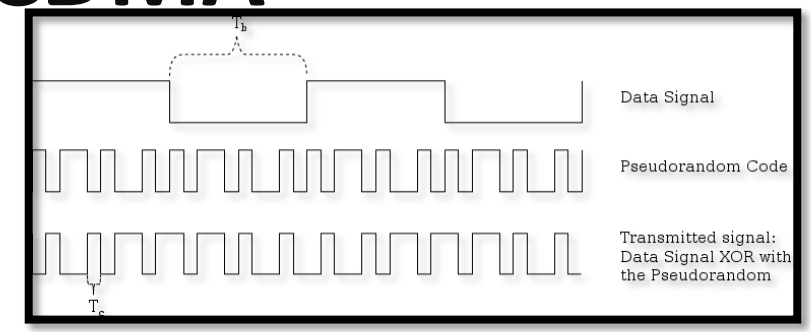


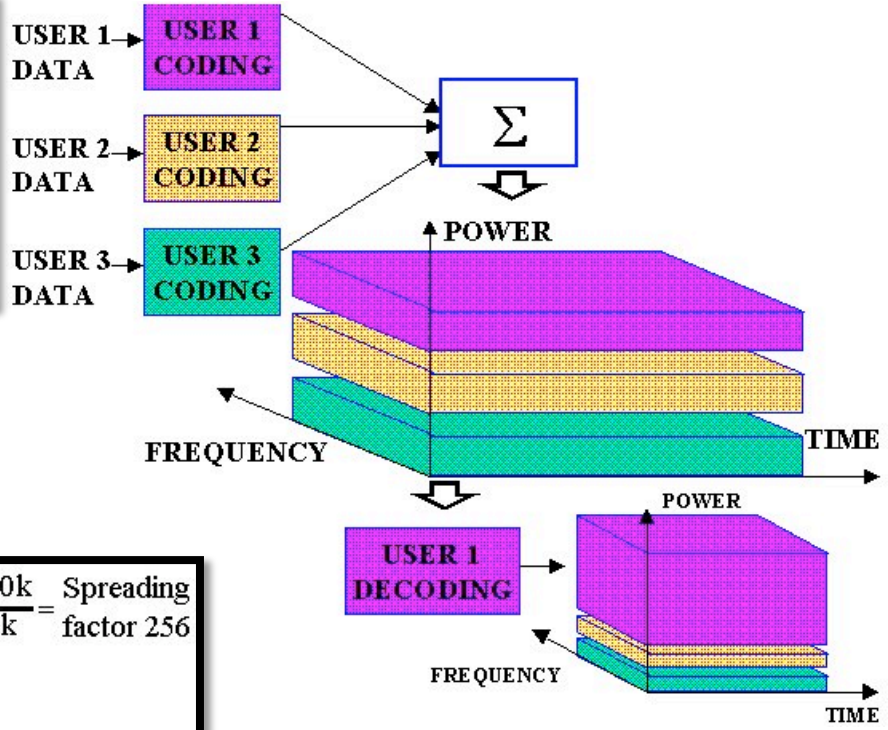
When “people” start using it?

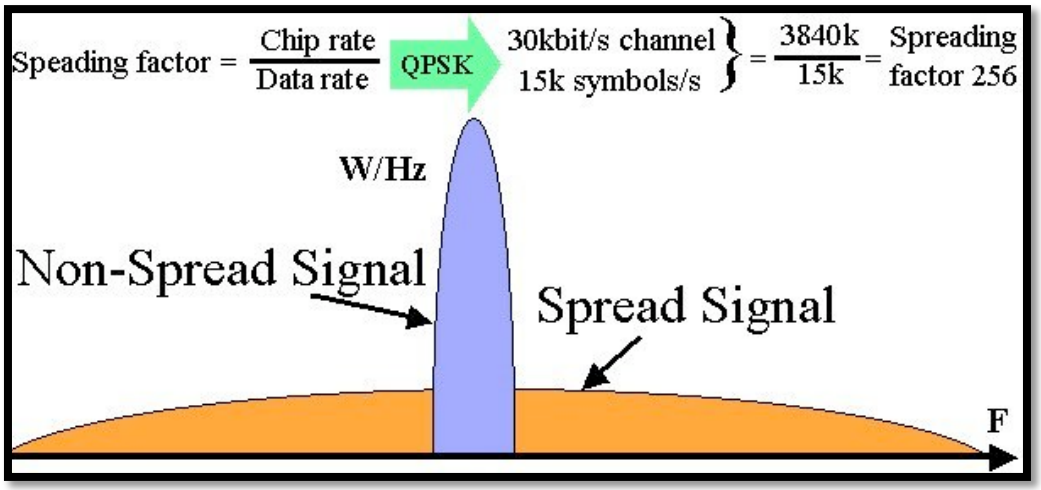
- 2G- digital voice
- GSM in Europe – *TDMA*
- IS-95 in US - *CDMA*
- Frequency allocation problem – no roaming



What is an Orthogonal Code? In CDMA







How about data?

- 2G – Packet-based data services
  - GSM
    - GPRS
      - Peak data rates up to 140Kbps
    - EDGE
      - Peak data rates up to 384Kbps
  - IS-95
    - IS-95A
      - Up to 14.4Kbps circuit switched data
    - IS-95B
      - Up to 64Kbps packet-switched data

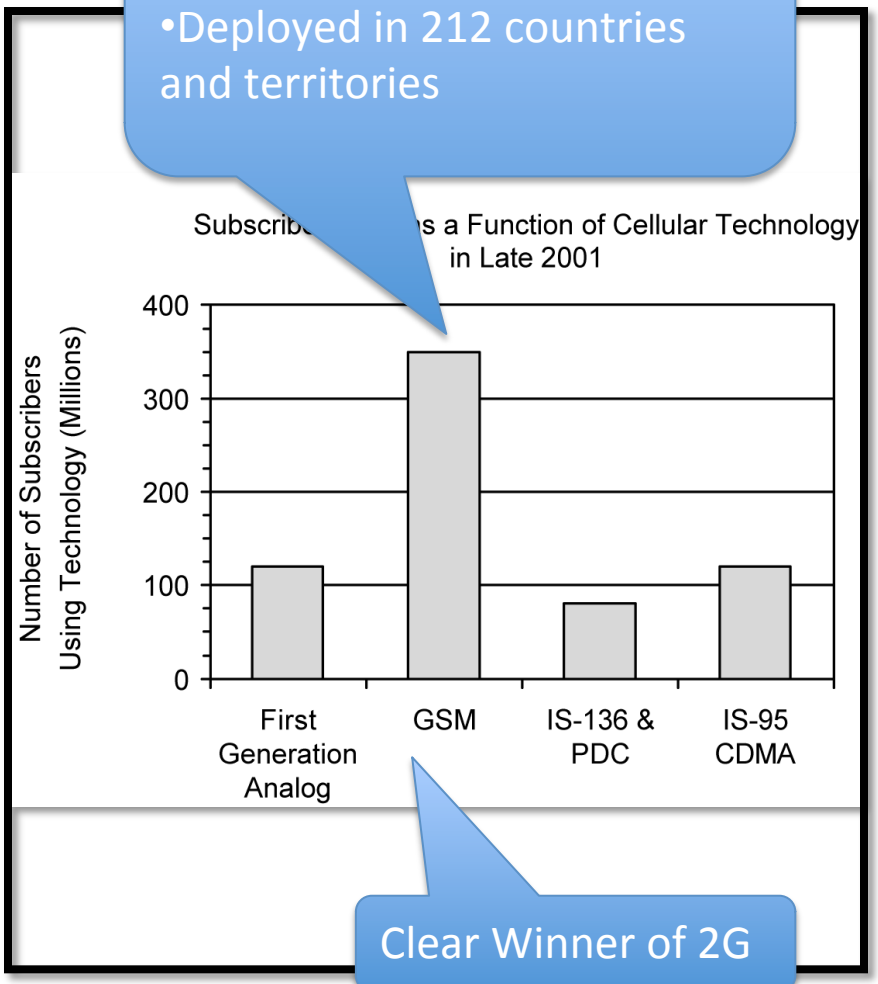
Radio Standards in North America up to 2G

Table 1.1 Major Mobile Radio Standards in North America

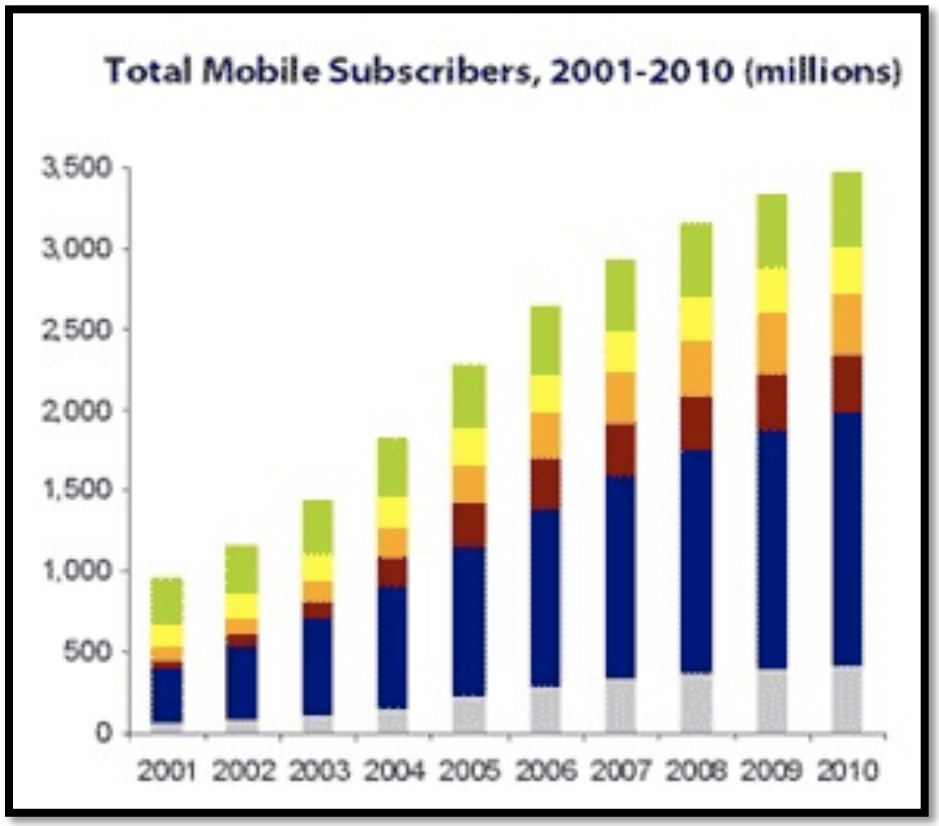
Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
AMPS	Cellular	1983	FDMA	824-894 MHz	FM	30 kHz
NAMPS	Cellular	1992	FDMA	824-894 MHz	FM	10 kHz
USDC	Cellular	1991	TDMA	824-894 MHz	π/4-DQPSK	30 kHz
CDPD	Cellular	1993	FH/Packet	824-894 MHz	GMSK	30 kHz
IS-95	Cellular/PCS	1993	CDMA	824-894 MHz 1.8-2.0 GHz	QPSK/BPSK	1.25 MHz
GSC	Paging	1970s	Simplex	Several	FSK	12.5 kHz
POCSAG	Paging	1970s	Simplex	Several	FSK	12.5 kHz
FLEX	Paging	1993	Simplex	Several	4-FSK	15 kHz
DCS-1900 (GSM)	PCS	1994	TDMA	1.85-1.99 GHz	GMSK	200 kHz
PACS	Cordless/PCS	1994	TDMA/FDMA	1.85-1.99 GHz	π/4-DQPSK	300 kHz
MIRS	SMR/PCS	1994	TDMA	Several	16-QAM	25 kHz
iDen	SMR/PCS	1995	TDMA	Several	16-QAM	25 kHz

Adoption before 3G?

- Market Penetration %80
- Total num of subs: > **3B**
- Deployed in 212 countries and territories

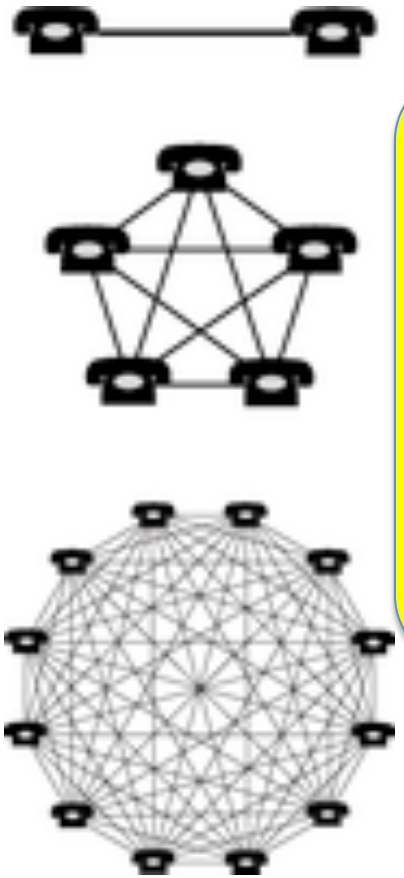


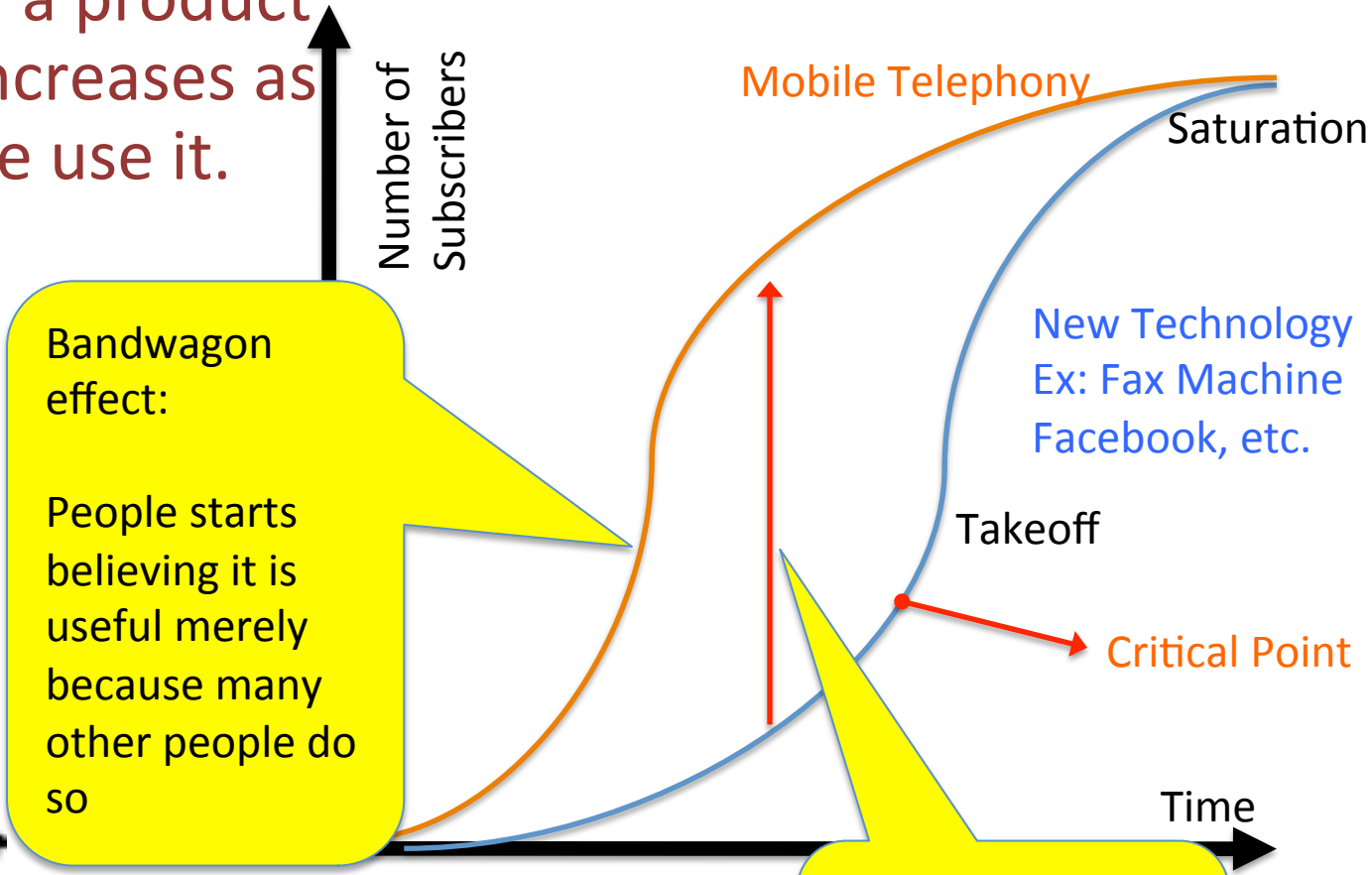
Clear Winner of 2G



How it is adopted? Network Externality

- the value of a product or service increases as more people use it.





Broadband and WiFi

- Started with DSL – Digital Subscribers Line
  - Utilizes twisted pair copper wire of the local loop of the public switched telephone network (PSTN)
    - Plain Old Telephone Service (POTS)
      - Utilizes 300 and 3.4KHz for voice communication
    - DSL
      - Utilizes beyon 3.4KHz
      - The length and quality of loop determines the upper limit
      - Utilizes Discrete Multitone Modulation
        - » OFDM: Orthogonal Frequency Division Multiplexing

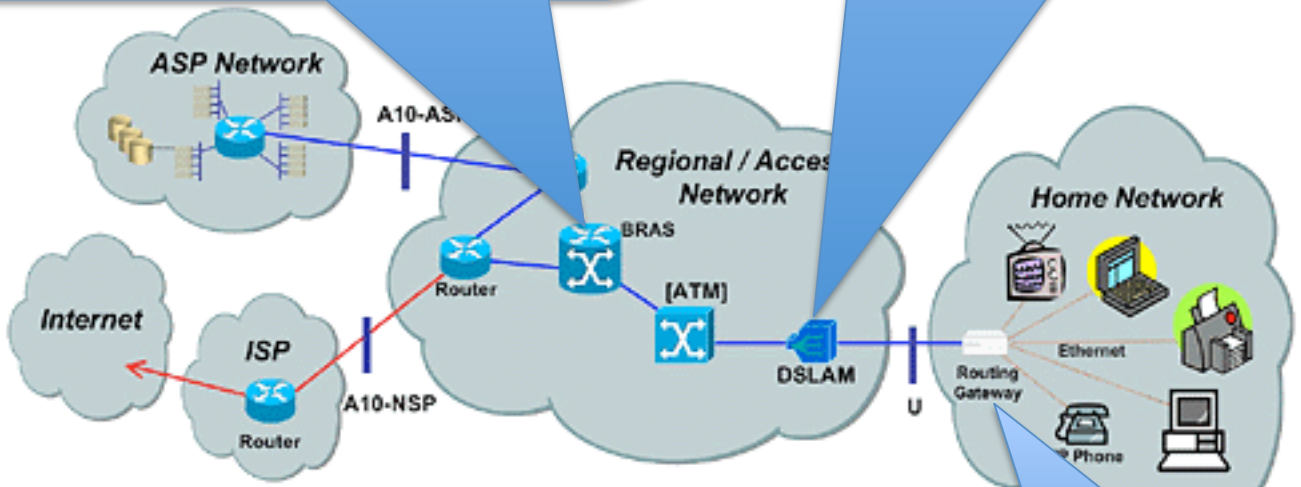
DSL Architecture

Broadband Remote Access Server

- Aggregates the output from DSLAMs
- Provides user PPP sessions over IP or ATM sessions
- Enforces quality of service (QoS) policies
- Routes traffic into an Internet service provider's backbone network

Digital Subscriber Line Access Multiplexer

a device for DSL service. Sending on the customer or downstream side, it intermixes voice traffic and data traffic on the customer's DSL line. Receiving on that side, it accepts and separates outgoing phone and data signals from the customer. It directs the data signals upstream to the appropriate carrier's network, and the phone signals to the voice switch.



DSL Modem

xDSL

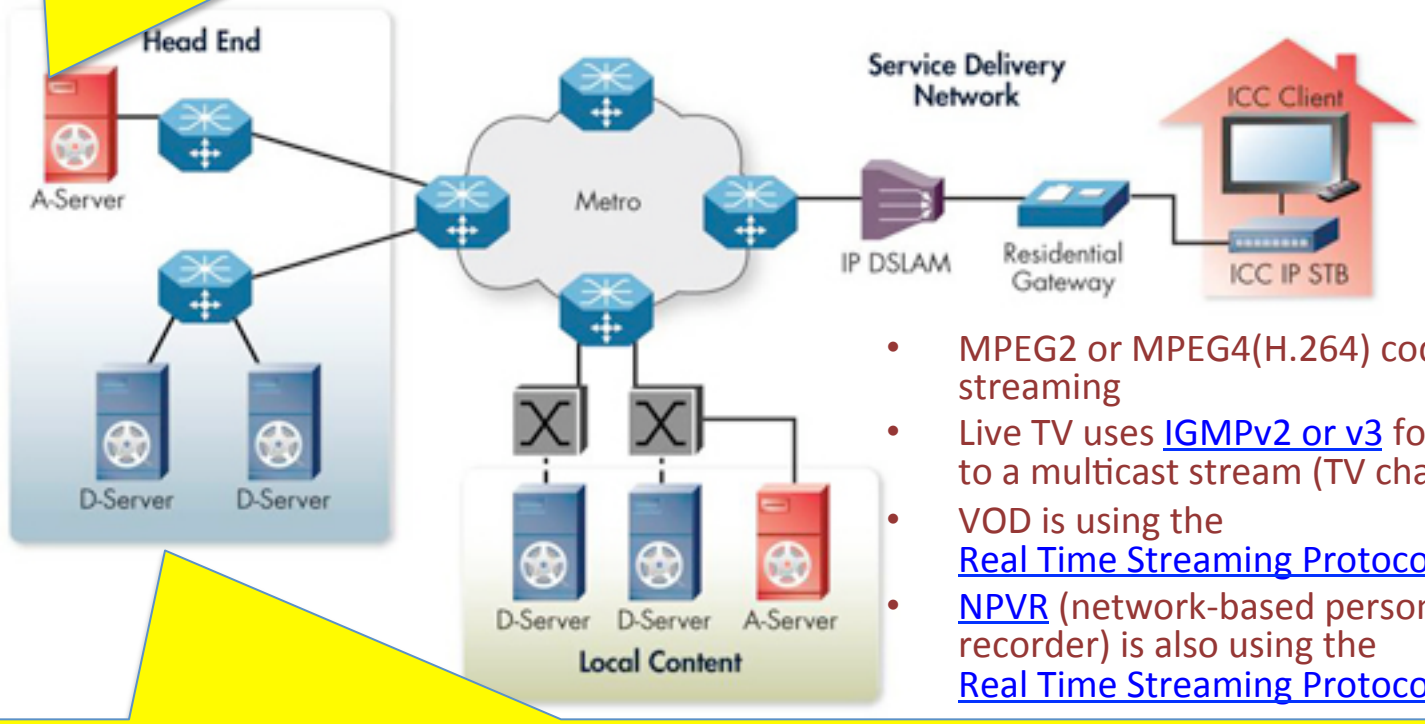
- Driven by DSL Forum – www.dslforum.com
- Several xDSL standards
  - ADSL
  - SHDSL
  - VDSL
  - ADSL2plus
  - VDSL2
  - and more

Holding 60% of the broadband subscribers
350M worldwide at the end of 2007
ADSL can deliver 8Mbps over about 2km
ADSL2plus can go up to 24Mbps

First it is used for Internet Connection, Now, data, voice, video and especially for IPTV

IPTV Architecture

Acquisition servers (A-servers) perform live content acquisition from various local and terrestrial sources for linear broadcast TV



- MPEG2 or MPEG4(H.264) codec for streaming
- Live TV uses IGMPv2 or v3 for connecting to a multicast stream (TV channel)
- VOD is using the Real Time Streaming Protocol (RTSP).
- NPVR (network-based personal video recorder) is also using the Real Time Streaming Protocol (RTSP).

Distribution servers (D-servers) are used to distribute frequently used content from various points of presence in the provider's network for faster access and to minimize channel switching time.

Cable Modem

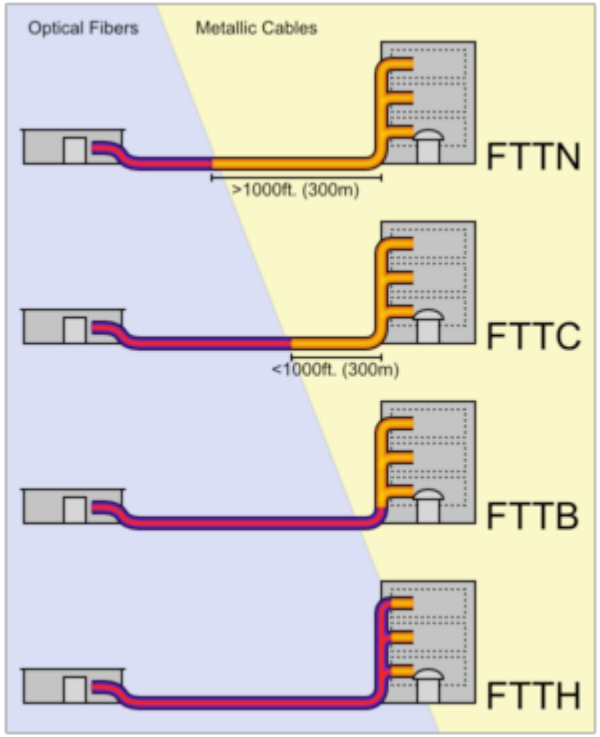
- Deliver high-speed data transfer over an existing coaxial Cable TV (CATV)
- Driven by Cable-Labs, founded in 1988
- Defines DOCSIS – Data Over Cable Service Interface Specification
  - Services include
    - Multimedia services
    - IP telephony
    - Multimedia conferencing
    - Interactive gaming
    - General multimedia applications
    - VoD Metadata and HDTV

Fiber to x - FTTx

- Besides copper wire or coaxial cable for “last mile” delivery, there is also **fiber**

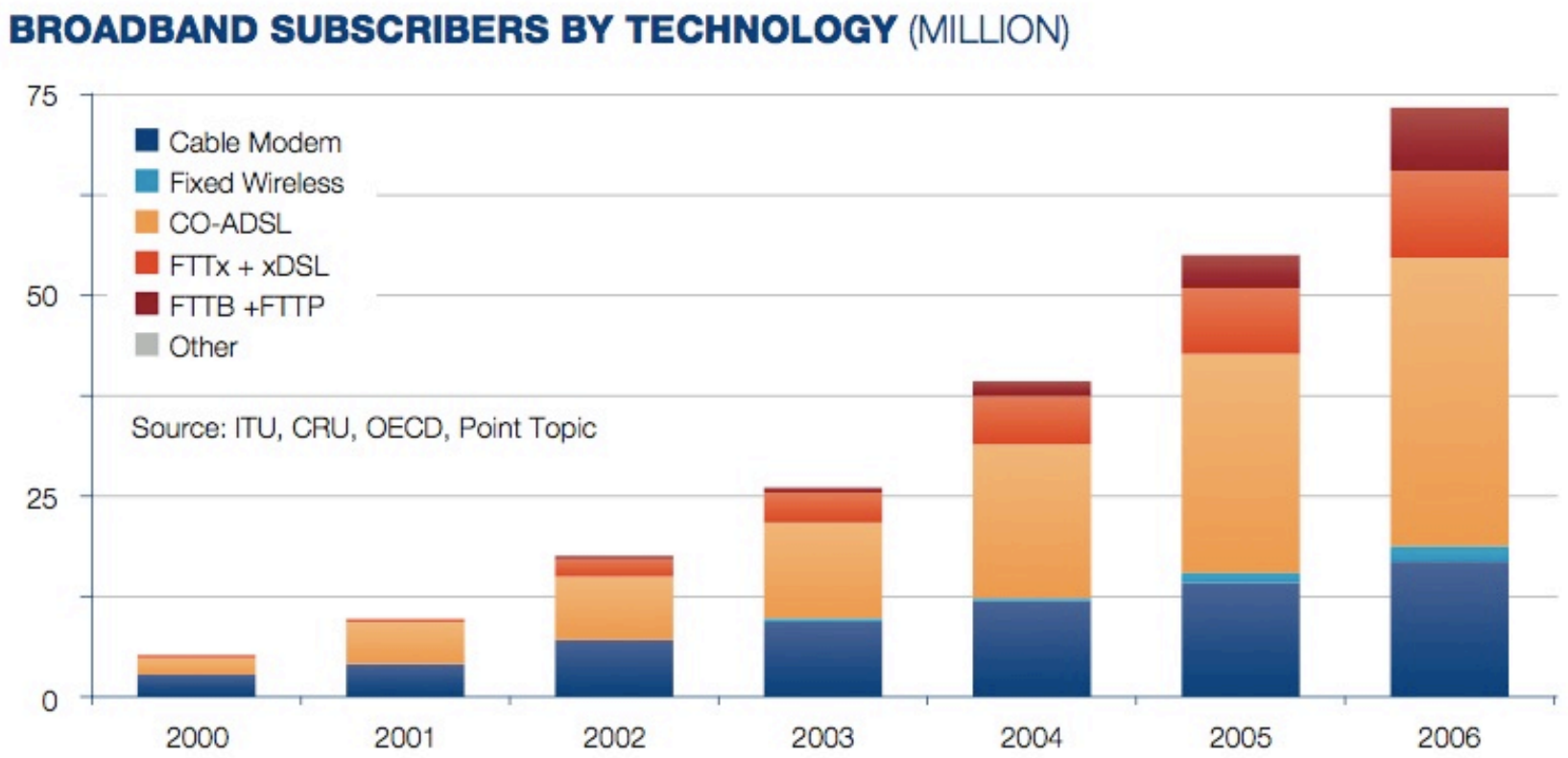
Data rate>1Gbps

Active or Passive Networks



- FTTH- fiber-to-the-home over an optical fiber
- FTTN, fiber-to-the-node
- FTTC, fiber-to-the-curb
- FTTB, fiber-to-the-building
- FTTP, fiber-to-the-premises

Broadband Subscribers by Technology



WLAN – “last feet” wireless

- Wireless Local Area Networking
  - Debut of IEEE with IEEE 801.11 and WiFi Alliance
  - Operates in unlicensed frequency
  - Single frequency network, multiplexing is *CSMA*
    - ISM bands – Industrial, Scientific, and Medical bands
      - 900Mhz, 2.4Ghz, and 5.8Ghz
    - U-NII band – Unlicensed National Information Infrastructure band
      - 5GHz
    - WLAN is secondary user in ISM, primary in U-NII

What is *CSMA*?

Carrier Sense Multiple Access

CSMA-CD (Collision Detection) is utilized in Ethernet

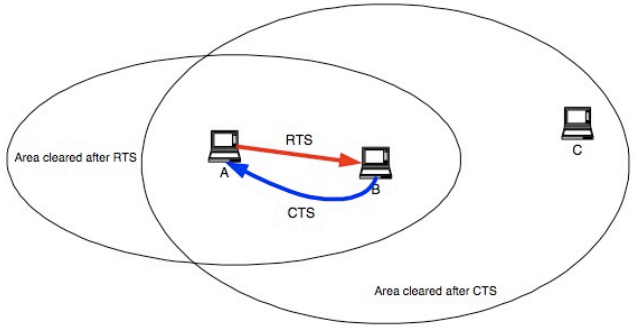
CSMA-CA (Collision Avoidance) is utilized in Wireless LAN

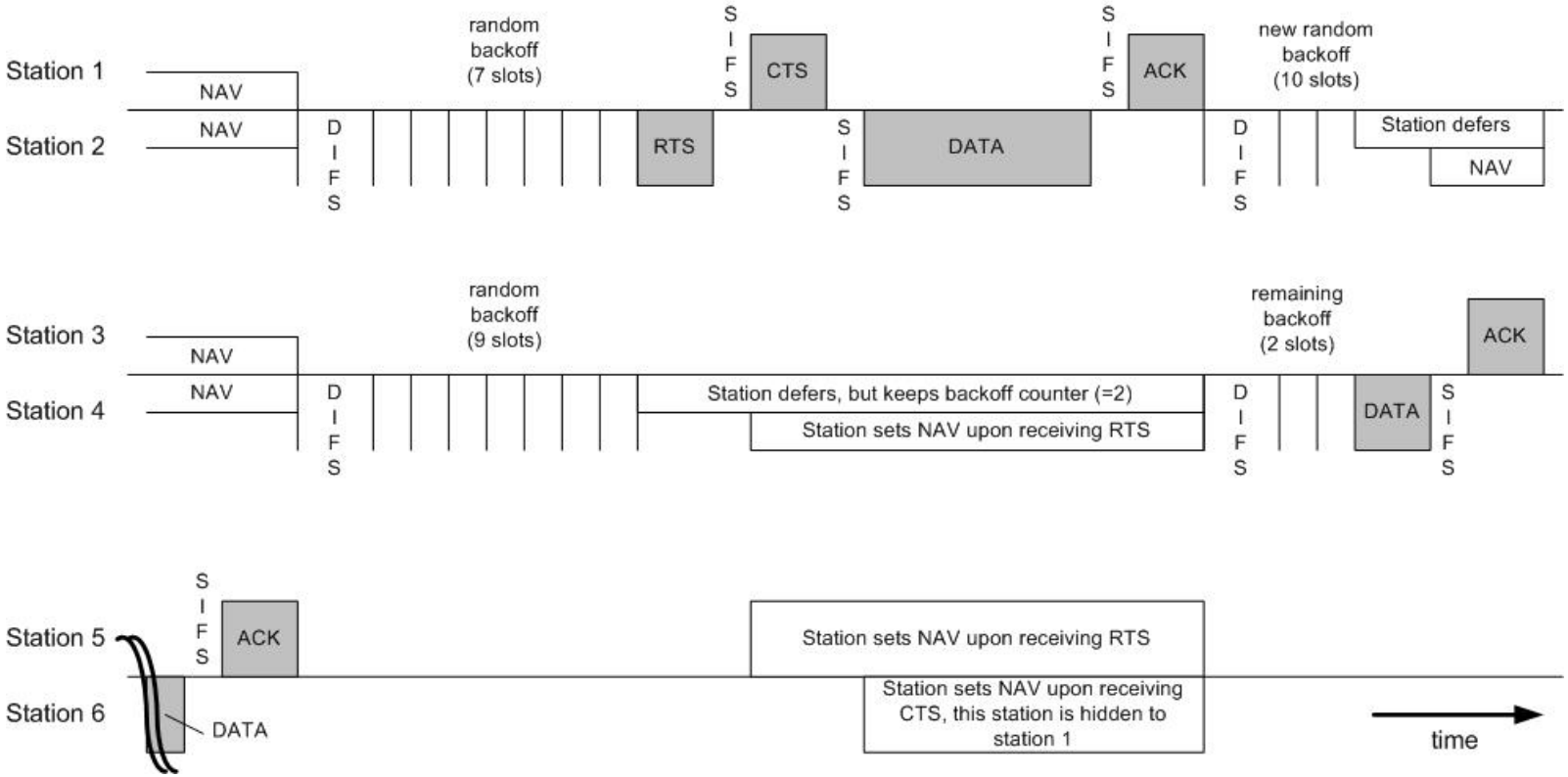
CSMA/CA

- Step1: Listen the channel
- Step2: Transmit if channel is idle
- Step3: If channel is busy, wait until transmission stops plus a contention period, which a random period to ensure fairness. A node decrements the backoff counter if it detects the channel idle for a fixed amount of time.
- Step4: Node transmits when back-off counter is zero.
- Step5: If the transmission is unsuccessful, no ACK, contention window is selected from a random interval, which is twice the previous random interval. The process is repeated until it gets a free channel.

CSMA/CA

Hidden Node Problem





CSMA/CA Throughput

- Single Frequency Network – everyone's desire
  - It is possible with 802.11 CSMA/CA however quality of service is not guaranteed!!!

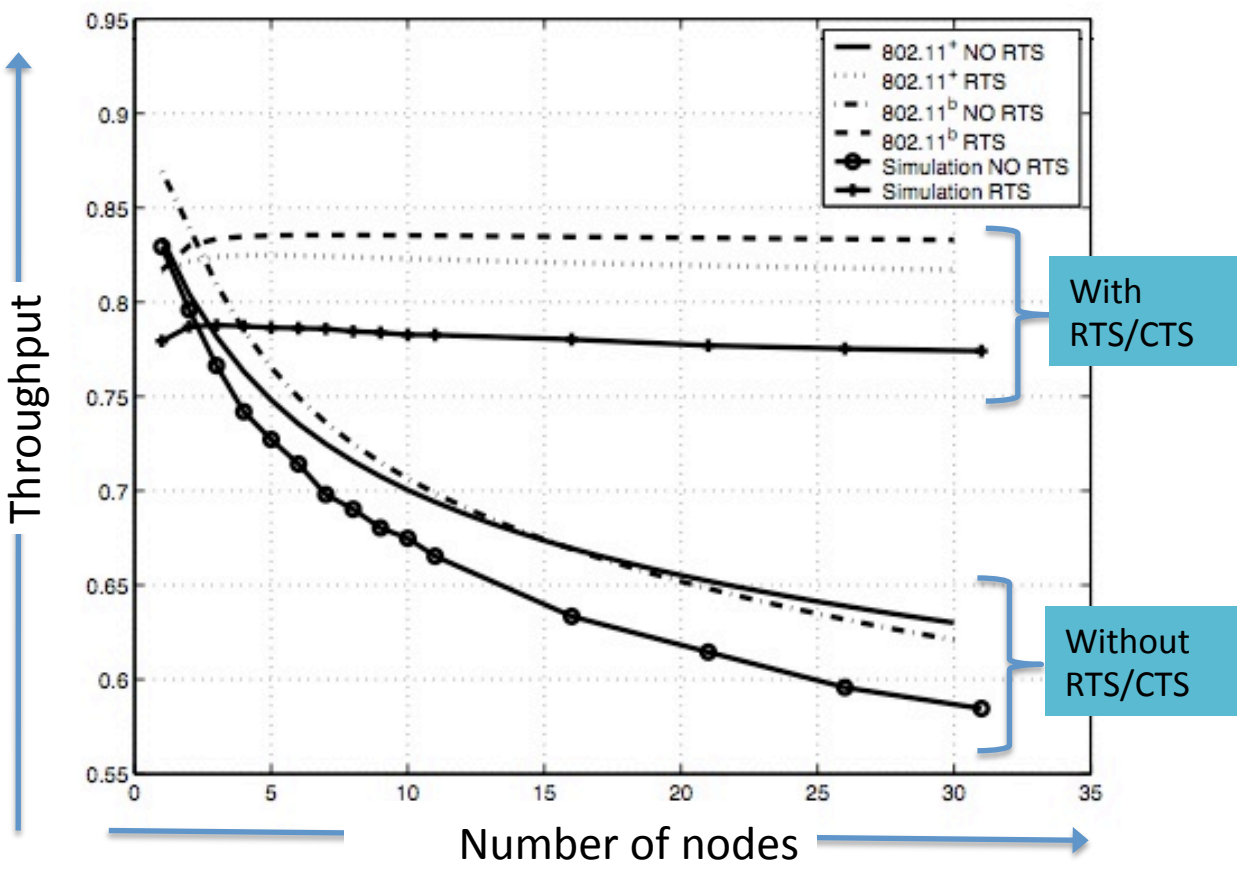
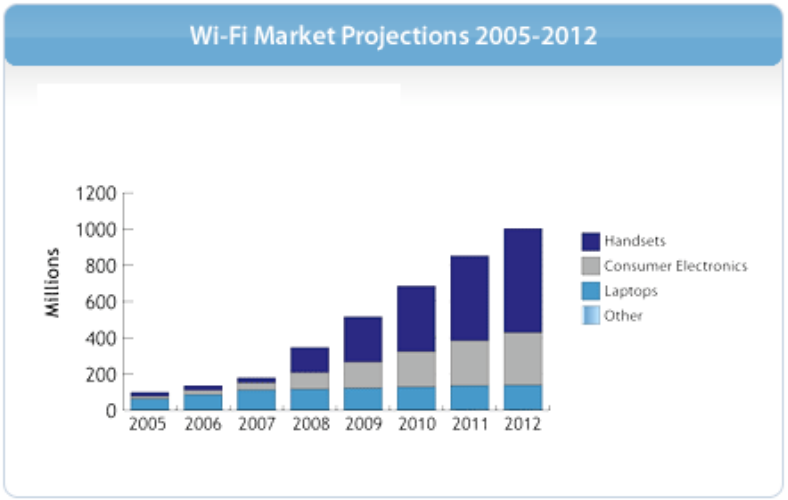


Figure 3.17: Throughput for multi-level backoff

*I-WLAN, PhD Dissertation, 2004, M. Ergen UC Berkeley

IEEE 802.11 Family

- IEEE 802.11b
  - Direct spread spectrum at 2.4GHz
  - First standard : 3 channels : 11 Mbps :
- IEEE 802.11a
  - 300Mhz of 5.9GHz only – operates with OFDM
- IEEE 802.11g
  - Operates in 2.4GHz with same design of 802.11a: 54Mbps
- IEEE 802.11e
  - MAC Standard : QoS support
- IEEE 802.11n
  - with MIMO-OFDM: <600Mbps
- IEEE 802.11p
  - DSRC for Vehicular Networks



3G – Third Generation

- In third generation – two camps aroused
  - However they both adopted ***WCDMA*** – Wideband CDMA
  - And formed in 1998

- 3GPP: Third Generation Partnership Project
  - European Telecommunications Standards Institute (ETSI) (Europe)
    Association of Radio Industries and Businesses/Telecommunication Technology Committee (ARIB/TTC) (Japan),
  - China Communications Standards Association (CCSA) (China)
  - Alliance for Telecommunications Industry Solutions (ATIS) (North America)
  - Telecommunications Technology Association (TTA) (South Korea).

- 3GPP2: Third Generation Partnership Project 2
  - ARIB/TTC (Japan)
  - CCSA (China)
  - Telecommunications Industry Association (TIA) (North America)
  - TTA (South Korea)
  - Driven by Qualcomm in USA

- To fulfill the requirements of ITU's IMT-2000

ITU and IMT-2000

- **International Telecommunication Union** is the eldest organization in the UN family still in existence. It was founded as the *International Telegraph Union* in Paris on 17 May 1865 and is today the leading United Nations agency for information and communication technology issues, and the global focal point for governments and the private sector in developing networks and services.

  - **ITU-R Radiocommunication**
  - **ITU-T - Standardization**
  - **ITU-D Development**

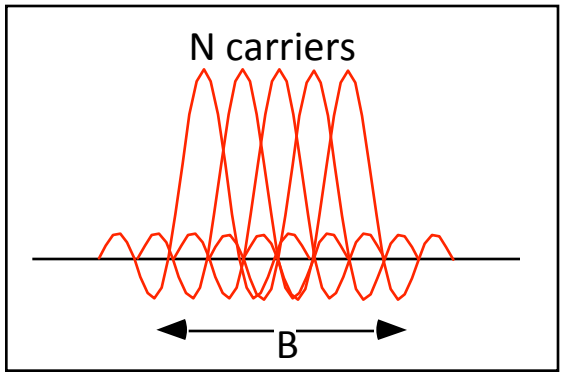
IMT-2000

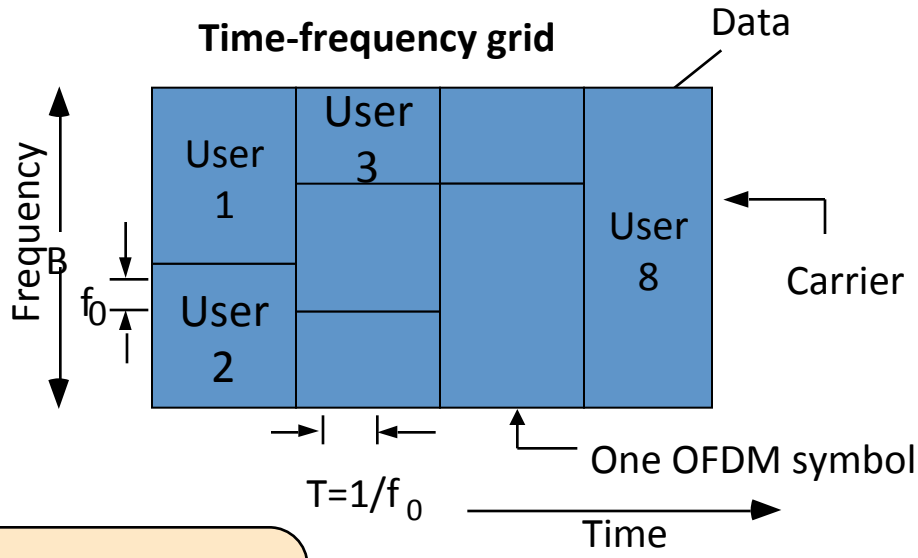
- **International Mobile Telecommunications-2000 (IMT-2000)** is the global standard for third generation (3G) wireless communications, defined by a set of interdependent ITU Recommendations.
- IMT-2000 is particularly a framework that defines the criteria of ubiquitous support. The key criterias are
  - High transmission rates
  - Fixed line voice quality
  - Global roaming and circuit switched services support
  - Multiple simultaneous services
  - Increased capacity and spectral efficiency
  - Symmetric and asymmetric transmission of data

UMTS/WCDMA	CDMA Direct Spread
CDMA2000	CDMA Multi-Carrier
UMTS-TDD	Time-Code
TD-SCDMA	Time-Code
UWC-136	Single Carrier
IS-136	Single Carrier
EDGE	Single Carrier
DECT	FDMA/TDMA
WiMAX	OFDMA TDD

Another multiple access scheme ***OFDMA***

What is OFDMA?





Features

- **No intercarrier guard bands**
- **Controlled overlapping of bands**
- **Maximum spectral efficiency (Nyquist rate)**
- **Easy implementation using IFFTs**

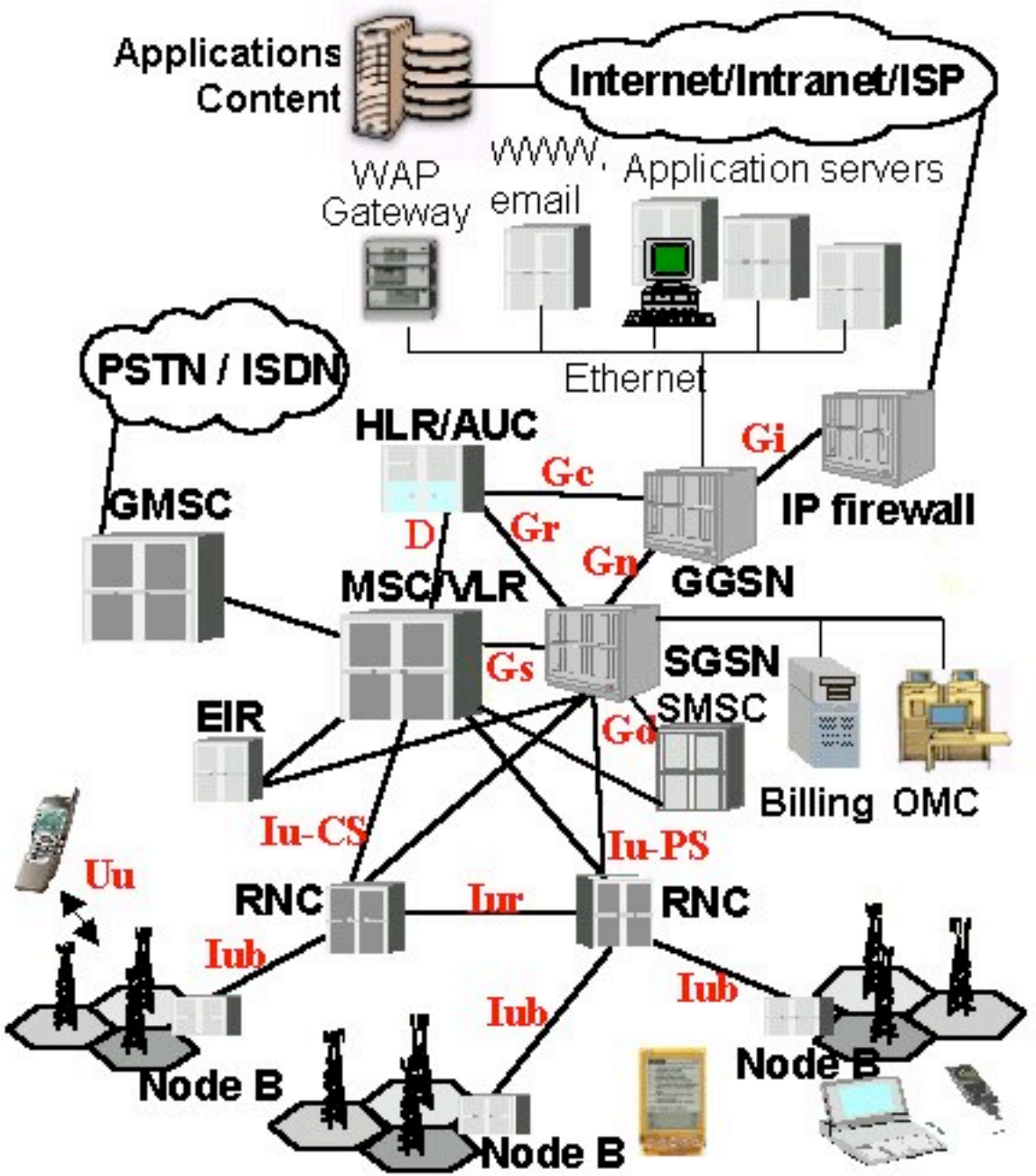
Intercarrier Separation = 1/(symbol duration)

Modulation technique

A user utilizes some carriers to transmit its data as coded quantity at each frequency carrier, which can be quadrature-amplitude modulated (QAM).

3GPP

- UMTS
  - NodeB
  - SGSN
  - GGSN
  - MSC
  - HLR
  - Iu-CS
  - Iu-PS
  - Iu-b



3GPP

- UMTS: Universal Mobile Telecommunications Systems based on WCDMA
  - After GSM, GPRS and EDGE
  - Rel-99: introduced in 2000
    - 5MHz channel
  - Rel-4: Introduced in 2001
    - Separated the call and bearer network
  - Rel-5: Introduced HSDPA
    - Spectral efficiency with High Speed Downlink Packet Access
    - Introduced IMS – IP Multimedia Subsystem and UTRAN
      - IP UMTS Terrestrial Radio Access Network

3GPP

- Rel6: introduced in 2005
  - HSUPA: High Speed Uplink Packet Access
  - MBMS: Multimedia Broadcast Multicast Service
    - New term HSPA: HSDPA+HSUPA
    - 16QAM in DL and QPSK in UL
- Rel7: focuses on MIMO and flat-IP
  - GTP tunneling to connect packet switch to radio access network
    - New term HSPA+
    - Interference aware receiver- takes account of interfering cell as well as serving cell
    - 64QAM with MIMO
    - CPC: Continuous Packet Connectivity
      - Keeps more users in the idle mode
    - RNC is integrated to NodeB
    - HSPA+ is missing link between HSPA and LTE
    - Enabler of Femtocell
- Rel8: LTE – Long Term Evaluation – 4G

3GPP2

- CDMA2000
  - 1x EV-DO Rel 0
    - Data-centric delivers up to 2.4Mbps in FL and 153Kbps in RL in a single 1.25MHz FDD – real networks it is around 300-700Kbps in FL and 70-90Kbps in RL
    - "Always on" user experience as in IP
    - Adaptive Modulation and Coding and Hybrid ARQ
  - 1x EV-DO Rev A
    - Supports delay sensitive, real-time, and concurrent voice and broadband data applications.
    - Utilizes OFDM for multitasking of multimedia
    - All-IP based architecture
    - 3.1Mbps in FL and 1.8Mbps in RL in 1.25MHz FDD
    - Real networks it is around 450-800Kbps in FL and 300-400 Kbps in RL

FL: Forward Link - Downlink
RL: Reverse Link - Uplink

3GPP2

- 1x EV-DO Rev B
  - Dynamic bandwidth allocation by aggregating multiple 1.25MHz Rev-A channels
  - Peak data rates scale with the number of carriers aggregated
  - 15 aggregated channels – 46.6Mbps in FL and 27Mbps in RL.
  - 5MHz aggregation – peak data rates is around 14.7Mbps.
  - OFDM based multitasking and introduces lower latency for delay sensitive applications.
- 1x EV-DO Rev C – UMB – Ultra Mobile Broadband – 4G
  - standard is there but abandoned

Broadband Wireless

- Started with fixed access to compete with DSL and cable modem
  - LMDS- Local Multipoint Distribution Systems
    - Wireless alternative to fiber and coaxial cables in the late 1990s
    - Utilized 28 & 31GHz
    - Several hundreds of megabits per second
    - Roof-top antennas and line-of-sight (LOS)
    - Modified version of DOCSIS
  - MMDS: Multichannel Multipoint Distribution Services
    - 2.5Ghz – become popular in rural areas
    - Modified version of DOCSIS – DOCSIS+
    - Greater range then LMDS but still required LOS

Broadband Wireless

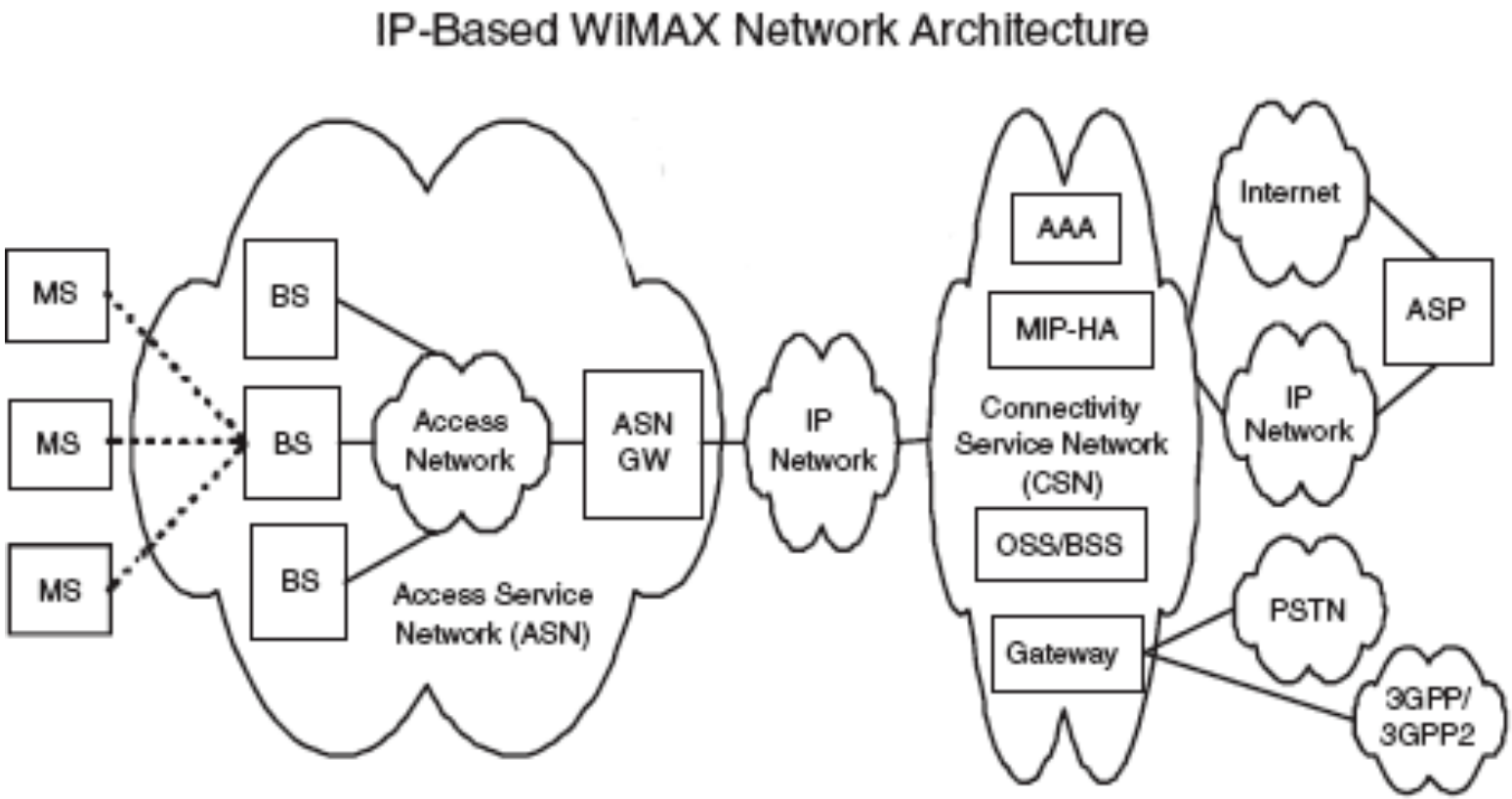
- IEEE 802.16 - Wireless Metropolitan Area Network (Wireless MAN)
  - Begun in 1998 by IEEE
  - Tackled LOS challenge by adopting OFDM
  - WirelessMAN-SC – first standard in 2001
    - Single carrier for operation in 10-66GHz with LOS
  - Wireless MAN-Sca
    - IEEE 802.16a-2003
    - Non-LOS is addressed in 2-11GHz band for licensed and unlicensed spectrum
    - Ratified with 802.16d in 2003 and finalized as 802.16-2004.

Broadband Wireless

- WirelessMAN-OFDM
  - NLOS fixed access for 2-11GHz
  - Finalized in 802.16-2004 standard
  - 256 Subcarriers
- WirelessHUMAN
  - Similar to OFDM physical layer
  - License exempt bands
- WirelessMAN-OFDMA
  - 2048 carriers
  - 802.16e-2005 for mobile access
  - Scalable channel bandwidths from 1.25Mhz to 20Mhz with FFT

Mobile WiMAX

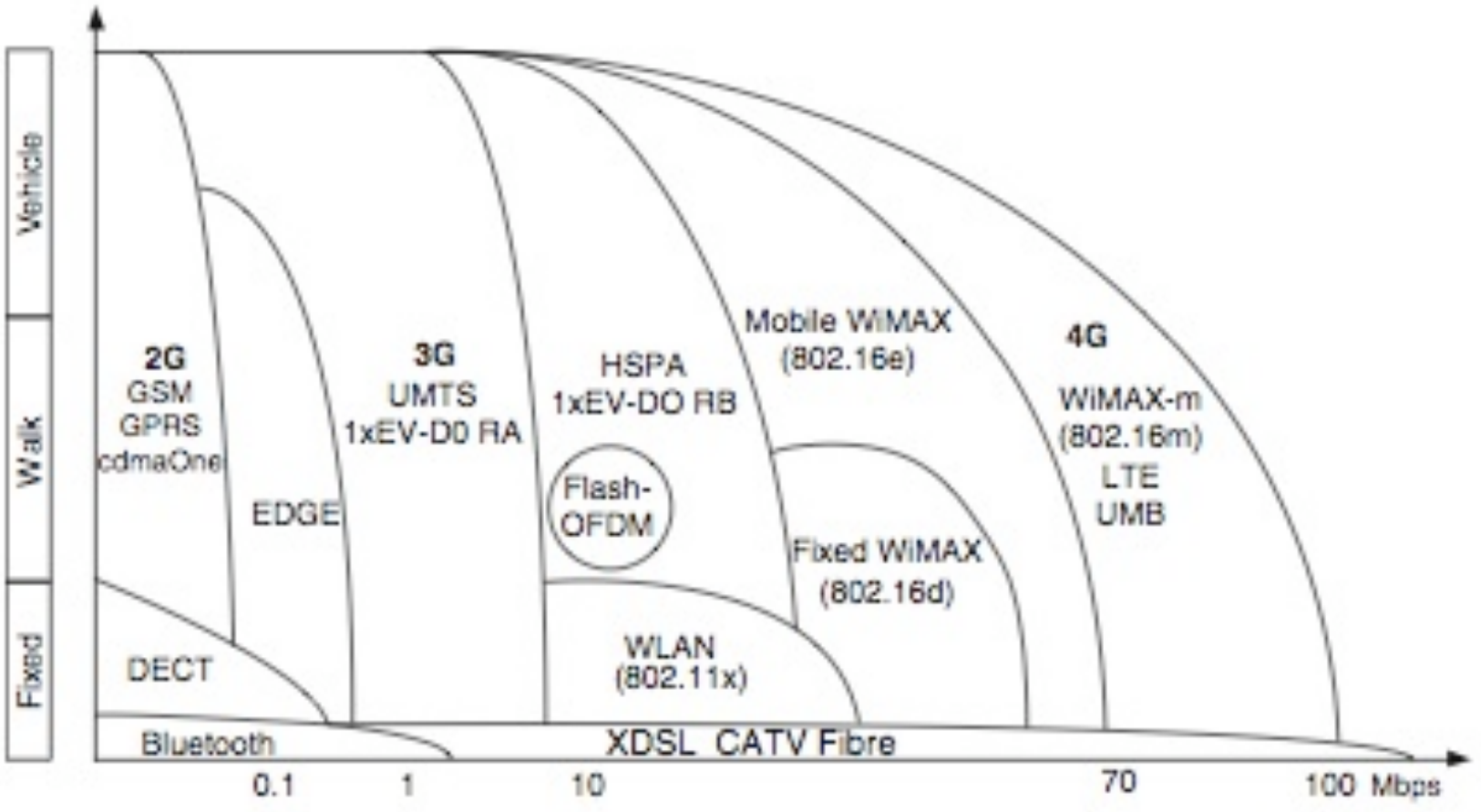
- Architecture



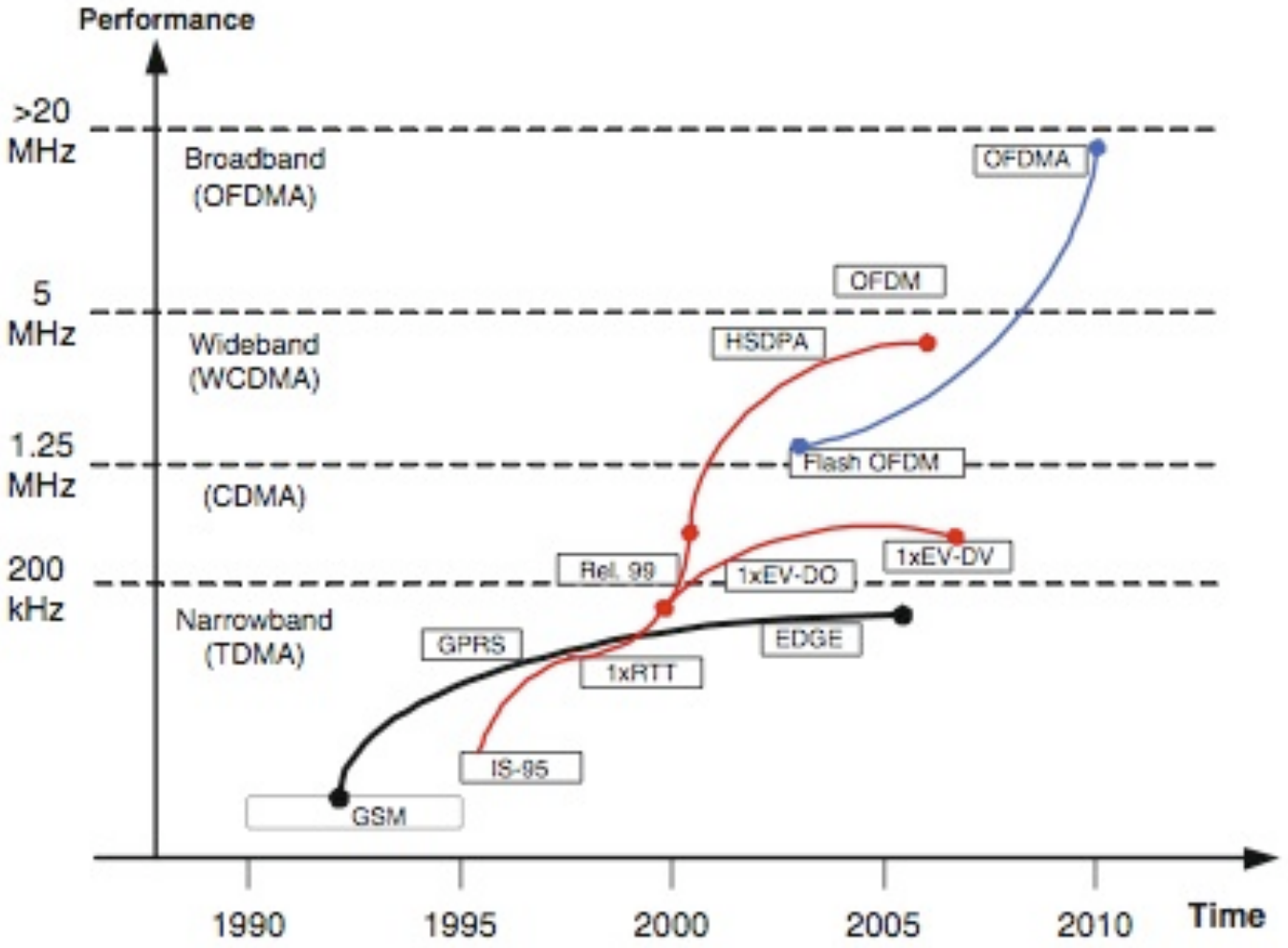
Mobile WiMAX

- Adopts OFDMA
  - Faces the challenge of mobility unlike 3G which faces the challenge of data rate.
  - Driven by WiMAX Forum
  - Delivers mobility at Vehicular Speeds
    - Adaptive Modulation and Coding
    - Hybrid ARQ
    - Fast Scheduling
    - Bandwidth efficient handover
    - EV-DO and HSPA are FDD, WiMAX is first TDD now FDD is introduced
    - Operating in 2.5GHz
    - 2x2 MIMO

4G Map

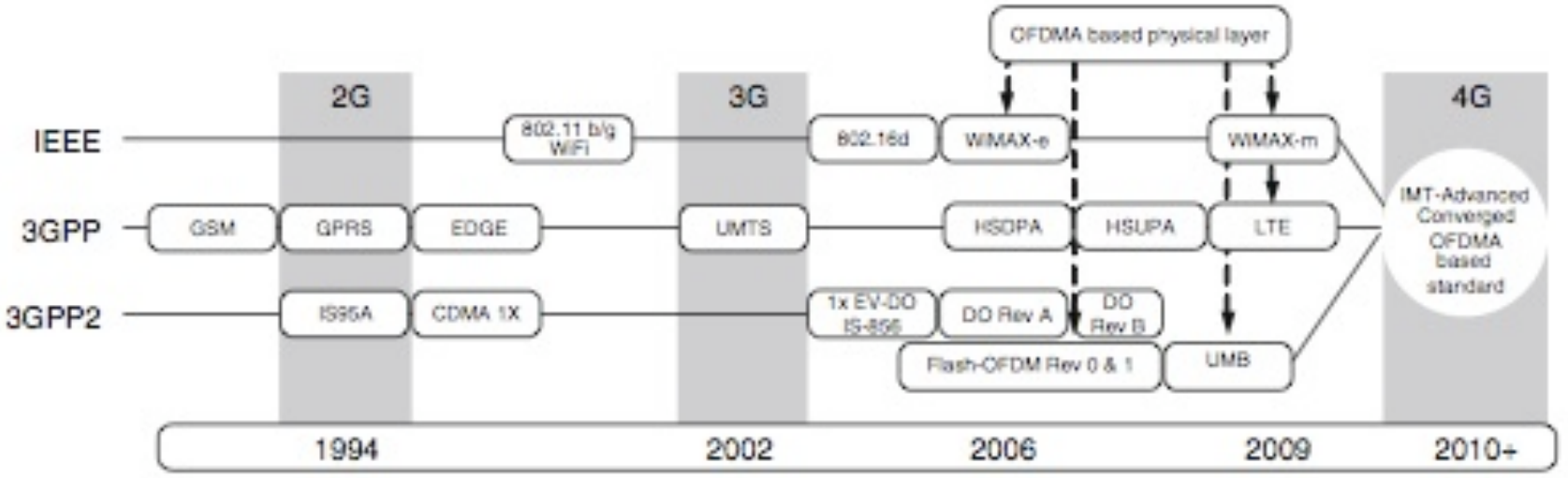

Vehicle
Walk
Fixed
2G
GSM
GPRS
cdmaOne
EDGE
3G
UMTS
1xEV-D0 RA
HSPA
1xEV-DO RB
Flash-
OFDM
Mobile WiMAX
(802.16e)
4G
WiMAX-m
(802.16m)
LTE
UMB
Fixed WiMAX
(802.16d)
DECT
WLAN
(802.11x)
Bluetooth
XDSL CATV Fibre
0.1
1
10
70
100 Mbps

Modulation Evolution



Convergence towards 4G

Change from WCDMA to OFDMA will be the second significant change after TDMA to WCDMA – WCDMA has restriction to scale the bandwidth…



IMT- Advanced

- Defines the standard of 4G
- ITU-R considers data rates up to 100Mbps for high mobility and 1Gbps for low mobility
  - WiMAX-m which is IEEE 802.16m with MIMO
  - LTE with MIMO

Key Features of Mobile Broadband 1/2

- Increased data rates
  - OFDMA, higher modulation, AMC, turbo coding, ARQ, MIMO
- High Spectral Efficiency
  - Reduce cost of per bit
- Flexible radio planning
  - SON: Self-Organizing Network
- Reduced latency
  - Round-trip-times 10ms or less
- All-IP architecture
  - “flat” all-ip based core network

Key Features of Mobile Broadband 2/2

- Interworking
  - Internetworking of existing technologies
- Open Interfaces
  - Multi-vendor network operation
- Spectral flexibility
  - Scalable bandwidths
- Cost reduction capabilities
  - MVNO
- Support for data centric services
  - Revert their declining ARPU

Summary

- New technologies are emerging due to the urge of spectral efficiency.
- OFDMA is selected as the air interface of various standards.
- All-IP-based architecture is being adopted for networks .
- Mobile WiMAX and LTE are contending for such an architecture.

References

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