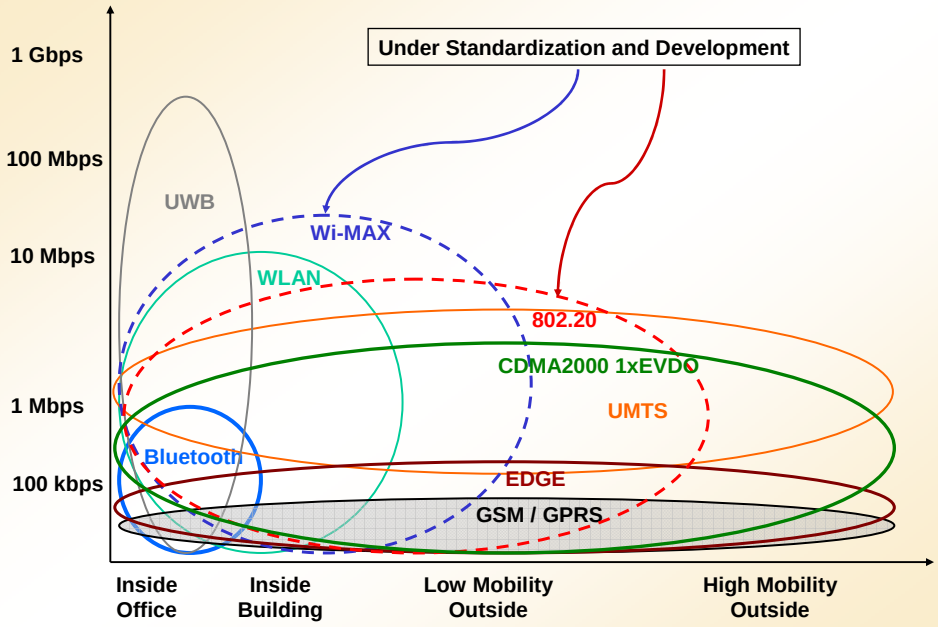
EE 577 - Wireless and Personal Communications

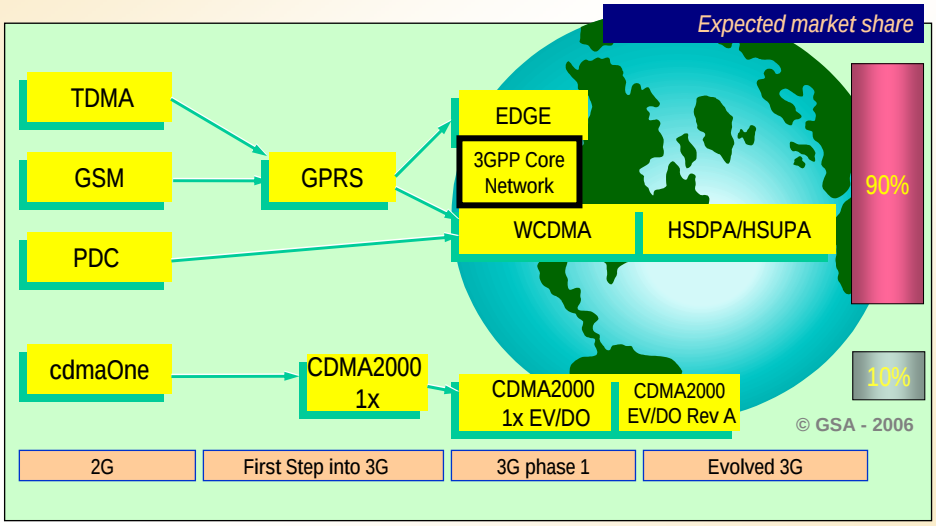
Broadband Wireless Access



Existing Wireless Systems

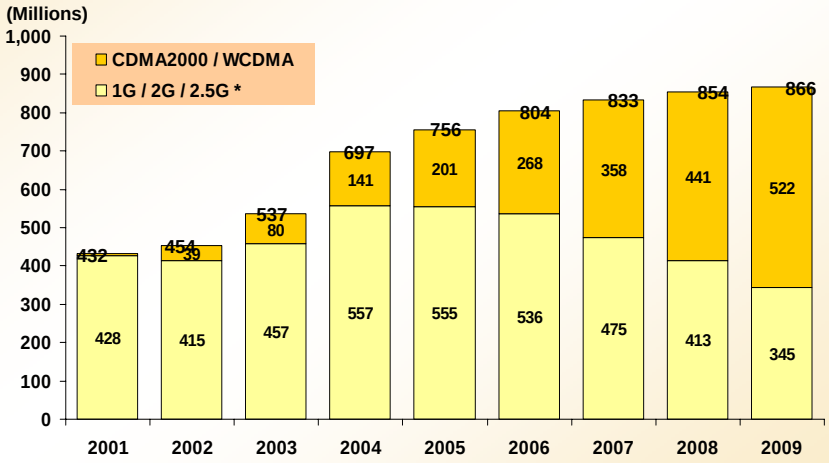
- 3G Cellular (WCDMA)
  - Frequency Division Duplex (FDD): Paired spectrum
  - Time Division Duplex (TDD): Allows “asymmetric” traffic (adjust time slots in uplink and downlink)
  - Lately: HSDPA and HSUPA
- 3G Cellular (CDMA2000, 1x, 3x, 1xEV-DO, 1xEV-DV)
- Wi Fi
  - 802.11, 802.11b and 802.11g
  - Unlicensed frquency band
- WiMAX
  - 802.16d (fixed); 802.16e (“nomadic”)
  - 2-6 GHz band; 1.5 – 20 Mbps symmetrical BW

3G Evolution

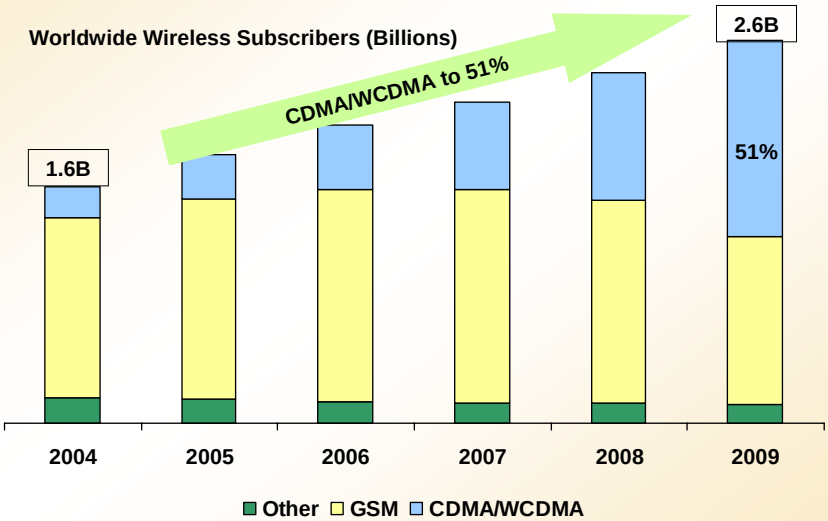


Global Wireless Handset Shipments

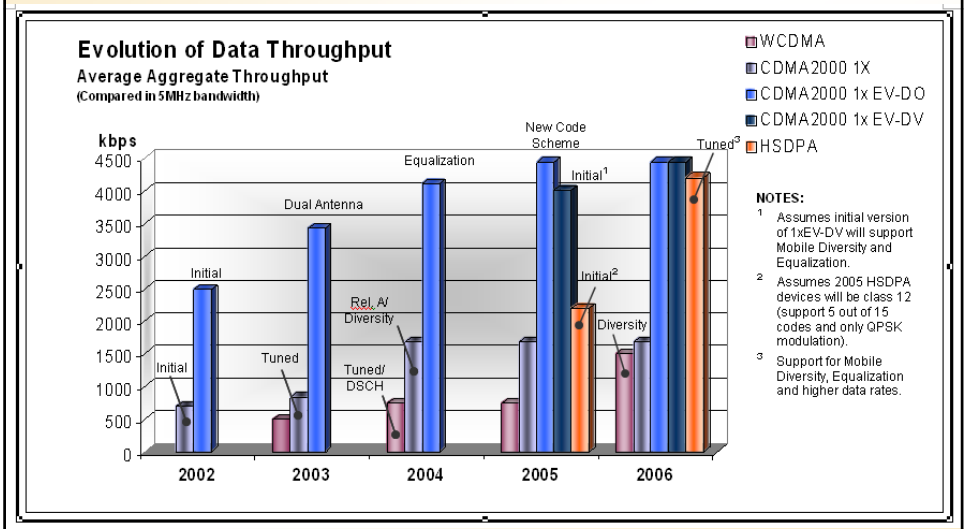
3G (CDMA2000 and WCDMA) will make up 60% of total shipments by 2009



CDMA/WCDMA Becomes the Dominant Wireless Technology



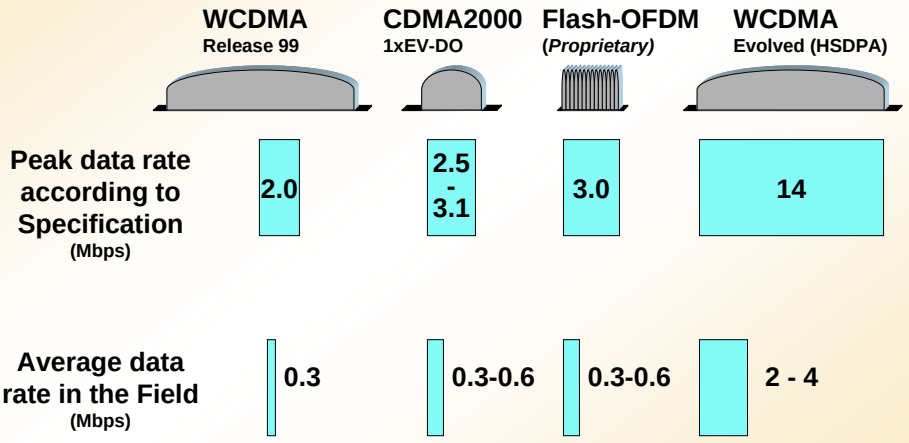
Data Capacity Evolution of 3G Technologies



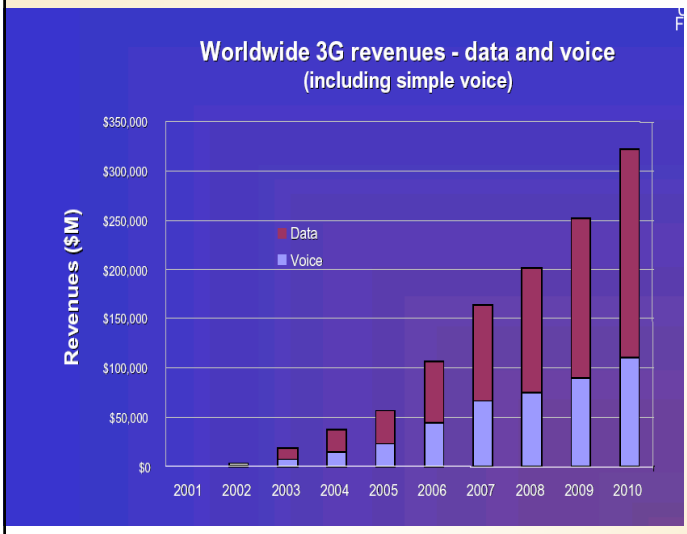
Peak Bit Rates Comparison

	Channel Bandwidth	FDD/TDD	Peak bit-rate DL	Peak Bit-rate UL	Standards compliant
GSM/GPRS	200KHz	FDD	160 kbps	160 kbps	3GPP
EDGE		FDD	480 kbps	480 kbps	3GPP
WCDMA	5Mhz	FDD/TDD	2 Mbps	2 Mbps	3GPP
HSDPA		FDD	14.4 Mbps	7.68 Mbps	3GPP
CDMA2000 1x	1.25 MHz	FDD	640 kbps	450 kbps	3GPP2
1xEV-DO		FDD	3.1 Mbps	1.8 Mbps	3GPP2
1xEV-DV		FDD	3.1 Mbps	1.8 Mbps	3GPP2
IEEE 802.16d	-20 MHz	FDD/TDD	- 75 Mbps	- 75 Mbps	IEEE
Flarion	1.25 MHz	FDD	3.2 Mbps	900 kbps	—

User Data Rates

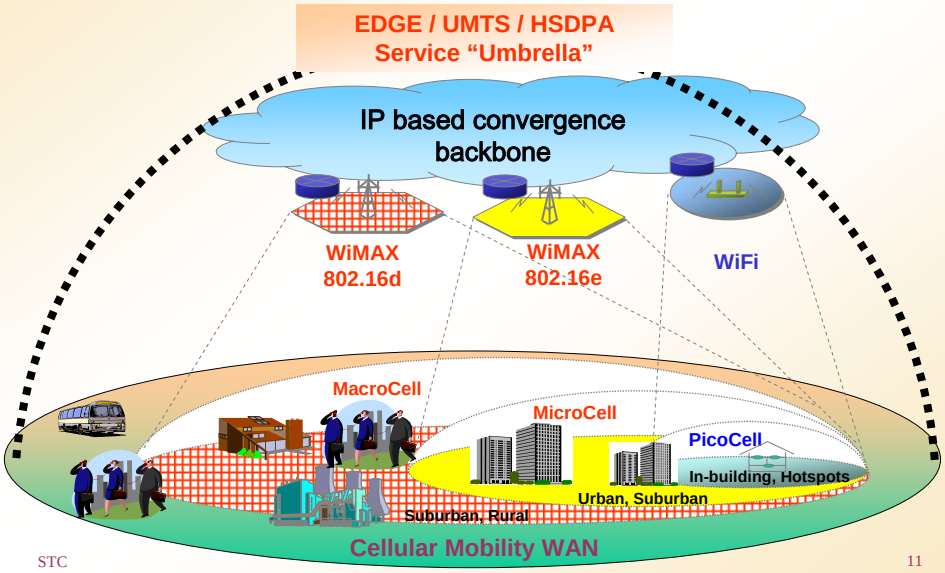


3G+ Systems



- Based on existing 3G spectrum (not new spectrum).
- By 2010, 66% of the revenues will come from data services
- UMTS - Release 99/4 systems alone will not be capable to meet these demands.
- Ultra high speed packet data service (10.8 Mbps)
- All-IP Core Network.

A converged 3G+, WiMAX and WiFi wireless network on a common IMS backbone will provide the lowest cost technology with the widest range of functionality



Wireless LANs

WLAN Applications

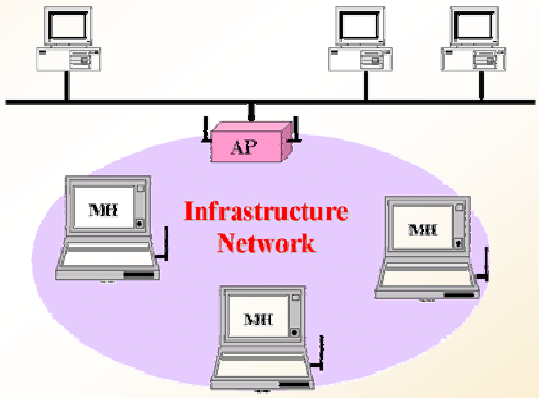
- Inadequate wired infrastructure
- Need for flexible LANs with mobility
- Hospitals, libraries, production, internet access, coffee shops, training sites, etc…
- **Benefits:**
  - Portability
  - Speed (compared to cellular)
  - Simplicity of installation
  - Scalability

WLAN Components

- **RF medium:**
  - Spectrum
  - Properties/impairments/interference
  - Antennas
- **Physical layer:**
  - Modulation/encoding
  - Wireless link
- **MAC layer:**
  - DCF – distributed coordination function
  - PCF – point coordination function

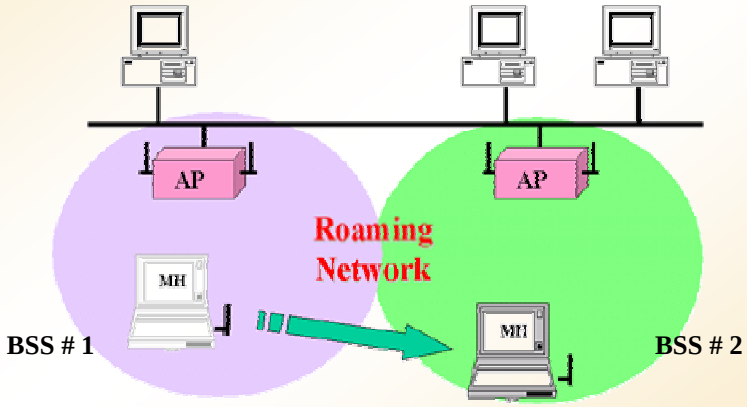
Basic Service Set (BSS)

Set of stations operating in a fully-connected network with an AP



Extended BSS (EBSS)

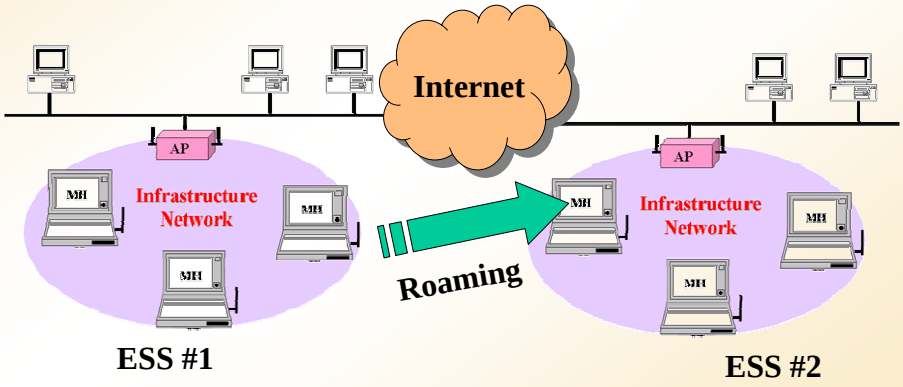
Several BSSs covering an area



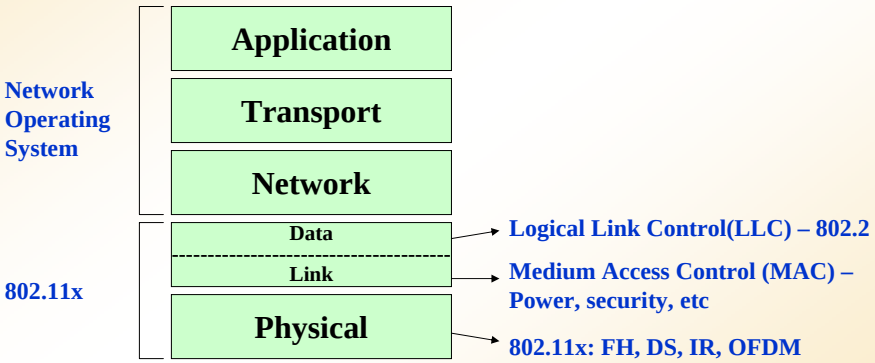
BSS: Basic Service Set
ESS: Extended Services Set

Distributed System (DS)

A system that interconnects different BSSs via APs



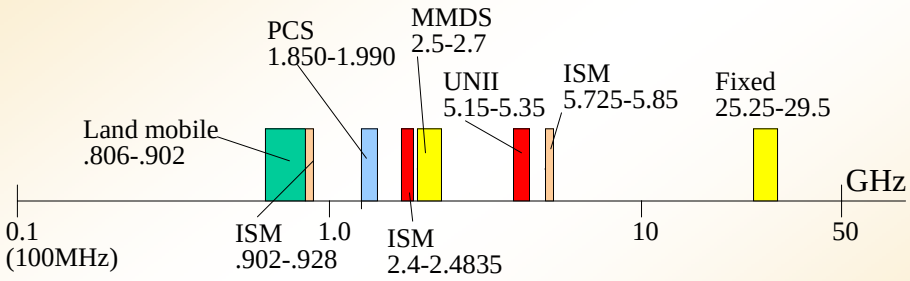
WLAN Layered Structure



WLAN Physical Layer Standards

- **802.11 - (ISM - 2.4 GHz):**
  - Infra-Red (IR), FHSS, DSSS
  - Data rate: 1-2 Mbps
- **802.11b (Wi-Fi) - (ISM - 2.4 GHz):**
  - DSSS - 11 Mbps
- **802.11a - (U-NII – 5 GHz):**
  - OFDM - 54 Mbps
- **802.11g - (ISM - 2.4 GHz):**
  - OFDM - 54 Mbps
  - backward compatible with 802.11b
- **All Share the same MAC layer**

Unlicensed Spectrum



- **ISM:** Industrial, Scientific, and Medical band, shared by multiple services including WLAN in 2.4GHz band
- **UNII:** Unlicensed National Information Infrastructure

IEEE 802.11

- Final draft issued in 1997.
- Standard is approved by FCC, ETSI.
- **Band of operation:** ISM: 2400 – 2483.5 MHz.
- Technologies:
  - Radio (RF): FHSS and DSSS.
  - Infra Red (IR).
- **Modulation:**
  - BPSK @ bit rate of 1 Mbps.
  - QPSK @ bit rate of 2 Mbps.

Spread Spectrum

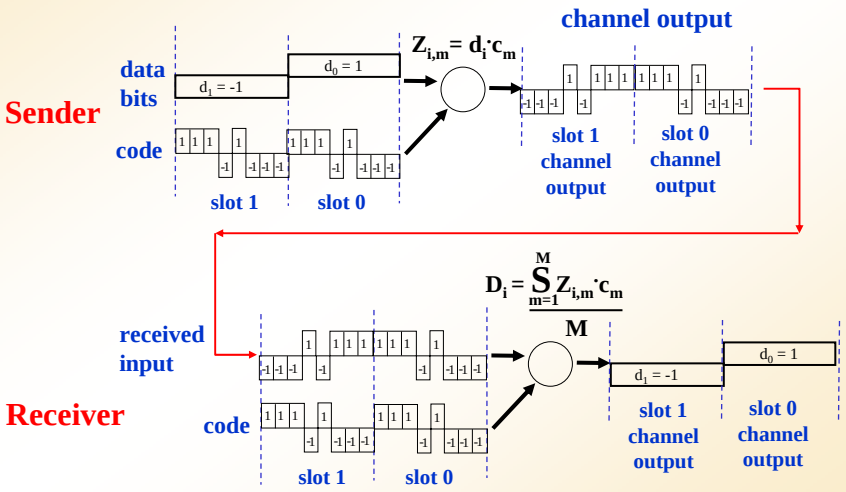
- Most popular now
- Spread signal spectrum over entire channel
- Reduce effect of noise
- Reduce interference with other users

- **Two Types:**
  - Frequency hopping spread spectrum (FHSS)
  - Direct sequence spread spectrum (DSSS)

Frequency Hopping (FHSS)

- Change carrier frequency every few mille-seconds (**dwell time**)
- Hopping occurs between **79 1-MHz channels**
- **Dwell time** = 390 time slots, ~ 0.4 sec
- **Modulation used with FHSS:**
  - 2/4-level DPSK – (1/2 bits per cycle) – restrict power narrowbands – good for secondary users
  - Data whitening – scramble data

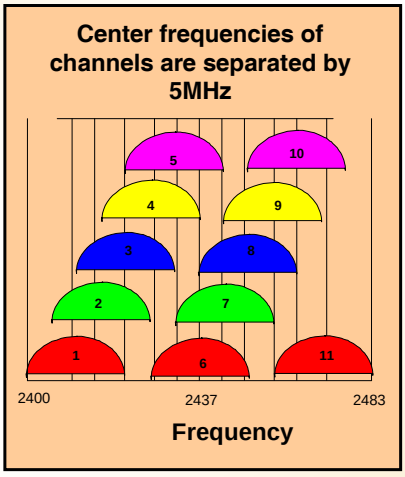
Direct Sequence Spread Spectrum (DSSS)



IEEE 802.11b

- Final draft was issued in 1999.
- Standard approved by FCC, ETSI.
- Band of operation - ISM: 2400 – 2483.5 MHz.
- Defines only one RF technology: **DSSS**.
- Offers three **22-MHz** non-overlapping channels.
- Bit rate up to 11 Mbps
- Backward compatible with IEEE 802.11.
- **Channels:**
  - North America: 11 channel.
  - Europe: 13 Channels.
  - Japan: 14 Channels.

802.11b Channel Allocation



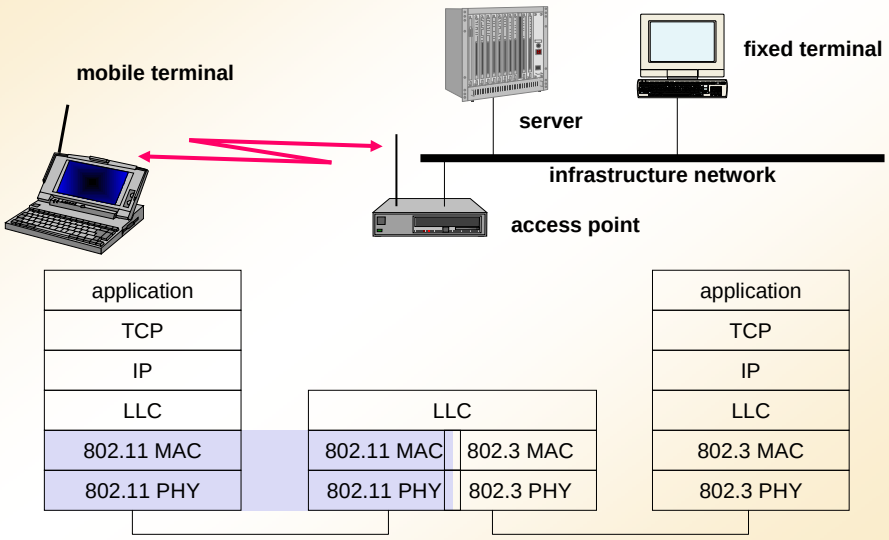
IEEE 802.11a

- Final draft issued in 2000.
- Standard approved by FCC.
- Bands of operation:
  - 5.15 – 5.25 GHz,
  - 5.25 – 5.35 GHz
  - 5.725 – 5.825 GHz.
- Based on the use of Orthogonal Frequency Division Multiplexing (OFDM).
- Bit rates up to 54 Mbps.
- Offers eight **20-MHz** non-overlapping channels.

IEEE 802.11g

- Finalized by end of 2003.
- Operates in the same band as IEEE 802.11b, around 2.4 GHz (ISM band).
- Offers three non-overlapping channels.
- Bit rates up to 54 Mbps using OFDM.
- Offers backward compatibility with IEEE 802.11b.

Data Link Layer



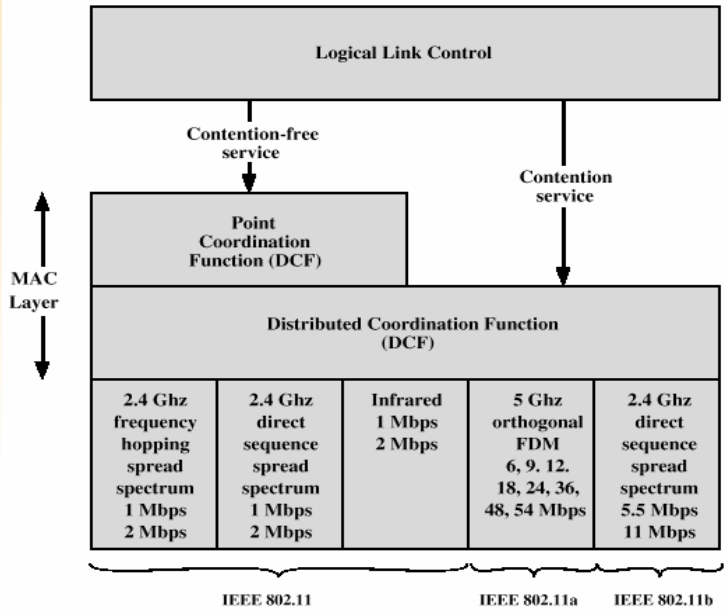


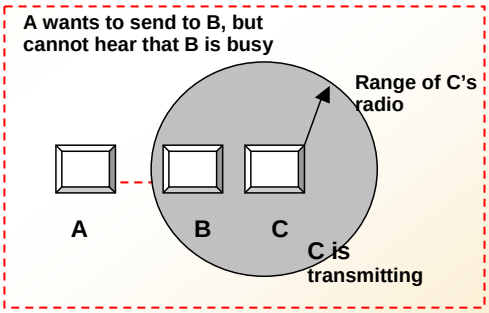
Figure 14.5 IEEE 802.11 Protocol Architecture

Differences From Ethernet

- **Ethernet** operates with **CSMA/CD** protocol.
- With **wireless LANs** that idea does not work well because of:
  - **Multipath fading** of a radio signal
  - Users can not hear all other users
  - Great deal of **portability -** by portability of a laptop the list of printers becomes invalid
- Roaming from an access point to another

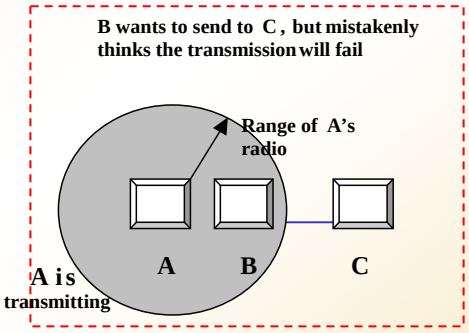
Hidden Terminal Problem

- CSMA inefficient in presence of hidden terminals
- A wants to send to B, but can not hear that B is busy
- A and C cannot hear each other because of obstacles or signal attenuation; so, their packets collide at B

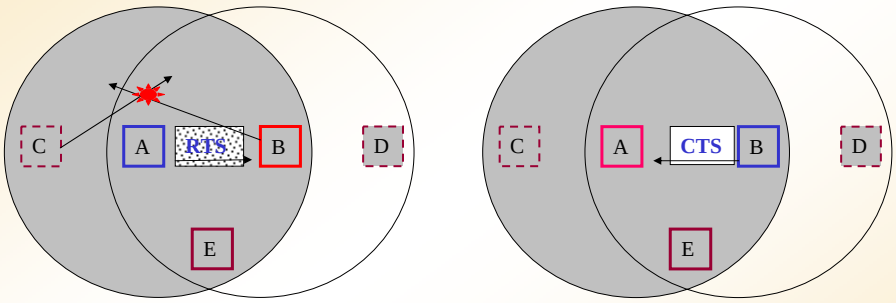


Exposed Station Problem

- B wants to send to C so it senses the channel.
- It falsely concludes that it may not send to C since A is transmitting to D.
- In addition, most radios are half duplex.
- As a result of these problems, 802.11 does not use CSMA/CD



Solution: CSMA/CA



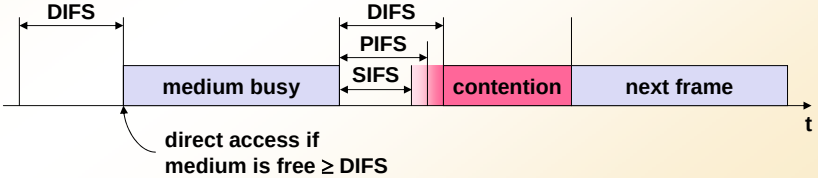
- **A** sending an **RTS** (request-to-send) to B
- **B** responding with a **CTS** (clear-to-send) to **A**.
- After **CTS** is received, **A** begins **transmission**

CSMA/CA

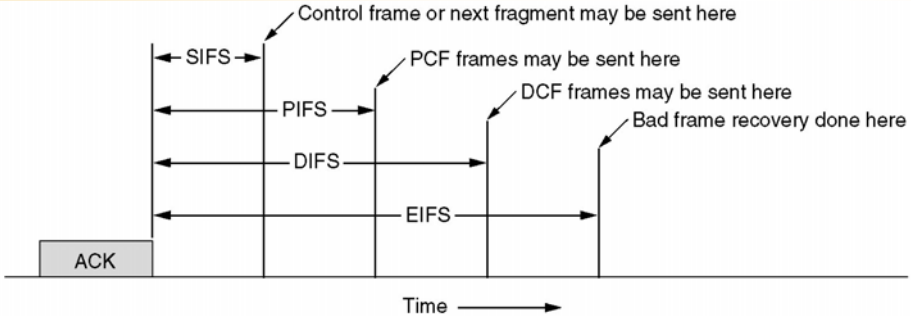
- Anyone hearing **RTS** must remain **silent** until **CTS** to be transmitted back to **A.**
- Anyone hearing **CTS** must remain **silent** during the upcoming data transmission, whose **duration** is determined from **CTS.**
- **C is within** range of **A,** but **not within** range of **B.**
  => it hears **RTS from A**, but not **CTS from B**
- Since it does not interfere with the **CTS**, it is **free to transmit while the data frame is being sent.**
- **D** is within range of **B** but **not A**.
  => It does not hear **RTS** but hears **CTS**
- Hearing **CTS**, it waits about to receive a frame, so it holds sending anything until that is expected to be finished.
- **E** hears both RTS and CTS and must be silent

802.11 MAC Protocol: Priorities

- Defined through different IFS's
- SIFS (Short Inter Frame Spacing):
  - Highest priority, for ACK, CTS, polling response
- PIFS (PCF IFS):
  - Medium priority, for time-bounded service using PCF
- DIFS (DCF IFS):
  - Lowest priority, for asynchronous data service



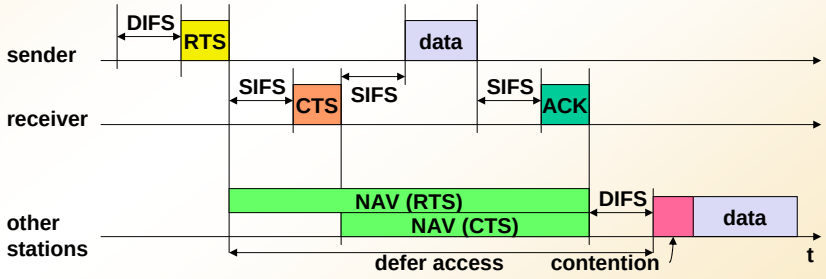
Interframe Spacing in 802.11



- **Short Interframe Spacing (SIFS):** Single dialog the chance to go first
- **PCF IFS (PIFS):** Station sending a data frame sequence to finish its frame without anyone interfering
- **DCF IFS (DIFS):** Other stations requesting the medium

Distributed Coordination Function (DCF)

- The sender senses the medium and wait until it is free
- Wait for **DIFS** (**DCF IFS**), then the sender sends **RTS**
- After **SIFS** (Short IFS) the receiver sends **CTS**
- Sender can now send data at once, ACK via ACK
- **Network Allocation Vector:** for silent stations



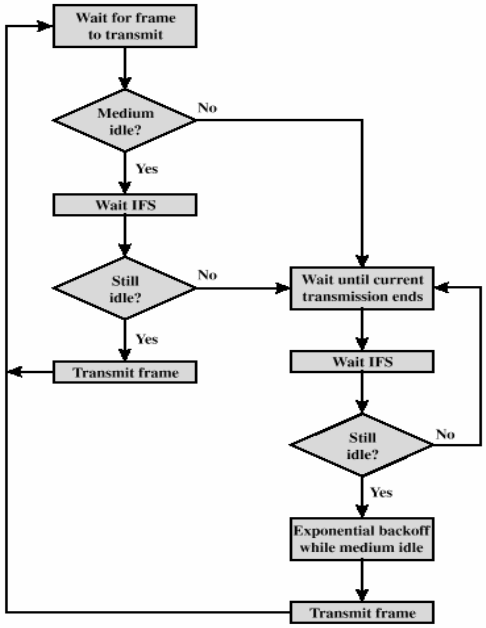
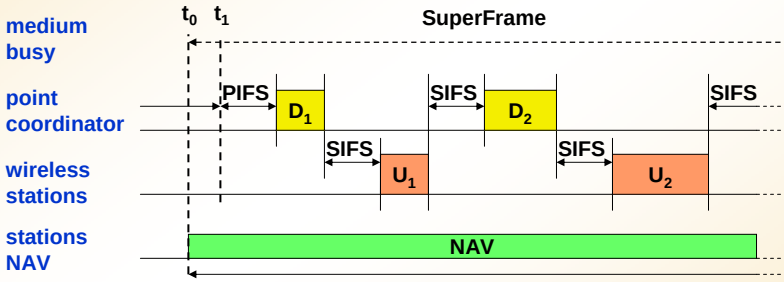


Figure 14.6 IEEE 802.11 Medium Access Control Logic

Point Coordination Function (PCF)

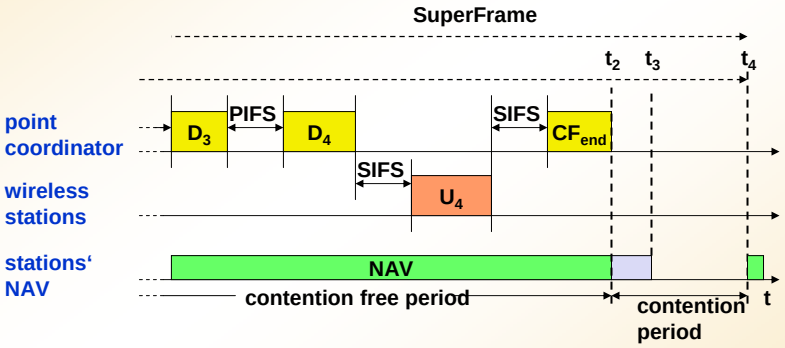
- AP polls MSs, asking them to send - No collision.
- AP broadcasts a **beacon frame** (10 to 100 times per second).
- The beacon frame contains system parameters, such as **hopping sequences** and **dwell times** (for FHSS), **clock synchronization**,..
- It invites new stations to sign up for **polling service**.
- **PCF** and **DCF** can coexist within one cell.

MAC - PCF

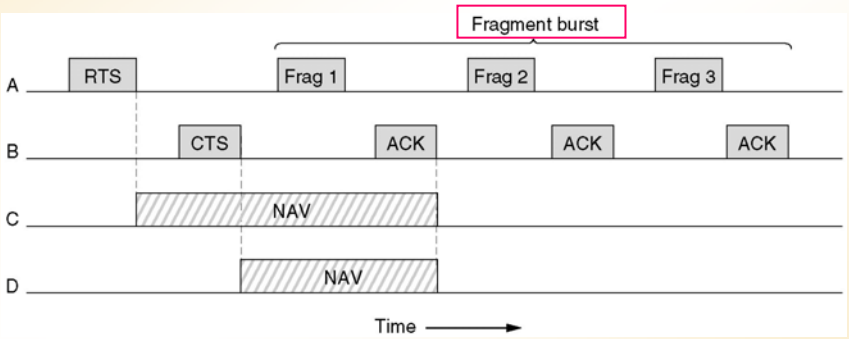


Like polling

MAC - PCF



MAC Protocol: Fragments



Stop-and-Wait Protocol

MAC Process

- A station that wants to transmit will first sense the medium.
- If the medium is idle, waits for a **DIFS**.
- If no other station transmits, then the station will transmit a short **RTS** packet with required **duration**.
- **Duration** = total transmission time for all further packets that will be transmitted (CTS, data, ACK, plus IFS).
- **AP** responds with a **CTS**, with the **same duration** information.
- Receipt of the CTS packet indicates to the transmitter that permission is granted to start the **data transmission**. .

MAC Process

- If the transmitter **does not** receive a **CTS**, it retries until it either receives ACK or times out after a given number of re-transmissions.
- **CTS** is received by all MSs, notifying them that another unit will transmit for the **duration** requested.
- MSs will know when the medium will be available again.
- MSs may not have received the **RTS** because the original transmitting unit is out of range.
- The transmitting station sends its **data frame** to the AP.
- AP checks the **CRC** of the packet and, if correct, returns an **ACK** packet to confirm successful transmission.

MAC Process

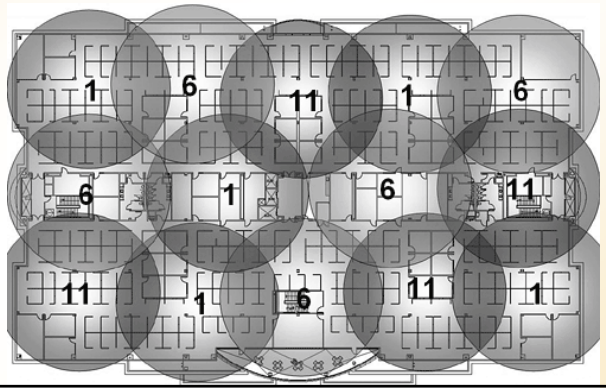
- **Duration** in CTS protects the data transmission from collisions.
- If the **data packet** is **very short**, RTS may include all the data to be transmitted.
- If **RTS** contains data, the CTS packet contains a duration of **zero**, and simply acts as an **ACK**.
- Typical WLAN protocols use packets several hundred bytes long (up to **2312 bits**).
- **Smaller packets** are preferable because:
  - Probability of a corrupted packet increases with packet size
  - In the case of packet corruption, a smaller the packet requires less overhead if it is necessary to re-transmit.

Contention Window

- If a station senses the medium as busy, it backs off using **binary exponential backoff** algorithm
- The maximum number of this algorithm is called the **contention window (CW)**
- A station starts with a minimum CW size set up according to maximum propagation delay
- Once it senses busy medium, it doubles the CW
- This doubling continues until a maximum is reached, called maximum CW
- Heavy load => large CW => high throughput
- Small load => small CW => high throughput

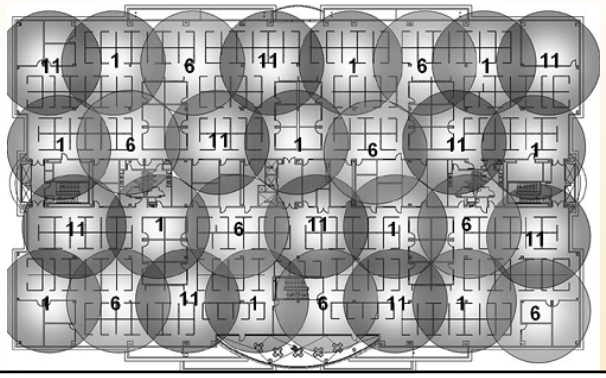
Coverage-Oriented Design

- Provides maximum coverage with least APs
- Low packet rate and low bandwidth applications
- Uses 14 APs and 25-30 users/AP



Capacity-Oriented Design

- Used in high density areas
- High packet rate and latency sensitive applications
- Uses 30 APs and 12 users/AP



802.11n Task Group

- High throughput study group formed 2002
- Gained approval March 2003
- **Predictions** for next generation WLAN:
  - 50% annual growth in coming 4 years
  - MAC throughput of 100 Mbps
  - MAC and Physical layers will be enhanced by a factor 2-4
- Most attractive PHY layer enhancement
  - Multiple antenna schemes (2 to 4 antennas)
  - Antenna selection and beamforming
  - Smart Antennas

WiMAX

WiMAX

- **WiMAX:** Worldwide Interoperability for Microwave Access.
- A Forum that ensures interoperability of IEEE 802.16 and other standards (e.g. ETSI HiperMAN)
- Equivalent in purpose to Wi-Fi Alliance for 802.11
- Sets up certification labs for testing equipment
- Provides WiMAX-Certified stamp for approval of interoperability of products
- Wi-Fi and WiMAX are complementary

WiMAX Objectives

- Serves fixed, portable and mobile applications
- **Lower price** through standardization and mass production
- **Interoperability** with other BWA systems and existing Wi-Fi solutions
- **Volume** will be driven by portability/mobility (e.g. notebooks/PDAs)

WiMAX Spectrum

- Supports both **licensed** and **unlicensed** spectrum
- **Unlicensed Spectrum:**
  - No initial cost but limited scalability.
  - Expect RF interference to be a significant issue.
  - Mostly for point-to-point implementations at higher frequencies.
- **Licensed Spectrum:**
  - Initial cost to acquire spectrum.
  - Allows complete control over RF planning and thus interference is limited
  - Point-to-multipoint implementation at lower frequencies with non-line of sight (NLOS) capabilities.

WiMAX Spectrum

- **10 - 66 GHz**
  - Short wavelength
  - Line-of-sight (LOS) required
  - Negligible multipath
- **2 – 11 GHz**
  - Longer wavelength
  - Improved range and in-building penetration
  - LOS not required
  - Multipath effects may be significant

IEEE 802.16 Evolution

802.16 Dec 2001	Fixed wireless broadband air interface for 10–66 GHz Line-of-sight only Point-to-Multi-Point applications
802.16a Jan 2003	Extension for 2-11 GHz Non-line-of-sight Point-to-Multi-Point applications Range-rate tradeoff
802.16d Oct 2004	Revised and replaced previous versions WiMAX System Profiles
802.16e Mid 2006	An amendment to 802.16d to support mobility MAC/Physical layer enhancements vehicular speeds

IEEE 802.16 Standards

	802.16	802.16a	802.16e
Completed	December 2001	January 2003 (802.16a)	2006
Spectrum	10 - 66 GHz	< 11 GHz	< 6 GHz
Applications	Line of Sight Only	Non Line of Sight	Non Line of Sight
Bit Rate	32 – 134 Mbps in 28MHz channel bandwidth	Up to 75 Mbps in 20MHz channel bandwidth	Up to 15 Mbps in 5MHz channel bandwidth
Modulation	QPSK, 16QAM and 64QAM	OFDM 256 sub-carriers QPSK, 16QAM, 64QAM	OFDM 1024 sub-carriers
Mobility	Fixed	Fixed, Portable	Nomadic Mobility
Channel Bandwidths	20, 25 and 28 MHz	Scalable 1.5 to 20 MHz	Same as 802.16a with UL sub-channels
Typical Cell Radius	2-5 km	7 to 10 km Max range 50 km	2-5 km

IEEE 802.16

- Published in 12/2001.
- Point-to-multipoint broadband wireless access
- Operates in 10-66 GHz licensed spectrum
- Data rates up to 134 Mbps
- Range up to 50 km
- Requires directional line-of-sight (LOS) propagation
- Provides a cost-effective “Last Mile” solution.
- **Full duplex:** a hybrid TDD/FDD duplexing scheme.
- Support of multiple services with QoS

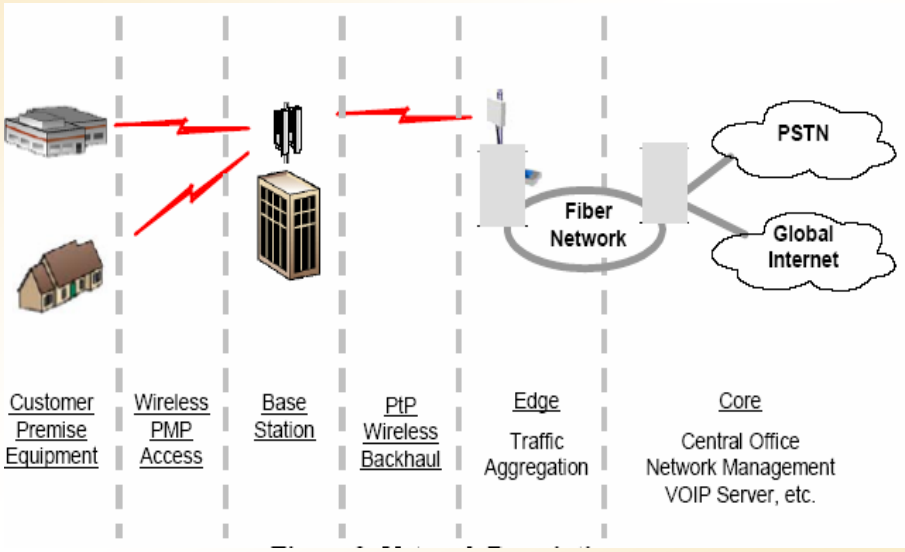
IEEE 802.16a

- Approved in 1/2003.
- 802.16a came to address the following:
  - Operation in 2-11 GHz unlicensed spectrum
  - Eliminates need for directional LOS propagation => NLOS propagation
  - Greater range at lower data rates

Mobile WiMAX - IEEE 802.16e

- Approved in 2006.
- 802.16e came to address the following:
  - Operation in 2-6 GHz licensed spectrum
  - Support of mobility at moderate speeds (60 Km/hr)
  - NLOS implementation through a cellular structure
  - High data rates using advanced PHY layer techniques

IEEE 802.16



IEEE 802.16

- Variety of channel bandwidths supported (integer multiples of 1.5 MHz and 1.75 MHz)
- This insures interoperability worldwide

Freq Band (MHz)	Duplexing	Channelisation (MHz)
2500 - 2690	TDD	5.0 / 5.5
	FDD	5.0 / 5.5

Freq Band (MHz)	Duplexing	Channelisation (MHz)
3400 - 3600	TDD	3.5
		7.0
	FDD	3.5
		7.0
5725 - 5850	TDD	10

Profiles are for PMP systems only and are for 256 OFDM

802.16 Physical Layer

- Data rates determined by exact modulation and coding schemes
- TDD and FDD supported in 802.16 to accommodate burst profiling
- 802.16d adds OFDM and OFDMA to support NLOS multipath propagation

Channel Width (MHz)	Bit Rate (Mbps) QPSK	Bit Rate (Mbps) 16-QAM	Bit Rate (Mbps) 64-QAM
20	32	64	96
25	40	80	120
28	44.8	89.6	134.4

IEEE 802.16e PHY Layer

- Physical Layer Options (SC, SCa, OFDM, OFDMA)
- Multiple options for:
  - Channel bandwidths
  - Frame lengths
  - Duplexing modes (TDD, FDD)
  - Channel coding and modulation
- Support for multiple antenna technology
  - Adaptive antenna systems (AAS)
  - TX diversity (STC, MIMO)
- Link adaptation
  - Adaptive modulation and coding per subscriber
  - Scheduling to enhance network capacity

IEEE 802.16e PHY Modes

	Designation	Applicability
	Single-Carrier (SC)	10 -66 GHz
	Single-Carrier – a (SCa)	Below 11GHz Licensed bands
→ 802.16d	OFDM	Below 11GHz Licensed bands
→ 802.16e	OFDMA	Below 6GHz Licensed bands

Data Rates and Range

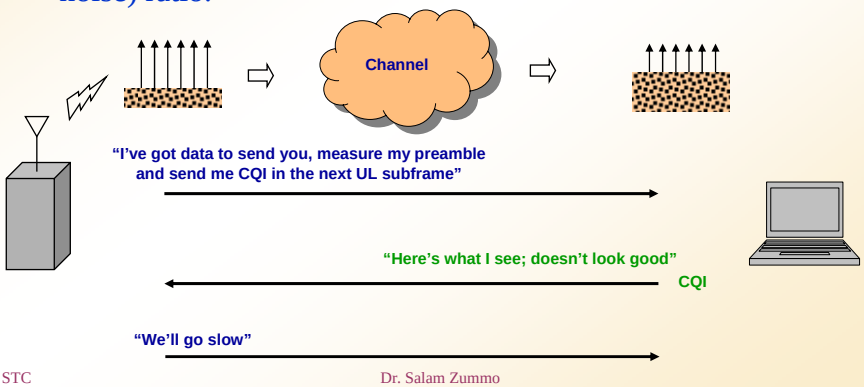
Standard	Data Rate	Range
802.16d	Up to 75 Mbps (20 Mhz channel)	6 - 16 Kms
802.16e	Up to 30 Mbps (10 Mhz channel)	1 - 5 Kms

Mobile WiMAX Technologies

- Orthogonal Frequency Division Multiple Access (OFDMA)
- OFDMA using 1024 carriers
- Adaptive time-division duplexing (TDD) and frequency-division duplexing (FDD)
- Adaptive modulation and coding
- Hybrid Automatic-Repeat Request (HARQ) for retransmission
- Diversity using MIMO and space-time coding
- Antenna array systems (AAS) to suppress interference (smart antennas)

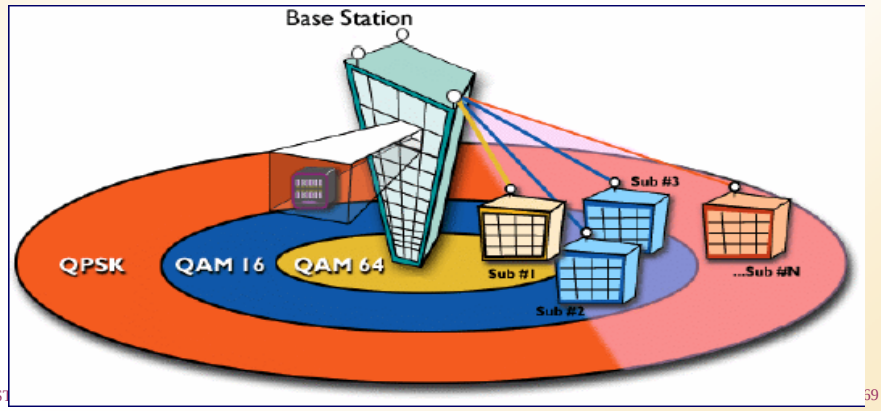
Channel Quality Indicator

- BS uses Adaptive Modulation and Coding (AMC) to send data to the subscriber stations to optimize throughput.
- BS needs to know how the channel looks to the subscriber so it tells subscriber to measure the carrier to (interference plus noise) ratio.



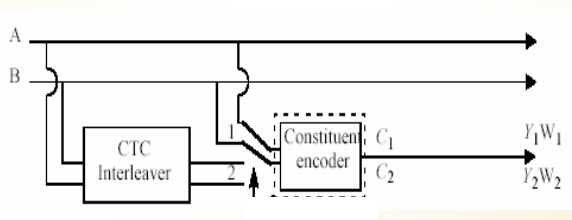
Adaptive Modulation & Coding

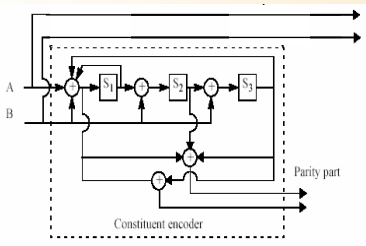
- Bit rate adaptation is achieved using adaptive modulation & coding.
- When you are near to the BS => offered high speed,
- When you are far, reliability decreases => offered lower speed.



802.16e Modulation and Coding

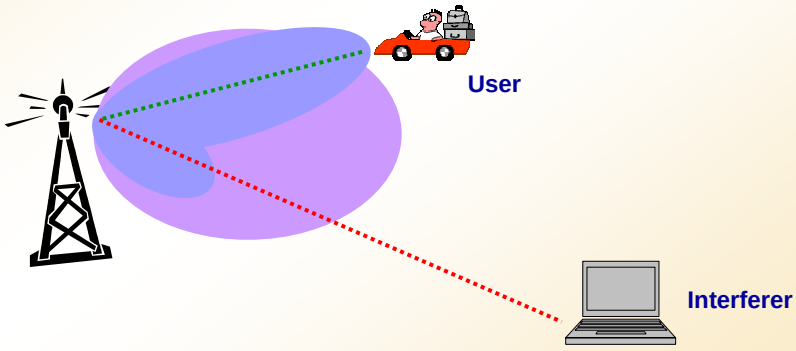
- BS and MS *nominally* support QPSK, 16-QAM and 64-QAM
- **Mandatory:** tail-biting convolutional code (K=7)
- **Optional:** Block turbo code (BTC), Convolutional turbo code (CTC)
- CTC encoder is similar performance to 3GPP
- Optional LDPC code under study





Adaptive Antenna Systems

- Make measurements of the channel
- Compute gain and phase coefficients to adapt beam pattern
- Increase link gain, reduce interference



Hybrid Automatic Repeat-Request (HARQ)

- Self-optimizing and adjusts automatically to channel conditions
  - Adds redundancy only when needed
  - Receiver saves failed transmission attempts to help future decoding (Chase Combining)
  - Every transmission helps to increase the packet success probability
- Enabled by *N*-Channel Stop-and-Wait ARQ
  - Receiver sends an ACK or NAK in response to each transmission

QoS Support

QoS Category	Applications	QoS Specifications
UGS Unsolicited Grant Service	VoIP	• Maximum Sustained Rate • Maximum Latency Tolerance • Jitter Tolerance
rtPS Real-Time Polling Service	Streaming Audio or Video	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency Tolerance • Traffic Priority
ErtPS Extended Real-Time Polling Service	Voice with Activity Detection (VoIP)	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency Tolerance • Jitter Tolerance • Traffic Priority
nrtPS Non-Real-Time Polling Service	File Transfer Protocol (FTP)	• Minimum Reserved Rate • Maximum Sustained Rate • Traffic Priority
BE Best-Effort Service	Data Transfer, Web Browsing, etc.	• Maximum Sustained Rate • Traffic Priority

802.16 vs. 802.11

	802.16	802.11
Cell Coverage	Up to few blocks	Typical max range: 200–250m
Service Area	Scales up to city-wide coverage	Campus wide
Spectrum	10 – 66 GHz (802.16) 2 – 11 GHz (802.16a)	2.4 GHz (802.11b) 5 GHz (802.11a)
Bit rate	Up to 134 Mbps	Up to 54 Mbps

802.16 vs. 802.11

	802.16	802.11
Duplexing	Full-duplex	Simplex (CSMA/CA)
Users	Provides broadband wireless access for buildings	Provides wireless access for mobile users
Mobility	will eventually evolve to support mobile users	Supports mobility and inter-cell roaming

802.16 vs. 802.11

	802.16	802.11
Connectivity	Connects to UMTS, ATM core networks	Connects to wired Ethernet backbones
Cost	High initial investment requirements	Low initial cost. Low running cost.
Target Market	Public. Provides high-speed connection to meet business demands	Private. To address mobility requirement in an organization
Service Provider	ISP, Telecom companies	Local to the organization

IEEE802.16e Summary

- **802.16e Pros**
  - Scalable Bandwidths
  - Performs well in high delay spread environments
  - Higher data rates
  - TDD allows for deployment with less spectrum
  - Supports multiple antenna technologies
- **802.16e Cons**
  - High peak-to-average power ➔ nonlinear amplifiers distortion
  - How will it perform in high interference environment?
  - What is performance in high Doppler?
  - Signaling overhead
  - Spectrum availability
  - Network layers not clearly defined yet

Flarion Flash OFDM

- Proprietary technology of Flarion Inc USA
  - May evolve into a standard in next one / two years
- First mobile OFDMA technology to be commercially deployed
- 1.25 + 1.25 MHz
- Evolution to 5 + 5 MHz
- Spectrum re-use 1/1 in every sector
- Peak Date rate: DL – 3 Mbps
UL – 1.5 Mbps
- VoIP based voice service with low latency
- QoS for data services