Wireless LANs

Mobility

Flexibility

Hard to wire areas

Reduced cost of wireless systems

Improved performance of wireless systems

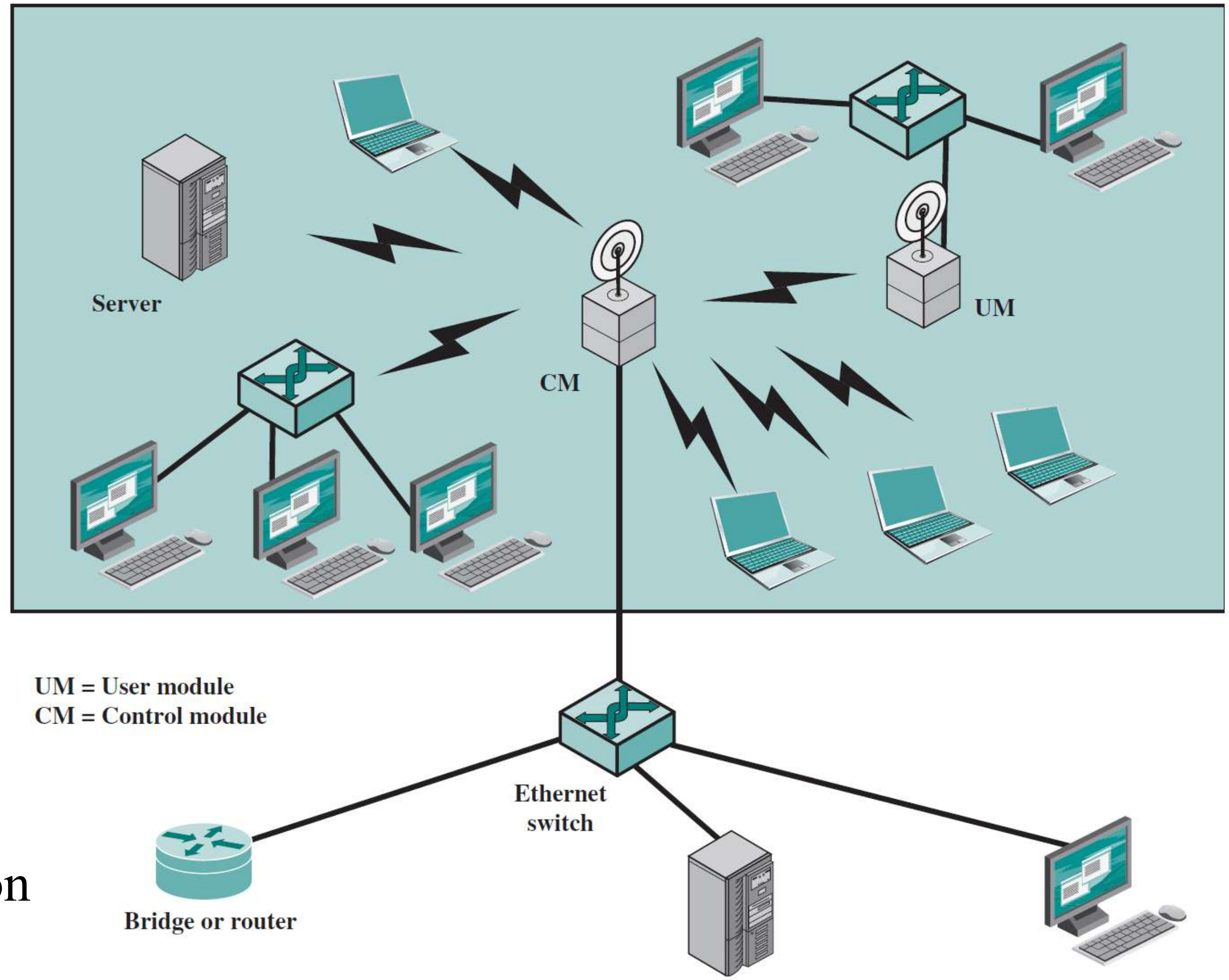
Wireless LAN Applications

LAN Extension

Cross building interconnection

Nomadic access

Ad hoc networks



Single Cell Wireless LAN

Wireless LANs (WLANs):

- Use Radio Frequencies (RF) instead of cables at the physical layer and MAC sublayer of the data link layer.
- Connect clients to a network through a wireless access point (AP) or wireless router, instead of an Ethernet switch.

Characteristic	802.11 Wireless LAN	802.3 Ethernet LANs
Physical Layer	Radio Frequency (RF)	Cable
Media Access	Collision Avoidance	Collision Detection
Availability	Anyone with a radio NIC in range of an access point	Cable connection required
Signal Interference	Yes	Inconsequential
Regulation	Additional regulation by country authorities	IEEE standard dictates

LAN Extension

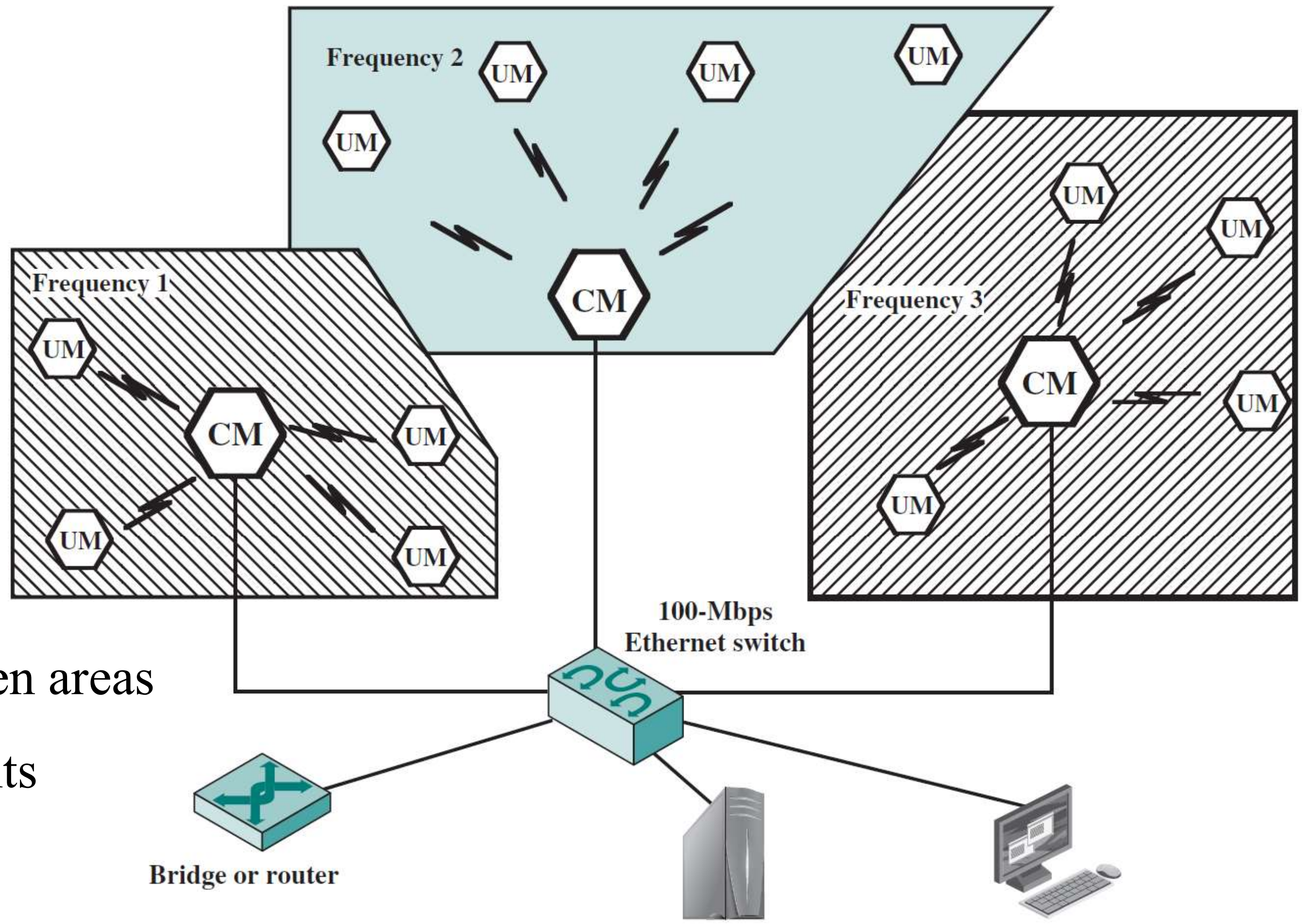
Buildings with large open areas

- Manufacturing plants
- Warehouses

Historical buildings

Small offices

May be mixed with fixed wiring system



Multi Cell Wireless LAN

Cross Building Interconnection

Point to point wireless link between buildings

Typically connecting bridges or routers

Used where cable connection not possible,

e.g. across a street

Nomadic Access

Mobile data terminal, e.g. laptop

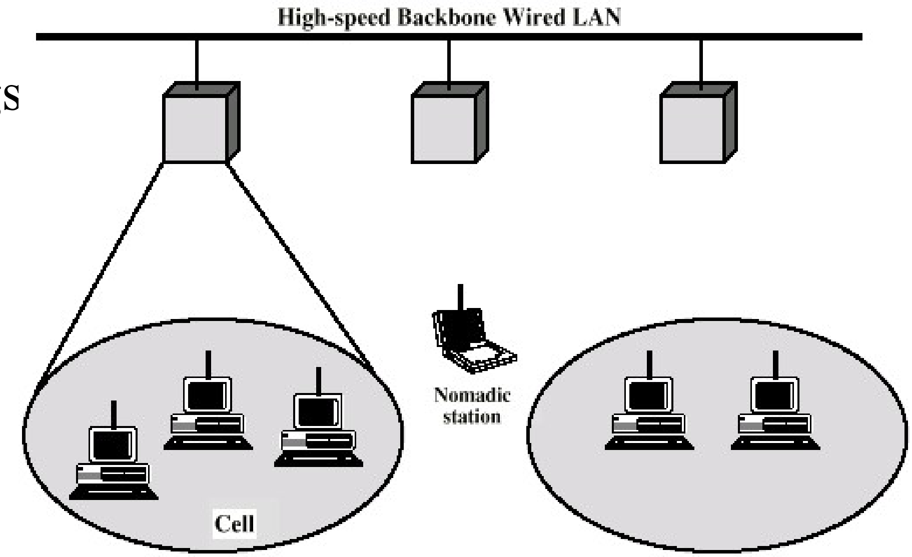
Transfer of data from laptop to server

Campus or cluster of buildings

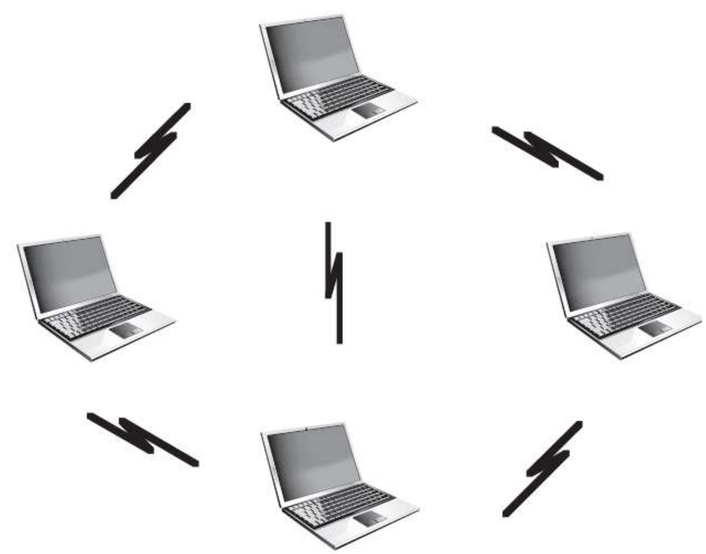
Ad Hoc Networking

Peer to peer

Temporary, e.g. conference



(a) Infrastructure Wireless LAN


(b) Ad hoc LAN

Wireless LAN Requirements

Throughput

Number of nodes

Connection to backbone

Service area

Battery power consumption

Transmission robustness and security

Collocated network operation

License free operation

Handoff/roaming

Dynamic configuration

Wireless LAN Technology

Infrared (IR) LANs

-Infrared Data Association: www.irda.org

Spread spectrum Radio LANs

Narrow band microwave

Comparative table

	Infrared		Spread Spectrum		Radio
	Diffused Infrared	Directed Beam Infrared	Frequency Hopping	Direct Sequence	Narrowband Microwave
Data rate (Mbps)	1 to 4	1 to 10	1 to 3	2 to 20	10 to 20
Mobility	Stationary/mobile	Stationary with LOS	Mobile	Stationary/mobile	
Range (ft)	50 to 200	80	100 to 300	100 to 800	40 to 130
Detectability	Negligible		Little		Some
Wavelength/ frequency	λ: 800 to 900 nm		902 to 928 MHz 2.4 to 2.4835 GHz 5.725 to 5.85 GHz		902 to 928 MHz 5.2 to 5.775 GHz 18.825 to 19.205 GHz
Modulation technique	ASK		FSK	QPSK	FS/QPSK
Radiated power	—		<1W		25 mW
Access method	CSMA	Token Ring, CSMA	CSMA		Reservation ALOHA, CSMA
License required	No		No		Yes unless ISM

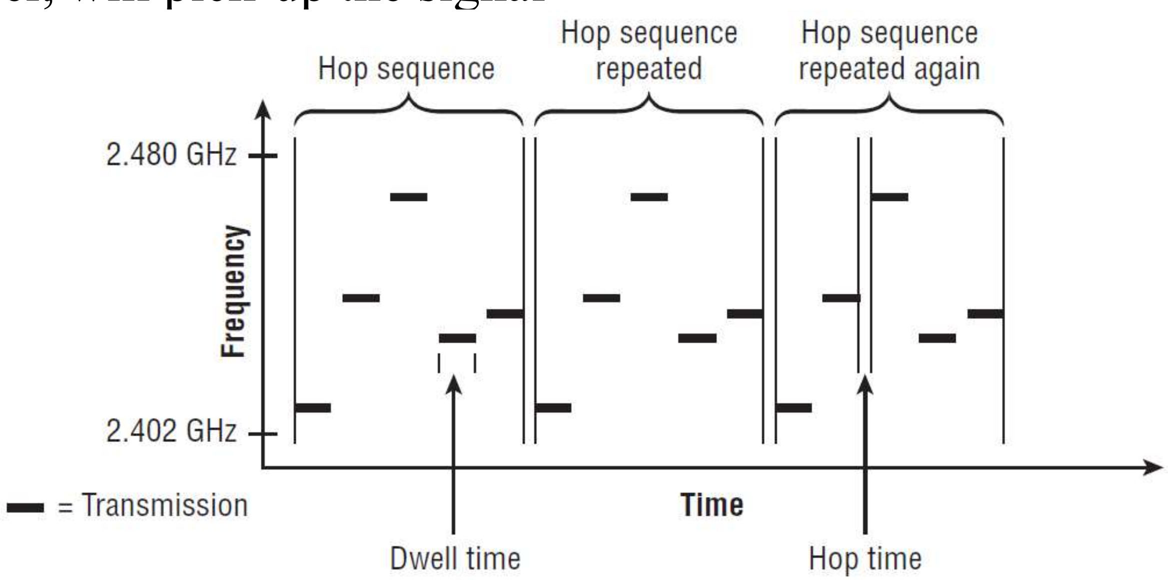
Spread Spectrum

FDM based technique using multiple carriers for the same data; improving reliability

Efficient for radio transmissions, where electromagnetic interferences or moving objects may change the optimum carrier frequency. Also energy consumption is low, so ideal for RF communications.

Spread Spectrum arranges for a sender to send signal on a set of carrier frequencies, the receiver checking all carrier frequencies. So the signal is spread over a wider bandwidth. Two techniques:

Frequency hopping (FHSS): signal is broadcast over a seemingly random series of RF carriers (use of table-derived frequencies), hopping from one frequency to another, at split-second intervals; the receiver, hopping between frequencies in synchronization with the sender, will pick-up the signal

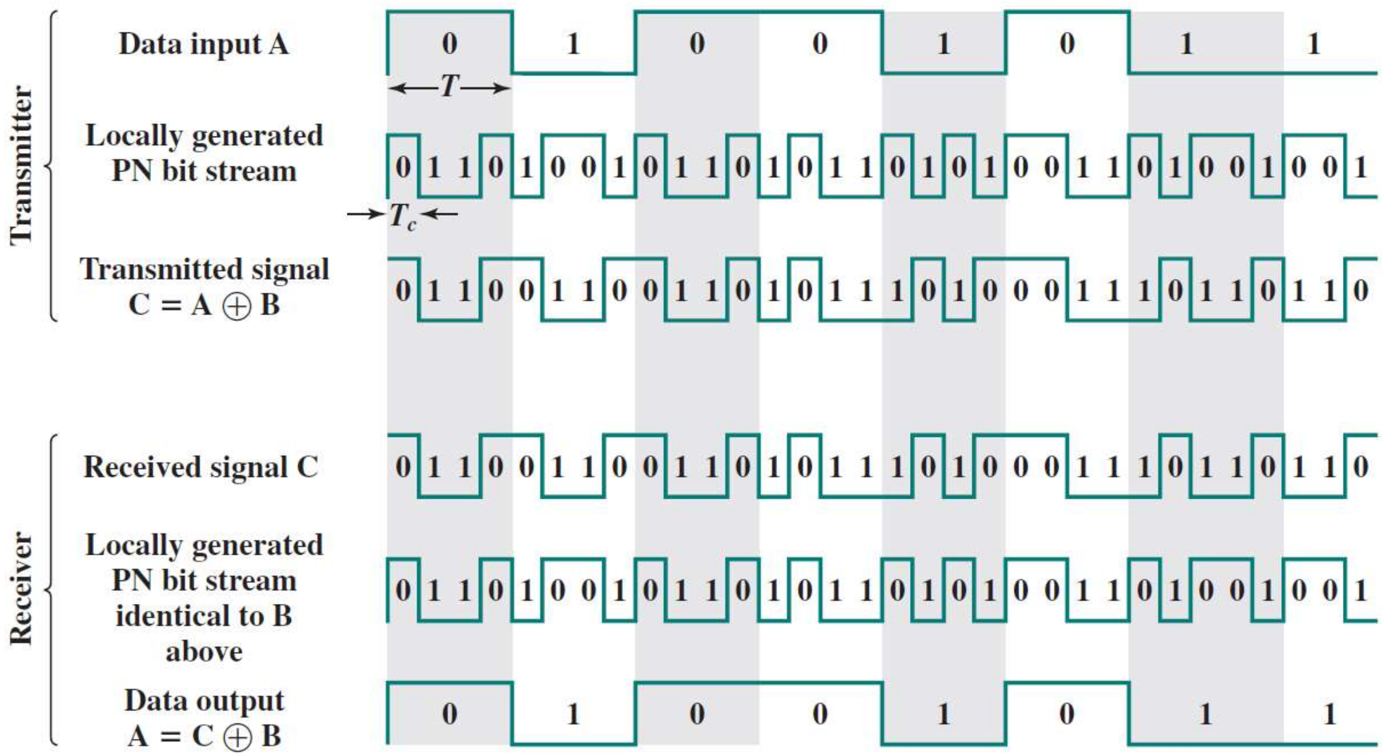


Spread Spectrum

Direct sequence (DSSS): each bit in the original signal is represented by multiple bits in the transmitted signal – chipping code- (using more bits, wider bandwidth).
One technique: to combine the original digital information stream with a pseudo-random bit stream, by using a XOR function; a ‘1’ in data stream will invert the pseudorandom bit stream, a ‘0’ will pass unchanged the chipping code.

Barker code:
Binary data 1 = 1 0 1 1 0 1 1 1 0 0 0
Binary data 0 = 0 1 0 0 1 0 0 0 1 1 1

Input		Output
A	B	A xor B
0	0	0
0	1	1
1	0	1
1	1	0



FHDS versus DSSS:

FH systems use a radio carrier that “hops” from frequency to frequency in a pattern known to both transmitter and receiver

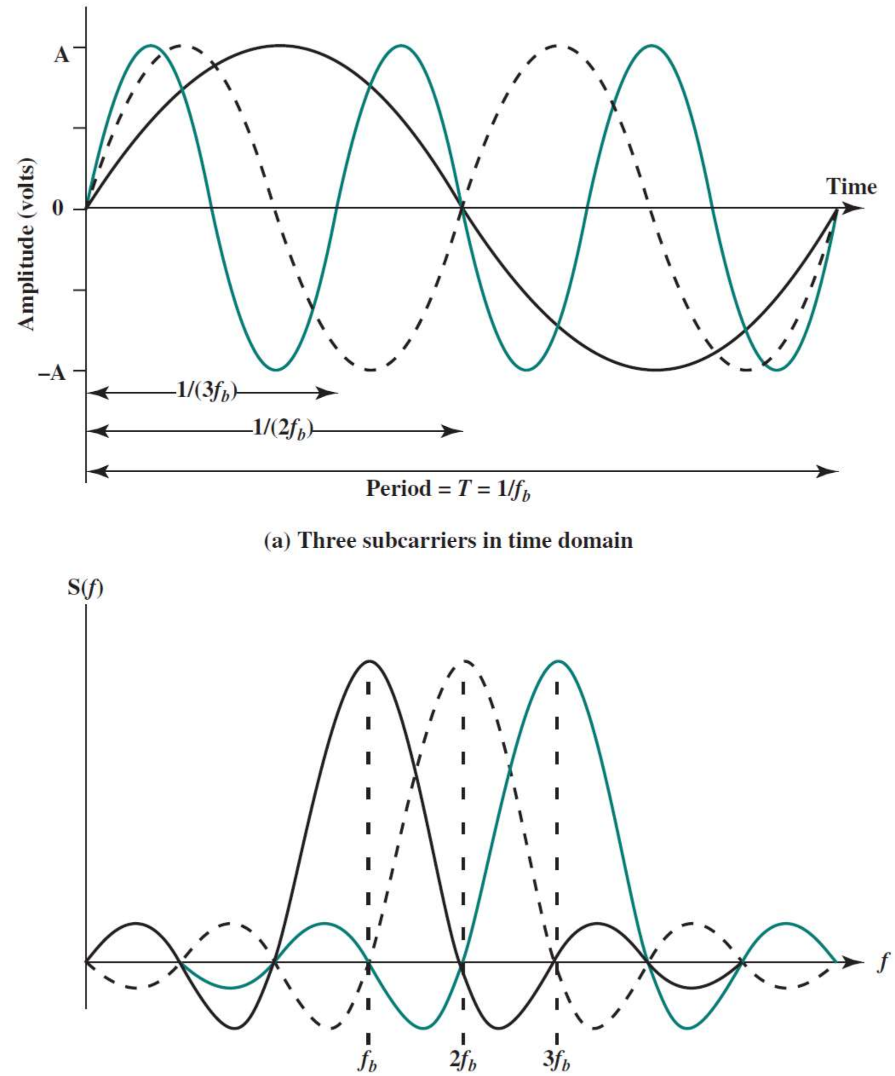
- Easy to implement
- Resistance to noise
- Limited throughput (2-3 Mbps @ 2.4 GHz)

DS systems use a carrier that remains fixed to a specific frequency band. The data signal is spread onto a much larger range of frequencies (at a much lower power level) using a specific encoding scheme.

- Much higher throughput than FH (up to 11 Mbps)
- Better range
- Less resistant to noise (made up for by redundancy – it transmits at least 10 fully redundant copies of the original signal at the same time)

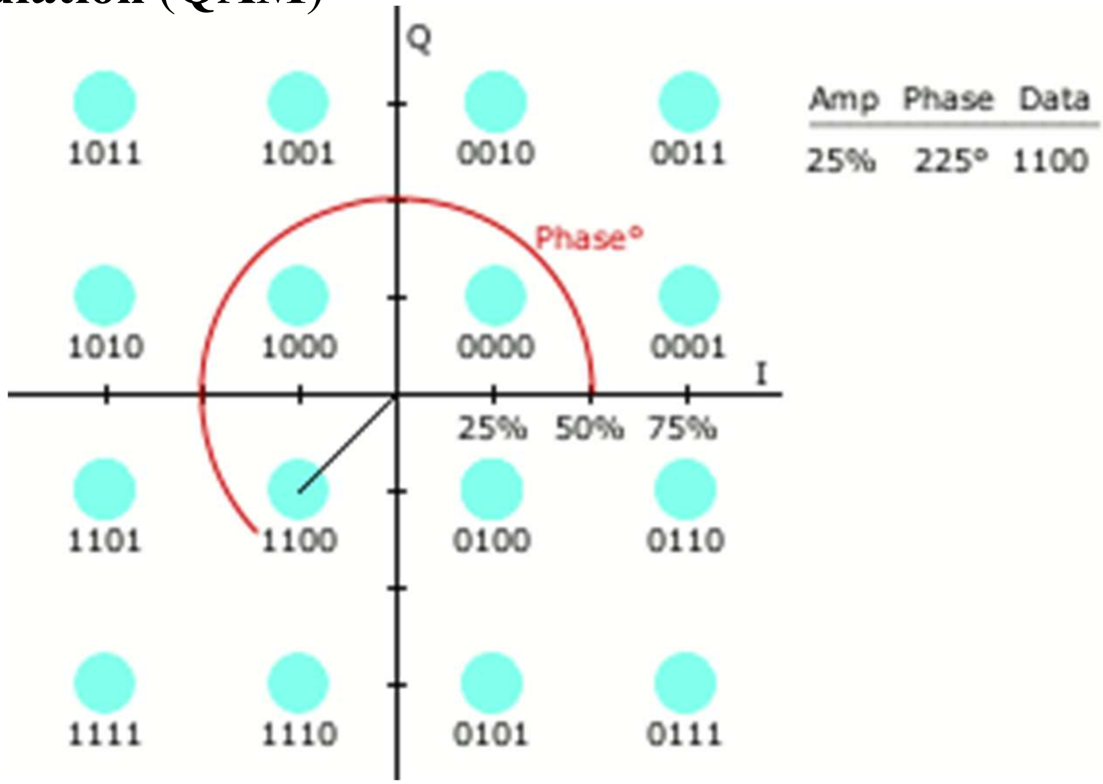
OFDM (Orthogonal Frequency Division Modulation)

- Transmitting large amounts of digital data over a radio wave
- OFDM works by splitting the radio signal into multiple smaller sub-signals that are then transmitted simultaneously at different frequencies to the receiver
- Reduces the crosstalk (interferences) in wireless transmissions
- Use in WLANs



(a) Three subcarriers in time domain

Quadrature amplitude modulation (QAM)



Digital 16-QAM with example constellation points (image from Wikipedia)

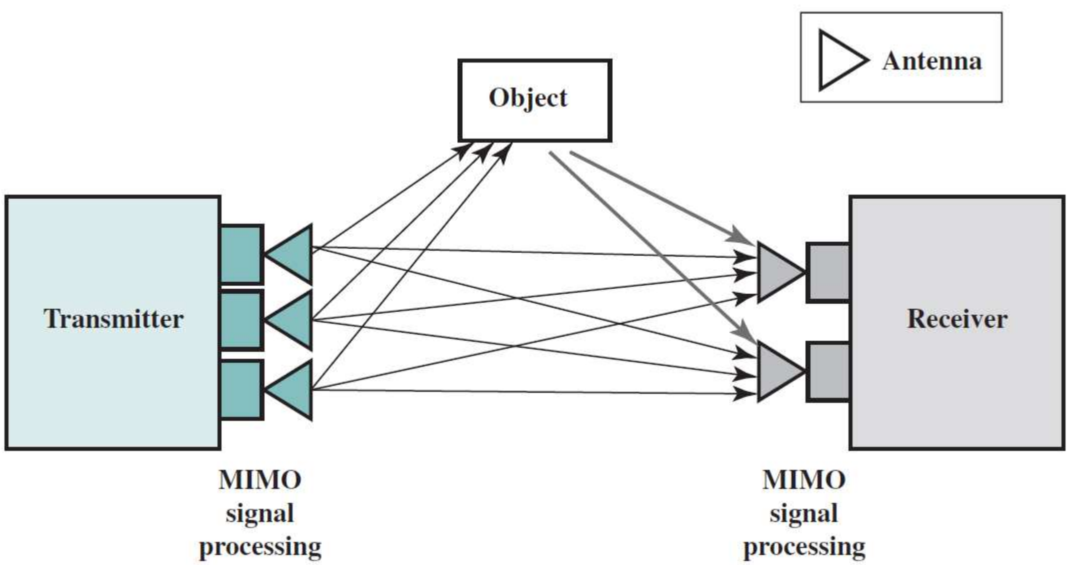
Example:
Use of a 256 QAM carrier; 1024bytes/sec would require less than 1KHz
OFDM 2000 means grouping 2000 carriers at different frequencies
For 8000 carriers QAM 256 at 1024bytes/sec, would give a throughput of 64Mbps for a spectrum band of 6MHz; extensive use in digital TV

Multiple-input-multiple-output (MIMO) antenna architecture

Key technology in evolving high-speed wireless networks => better receive signal

MIMO scheme

- the transmitter and receiver employ multiple antennas
- source
  - data stream divided into *n* substreams, one for each of the *n* transmitting antennas => multiple input
- Receiver
  - *m* antennas receive the transmissions from the *n* source antennas via a combination of line-of-sight transmission and multipath => multiple output



Industrial, scientific, and medical (**ISM**) frequency bands
- Different RF regulatory bodies

Lower Frequency MHz	**Upper Frequency MHz**	**Comments**
2400	2500	Often referred to as the 2.4 GHz band, this spectrum is the most widely used of the bands available for Wi-Fi. Used by 802.11b, g, & n. It can carry a maximum of three non-overlapping channels.
5725	5875	This 5 GHz band or 5.8 GHz band provides additional bandwidth, and being at a higher frequency, equipment costs are slightly higher, although usage, and hence interference is less. It can be used by 802.11a & n. It can carry up to 23 non-overlapping channels, but gives a shorter range than 2.4 GHz.

From: http://www.radio-electronics.com/

*Unlicensed National Information Infrastructure (**U-NII**) bands*
- Different RF regulatory bodies

Band	**Frequency**	**Channels**
U-NII-1	5.15 GHz – 5.25 GHz	4 channels
U-NII-2	5.25 GHZ – 5.35 GHz	4 channels
U-NII-2 Extended	5.47 GHZ – 5.725 GHz	12 channels*
U-NII-3	5.725 GHz – 5.85 GHz	5 channels

Wireless LANs – standard IEEE 802.11

A family of wireless LAN (WLAN) specifications developed by a working group at the Institute of Electrical and Electronic Engineers (IEEE)
Defines standard for WLANs using the following four technologies:

Frequency Hopping Spread Spectrum (FHSS)
Direct Sequence Spread Spectrum (DSSS)
Infrared (IR)
Orthogonal Frequency Division Multiplexing (OFDM)

Versions: 802.11a, 802.11b, 802.11g, 802.11e, 802.11f, 802.11i

802.11a offers speeds with a theoretically maximum rate of 54Mbps in the 5 GHz band; implements OFDM
-Industrial, scientific, and medical (ISM) frequency bands

802.11b offers speeds with a theoretically maximum rate of 11Mbps at in the 2.4 GHz spectrum band; implements DSSS, less power, but more noise-dependent
-Industrial, scientific, and medical (ISM) frequency bands
-much more crowded frequency space

802.11a vs. 802.11b	802.11a	802.11b
Raw data rates	Up to 54 Mbps (54, 48, 36, 24,18, 12 and 6 Mbps)	Up to 11 Mbps (11, 5.5, 2, and 1 Mbps)
Range	50 Meters	100 Meters
Bandwidth	UNII and ISM (5 GHz range)	ISM (2.4000—2.4835 GHz range)
Modulation	OFDM technology	DSSS technology

802.11g is a new standard for data rates of up to a theoretical maximum of 54 Mbps at 2.4 GHz

802.11g is a high-speed extension to 802.11b

Compatible with 802.11b
High speed up to 54 Mbps
2.4 GHz (vs. 802.11a, 5 GHz)
Using ODFM for backward compatibility
Adaptive Rate Shifting

Protocol	Frequency Band	Compatibility	Theoretical Rate	Actual Rate
802.11a	5 GHz	N/A	54 Mbit/s	About 22 Mbit/s
802.11b	2.4 GHz	N/A	11 Mbit/s	About 5 Mbit/s
802.11g	2.4 GHz	Compatible with 802.11b	54 Mbit/s	About 22 Mbit/s

802.11n

- 2.4 & 5 GHz frequency bands
- *High Throughput (HT)*, that provides PHY and MAC enhancements to support data rates of up to 600 Mbps
- 40 MHz channels
- use *multiple-input, multiple-output (MIMO)* technology in addition with OFDM technology.
  - multiple receiving and transmitting antennas
  - capitalizes on the effects of multipath as opposed to compensating for or eliminating multipath

802.11ac

5 GHz frequency bands (2.4 GHz ISM band cannot provide needed frequency space)

- *Very High Throughput (VHT)*
- 80 MHz and 160 MHz channels
- 256-QAM modulation
- designed to transmit and receive up to eight spatial streams

	802.11n	802.11n IEEE Specification	802.11ac Wave 1 Today	802.11ac Wave2 WFA Certification Process Continues	802.11ac IEEE Specification
Band	2.4 GHz & 5 GHz	2.4 GHz & 5 GHz	5 GHz	**5 GHz**	5 GHz
MIMO	Single User (SU)	Single User (SU)	Single User (SU)	**Multi User (MU)**	Multi User (MU)
PHY Rate	450 Mbps	600 Mbps	1.3 Gbps	**2.34 Gbps - 3.47 Gbps**	6.9 Gbps
Channel Width	20 or 40 MHz	20 or 40 MHz	20, 40, 80 MHz	20, 40, 80, **80-80, 160** MHz	20, 40, 80, 80-80, 160 MHz
Modulation	64 QAM	64 QAM	256 QAM	256 QAM	256 QAM
Spatial Streams	3	4	3	3-**4**	8
MAC Throughput*	293 Mbps	390 Mbps	845 Mbps	1.52 Gbps- 2.26 Gbps	4.49 Gbps

* Assuming a 65% MAC efficiency with highest MCS

Future Wi-Fi Frequencies

- Very High Throughput (VHT) technology: ***60GHz***
- ***White-Fi:*** use of Wi-Fi technology in the unused television RF spectrum also known as TV white space

Key IEEE 802.11 Standards

Standard	Scope
IEEE 802.11a	Physical layer: 5-GHz OFDM at rates from 6 to 54 Mbps
IEEE 802.11b	Physical layer: 2.4-GHz DSSS at 5.5 and 11 Mbps
IEEE 802.11c	Bridge operation at 802.11 MAC layer
IEEE 802.11d	Physical layer: Extend operation of 802.11 WLANs to new regulatory domains (countries)
IEEE 802.11e	MAC: Enhance to improve quality of service and security mechanisms
IEEE 802.11g	Physical layer: Extend 802.11b to data rates >20 Mbps
IEEE 802.11i	MAC: Enhance security and authentication mechanisms
IEEE 802.11n	Physical/MAC: Enhancements to enable higher throughput
IEEE 802.11T	Recommended practice for the evaluation of 802.11 wireless performance
IEEE 802.11ac	Physical/MAC: Enhancements to support 0.5–1 Gbps in 5-GHz band
IEEE 802.11ad	Physical/MAC: Enhancements to support ≥ 1 Gbps in the 60-GHz band

Wireless LANs – standard IEEE 802.11continued

Basic service set (BSS - cell)

Set of stations using same MAC protocol

Competing to access shared medium

May be isolated

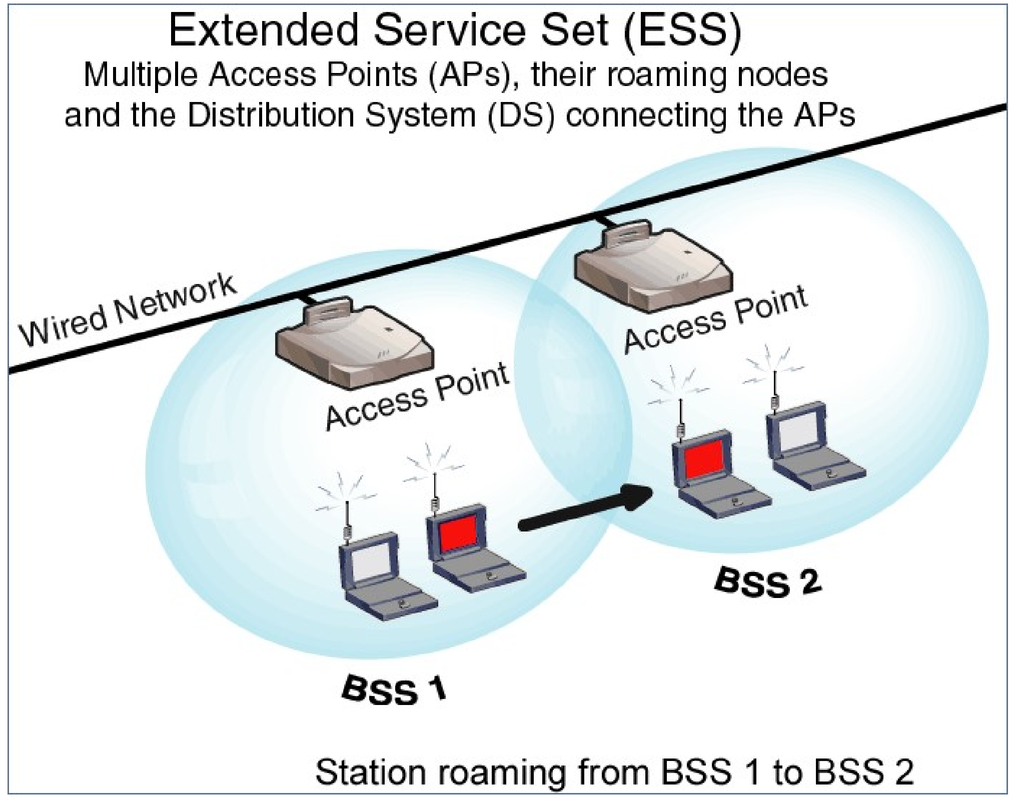
May connect to backbone via access point (bridge)

Extended service set (ESS)

Two or more BSS connected by

distributed system

Appears as single logic LAN to LLC level



Types of station

Based on mobility:

-No transition

Stationary or moves within direct communication range of single BSS

-BSS transition

Moves between BSSs within single ESS

-ESS transition

From a BSS in one ESS to a BSS in another ESS

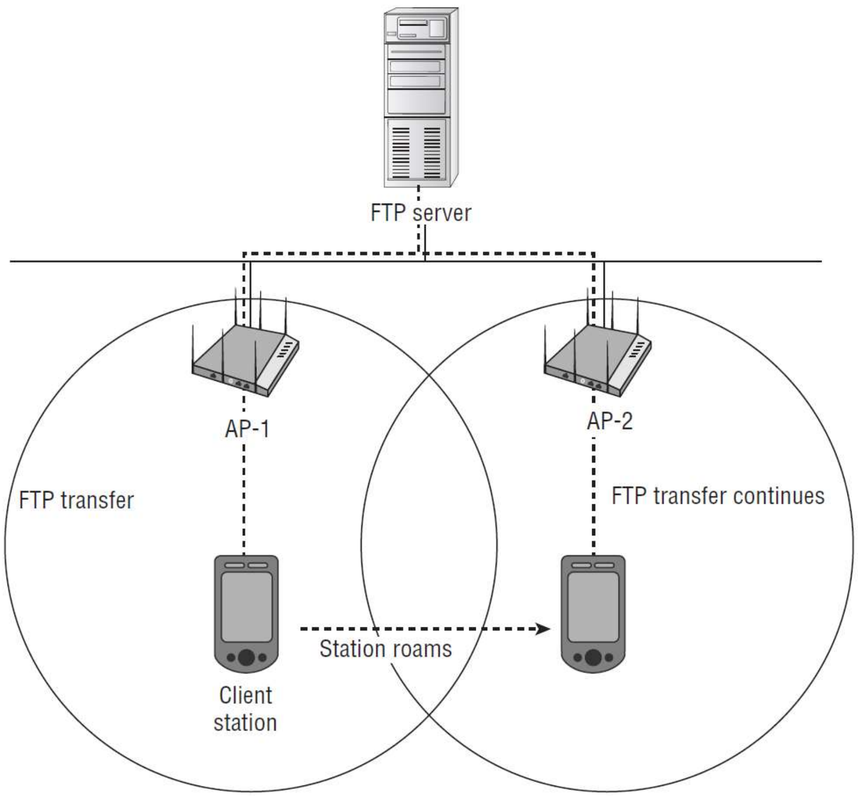
Disruption of service likely

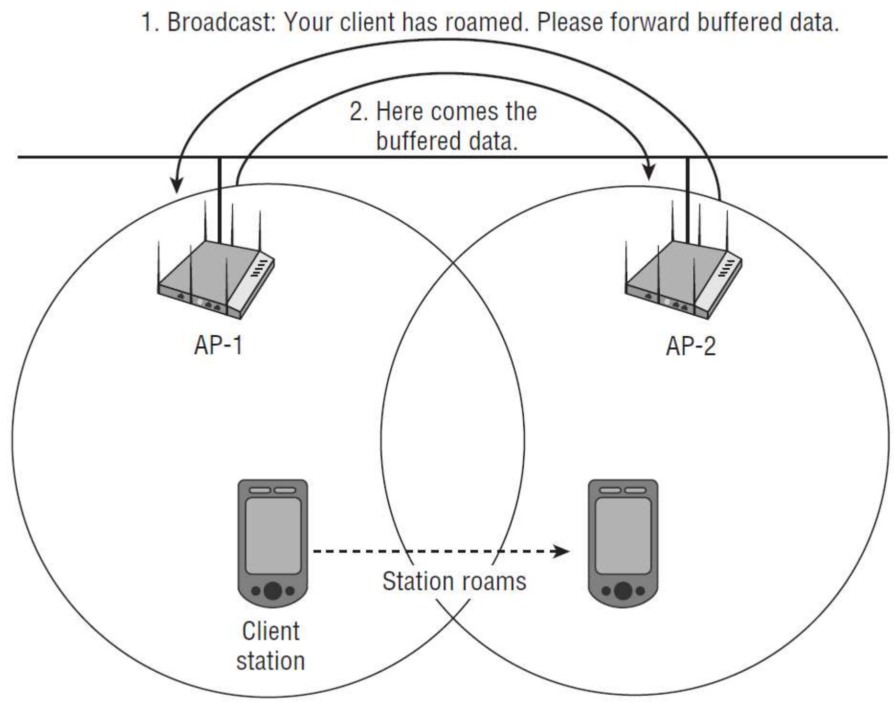
Mobility:

802.11 standard mandated that vendor access points support **roaming**

- allow client stations communicating through one AP to move and continue communications on a new AP (coverage area overlaps).

Seamless roaming





Association-Related Services

• **Association:**

- initial association between a station and an AP
- a station must identify itself before transmitting or receiving frames on a WLAN => association with an AP within a particular BSS
- the AP can communicate this information to other APs within the ESS to facilitate routing and delivery of addressed frames.

• **Reassociation:**

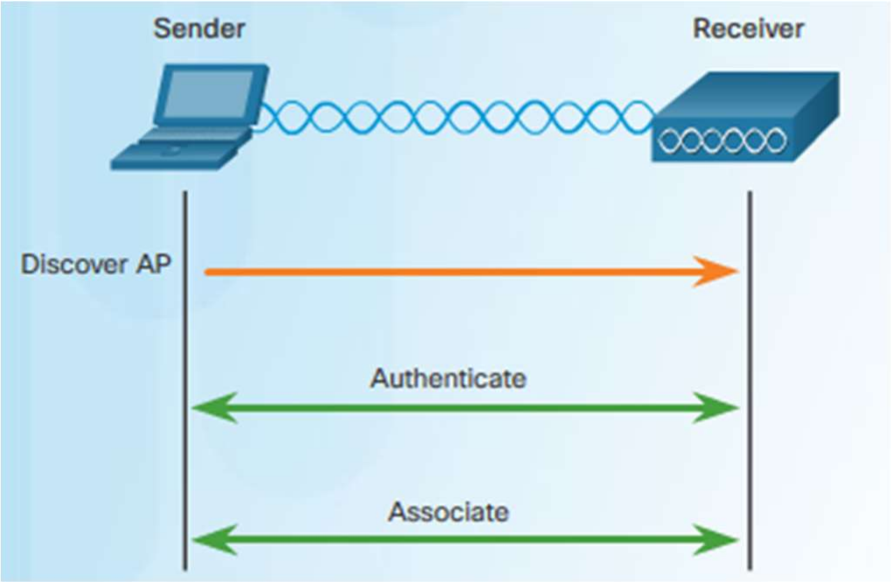
- an established association can be transferred from one AP to another, allowing a mobile station to move from one BSS to another.

• **Disassociation:**

- a station/AP notifies an existing association is terminated.
- a station should give this notification before leaving an ESS or shutting down

Wireless Network Operations

- Wireless client association process with AP includes discovering a new wireless AP, authenticating with that AP, then associating with that AP.
- Common configurable wireless parameters include:
  - **Network mode**
  - **SSID**
  - **Channel settings**
  - **Security mode**
  - **Encryption**
  - **Password**



- Wireless devices must discover and connect to an AP or wireless router. This process can be passive or active.
- The 802.11 standard was originally developed with two authentication mechanisms: **open authentication** provides wireless connectivity to any wireless device, and the **shared key authentication** technique is based on a key that is pre-shared between the client and the AP.

- Access Point (AP):
  - **Small network** – usually a wireless router that integrates the functions of a router.
  - **Large network** – can be many APs.
- Wireless LAN Controller (WLC):
  - Controls and manages the functions of the APs on a network.
  - Simplifies configuration and monitoring of numerous APs.
  - Controls Lightweight Access Points using the
  - Hardware or virtualized (cloud-based)

- Lightweight AP (LWAP):
  - Centralized management by WLC.
  - No longer acts autonomously.

Wireless LAN - Physical

Infrared

- 1Mbps and 2Mbps
- Wavelength 850-950nm

Direct sequence spread spectrum

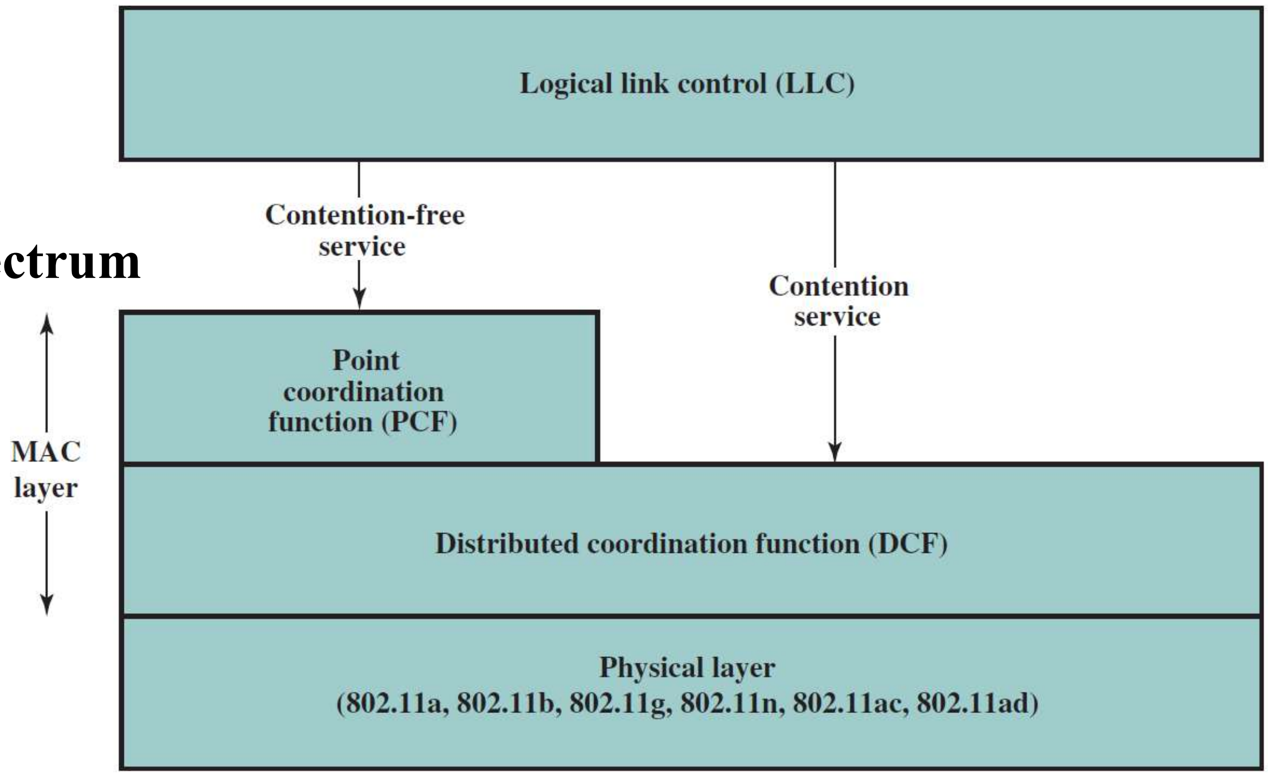
- 2.4GHz ISM band
- Up to 7 channels
- Each 1Mbps or 2Mbps

Frequency hopping spread spectrum

- 2.4GHz ISM band
- 1Mbps or 2Mbps

OFDM

Others



IEEE 802.11 Protocol Architecture

IEEE 802.11 Physical Layer Standards

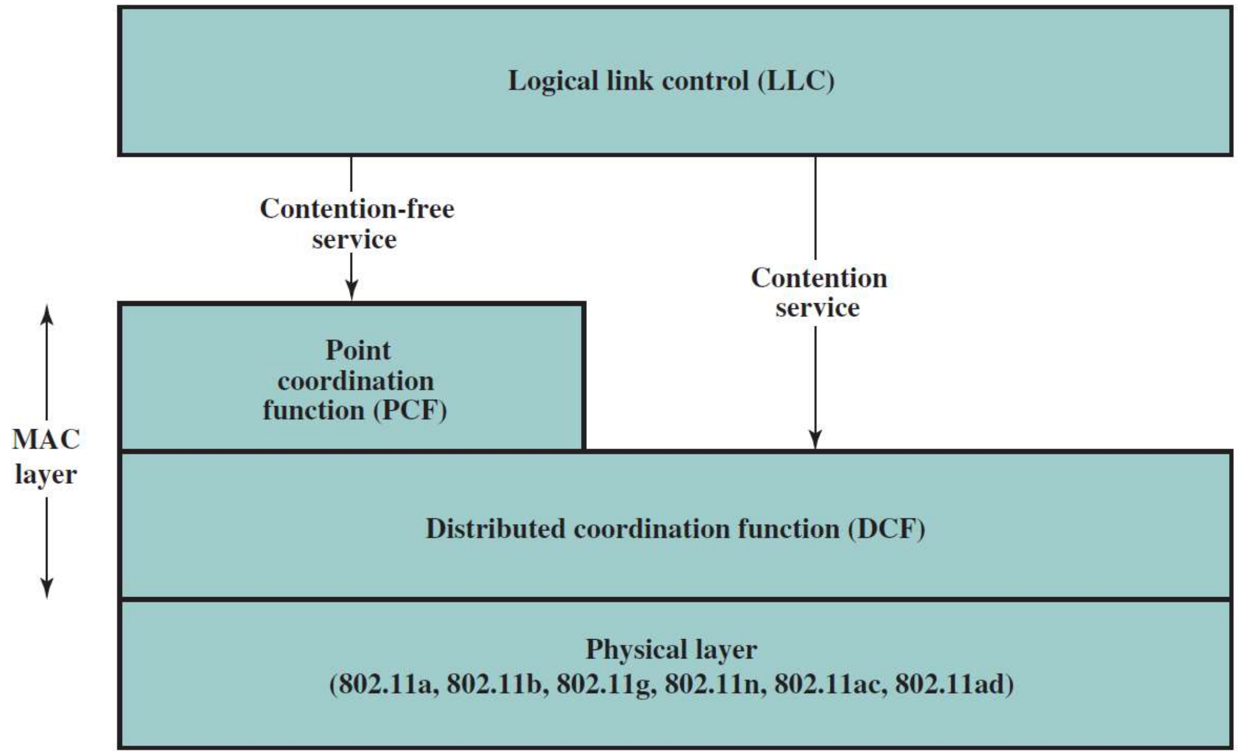
Standard	802.11a	802.11b	802.11g	802.11n	802.11ac	802.11ad
Year introduced	1999	1999	2003	2000	2012	2014
Maximum data transfer speed	54 Mbps	11 Mbps	54 Mbps	65 to 600 Mbps	78 Mbps to 3.2 Gbps	6.76 Gbps
Frequency band	5 GHz	2.4 GHz	2.4 GHz	2.4 or 5 GHz	5 GHz	60 GHz
Channel bandwidth	20 MHz	20 MHz	20 MHz	20, 40 MHz	40, 80, 160 MHz	2160 MHz
Highest order modulation	64 QAM	11 CCK	64 QAM	64 QAM	256 QAM	64 QAM
Spectrum usage	DSSS	OFDM	DSSS, OFDM	OFDM	SC-OFDM	SC, OFDM
Antenna configuration	1×1 SISO	1×1 SISO	1×1 SISO	Up to 4×4 MIMO	Up to 8×8 MIMO, MU-MIMO	1×1 SISO

Media Access Control (IEEE 802.11)

Distributed wireless foundation MAC (DWFMAC) – MAC algorithm

Sublayers:

Distributed coordination function (DCF)
- CSMA without collision detection
- No collision detection, due to the nature of WLAN signal (dynamic range of signals in medium, some are weak or noise affected)
- Set of delays (acts as a priority scheme) – for a fair access; based on IFS (InterFrame Space)

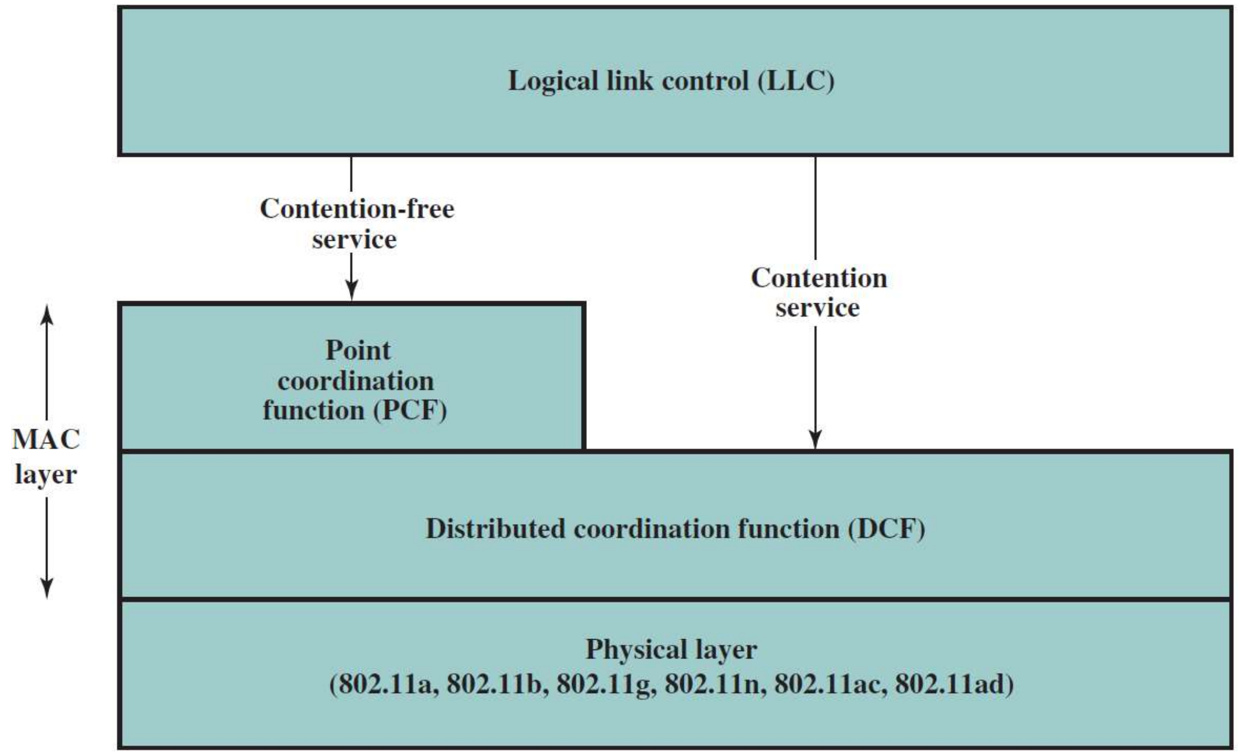


IEEE 802.11 Protocol Architecture

Media Access Control (IEEE 802.11)

Sublayers:

Point coordination function (PCF) – on top of DCF
- Polling of central master (point coordinator)
- Uses PIFS, and being shorter than DIFPS, can seize the medium and lock out traffic while issuing polls
- For preventing lock out of all traffic, use of **superframe**, allowing polling for first superframe half, and allowing contention period in the second half (see next slides)

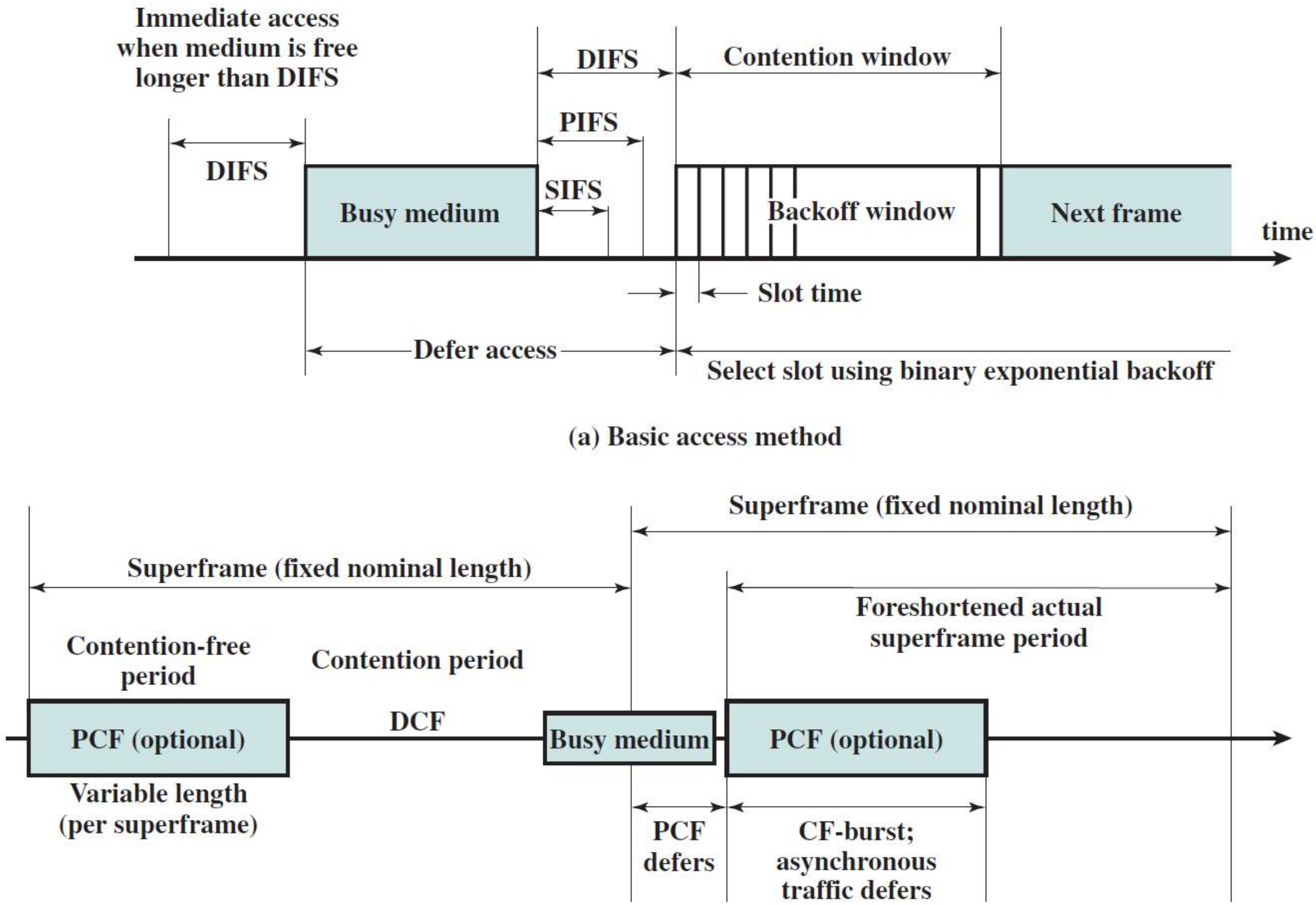


IEEE 802.11 Protocol Architecture

More on DCF:

Basic delay unit **IFS** (interframe space)
Three values for IFS:
-SIFS (Short IFS) – immediate response actions, used with ACKs, or for poll responses
-PIFS (Point coordination function IFS) – used by central controller when issuing polls
-DIFS (Distributed coordination function IFS) – minimum delay for asynchronous ordinary frames contending for access

General rules for CSMA access (802.11 MAC protocol):
-a station senses medium; if medium idle, waits for IFS seconds to see it remains idle ; then transmits
-If medium busy, waits till that transmission ends
-Current transmission over, delays own transmission with IFS; if medium idle uses a backoff algorithm waiting another period; if medium still idle, may transmit



(a) Basic access method

(b) PCF superframe construction

802.11 MAC Timing

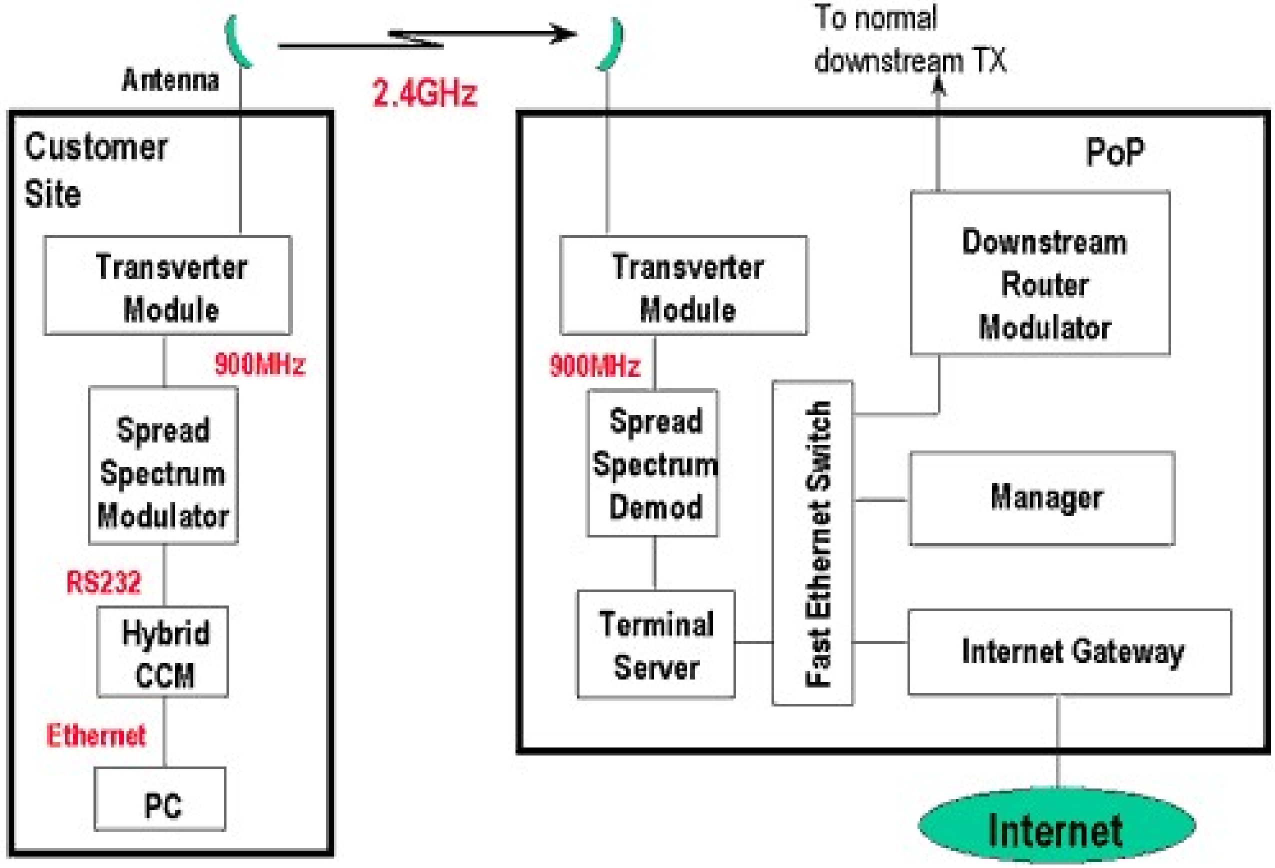
Wireless modems

Many kinds of wireless modems:

-RF modem for a wireless network (use of ISM bands)

-cellular modem for cellular communications, attached to the phone

Example: use the ISM Band for Wireless Return 900 MHz/2.4 GHz:

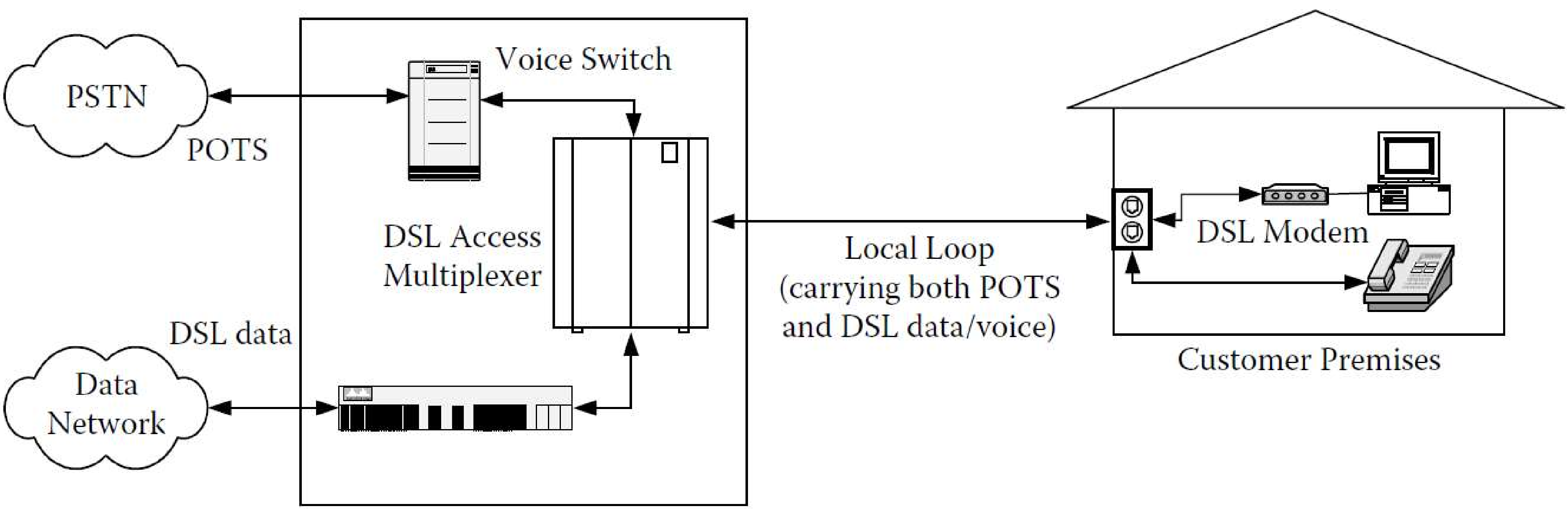


DSL (Digital Subscriber Line)

Link between subscriber and network (local loop); tens of millions installed; Reinstall?

⇒need for exploiting the existing base of TP wired structure; initially designed for voice-grade analog transmissions with 4kHz bandwidth, TP may carry data using signals over a spectrum of more than 1MHz => use of modems for digital high rate data transmissions, using currently installed twisted pair cable.

- DSL refers to the analog local loop between each customer premises and its local central office, and a DSL modem is required at each end of the loop



ADSL (Asymmetric Digital Subscriber Line)

ADSL initially designed for video-on-demand, now appropriate for high-speed Internet access.

Asymmetric because, from the user point, there is greater capacity downstream (from service provider to customer) than upstream.

ADSL uses FDM for managing the 1MHz bandwidth:

-Lowest 25kHz for voice (Plain Old Telephone Service): 0 to 4kHz for voice, rest for guard, avoiding interference with other channels

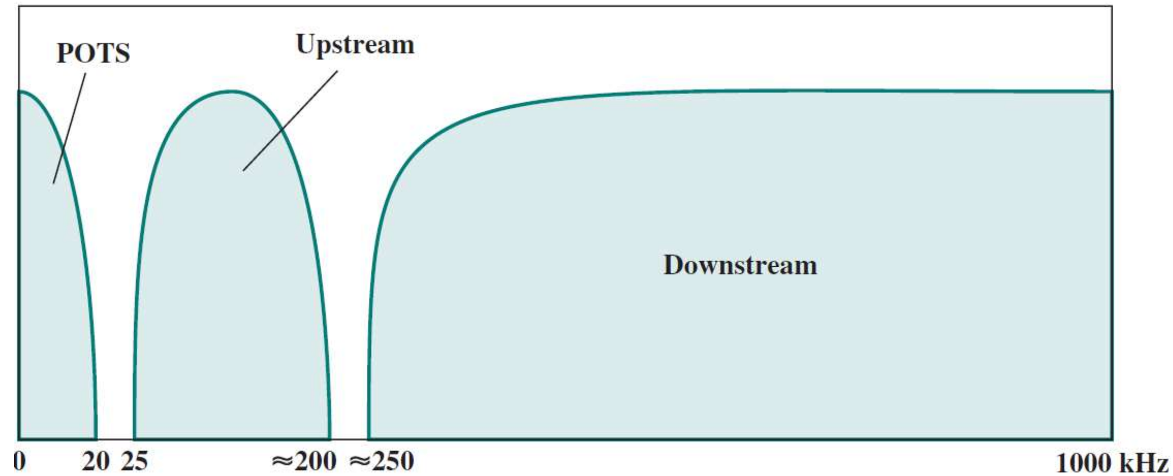
-Use echo cancellation or FDM to give (to allocate) two bands: one for upstream , one for downstream

-Use FDM within each of two bands.

Supports loop length in the range of 5.5km.

Echo Cancellation

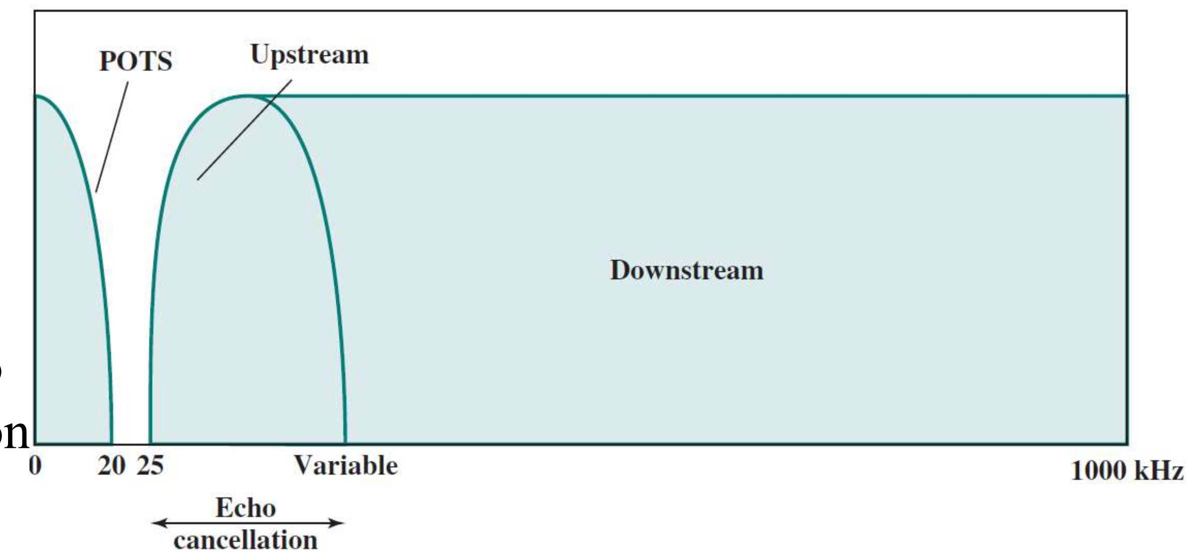
Signal processing technique, allowing digital transmissions in both directions on a single line simultaneously. The transmitter must subtract the echo of its own transmission from the incoming signal, to recover the signal sent by the other side.



(a) Frequency-division multiplexing

Advantages:

-more flexibility for upstream bandwidth changes, simply extending the area of overlap
-downstream bandwidth in the good part of the spectrum (not so many HFs) => a lower attenuation



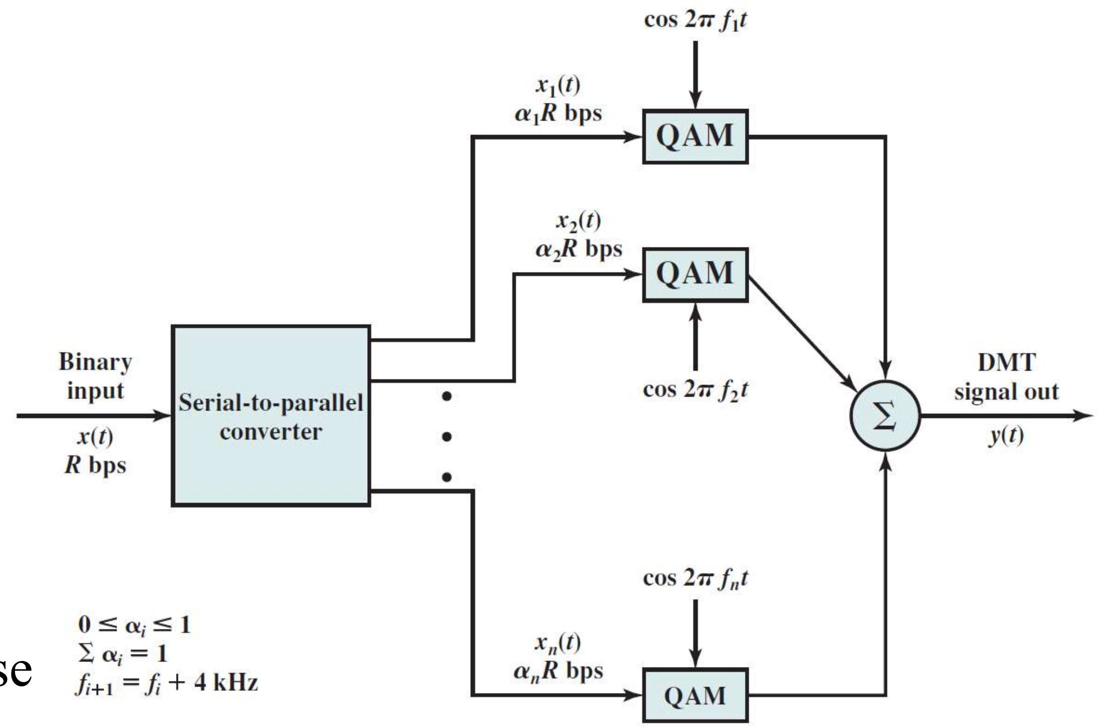
(b) Echo cancellation

DMT (Discrete Multitone)

DMT modem allows multiple carrier signals at different frequencies;

-upstream and downstream bandwidths are split in a number of 4kHz sub-channels, transmitting a number of bits on each channel.

Initially modem send test signal on each subchannel, and then use those subchannels with better signal to noise ratio.



If used 256 downstream subchannels at 4kHz, carring data at 60kbps, will result a data rate of 15.36Mbps. Transmission impairments bring this down to 1.5Mbps to 9Mbps.

Use of **QAM (Quadrature Amplitude Modulation)** – analog signaling technique, a combination of AM and PM. May assign different number of bits/transmitted signal.

Sample example: data string is split in two sub-strings. One sub-string modulates the carrier, the other modulates the carrier shifted with 90º. The composed QAM signal is the sum: $s(t) = d1(t)\cos 2\pi ft + d2(t)\sin 2\pi ft$. => signal has 4 states, for coding 2 bits.

xDSL – recent schemes for high-data speed transmissions on ADSL

High data rate DSL

Single line DSL

Very high data rate DSL

	ADSL	HDSL	SDSL	VDSL
Data Rate	1.5–9 Mbps downstream 16–640 kbps upstream	1.544 or 2.048 Mbps	1.544 or 2.048 Mbps	13–52 Mbps downstream 1.5–2.3 Mbps upstream
Mode	Asymmetric	Symmetric	Symmetric	Asymmetric
Copper Pairs	1	2	1	1
Range (24-Gauge UTP)	3.7–5.5 km	3.7 km	3.0 km	1.4 km
Signaling	Analog	Digital	Digital	Analog
Line Code	CAP/DMT	2B1Q	2B1Q	DMT
Frequency	1–5 MHz	196 kHz	196 kHz	≥10 MHz
Bits/Cycle	Varies	4	4	Varies

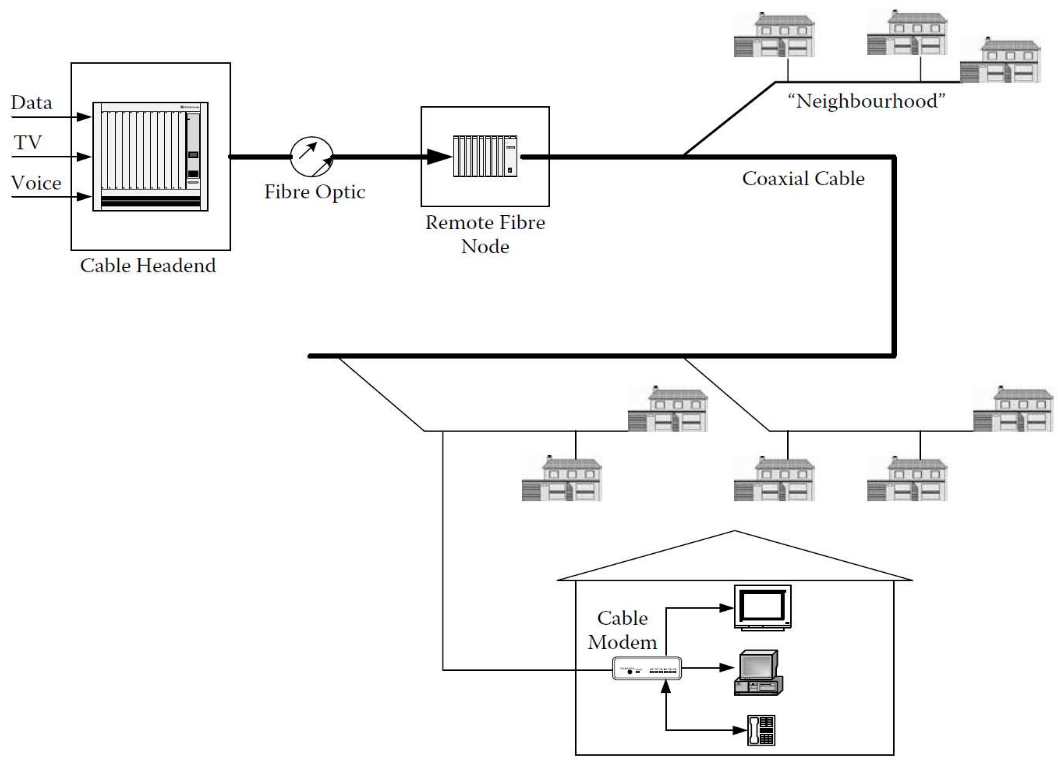
Alternative Broadband Access Technologies

Fiber-to-the-home (FTTH)

- common solution: using passive optical network (PON)
- a single transceiver in the CO serving multiple customers
- splitters and couplers to distribute the service among the different subscribers

Cable

- hybrid fiber-coax (HFC)
- fiber-optic cable carrying signals between the cable headend and fiber nodes in the network, from which existing coaxial cable is used to cover the "last mile" to the subscribers' premises.



Alternative Broadband Access Technologies

Wireless

- wireless local loop with the advantage that it doesn't need the installation of a transmission medium
- higher frequencies systems: 20 to 40 GHz, sometimes requiring line-of-sight (LOS) availability
- Lower frequency systems: 2,4GHz– 5GHz, with non-LOS transmission

BPL (Broadband over Power Line)

- use of the electric power supply network for the transmission of broadband data

Example: *IEEE 1901-2010 (IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications)*

- high-speed (>100 Mbps at the physical layer) communication
- transmission frequencies below 100 MHz
- BPL devices used for the first-mile/last-mile connection (<1500 m to the premise) and BPL devices used in buildings for local area networks (LANs) and other data distribution (<100 m between devices).