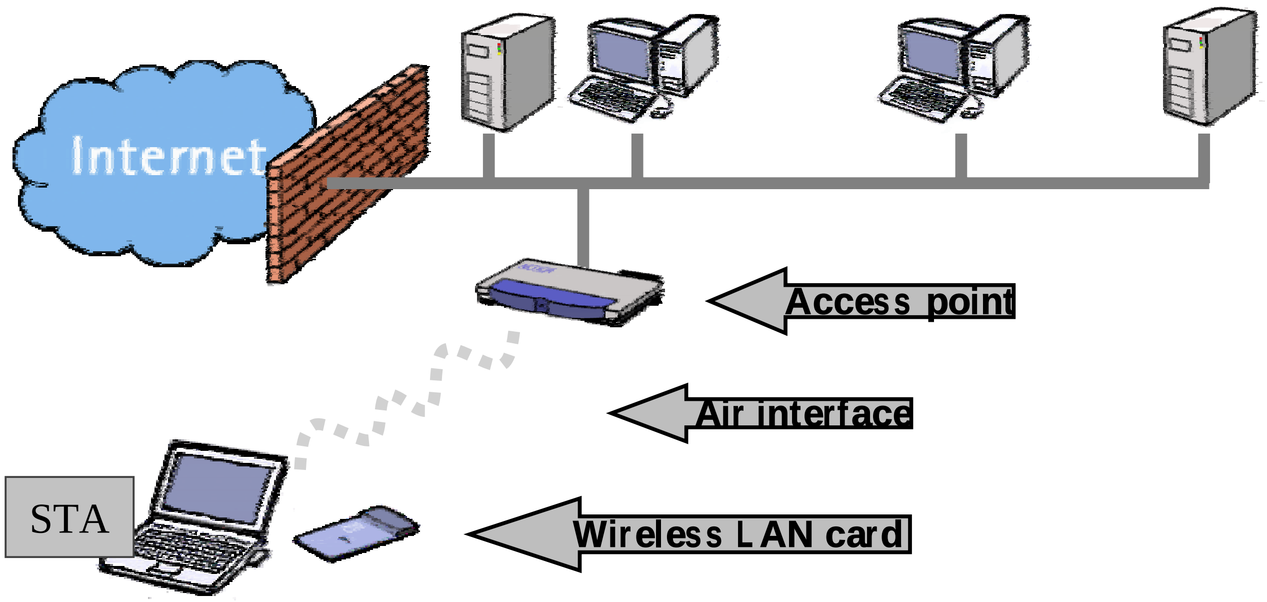
WLAN
Indoor Radio Network planning



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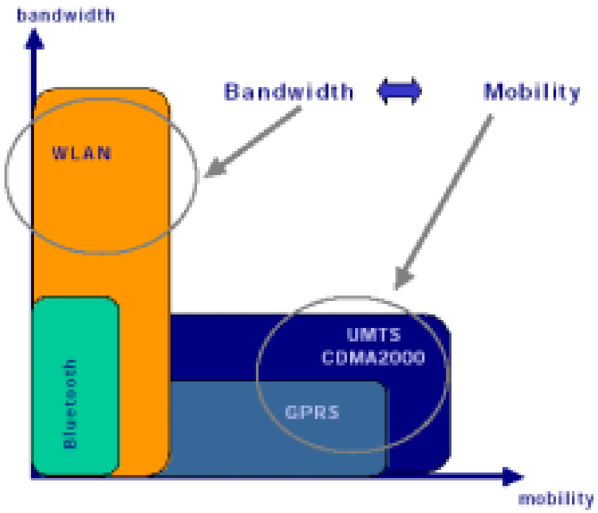
Outline

- WLAN general issues
- Wireless network topologies
- IEEE 802.11 layers
  - PHY
    - DSSS
    - FSSS
    - IR
    - 802.11a, b, g
    - OFDM
  - MAC
    - Access the wireless medium DCF /PCF
- Radio indoor propagation
- Network Planning for IEEE 802.11 WLAN
- Security
- Comparison with 3G systems
- References

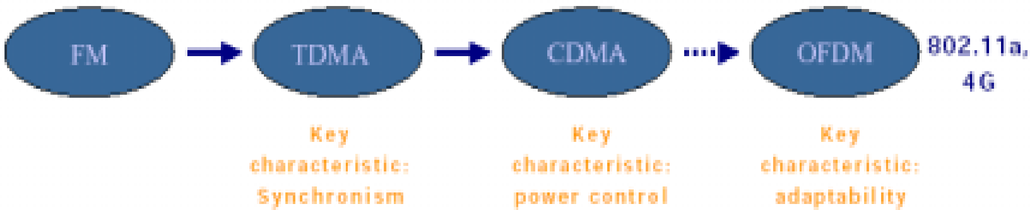
(Wireless LAN) WLAN

- Mobility
  - In usage scenarios:
    - Ah Hoc NTs
    - Public Access Zones: campus areas, airports, hotels
    - Small office and home (SHO)
    - Enterprices and Brach offices: all the applications used through the WLAN
- Installation
  - Less cabling
  - Wireless LAN can easily be moved to other location
- Costs
  - Installation costs may be lower
  - Saves when the LAN needs moving
- Scalability
  - Ad hoc networks
  - From one cell to multiple cell networks
- Spread Spectrum techniques to improve spectral efficiency
- Evolution toward All-IP core network architectures already def:



Perspective of UMTS-WLAN deployment**:** combine nationwide mobility with 3G networks and hot spot coverage with WLANs:

- complementary coverage and greater bandwidth
  - WLAN max connection range 100 m (300 m in outdoor)
  - 802.11b: 2,4 GHz with connection speeds reaching 11 Mbps
  - 802.11a: 5 GHz with connection speeds reaching 54 Mbps



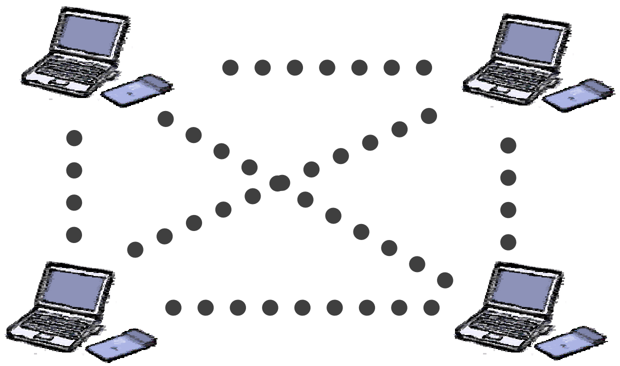
Access point (AP)

- Wireless hub (wireless equivalent to wired hub) and gateway to wired network
    - Used with an Ethernet connection
    - Used with an external modem
    - server
- Wireless network police (manager)
    - Compliant to IEEE802.11b DSSS with WEP authentication and encryption
- Network management tool
    - Easy management and monitoring through the Web, Telnet, TFTP, or HyperTerminal
    - It might support 1, 2, 5.5 and 11 Mbit/s, up to 54 Mbit/s

Wireless network topologies

Ad hoc (peer-to-peer) networks:

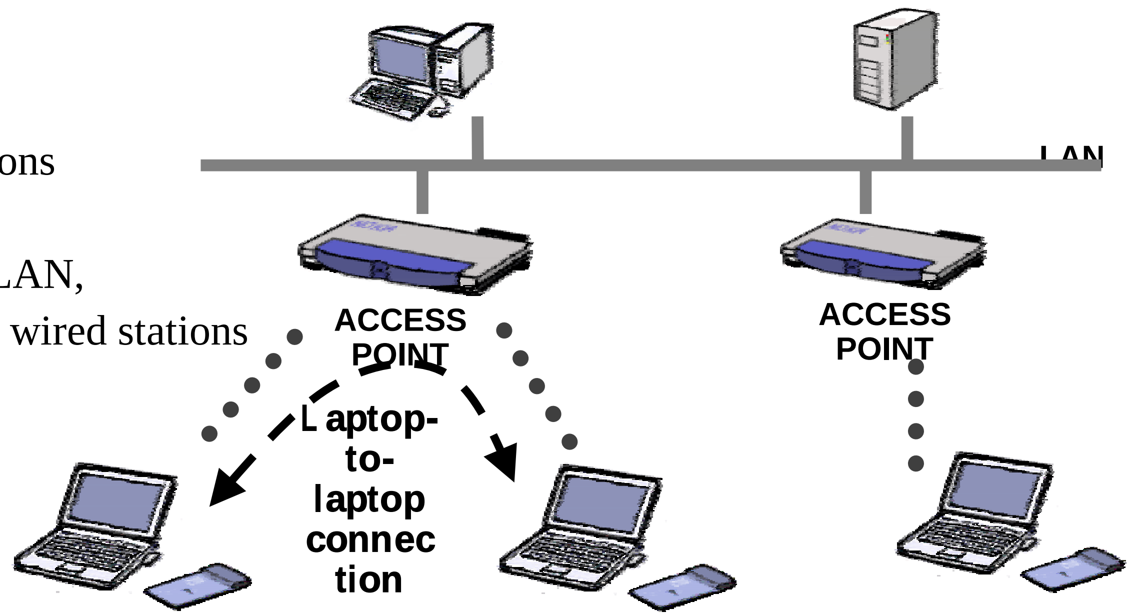
- Formed by wireless stations
- No AP needed
- Enables file and printer sharing



Infrastructure networks:

- Formed by an AP and wireless stations
- All communication via the AP
- The AP can be attached to a wired LAN,

and wireless stations communicate with wired stations



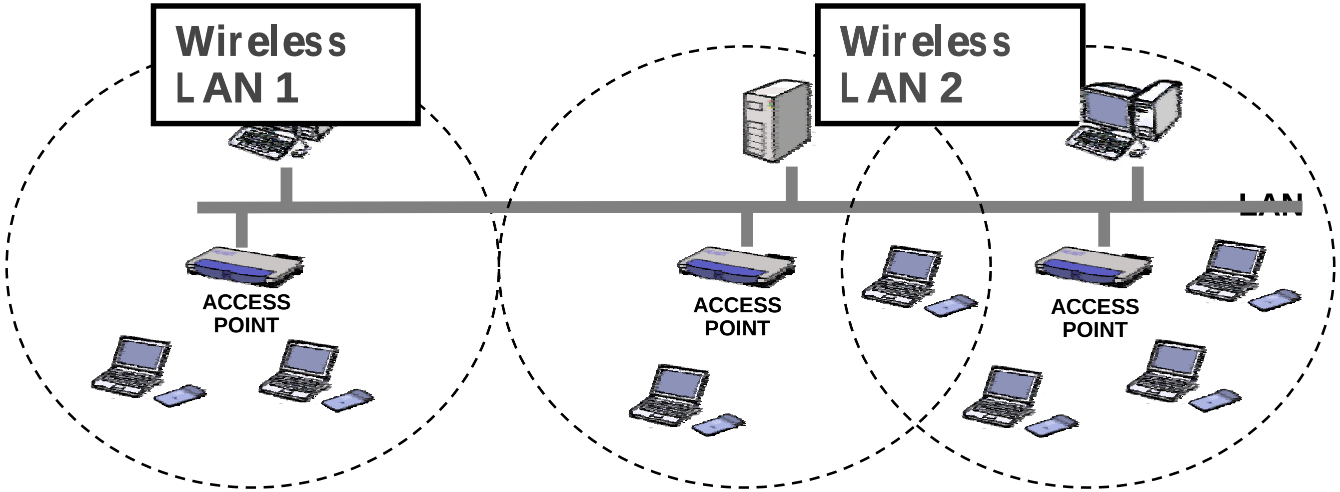
Multiple access points

Standard identifies basic message format to support roaming (implementation for NT vendors):

- when current AP connection lost
- when better AP available (roaming calculation): STA scans adjacent channels (Aps in ESSIDs)

Used to extend the range of a network or increase capacity, two ways presented:

- Same network name and on the same subnet (on the same LAN): **intra subnet roaming:**
  - Stations can roam with the same network name
  - Roaming is transparent to the user - it is automatic
  - Must be on same TCP/IP subnet
- Different network name but on the same LAN: **different logical networks**



IEEE 802.11 layers

- IEEE 802.11 is a wireless extension of IEEE 802 LAN standard family
  - shares the same Logical Link Control (LLC) layer with other fixed LAN standards (e.g.IEEE 802.3 Ethernet)

- IEEE 802.11 standard defines:
  - *Physical (PHY) layer*
  - *Medium access control (MAC)*
  - For both specification for wireless connectivity in the local area for
    - Fixed
    - Portable
    - or moving stations

IEEE 802.11 PHY layer

- Divided into two sub-layers:
  - *Physical Layer Convergence Procedure* (PLCP):
    - provides data encapsulation and transport
    - service to upper MAC layer
    - PLCP protocol data unit (PPDU) contains:
      - synchronization header, control bits, CRC checking and MAC layer data
  - *Physical medium dependent* (PMD) layer:
    - provides actual transmission and reception between stations via the wireless medium
    - provides modulation and demodulation for the frame transmission

- First version: standard June ´97. Defined:
  - delivering data rate of 1 and 2 Mbps
  - three PMD sub-layers including
    - *frequency hopping (FH)*
    - *direct sequence spread spectrum (DSSS)*
    - *infrared*
- Rel. ´99
  - added data rate of 5.5 and 11 Mbps DSSS layer: 802.11b
  - a new standard working at 5 GHz using OFDM: 802.11a
- Draft standard 2001, 802.11g currently under review of 802.11 group. [10] [11]
- Interoperability among 802.11 devices, compatibility and co-existence issues associated with technologies which includes BlueTooth

Direct Sequence Spread Spectrum system

Channel No.	1	2	3	4	5	6	7
Central Freq. (GHz)	2.412	2.417	2.422	2.427	2.432	2.437	2.442
Channel No	8	9	10	11	12	13	14
Central Freq. (GHz)	2.447	2.452	2.457	2.462	2.467	2.472	2.484

- PPDU (protocol data unit) frame structure of the PLCP
  - Preamble fields for receiver synchronization
  - Header fields contain control information
  - MPDU is actual data from the upper layer
- DSSS channels
  - standard specifies the operation of DSSS on 14 channels of different frequency
  - each channel have 22 MHz bandwidth with central frequency of each channel
    - channels are overlapping:
      - only three channels can work together without adjacent channels interference (e.g. 1, 6, and 11)
- DSSS Modulation
  - For 1 and 2 Mbps data transmission, the 11-chip Barker code is used for spectrum spreading
  - BPSK or QPSK modulation is carried to the base-band data respectively.
    - An 11 Mcps base-band signal (1 Mbps data times 11 for chip spreading) will occupy 22 MHz bandwidth using BPSK modulation.
    - A 22 Mcps signal (2 Mbps data times 11 for spreading) will occupy 22 MHz bandwidth using QPSK modulation.
  - For 5.5 and 11 Mbps data transmission, spreading scheme: Complementary Code Keying (CCK):
    - M-ray orthogonal keying modulation where one of the M's unique signal code words is chosen for txm
    - 5.5 Mbps txm: 4 bits grouped together, two used to decide the phase. Another two bits are used to select one from four complex code sequences.
      - The symbol rate is 1.375 Mbps and the occupied bandwidth is 22 MHz.
    - 11 Mbps txm: 8 bits grouped together.
      - The first two the same as in 5.5 Mbps
      - The left 6 bits are used to select one complex code from 64 combinations.
        - » the symbol rate is 1.375 Msps and bandwidth is 22 MHz
    - 4 types of DSSS models interoperable, share same preamble, header structure, same radio BW
    - Preambles and headers are modulated at 1 Mbps rate (differences in modulation rate only to MPDU)

FH Spread Spectrum system

- IEEE 802.11 defines FHSS PMD layer to deliver:
  – 1 Mbps and 2 Mbps data rate in 2.4 GHz band.
- PPDU packet structure:
  – Preamble: provides frame self-synchronisation
  – Header: provides control functions
- FHSS channel:
  – In Europe, USA, runs on 79 channels, from 2.402 GHz to 2.480 GHz.
  – channel spacing is 1MHz
  – 78 hopping sequences defined
    - in each sequence each of the 79-frequency elements is used once.
    - minimum frequency spacing in one hopping sequence is 6 MHz.
    - Three subsets are defined from 78 sequences with 26 for each.
- For minimizing interference → different cells use sequences from different subsets
  – IEEE 802.11 standard didn't specify the hop rate:
    - United States, 2.5 hops per second is the minimum requirement.
    - Japan, France, and Spain have defined a different number of channels and sequences for the FHHS mode.
    - the hop space and the hop rate may differ in different countries.
- Two different modulation methods defined for 1 and 2 Mbps date rates
  – 1 Mbps:two-level Gaussian frequency shift key (GFSK) with BT=0.5 modulation used. Nominal frequency deviation is +/- 160 KHz.
  – 2 Mbps: four level GFSK with BT=0.5 used. Four frequency deviations are +/- 216 KHz and +/- 72 KHz.

Infrared system

- The IEEE 802.11 infrared (IR) PHY layer uses:
  - pulse position modulation to transport 1 Mbps and 2 Mbps data rates using infrared light
  - It is limited to the LOS transmission or a single reflection environment
  - IR frame has the structures similar to the FHSS or DSSS system. So far there is no IR based WLAN product shown on the market.
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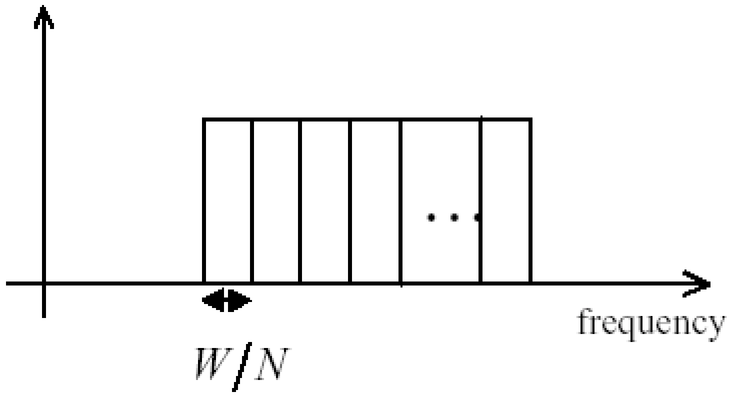
802.11a

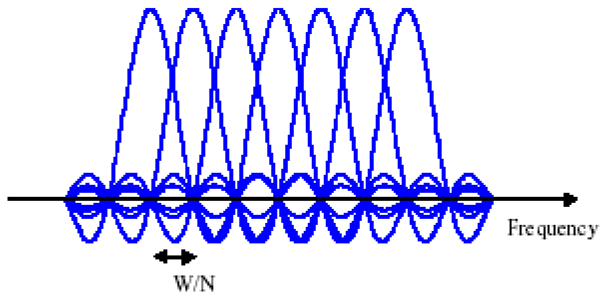
- Use Orthogonal Frequency Division Multiplexing (OFDM) method to deliver
  - up to 54 Mbps data rate in 5 GHz band: band belongs to the Unlicensed National Information Structure band (UNII).
  - Twelve sub-channels are defined and each channel has a 20 MHz bandwidth.
  - Eight different data rates are supported: 6, 9, 12, 18, 24, 36, 48, 54 Mbps.
    - For each sub-channel the OFDM system uses 52 sub-carriers that are modulated by using:
      - BPSK,
      - QPSK,
      - 16-QAM,
      - or 64-QAM, depending on the data rate
- Use Convolutional coding with rates 1/2, 2/3 or 3/4 for forward error correction
  - trade-off between data rate and coverage range.
    - e.g at 6 Mbps, the receiver sensitivity is –82 dBm;
    - at 54 Mbps, the receiver sensitivity is –65 dBm.
- The IEEE 802.11a standard is not compatible with the 802.11 or 802.11b standard
- PLCP frame structure of ODFM PMD:
  - Preamble contains 12 symbols for channel estimation and frame synchro (16 microseconds length)
  - Signal part, including length, parity check and tail field is 24 bits.
  - It is convolution-coded with 1/2 rate and then modulated to one OFDM symbol using BPSK. Service field, PSDU and other fields are modulated to OFDM symbols using different coding and modulation methods.

Orthogonal frequency division multiplexing (OFDM)

- A multicarrier communication system in which the frequency band (available spectrum) is composed of a number of narrowband carriers
  - Modulation and coding methods at different data rates association standardised
  - Each OFDM channel divided into 52 sub-carriers
    - 48 used to carry data (working in parallel)
    - 4 carriers used as pilot channels, frequency references
      - A pseudo-binary sequence is sent through the pilot channel to prevent the generation of the spectral line.
- Each carrier (a separate band frequency) is modulated with a symbol and multiplexed with other carriers:
  - Data is divided into parallel data streams each transmitted on an narrowband carrier.
- The carriers are modulated and demodulated using the Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) in OFDM transmitters and receivers: sin(x)/x spectra for subcarriers:
  - symbol duration is 4 microseconds --> occupied BW= 16.6 MHz.
- Great advantage: excellent spectral efficiency due to the close spacing because of the mutual orthogonality of the carriers →FFT operation creates carriers with sidebands that overlap with no mutual interference

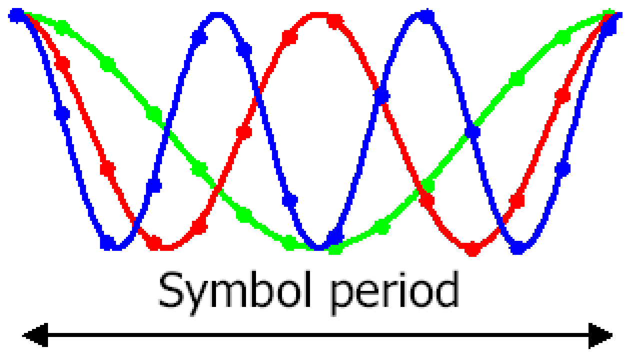
OFDM:data transmitted in parallel



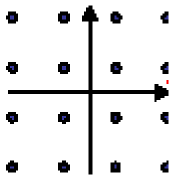


- Each subcarrier has a different frequency
- Frequencies chosen so that an integral number of cycles in a symbol period
- Data is carried by varying the phase or amplitude of each subcarrier (e.g QPSK, 4-QAM, 16-QAM, 64-QAM by varying complex numbers at the IFFT)
- Signals are mathematically orthogonal (carriers mutual orthogonal):

$$\int_0^T \sin\frac{2\pi kt}{T}\sin\frac{-2\pi lt}{T}dt = 0, \quad k \neq l$$



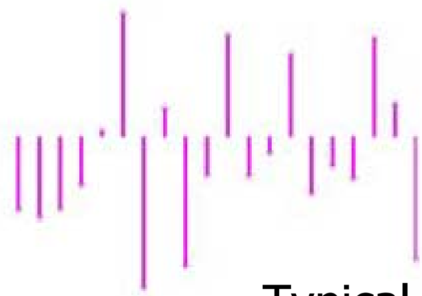
Baseband system

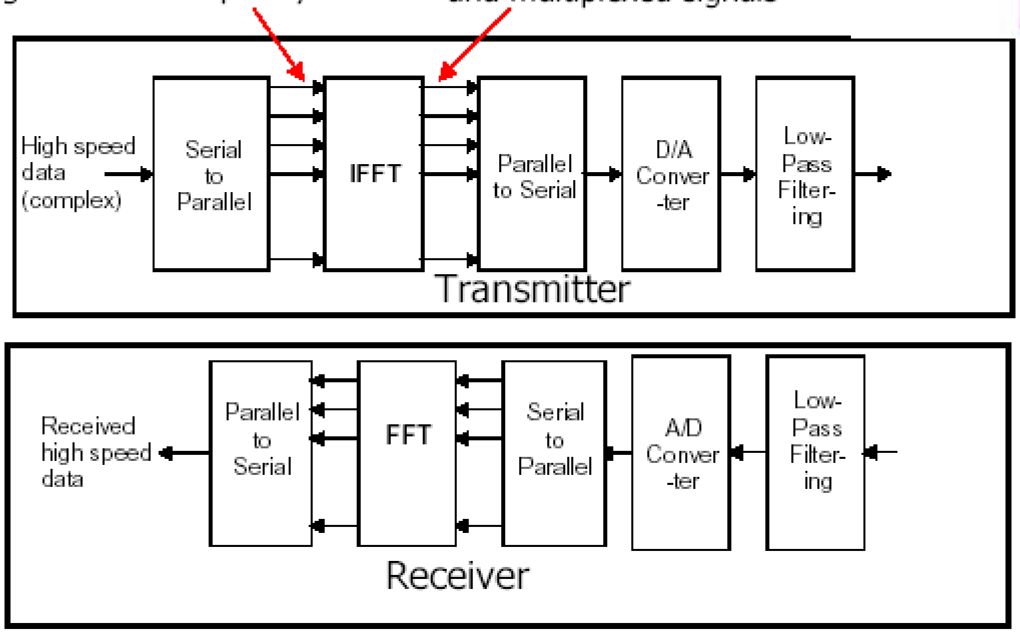


Complex value representing data is input to IFFT

Discrete frequency domain
Each input controls signal at one frequency

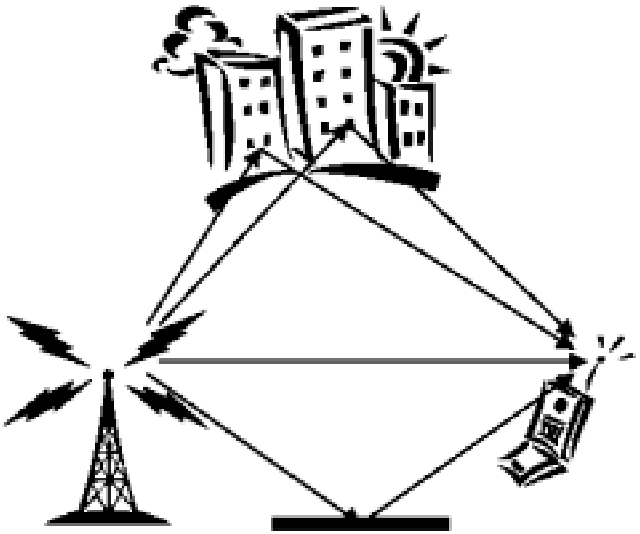
Discrete Time Domain
Samples of modulated and multiplexed signals





Typical IFFT Output Samples:
sum of many samples of many sinusoids (looks random)

OFDM: why?



•Spectral efficiency

•Resiliency to RF interference

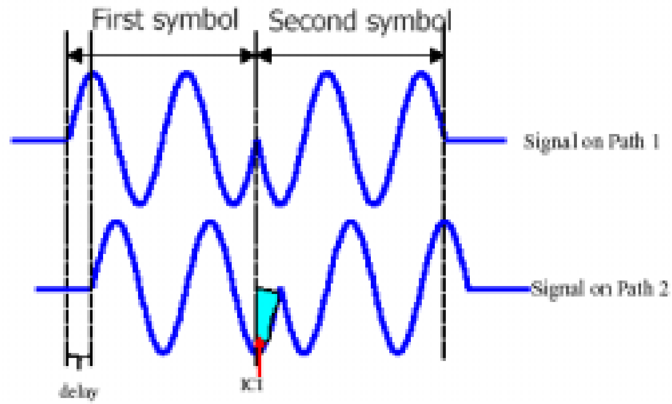
•Lower multi-path distortion

PB: Multipath transmission:

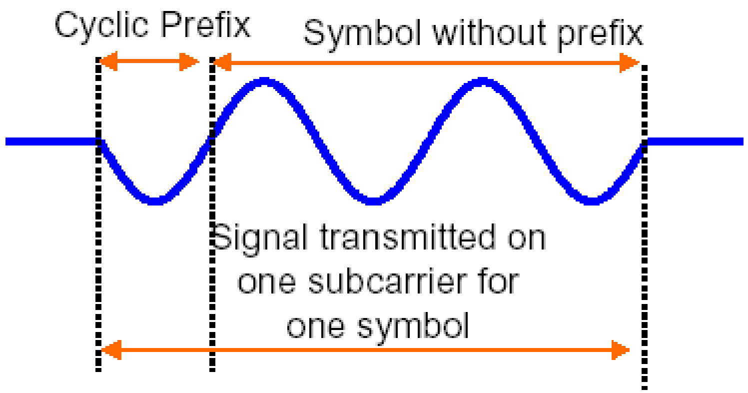
(more than one transmission path between TX and RX
→ received signal is the sum of many versions of the transmitted signal with varying delay and attenuation)

- Received signal at any time depends on a number of transmitted bits:
  - Intersymbol Interference (ISI) : gets worse when DR increases because it covers more symbol periods
  - Need equalizer in the RX to recover data:it becames too complicated when DR increases
- Equalizer for OFDM 'easy' DSP algorithm:
  - Data is transmitted in parallel longer symbol period (e.g. for N parallel streams, symbol period is N times as long)
  - Cyclic prefix trick to avoid residual ISI

Multipath enviroment and Cyclic Prefix

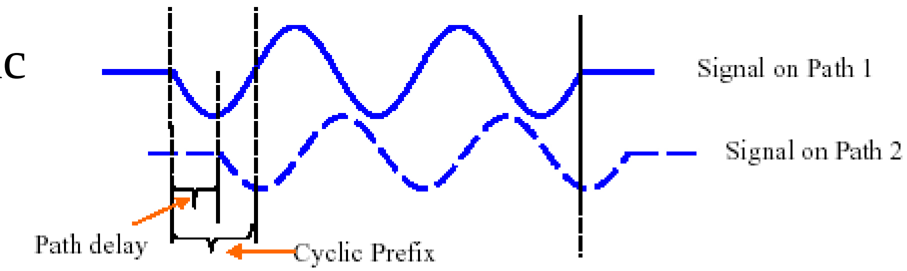


- Received signal (one subcarrier) in one symbol period is not a sinusoid:
  - Causes intercarrier interference (ICI)



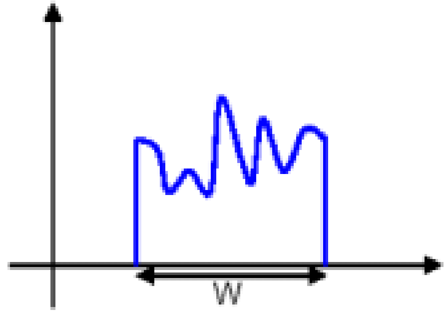
- Each symbol is cyclically extended:
  - Some loss in efficiency as cyclic prefix carries no new information

- If multipath delay is less than the cyclic prefix:
  - no intersymbol or intercarrier interference
  - amplitude may increase or decrease

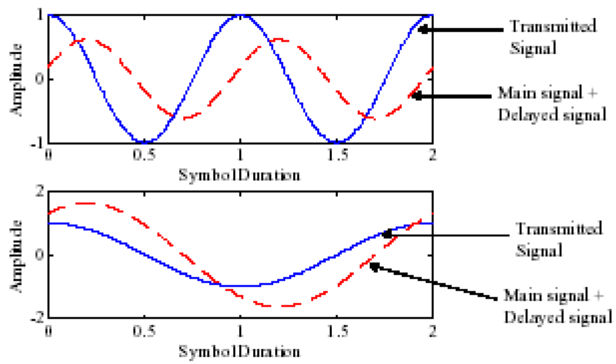


Frequency selective fading

- Multipath fading causes some frequencies to be attenuated:
  - Fading is approximately constant over narrow band
  - This is corrected in the receiver

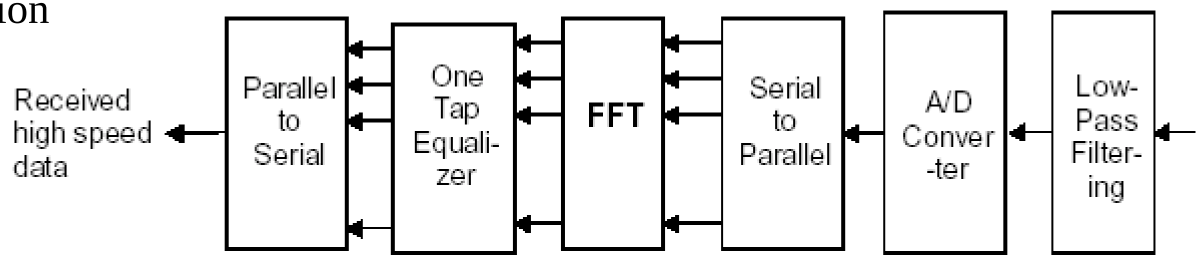


- Multipath delay causes change in amplitude and phase of each subcarrier
  - Change depends on subcarrier frequency
  - Corrected in receiver by one complex multiplication per subcarrier



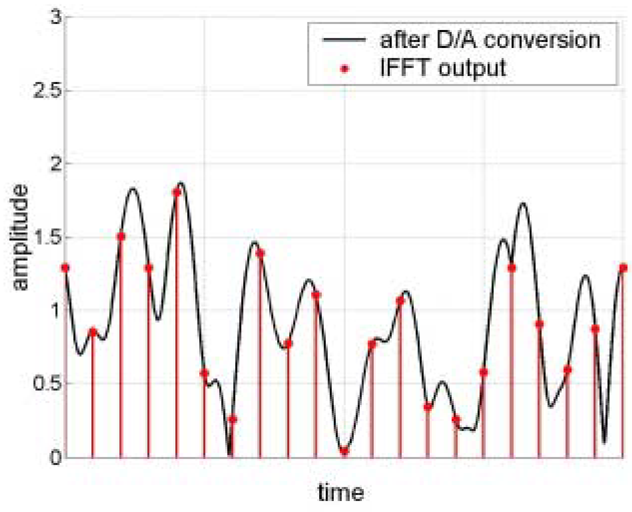
- Multipath fading corrected by single tap equalizer

- Change in phase and amplitude corrected by complex multiplication
- Receiver structure suited to DSP implementation

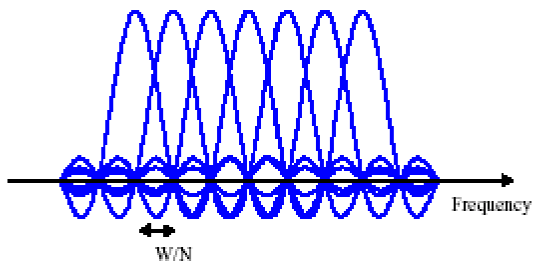


OFDM Problems

- High peak-to-average power ratio
  - peak signals power much greater than average signal power
  - need very linear amplifiers with large dynamic range
- Coding to avoid the peaks [Monash]
- Clip the peaks [La Trobe]
- Predistort the signal to compensate for the amplifier nonlinearity [Victoria University]



- Very sensitive to frequency errors tight specifications for local oscillators Doppler limitation
  - Individual subcarriers have sin(x)/x spectrum
  - Large sidelobes result in sensitivity to frequency offset
  - Subcarriers no longer orthogonal
  - Tight specifications on local oscillators



IEEE 802.11 Media Access (MAC) layer

- Goal of MAC layer provide access control functions:
  - e.g. addressing, access confirmation, frame checking sequence generation/checking and LLC PDU
- The MAC layer provides three major operations:
  - *Accessing the wireless medium*
  - *Joining a network*
  - *Providing authentication and privacy*
- The 802.11 employs access control technique: Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).
  - 802.11 cannot transmit and receive signals at the same time (no collision detection –CD- method)
  - Collision avoidance (CA) mechanism used:
    - A station transmits a packet when it detects the channel idle
    - Both the PHY and the MAC layer are involved in the status detection
      - The PHY layer senses the radio signal to determine whether a radio channel is free
      - The MAC layer monitors the duration field of on-going frames and uses this value to estimate the end time of the frame (duration field is in the header of Request to Send (RTS, sent by TX STA to transmit data) and Clear to Send(CTS, answer from RX STA, assures a stable medium) frames.
  - To decrease the probability of collision, a back-off algorithm (a STA waits a random backoff time,before sensing a busy channel to be idle) and an access spacing mechanism are applied
      - All the other (non-transmitting) STAs adjust a Network Allocation Vector (NAV) based on duration field (NAV: indicates how long the medium will be busy because of current data transmission) .

Access the wireless medium (DCF /PCF)

- Before transmitting a frame, the MAC layer has to gain control of radio resource. Two approaches are used:
  - *Distributed Co-ordination Function (DCF):*
    - radio resource is competed by all stations with no master control
    - With the random back-off mechanism and access spacing interval, the probability of collision can be minimized. Using handshaking methods, for example by sending Request To Send (RTS), Clear To Send (CTS) frames, the "hidden node" problem can be eliminated.
  - *Point Co-ordination Function (PCF):*
    - a point co-ordinate resides in the access point (AP) to control the transmission
    - Every station needs to be granted the right to send before it can send any packet
    - No contention check occurs at the centralized control
    - An option in the 802.11 standard → not all vendors support this option.

Joining the network

• Once one client station (STA) is powered on, it needs to search passively or actively for the existence of:

- other STAs
- or Access Points (AP)
- If any authentication result is successful, this STA can join the network and communicate with others.

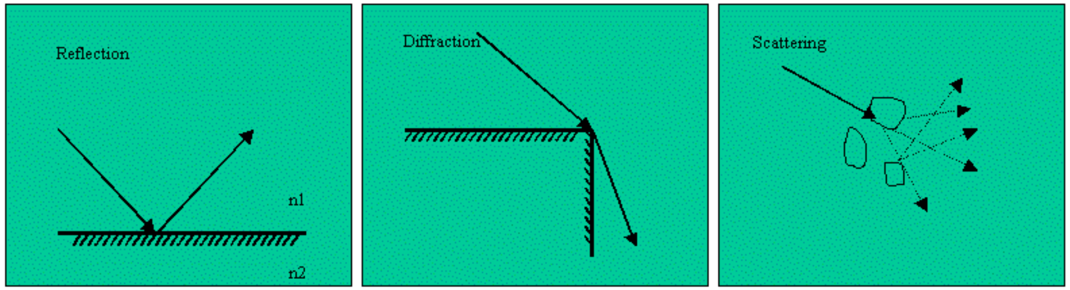
MAC layer frame structure

- Compatible with other IEEE 802.x MAC protocol.
- There are three types of frames:
  - Management frames: handle the functions of Association, Authentication, Probe, and Beacon
  - Control frames: handle Handshaking, Acknowledgement, Power control, etc
  - Data frames: carry the data package from the upper layer (LLC).

Indoor Radio propagation

Basic propagation phenomena:

1. Reflection
2. Diffraction
3. Scattering



--> manifest themselves in signal attenuation and delay

1. Electromagnetic wave impinges upon an obstruction with dimensions very large compared with the wavelength of a radio wave
   - A part of the energy is reflected back to the first medium by obeying Maxwell's Equations and boundary conditions
   - if the second medium is a perfect conductor all incident energy will be reflected back: total reflection
   - if perfect dielectric plane another part of the energy is transmitted into the second medium: penetration
2. Radio path is obstructed between the transmitter and receiver by some impenetrable object with a sharp edge.
   - explained by the Huygen's principle
   - can transfer the signal energy to the receiver even if no Light of Sight (LOS) route exists between transmitters and receivers.
3. Radio channel contains objects with dimensions that are of the same order, or less as the radio wavelength.
   - Radio energy is re-radiated in many other directions
   - diffuses or diminishes some part of the reflection energy
   - positive effect of scattering is that it brings some energy to the receiver where normal reflected or diffracted signal can not reach

Propagation parameters

1. Link budget
   - how far the TX and RX can be separated?
   - depends on many aspects:coverage, interference, transmitter power and battery life)
   - needs an estimation of the Signal to Noise Ratio (SNR) and path loss
2. Time dispersion (Multipath delay spread)
   - due to the Multipath structure existing between the TX and RX:

     transmitted signal and its delayed versions arrive at the RX at different time instant
   - it causes Inter Symbol Interference (ISI): times disperse nature of radio channel limits the maximum data transmission rate without utilising an equalizer at the receiver.
   - varies widely in mobile radio channels: power delay profile $P(\tau_i)$ used to characterize the power distribution of the multi-path signals (τ_i is an excess delay of the *i*-th element) (Several delay spread definitions)

Path loss

Log-Distance model:

$$PL(d) = PL(d_0) + 10n\log(d / d_0) + X_\sigma$$

***PL**:* local averaged received signal power

***d**:* distance between transmitter and receiver

PL(d₀): reference path loss at distance d_0(1 km for macrocells, 1 m for microcells) which is in far field of the TX's antenna

n: path loss index, indicates the level of energy decay with the distance. (In free space *n*=2)

$\boldsymbol{X_\sigma}$ zero-mean Gaussian r.v. (dB), reflects the variation on average received power (fixed $PL(d_0)$ and *n)*. If X_σ small --> good model for specific environments.

Multipath delay spread (def)

Mean delay spread: first moment of the power delay profile $m_\tau = \frac{\sum_i P(\tau_i)\cdot\tau_i}{\sum_i P(\tau_i)}$

Root mean square (RMS) delay spread: square root of the second central moment of the power delay profile

$$\sigma_\tau = \sqrt{\frac{\sum_i (\tau_i - m_\tau)^2 \cdot P(\tau_i)}{\sum_i P(\tau_i)}}$$

- describes the statistic multi-path characteristic of radio channels
- microsec outdoor radio system
- nanosec indoor radio system

Maximum excess delay (X dB): time period during which the power delay profile falls of X dB below its maximum value. (X about 30 dB)

Fading channel

Radio channels are time-variant because of the movement of environmental objects or receivers.

- Fast fading or slow fading radio channel depending on how rapid the channel property changes over time.
  - Based on relation between a signal's parameter (symbol rate) and a channel's parameters (RMS Delay Spread and Doppler Spread)
- Doppler Spread, B_D: a measure of the spectral broadening to the signal $B_D = \frac{v}{c} \cdot f_c$
  - v is the velocity of mobile, c is the light speed constant
  - f_c is the carrier frequency
- Coherent time T_C: reciprocal of Doppler Spread
  - characterises the time varying nature of the radio channel (if smaller than the symbol period --> the channel is thought of as a fast fading channel)

Small scale fading describes:

- rapid fluctuations of the received signal power over a short period of time
- the travel distance due to the destructive addition of multi-path signals.

Fading amplitude distribution:

Flat fading channel:

•strength of signal varies with time but spectral characteristics preserved

•Measurements shown that the fading obeys to Rayleigh (1) or Ricean (2) distribution (difference between the two model: is there a LOS component existing among multi-path signals?)

$$P_{Rayleigh}(r) = \begin{cases} \frac{r}{\sigma^2} \exp(-r^2/2\sigma^2) \to (0 \le r \le \infty) \\ 0 \to (r < 0) \end{cases}$$

Rayleigh PDF (1)

$$P_{Ricean}(r) = \begin{cases} \frac{r}{\sigma^2} \exp(-\frac{(r^2 + A^2)}{2\sigma^2}) I_0(\frac{Ar}{\sigma^2}) \to (0 \le r \le \infty) \\ 0 \to (r < 0) \end{cases}$$

Ricean PDF (2)

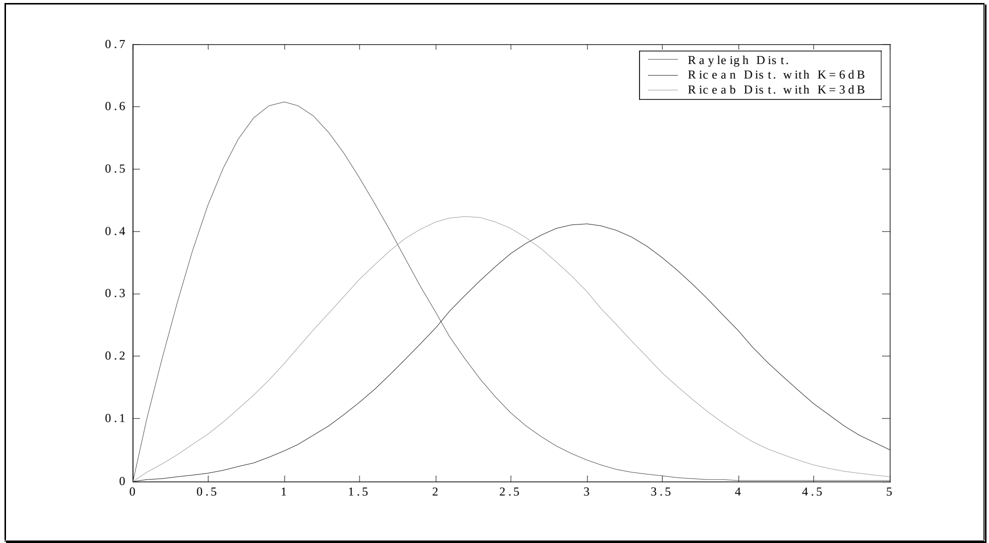
When also a dominant line-of-sight (direct) signal component may appear at the receiver.

σ_r= 1 (σ: RMS received voltage signal)

K=3, 6 dB (Rice factor)

$$K(dB) = 10 \log(A^2 / 2\sigma^2)$$

A: peak amplitude of LOS component



System parameters

- *Coherence bandwidth, B_c*: measure of frequency range over which the radio channel can be thought to be flat. (It is related to RMS delay spread of the channel)
  - $B_c \cong 1/50\sigma_\tau$ with the frequency correlation of 0.9
  - $B_c \cong 1/5\sigma_\tau$ with the frequency correlation of 0.5
  - Rule of Thumb: if a digital signal has a symbol duration which is more than ten times the RMS delay spread σ_τ

    --> no equalizer is required for a bit error rates better than 10^{-3}
- *Frequency selective channel*: different frequency components of a transmitted signal experience different gains when across a radio channel.

  • In time domain, such a channel will induce inter symbol interference (ISI) to transmitted signal, and the wave shape of signal is changed.

  --> equalization technique is required to cancel the effect of ISI

Indoor radio propagation model

Characteristics in indoor environments compared with outdoor radio systems and applications :

- distance between a TX and RX is shorter
- power output of a TX is much lower
- emc wave propagation complicated due to:
  - the variation of building size, shape, structure, construction material
  - TX and RX positions, and patterns of antenna radiation. Mutual visibility between the transmitter and receiver antenna, the environments classification: line-of-sight (**LOS**), obstruct LOS (**OLOS**) and non-LOS (**NLOS**)
  - Other factors: age of the building, neighbouring buildings, % of windows, people density and level of human activity

Four groups of models: - statistical models, which rely on extensive measurements (1, 2, 3)

- a site-specific model, which is based on the electromagnetic wave propagation theory or geometrical optics (4)

(1) narrow-band (for large scale propagation)

(2) empirical wide-band: >>study of the power delay profile

>> interested in RMS delay spread values,

>> the number of delay components for different types of environments

(3) time variation: study Doppler spread characteristic (e.g. the effects of human movement to the radio channel)

(4) deterministic: force methods to physically simulate indoor radio propagation

(1) Empirical narrow-band model

- Focus on path loss of a radio wave in its propagation
- Based on the measurement results on different kind of building categories. Parameters can be adjusted to fit best for each type of environment.

(1) One-slop model: simplest path loss model

$$L = L_0 + 10n \cdot \log(d)$$

(2) Multi-Wall model: COST 231 Multi-Wall model given in (3),

- defines path loss as the free-space loss plus excess loss introduced by
  - walls and floors
  - non-linear effect of multi-floor losses

expresses the total wall loss as a sum of individual wall loss

$$L = L_{FS} + L_c + \sum_{i=1}^{l} K_{wi} L_{wi} + K_f^{\left[\frac{K_f+2}{K_f+1} - b\right]} L_f \qquad (3)$$

L_{FS} free space loss; L_C is constant loss (for measurement calibration, normally close to zero)

K_{wi} number of penetrated wall of type i; K_f is the number of penetrated floors

L_{wi} loss of wall type i; two types of walls used: a light wall, no weight, like plasterboard, particleboard, or a thin concrete wall. The second one is a heavy wall, a load-bearing wall or other thick concrete wall; L_f is loss of the floor

Multi-Wall model

COST 231 Multi-Wall model reference parameters (wall or floor loss based on statistical measurement results)

Parameter(s)	Light Wall Loss (dB)	Heavy Wall Loss (dB)	Floor Loss (dB)	Multi-floor Non-linear factor b
Value	3.4	6.9	18.3	0.46

•Actual loss depends on - permittivity and conductance (ε and σ) of the construction material

- incident angle θ_{in}
- polarization pattern of the signal in view of the reflection plane also affects the r.f. reflection coefficient.

• If radio wave incident from free space to the interface plane of two dielectrics materials with μ, the reflection coefficient:

$$\Gamma_{//} = \frac{-\varepsilon \sin\theta_i + \sqrt{\varepsilon - \cos^2\theta_i}}{\varepsilon \sin\theta_i + \sqrt{\varepsilon - \cos^2\theta_i}}$$

$$\Gamma_{\perp} = \frac{\sin\theta_i - \sqrt{\varepsilon - \cos^2\theta_i}}{\sin\theta_i + \sqrt{\varepsilon - \cos^2\theta_i}}$$

ε: complex dielectric constant given by $\varepsilon = \varepsilon_0\varepsilon_r - j\varepsilon'$, ε_0 is a constant (8.85 x 10^{-12} F/m).

// denotes the E-field of the wave parallel to the incidence plane

$\perp$ denotes the E-field of the wave normal to the incidence plane The permittivity values of commonly used construction materials are available

If the reflector is a perfect conductor, then all the incidental energy will be reflected back and practically no wave penetration can happen.

(2) Empirical wide-band model [2,3]

•The COST 231 report (through measurement results) shows for the RMS-delay spread:

- •the lowest value in dense environments
- •larger values in open and large environments.

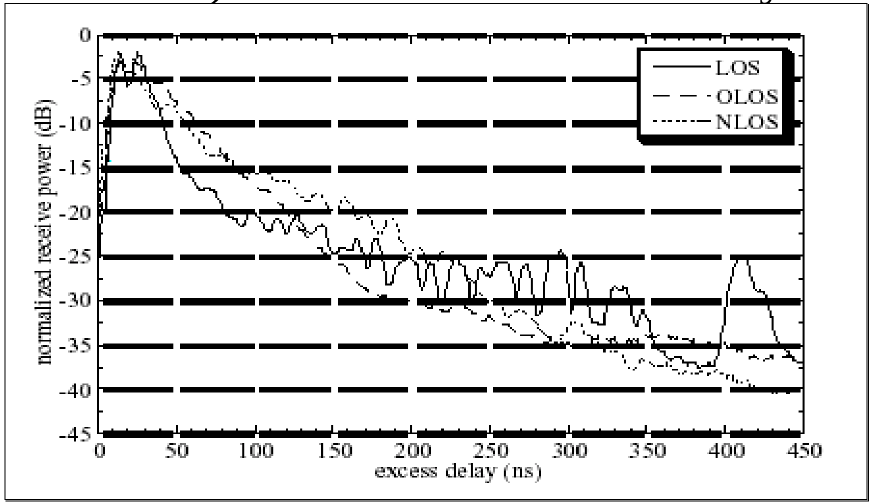


FIG. Typical average power delay profiles in LOS, NLOS, and OLOS conditions

TABLE. Sample of delay spread statistics, (based on extensive measurements in different kinds of buildings)

Environment	Dense			Open				Large			
Average rms. Delay (ns)	22.5	15.3	20.0	19.3	35.0	17.7	30.5	27.7	55.4	79.4	67.4

•Measurements show that:

- • within the same distance, the LOS channel has a smaller RMS delay spread than the NLOS or OLOS channels.
- •RMS delay spread increases with the distance of TX-RX separation.
  - --> power loss
  - --> increased delay spread can deteriorate system performance

(3) Time variation model

• Time variations of indoor radio channels introduced by several mechanisms:

- •movement of mobile stations;
- •change of orientation of antennas due to their non-isotropic pattern;
- •movement of scattering objects near mobile stations.

-->the fast fluctuation of signal strength over a small distance is known as the vector addition of multi-path signals.

•In indoor environment, human beings are the most important source of scattering or shadowing:

- •Measurements show that a body across the radio link close to a receiver can introduce a fading of up to 20 dB. Random movement of people near a fixed receiver cause signal fading similar to the case in which the receiver is moving in small scale .

Deterministic model

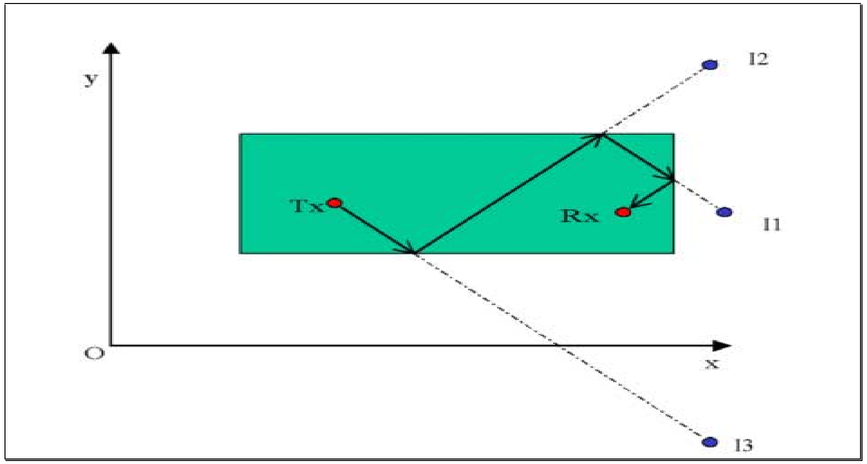
- Simulate physically the propagation of radio waves
- Does not rely on extensive measurement (unlike statistical models), but requires construction information of indoor environment for calculating signal levels inside the building.
- Instead of solving the Maxwell's equation, Geometry Optics approximation is often used due to its simplicity:
  - Radio propagation is modelled as ray propagation
    - two types of ray-tracing methods: image method and brute-force ray tracing.

Image method: models objects in indoor environment (wall, floor as reflection mirror)

- -> For LOS propagation it is easy to get the ray route by connecting TX and RX.

- -> For single reflection, the radio source is mirrored to a particular plane, where the reflection point can be easily located, and then the propagation path can be obtained by connecting the TX point, the reflection point, and the RX point.

- With the same principle, a radio path with more reflection points can be obtained. Fig shows an example of radio path with three reflections happened between a TX and RX.



•For lower geometry complexity:

•when case reflection is the dominant of propagation phenomena (otherwise increasing the computation load)

Diversity techniques

Powerful technique: provides improvement on radio link performance with a relative low cost:

- Avoids using channel estimation (like in equalization), which requires training sequence or overhead in a data frame
- Explores the random nature of radio channels and utilises information provided by different paths.

Many different diversity methods available:

- space diversity
- frequency diversity
- polarization diversity
- angular diversity
- time diversity.

Diversity combining methods

- Utilises the information provided by different diversity channels
- Selection Combining: simple approach that selects the signal branch with the best S/N ratio.
- Maximal Ratio Combination combines diversity branches coherently and thus requires more complicated receiver.
  - HP. *M* independent Raleigh fading channels, each channel has the same SNR = Γ
    - Selection Combining has the average SNR $\bar{\gamma}_m = \Gamma \times \sum_{k=1}^{M} 1/k$
    - Maximum Ratio Combining has the average SNR $\bar{\gamma}_M = \sum_{k=1}^{M} \bar{\gamma}_i = M\Gamma$

      (It can have better diversity gain)
  - If the channels are not fully independent --> the diversity gain will decrease.

• High correlation between channels implies that if one channel is suffering from a deep fading, its diversity peer will meet a similar problem --> no protection can be acquired from diversity.

•In a Ricean fading environment, the correlation coefficient between two neighbouring channels is larger than in a Rayleigh fading environment, since the same LOS element is present in both diversity channels.

Space diversity and polarity diversity

- Space diversity (7-8 dB gain) is implemented by spatial separation of receiver antennas.
  - In indoor environments, a wide angular spread is expected which allows a small antenna separation.
  - Conventionally assumed that under Omni-directional wave incidence the minimal distance between two diversity antenna is about $\lambda/2$ or 0.4λ [4] Measurements show that in NLOS environments, the correlation factor drops to a level of 0.4~0.6 at a fraction of a wavelength antenna separation
- Polarity diversity (9-10 dB gain) can be applied due to depolarization phenomena. The reflection, scattering, absorption, or human body may alter the polarity of radio signals. The amount of depolarization determines the gain from polarity diversity.
  - Measurements show the cross-polarization effect in various propagation conditions.
  - Polarization diversity antennas can be placed closely together or even coincidentally without any significant mutual interference

WLAN antennas

- Antennas (Omni-directional and directional) with
  - different gain (dBi, the ratio of the maximum radiation intensity to the average radiation intensity)
  - radiation pattern (graphical representation of radiation of the antenna measured in two orthogonal planes: vertical and horizontal in a polar structure)
  - polarization used in different environments for providing a better coverage and capacity for a radio network.
- *Omni-directional antenna*: provides a 360 degree radiation pattern on horizontal plane. (e.g. $\lambda/2$ dipole antenna, which provides a 2.14 dBi gain)
- *Directional antennas* designed to transmit more energy in one direction (e.g. Yagi antenna, patch antenna, or parabolic dish antenna).

  -->more narrow the 3dB bandwidth, the more gain the antenna provides.

PCMCIA integrated antenna

- Approaches to arrange antenna in a small space
- Diversity or polarity diversity implemented:
  - Polarization diversity solves the problem that dimensions of mobile terminal limit the spatial separation of diversity antennas in designing of a PCMCIA integration antenna.
- A standard type PCMCIA WLAN card includes
  - a baseband part
  - a radio transceiver unit part
  - an antenna part on the extended body of the card.

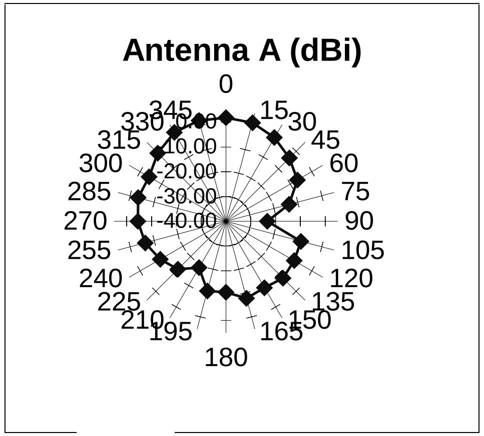
Different approaches have been made to arrange antenna in a small space (3 cm x 5cm x 0.5 cm). Fig shows the space diversity antenna radiation patterns plot:

Gain of the PCMCIA antenna is poor(average less than 0 dBi) because:

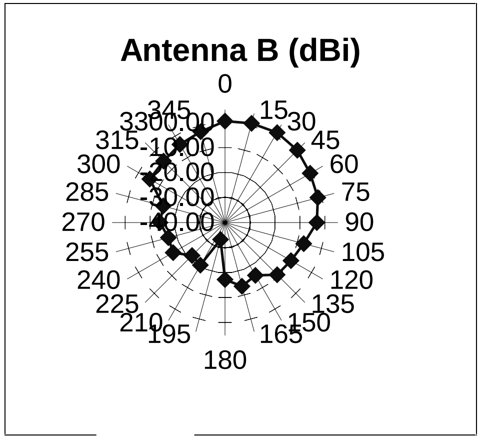
- Omni-directional since the radio signal can come from any direction.

- Gain is limited by the size of PCMCIA card.

OSS: radiation pattern is not real omni-directional. In some direction, the gain can be less than –30 dBi, which means very strong attenuation. Two diversity branches are placed in certain directions in which two deep fading directions are apart from each other.



(a)



(b)

NETWORK PLANNING FOR IEEE 802.11 WLAN

- To maximise network performance with defined budget and equipment
  - Network performance includes dependent aspects: throughput, coverage, roaming, interference, security, etc.
    - -->the planning process helps controlling the project in a systematic manner, in which all relevant information is collected and analysed beforehand in order to avoid costly correction.
- Planning process includes:
  - Requirement management
  - Investigating existing network
  - Coverage planning
  - Capacity planning
  - and frequency planning

Requirement management

- Consists of
  - requirement collection
  - requirement analysis (a critical phase because the system must fulfil customer's needs or expectations)

- Business requirement**:** e.g. budget, time frame, and human resource

  - Management interested in the impact of new technology on productivity of their workforce. The model of a Return of Investment (ROI) usually can stimulate top management to make a decision.

- Functional requirement: describes what new functionality the wireless network plans to provide.

  - E.g. In campus environment, the wireless network may provide general Internet accesses for student and faculty.

  - E.g. In corporation environment, it may provide a secure mobile connection to the company's Intranet.

- Performance requirement: quality of service requested by certain group of users. (e.g.network coverage, data throughput, equipment compatibility and others)

- Management requirement e.g. network management interface, interface to backbone, IP address allocation mechanism, authentication & data security features, and technical support services (to minimized)

- Requirements collected from different user groups put together, discussed, balance or compromise is necessary between different requirements.

- *Validation* and *verification* processes will be arranged.

- Important to document requirements in a clear and easily understood format.

Investigating existing environments

- Good understanding of existing wired network structure is helpful in designing the WLAN network (extension)
  - Useful information: the positions of Ethernet outlets or electricity sockets.
  - To minimise extra cabling work and not disturb existing network services.
  - Besides the physical layer information, the structure of the upper layer of the existing network should also be investigated. For example, the IP address allocation principal, Virtual LAN structure, network services, security policy, etc. should be investigated.
- Baseline of network planning (investigation started from reviewing the blueprint of the areas, e.g. in AutoCAD format, a site visit may be necessary in some cases to check out of date doc.):
  - constructional structure of planning areas
  - functionality of each area
- Interference survey Interference avoidance is very critical for designing a WLAN as it operates in an uncontrolled ISM band. A network planning without interference analysis may cause serious consequences in network performance

  With a spectrum analyzer or other channel scan tools, the network planner tries to locate
  - source of interference source to the planned network, their used frequencies and their power level.
  - Interference may come from other 802.11 WLAN systems, Bluetooth terminals, Microwave ovens, or other radio systems.

• **Output of this phase of work is a report**, containing the following information:

1. *Customer information*: work group name, address, contact person, etc.

2. *Site information*: information on building structures, construction materials, and possible restrictions on radio equipment installation.

3. *Interference survey results*: interference sources and their severity assessment.

4. *Networking information*, Ethernet interface specification, locations of Ethernet Switches or access outlets, IP allocation mechanisms or VLAN configurations.

Coverage planning

- Core of the WLAN planning process:
  - based on the information obtained from requirement analysis and environment investigation, network planning is focused on finding the places of installing access point, with suitable antenna patterns

  - Link Budget
  - Locate AP positions
  - Computer-aided planning
  - Field measurements and site survey

Link Budget

- **The calculation determines the coverage range under certain access point**.
- **The received power on a mobile station (downlink, uplink):**
  - P_{AP_TX} output power of AP
  - G_{xx_Ant} gain of the antennas $$P_{MS\_RX} = P_{AP\_TX} + G_{MS\_Ant} - L_{MS} - L_{path} - L_{AP} + G_{AP\_Ant}$$
  - L_{MS}, L_{AP} cable attenuations between antenna and terminal; L_{path} power loss during signal propagation. The formula of the upper link received power calculation has the similar format.
- The **maximum output power** of the WLAN product is specified in different countries:
  - In USA, limitation is 1 W for DSSS type of WLANs
  - In Europe, level of 100 mW (EIRP)
  - In Japan, 10 mW/MHz
- **Receiver sensitivity** varies, which depends on the chipset and the data rate.
  - At the 11Mbps rate, most WLAN vendors claim the sensitivity to be at the level of –84 dBm with a FER less than 10^{-5}
- A certain **level of margin** should be reserved to act against fast fading or shadowing effects.
  - Target for STAs: received level of –70 dBm at boundary of coverage.
  - The antenna gain varies from 0 dBi to tens of dBi. If strong gain usually antennas have narrow radio beam --> tradeoff between the distance of TX-RX separation and the angular width of the coverage.
  - Selecting a suitable antenna for a specific environment can effectively improve coverage efficiency and decrease interference to other systems. Cable loss between the antenna and the terminal should also be considered. For example, a common used LMR-195 cable has attenuation of 0.6 dB/m at 2.4 GHz frequency band. Each connector may cause 1 dB loss

Locate AP positions

- This is a primary planning step based on blueprint of building (fixed installation of an AP or antenna is preferred)

  Other important aspects:

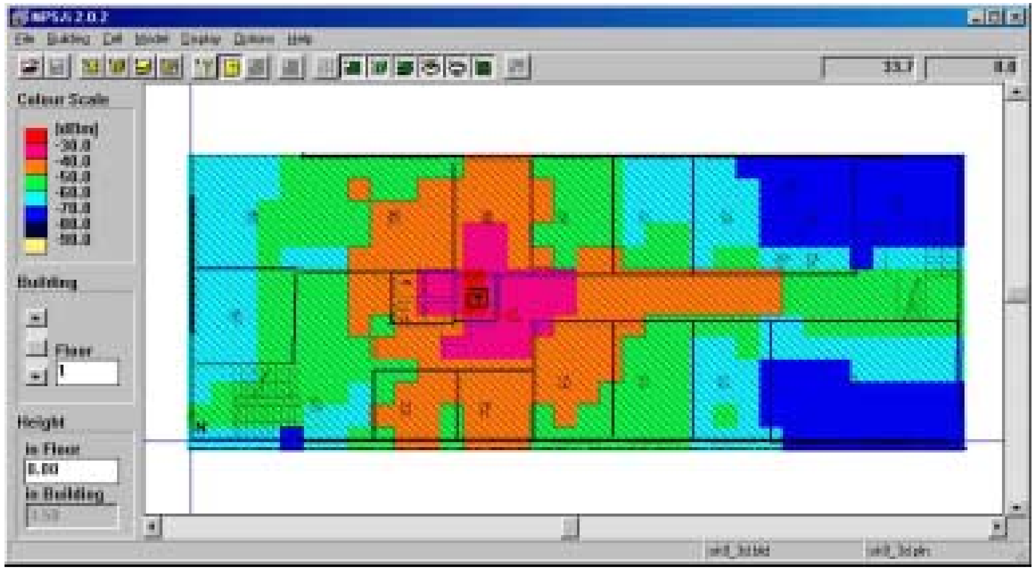
  - furniture (not shown)
  - any large obstacle existing in the area under planning
    - e.g. metal bookshelves or cabinets can cause very strong signal attenuation. The existing network infrastructure affects much of the implementation of the WLAN. For a quick rollout, extra cabling work is always burdensome and should be minimized. Sometimes it is expensive to install power sockets in your selected place. The available resources are always good to use first. By this principle there may have to be certain compromise between best performance and easier installation. Currently many Ethernet switches in the market support transmitting DC power over CAT-5 Ethernet cables. This solution can reduce some cabling work on power supply.
  - Aesthetic requirements or health considerations: e.g.uncomfortable seeing antennas out through the ceilings.
- Currently selecting AP locations in most WLAN planning practice is a "best-guessing" approach:
  - Selection is based on the information acquired from user requirements and field investigation.
  - Selection is dependent upon much on people's experience in the field. If more than one candidate sites are selected, a computer aided planning tool is used to make comparison and optimization

Computer-aided planning

- A radio network planning tool simulates radio propagation in a designed environment:
  - Graphical interface is often provided for building modeling and result presentation
  - The difference between using different AP installations and antenna patterns can be quickly compared.
- Benefits:
  - modify network parameters easily and check results instantly.
  - save much time and manpower on the planning period.
  - the installation of an AP may be easily decided with only few measurements
- In indoor propagation planning tool design there are two different design approaches:
  - *statistical propagation model*: less computation time where the NT planning and optimization process quickly. But parameters used in the planning are statistical results from earlier measurements --> its validity to the area under planning is unsure (e.g. attenuation loss of walls and ceilings, power-decay indexes vary case by case. A lot of experience is required to adjust the parameters to fit your planning case)
  - *ray-tracing model*. strong computer power and long computing time. The parameters used include dimensions of objects, complex permittivity of construction materials, angular spacing of the ray, noise floor of receivers and some others. Suitable parameter setting for accuracy of the simulation and shorten computation time.

    Still, some experience is needed to adjust the parameters to fit your planning practice

NPS/I



Field measurements and site survey

- In computer-aided planning (environment is much simplified) natural a certain level of error or offset existing between the measurement and simulation. Knowledge of error used to improve the accuracy of planning in similar environments later.
- Measurements used to check:
  - the actual coverage of the network
  - whether the coverage plan is realized in the real situation. The basic tool used in WLAN measurement is a wireless PC card and its utility software, e.g. client manager.
  - Types of tools can display signal strength, SNR, packet error ratio, etc. Some tools that support periodic scanning and auto-discovery of stations on all channels can be used to find interfering WLAN systems.
- Advanced site survey tools available: for trouble-shooting of WLAN networks. Tools as network analyzers, which can trace both physical and data link layer data.
  - On the PHY layer, they can monitor radio performance and check the source of interference
  - On the data link layer, they can analyse protocol layer error, and maintain network security and service performance.
  - E.g. Site survey tool is ProCycle™ which is developed by SoftBit, a Finnish company
    - An integrated tool supporting signal/interference measurement, data post-processing, coverage visualization, throughput testing, report generation and other functionalities.

Capacity planning

- Theoretical data transport rate of the IEEE 802.11b is 11 Mbps. However:
  - due to the CSMA/CA mechanism used in the MAC layer
  - management frames used both in physical and data link layer,

  --> the effective data throughput of the WLAN is only 6.5 Mbps [5]
  - When the data rate drops to 5.5 Mbps or 2 Mbps due to weak signal level or lower SNR, the actual date throughput drops also.

- # of supported users in one cell is also limited:
  - by the processing power of AP hardware: some features consume much of the resources of the AP:
    - AP processes functions like authentication, association, encryption and roaming, etc. Some high-end APs integrate proprietary functions such as a VPN server, or Access Control List functionality, etc

TABLE Typical traffic load in different environ, # simultaneous users severed

Environment	Traffic content	Traffic Load	Number of simultaneous users		
			11Mbps	5.5Mbps	2Mbps
Corporation Wireless LAN	Web, Email, File transfer	150 kbits/user	40	20	9
Branch Office Network	All application via WLAN	300 kbits/user	20	10	4
Public Access	Web, Email, VPN tunneling	100 kbits/user	60	30	12

The supported user number claimed by different vendors varies from 20 to 200 --> selection product which meets capacity requirement.

Frequency planning

- It focuses on:
  - choosing correct frequency channels for APs and client terminals.
    - Since the WLAN operates on ISM band, RF interference issues continuously exist as a risk to the operation performance of your WLAN network.
    - The IEEE 802.11 uses the CSMA/CA protocol as a medium access control method. If an interference signal is present at certain channel, that channel will be considered busy and all other stations will have to wait until interference disappears. Several interference sources have serious effects to IEEE 802.11 WLANs:
      - Interference from other WLAN systems
      - Interference from microwave ovens
      - Interference from Bluetooth devices

Interference from other WLAN systems

- While the number of cells and positions of APs are decided in earlier planning phases, a radio channel or a frequency point will be allocated to each AP.

  --> Interference from other WLAN elements, either from other networks or its own network, are all relevant to frequency selection.

  – The IEEE 802.11 standard defines 14 overlapped radio channels.

    -->Two channels with a 5-channel separation do not interfere each other. For example, Channel 1, 6, and 11 can work in the same area without interference. Clearly the frequency resource for 802.11 is very limited.

- In coverage planning, a certain level of fading margin was reserved for receivers at cell border:
  – When two cells have the same size overlap-->signal levels from both APs have similar strengths The data throughput in the overlapping area will deteriorate if the frequency space of the two APs is less than 25 MHz. (It is assumed that signal levels received from the both APs are strong enough to have the full capacity and therefore the interference is the only reason to deteriorate the network performance)

•The effect of interference can be minimized through the use of some counter-measures: adjusting channel spacing, decreasing AP's output power, using directive antennas, using smaller packet fragment sizes, using high speed PC cards, using load sharing mechanisms, etc.

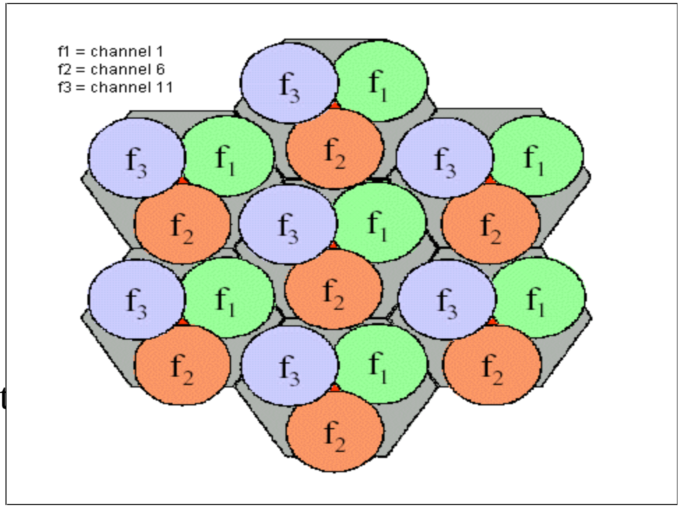
- Ex. three 120-degree sector antennas in a flat coverage planning
- Several advantages in using sectored configuration:

  •More capacity, since there are three frequencies (channels) for one cell

  •Stronger signal level, since there is a higher gain of directive antenna

  •Better frequency reuse, since the sector antenna can be down-tilted to ground and less power will be radiated to the horizontal plane

  •Good front to back ratio (F/B), which can reduce the interference from/t the stations behind the sector antenna



Interference from microwave oven

- Microwave ovens radiate radio signals at the ISM band.
  - Central frequency varies with different magnetron components. (it varies from 2450 MHz to 2458 MHz)
  - Some work reported that radiation emission of Microwave ovens exists also at 1.9 GHz band and second harmonics band (4.9 GHz)
  - Ovens have the strongest emission at the 2.45 GHz band
    - it leads a strong interference to the 802.11 WLAN system operating on the radio band from 2.412 GHz to 2.462 GHz.
- The signal radiated has bursty impulsive characteristics in time domain and the bursts are periodic (burst period is measured = 10 µs, active part is 5 µs)
  - Measured from 3 meters away, the active pulse has a power level of 18 dBm, which is stronger than the power of most IEEE 802.11 products
  - As one symbol period in 802.11 DSSS is one µs, multiple symbols are corrupted in one noise burst. Measurement result shows, in a LOS situation, that a minimum of 21 meters distance is required for eliminating the effect of interference.
- A solution for microwave oven interference is to keep the oven away from the WLAN's working area or to install an RF absorber to the microwave oven.

Interference from Bluetooth

- Bluetooth:
  - stack of protocols
  - realizes wireless data communication between mobile terminals
  - standard supported by the Bluetooth Special Interest Group (SIG, Ericsson, IBM, Intel, Nokia, and Toshiba in 1998)
- Work in ad-hoc mode and is intended to be a cable replacement technology:
  - low data rate (max capacity is 740Kbps per piconet)
  - low power output
  - small coverage area
- Operate at the same ISM band from 2.4 GHz to 2.485 GHz
- Use the FHSS with 79 channels with the hop rate of 1600 hops per second.
  - Each channel is 1 MHz in width.
  - The collision of WLAN and Bluetooth packages is unavoidable if two systems are operating in the same area.
    - Assuming Bluetooth has the packet period of 635 μs and 11 Mbps WLAN works with the 1500 Byte MAC layer payload, the probability of a WLAN frame collision with Bluetooth packets is about 48% to 62% [6]: this heavy collision ratio will seriously deteriorate the performance of WLAN.
    - Other factors, (relative level of two signals, the activity of Bluetooth terminals, the packet size of WLAN system, etc) effects also the frame error rate: many researches give throughout analysis on WLAN performance under Bluetooth interference [7].
- The coexistence of two technologies will certainly continue for a long time
  - many solutions have been proposed to solve the interference problem. As a practical solution, limiting the usage of Bluetooth terminals or limiting its power level in the WLAN area can eliminate the interference
  - The IEEE 802.15 has a task group working on the issue. So far there is no official standard published.

Security

- IEEE provides for security via two methods:
  - Authentication: a STA is verified to have authorisation to communicate inside the NT in a given coverage area (between AP and each STA in infrastructure mode)
    - Open system: any STA may request authentication, the STA which receives it grant it only to a Sta on a user-defined list.
    - Shared key: only STAs with secret encrypted key can be authenticated.
  - Encryption: provides a level of security comparable with fixed LAN
    - Wired equivalent privacy (WEP): it uses RC4 PRNG algorithm from RSA Data Security to meet the following criteria:
      - reasonably strong
      - self-synchronising
      - exportable
      - optional

3G versus 802.11: a comparison

	3G	WLAN
Data Rates	Up to 2Mpbs (indoor)	High DRs: 802.11b up to 11Mpbs 802.11a up to 55Mpbs (practical DR half of theoretical one)
Security	Much more secure environment	WEP mechanism very insecure
Handover	Part of the specs	Currently not implemented (not yet developed) In future solutions IP-based
Cost of the network	Expensive to install (BTS expensive)	Cheap to install (AP cheaper)
Coverage area (per BTS/AP)	About 8km	15-150m
Spectrum	Licensed (not to be interfered with, when txm in its licensed spectrum allocation)	Unlicensed (2.4 GHz and 5GHz): wireless services use shared, unlicensed spectrum: background noise: more users, more congestion and more interference →no QoS
Suported media	Voice and Data	Primarily data, VoIP in future
Connectivity	Seamless (anytime, anywhere): ubiquitous coverage continuous mobility (staying connected when travelling)	Interrupted: in limited location (hotspots): coverage range limited facilities mobility (local connectivity: move devices around)
Use of sprectrum	Efficient spread spectrum:WCDMA Support a large number of users Robustness to multipath: DS-CDMA: superior multipath capabilities? (Low probability of detection by an enemy and its resistance to jamming)	

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HOMEWORK

l List briefly the main differences between 802.11a and 802.11.b (in terms of bandwidth, capacity, coverage).

2 Explain why 802.11a that operates in 5GHz bands has a lower coverage area compared to 802.11b. (Consider link budget and path loss)

3 Explain briefly why CSMA/CD (Ethernet) is not possible in WLAN (consider also the attenuation)

4 The MAC access mechanism is improved by using the Request-to-Send (RTS)/Clear-to-Send (CTS) and NAV packets for a better sharing of the medium (see the Timing Diagram below).

Explain briefly the relationship between:

- a The size of data packet issued to a RTS packet.
- b Number of times the TX STA resends a RTS if it does not receive a CTS packet from the previously sent RTS packet.

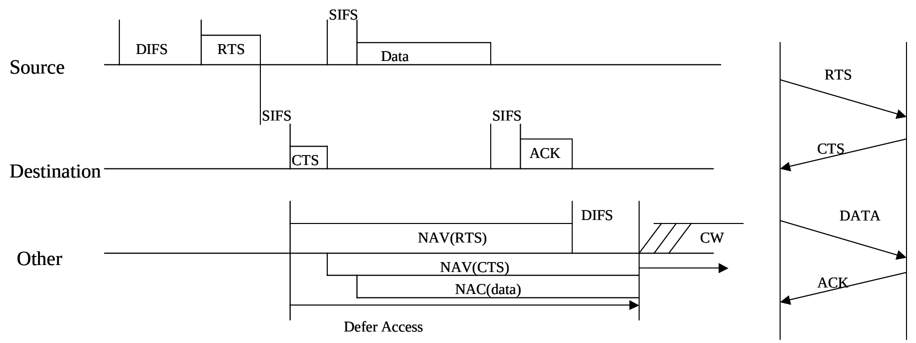

FIG. Timing Diagram

Note that Short Inter-frame Space (SIFS) and DCF-IFS(DIFS) are mandatory periods of idle time used.

E.g.Transmission possible when the channel is stable (idle) for at least an DIFS

APPENDIX: **Terms and Definitions**

- **Access control:** The prevention of unauthorized usage of resources.
- **Access point (AP):** Any entity that has station functionality and provides access to the distribution services, via the wireless medium (WM) for associated stations.
- **Ad hoc network:** A network composed solely of stations within mutual communication range of each other via the wireless medium (WM). An ad hoc network is typically created in a spontaneous manner. The principal distinguishing characteristic of an ad hoc network is its limited temporal and spatial extent. These limitations allow the act of creating and dissolving the ad hoc network to be sufficiently straightforward and convenient so as to be achievable by non-technical users of the network facilities i.e., no specialized “technical skills” are required and little or no investment of time or additional resources is
- required beyond the stations that are to participate in the ad hoc network. The term *ad hoc* is often used as slang to refer to an independent basic service set (IBSS).
- **Association:** The service used to establish access point/station (AP/STA) mapping and enable STA invocation of the distribution system services (DSSs).
- **Authentication:** The service used to establish the identity of one station as a member of the set of stations authorized to associate with another station.
- **Basic service area (BSA):** The conceptual area within which members of a basic service set (BSS) may communicate.
- **Basic service set (BSS):** A set of stations controlled by a single coordination function.
- **Basic service set (BSS) basic rate set:** The set of data transfer rates that all the stations in a BSS will be capable of using to receive frames from the wireless medium (WM). The BSS basic rate set data rates are preset for all stations in the BSS.
- **Broadcast address:** A unique multicast address that specifies all stations.

APPENDIX: **Terms and Definitions**

- **Channel:** An instance of medium use for the purpose of passing protocol data units (PDUs) that may be used simultaneously, in the same volume of space, with other instances of medium use (on other channels) by other instances of the same physical layer (PHY), with an acceptably low frame error ratio due to mutual interference. Some PHYs provide only one channel, whereas others provide multiple channels. **Coordination function:** The logical function that determines when a station operating within a basic service set (BSS) is permitted to transmit and may be able to receive protocol data units (PDUs) via the wire-less medium (WM). The coordination function within a BSS may have one point coordination
- function (PCF) and will have one distributed coordination function (DCF).
- **Coordination function pollable:** A station able to (1) respond to a coordination function poll with a data frame, if such a frame is queued and able to be generated, and (2) interpret acknowledgments in frames sent to or from the point coordinator.
- **De-authentication:** The service that voids an existing authentication relationship.
- **Directed address:** A frame that is addressed to a single recipient, not a broadcast or multicast frame.
- **Disassociation:** The service that removes an existing association.
- **Distributed coordination function (DCF):** A class of coordination function where the same coordination function logic is active in every station in the basic service set (BSS) whenever the network is in operation.
- **Independent Basic Service Set (IBSS):** A BSS that forms a self-contained network, and in which no access to a Controlling Access Point (AP) is available.
- **Infrastructure BSS:** The infrastructure includes the access point (AP), and stations.
- **Medium access control (MAC) management protocol data unit (MMPDU):** The unit of data exchanged between two peer MAC entities to implement the MAC management protocol.
- **Medium access control (MAC) protocol data unit (MPDU):** The unit of data exchanged between two peer MAC entities using the services of the physical layer (PHY).
- **Medium access control (MAC) service data unit (MSDU):** Information that is delivered as units between MAC service access points (SAPs).
- **Mobile station:** A type of station that uses network communications while in motion.

APPENDIX: **Terms and Definitions**

- **Multicast:** A medium access control (MAC) address that has the group bit set. A multicast MAC service data unit (MSDU) is one with a multicast destination address. A multicast MAC protocol data unit (MPDU) or control frame is one with a multicast receiver address.
- **Network allocation vector (NAV):** An indicator, maintained by each station, of time periods when transmission onto the wireless medium (WM) will not be initiated by the station whether or not the station's clear channel assessment (CCA) function senses that the WM is busy.
- **Point coordination function (PCF):** A class of possible coordination functions in which the coordination function logic is active in only one station in a basic service set (BSS) at any given time that the network is in operation.
- **Portable station:** A type of station that may be moved from location to location, but that only uses network communications while at a fixed location.
- **Re-association:** The service that enables an established association [between access point (AP) and station (STA)] to be transferred from one AP to another (or the same) AP.
- **Station (STA):** Any device that contains an IEEE 802.11 conformant medium access control (MAC) and physical layer (PHY) interface to the wireless medium (WM).
- **Station basic rate:** A data transfer rate belonging to the extended service set (ESS) basic rate set that is used by a station for specific transmissions. The station basic rate may change dynamically as frequently as each medium access control (MAC) protocol data unit (MPDU) transmission attempt, based on local considerations at that station.
- **Station service (SS):** The set of services that support transport of medium access control (MAC) service data units (MSDUs) between stations within a basic service set (BSS).
- **Time unit (TU):** A measurement of time equal to 1024 μs.
- **Unicast frame:** A frame that is addressed to a single recipient, not a broadcast or multicast frame.
- **Wireless medium (WM):** The medium used to implement the transfer of protocol data units (PDUs) between peer physical layer (PHY) entities of a wireless local area network (LAN).

APPENDIX: STANDARD OVERVIEW

Standard	Operating Frequency	Maximum data rate
IEEE 802.11	• Frequency Hopping Spread Spectrum in the 2.4 GHz Band • Direct Sequence Spread Spectrum in the 2.4 GHz Band • InfraRed	1 or 2 Mbps
IEEE802.11b	Direct Sequence Spread Spectrum in the 2.4 GHz Band	5.5 or 11 Mbps
IEEE802.11a	Orthogonal frequency division Multiplexing in the 5GHz band	Upto 54Mbps

Upcoming Standards: MAC:

802.11 i - Enhanced Security Mechanism

802.11 e - MAC enhancement – QoS

802.11 f - Inter Access Point Protocol

PHY:

802.11g – Extension to 802.11b

APPENDIX: examples of band allocation