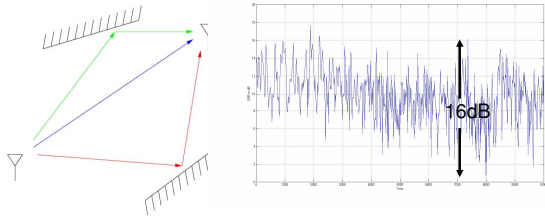


Small-scale multipath fading



• Multipath fading due to **constructive** and **destructive** interference of the transmitted waves at very high carrier frequency.

Wireless Networks 1

Multipath Channel as LTI System

□ Wireless channels can be modeled as LTI systems:

$$y(t) = \sum_i a_i x(t - \tau_i)$$

where a_i, τ_i are the gain and delay of path i .

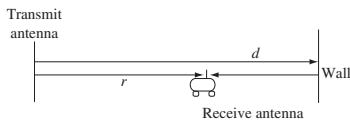
□ The impulse response is:

$$h(\tau) = \sum_i a_i \delta(\tau - \tau_i)$$

with frequency response $H(f)$.

Wireless Networks 4

Example



□ Difference in phases of direct and reflected waves:

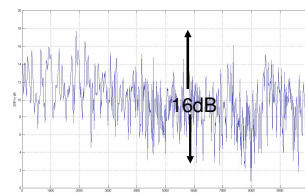
$$\frac{2\pi}{\lambda} [(2d - r) - r] + \pi = \frac{4\pi}{\lambda} (d - r) + \pi$$

where λ is the wavelength of the signal.

□ Movement of $\lambda/4$ goes from a peak to a valley. (this is 0.3m at frequency 900 MHz)

Wireless Networks 2

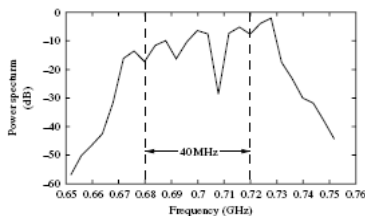
How to turn unreliable physical channel into a reliable link?



□ If a bit is sent when the channel is in deep fade, it will be lost.

Wireless Networks 5

Fading is also Frequency Selective



Why?

Δ in wavelength = $\frac{4\pi}{\lambda} (d - r) + \pi = \frac{4\pi f}{c} (d - r) + \pi$
depends on frequency.

When f changes by $c/[4(d-r)]$, valley becomes peak.

Wireless Networks 3

Diversity

□ Let probability in deep fade = p (say 0.2, unacceptable.)

□ Provide L independent "looks" at the information bit.

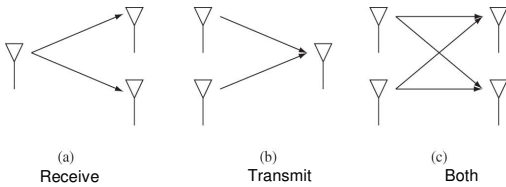
□ As long as at least one of the "looks" are not in deep fade, then information can be recovered.

□ Probability of error reduced to p^L .

□ The independent looks can be at different points in space (time) or frequency.

Wireless Networks 6

Spatial Diversity via Antennas



Antennas should be at a wavelength or more apart.

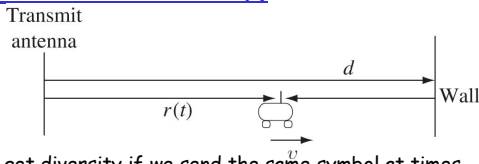
Wireless Networks 7

Frequency Diversity

- Multipath wireless channels are frequency-selective.
- By repeating the same information bit at different frequencies (frequency hopping), we get frequency diversity.

Wireless Networks 10

Spatial Diversity via Motion (aka. Time Diversity)



Can get diversity if we send the same symbol at times separated by approximately λ/v seconds apart.

For 900 MHz cellular and vehicular speed of 100 km/hr, $\lambda/v = 10$ milliseconds.

If the delay constraint is D milliseconds, then we can send the symbol D/10 times, so as to get D/10-fold diversity.

Wireless Networks 8

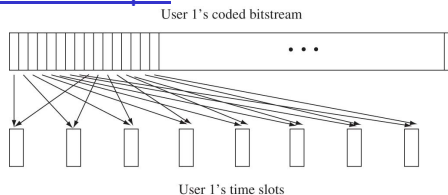
Glamorous History of Frequency Hopping



Hedy LaMarr: inventor of frequency hopping

Wireless Networks 11

Time Diversity via Interleaving: GSM Example

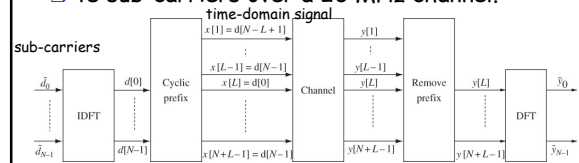


- Amount of time diversity limited by delay constraint and how fast channel varies.
- In GSM, delay constraint is 40ms (voice).

Wireless Networks 9

Example: OFDM in 802.11a

- 48 sub-carriers over a 20 MHz channel.



- Information is conveyed in the frequency domain, and converted into time-domain signal by IDFT.

Wireless Networks 12

OFDM in 802.11a

- Channel bandwidth determines the total symbol rate (number of sub-carriers x symbol rate of each sub-carrier)
- Aggregate data rates range from 6,9, 12, 18, 24, 36, 48, 54kbps, depending on how many bits are modulated into each transmitted symbol on each carrier.
- When channel strength is strong, the number of possible levels each symbol can take on is larger, conveying more bits per symbol. (eg. 2, 4 or 8 levels)
- By coding and interleaving over the sub-carriers, frequency diversity is achieved.
- Repeating the same symbol across different sub-carriers is the simplest form of coding: repetition coding. Higher spectral efficiency can be achieved by more efficient coding.