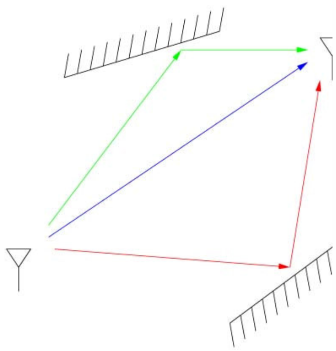
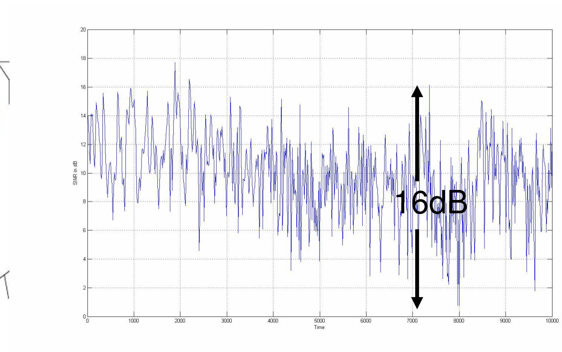
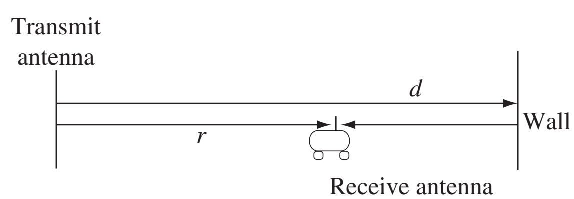
Small-scale multipath fading





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

Example



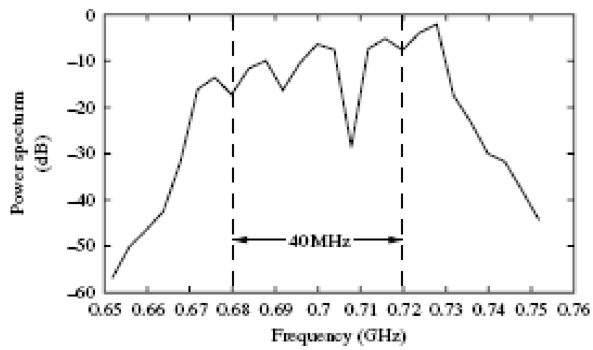
- Difference in phases of direct and reflected waves:

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

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)

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.

Multipath Channel as LTI System

- Wireless channels can be modeled as LTI systems:

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

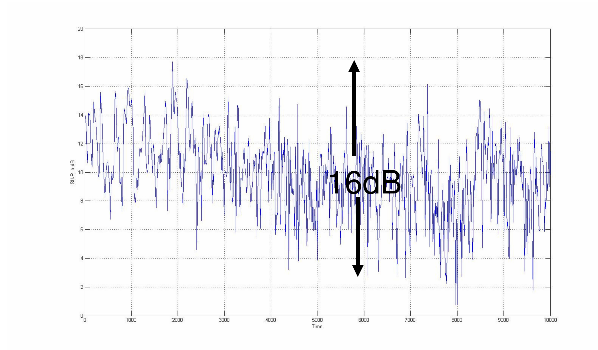
where a_i,τ_i are the gain and delay of path i.

- The impulse response is:

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

with frequency response H(f).

How to turn unreliable physical channel into a reliable link?

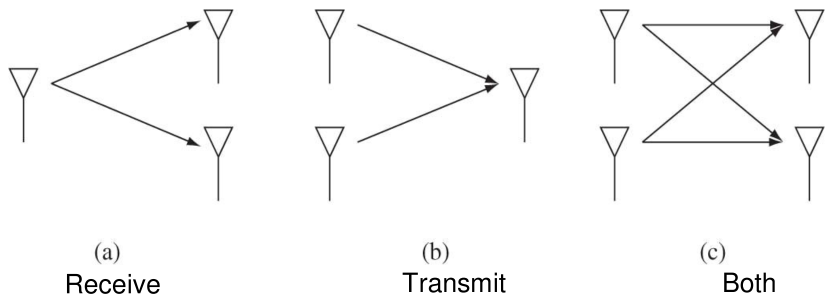


- If a bit is sent when the channel is in deep fade, it will be lost.

Diversity

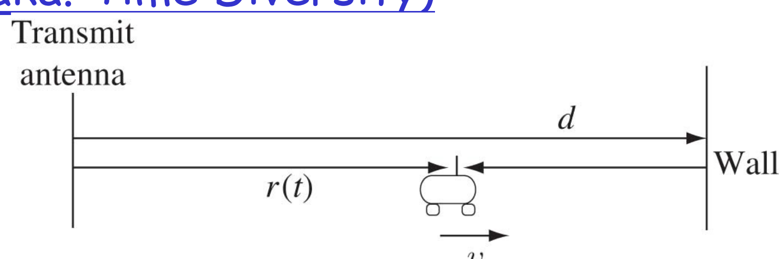
- Let probability in deep fade = p (say 0.2, unacceptable.)
- Provide L independent "looks" at the information bit.
- As long as at least one of the "looks" are not in deep fade, then information can be recovered.
- Probability of error reduced to p^L.
- The independent looks can be at different points in space (time) or frequency.

Spatial Diversity via Antennas



Antennas should be at a wavelength or more apart.

Spatial Diversity via Motion (aka. Time Diversity)

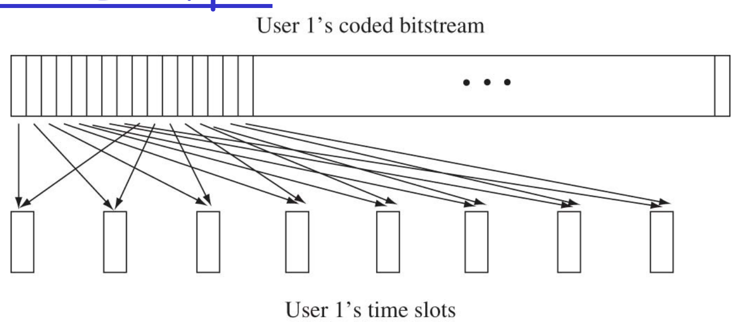


Can get diversity if we send the same symbol at times separated by approximately λ/v seconds apart.

For 900 MHz cellular and vehicular speed of 100 km/hr, λ/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.

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).

Frequency Diversity

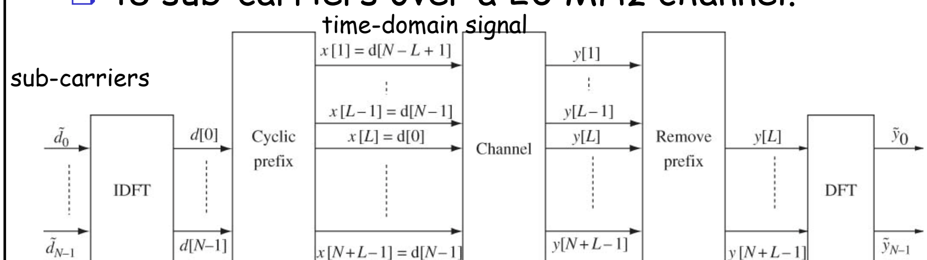
- Multipath wireless channels are frequency-selective.
- By repeating the same information bit at different frequencies (frequency hopping), we get frequency diversity.

Glamorous History of Frequency Hopping

Hedy LaMarr: inventor of frequency hopping

Example: OFDM in 802.11a

- 48 sub-carriers over a 20 MHz channel.



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

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.