EEC 687 Mobile Computing (Spring, 2009)

Mobile Communications

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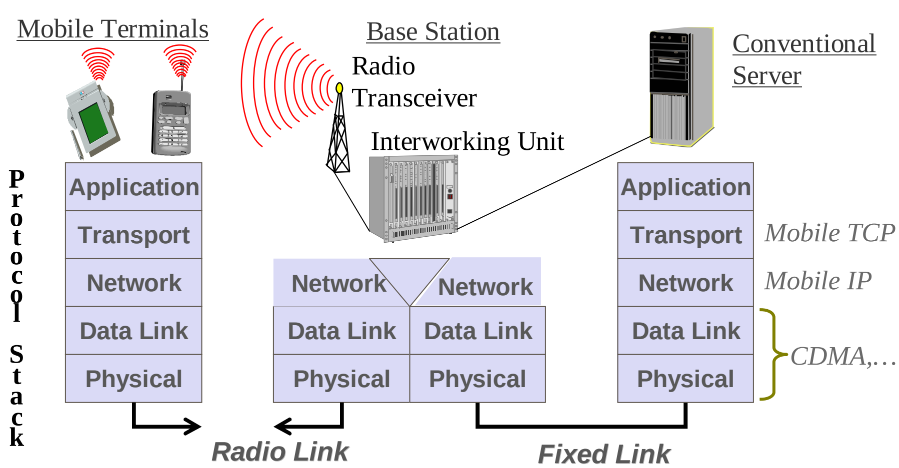
Simplified Reference Model



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Signals

- ❑ physical representation of data
- ❑ function of time and location
- ❑ classification
  - ➢ continuous time/discrete time
  - ➢ continuous values/discrete values
  - ➢ analog signal = continuous time and continuous values
  - ➢ digital signal = discrete time and discrete values

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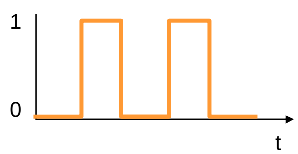
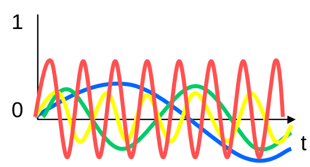
Fourier representation of periodic signals

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$



ideal periodic signal



real composition
(based on harmonics)

- Digital signals (sequence of 0 & 1) need:
  - infinite frequencies for perfect transmission
  - modulation with a carrier signal for transmission

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Signal Propagation: Fading

- ❑ Strength of the signal decreases with distance between transmitter and receiver: path loss
  - Usually assumed inversely proportional to distance to the power of 2.5 to 5
- ❑ Slow fading (shadowing) is caused by large obstructions between transmitter and receiver
- ❑ Fast fading is caused by scatterers in the vicinity of the transmitter

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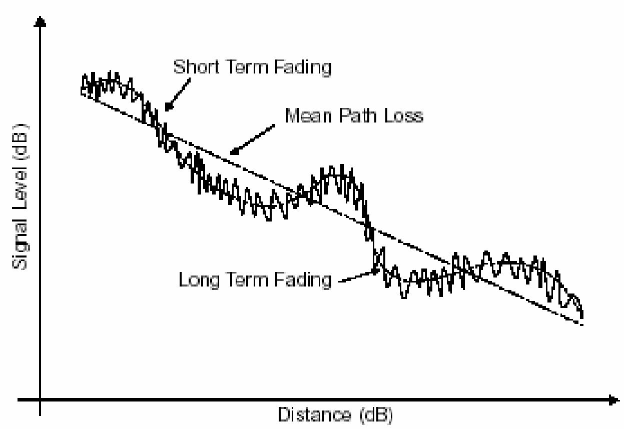
Signal Propagation: Fading



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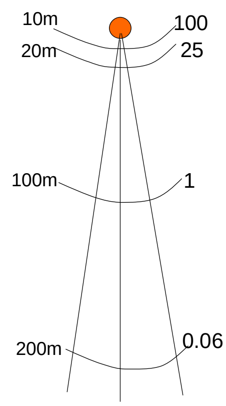
Transmitting Radio Signals

- Free space model
  - No matter exists between the sender and the receiver
  - Signal power is attenuated as $1/d^2$
- Ground reflection model
  - Signal power is attenuated as $1/d^4$
  - In short distance, free space model applies
  - Reference distance
    - 100 meters for outdoor low-gain antennas 1.5 meters above the ground place operating in 1-2GHZ band



Longer radio range requires much stronger power !!!

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18.1 Free space model

The free space propagation model assumes the ideal propagation condition that there is only one clear line-of-sight path between the transmitter and receiver. H. T. Friis presented the following equation to calculate the received signal power in free space at distance d from the transmitter [12].

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \quad (18.1)$$

where P_t is the transmitted signal power. G_t and G_r are the antenna gains of the transmitter and the receiver respectively. $L(L \geq 1)$ is the system loss, and λ is the wavelength. It is common to select $G_t = G_r = 1$ and $L = 1$ in *ns* simulations.

18.2 Two-ray ground reflection model

A single line-of-sight path between two mobile nodes is seldom the only means of propation. The two-ray ground reflection model considers both the direct path and a ground reflection path. It is shown [29] that this model gives more accurate prediction at a long distance than the free space model. The received power at distance d is predicted by

$$P_r(d) = \frac{P_t G_t G_r {h_t}^2 {h_r}^2}{d^4 L} \quad (18.2)$$

where h_t and h_r are the heights of the transmit and receive antennas respectively. Note that the original equation in [29] assumes $L = 1$. To be consistent with the free space model, L is added here.

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18.3 Shadowing model

The shadowing model consists of two parts. The first one is known as path loss model, which also predicts the mean received power at distance d, denoted by $\overline{P_r(d)}$. It uses a close-in distance d_0 as a reference. $\overline{P_r(d)}$ is computed relative to $P_r(d_0)$ as follows.

$$\frac{P_r(d_0)}{\overline{P_r(d)}} = \left(\frac{d}{d_0}\right)^{\beta} \quad (18.4)$$

β is called the path loss exponent, and is usually empirically determined by field measurement. From Eqn. (18.1) we know that $\beta = 2$ for free space propagation. Table 18.1 gives some typical values of β. Larger values correspond to more obstructions and hence faster decrease in average received power as distance becomes larger. $P_r(d_0)$ can be computed from Eqn. (18.1).

The path loss is usually measured in dB. So from Eqn. (18.4) we have

$$\left[\frac{\overline{P_r(d)}}{P_r(d_0)}\right]_{dB} = -10\beta \log\left(\frac{d}{d_0}\right) \quad (18.5)$$

The second part of the shadowing model reflects the variation of the received power at certain distance. It is a log-normal random variable, that is, it is of Gaussian distribution if measured in dB. The overall shadowing model is represented by

$$\left[\frac{P_r(d)}{P_r(d_0)}\right]_{dB} = -10\beta \log\left(\frac{d}{d_0}\right) + X_{dB} \quad (18.6)$$

where X_{dB} is a Gaussian random variable with zero mean and standard deviation σ_{dB}. σ_{dB} is called the shadowing deviation, and is also obtained by measurement. Table 18.2 shows some typical values of σ_{dB}. Eqn. (18.6) is also known as a log-normal shadowing model.

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Environment		β
Outdoor	Free space	2
	Shadowed urban area	2.7 to 5
In building	Line-of-sight	1.6 to 1.8
	Obstructed	4 to 6

Table 18.1: Some typical values of path loss exponent β

Environment	σ_{dB} (dB)
Outdoor	4 to 12
Office, hard partition	7
Office, soft partition	9.6
Factory, line-of-sight	3 to 6
Factory, obstructed	6.8

Table 18.2: Some typical values of shadowing deviation σ_{dB}

```
# first set values of shadowing model
Propagation/Shadowing set pathlossExp_ 2.0   ;# path loss exponent
Propagation/Shadowing set std_db_ 4.0        ;# shadowing deviation (dB)
Propagation/Shadowing set dist0_ 1.0         ;# reference distance (m)
Propagation/Shadowing set seed_ 0            ;# seed for RNG
```


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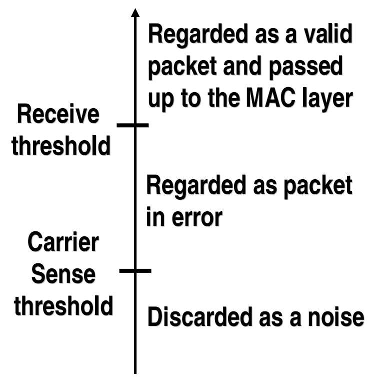
Receiving Radio Signals

- The power level of a received packet is compared to two values



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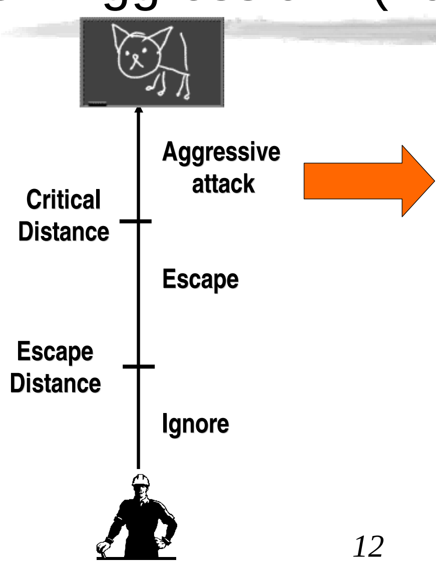
"On Aggression" (1971)



In the woods,
- A lion considers safer,
- In other words, the Escape distance becomes shorter

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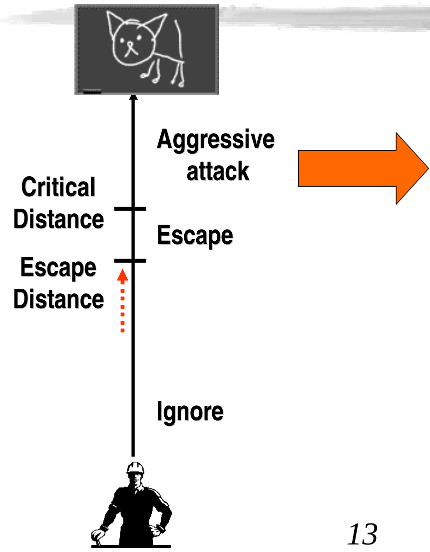

In the woods,
- A lion considers safer,
- In other words, the Escape distance becomes shorter
- A hunter approaches closer than possible
- The lion all of a sudden finds him within the Critical distance
- And it…

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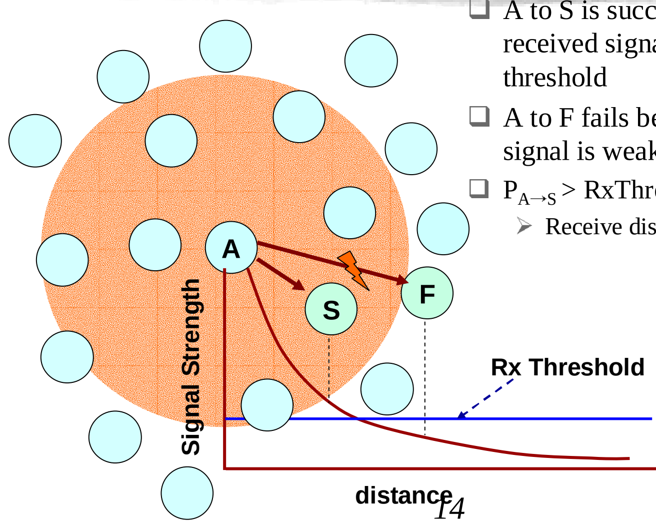
Receive Threshold



- A to S is successful because the received signal is stronger than the Rx threshold
- A to F fails because the received signal is weaker than the Rx threshold
- $P_{A \rightarrow S}$ > RxThreshold = -82 dBm
  - Receive distance (238m)

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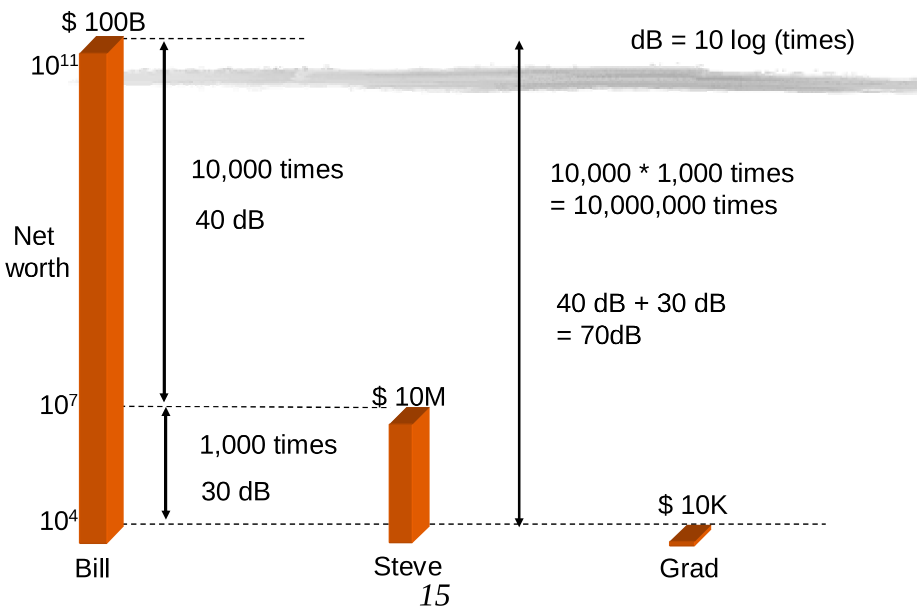
dB (relative measure)



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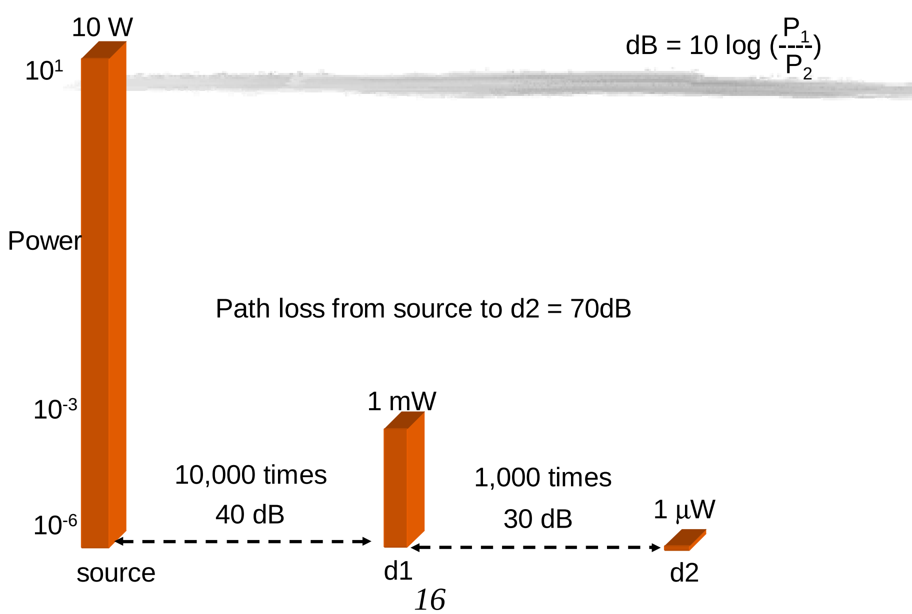
Path loss in dB



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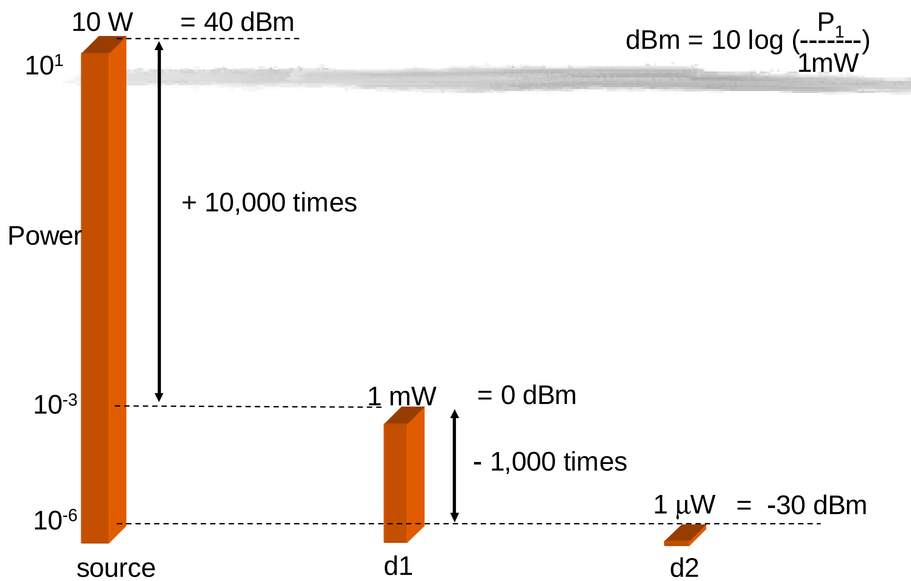
dBm (absolute measure of power)



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Let's Do the Math

- In the 915 MHz WaveLAN radio hardware (free)
  - Transmit power (Pt) = 24.5 dBm = ??? Watts
  - Receive sensitivity = -64.5 dBm = ??? Watts

  - Receiving distance (Pr > Rth) = ??? m
    - $Pr(d) = Pt * Gt Gr ht^2 hr^2 / (4\pi)^2 L d^2$
    - $Gt = Gr = 1$, $L = 1$, $\lambda = 3x10^8/915x10^6 = 0.328$

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Let’s Do the Math

- In the 915 MHz WaveLAN radio hardware (two-ray)
  - Transmit power (Pt) = 24.5 dBm = ??? Watts
  - Receive sensitivity (Rth) = -64.5 dBm = ??? Watts
  - Receiving distance (Pr > Rth) = ??? m
    - $Pr(d) = Pt*GtGr\lambda^2/Ld^4$
    - Gt=Gr=1, ht=hr=1.5, L=1
  - Carrier sense sensitivity (Cth)= -78dBm = ??? Watts
  - Carrier sense distance (Pr > Cth) = ??? m

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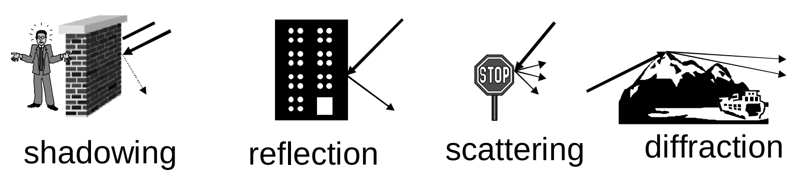
Signal Propagation: Others

- Receiving power additionally influenced by



- Multipath propagation : Signal can take many different paths between sender and receiver, which makes the correct comm. difficult

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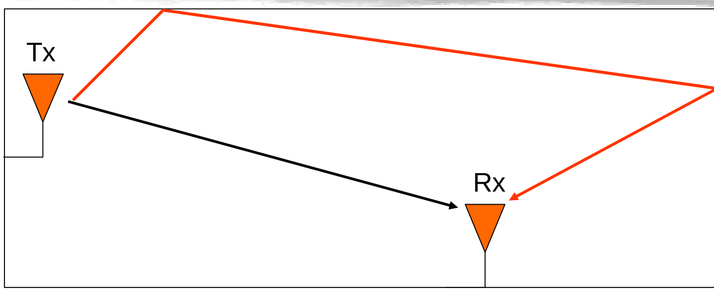
Signal Propagation: Multipath



Effects of multipath

- Fading
- Varying doppler shifts on different multipath signals
- Time dispersion (causing inter symbol interference)

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Physical Impairments: Noise

- ❑ Unwanted signals added to the message signal
- ❑ May be due to signals generated by natural phenomena such as lightning or man-made sources, including transmitting and receiving equipment as well as spark plugs in passing cars, wiring in thermostats, etc.
- ❑ Sometimes modeled in the aggregate as a random signal in which power is distributed uniformly across all frequencies (white noise)
- ❑ Signal-to-noise ratio (SNR) often used as a metric in the assessment of channel quality

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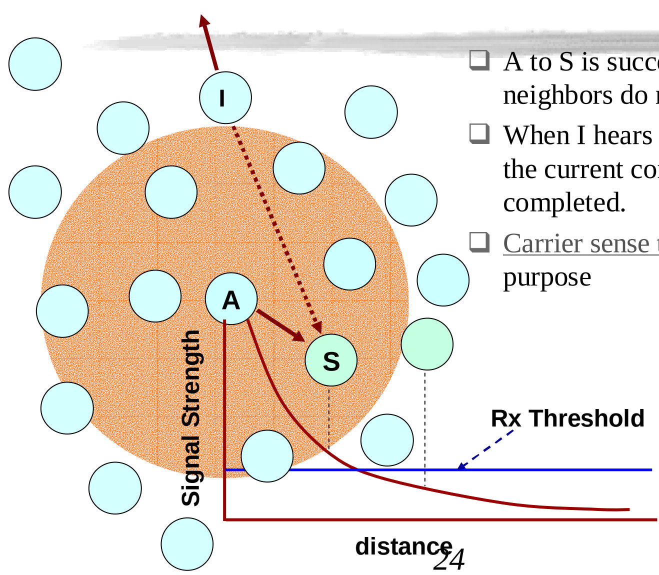
Physical Impairments: Interference

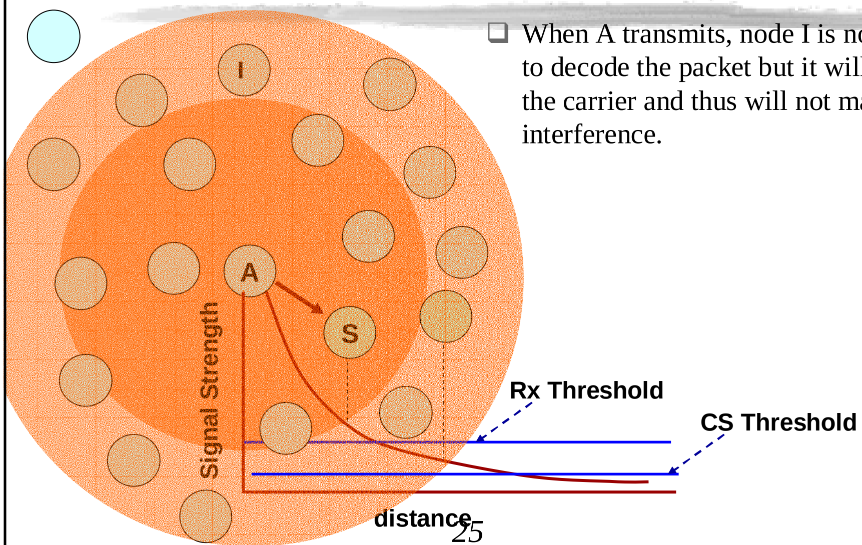
- ❑ Signals generated by communications devices operating at roughly the same frequencies may interfere with one another
  - ➢ Example: IEEE 802.11b and Bluetooth devices, microwave ovens, some cordless phones
  - ➢ CDMA systems (many of today's mobile wireless systems) are typically interference-constrained
- ❑ Signal to interference and noise ratio (SINR) is another metric used in assessment of channel quality

Capture/Carrier Sense Threshold



- ❑ A to S is successful only when its neighbors do not cause interference.
- ❑ When I hears something, I waits until the current communication is completed.
- ❑ Carrier sense threshold is used for this purpose

Capture/Carrier Sense Threshold



- When A transmits, node I is not able to decode the packet but it will sense the carrier and thus will not make any interference.

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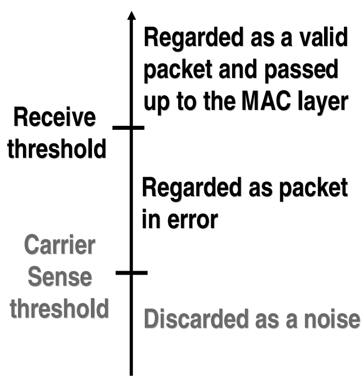
Receiving Radio Signals

- The power level of a received packet is compared to two values



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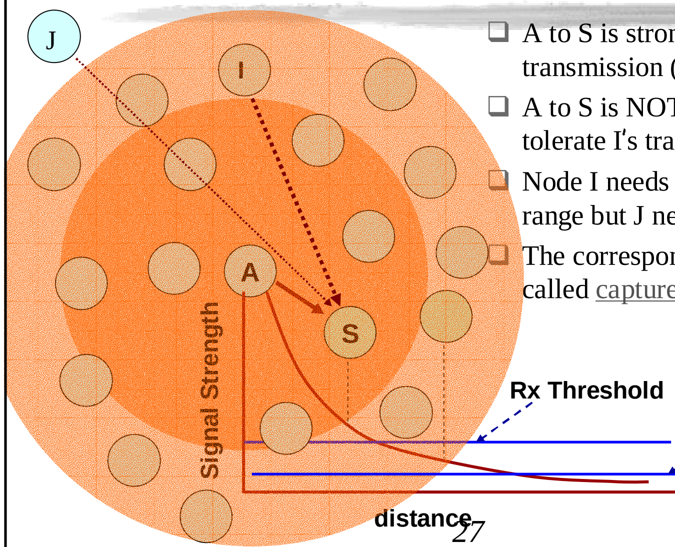
Determining Carrier Sense Threshold



- A to S is strong enough to tolerate J's transmission (SIR)
- A to S is NOT strong enough to tolerate I's transmission
- Node I needs to be covered in the CS range but J needs not.
- The corresponding SIR requirement is called capture threshold (10 dB)

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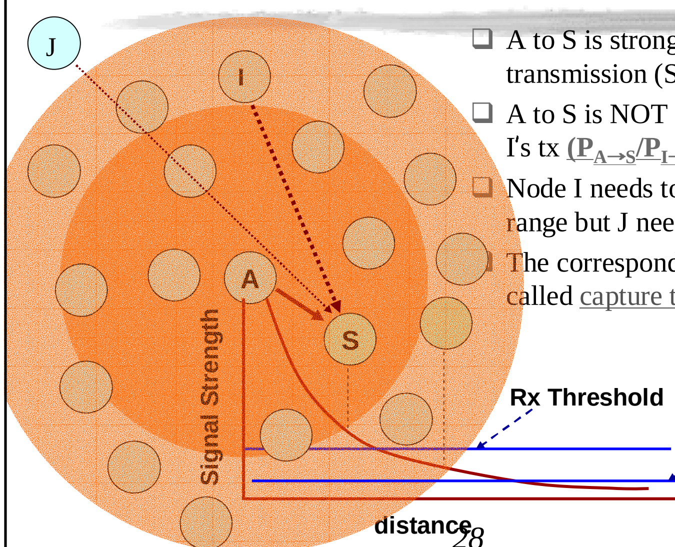
Determining Carrier Sense Threshold



- A to S is strong enough to tolerate J's transmission (SIR) **$(P_{A \to S}/P_{J \to S} < 10dB)$**
- A to S is NOT strong enough to tolerate I's tx **$(P_{A \to S}/P_{I \to S} > 10dB)$**
- Node I needs to be covered in the CS range but J needs not.
- The corresponding SIR requirement is called capture threshold (10 dB)

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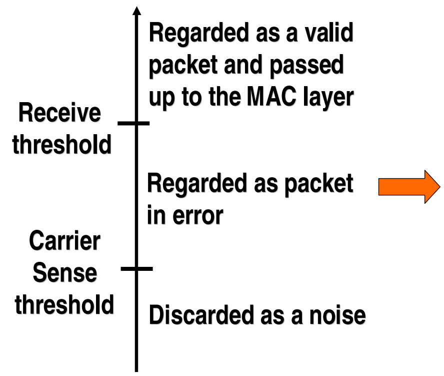
Receiving Radio Signals

"signal capturing"

- The power level of a received packet is compared to two values



If the receiver receives one signal while receiving another (conflict),

- P(old)/P(new)>10dB, can still receive the old one (new packet is dropped)

- Otherwise, it is a "collision" and both packets are dropped

IEEE 802.11/a/b Physical layer

Table 14.4 IEEE 802.11 Physical Layer Specifications

(a) Direct sequence spread spectrum

Data rate	Chipping code length	Modulation	Symbol rate	Bits/symbol
1 Mbps	11 (Barker sequence)	DBPSK	1 Msps	1
2 Mbps	11 (Barker sequence)	DQPSK	1 Msps	2
5.5 Mbps	8 (CCK)	DBPSK	1.375 Msps	4
11 Mbps	8 (CCK)	DQPSK	1.375 Msps	8

(b) Frequency-hopping spread spectrum

Data rate	Modulation	Symbol rate	Bits/symbol
1 Mbps	Two-level GFSK	1 Msps	1
2 Mbps	Four-level GFSK	1 Msps	2

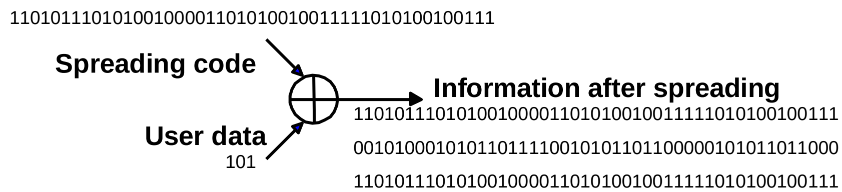
(c) Infrared

Data rate	Modulation	Symbol rate	Bits/symbol
1 Mbps	16-PPM	4 Msps	0.25
2 Mbps	4-PPM	4 Msps	0.5

(d) Orthogonal FDM

Data rate	Modulation	Coding rate	Coded bits per subcarrier	Code bits per OFDM symbol	Data bits per OFDM symbol
6 Mbps	BPSK	1/2	1	48	24
9 Mbps	BPSK	3/4	1	48	36
12 Mbps	QPSK	1/2	2	6	48
18 Mbps	QPSK	3/4	2	96	72
24 Mbps	16-QAM	1/2	4	192	96
36 Mbps	16-QAM	3/4	4	192	144
49 Mbps	64-QAM	2/3	6	288	192
54 Mbps	16-QAM	3/4	6	288	216

Direct Sequence Spread Spectrum (DSSS)



- Data signal is multiplied by a spreading code, and resulting signal occupies a much higher frequency band
- Spreading code is a pseudo-random sequence

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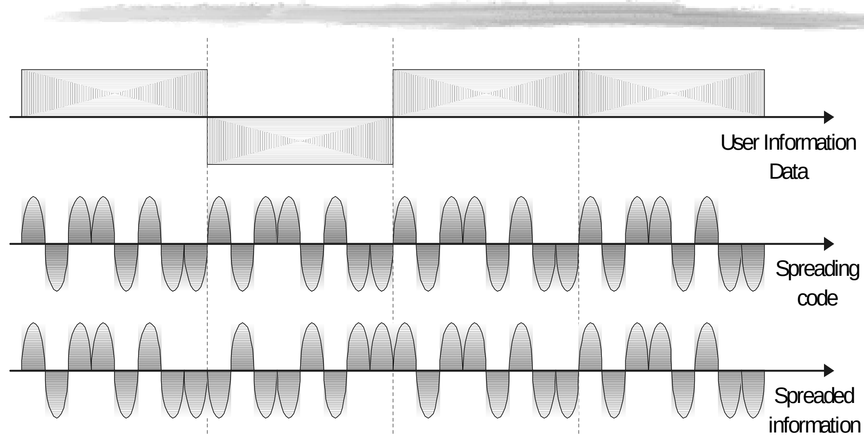
DSSS Example



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Why Spread Spectrum?

- Spread spectrum signals are distributed over a wide range of frequencies and then collected back at the receiver
  - These wideband signals are noise-like and hence difficult to detect or interfere with
- Initially adopted in military applications, for its resistance to jamming and difficulty of interception
- More recently, adopted in commercial wireless communications

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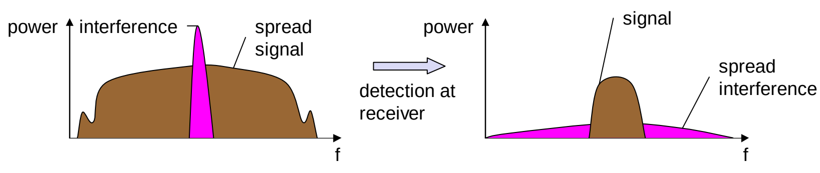
Spread Spectrum

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- Solution: spread the narrow band signal into a broad band signal using a special code



protection against narrowband interference

- Side effects:
  - coexistence of several signals without dynamic coordination
  - tap-proof

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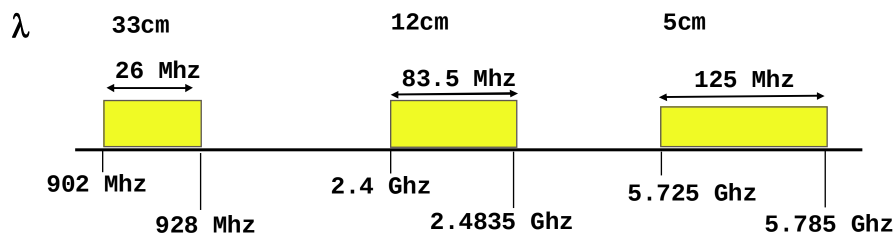
Cf. Unlicensed Radio Spectrum



cordless phones
baby monitors
Wireless LANs

802.11
Bluetooth
Microwave oven

unused