Digital Radio Transmission - Problems

Radio Transmission

- Problem: there is no wiring or cables with radio transmissions
- Radio signals can become week to an unacceptable level
- Is the radio interface limited by noise or by interference?

Transmission Problems

- Path Loss
- Fading
  - Log-normal fading
  - Rayleigh or multipath fading
- Time Dispersion
- High BER
- Radio switch-over times
- Hidden terminal problem
- Signal lock-on

Path Loss (L_S)

- The received signal becomes weaker with the increasing distance between transmitting unit (Tx) and receiving (Rx) unit.
- In a free space propagation environment:
  - $L_s \sim d^2 f^2$

Assuming, that the two units are relatively close (to be used, e.g., in an cellular environment)

Path Loss (L_S)

- Non-ideal ground plane must be considered in an non-open environment.
  - $L_s \sim d^4 f^2$

In practice more complex models (Egli or Okomura models) are used. When modeling radio layer for ad hoc networks more sophisticated models may be used.

Log-normal Fading

- Caused by the shadowing effect of obstacles. When nodes move around, signal strength can vary depending on the obstacles between the Tx and Rx nodes.
- The minimums in a signal strength are called *fading dips*.

Log-normal Fading

- Log-normal: the logarithm of the signal strength takes the form of a normal distribution (bell curve with negative exponential convergence) around a mean value.
- The distance between fading dips is typically some 10 to 20 meters in a GSM (900MHz) environment.

Rayleigh Fading

- Caused by the signal taking more than one path from Tx to Rx due to signal “bouncing” of from obstacles.
- Especially hard problem in urban environments.
- There is usually no line-of-sight, the signal reaches the destination via several reflections against obstacles (buildings, etc.).

Rayleigh Fading

- The received signal is a sum of many identical but time dispersed signals.
- Since signals have to be added like vectors (they have phase and amplitude), the sum of the received signals can easily reach an unacceptable low value.

Rayleigh Fading

- The distance between two fading dips (d_{rf}) is about half a wavelength.

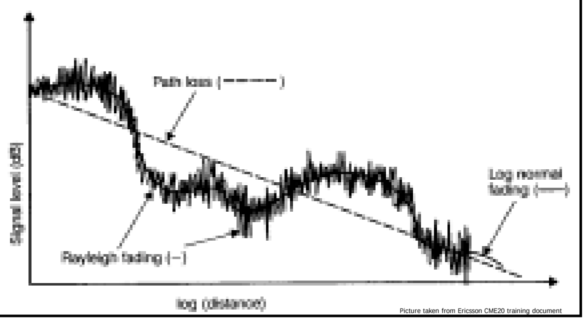
Frequency	d_{rf}
800 MHz	0.187m
1700 MHz	0.088m
2.4 GHz	0.0625m
5.2 GHz	0.029m

Rayleigh Fading an Example

- Since the distance between two fading dips (d_{rf}) is about half a wavelength:

  If you travel with a speed of 50km/h (~30mph) using your 800MHz handset, the mean time between Rayleigh fading dips is approximately 13.3msec !!

Total Fading Signal

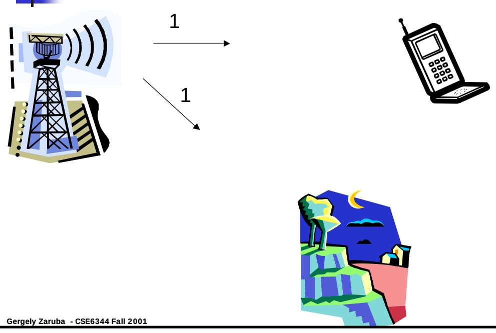


Picture taken from Ericsson CME20 training document

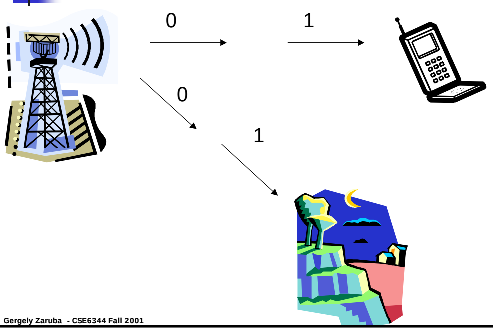
Time Dispersion

- The problem again lies in reflection of signals from obstacles.
- Time dispersion causes inter symbol interference, meaning, that consecutive symbols interfere with each other.

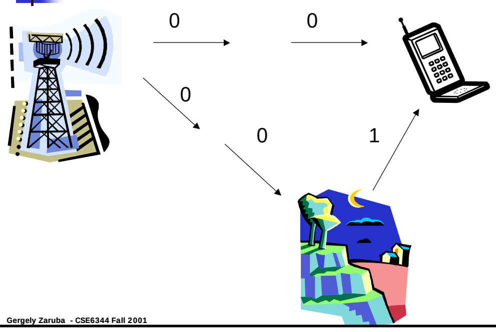
Time Dispersion



Time Dispersion



Time Dispersion



High Bit Error Rate (BER)

- The BER **difference** between optical and wireless transmission is in the order of $10^7 – 10^{10}$; values down to 10^{-3} are not uncommon
- Furthermore, errors are likely to appear in bursts (lightning, interference of other devices, etc.)

Radio Switch-over Times

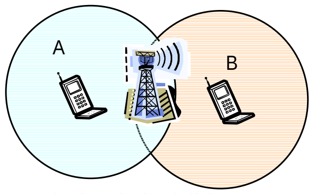
- Most radio equipment is half-duplex:
  - It does not make sense to send and receive on the same frequency at the same time.
  - Building blocks of receivers can be “recycled” in the transmitters, reducing cost.
- Tx and Rx functions are not interleaved and usually employ different frequencies.
- To switch the radio from reception to transmission, the internal circuits have to stabilize (PLLs, etc.). This can take quite a bit of time. (E.G., 220µs is allowed in Bluetooth)

Signal Lock-on

- If a radio starts receiving a signal, it locks itself on the signal (e.g., using PLLs).
- If there is another signal interfering after the lock-on the receiver circuits may still receive the first signal (signal carriers are unlikely to be on the "exact" same frequency).
- More of a phenomenon than a problem, although it can cause some strange effects.

Hidden terminal problem

- Can cause serious problems in wireless LANs and ad hoc networks:



- A's transmission is invisible to B and vice-versa.

Digital Radio Transmission - Solutions

Power Control

- To reduce interference Tx units can progressively reduce transmission power.
- Rx unit determines the reception power and informs the transmitting party on the reception level.
- Primary function is (was) not to save power from batteries nor is it to reduce radiation pollution harmful to the body.

Channel Coding

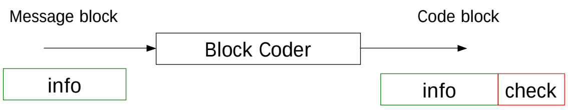
- Wireless medium is know for high BER
- We have to allow certain amount of errors and still be able to restore information or detect errors.
- Some redundancy needs to be built in in the data stream.

Channel Coding

- Two kinds of error control codes:
  - Block codes and
    - Convenient if data is sent in blocks. Mainly used to detect errors with Automatic Repeat Request (ARQ).
  - Convolutional codes
    - More associated with error correction (e.g., when ARQ is not available)

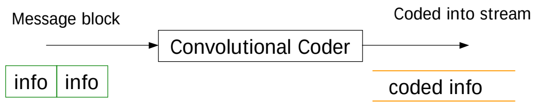
Channel Coding - Block Codes

- We add a number of check bits to the information bits.



Channel Coding – Conv. Codes

- The block of encoded digits depends not only on the digits in the current message block but also on that of the preceding blocks.



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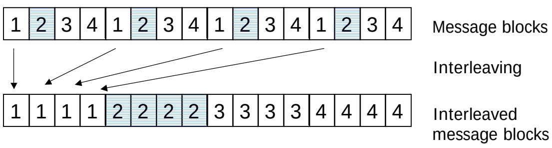
Interleaving

- Bit errors come in bursts.
- Channel coding is to correct single errors.
- Results in delay



- Can be more than one level

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Frequency Hopping

- Rayleigh fading is frequency dependent
  - Fading dips occur at different places for different frequencies
- Let us change carrier frequency between a number of frequencies
  - We only lose a fraction of information
- Spreads out the spectrum of transmission (fast frequency hopping is a Digital Spread Spectrum (DSS) technique)

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Advanced Modulation Techniques

- Amplitude modulation (AM) is far away past.
- So is frequency modulation (FM).
- Digital modulations are used for independence from the received signal amplitude (e.g., Gaussian Minimum Shift Keying (GMSK – used in GSM) that is a phase modulator with a Gaussian filter to smooth out the signal)

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Equalizers

- An optimum receiver is adopted to the type of channel used for transmission, meaning that the receiver has to be always aware of the current state of the channel and adjust itself to the channel.
- Equalizer creates a model of the channel by listening to a well-known training sequence.

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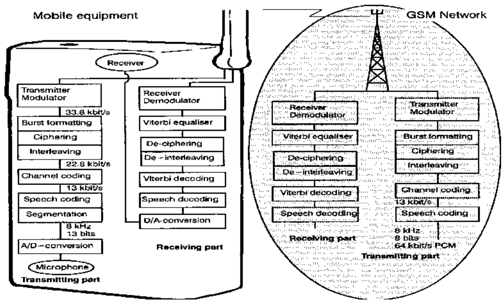
Radio Transmission in GSM



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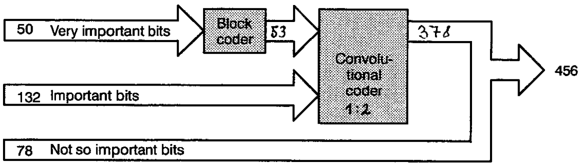
Example of Coding: GSM

The speech is divided into 20ms segments. These 20ms speech segments are digitized and speech coded. The speech coder delivers 260 bits for each segment, which are divided into:



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