Mobile Ad Hoc Networks

Physical Layer

2nd Week

25.04.-27.04.2007

CoNe
Freiburg

University of Freiburg
Computer Networks and Telematics
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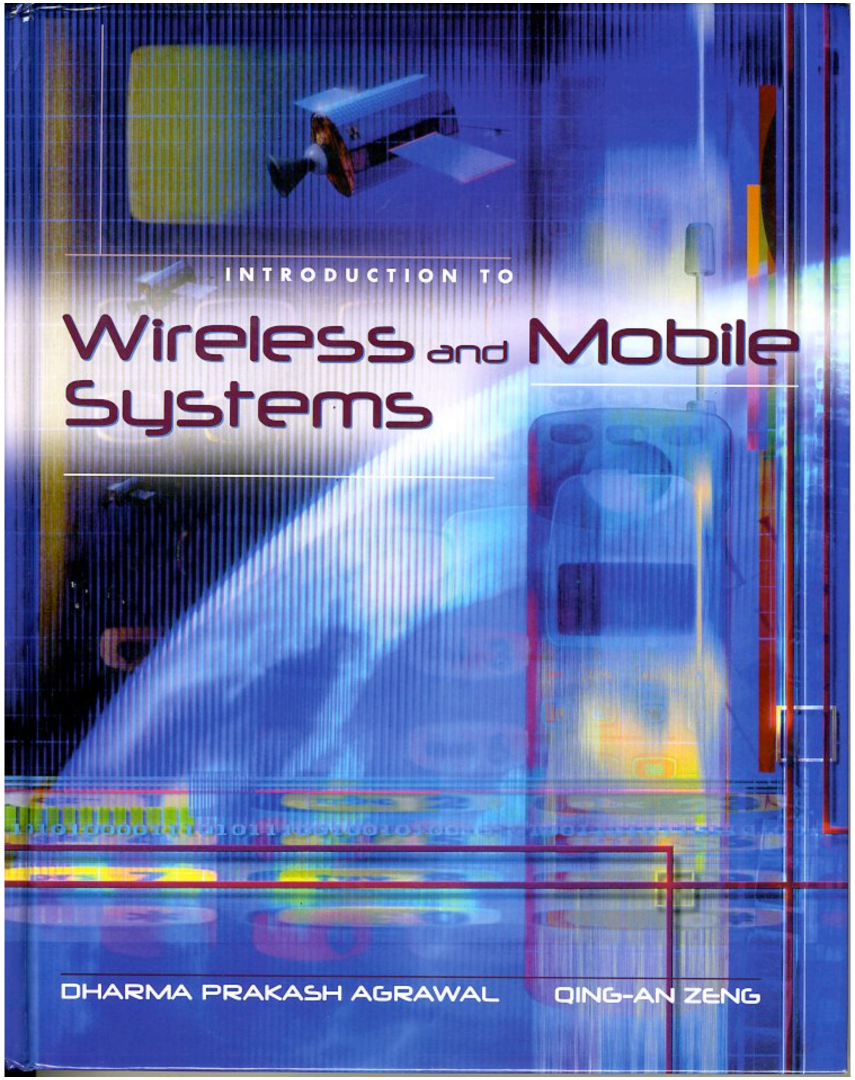
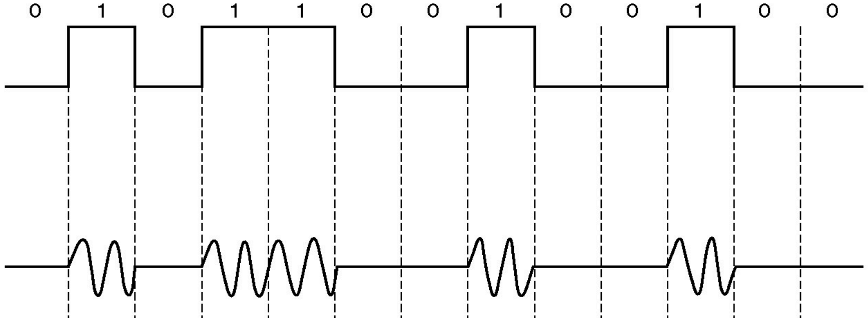
Another Book on Wireless Communication

- **Introduction to Wireless and Mobile Systems**
  - Dharma Prakash Agrawal
  - Qung-An Zeng
  - Thomson 2003
- **Used for this presentation**


INTRODUCTION TO
Wireless and Mobile Systems
DHARMA PRAKASH AGRAWAL QING-AN ZENG

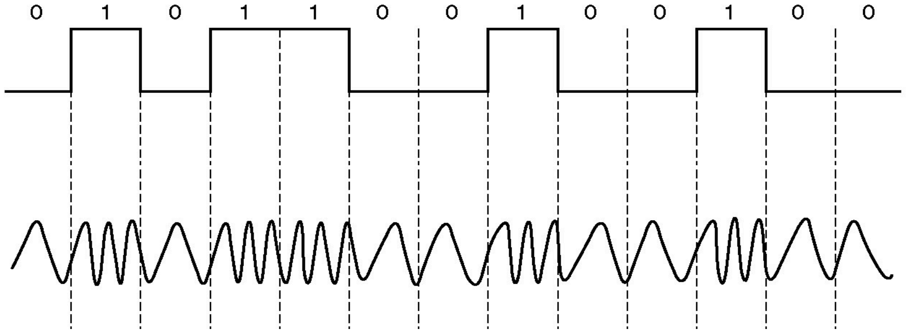
Basic Modulation

- *Amplitude Shift Keying (ASK)*



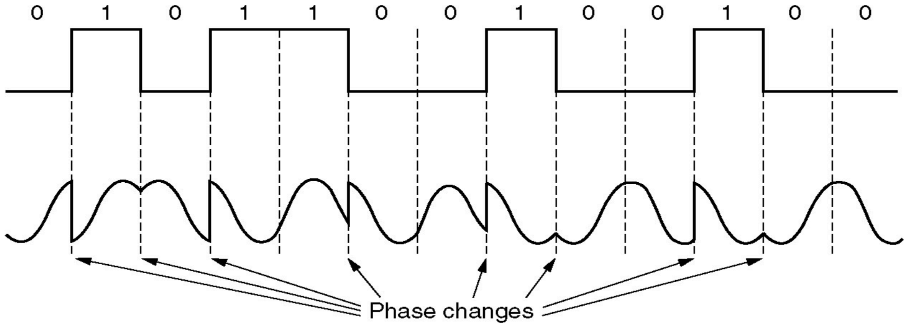
$$s_i(t) = \sqrt{\frac{2E_i(t)}{T}} \cdot \sin(\omega_0 t + \phi)$$

- *Frequency Shift Keying (FSK)*



$$s_i(t) = \sqrt{\frac{2E}{T}} \cdot \sin(\omega_i(t) \cdot t + \phi)$$

- *Phase Shift Keying (PSK)*



$$s_i(t) = \sqrt{\frac{2E}{T}} \cdot \sin(\omega_0 t + \phi_i(t))$$

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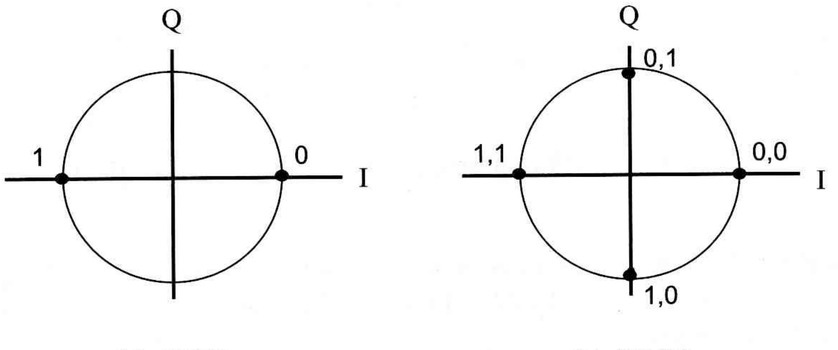
BPSK, QPSK & π/4-QPSK

- **Binary Phase Shift Keying**
  - Use phase shift of 0 and π (0°/180°)
  - for bit 0 and 1
- **Quadratic Phase Shift Keying**
  - Use phase shift of 0, π/2, π, 3π/2 for information 00,01,10,11
- **π/4-QPSK**
  - Information is encoded by the changes in the phase shift
  - Adding a phase shift of 0, π/4, π/2, ..., 7π/4 to the existing phase encodes 000, 001, 010,..., 111



(a) BPSK

(b) QPSK

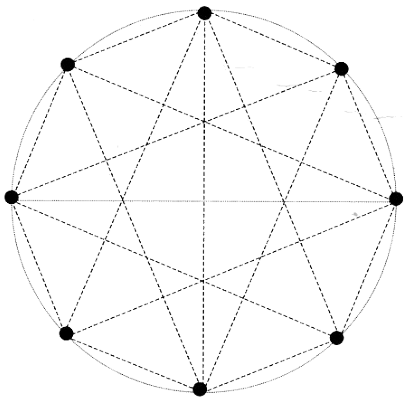
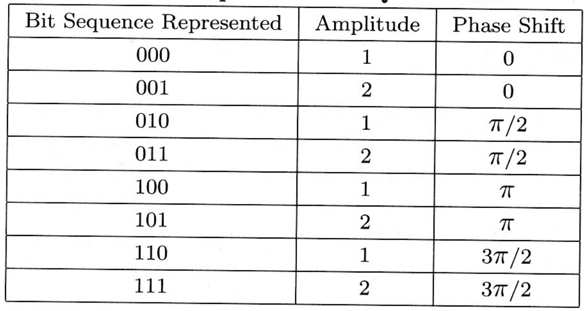


Figure 7.25: All possible state transitions in $\pi/4$QPSK.

QAM

- **Quadrature Amplitude Modulation (QAM)**
  - combination of amplitude modulation and phase shift keying
  - 3 bits per baud (signals per second) can be encoded
  - E.g. baud rate of 1200 Hz results in bit-rate of 3600 bits/s
- **16QAM**
  - splits the signal into phases amplitudes
  - in the diagram the angle describes the phase and the distance from the center the amplitude
- **64QAM, 256QAM,...**
  - further increase of bit rate will eventually result in higher bit error rate (BER)

Table 7.1 A Representative QAM Table



Bit Sequence Represented	Amplitude	Phase Shift
000	1	0
001	2	0
010	1	$\pi/2$
011	2	$\pi/2$
100	1	π
101	2	π
110	1	$3\pi/2$
111	2	$3\pi/2$

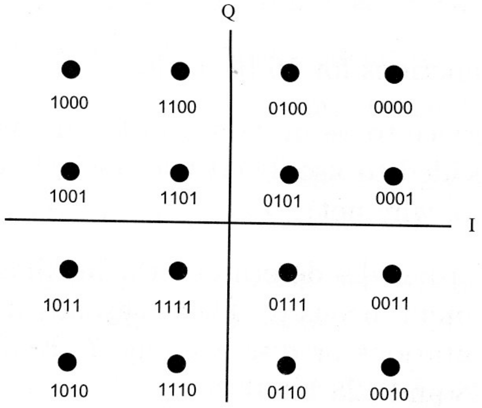


Figure 7.26: Rectangular constellation of 16QAM.

Noise and interference

- **So far: only a single transmitter assumed**
  - Only disturbance: self-interference of a signal with multi-path “copies” of itself
- **In reality, two further disturbances**
  - ***Noise*** – due to effects in receiver electronics, depends on temperature
    - Typical model: an additive Gaussian variable, mean 0, no correlation in time
  - ***Interference*** from third parties
    - Co-channel interference: another sender uses the same spectrum
    - Adjacent-channel interference: another sender uses some other part of the radio spectrum, but receiver filters are not good enough to fully suppress it
- **Effect: Received signal is distorted by channel, corrupted by noise and interference**

Symbols and bit errors

- **Extracting symbols out of a distorted/corrupted wave form is fraught with errors**
  - Depends essentially on strength of the received signal compared to the corruption
  - Captured by ***signal to noise and interference ratio (SINR) given in decibel:***

$$\mathrm{SINR} = 10 \log_{10} \left(\frac{P_{\mathrm{recv}}}{N_0 + \sum_{i=1}^{k} I_i} \right)$$

- **SINR allows to compute** *bit error rate* **(***BER***) for a given modulatio**
  - Also depends on data rate (# bits/symbol) of modulation

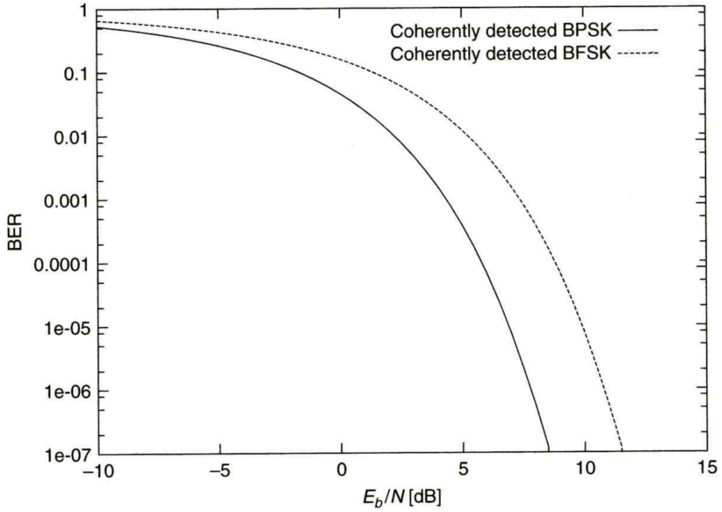
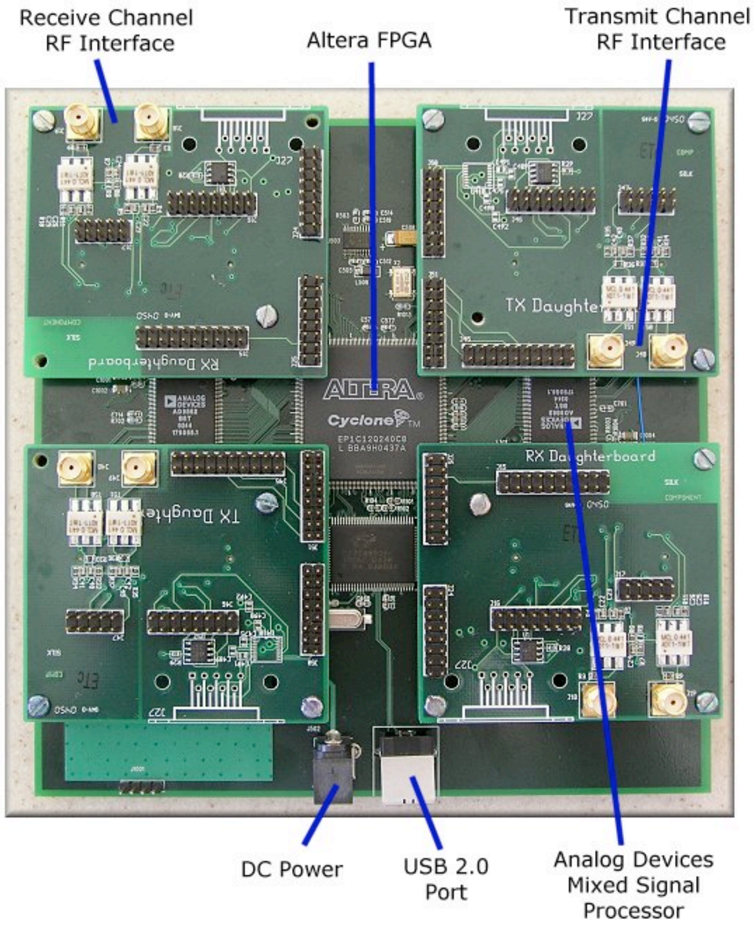


Figure 4.7 Bit error rate for coherently detected binary PSK and FSK

Software Defined Radio

- **Can send and receive any frequency and any modulation**
  - e.g. 4 MHz to 400 MHz
  - e.g. FM, AM, QAM
- **Uses programmable hardware and is controlled by software**
  - Hardware:
    - FPGA (field programmable gate array), or
    - Universal computer
- **Flexible use for upcoming new radio communication**



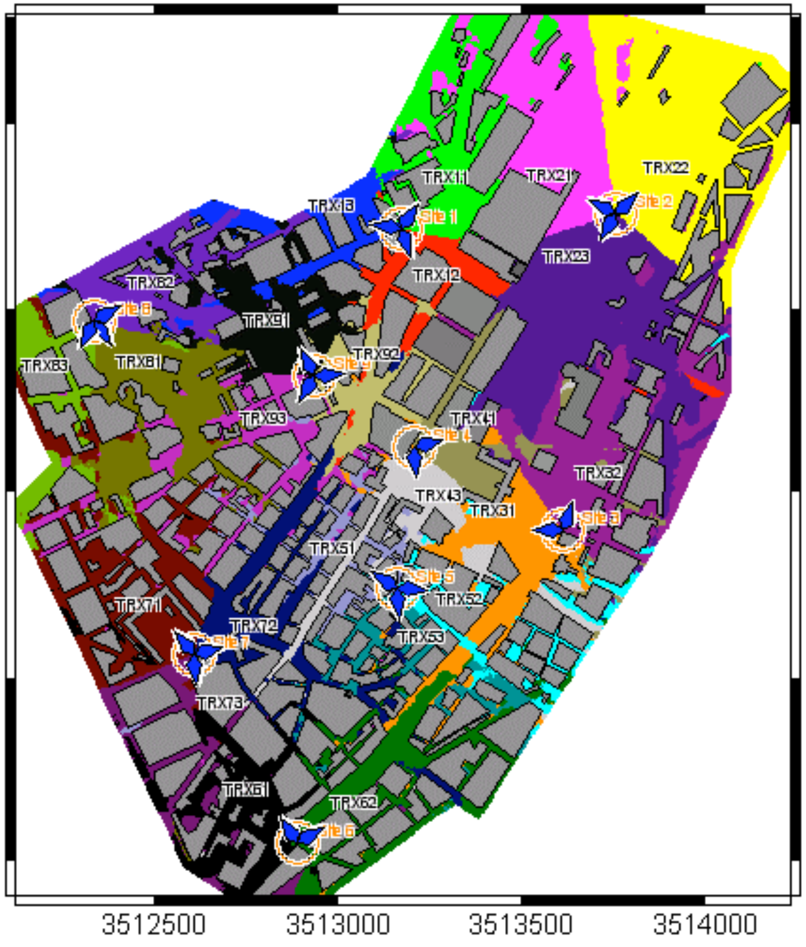
Ettus Research: Universal Software Radio Peripheral (USRP)

Sharing the Medium

- **Space-Multiplexing**
  - Spatial distance
  - Directed antennae
- **Frequency-Multiplexing**
  - Assign different frequencies to the senders
- **Time-Multiplexing**
  - Use time slots for each sender
- **Spread-spectrum communication**
  - Direct Sequence Spread Spectrum (DSSS)
  - Frequency Hopping Spread Spectrum (FHSS)
- **Code Division Multiplex**

Space Division Multiple Access Cellular Networks

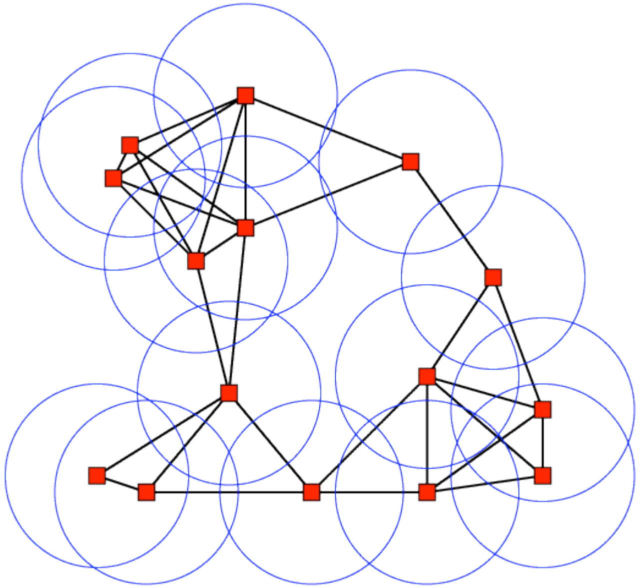
- **Cellular Networks**
    - Mobiles use closest base station
    - Leads (in an ideal situation) to a Voronoi diagram division of the space
- **Directional antennae**
    - Divide the area of each base station in smaller subsets
- **Power Control**
    - E.g. UMTS networks „breathe“,
    - i.e. base stations with large number of participants reduce the sending power
    - So, neighbored base stations can take over some of the mobile nodes of the overcrowded base station

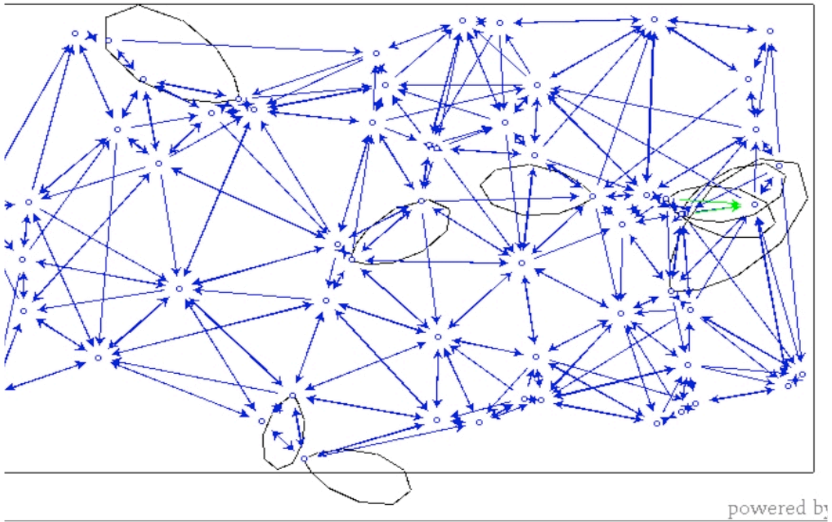


Prediction of UMTS cells
Courtesy of AWE Communications

Space Division Multiple Access: MANET

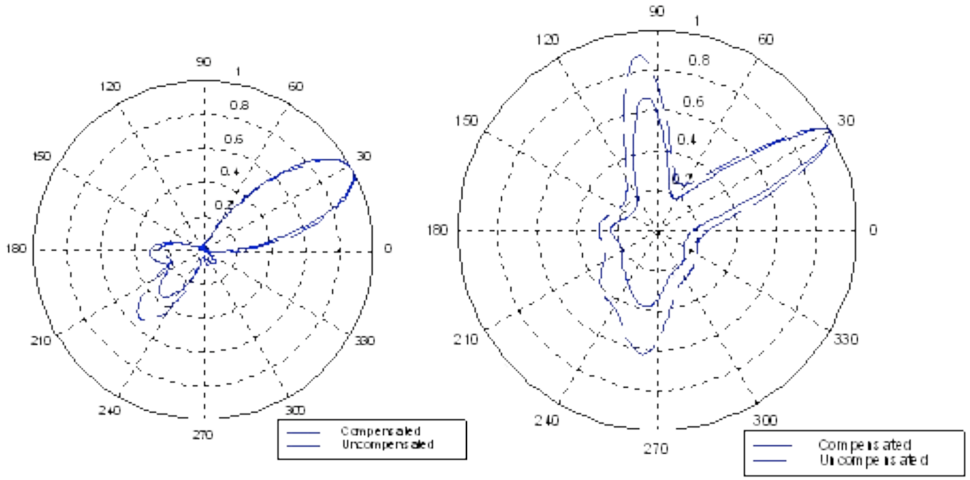
- **Power Control of the sender**
  - Reducing the sending power
    - decreases the chance of interferences
    - Increases the maximum throughput for ad-hoc-networks
    - decreases the energy consumption
  - Possible use of multiple sending power strengths
  - Temporarily switched off
    - decreases energy consumption
- **Directional Antenna**
  - Increase the maximum throughput
  - Decrease energy consumption
  - Problematic for Medium Access





Space Division Multiple Access: Smart Antennae

- **Smart Antennae**
  - Antennae array with signal processing
  - Identifies the direction of arrival (DOA)
  - Beamforming capability
- **Usage**
  - RADAR, Radio astronomy, Satellite communication
  - Cellular systems like UMTS
  - IEEE 802.11n
- **DOA**
  - identification of (multiple) users
  - localization
- **Directional sending (beamforming)**
  - reduces interferences
  - increases throughput
  - reduces sender power

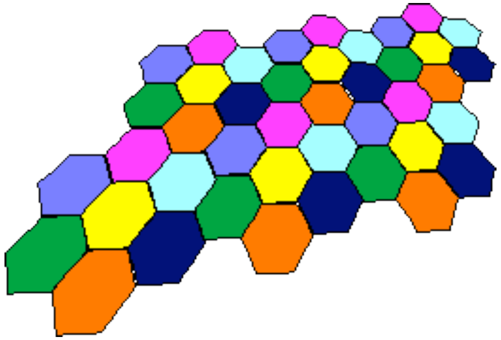


Prof. Dandekar,
Drexel University

Courtesy of IMST GmbH

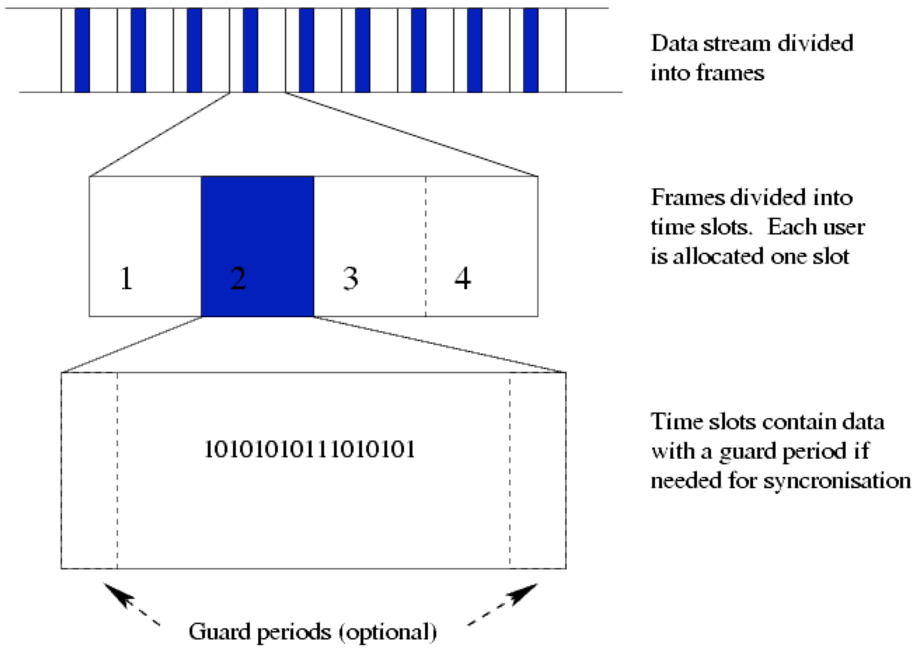
Frequency Division Multiple Access (FDMA)

- **Neighbored links or cells are using different frequencies**
  - with sufficient distance
- **Used in cellular networks like**
  - GSM, UMTS
- **Allocation**
  - is a combinatorically hard problem (coloring problem - NP-hard)
  - static allocation for cellular networks
  - dynamic allocation necessary for mobile ad-hoc networks



Time Division Multiple Access (TDMA)

- **Time slots are assigned to the participants**
- **Static or flexible assignment**
- **Features:**
  - Single frequency can be shared with multiple users
  - Slots can be assigned on demand
- **Used in**
  - GSM, GPRS, UMTS,...
- **Common method for**
  - MANET
- **Implicitly provided by Medium Access (MAC)**



wikipedia.com

Frequency Hopping Spread Spectrum (FHSS)

- **Change the frequency while transfering the signal**
  - Invented by Hedy Lamarr, George Antheil
- **Slow hopping**
  - Change the frequency slower than the signals come
- **Fast hopping**
  - Change the frequency faster

Spread-Spectrum Communication: DSSS

- **Direct Sequence Spread Spectrum (DSSS)**
  - Transmitted signal takes up more bandwidth (frequencies)
  - It „spreads“ over the full „spectrum“ of frequencies
- **Originally intended for military use to „jam“ all frequencies**
- **Phase Modulation with a pseudo-random code symbols**
  - Collection of symbols, called chip, encode a bit

Direct Sequence Spread Spectrum

- **A Chip is a sequence of bits (given by {-1, +1}) encoding a smaller set of symbols**
  - E.g. Transform signal: 0 = (+1,+1,-1), 1=(-1,-1,+1)

0	1
+1 +1 -1	-1 -1 +1

- **Decoding (Despreading):**
  - Compute inner product for bits c_i of the received signals s_i and the chips $c_0 = -c_1$:

$$\sum_{i=1}^{m} c_{0,i} s_i \qquad \sum_{i=1}^{m} c_{1,i} s_i$$

  - When an overlay of the same, yet shifted, signals is received then the signal can be deconstructed by applying dedicated filters
- **DSSS is used by GPS, WLAN, UMTS, ZigBee, Wireless USB based on an**
  - Barker Code (11Bit): +1 +1 +1 −1 −1 −1 +1 −1 −1 +1 −1
  - For all v<m

$$\left| \sum_{i=1}^{m} a_j a_{j+v} \right| \leq 1$$

Code Division Multiple Access (CDMA)

- **Use chip sequence such that each sender has a different chip C with**
  - $C_i \in \{-1,+1\}^m$
  - $-C_i = (-C_{i,1}, -C_{i,2}, \ldots, -C_{i,m})$
- **For all i≠j the normalized inner product is 0:**

$$C_i \bullet C_j = \frac{1}{m} C_i \cdot (C_j)^T = \frac{1}{m} \sum_{k=1}^{m} C_{i,k} C_{j,k} = 0 \ .$$

- **If synchronized the receiver sees linear combination of A and B**
- **By multiplying with proper chip he can decode the message.**

CDMA (Example)

- **Example:**
  - Code C_A = (+1,+1,+1,+1)
  - Code C_B = (+1,+1,-1,-1)
  - Code C_C = (+1,-1,+1,-1)
- **A sends Bit 0, B send Bit 1, C does not send:**
  - $V = C_1 + (-C_2) = (0,0,2,2)$
- **Decoded according to A: $V \bullet C_1 = (0,0,2,2) \bullet (+1,+1,+1,+1) = 4/4 = 1$**
  - equals Bit 0
- **Decoded according to B: $V \bullet C_2 = (0,0,2,2) \bullet (+1,+1,-1,-1) = -4/4 = -1$**
  - equals Bit 1
- **Decoded according to B: $V \bullet C_3 = (0,0,2,2) \bullet (+1,-1,+1,-1) = 0$**
  - means: no signal.

Thank you!

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