Game Theory

Department of Electronics

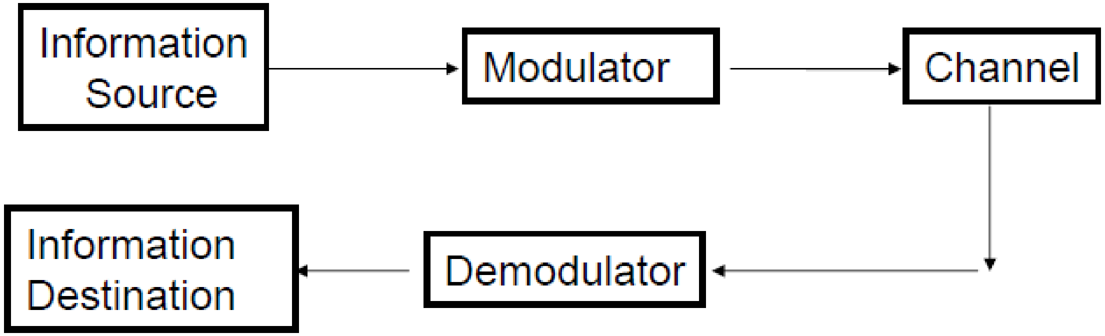
EL-766

Fall 2015

Wireless Communications

- “Wireless Communications: Principles and Practice”, T.S. Rappaport, December 2001, Prentice Hall

Wireless Communication: Simple Model



Assume information source is digital: generates a string of bits that must be transmitted using electromagnetic waves (no wires)

- modulates a carrier
- sinusoidal signals – suitable carriers, $A\sin(2\pi ft+\theta)$ characterized by
    - amplitude: amplitude modulation
    - frequency: frequency modulation
    - phase: phase modulation

Example: BPSK:

$$s_0(t) = A\sin(2\pi f_c t + \pi) = -A\sin(2\pi f_c t),\ 0 \le t \le T$$

$$s_1(t) = A\sin(2\pi f_c t),\ 0 \le t \le T$$

Different Modulation Methods

- QPSK: modulate both the sine and cosine (the quadrature) carrier

$$A_1 \sin(2\pi f t + \theta) + A_2 \cos(2\pi f t + \theta)$$

  - Better spectral efficiency:

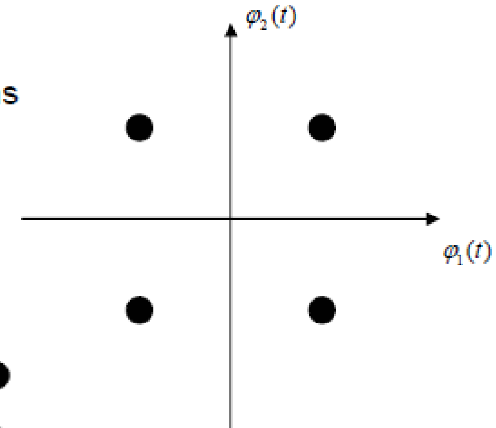
$$\text{Spectral Efficiency} = \frac{\text{Bit rate}}{\text{Transmission Bandwidth}} \quad (bps/Hz)$$

- Can you improve further the spectral efficiency?
  - M-ary modulation
    - Example M - QAM $A_1, A_2 = \pm 1, \pm 3, \ldots, \pm \sqrt{M} - 1$
      - $\log_2 M$ bits encoded into one symbol
  - Large M – higher rates!!!
    - Question: can we get unlimited high rates for a given bandwidth by increasing M ?

Signal Constellation and Detection

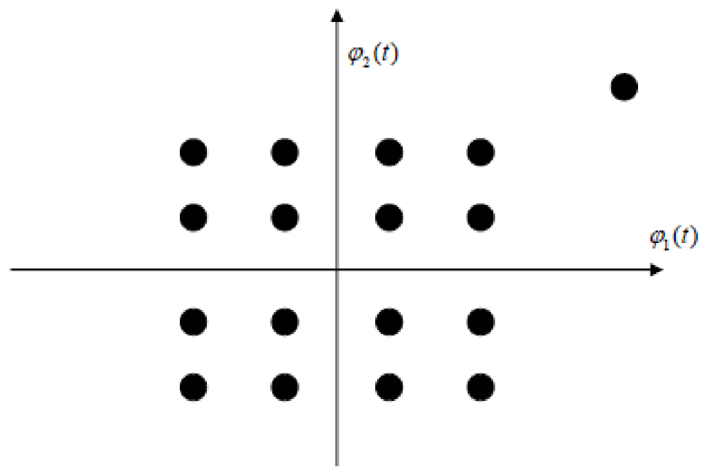
- 4-QAM: $A_1 \sin(2\pi ft+\theta)+A_2\cos(2\pi ft+\theta)=A_1\varphi_1(t)+A_2\varphi_2(t)$

$$\left.\begin{cases} A_1=\pm1 & \varphi_1=\sin(2\pi ft) \\ A_2=\pm1 & \varphi_2=\cos(2\pi ft) \end{cases}\right\}$$ bases functions



- 16 –QAM

$$\begin{cases} A_1=\pm1,\pm3 \\ A_2=\pm1,\pm3 \end{cases}$$



  - Higher constellation, less room for errors
  - Problem: channel introduces noise, fading, distortions

The Physical Channel

- Higher-order (M-ary) → increased spectral efficiency
- Rate of reliable data transmission

  → limited by impairments due to physical properties of the channel:

  - noise (receiver & background)
  - path losses (spatial diffusion & shadowing)
  - multipath (fading & dispersion)
  - interference (multiple-access & co-channel)
  - dynamism (mobility, random-access & bursty traffic)
  - limited transmitter power

Noise

- Noise present in all communication systems.
  - White Gaussian noise:
    - spectrum constant for all frequencies
    - pdf is Gaussian
  - Key parameter of noise:
    - zero mean
    - spectral height No/2 = σ^2 (variance of the noise)

  - Key performance parameter when no interference is present:
    - SNR = Eb/No (signal-to-noise ratio) (Eb = received energy per bit)
    - Determines BER (bit error rate)
      - Different BER for different modulation types

Propagation Models

- Two basic types of propagation effects:
  - Large-scale (spatial diffusion & shadow fading)
  - Small-scale (multipath fading)

- Propagation in free space: ignores any interactions
  - Antenna radiates a sine wave with the carrier frequency

$$f = \frac{c}{\lambda} \qquad c = 3 \times 10^8 \quad \text{speed of light}$$

  - Friis free space equation:

$$P_r = P_t \left(\frac{\lambda}{4\pi r} \right)^2 g_t g_r$$

P_t = transmit power
P_r = received power
g_t, g_r = transmit/receive antenna gains
r = distance between the antennas

Attenuation

Propagation along the earth's surface: 2-ray model

- Flat earth assumption
- Ground wave reflected
  - -Delay
  - -Phase shift
  - -Attenuation

$$P_r = P_t \left(\frac{h_t h_r}{r^2} \right)^2 g_t g_r$$

Approximation path loss model with n = path loss coefficient:

$$P_r = P_t g_t g_r \frac{const}{r^n}$$

-for omnidirectional antennas: $g_t = g_r = 1$

Large and Small Time Scale Fading

Fading effects - different at different time scales

- the instantaneous signal envelope (short time scales (ms)) is
  - Rayleigh distributed (NLOS)
  - Rice distributed (LOS)
- the mean value of the Rayleigh (or Rice) distribution can be considered a constant for the shorter time scales, but in fact it is a random variable with a lognormal distribution (large time scales (seconds))
  - caused by the changes in scenery (occur on a larger time scale)
- the mean of the Lognormal distribution varies with the distance from the transmitter according to the path loss law
  - If the mobile moves away or towards the transmitter (e.g. base station) the received signal will also vary in time, according to the appropriate power law loss model (e.g. free space: decreases proportional with the square of the distance, etc.)

Sharing the Spectrum: Multi-user Communications

Multiple users' transmissions interfere with each other

- Users need to be separated
  - Frequency (FDMA)
  - Time (TDMA)
  - Using different codes (CDMA)
  - In space (spatial separation in cellular and ad hoc networks)
- Performance measure: BER (Bit error rate)
  - characteristic for the type of service (e.g. req. voice BER $\cong 10^{-2}$).
  - Can be mapped into a SIR (SINR) (Signal to Interference plus noise ratio) requirement

Network architecture: Users may all transmit to the same access point (cellular, wireless LAN), or they can use peer-to-peer communication (ad hoc network)

- no wires → soft link concept – depends on the reception quality

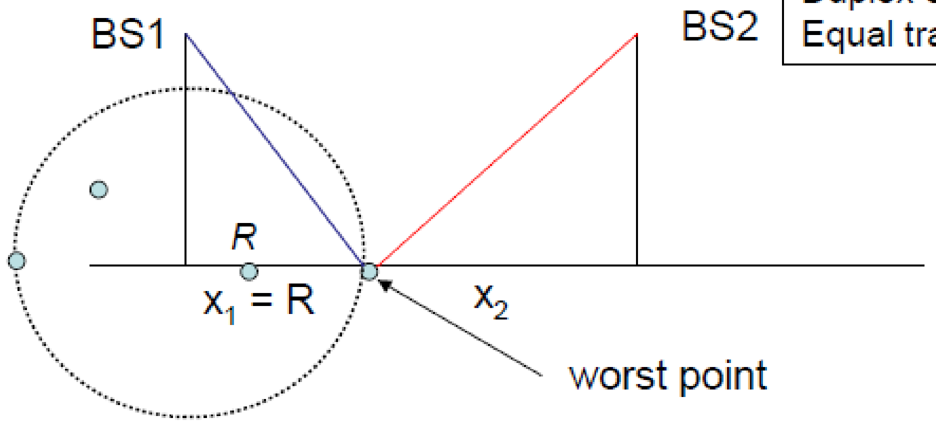
Interference Example: Channel Reuse

-How should we design a cellular system
    -One base station (BS), high power and large coverage?
    -Split into cells to accommodate a larger density of users?

Example: 2 BS use the same channels and are situated at distance D
Question: how should we choose D/R (R is the coverage radius for one cell,
Such that all users meet their target SIR (signal-to-interference ratio)
    - SIR maps the bit error rate performance (BER)

- Example – continuation

Assume noise is 0
Channel impairment is determined by other users using the same channel
Duplex communication
Equal transmission powers



$D = x_1 + x_2$
T = target SIR in dB

$$\left.\begin{aligned}\overline{P_S} &= \frac{const}{x_1^{\,n}} P_t \\ \overline{P_I} &= \frac{const}{x_2^{\,n}} P_t\end{aligned}\right\} \Rightarrow \overline{SIR} = \frac{\overline{P_S}}{\overline{P_I}} = \left(\frac{x_2}{x_1}\right)^n = \left(\frac{D-R}{R}\right)^n$$

$$\overline{SIR}_{dB} = 10 \log_{10} \overline{SIR} = 10\, n \log_{10}\left(\frac{x_2}{x_1}\right) \geq T$$

- Example – continuation

$$\frac{x_2}{x_1} \geq 10^{\frac{T}{10n}} \Rightarrow \frac{D}{R} \geq 1 + 10^{\frac{T}{10n}}$$ → want small or big number?

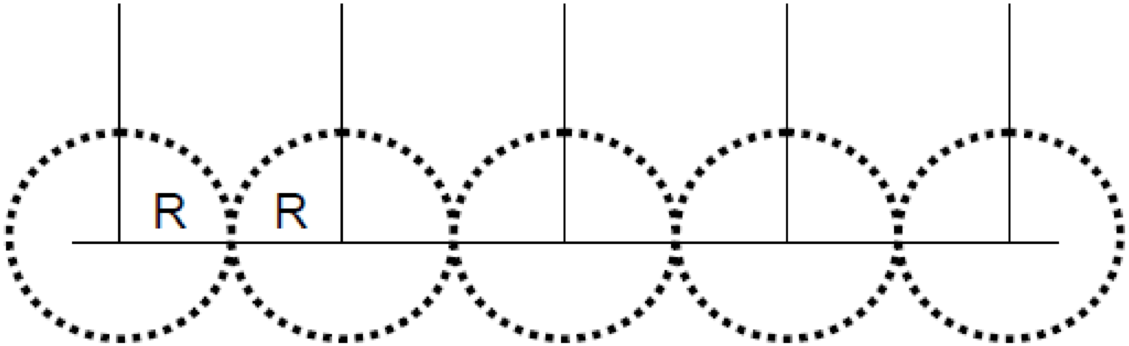
From cellular efficiency point of view -> want small numbers

The effective number of channels/cell = total number of channels/ cell reuse factor (N)

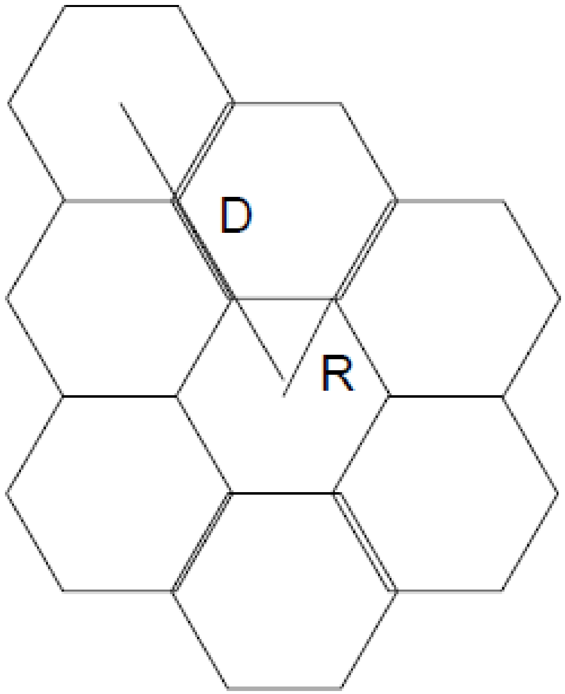
How to determine N for given SIR requirement ?

For base stations situated in a straight line, it can be shown that

$$N = \frac{1}{2}\frac{D}{R}$$



- For hexagonal cells



$$N = \frac{1}{3}\left(\frac{D}{R}\right)^2$$

For CDMA systems: N=1

We can define the cellular efficiency:

$$\eta = \frac{B_S}{B_C N} \text{ channels/cell}$$

B_S = spectrum allocated to the cellular system
B_C = bandwidth/channel
N = channel reuse

Sharing the spectrum: CDMA

- Basic CDMA principle: all users transmit simultaneously using the same frequency band and are characterized by different signature sequences codes $\mathbf{s}_i$, $i=1,2,\ldots, K$ (K = number of users)
  - Signature codes can be selected to be orthogonal: users are completely separated from each other $\mathbf{s}_i^T \mathbf{s}_j = 0;\ i \neq j\ \ \mathbf{s}_i^T \mathbf{s}_i = 1$

    Disadvantages:

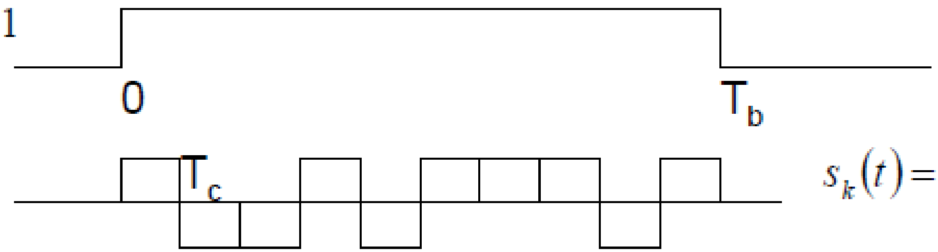
    - number of users that can be supported in the system is limited by the number of orthogonal codes
      - If length of code is N, $\max\{K\} = N$
    - Orthogonality cannot be maintained for asynchronous transmission

  - Codes can also be selected non-orthogonal but with small cross-correlations
    - Random codes – all entries are -1 or 1 with equal probability (coin flips)
    - Pseudo-random codes (IS-95 cellular CDMA) – m-sequences
      - very long sequences cyclically repeated (generated by linear shift registers) – appear as random
      - different statistical properties than random codes

Simple single user CDMA system

$b_k(t) = b_k \times p_T(t)$ - bit waveform

$b_k = +1$



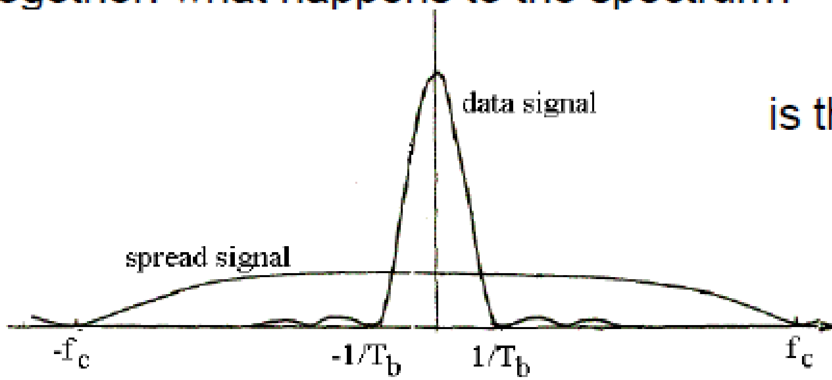
$N = \frac{T_b}{T_c}$ = spreading gain

$$s_k(t) = \frac{1}{\sqrt{N}} \sum_{j=1}^{N} s_{ij} p_{T_c}\left(t-(j-1)T_c\right)$$

- signature sequence waveform

-signature sequence code: $s = [+1,-1,-1,+1,-1,+1,+1,+1,-1,+1]$

- Multiply them together: what happens to the spectrum?



is this good or bad?