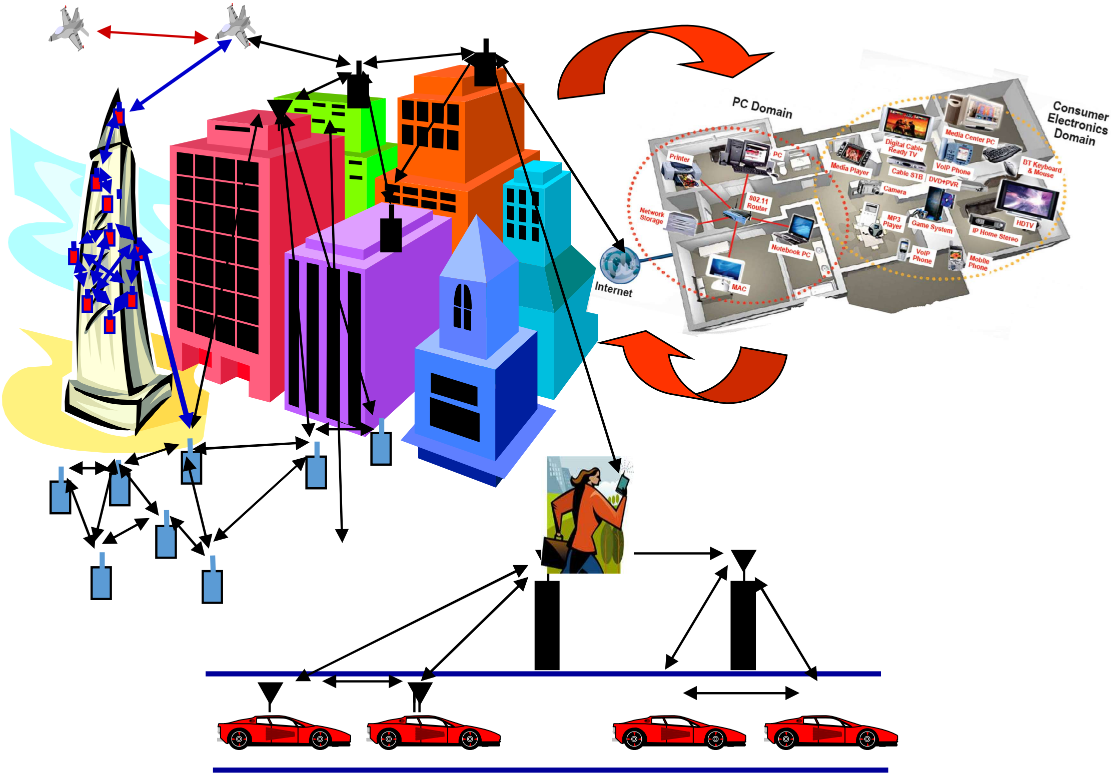
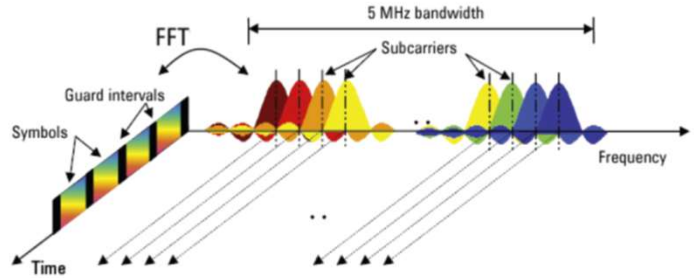
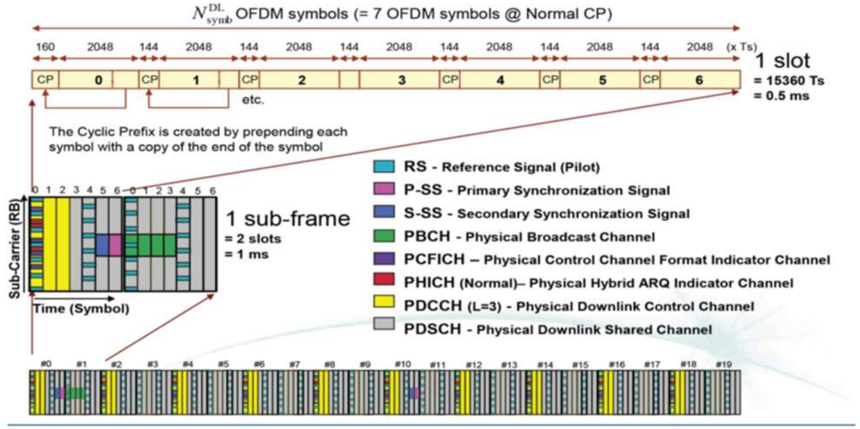
IEE 2620: System Aspects in Communications

Professor Muhammad Mahtab Alam

Lecture 13







Outline

- Brief follow-up from last lecture

- Wireless Channel and Multi Antenna Systems
  - Motivations for the development of MIMO systems
  - Wireless Channel Characteristics
  - Fading in Wireless Channel
- Spread Spectrum Communication Systems
- Spread Spectrum Communication Methods
  - Direct Sequence Spread Spectrum (DSSS)
  - Frequency Hopping Spread Spectrum (FHSS)
- Summary

Wireless Channel and Multi Antenna Systems

Wireless Channel Characteristics (1/4)

- When the signal is transmitted over the wireless channel, it encounters four main effects:
  - Attenuation
  - Delay
  - Multipath
  - Doppler Effect (if there is any relative motion between transmitter and receiver).

Wireless Channel Characteristics (2/4)

- Attenuation and Delay
  - Due to the unavoidable physical disturbances, these effects are present in almost every wireless system. This may be rain drops, trees etc. The electromagnetic waves travel through the atmosphere and they loose energy and take some time to reach the receiver.
  - For example, in case of rain drops, the waves collide with the rain drops, heat them up and loose a part of energy.

Wireless Channel Characteristics (3/4)

- Multipath phenomena
  - Due to various scatters and obstacles, the transmitted signal reaches the receiver in one or more versions.
  - Each version with a different time delay. These different versions form the composite signal at the receiver which may vary in amplitude and phase.

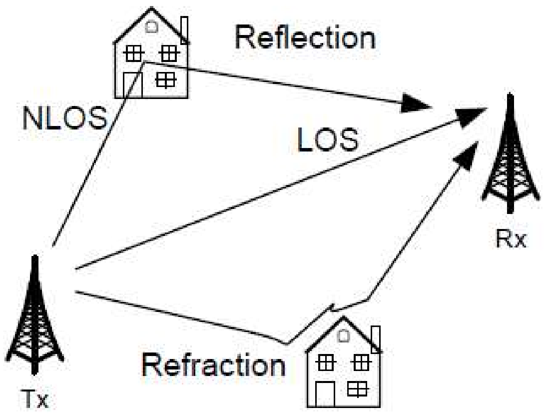


Illustration of multipath propagation. NLOS means non-line of sight and LOS is simply line of sight.

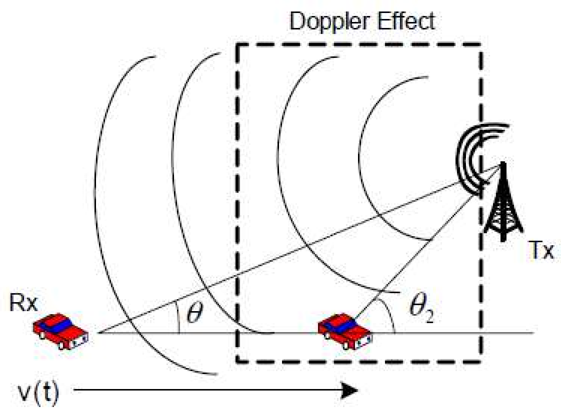
Wireless Channel Characteristics (3/4)

- Doppler Effect
  - This effect occurs when there is a relative motion between the transmitter and the receiver.
  - Due to this effect, there is a phase change in the received signal and hence the shift in frequency. This shift in frequency, also known as the Doppler shift is [Rappaport, 1996]:

$$f_d = (v/\lambda)\dot{c}os\theta$$

  - where fd is the Doppler shift, v is the velocity at which transmitter or receiver is moving, λ is the wavelength and is the angle of arrival of the received signal with respect to the direction of motion.
  - The illustration of the Doppler effect can be

seen in the Figure.



Aspirations - What we want

High data rate wireless communications links with transmission rates of Giga bit/second (will quantify a “bit” shortly)

Provide high speed links that still offer good Quality of Service (QoS) (will be quantified mathematically)

Aspirations of a System Designer

High data rate → Achieve "Channel Capacity (C)"

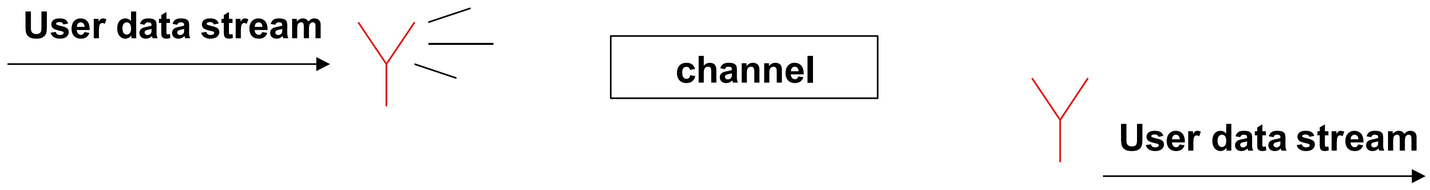
Quality → Minimize Probability of Error (P_e)

Real-life Issues →

- Minimize complexity and cost of implementation of proposed system
- Minimize transmission power required (translates into SNR)
- Minimize Bandwidth (frequency spectrum) Used

Antenna Configurations

Single-Input-Single-Output (SISO) antenna system



- Theoretically, the 1+ Gbps barrier can be achieved using this configuration if you are allowed to use much power and as much BW as you so..
- Extensive research has been done on SISO under power and BW constraints. A combination a smart *modulation*, *coding* and *multiplexing* techniques have yielded good results but far from the 1+ Gbps barrier

MIMO Antenna Configuration

Use multiple transmit and multiple receive antennas for a single user

Now this system promises enormous data rates!

Data Units

Will use the following terms loosely and interchangeably,

- Bits (lowest level): +1 and -1
- Symbols (intermediate): A group of bits
- Packets (highest level): Lots and lots of symbols

Shannon's Capacity (C)

- Given a unit of Bandwidth (Hz), the max error-free transmission rate is

$$C = \log_2(1+SNR) \text{ bits/s/Hz}$$

<u>Define</u>

R: data rate (bits/symbol)

R_S: symbol rate (symbols/second)

W: allotted BW (Hz)

- Spectral Efficiency is defined as the number of bits transmitted per second per Hz

$$\frac{R \times R_S}{W} \quad \textbf{(bits/s/Hz)}$$

As a result of filtering/signal reconstruction requirements, $R_S \leq W$.
Hence Spectral Efficiency = R (if $R_S = W$)

- **If I transmit data at a rate of $R \leq C$, I can achieve an arbitrarily low probability of error (P_e)**

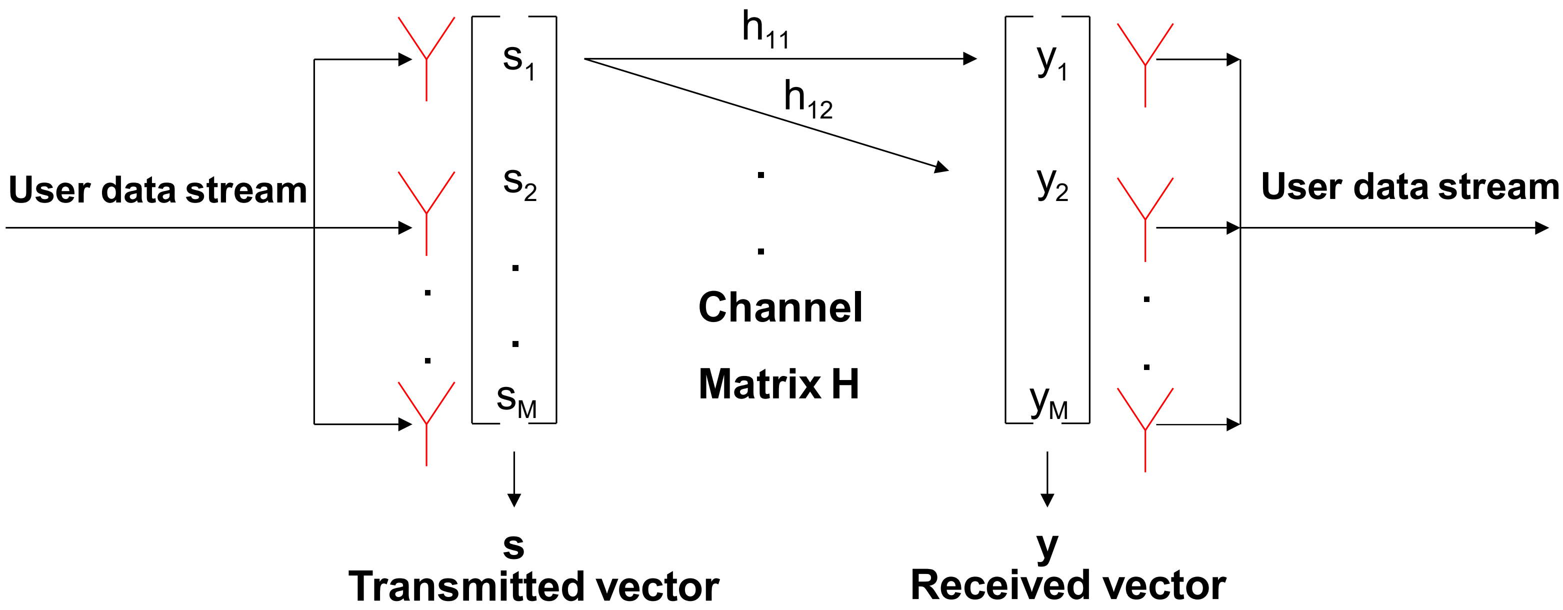
Spectral Efficiency

Spectral efficiencies of some widely used modulation schemes

Scheme	b/s/Hz
BPSK	1
QPSK	2
16-QAM	4
64-QAM	6

The Whole point: Given an acceptable P_e, realistic power and BW limits, MIMO Systems using smart modulation schemes provide much higher spectral efficiencies than traditional SISO

MIMO System Model



$$\mathbf{y} = \mathbf{Hs} + \mathbf{n}$$

Where **H** =
$$\begin{array}{c c} & \xleftarrow{\qquad M_T \qquad} \\ M_R & \begin{bmatrix} h_{11} & h_{21} & \cdots\cdots & h_{M1} \\ h_{12} & h_{22} & \cdots\cdots & h_{M2} \\ . & . & \cdots\cdots & . \\ h_{1M} & h_{2M} & \cdots\cdots & h_{MM} \end{bmatrix} \end{array}$$

h_{ij} is a Complex Gaussian random variable that models fading gain between the i^{th} transmit and j^{th} receive antenna

Spread Spectrum Communication

Spread Spectrum Introduction

- Figure 1 represents a narrow band signal in the frequency domain. These narrowband signals are easily jammed by any other signal in the same band. Likewise, the signal can also be intercepted since the frequency band is fixed and narrow (i.e. easy to detect).

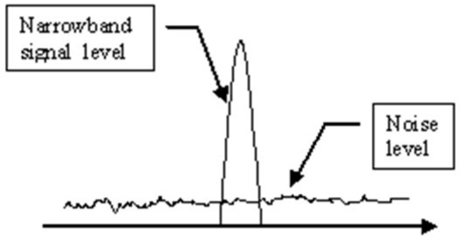
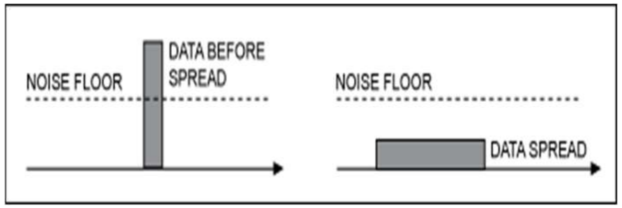


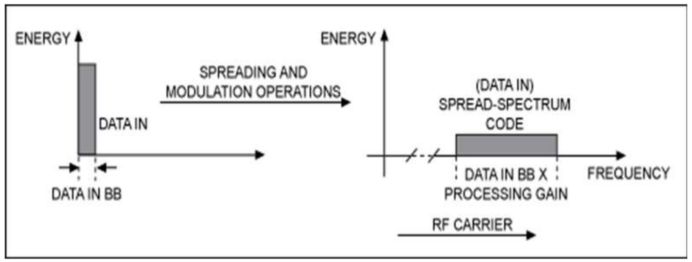
Figure 1: Narrow band signal, relatively easy to jam or intercepted.

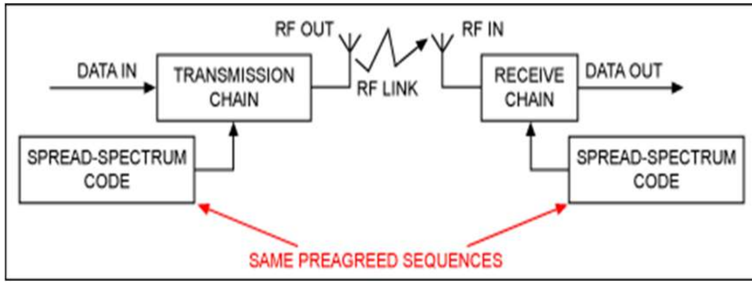
- Spread Spectrum refers to a system originally developed for military applications, to provide secure communications by spreading the signal over a large frequency band.
- Spread spectrum also mitigates the performance degradation due to ISI and narrowband interference.
- The ISI rejection and bandwidth sharing capabilities of spread spectrum are very desirable in cellular systems and wireless LANs. As a result, spread spectrum is the basis for both 2nd and 3rd generation cellular systems.

Spread Spectrum Principle

- Spread spectrum is a modulation method applied to digitally modulated signals that increases the transmit signal bandwidth to a value much larger than is needed to transmit the underlying information bits.
- The following three properties are needed for a signal to be spread spectrum modulated [1]:
  - The signal occupies a bandwidth much larger than is needed for the information signal.
  - The spread spectrum modulation is done using a spreading code, which is independent of the data in the signal.
  - De-spreading at the receiver is done by correlating the received signal with a synchronized copy of the spreading code.

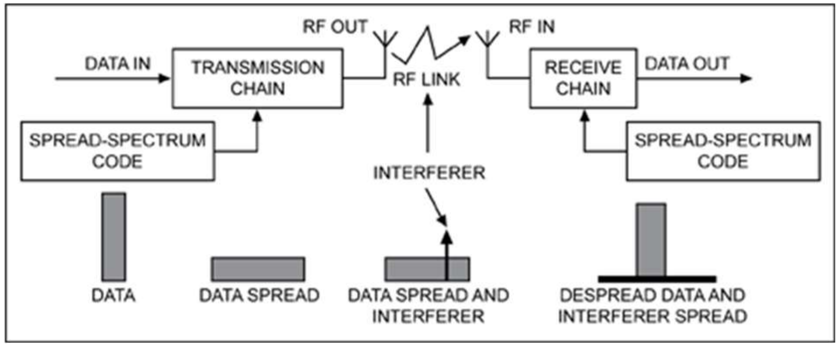






Benefits of Spread Spectrum

- **Resistance to Interference and Anti jamming Effects**
  - There are many benefits to spread-spectrum technology. Resistance to interference is the most important advantage. Intentional or unintentional interference and jamming signals are rejected because they do not contain the spread-spectrum key.
  - Only the desired signal, which has the key, will be seen at the receiver when the de-spreading operation is exercised.



A spread-spectrum communication system. Note that the interferer's energy is spread while the data signal is despread in the receive chain.

Resistance to Fading (Multipath Effects)

- Wireless channels often include multiple-path propagation in which the signal has more than one path from the transmitter to the receiver. Such multipath can be caused by atmospheric reflection or refraction, and by reflection from the ground or from objects such as buildings.
- The reflected path (R) can interfere with the direct path (D) in a phenomenon called fading. Because the de-spreading process synchronizes to signal D, signal R is rejected even though it contains the same key.
- Methods are available to use the reflected-path signals by despreading them and adding the extracted results to the main one.

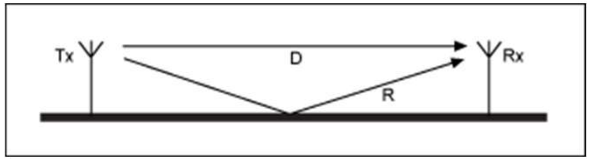


Illustration of how the signal can reach the receiver over multiple paths.

Spread Spectrum Communication Methods

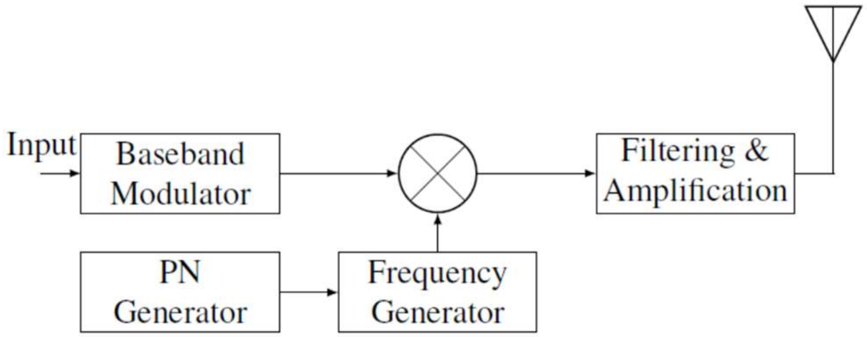
- *Frequency-hopping spread-spectrum (FHSS)*
- *Direct-sequence spread-spectrum (DSSS)*

    - DSSS is employed in 2G CDMA systems
        - IS-95, cdma2000
    - DSSS is employed in all 3G cellular systems
        - UMTS and HSPA
    - DSSS was used in legacy IEEE 802.11 (WiFi)

FHSS Communication Systems

- In FHSS communication systems the data signal is modulated onto a carrier signal, and the frequency of the carrier signal is changed periodically (as shown in figure), which helps the system avoid narrowband interference.
- FHSS is divided into "fast frequency hopping" and "slow frequency hopping" based on the amount of data bits sent per frequency hop.
- For both types of FHSS communication systems the processing gain is defined by the ratio of the total bandwidth (B_{ss}) of all the channels to the minimum required bandwidth (B_d) of a single channel, i.e. by the number of channels Nc with bandwidth B_d in B_{ss}.

$$G_p = B_{ss} / B_d$$



Generic frequency-hopping spread spectrum transmitter.

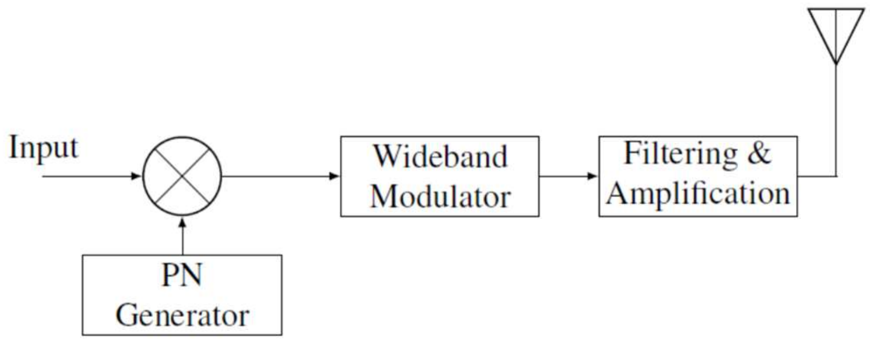
FHSS Communication Systems

- Jamming margin for FHSS systems is not clearly defined, because for FHSS systems interference with demodulation occurs only when the interferer is within the current channel.
- Interference in one channel though has no effect on the other channels as long as channel filters have sufficient selectivity.
- The throughput of an FHSS system goes to zero only when the jamming signal is present on all available channels.
- This differs from DSSS, where a single interferer with enough power can reduce the throughput to zero.

DSSS Communication Systems

- In DSSS communication systems the data signal is multiplied with a PN code (as shown in Figure below), which has a higher rate than the data signal.
- A faster signal results in greater spectrum width and the multiplied signal has the same bandwidth as the PN signal used for coding.
- For DSSS communication systems the processing gain is defined by the ratio of the bandwidth of the PN signal to **the bandwidth of the data signal, i.e. by the number of PN bits to data bits.**

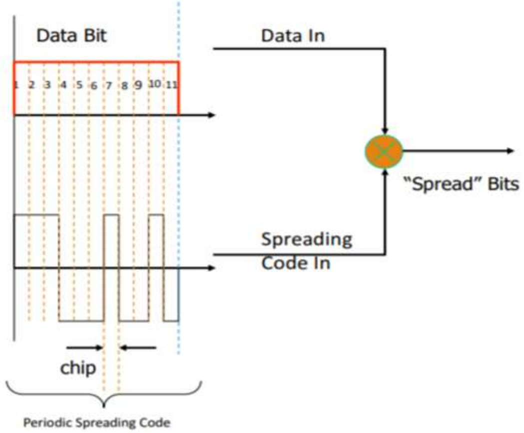
$$G_p = B_{ss} / B_d$$
$$= T_b / T_c = N_c$$



DSSS Modulation

- Instead of transmitting a rectangular pulse for a zero or a one, we transmit a sequence of narrower rectangular pulses
- The narrow pulses are called “chips”
  - You often see references to “chips/sec” instead of bits/sec
- The easiest way of creating a DSSS signal is to multiply one period of the spreading sequence with each data symbol
  - Example: IEEE 802.11
    - Barker sequence: [1 1 1 -1 -1 -1 1 -1 -1 1 -1]
    - To transmit a “0”, you send [1 1 1 -1 -1 -1 1 -1 -1 1 -1]
    - To transmit a “1” you send [-1 -1 -1 1 1 1 -1 1 1 -1 1]
  - Sometimes parts of the spreading sequence are multiplied with the data symbol

- The original data stream is “chipped” up into a pattern of pulses of smaller duration
- Good **autocorrelation** properties
- Good **cross-correlation** properties with other patterns
- Each pattern is called a spread spectrum code or spread spectrum sequence

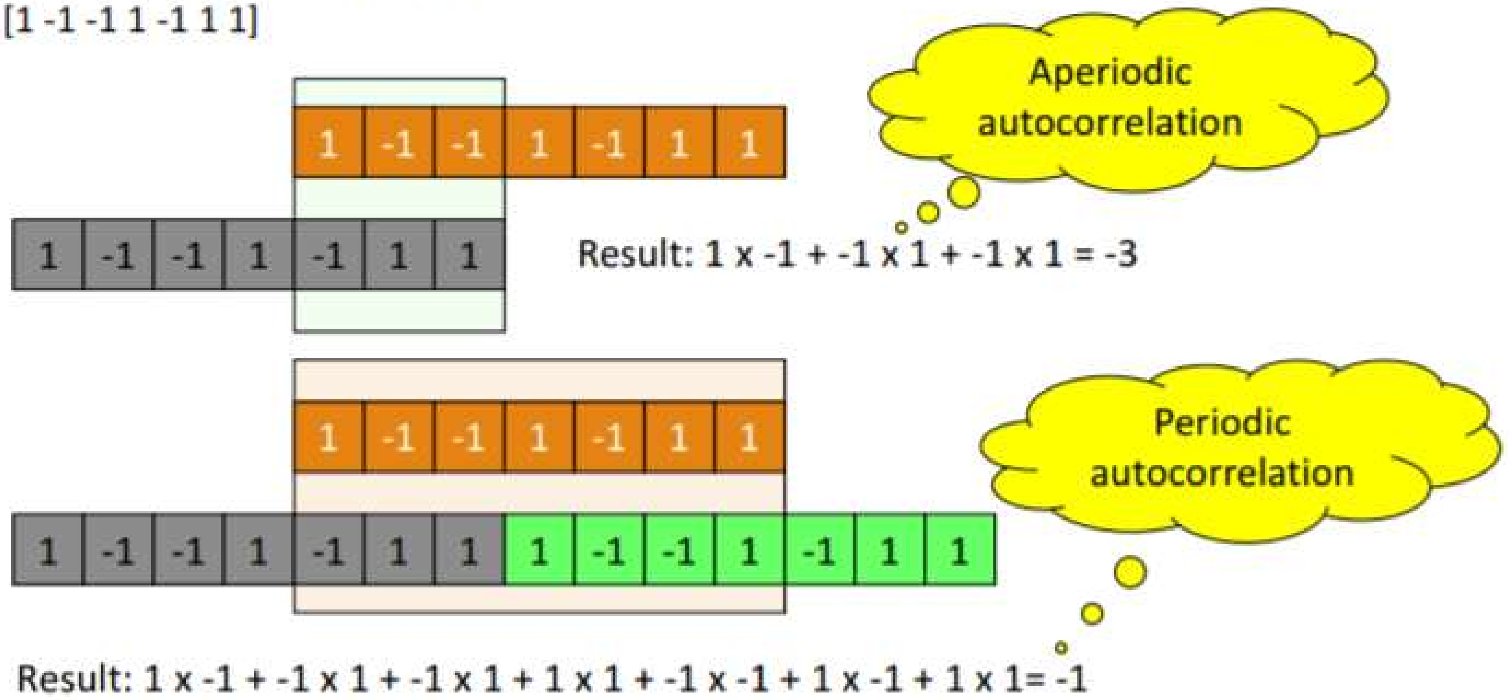


Processing Gain

- Definition of processing gain
  - The duration of a chip is usually represented by T_c
  - The duration of the bit is T
  - The ratio $T/T_c = N$ is called the "processing gain" of the DSSS system
- The processing gain is also the ratio between the bandwidth of the spread signal to the bandwidth of the data signal
- In many cases, this is also the ratio of the height of the autocorrelation peak to the maximum sidelobe
  - This ratio depends on the spreading code properties

Autocorrelation

- Consider the spreading sequence
  - [1 -1 -1 1 -1 1 1]



A few years ago – MSc Thesis

- Jamming of Unmanned Aerial Vehicle Remote Control Systems Using Software Defined Radio

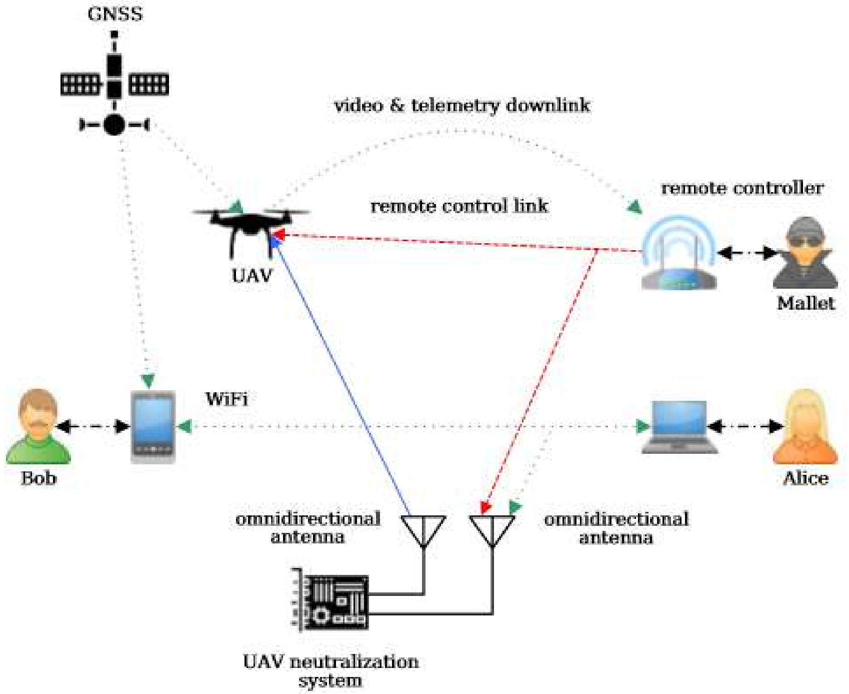


Fig. 1. The considered threat model. The UAV remote control signal is shown with a dashed line. The jamming signal used for neutralizing the UAV is shown with a solid line. The signals which are not considered or should not be interfered with are shown with dotted lines.