UNIVERSITE DE RENNES 1

Les transmissions radio

Bernard Cousin

Les pionniers du sans fil (1800-1900)

- Claude Chappe, 1793 :
  - *Inventeur du premier système de transmission à base de sémaphores (mécanique et visuel) et d'un code*
- Samuel Morse, 1837 :
  - *Inventeur de l'alphabet à deux signaux qui porte son nom et du télégraphe électrique*
- Thomas Edison, 1878 :
  - *Pionnier de la transmission à longue distance filaire et inventeur du phonographe (Enregistrement et restitution de la voix)*
- Guglielmo Marconi, 1895 :
  - *Première transmission par radio*

L'histoire du Wireless Networking

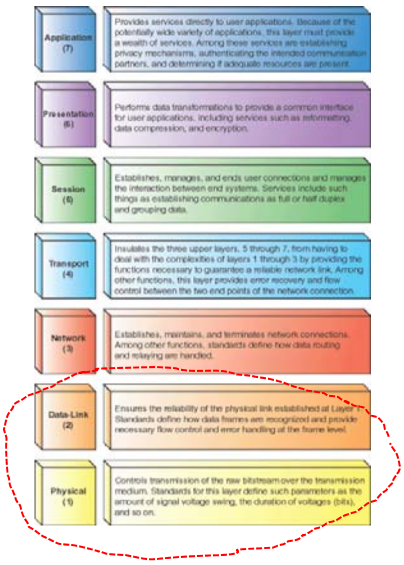
- 1900 :
  - Première télécommunication sans fil en France (Marconi à partir de la tour Eiffel)
- 1948 :
  - Claude Shannon et la théorie de l'information
- 1986 :
  - Naissance de l'Internet
- 2000 :
  - Large diffusion publique de l'internet sans fil

Architecture d'interconnexion

- Le modèle OSI
  - Chaque couche met en œuvre un (ou plusieurs) protocole(s) de communications entre entités distantes
  - Afin de rendre un service à la couche supérieure
  - En s'appuyant sur le service (moins élaboré) fourni par la couche inférieure

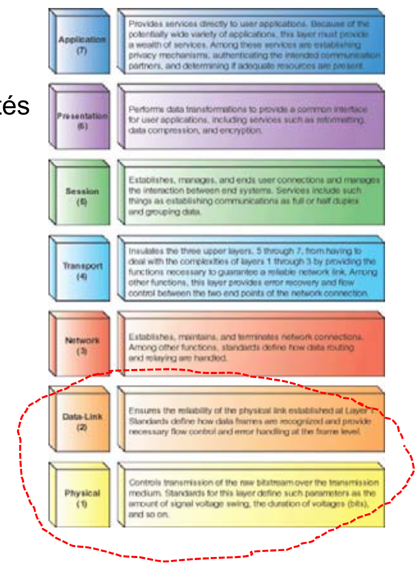
Les couches radios

- Les couches
  - Liaison de données
  - Physique
- Exemples :
  - Ethernet (IEEE 802.3), Wifi (IEEE 802.11), Bluetooth (IEEE 802.15.4), Zigbee, HDLC (ISO 3309), GSM, HyperLan
- Organismes de normalisation:
  - IEEE, ITU-T, 3GPP, ETSI



Les couches radios

- La couches Liaison de données
  - Transmission de trames entre entités <u>adjacentes</u>
  - Identification et distribution
  - Fragmentation
  - Contrôle d'erreur
- La couche Physique :
  - Adaptation à l'environnement
  - Codage
  - Modulation



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- 802.11 Réseaux sans fil : La référence. Matthew Gast (Traduction d'Hervé Soulard). Editions O'Reilly, 2005.

- Certaines figures sont issues de :
  - Toufik AHMED (Université de Bordeaux), Bénédicte LEGRAND (Université Pierre et Marie Curie), Yassine HADJADJ (Université de Rennes 1), Philippe JACQUET (INRIA), ou W. STALLINGS

Plan

- Introduction à la transmission sans fil
- Présentation des réseaux sans fil
  - Le spectre
  - Le multiplexage
- La transmission radio : les problèmes
  - L'atténuation
  - Les bruits
  - La propagation multi-trajet
- Les solutions
- La transmission par étalement de spectre

Caractéristiques des réseaux sans fil

- Avantages
  - Très flexibles (souplesse) dans la zone de réception
  - Pas ou peu de planification nécessaire (c.-à-d. réseaux ad-hoc)
  - Presque pas de difficultés de câblage (par ex. bâtiments historiques, …)
  - Plus robuste en situation de désastre … et déconnexion de câble !
  - Support de la mobilité

Caractéristiques des réseaux sans fil

- Désavantages
  - Faible bande passante (c.-à-d. 1-54 Mbit/s)
    - bande passante partagée …
  - Beaucoup de solutions propriétaires
    - établissement de normes lent (voir IEEE 802.11, et encore plus Hiperlan)
  - Contraintes nationales (agence de régulation des télécoms)
  - Coordination des législations internationales sont difficiles
    - e.g., IMT-2000 (technologies d'accès radio des systèmes cellulaires de la troisième génération de l'ITU-T … incluant WIMAX)

Objectifs des réseaux locaux sans fil

- Communication de données numériques sans fil entre entités adjacentes :
  - Facilité d'utilisation et d'installation
  - Itinérance naturelle
  - Coopération spontanée dans les réunions (réseaux ad-hoc)
  - Technologie de transmission doit être adaptée et robuste
  - Faible consommation de puissance (durée de batterie)
  - Pas de licence d'utilisation (pas toujours le cas …)
  - Sécurité (des données), respect de la vie privée (pas de collectes de données de l'utilisateur), sanitaire (niveau d'émission radio faible)
  - Possibilité de localisation (services liés à l'endroit où on se trouve)
  - Transparence vis-à-vis des applications et des couches supérieures

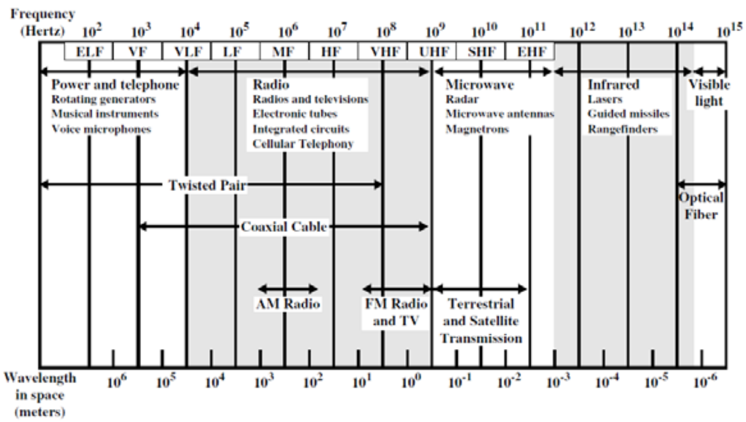
Exemples d'application des réseaux sans fil

- *Mise en place d'un réseau dans un bâtiment historique*
- *Mise en place d'un réseau de courte durée (chantiers, expositions, locaux temporaires, zones dévastées)*
- *Interconnexion automatique et constante de tous les participants d'une réunion*
- *Accès sans fil aux infos enregistrées sur chaque patient pendant les visites médicales au lit des patients*
- *Véhicules s'ouvrant à l'approche de leur propriétaire, ou communiquant directement avec la pompe à essence*
- *Porte d'entrée se déverrouillant automatiquement, système d'alarme se mettant en veille et les lumières s'allumant*

General Frequency Ranges

- Ondes lumineuses
- Infrared frequency range
  - Roughly, 3×10^{11} to 2×10^{14} Hz
  - Useful in local point-to-point multipoint applications within confined areas
- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- Ondes sonores

Spectre électromagnétique



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

Terrestrial Microwave

- Description of common microwave antenna
  - Parabolic dish (3 m in diameter)
  - Fixed rigidly and focuses a narrow beam
  - Achieves line-of-sight transmission to receiving antenna
  - Located at substantial heights above ground level
- Applications
  - Long haul telecommunications service
  - Short point-to-point links between buildings

Satellite Microwave

- Description of communication satellite
  - Microwave relay station
  - Used to link two or more ground-based microwave transmitter/receivers
  - Receives transmissions on one frequency band (uplink), amplifies or repeats the signal, and transmits it on another frequency (downlink)
- Applications
  - Television distribution
  - Long-distance telephone transmission
  - Private business networks

Broadcast Radio

- Description of broadcast radio antennas
  - Omnidirectional
  - Antennas not required to be dish-shaped
  - Antennas need not be rigidly mounted to a precise alignment
- Applications
  - Broadcast radio
    - VHF and part of the UHF band; 30 MHZ to 1GHz
    - Covers FM radio and UHF and VHF television

Multiplexing

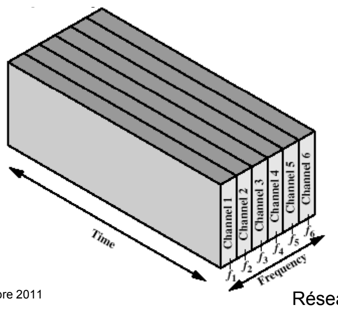
- Capacity of transmission medium usually exceeds capacity required for transmission of a single signal
- Multiplexing - carrying multiple signals on a single medium
  - More efficient use of transmission medium

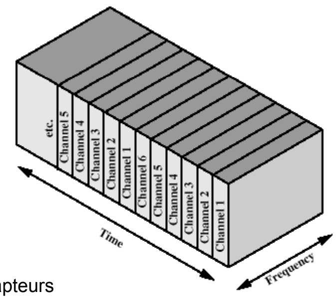
Reasons for Widespread Use of Multiplexing

- Cost per kbps of transmission facility declines with an increase in the data rate
- Cost of transmission and receiving equipment declines with increased data rate
- Most individual data communicating devices require relatively modest data rate support

Multiplexing Techniques

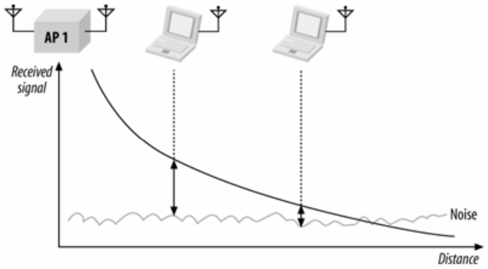
- Frequency-division multiplexing (FDM)
  - Takes advantage of the fact that the useful bandwidth of the medium exceeds the required bandwidth of a given signal
- Time-division multiplexing (TDM)
  - Takes advantage of the fact that the achievable bit rate of the medium exceeds the required data rate of a digital





Atténuation

- Atténuation :
  - $4 (\pi d / \lambda)^2$
    - Distance : d
    - Longueur d'onde : λ



Categories of Noise

- Thermal noise
- Intermodulation noise
- Crosstalk
- Impulse noise

Thermal Noise

- Thermal noise due to agitation of electrons
- Present in all electronic devices and transmission media (Cannot be eliminated)
- Function of temperature
- Particularly significant for satellite communication

- Amount of thermal noise to be found in a bandwidth of 1 Hz in any device or conductor is:

$$N_0 = \mathrm{k}T \; (\mathrm{W/Hz})$$

  - N_0 = noise power density in watts per 1 Hz of bandwidth
  - k = Boltzmann's constant = 1.3803 * 10^{-23} J/K
  - T = temperature, in kelvins (absolute temperature)

Thermal Noise

- Noise is assumed to be independent of frequency
- Thermal noise present in a bandwidth of *B* Hertz (in watts):

$$N = \mathrm{k}TB$$

or, in decibel-watt

$$N = 10 \log \mathrm{k} + 10 \log T + 10 \log B$$
$$= -228.6 \,\mathrm{dBW} + 10 \log T + 10 \log B$$

Noise Terminology

- Intermodulation noise – occurs if signals with different frequencies share the same medium
  - Interference caused by a signal produced at a frequency that is the sum or difference of original frequencies
- Crosstalk – unwanted coupling between signal paths
- Impulse noise – irregular pulses or noise spikes
  - Short duration and of relatively high amplitude
  - Caused by external electromagnetic disturbances, or faults and flaws in the communications system

Expression E_b/N_0

- Ratio of signal energy per bit to noise power density per Hertz

$$\frac{E_b}{N_0} = \frac{S/R}{N_0} = \frac{S}{\mathrm{k}TR}$$

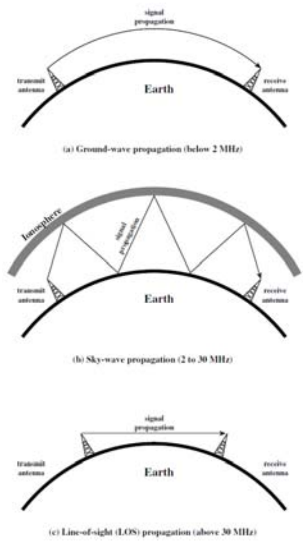
- The bit error rate for digital data is a function of E_b/N_0
  - Given a value for E_b/N_0 to achieve a desired error rate, parameters of this formula can be selected
  - As bit rate R increases, transmitted signal power must increase to maintain required E_b/N_0

Other Impairments

- Atmospheric absorption
  - water vapor and oxygen contribute to attenuation
- Multipath
  - obstacles reflect signals so that multiple copies with varying delays are received
- Refraction
  - bending of radio waves as they propagate through the atmosphere

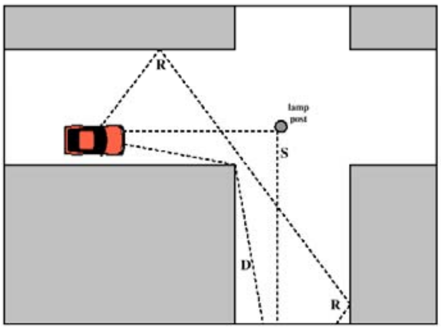
Propagations des ondes

- Par ondes de surface
  - < 2 Mhz
- Ionospéhrique
  - [2-30] Mhz
- En vue directe
  - > 30 Mhz



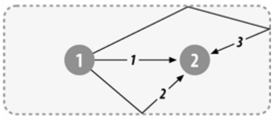
Cause of Multipath Propagation

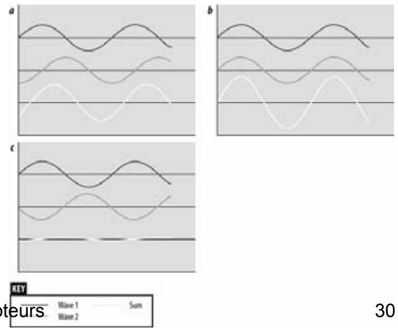
- Reflection
  - occurs when signal encounters a surface that is large relative to the wavelength of the signal
- Diffraction
  - occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave
- Scattering
  - occurs when incoming signal hits an object whose size in the order of the wavelength of the signal or less



Effects of Multipath Propagation

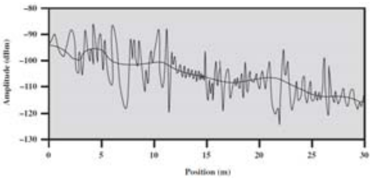
- Multiple copies of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult
- Intersymbol interference (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit





Types of Fading

- Evanouissement de la longueur d'onde (m)
  - Fast fading (plus petit/rapide que la longueur d'onde)
  - Slow fading (plus grand/lent que la longueur d'onde)
    - 1 Ghz =/= 30 cm
- Flat fading
  - Indépendant de la longueur d'onde
- Selective fading
  - Fonction de la longueur d'onde
- Evanouissement de canal
  - Additive White Gaussian Noise (AWGN)
  - Rayleigh fading
    - Plusieurs chemins mais pas de chemin prépondérant
  - Rician fading
    - Plusieurs chemins et un chemin préprondérant (d'un facteur K)



Solutions: Error Compensation Mechanisms

- Forward error correction
- Adaptive equalization
- Diversity techniques

Forward Error Correction

- Transmitter adds error-correcting code to data block
  - Code is a function of the data bits
- Receiver calculates error-correcting code from incoming data bits
  - If calculated code matches incoming code, no error occurred
  - If error-correcting codes don't match, receiver attempts to determine bits in error and correct

Adaptive Equalization

- Can be applied to transmissions that carry analog or digital information
  - Analog voice or video
  - Digital data, digitized voice or video
- Used to combat intersymbol interference
- Involves gathering dispersed symbol energy back into its original time interval
- Techniques
  - Lumped analog circuits
  - Sophisticated digital signal processing algorithms

Diversity Techniques

- Diversity is based on the fact that individual channels experience independent fading events
- Space diversity
  - Techniques involving physical transmission path
  - Antennes multiples (et directives)
- Frequency diversity
  - Techniques where the signal is spread out over a larger frequency bandwidth or carried on multiple frequency carriers
- Time diversity
  - Techniques aimed at spreading the data out over time

Spread Spectrum

- Input is fed into a channel encoder
  - Produces analog signal with narrow bandwidth
- Signal is further modulated using sequence of digits
  - Spreading code or spreading sequence
  - Generated by pseudonoise, or pseudo-random number generator
  - Effect of modulation is to increase bandwidth of signal to be transmitted
- On receiving end, same digit sequence is used to demodulate the spread spectrum signal
- Signal is fed into a channel decoder to recover data

Spread Spectrum

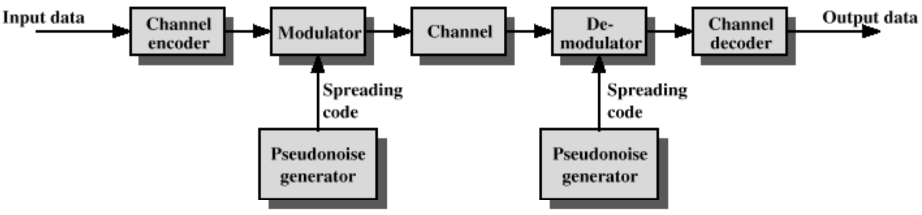


Figure 7.1 General Model of Spread Spectrum Digital Communication System

Spread Spectrum

- What can be gained from apparent waste of spectrum?
  - Immunity from various kinds of noise and multipath distortion
  - Can be used for hiding and encrypting signals
  - Several users can independently use the same higher bandwidth with very little interference

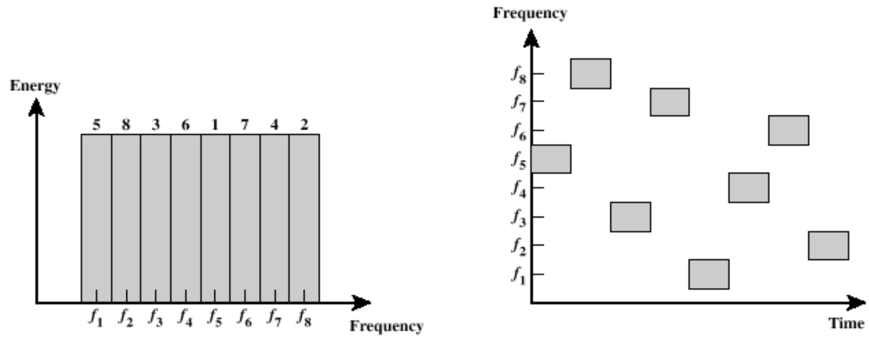
Frequency Hoping Spread Spectrum (FHSS)

- Signal is broadcast over seemingly random series of radio frequencies
  - A number of channels allocated for the FH signal
  - Width of each channel corresponds to bandwidth of input signal
- Signal hops from frequency to frequency at fixed intervals
  - Transmitter operates in one channel at a time
  - Bits are transmitted using some encoding scheme
  - At each successive interval, a new carrier frequency is selected

Frequency Hoping Spread Spectrum

- Channel sequence dictated by spreading code
- Receiver, hopping between frequencies in synchronization with transmitter, picks up message
- Advantages
  - Eavesdroppers hear only unintelligible blips
  - Attempts to jam signal on one frequency succeed only at knocking out a few bits

Frequency Hoping Spread Spectrum

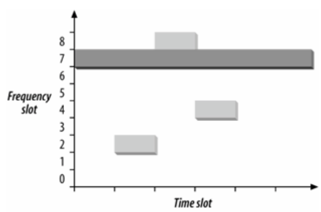


(a) Channel assignment (b) Channel use

Figure 7.2 Frequency Hopping Example

Frequency Hoping Spread Spectrum

- Évitement d'une interférence avec une plage de fréquences bruitée



- Evitement d'une autre transmission "orthogonale"

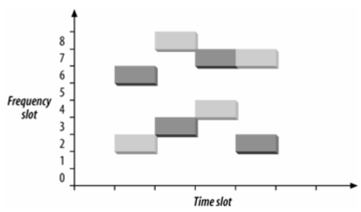
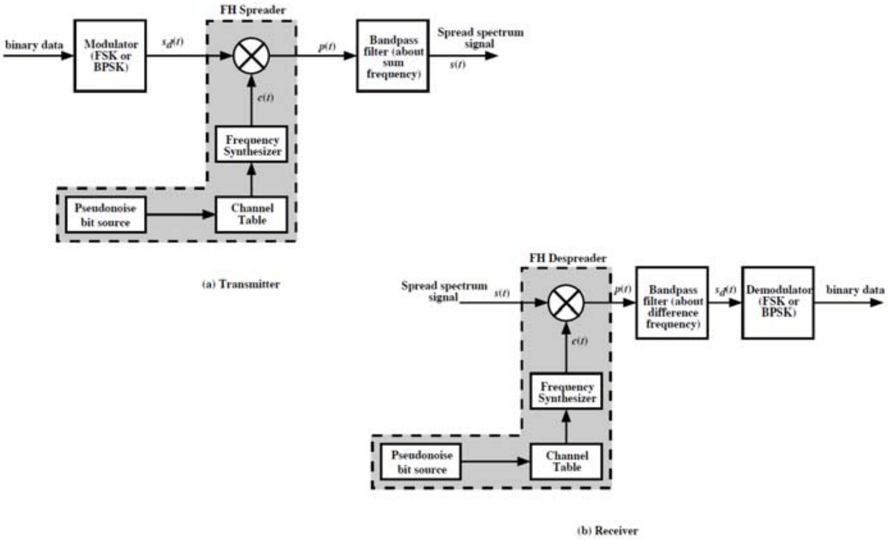


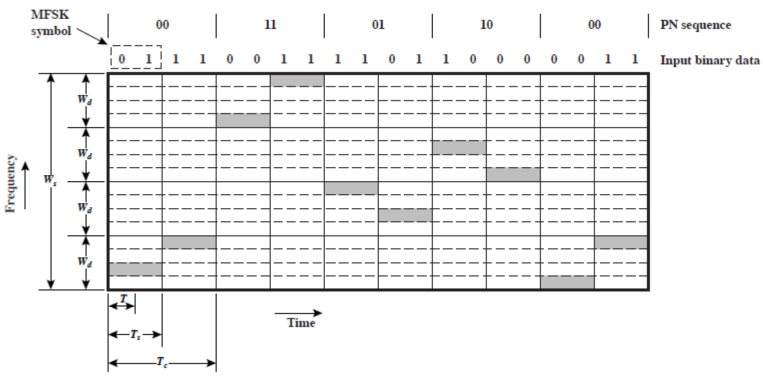
Schéma FHSS



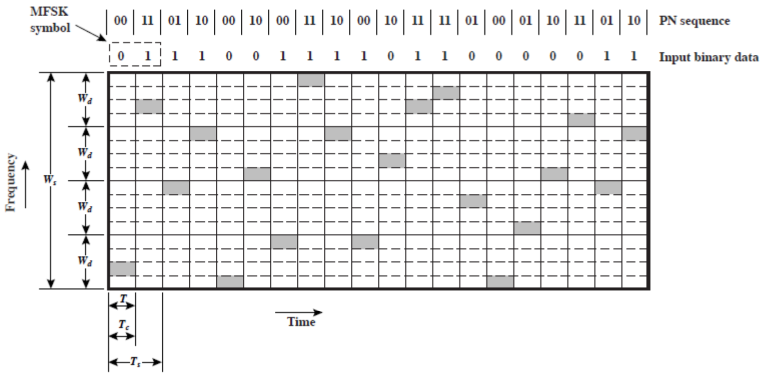
FHSS using MFSK

- MFSK signal is translated to a new frequency every T_c seconds by modulating the MFSK signal with the FHSS carrier signal
- For data rate of *R:*
  - duration of a bit: $T = 1/R$ seconds
  - duration of signal element: $T_s = LT$ seconds
- $T_c \geq T_s$ - slow-frequency-hop spread spectrum
- $T_c < T_s$ - fast-frequency-hop spread spectrum

FHSS using MFSK



FHSS using MFSK



FHSS Performance Considerations

- Large number of frequencies used
- Results in a system that is quite resistant to jamming
  - Jammer must jam all frequencies
  - With fixed power, this reduces the jamming power in any one frequency band
- Synchronization of sender and receiver is required

Direct Sequence Spread Spectrum (DSSS)

- Each bit in original signal is represented by multiple bits in the transmitted signal
- Spreading code spreads signal across a wider frequency band
  - Spread is in direct proportion to number of bits used
- One technique combines digital information stream with the spreading code bit stream using exclusive-OR
- See next Figure

Direct Sequence Spread Spectrum (DSSS)

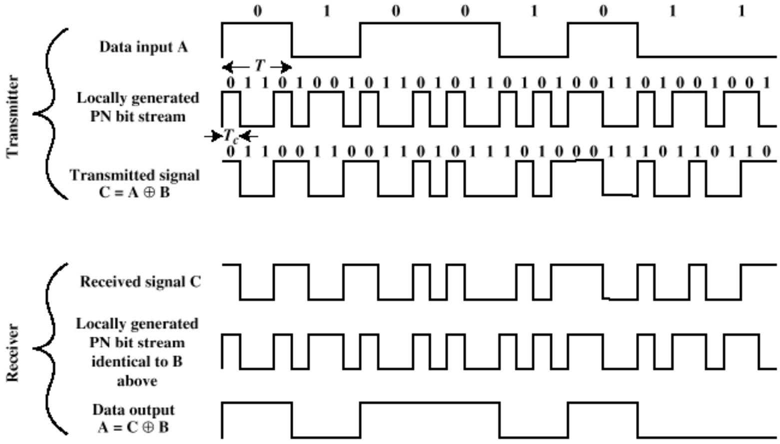


Figure 7.6 Example of Direct Sequence Spread Spectrum

DSSS using BPSK

- Multiply BPSK signal,

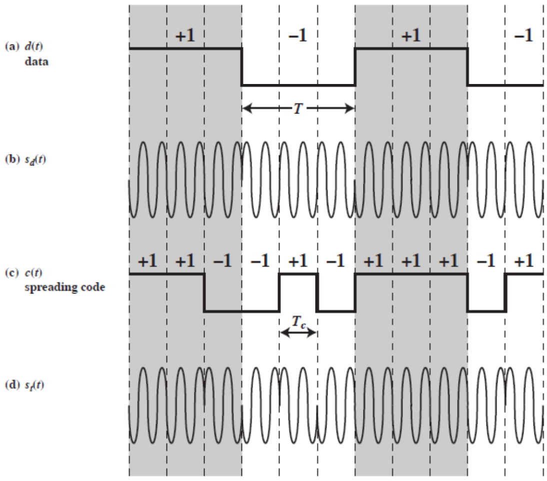
  $$s_d(t) = A\, d(t) \cos(2\pi f_c t)$$

  by $c(t)$ [takes values +1, -1] to get

  $$s(t) = A\, d(t) c(t) \cos(2\pi f_c t)$$

  - A = amplitude of signal
  - f_c = carrier frequency
  - d(t) = discrete function [+1, -1]
- At receiver, incoming signal multiplied by $c(t)$
  - Since, $c(t) * c(t) = 1$, incoming signal is recovered
- See next Figure

DSSS using BPSK



DSSS using BPSK

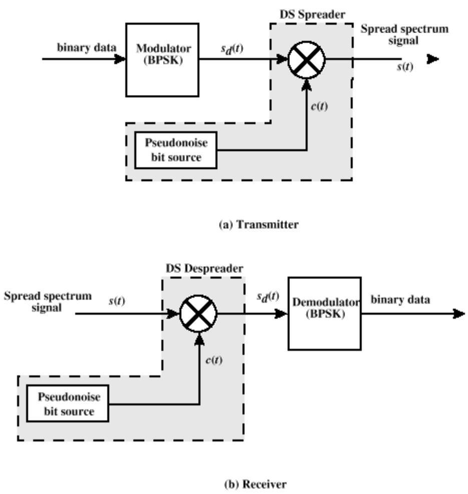
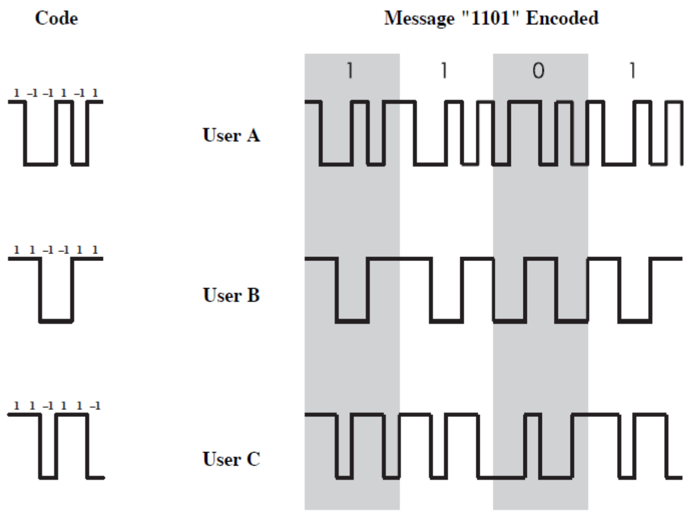


Figure 7.7 Direct Sequence Spread Spectrum System

Code-Division Multiple Access (CDMA)

- Basic principles of CDMA
  - *D* = rate of data signal
  - Break each bit into *k* *chips*
    - Chips are a channel-specific fixed pattern
  - Chip data rate of new channel = *k* * *D*
  - *See next Figure*

Code-Division Multiple Access (CDMA)



CDMA Example

- If k=6 and channel code is a sequence of '1's and '-1's
  - For a '1' bit, A sends code as chip pattern
    - <c1, c2, c3, c4, c5, c6>
  - For a '0' bit, A sends complement of code
    - <-c1, -c2, -c3, -c4, -c5, -c6>
- Receiver shares the sender's channel code and performs electronic decoding function

$$S_u(d) = d1 \times c1 + d2 \times c2 + d3 \times c3 + d4 \times c4 + d5 \times c5 + d6 \times c6$$

- <d1, d2, d3, d4, d5, d6> = received chip pattern
- <c1, c2, c3, c4, c5, c6> = user u's channel code

CDMA Example

- User A's channel code = <1, –1, –1, 1, –1, 1>
  - To send a 1 bit = < 1, –1, –1, 1, –1, 1>
  - To send a 0 bit = <–1, 1, 1, –1, 1, –1>
- User B's channel code = <1, 1, –1, – 1, 1, 1>
- User C's channel code = <1, 1, –1, 1, 1, 1>

- Receiver X receiving A's chip code for '1'
  - (X's channel code) x (received chip pattern)
    - $S_A(<1,-1,-1,\ 1,-1,\ 1>) = 6$ => "1"
    - $S_B(<1,-1,-1,\ 1,-1,\ 1>) = 0$ => "signal ignored"
      - (A and B channel codes are orthogonal)
    - $S_C(<1,-1,-1,\ 1,-1,\ 1>) = 2$ => "signal ignored"

Categories of Spreading Sequences

- Spreading Sequence Categories
  - PN sequences
  - Orthogonal codes
- For FHSS systems
  - PN sequences most common
- For DSSS systems not employing CDMA
  - PN sequences most common
- For DSSS CDMA systems
  - Orthogonal codes (or PN sequences)

PN Sequences

- Pseudo-random generator produces periodic sequence that appears to be random
- PN Sequences
  - Generated by an algorithm using initial seed
  - Sequence isn't statistically random but will pass many test of randomness
  - Unless algorithm and seed are known, the sequence is impractical to predict
  - Sequences referred to as pseudorandom numbers or pseudonoise sequences

Important PN Properties

- Randomness
  - Uniform distribution
    - Balance property: P("1") = ½
    - Run property : P("111") = 1/8
  - Independence
  - Correlation property
- Unpredictability

Linear Feedback Shift Register Implementation

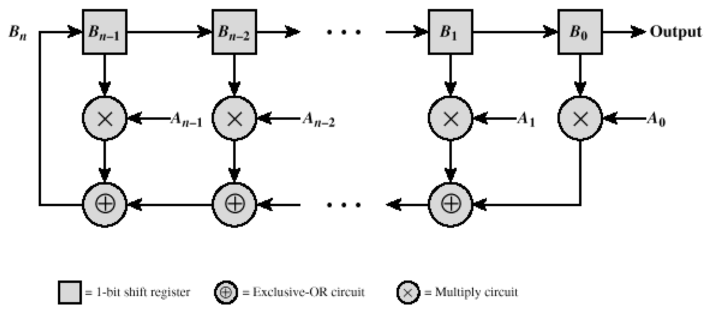


Figure 7.12 Binary Linear Feedback Shift Register Sequence Generator

Properties of M-Sequences

- Property 1:
  - Has 2^{n-1} ones and 2^{n-1}-1 zeros
- Property 2:
  - For a window of length n slid along output for N (=2^{n-1}) shifts, each n-tuple appears once, except for the all zeros sequence
- Property 3:
  - Sequence contains one run of ones, length n
  - One run of zeros, length n-1
  - One run of ones and one run of zeros, length n-2
  - Two runs of ones and two runs of zeros, length n-3
  - …
  - 2^{n-3} runs of ones and 2^{n-3} runs of zeros, length 1

Properties of M-Sequences

- Property 4:
  - The periodic autocorrelation of a ±1 m-sequence is

$$R(\tau) = \begin{cases} 1 & \tau = 0, \mathrm{N}, 2\mathrm{N}, \ldots \\ -\dfrac{1}{N} & \text{otherwise} \end{cases}$$

Definitions

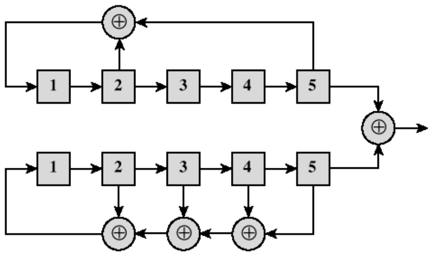
- Correlation
  - The concept of determining how much similarity one set of data has with another
  - Range between –1 and 1
    - 1 The second sequence matches the first sequence
    - 0 There is no relation at all between the two sequences
    - -1 The two sequences are mirror images
- Auto correlation
  - The comparison between a shifted copy of a sequence with itself
- Cross correlation
  - The comparison between two sequences from different sources, one of them being shifted

Advantages of Cross Correlation

- The cross correlation between an m-sequence and noise is low
  - This property is useful to the receiver in filtering out noise
- The cross correlation between two different m-sequences is low
  - This property is useful for CDMA applications
  - Enables a receiver to discriminate among spread spectrum signals generated by different m-sequences

Gold Sequences

- Gold sequences constructed by the XOR of two m-sequences with the same clocking
- Codes have well-defined cross correlation properties
- Only simple circuitry needed to generate large number of unique codes
- Plus performant que les M-sequences pour DSSS avec CDMA



Orthogonal Codes

- Orthogonal codes
  - All pairwise cross correlations are zero
  - Fixed- and variable-length codes used in CDMA systems
  - For CDMA application, each mobile user uses one sequence in the set as a spreading code
    - Provides zero cross correlation among all users
- Types of Orthogonal codes
  - Walsh codes (fixed length)
  - Variable-Length Orthogonal codes
    - Permet de générer des débits différents

Walsh Codes

- Set of Walsh codes of length *n* consists of the n rows of an *n* ´ *n* Walsh matrix:
  - $W_1 = (0)$
    - *n* = dimension of the matrix

$$W_{2n} = \begin{pmatrix} W_n & W_{2n} \\ W_n & \overline{W_n} \end{pmatrix}$$

  - Every row is orthogonal to every other row and to the logical not of every other row
  - Requires tight synchronization
    - Cross correlation between different shifts of Walsh sequences is not zero

Typical Multiple Spreading Approach

- Spread data rate by an orthogonal code (channelization code)
  - Provides mutual orthogonality among all users in the same cell
- Further spread result by a PN sequence (scrambling code)
  - Provides mutual randomness (low cross correlation) between users in different cells

Conclusion

- Les réseaux sans fil offrent une communication flexible
- L'environnement n'est pas sûre
- Les techniques d'étalement de spectre permettent une adaptation efficace