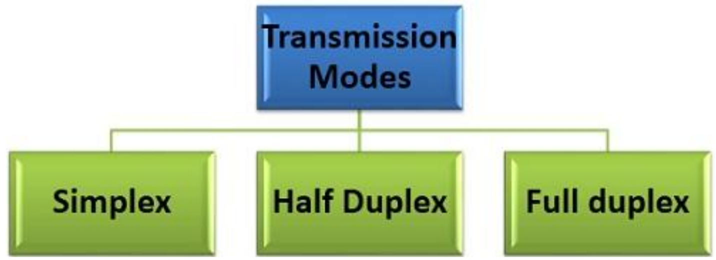
Multiple Access Techniques

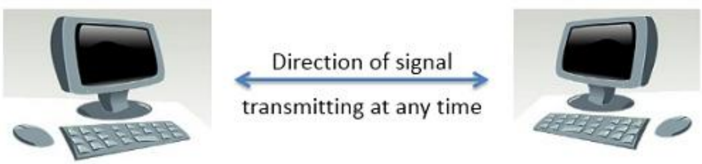
EE442 – Spring 2017
Lecture 13

Multiple Access is the use of multiplexing techniques to provide communication service to multiple users over a single channel. It allows for many users at one time by sharing a finite amount of spectrum.

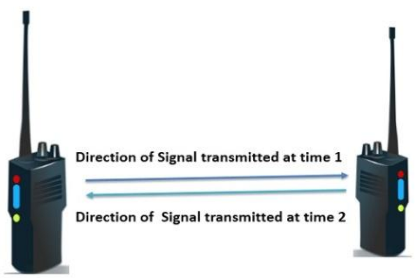
Simplex, Half Duplex and Full Duplex



Simplex
(one direction only)



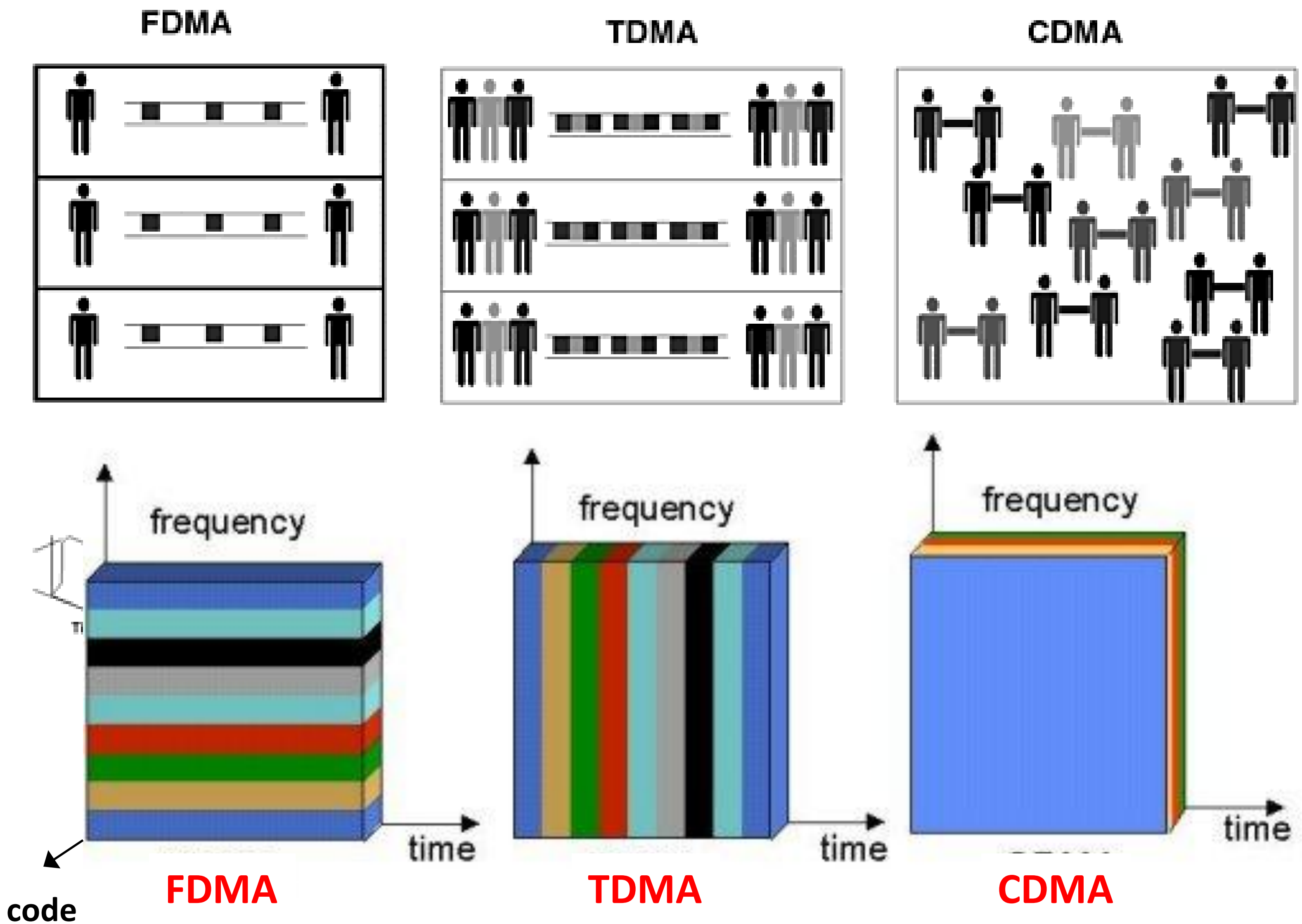
Full Duplex
(both directions anytime)



Half Duplex
(one direction at a time)

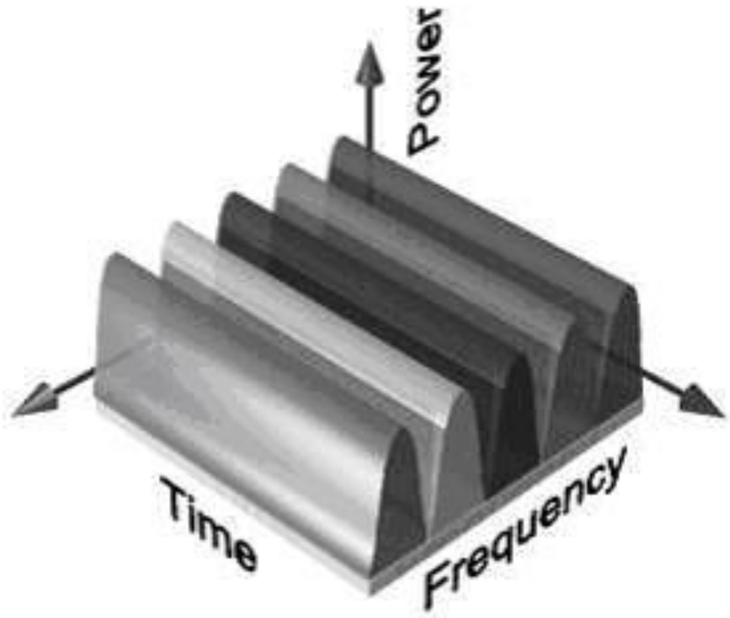
http://techdifferences.com/difference-between-simplex-half-duplex-and-full-duplex.html

Multiple Access Options: Frequency, Time or Code



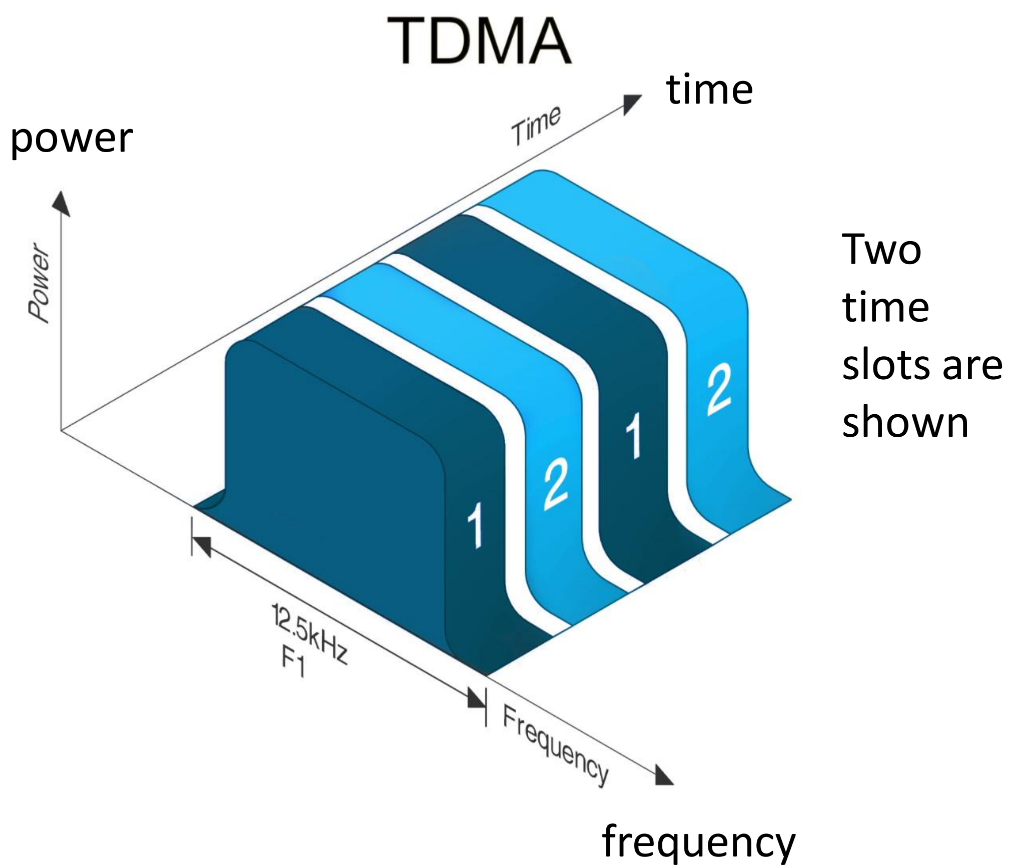
Frequency Division Multiple Access

The available bandwidth is subdivided into a number of narrower band channels. Each user is allocated a unique frequency band in which to transmit and receive on.



Wavelength Division Multiple Access (WDMA) is a related to FDMA. Wavelength is used in optical fiber communication systems to partition channels. All wavelengths propagate within a single optical fiber.

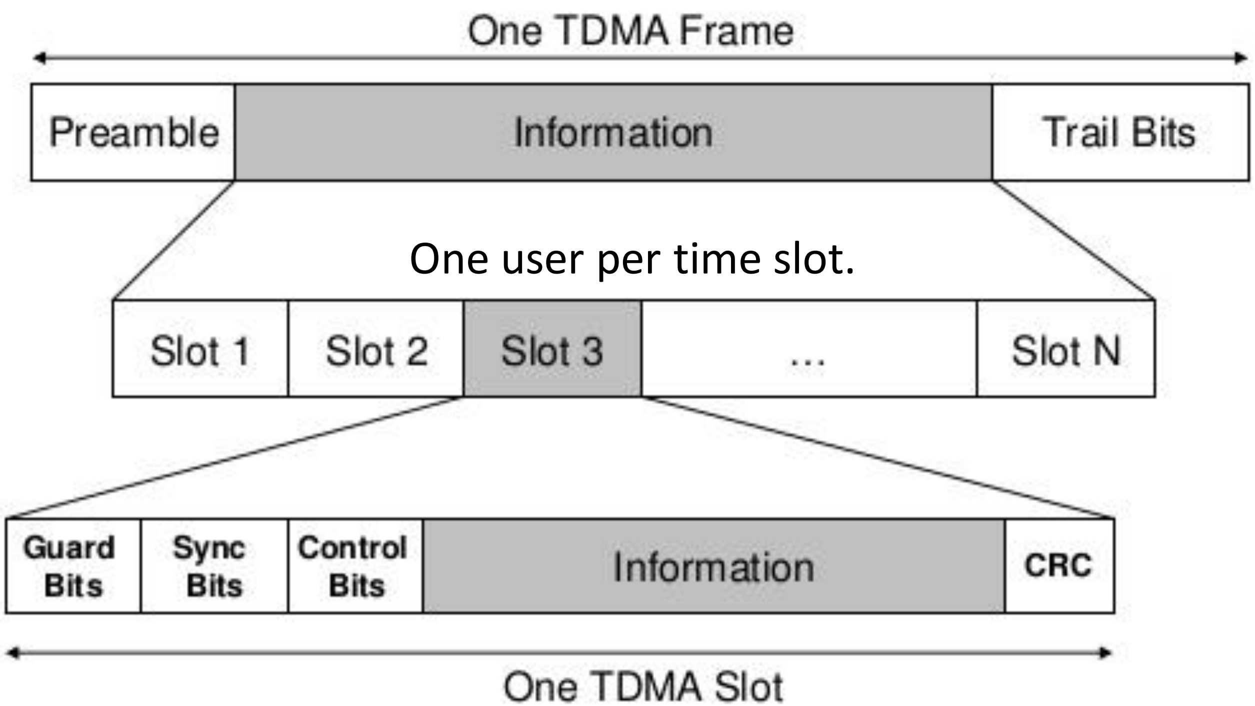
Time Division Multiple Access



How is synchronization achieved in TDMA?

Time Domain Multiple Access Frame

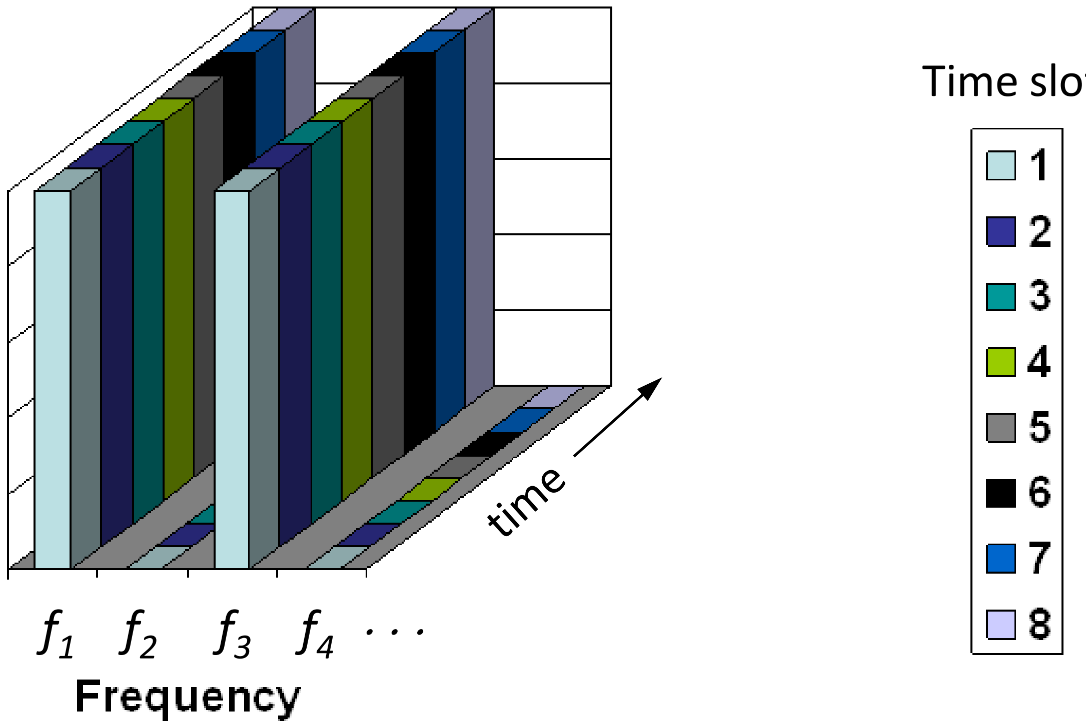
Frames are used to allow the communication receiver to be able to determine where each users data is locate within the bit stream it receives.



This frame repeats in time

https://www.slideshare.net/kaushalkabra5/chapter-7-multiple-access-techniques

GSM Cellular Uses Both FDMA and TDMA



GSM uses a combination of both TDMA and FDMA techniques. The FDMA element divides the assigned frequency of **25 MHz bandwidth** into **124 carrier frequencies**, all spaced 200 kHz apart. The carriers are also divided in time using TDMA. Different users of each RF channel are allocated different time slots (there are 8 time slots per channel).

GSM Cellular Example: Number of Users Supported by GSM

The uplink band in GSM has a total of **25 MHz of bandwidth** and each radio channel has an assigned bandwidth of **200 kHz**. The number of radio channels (*FDMA*) is

$$N_{channels} = \frac{25 \times 10^6 \text{ Hz}}{2 \times 10^5 \text{ Hz/channel}} = 125 \text{ channels}$$

Actually, in practice GSM uses **124 channels** (not 125 channels).

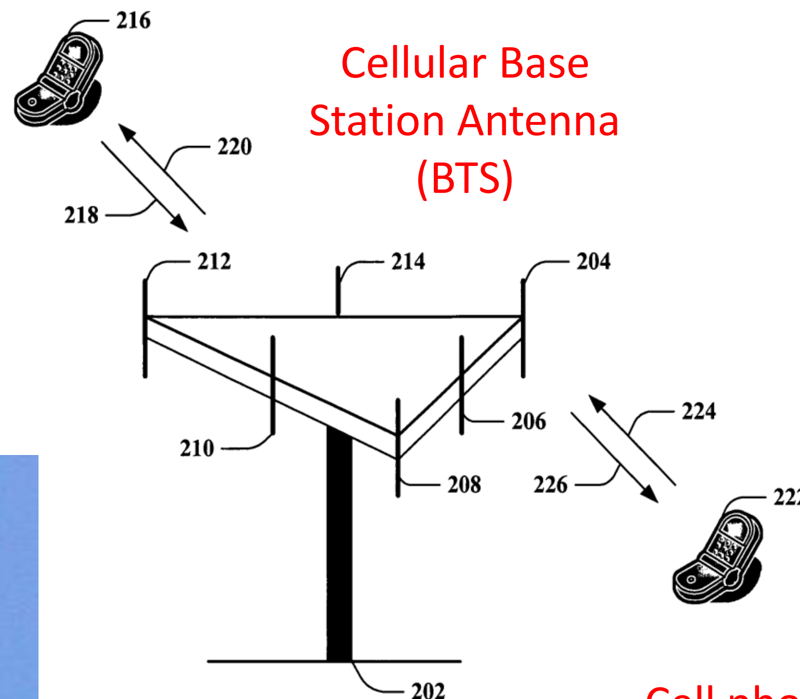
Each channel is divided into 8 time slots, so 8 users are allowed per radio channel (*TDMA*). The maximum number of users is then

$$N_{users} = 124 \text{ channels} \times 8 \text{ users/channel} = 992 \text{ users}$$

GSM also has a corresponding downlink band for sending signals to the mobile phone. For GSM the uplink and downlink frequency bands are **890 to 915 MHz** and **935 to 960 MHz**, respectively. (Europe)

Spatial Division Multiple Access

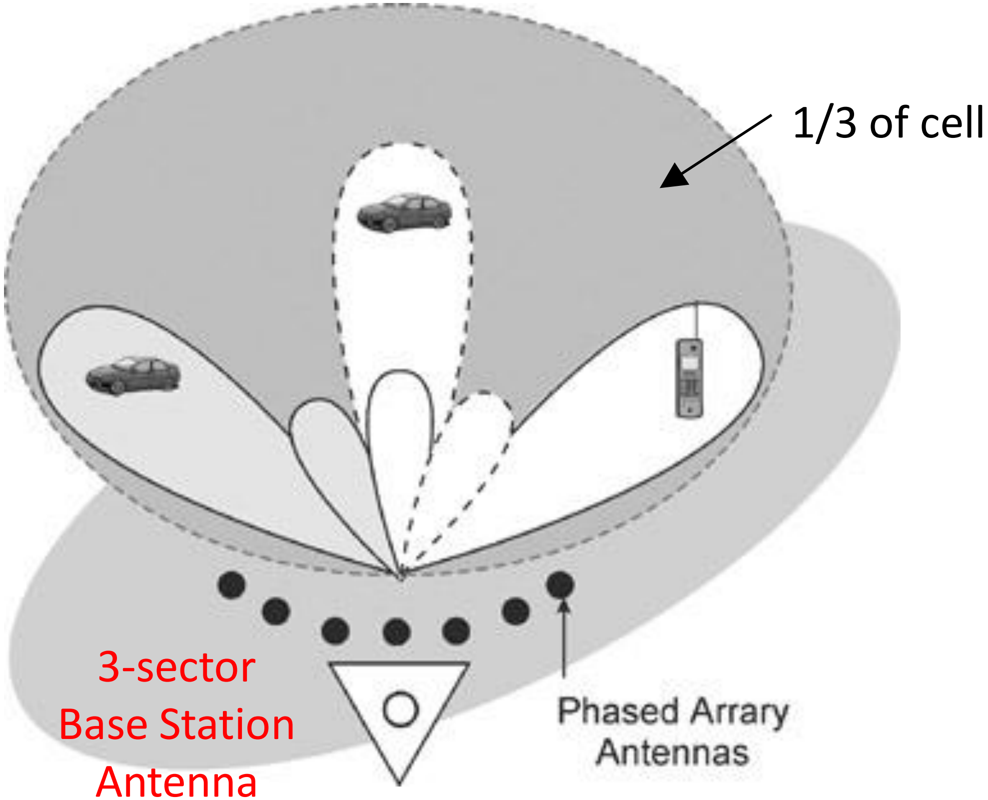
EXAMPLE: Cellular telephony uses sectored base station antenna.



http://www.google.ms/patents/US8363603

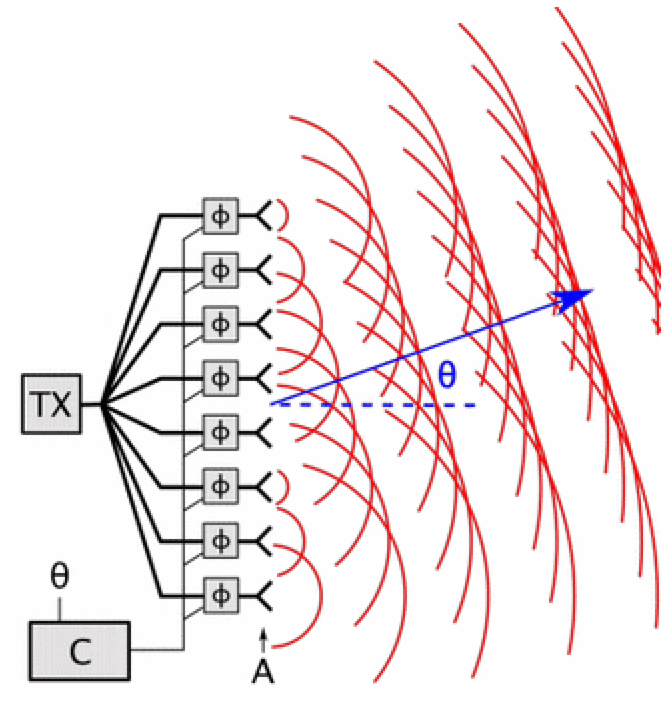
Beam Division Multiple Access (BDMA)

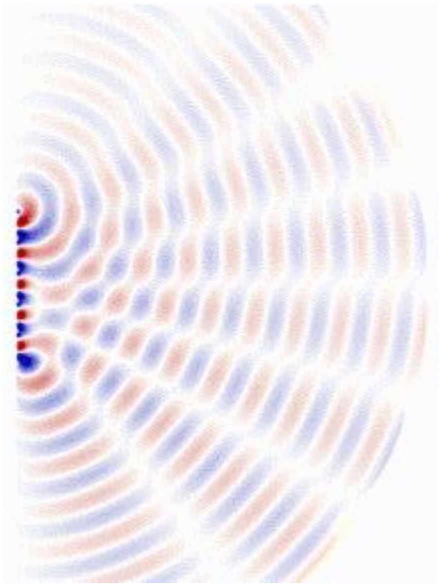
Also known as "**Spatial Division Multiple Access**" (SDMA)



BDMA uses multiple radiators to form multiple beams simultaneously in a mobile telephone cell, thus, providing for multiple access.

Beam Steering in a Phased Array Antenna





https://en.wikipedia.org/wiki/Phased_array

Beam Division Multiple Access (BDMA) in Satellite Systems

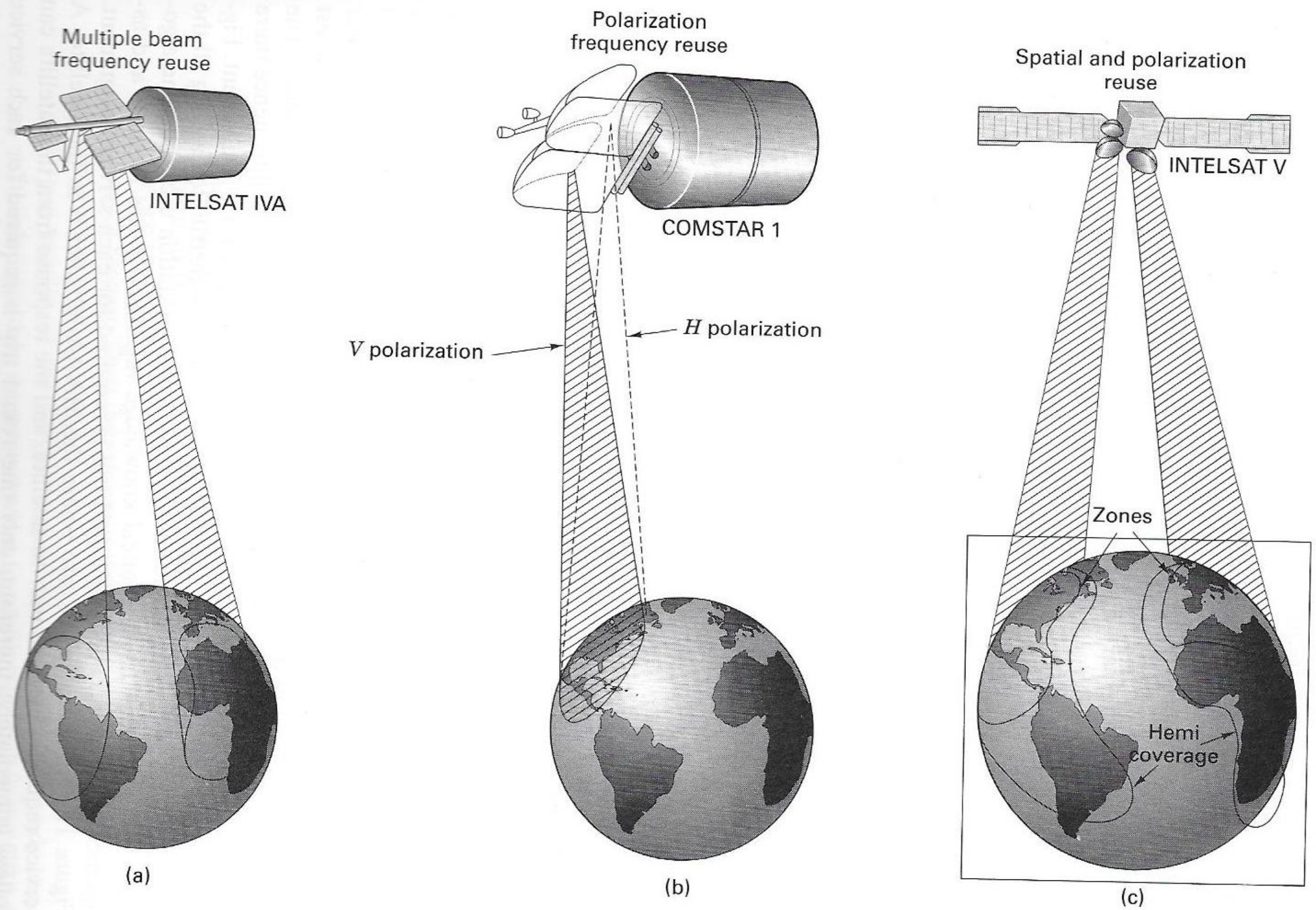


Figure 11.16 SDMA and PDMA. (a) INTELSAT IVA. (b) COMSTAR 1. (c) INTELSAT V (Atlantic coverage).

From Bernard Sklar, Digital Communications, 2nd edition, page 675.

Code Division Multiple Access (CDMA) – I

The CDMA standard was originally designed by Qualcomm in the U.S. and is primarily used in the U.S. and portions of Asia by other carriers.

Salient Features of CDMA:

CDMA is based on the spread spectrum technique

1. In CDMA, every channel uses the full available spectrum.
2. Individual conversations are encoded with a pseudo-random digital sequence and then transmitted.
3. CDMA consistently provides better capacity for voice and data communications, allowing more subscribers to connect at any given time.

CDMA is the common platform on which 3G technologies are built. It is used by Verizon, and Sprint .

A duplex method whereby the Uplink and the Downlink transmissions use two separate frequency bands −

Uplink − 1920 MHz to 1980 MHz
Downlink − 2110 MHz to 2170 MHz
Bandwidth − Each carrier located at center in 5 MHz band

Code Division Multiple Access (CDMA) – II

CDMA allows up to 61 concurrent users in a 1.2288 MHz channel by processing each voice packet with its PN code. There are 64 Walsh codes available to differentiate between calls. Operational limits and quality issues will reduce the maximum number of calls somewhat lower than this value.

In fact, many different "signals" baseband with different spreading codes can be modulated on the same carrier to allow many different users to be supported. Using different orthogonal codes, interference between the signals is minimal. Conversely, when signals are received from several mobile stations, the base station is capable of isolating each because they have different orthogonal spreading codes.

To continue with CDMA we next discuss **spread spectrum techniques**.

Spread Spectrum Techniques

Lathi & Ding

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Typical applications for the resulting short-range data transceivers include satellite-positioning systems (GPS), 3G mobile telecommunications, W-LAN (IEEE® 802.11a, IEEE 802.11b, IEEE 802.11g), and Bluetooth®.

Why Use Spread Spectrum?

1. **Reduced crosstalk and interference**
2. **Better voice quality/data integrity**
3. **Lower susceptibility to multipath fading**
4. **Much improved security with minimum complexity**
5. **Allows for co-existing signals over a wide bandwidth**
6. **Within ISM band one can have greater signal power**
   $\Rightarrow$ greater distance
7. **Hard to detect it presence**
8. **Hard to intercept and/or spoof**
9. **Harder to jam a spread spectrum signal**

Spread Spectrum In General

Spread spectrum is Wideband Modulation and uses a PN code

Primary benefits:

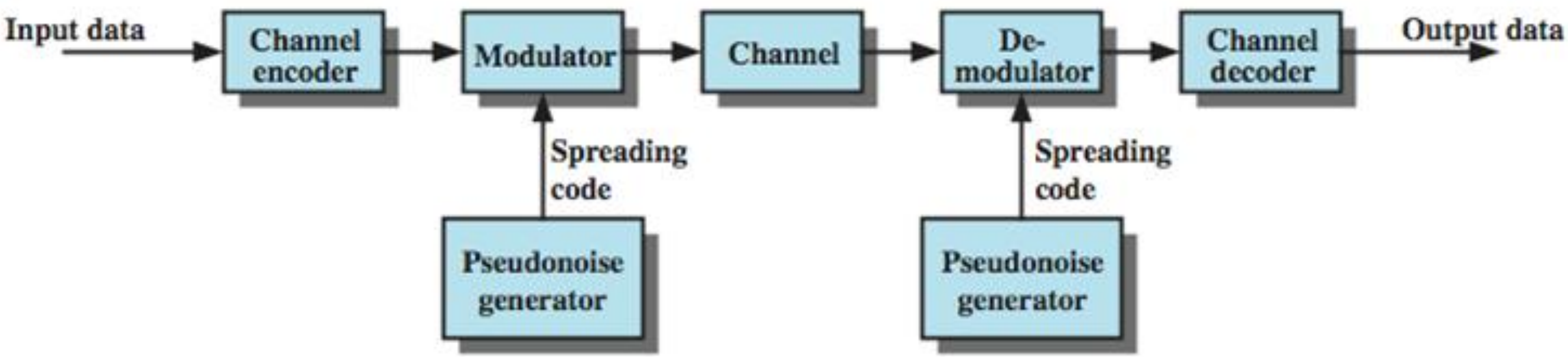
1. Provides data or message security
2. Resistant to interference and jamming
3. It allows for band sharing

Two approaches:

1. **Frequency Hopping Spread Spectrum** (**FHSS**)
   Data is constant but
   Frequency is pseudo random
2. **Direct Sequence Spread Spectrum** (**DSSS**)
   Data is randomized
   Frequency band is constant
3. **Time Hopping Spread Spectrum** (**THSS**)
   Not as widely used – not covered here
   (But most efficient use of bandwidth)

General Model of Spread Spectrum Systems

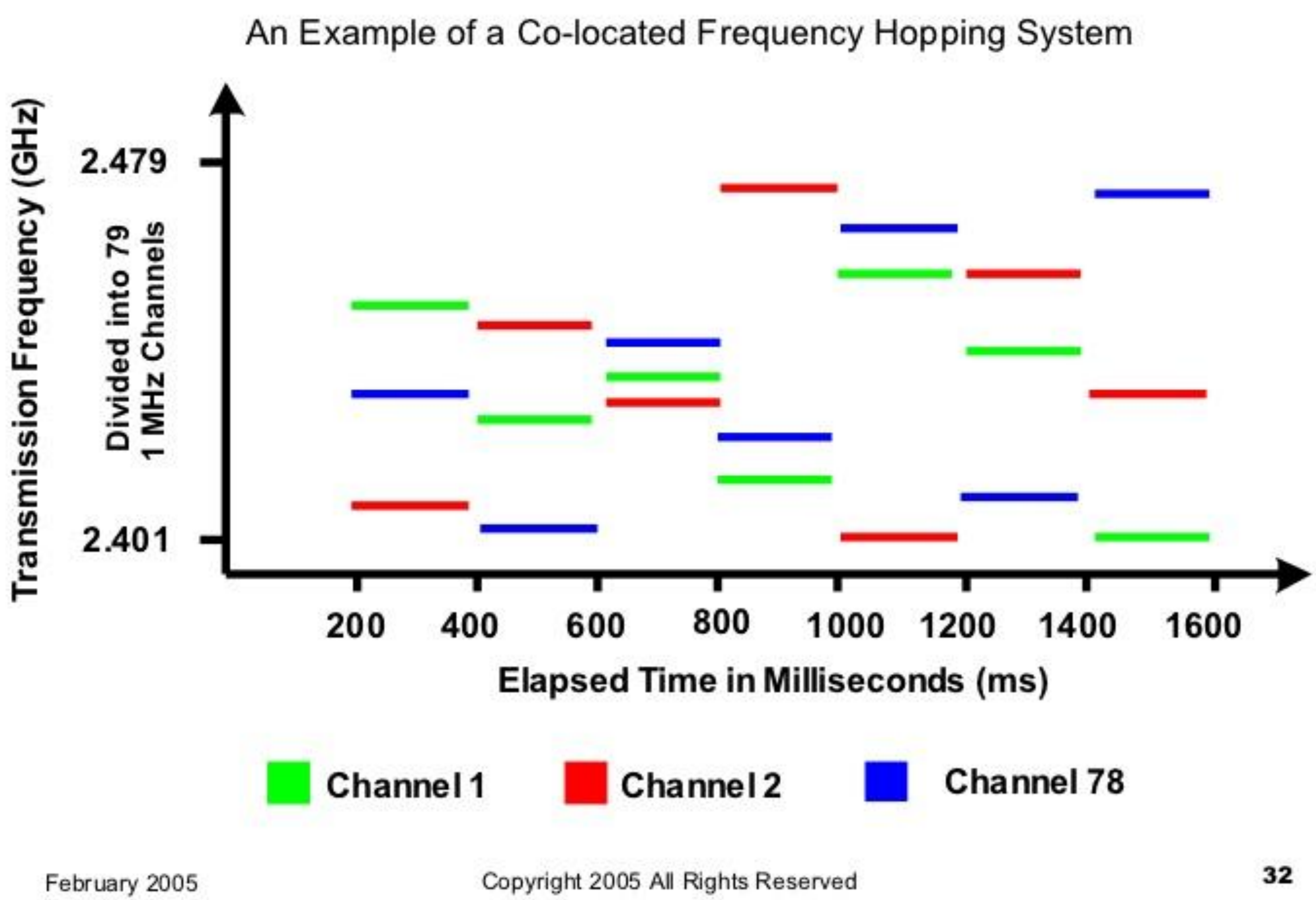
Channel



- Spreading code/sequence is generated by a pseudorandom generator, using a seed and is deterministic (not actually statistically random).
- Modulator using the spreading code to modulate its input to a much wider bandwidth output for transmission.
- Demodulator using the same spreading code to demodulate the spread spectrum signal.

http://ironbark.xtelco.com.au/subjects/DC/lectures/22/

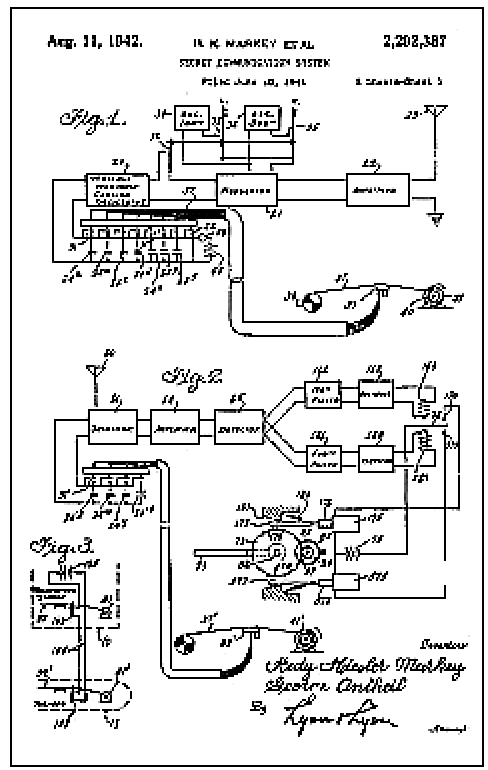
Basic Concept of Frequency Hopping Spread Spectrum



https://www.slideshare.net/HILDA519/spread-spectrum-modulation

FHSS First Proposed by Hedy Lamarr & G. Antheil

During World War II, Hedy Lamarr and composer George Antheil realized that radio-controlled torpedoes, which could be important in the naval war, could easily be jammed, thereby causing the torpedo to go off course. With the knowledge she had gained about torpedoes from her first husband, and using a method similar to the way piano rolls work, they drafted designs for a new **frequency-hopping, spread-spectrum** technology that they later patented.



Collision Avoidance in Frequency Hopping Spread Spectrum

Collisions at the same frequency-timeslot is not a problem with a single user, but with multiple users collisions can be a problem if two of the users attempt to use the same frequency-time slot.

This is avoided by careful selection of the each PN code assigned to each of the multiple users.

802.11 & Bluetooth Use Frequency Hopping Spread Spectrum

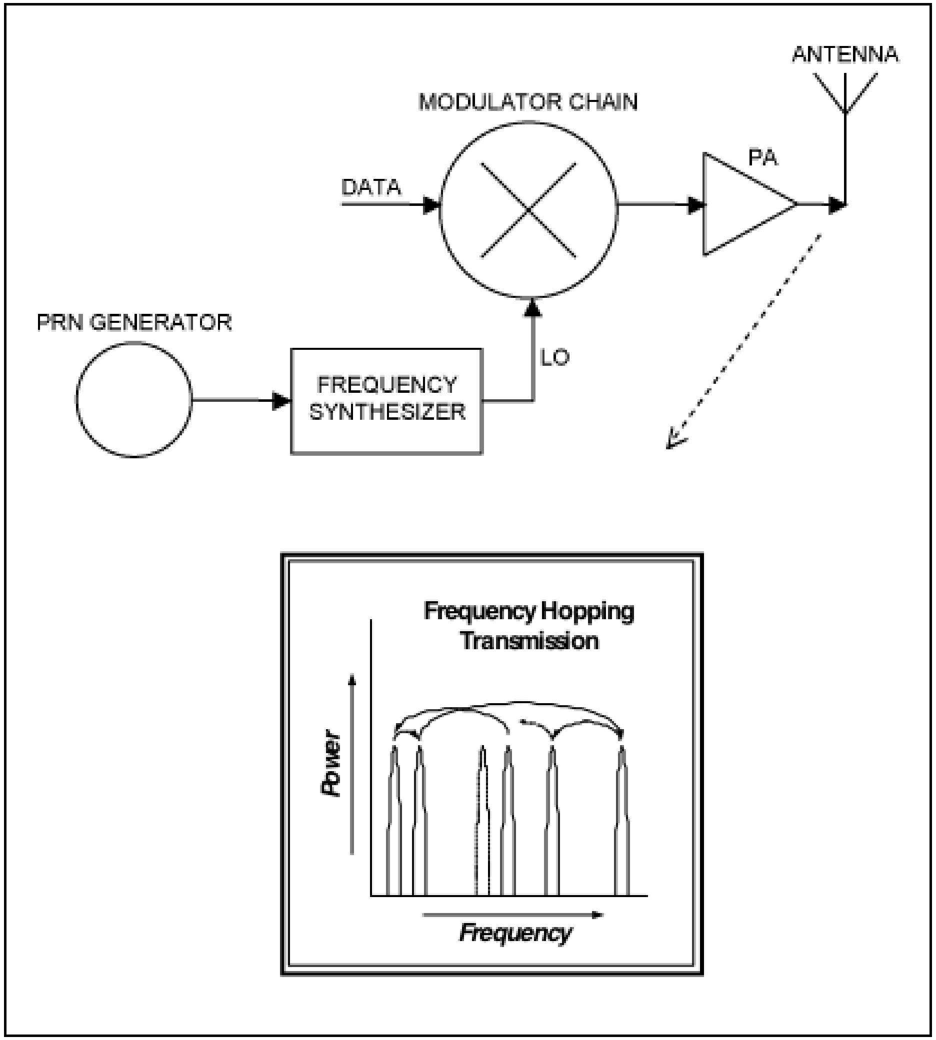
Parameter	802.11b FHSS	Bluetooth (basic rate)
Frequency Band	ISM (2.4 to 2.48 GHz)	ISM (2.4 to 2.48 GHz)
Duplex Format	TDD	TDD
Single-channel Bandwidth	1 MHz	1 MHz
Number of channels L	79	79
BT_s product	0.5	0.5
Modulation	GFSK-2	GFSK-2 & GFSK-4
Data Rate	1 Mbps & 2 Mbps	723.1 kbps
Hopping Rate	2.5 to 160 Hz	1,600 Hz

TDD = Time Division Duplex
GFSK = Gaussian Frequency Shift Keying

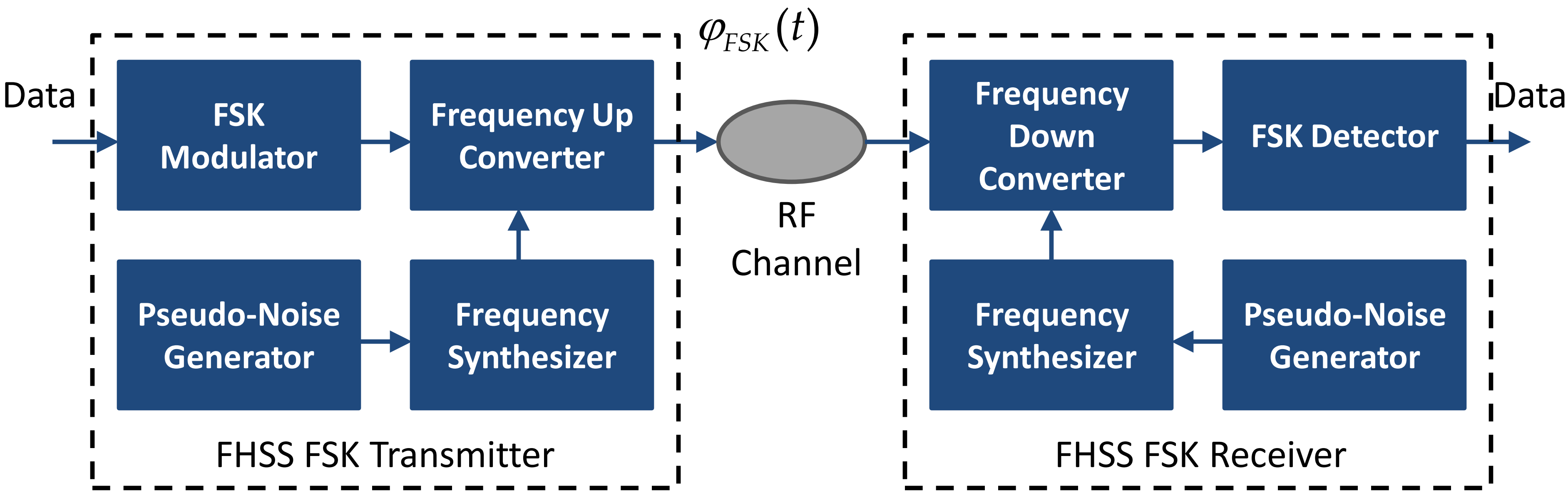
Frequency Hopping Spread Spectrum (FHSS)

Frequency Hopping Spread Spectrum (FHSS) signal is broadcast over multiple frequencies in a pseudo – random pattern (*aka* pseudo-noise pattern).

Both transmitter and receiver must know the pseudo-random pattern to successfully receive a communication.



Frequency Hopping Spread Spectrum Transmitter & Receiver



Note: Most FHSS communication systems adopt binary or M-ary FSK modulation. This makes for systems that do not need coherent detection.

Lathi & Ding
Figure 12.1
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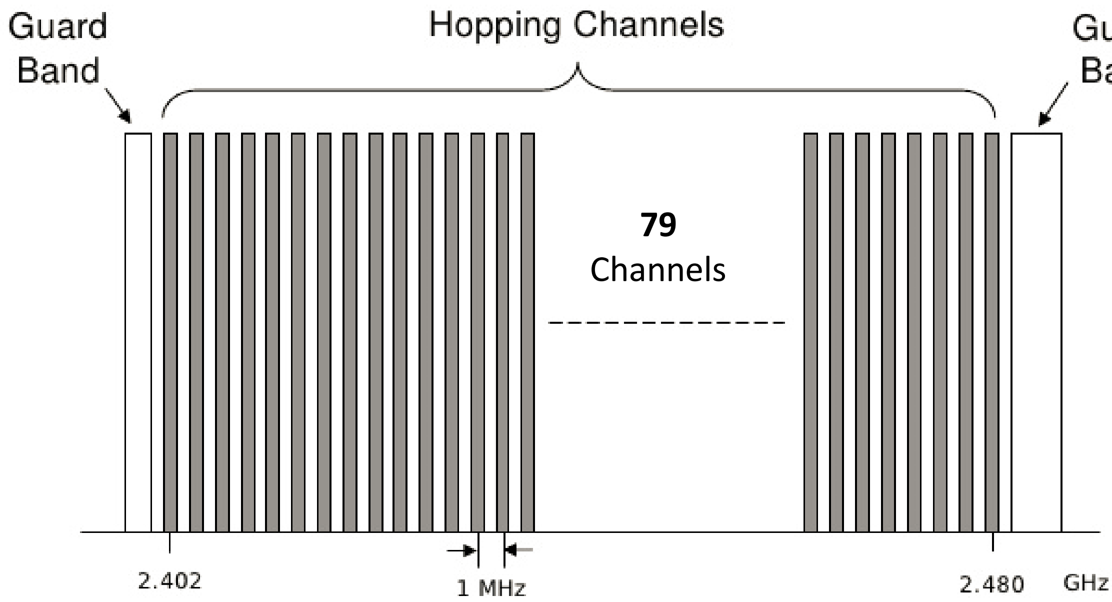
Bluetooth Overview

A *Bluetooth®* device uses radio waves instead of wires or cables to connect to a phone or computer. A Bluetooth product, like a headset or watch, contains a tiny computer chip with a Bluetooth radio and software that makes it easy to connect.

When two Bluetooth devices want to talk to each other, they need to pair. Communication between Bluetooth devices happens over short-range, ad hoc networks known as piconets. A piconet is a network of devices connected using Bluetooth technology. When a network is established, one device takes the role of the master while all the other devices act as slaves. Piconets are established dynamically and automatically as Bluetooth devices enter and leave radio proximity.

https://www.bluetooth.com/what-is-bluetooth-technology

Frequency Hopping Spread Spectrum (FHSS) in Bluetooth



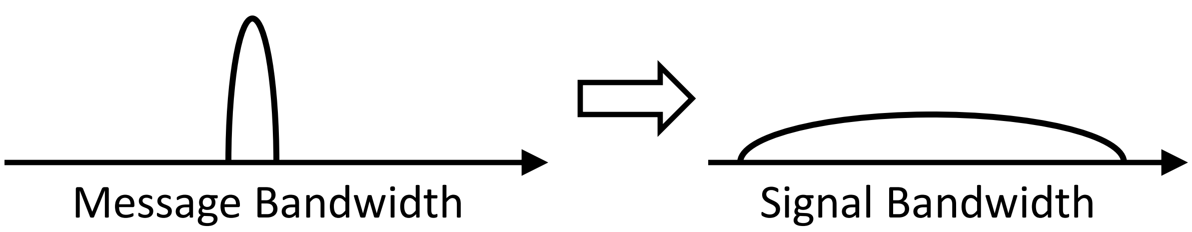
Bluetooth is a wireless technology standard for exchanging data over short distances (using radio waves in the ISM band from 2.4 to 2.485 GHz). Bluetooth is a packet-based protocol.

To minimize interference, it uses Frequency Hopping Spread Spectrum (FHSS). The FHSS signaling methodology uses time switching among **79 channels**, each with **1 megahertz (1 MHz) bandwidth** and **hopping rate = 1,600 times per second** between channels (up to **8 channels**).

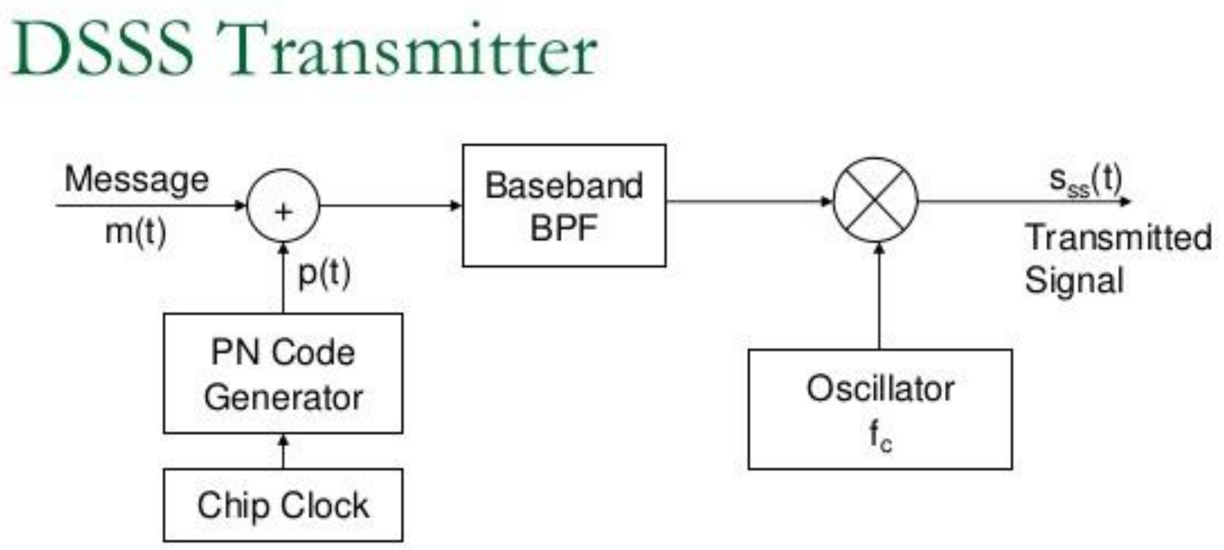
Direct Sequence Spread Spectrum (DSSS)

Direct Sequence Spread Spectrum (DSSS) is a spread spectrum technique whereby the original data signal is multiplied with a pseudo random noise spreading code. The spreading code has a higher chip rate (chip rate is the bit rate of the code), resulting in a wideband time continuous scrambled signal.

In DSSS the message signal is modulated with a bit sequence known as the **Pseudo Noise** (**PN**) code. The PN code consists of sequence of pseudo-random pulses of much shorter duration (→ larger bandwidth) than the pulse duration of the message signal. Thus, the message signal is chopped up and this results in a signal with a bandwidth about as large as that of the PN sequence. In this context the duration of the PN code is referred to as the chip duration.



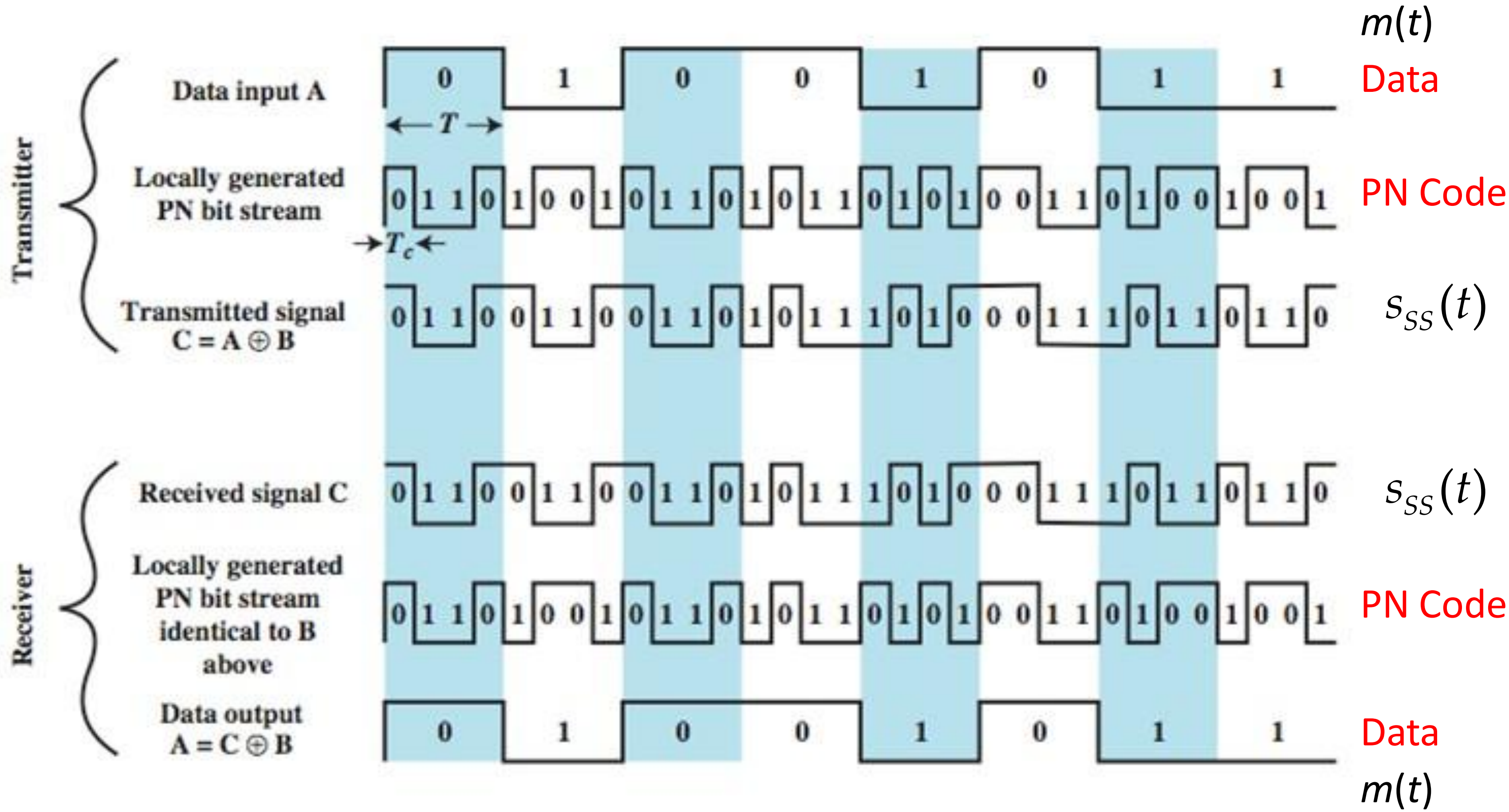
Direct Sequence Spread Spectrum Transmitter



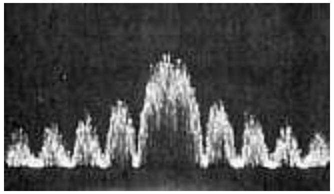
$$s_{SS}(t) = \sqrt{\frac{2E_S}{T_S}} m(t) \cdot p(t) \cos\left(\omega_c t\right)$$

https://www.slideshare.net/kaushalkabra5/chapter-7-multiple-access-techniques

How Direct Sequence Spread Spectrum (DSSS) Operates

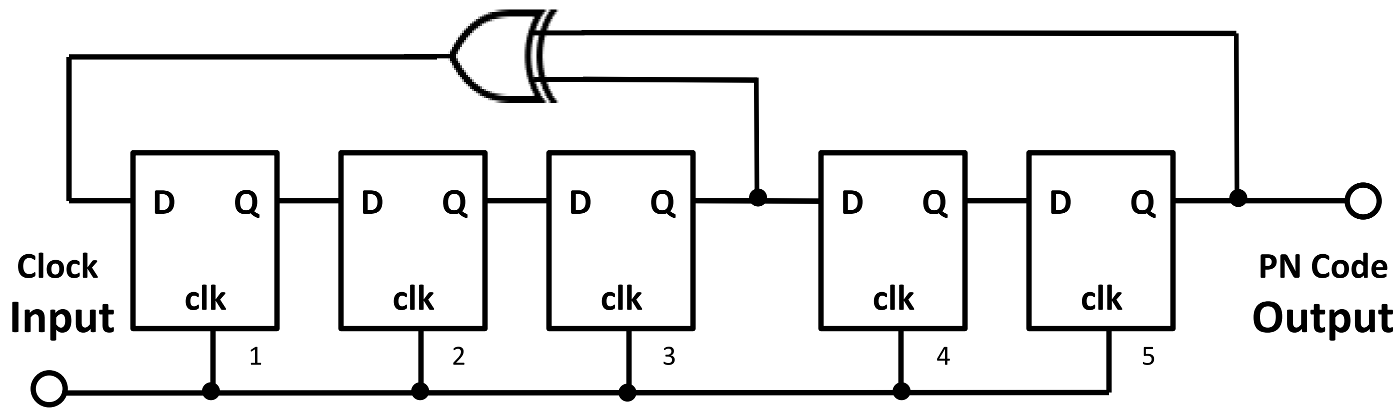


Spectrum:



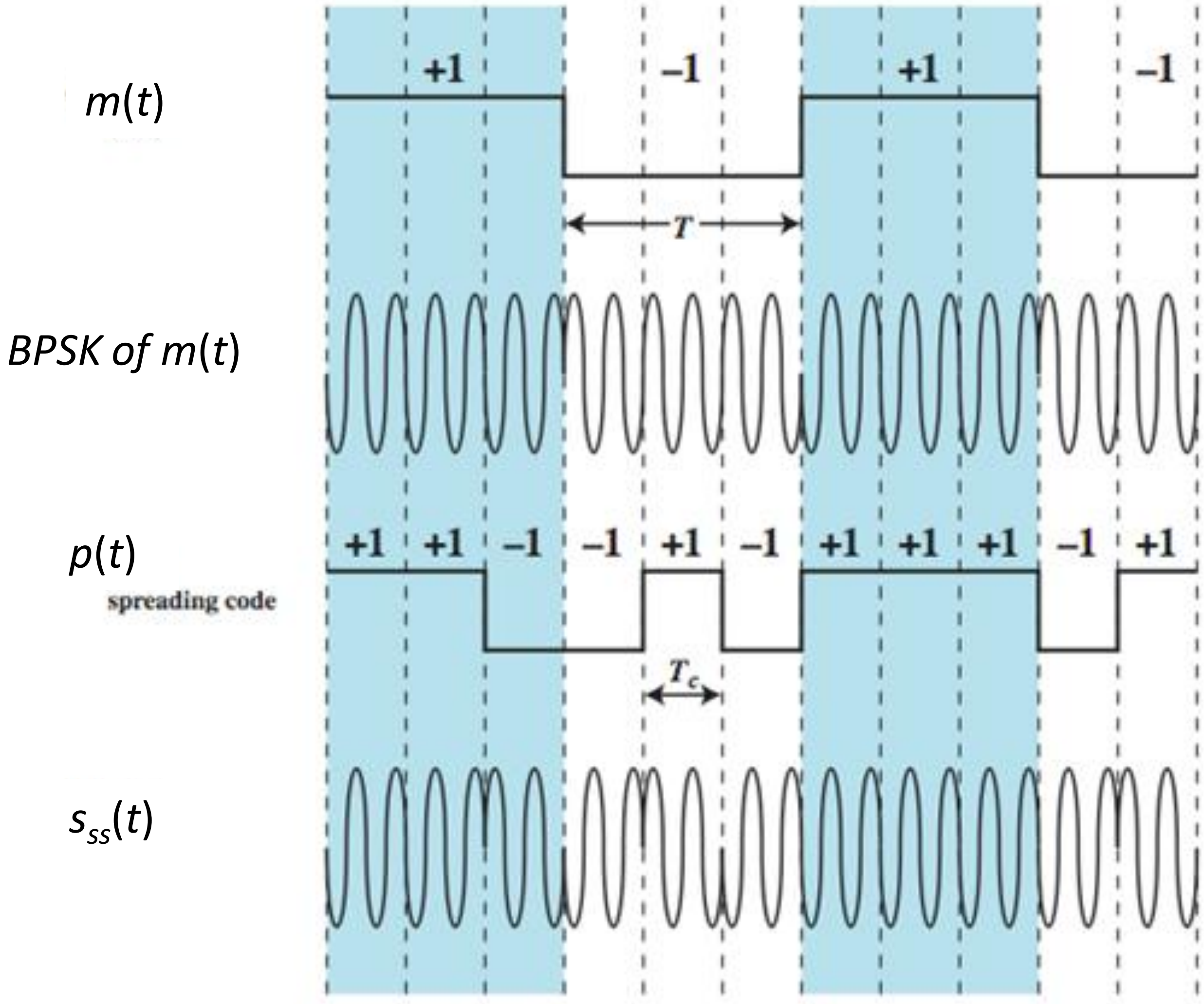
Pseudo-Noise (PN) Sequence Generator Circuit

Bit length of PN code generation = $\mathbf{2^n - 1 = 2^5 - 1 = 31}$



Can be expanded to increase length of the PN code.

DSSS Example: BPSK modulation of Data



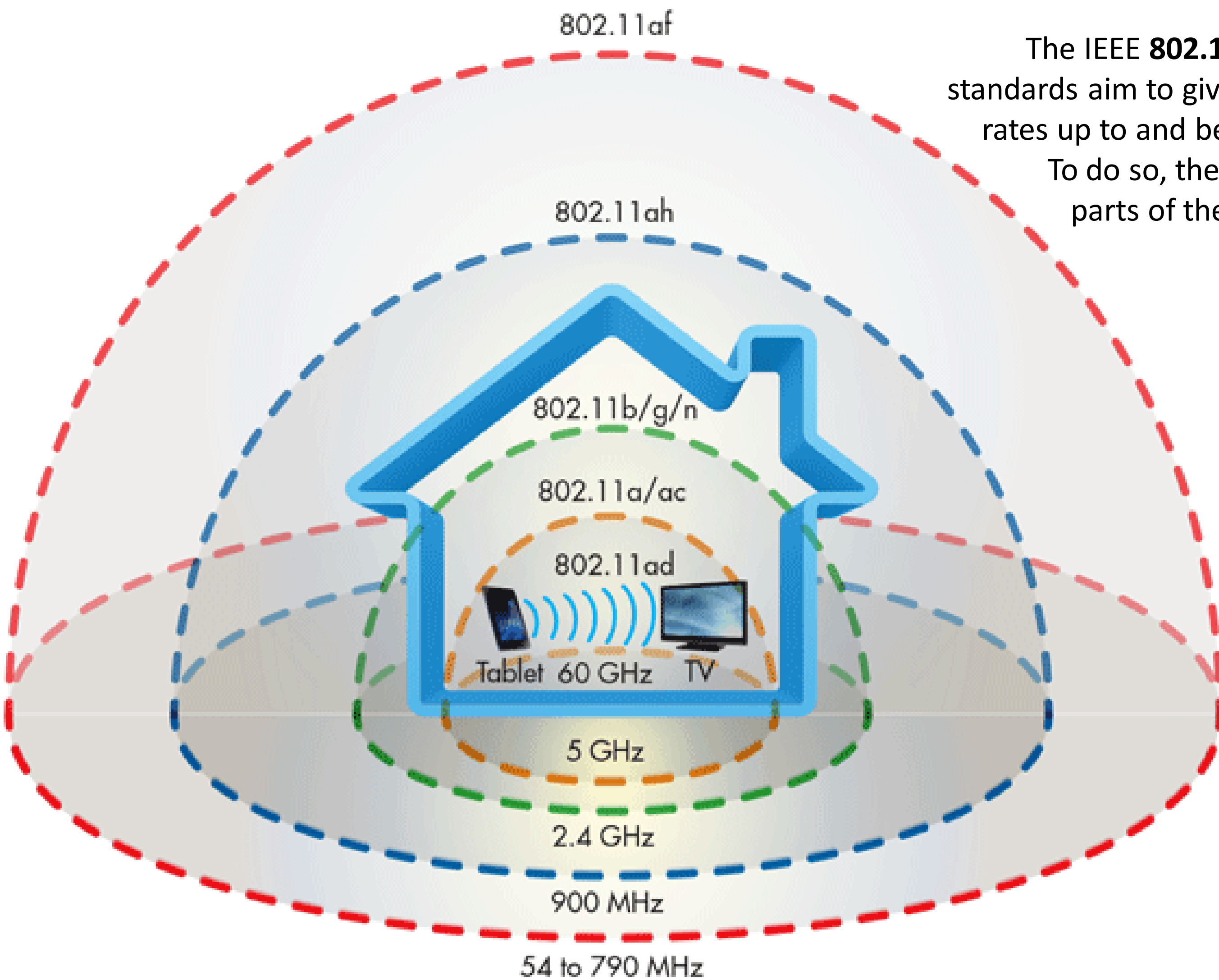
http://ironbark.xtelco.com.au/subjects/DC/lectures/22/

Comparing 802.11a, b, g, n and ac

Wireless Transmission 802.11 Protocols					
Standards	**Year Established**	**Band Frequency**	**Maximum Data Transfer**	**Channel Bandwidth**	**Antenna Configuration**
802.11a	1999	5 GHz	54 Mbps	20 MHz	1 x1 SISO
802.11b	1999	2.4 GHz	11 Mbps	20 MHz	1 x1 SISO
802.11g	2003	2.4 GHz	54 Mbps	20 MHz	1 x1 SISO
802.11n	2009	2.4 & 5 GHz	600 Mbps	20 & 40 MHz	Up to 4x4 MIMO
802.11ac	2013	5 GHz	1.3 Gbps	20, 60, 80, 160 MHz	Up to 3x3 SU-MIMO
802.11ac Wave 2	2015	5 GHz	3.47 Gbps	20, 60, 80, 80+80, 160 MHz	Up to 4x4 SU-MIMO & MU-MIMO

SISO = Single Input Single Output
MIMO = Multiple Input Multiple Output
SU = Single User and **MU** = Multiple User

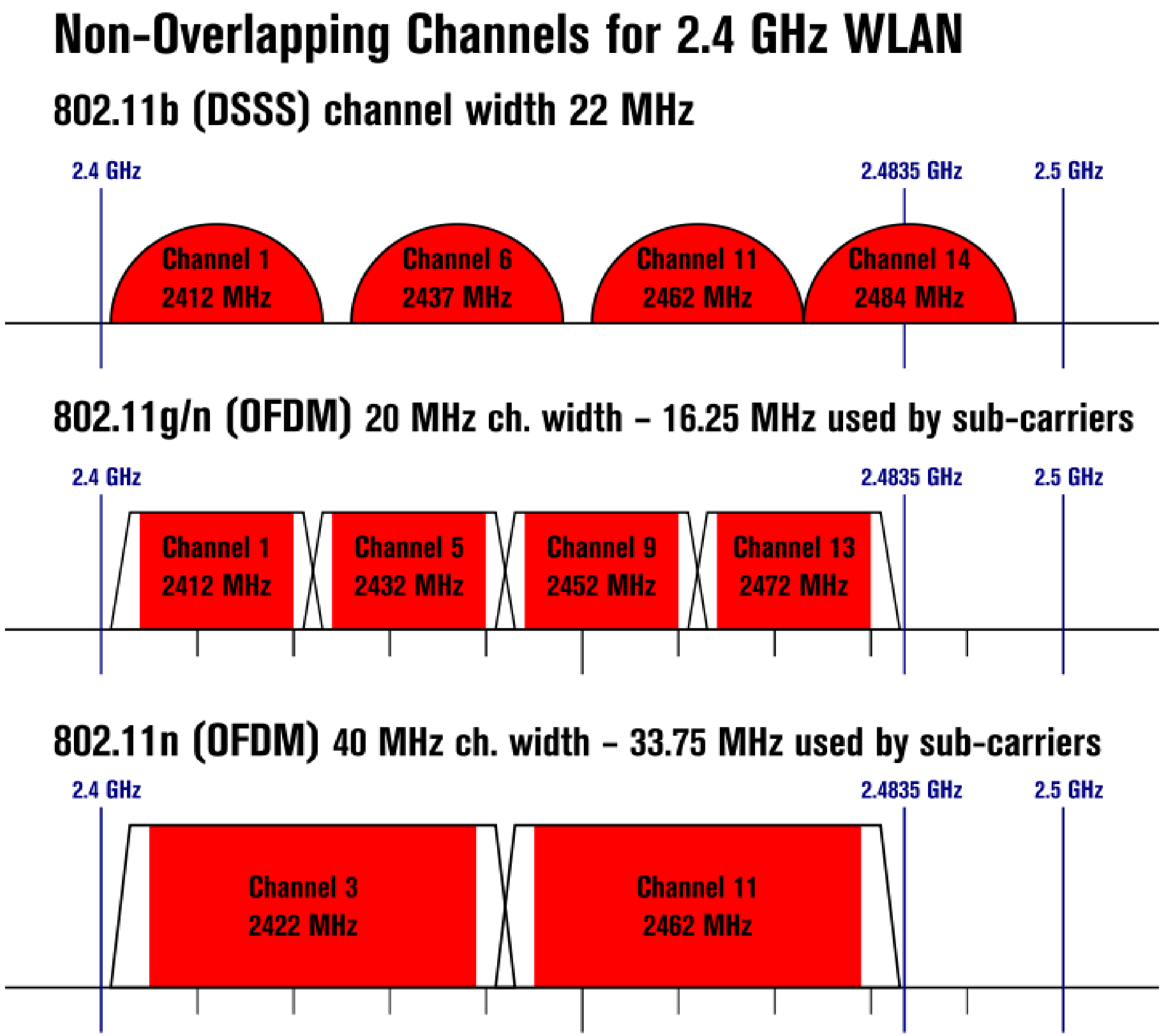
IEEE 802.11 Wi-Fi Versions



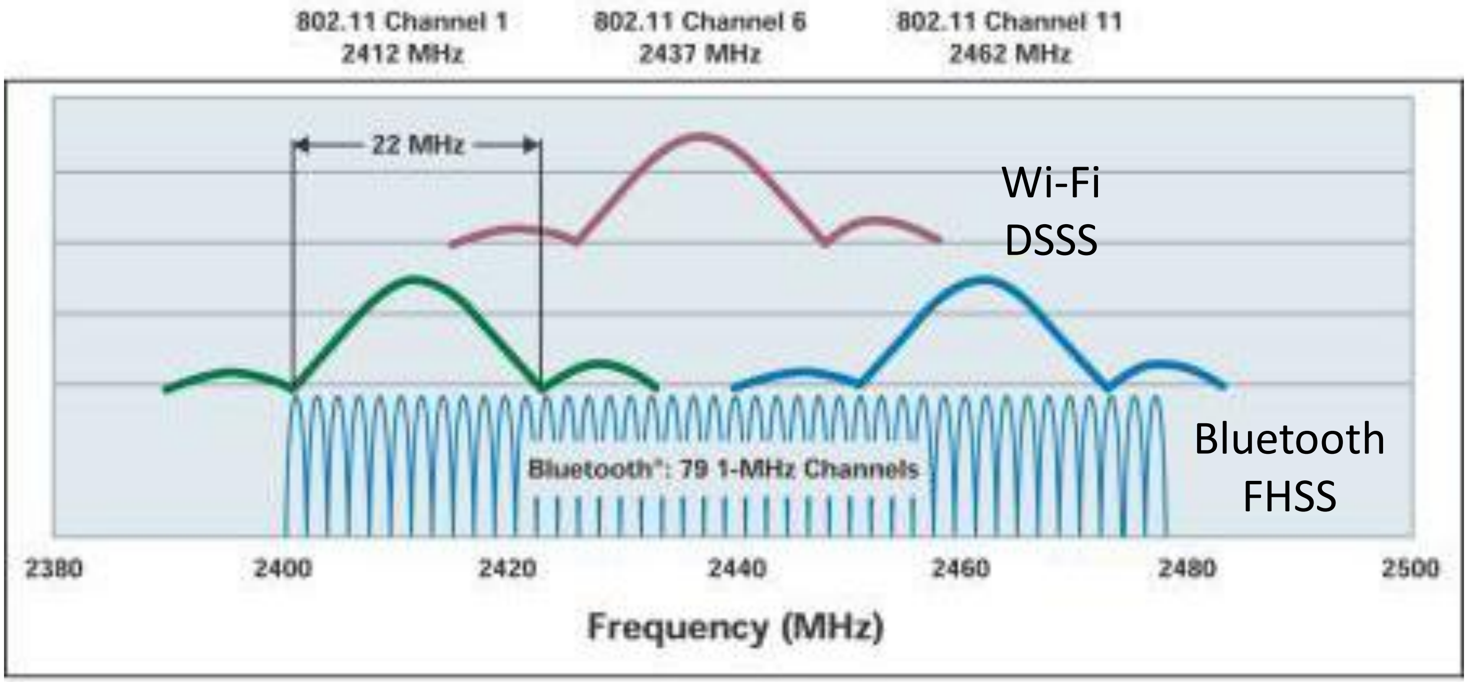
The IEEE **802.11af** and **802.11ah** standards aim to give reasonable data rates up to and beyond a kilometer. To do so, they occupy different parts of the 1-GHz spectrum.

http://mwrf.com/active-components/what-s-difference-between-ieee-80211af-and-80211ah

IEEE 802.11 Wi-Fi Channels

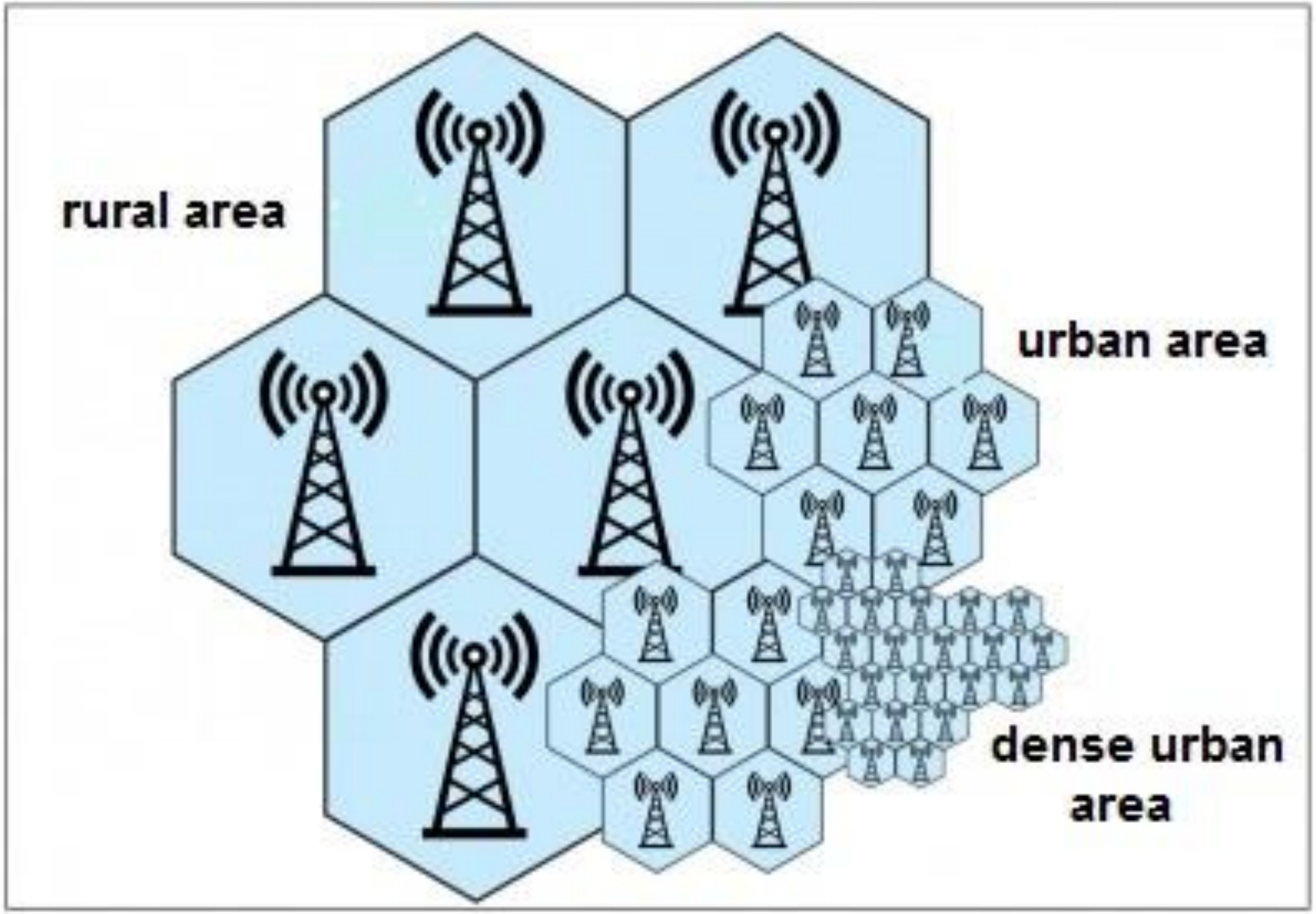


Bluetooth and Wi-Fi Share the Same Frequency ISM Band



Additional Slides

Organization of Cells Within a Cellular Network



Cells vary in size