Mobile Communications

TCS 455

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Lecture 16

Office Hours:
BKD 3601-7
Tuesday 14:00-16:00
Thursday 9:30-11:30

Announcements

- Read
  - Chapter 9: 9.1 – 9.5
- Midterm Results
  - Mean: 80.5
  - Std: 13.1
- SIIT Job Fair 2010

SIIT Job Fair 2010

- **Wednesday January 13**
- Ground Floor & In front of UFM Bakery
- @ SIIT Main Building, Rangsit Campus
- Time: 9.00 – 16.00 hrs.
- Prepare several sets of
  - copy of transcript
  - resume
  - 1 inch photo

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Chapter 4

Multiple Access

Office Hours:
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Tuesday 14:00-16:00
Thursday 9:30-11:30

Recall: Lecture 13

- Duplexing: Talk and listen simultaneously
  - **Forward channel/link** or **downlink (DL)** is used for communication from the infrastructure to the users/stations
  - **Reverse channel/link** or **uplink (UL)** is used for communication from users/stations back to the infrastructure.
- Two techniques
  1. Frequency division duplexing (FDD)
  2. Time division duplexing (TDD)
- Most commercial cellular systems are based on FDD.
  - Since the powers of the transmitted and received signals typically differ by more than 100 dB at the transmitter,
    - The signals in each direction occupy bands that are separated far apart (tens of MHz), and
    - A device called a **duplexer** is required to filter out any interference between the two bands.

Parameter	Fixed WiMAX	Mobile WiMAX	HSPA	1x EV-DO Rev A	Wi-Fi
Standards	IEEE 802.16-2004	IEEE 802.16e-2005	3GPP Release 6	3GPP2	IEEE 802.11a/g/n
Peak down link data rate	9.4Mbps in 3.5MHz with 3:1 DL-to-UL ratio TDD; 6.1Mbps with 1:1	46Mbps[a] with 3:1 DL- to-UL ratio TDD; 32Mbps with 1:1	14.4Mbps using all 15 codes; 7.2Mbps with 10 codes	3.1Mbps; Rev. B will support 4.9Mbps	54 Mbps[b] shared using 802.11a/g; more than 100Mbps peak layer 2 throughput using 802.11n
Peak uplink data rate	3.3Mbps in 3.5MHz using 3:1 DL-to-UL ratio; 6.5Mbps with 1:1	7Mbps in 10MHz using 3:1 DL-to-UL ratio; 4Mbps using 1:1	1.4Mbps initially; 5.8Mbps later	1.8Mbps	
Bandwidth	3.5MHz and 7MHz in 3.5GHz band; 10MHz in 5.8GHz band	3.5MHz, 7MHz, 5MHz, 10MHz, and 8.75MHz initially	5MHz	1.25MHz	20MHz for 802.11a/g; 20/40MHz for 802.11n
Modulation	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM	QPSK, 8 PSK, 16 QAM	BPSK, QPSK, 16 QAM, 64 QAM
Multiplexing	TDM	TDM/OFDMA	TDM/CDMA	TDM/ CDMA	CSMA
Duplexing	TDD, FDD	TDD initially	FDD	FDD	TDD
Frequency	3.5GHz and 5.8GHz initially	2.3GHz, 2.5GHz, and 3.5GHz initially	800/900/1,800/ 1,900/ 2,100MHz	800/900/ 1,800/ 1,900MHz	2.4GHz, 5GHz
Coverage (typical)	3–5 miles	< 2 miles	1–3 miles	1–3 miles	< 100 ft indoors; < 1000 ft outdoors
Mobility	Not applicable	Mid	High	High	Low

Multiple Access Techniques

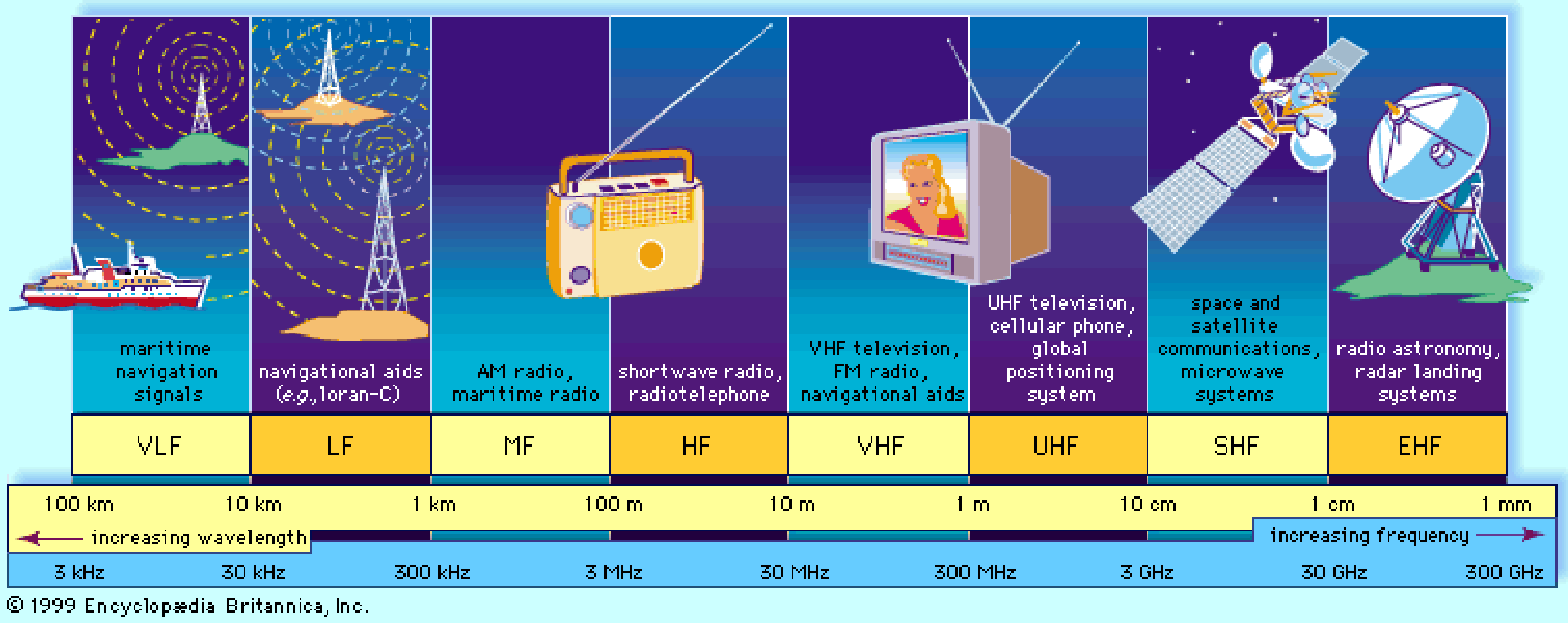
- Allow **many** mobile users to **share** simultaneously a finite amount of radio spectrum.
- For high quality communications, this must be done without severe degradation in the performance of the system.
- Important access techniques
  1. Frequency division multiple access (FDMA)
  2. Time division multiple access (TDMA)
  3. Spread spectrum multiple access (SSMA)
     - Frequency Hopped Multiple Access (FHMA)
     - Code division multiple access (CDMA)
  4. Space division multiple access (SDMA)
  5. Random access
     - ALOHA

Multiple Access Techniques (intro.)

- We have already talked about a multiple access technique!
  - FDMA

Radio-frequency spectrum

- Commercially exploited bands



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$$c = f\,\lambda$$

3×10^8 m/s

Frequency

Wavelength

Spectrum Allocation

- Spectral resource is limited.
- Most countries have government agencies responsible for allocating and controlling the use of the radio spectrum.
- Commercial spectral allocation is governed
  - globally by the International Telecommunications Union (**ITU**)
    - ITU Radiocommunication Sector (**ITU-R**) is responsible for radio communication.
  - in the U.S. by the Federal Communications Commission (**FCC**)
  - in Europe by the European Telecommunications Standards Institute (ETSI)
  - In Thailand by the National Telecommunications Commission (**NTC**; สำนักงานคณะกรรมการกิจการโทรคมนาคมแห่งชาติ; กทช.)
- Blocks of spectrum are now commonly assigned through **spectral auctions** to the highest bidder.

US licensed spectrum

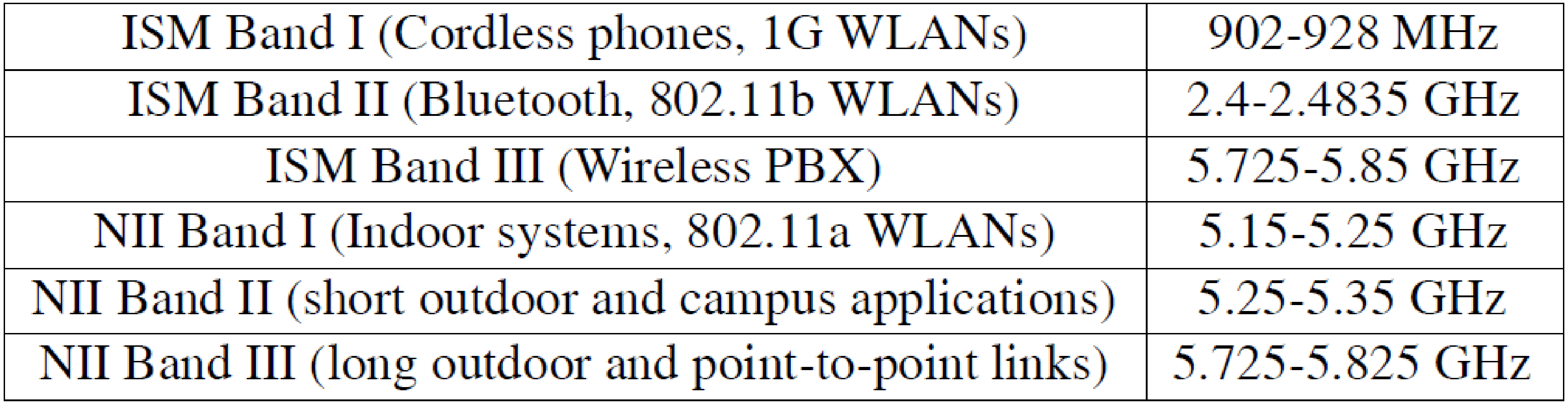
AM Radio	535-1605 KHz
FM Radio	88-108 MHz
Broadcast TV (Channels 2-6)	54-88 MHz
Broadcast TV (Channels 7-13)	174-216 MHz
Broadcast TV (UHF)	470-806 MHz
3G Broadband Wireless	746-764 MHz, 776-794 MHz
3G Broadband Wireless	1.7-1.85 MHz, 2.5-2.69 MHz
1G and 2G Digital Cellular Phones	806-902 MHz
Personal Communications Service (2G Cell Phones)	1.85-1.99 GHz
Wireless Communications Service	2.305-2.32 GHz, 2.345-2.36 GHz
Satellite Digital Radio	2.32-2.325 GHz
Multichannel Multipoint Distribution Service (MMDS)	2.15-2.68 GHz
Digital Broadcast Satellite (Satellite TV)	12.2-12.7 GHz
Local Multipoint Distribution Service (LMDS)	27.5-29.5 GHz, 31-31.3 GHz
Fixed Wireless Services	38.6-40 GHz

Unlicensed bands

- In addition to spectral auctions, spectrum can be set aside in specific frequency bands that are **free to use** with a license according to a specific set of **etiquette rules**.
- The purpose of these unlicensed bands is to encourage innovation and low-cost implementation.
- Many extremely successful wireless systems operate in unlicensed bands, including **wireless LANs, Bluetooth, and cordless phones**.
- A major difficulty is that they can be killed by their own success.
  - If many unlicensed devices in the same band are used in close proximity, they generate much interference to each other, which can make the band unusable.

Unlicensed bands (2)

- Unlicensed spectrum is allocated by the governing body within a given country.
- Often countries try to match their frequency allocation for unlicensed use so that technology developed for that spectrum is compatible worldwide.
- The following table shows the unlicensed spectrum allocations in the U.S.



ISM Band I (Cordless phones, 1G WLANs)	902-928 MHz
ISM Band II (Bluetooth, 802.11b WLANs)	2.4-2.4835 GHz
ISM Band III (Wireless PBX)	5.725-5.85 GHz
NII Band I (Indoor systems, 802.11a WLANs)	5.15-5.25 GHz
NII Band II (short outdoor and campus applications)	5.25-5.35 GHz
NII Band III (long outdoor and point-to-point links)	5.725-5.825 GHz

Licensed vs. Unlicensed Spectra

Licensed	Unlicensed
Typically nationwide Over a period of a few years From the spectrum regulatory agency	For experimental systems and to aid development of new wireless technologies
Bandwidth is very expensive	Very cheap to transmit on
No hard constraints on the power transmitted within the licensed spectrum but the power is expected to decay rapidly outside.	There is a maximum power constraint over the entire spectrum.
Provide immunity from any kind of interference outside of the system itself	Have to deal with interference

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

- ■ AERONAUTICAL MOBILE
- ■ AERONAUTICAL MOBILE SATELLITE
- ■ AERONAUTICAL RADIONAVIGATION
- ■ AMATEUR
- ■ AMATEUR SATELLITE
- ■ BROADCASTING
- ■ BROADCASTING SATELLITE
- ■ EARTH EXPLORATION SATELLITE
- ■ FIXED
- ■ FIXED SATELLITE
- ■ INTER-SATELLITE
- ■ LAND MOBILE
- ■ LAND MOBILE SATELLITE
- ■ MARITIME MOBILE
- ■ MARITIME MOBILE SATELLITE
- ■ MARITIME RADIONAVIGATION
- ■ METEOROLOGICAL AIDS
- ■ METEOROLOGICAL SATELLITE
- ■ MOBILE
- ■ MOBILE SATELLITE
- ■ RADIO ASTRONOMY
- ■ RADIODETERMINATION SATELLITE
- ■ RADIOLOCATION
- ■ RADIOLOCATION SATELLITE
- ■ RADIONAVIGATION
- ■ RADIONAVIGATION SATELLITE
- ■ SPACE OPERATION
- ■ SPACE RESEARCH
- ■ STANDARD FREQUENCY AND TIME SIGNAL
- ■ STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

- ■ GOVERNMENT EXCLUSIVE
- ■ GOVERNMENT/ NON-GOVERNMENT SHARED
- ■ NON-GOVERNMENT EXCLUSIVE

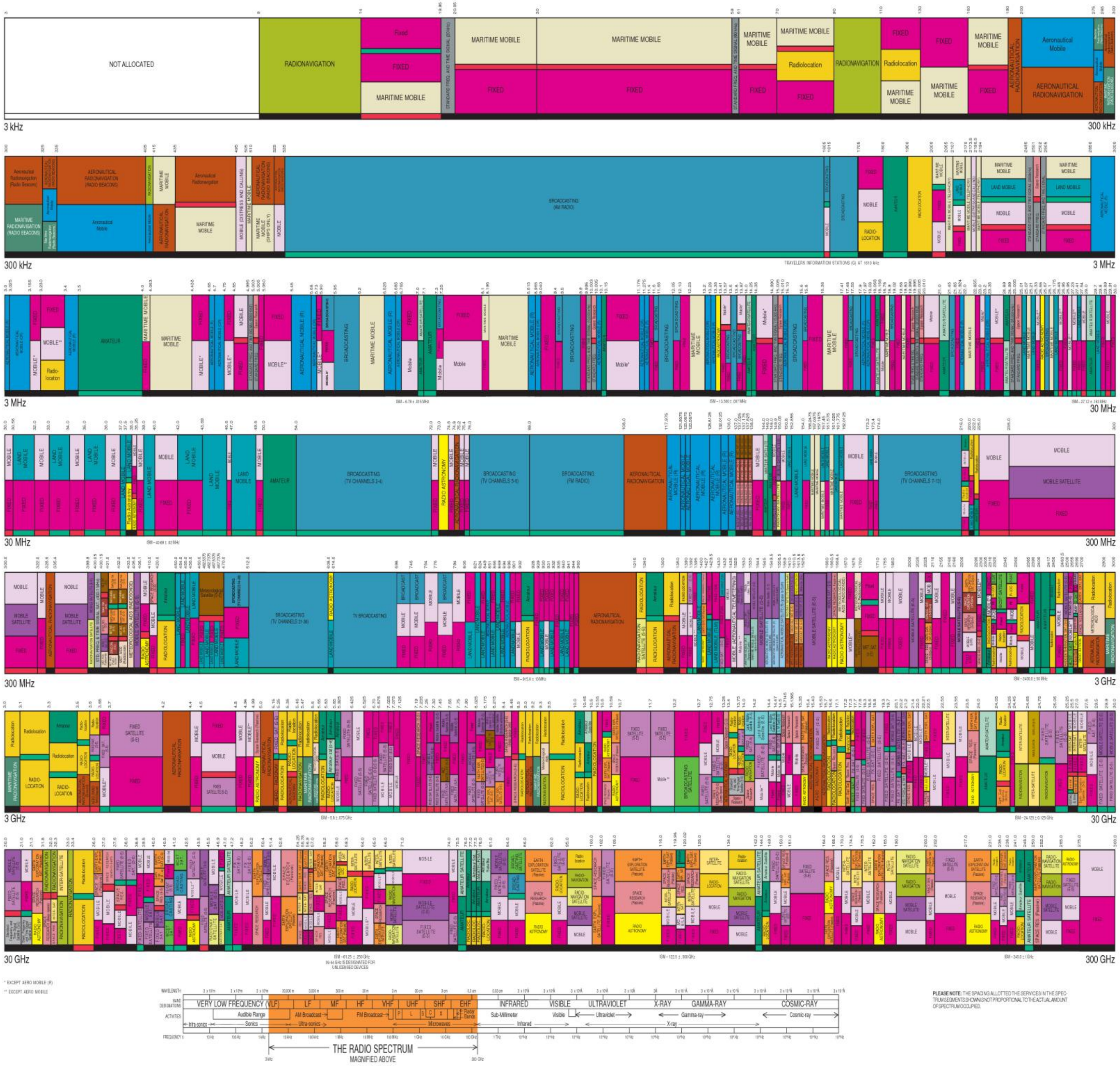
ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

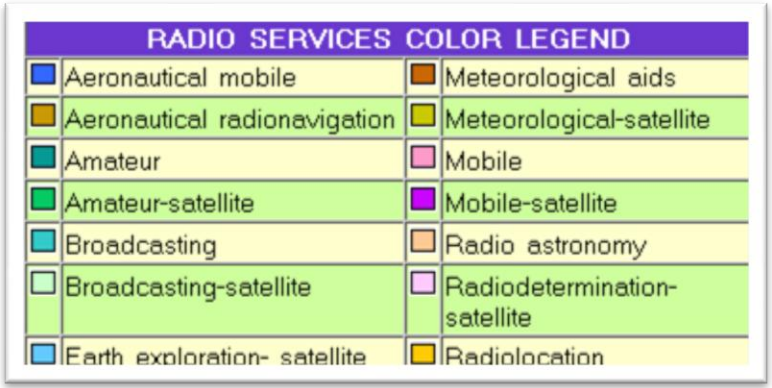
This chart is a graphic single-point-in-time portrayal of the Table of Frequency Allocations used by the NTIA. As such, it does not completely reflect all aspects, i.e., footnotes and recent changes Table of Frequency Allocations. Therefore, for complete information, users should consult the the current status of U.S. allocations.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

October 2003

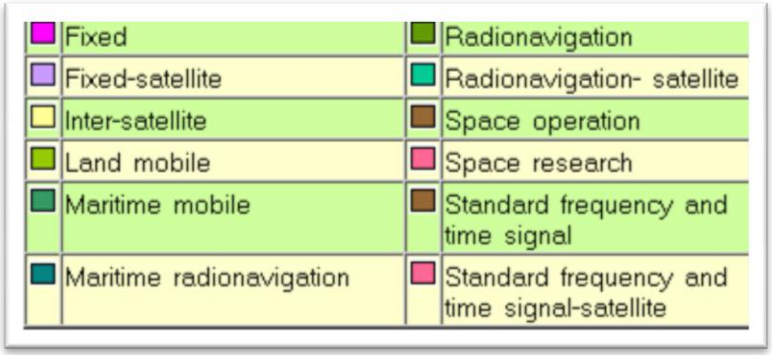


Thailand Freq. Allocations Chart

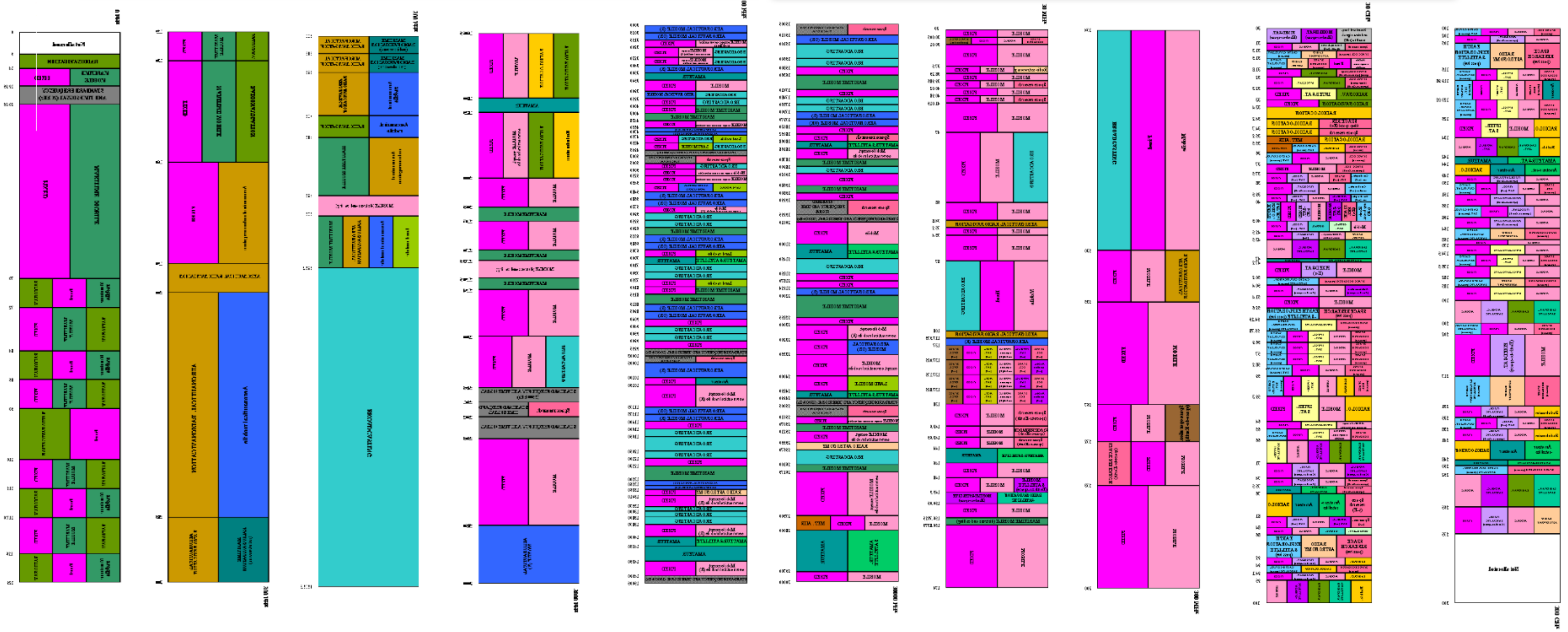


RADIO SERVICES COLOR LEGEND

■	Aeronautical mobile	■	Meteorological aids
■	Aeronautical radionavigation	■	Meteorological-satellite
■	Amateur	■	Mobile
■	Amateur-satellite	■	Mobile-satellite
■	Broadcasting	■	Radio astronomy
■	Broadcasting-satellite	■	Radiodetermination-satellite
■	Earth exploration- satellite	■	Radiolocation



■	Fixed	■	Radionavigation
■	Fixed-satellite	■	Radionavigation- satellite
■	Inter-satellite	■	Space operation
■	Land mobile	■	Space research
■	Maritime mobile	■	Standard frequency and time signal
■	Maritime radionavigation	■	Standard frequency and time signal-satellite



http://www.ntc.or.th/uploadfiles/freq_chart_thai.htm

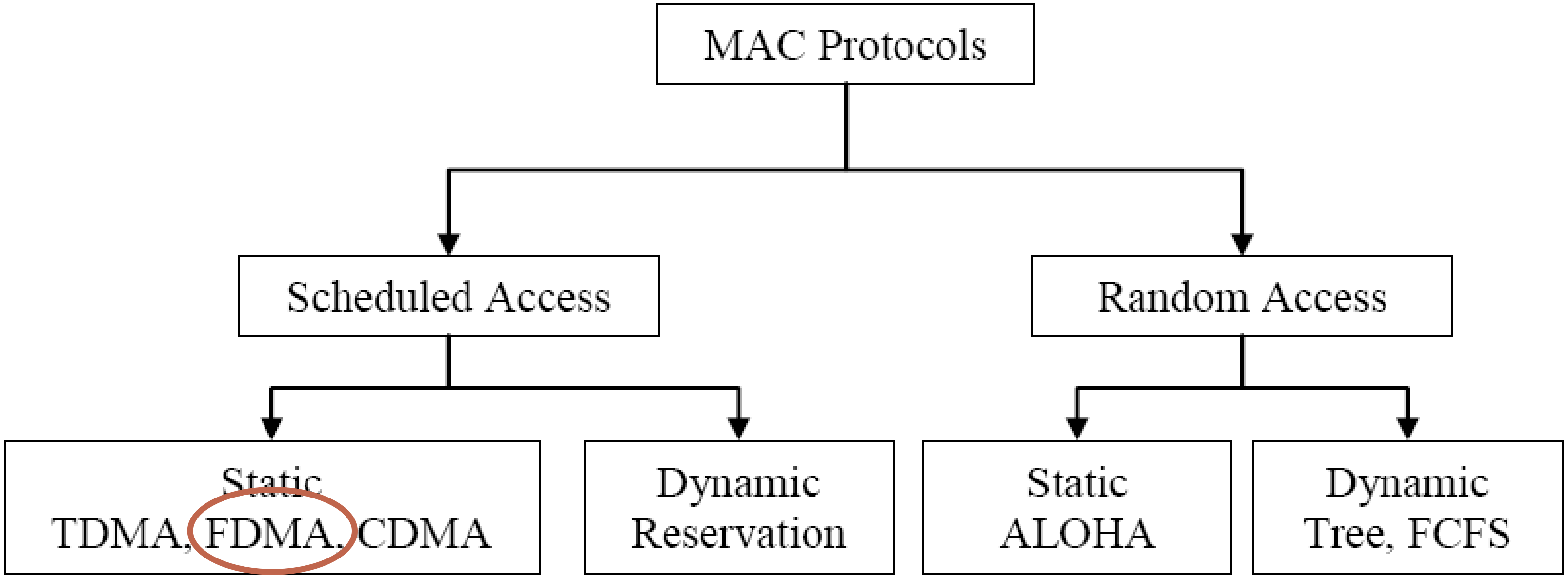
Spectrum Allocation (Final Words)

- Spectrum is a scarce resource.
- Spectrum is allocated in "chunks" in **frequency** domain.
  - "Chunks" are licensed to (cellular/wireless) operators.
  - FDMA
- All cellular phone networks worldwide use a portion of the radio frequency spectrum designated as **ultra high frequency (UHF)**.
  - The UHF band is also shared with television, Wi-Fi and Bluetooth transmission.
  - Due to historical reasons, radio frequencies used for cellular networks differ in the Americas, Europe, and Asia.
- Frequency bands recommended by ITU-R (in June 2003) for terrestrial Mobile telecommunication IMT-2000:
  - 806-960 MHz
  - 1710-2025 MHz
  - 2110-2200 MHz
  - 2500-2690 MHz
- Within a single cellular operator, the chunk is further divided into many **channels**.
  - Each channel has its own band of frequency.

Caution

- Mobile networks based on different standards may use the same “frequency chunk”.
  - For example, AMPS, D-AMPS, N-AMPS and IS-95 all use the 800 MHz “frequency chunk”.
  - This is achieved by the use of **different channels**.

Classifications of Medium Access Control (MAC)



Frequency division multiple access (FDMA)

- The *oldest* multiple access scheme for wireless communications.
- Used exclusively for multiple access in 1G down to individual resource units or physical channels.
- Assign individual channels to individual users.
    - Different carrier frequency is assigned to each user so that the resulting spectra do not overlap.
    - During the period of the call, no other user can share the same channel.
- **Band-pass filtering** (or heterodyning) enables separate demodulation of each channel.

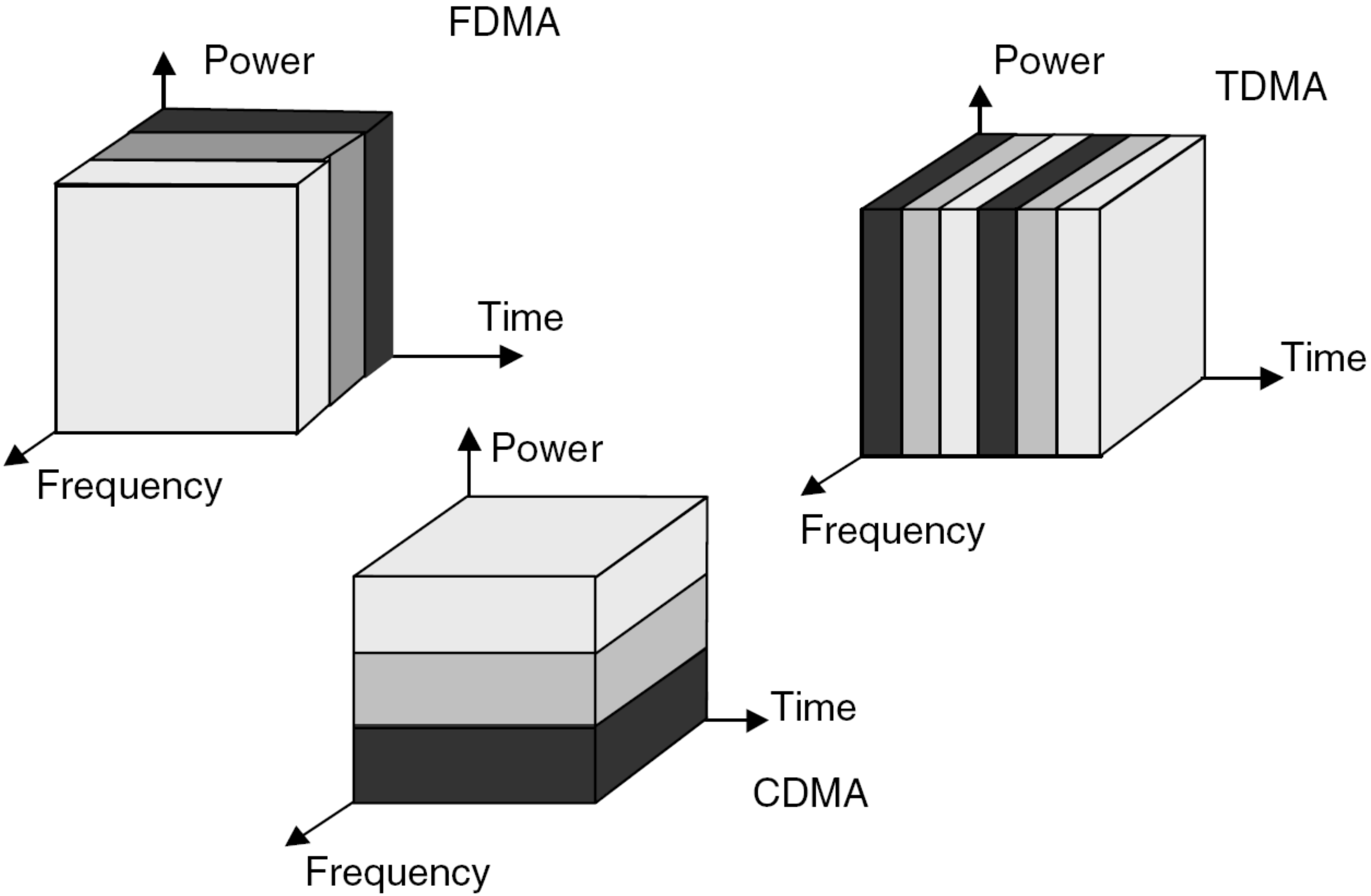
FDMA (2)

- If an FDMA channel is not in use, then it sits idle and can**not** be used by other users to increase or share capacity.
  - It is essentially a wasted resource.
- In FDD systems. the users are assigned a channel as a pair of frequencies.

Time division multiple access (TDMA)

- Divide the radio spectrum into **time slots**.
- In each slot only one user is allowed to either transmit or receive.
- A channel may be thought of as a particular time slot that reoccurs every frame, where *N* time slots comprise a frame.
- Transmit data in a **buffer-and-burst method**
  - The transmission for any user is non-continuous.
  - Digital data and digital modulation must be used with TDMA.
  - This results in low battery consumption, since the subscriber transmitter can be turned off when not in use (which is most of the time).
- An obvious choice in the 1980s for digital mobile communications.

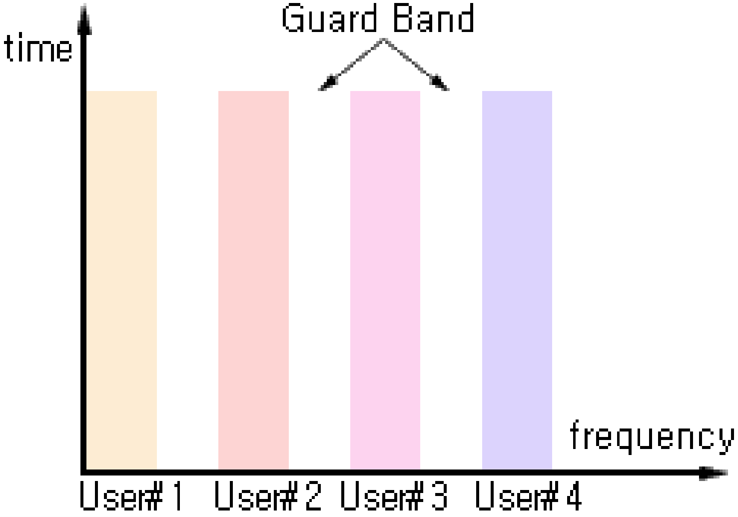
FDMA vs. TDMA


FDMA
Power
Time
Frequency
Power
TDMA
Time
Frequency
Power
Time
CDMA
Frequency

Tradeoffs

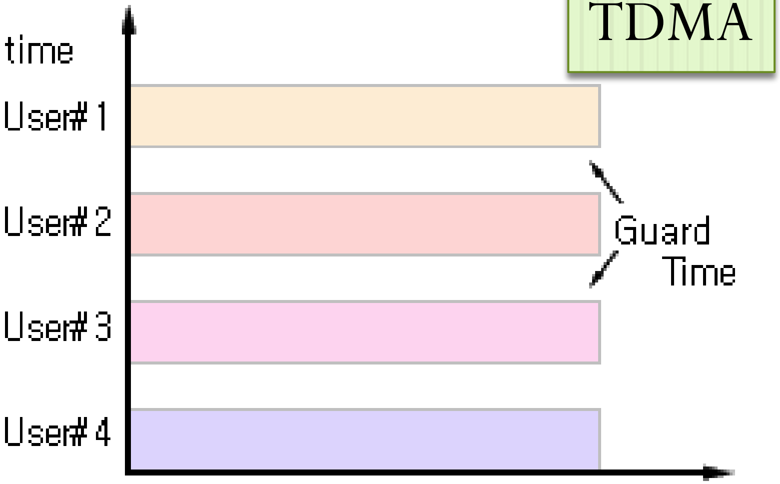
- TDMA transmissions are slotted
  - This requires the receivers to be **synchronized** for each data burst.
  - **Guard slots** are necessary to separate users. This results in larger overheads.
  - FDMA allows completely **uncoordinated transmission** in the time domain
    - No time synchronization among users is required.
- The complexity of FDMA mobile systems is lower when compared to TDMA systems, though this is changing as digital signal processing methods improve for TDMA.
- Since FDMA is a continuous transmission scheme, fewer bits are needed for **overhead** purposes (such as synchronization and framing bits) as compared to TDMA.
- FDMA needs to use costly **bandpass filters**.
  - For TDMA, no filters are required to separate individual physical channels.

Guard Band vs. Guard Time

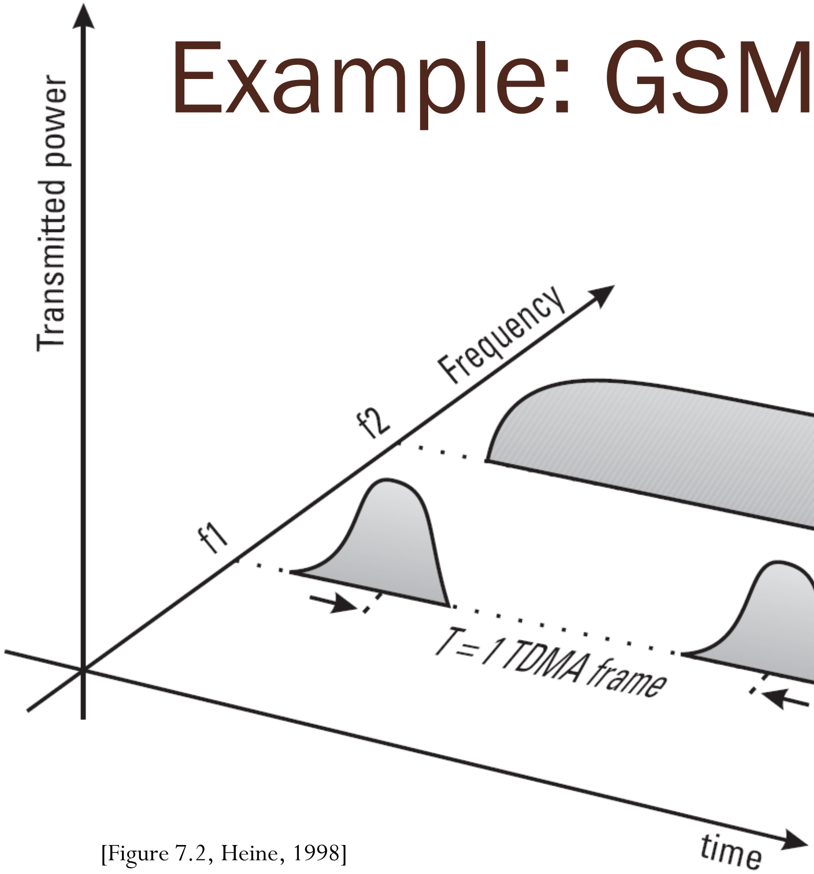


FDMA

TDMA



Example: GSM



FDMA

GSM FDMA/TDMA with one active time slot

[Figure 7.2, Heine, 1998]

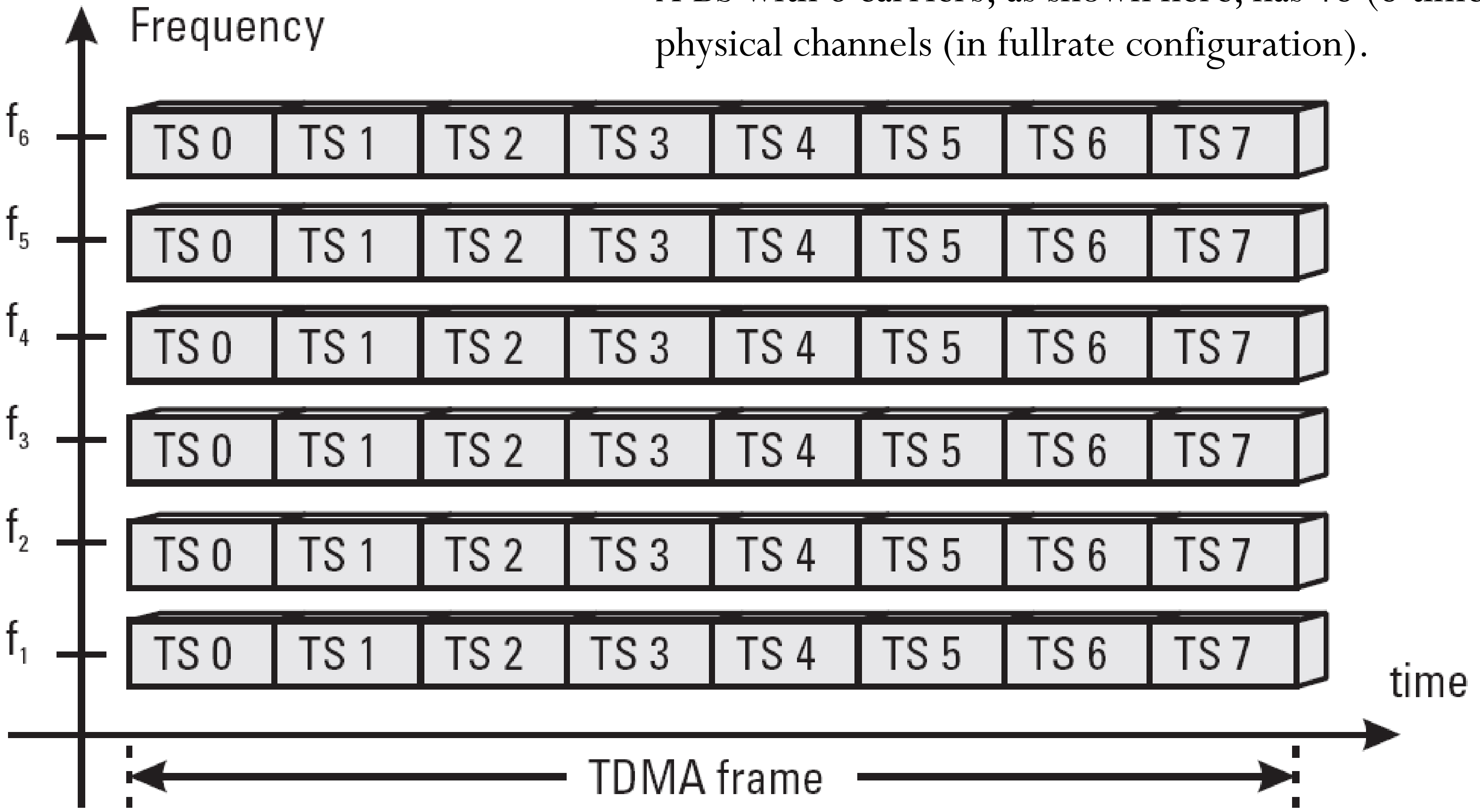
- GSM utilizes a combination of FDMA and TDMA
- Two-dimensional channel structure

- Each narrowband channel has bandwidth 200 kHz.
- Time is divided into slots of length T =577 µs.

The FDMA/TDMA structure of GSM

- In full-rate configuration, eight time slots (TSs) are mapped on every frequency.

A BS with 6 carriers, as shown here, has 48 (8 times 6) physical channels (in fullrate configuration).



f_6	TS 0	TS 1	TS 2	TS 3	TS 4	TS 5	TS 6	TS 7
f_5	TS 0	TS 1	TS 2	TS 3	TS 4	TS 5	TS 6	TS 7
f_4	TS 0	TS 1	TS 2	TS 3	TS 4	TS 5	TS 6	TS 7
f_3	TS 0	TS 1	TS 2	TS 3	TS 4	TS 5	TS 6	TS 7
f_2	TS 0	TS 1	TS 2	TS 3	TS 4	TS 5	TS 6	TS 7
f_1	TS 0	TS 1	TS 2	TS 3	TS 4	TS 5	TS 6	TS 7

[Figure 7.1, Heine, 1998]

Spread spectrum multiple access (SSMA)

- Historically spread spectrum was developed for *secure* communication and *military* uses.
- Spread spectrum signals have the following characteristics:
  - **Difficult to intercept** for an unauthorized person.
  - Easily **hidden**. For an unauthorized person, it is difficult to even detect their presence in many cases.
  - **Resistant to jamming**.
  - Provide a measure of immunity to distortion due to multipath propagation.
  - Asynchronous multiple-access capability.

SSMA conditions

Spread spectrum refers to any system that satisfies the following conditions [Lathi, 1998, p 406]:

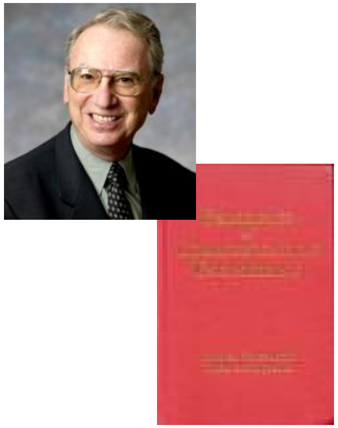
1. The spread spectrum may be viewed as a kind of modulation scheme in which **the modulated (spread spectrum) signal bandwidth is much greater than the message (baseband) signal bandwidth.**
2. The **spectral spreading** is performed by a **code** that is **independent** of the message signal.
   - This same code is also used at the receiver to despread the received signal in order to recover the message signal (from the spread spectrum signal).
   - In secure communication, this code is known only to the person(s) for whom the message is intended.

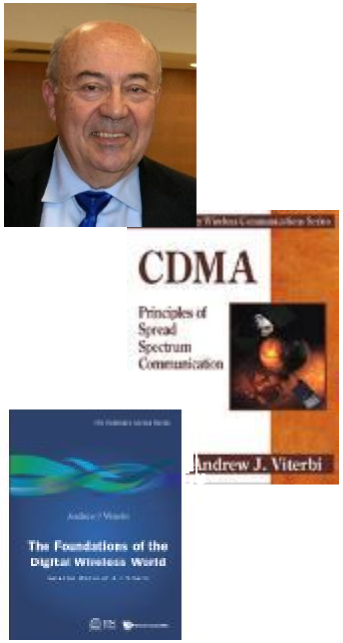
SSMA (2)

- The spread spectrum scheme increases the bandwidth of the message signal by a factor *N*, called the **processing gain**.
- Although we use much higher BW for a spread spectrum signal, we can also multiplex large numbers of such signals over the same band.
- Many users can share the same spread spectrum bandwidth without interfering with one another.
  - Achieved by assigning different code to each user.
  - Frequency bands can be reused without regard to the separation distance of the users.

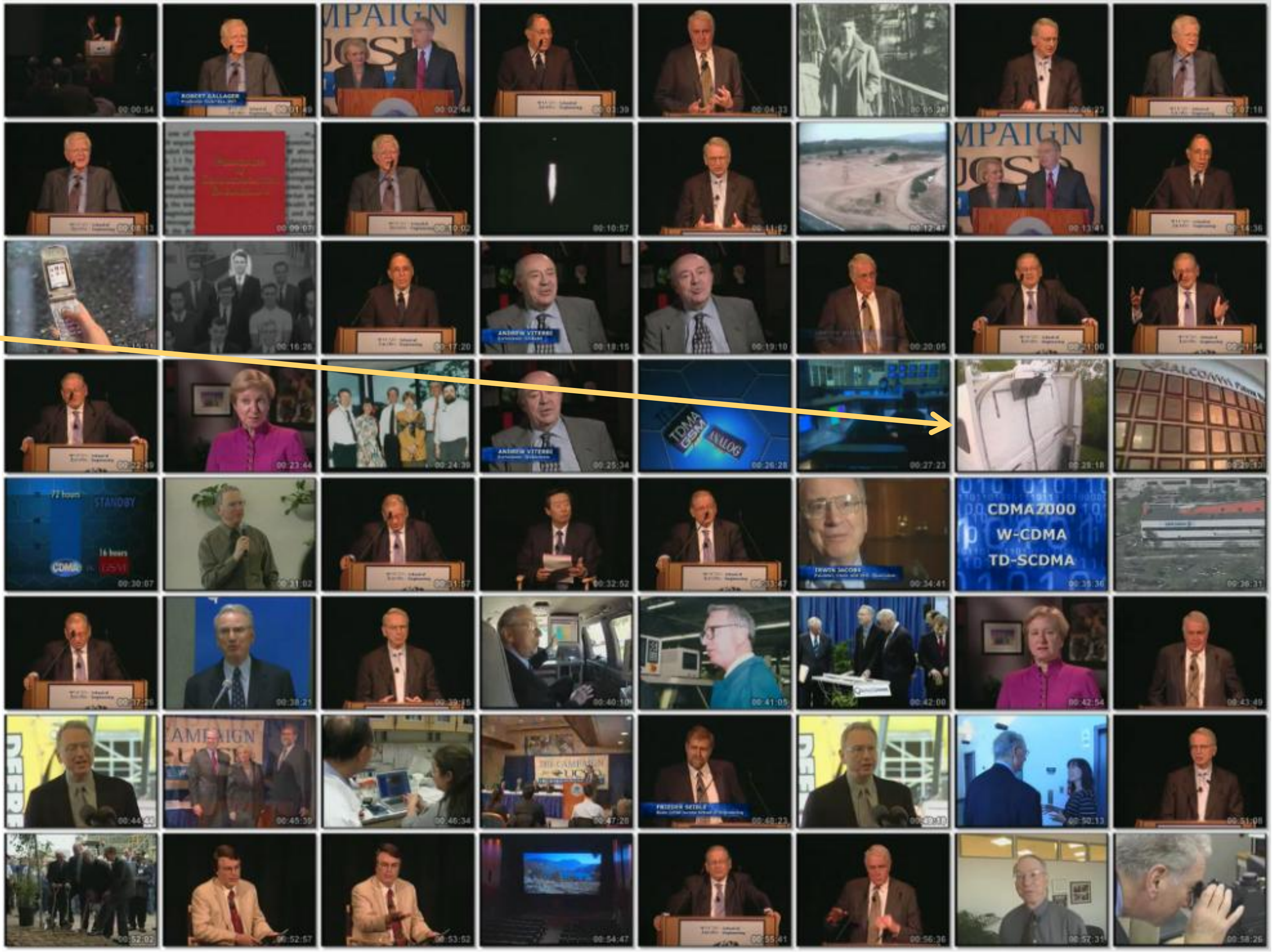
Code Division Multiple Access (CDMA)

- Qualcomm
- Founders: two of the most eminent engineers in the world of mobile radio
  - Irwin Jacobs is the chairman and founder
  - Andrew J. Viterbi is the co-founder
    - Same person that invented the Viterbi algorithm for decoding convolutionally encoded data.
- 1991: Qualcomm announced
  - that it had invented a new cellular system based on CDMA
  - that the capacity of this system was 20 or so times greater than any other cellular system in existence
- However, not all of the world was particularly pleased by this apparent breakthrough—in particular, GSM manufacturers became concerned that they would start to lose market share to this new system.
  - The result was continual and vociferous argument between Qualcomm and the GSM manufacturers.





Video



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PN Sequence Generation

- Section 13.4.1 in [Lathi, 1998]