# ECS455: Chapter 4

## Multiple Access

**Asst. Prof. Dr. Prapun Suksompong**

prapun@siit.tu.ac.th

Resource sharing < uplink/downlink (duplexing); different users

**Office Hours:**
BKD, 6th floor of Sirindhralai building

| | |
|---|---|
| Tuesday | 14:20-15:20 |
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| Friday | 9:15-10:15 |

Dr.Prapun Suksompong
prapun.com/ecs455



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**4.1 Duplexing: TDD and FDD**

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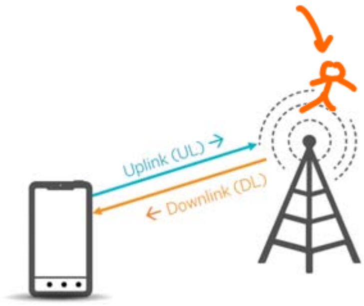
prapun.com/ecs455

# Duplexing

- Allow the subscriber to send "simultaneously" information to the base station while receiving information from the base station.
  - Voice : Talk and listen simultaneously.
- Definitions:
  - **Forward channel** or **downlink (DL)** is used for communication from the infrastructure to the users/stations
  - **Reverse channel** 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)

[Rappaport, 2002, Ch 9]



# Frequency Division Duplexing (FDD)

- Provide ***two distinct bands*** of frequencies (simplex channels) for every user.

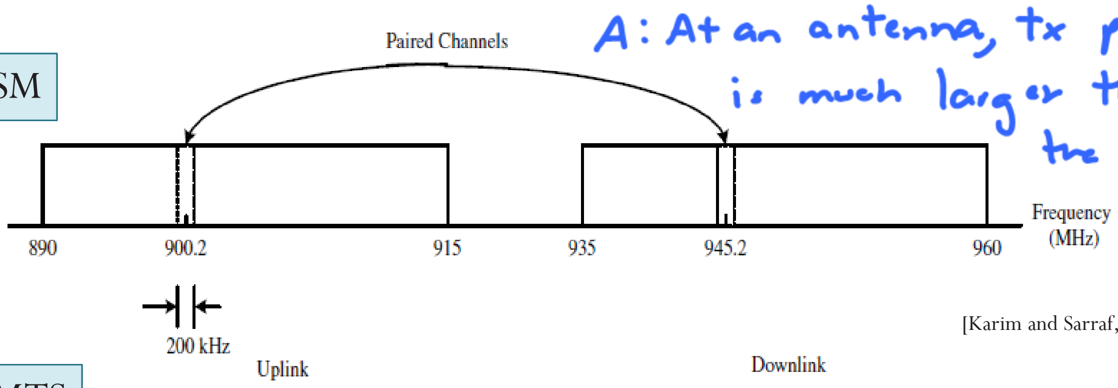
one band → simplex channel
two bands → duplex channel

- The **forward band** provides traffic from the base station to the mobile.
- The **reverse band** provides traffic from the mobile to the base station.
- Any *duplex* channel actually consists of two *simplex* channels (a forward and reverse).
- Most commercial cellular systems are based on FDD.

# FDD Examples

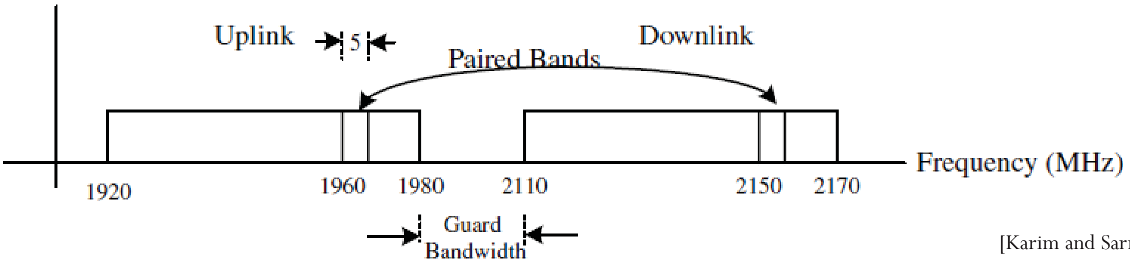
Q: Why do we need them to be far apart?
A: At an antenna, tx power is much larger than the Rx power.

2G GSM




[Karim and Sarraf, 2002, Fig 5-1]

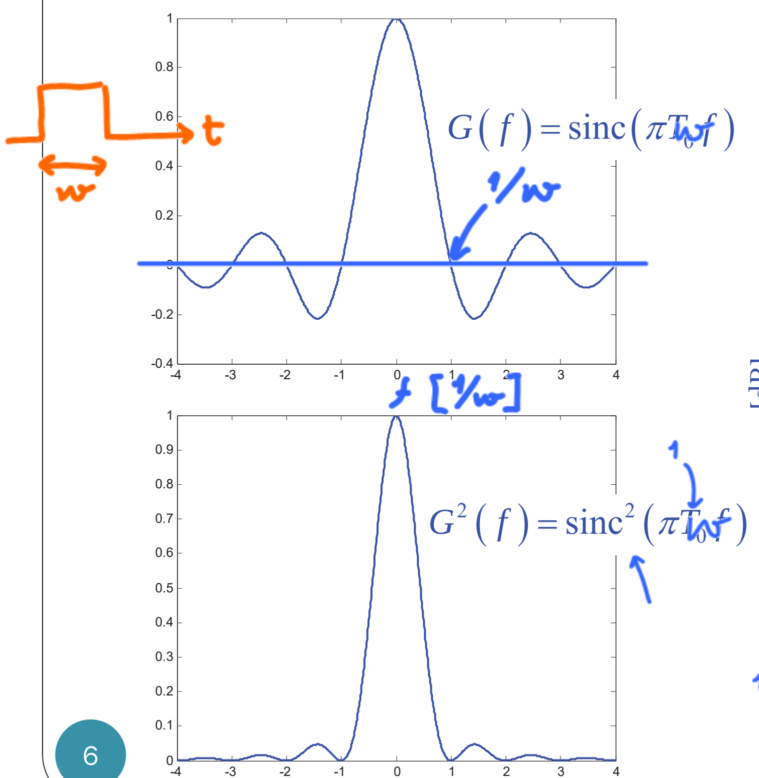
3G UMTS

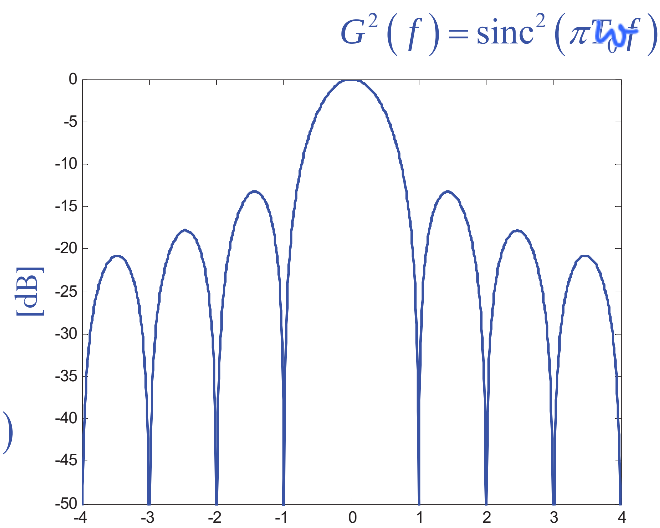



[Karim and Sarraf, 2002, Fig 6-1]



# Power of Sinc Function



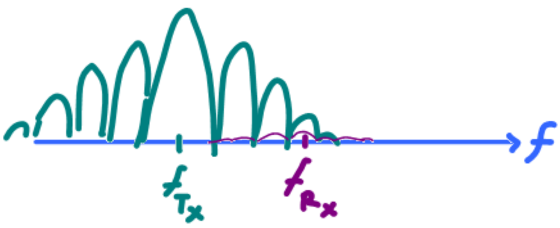




$10\log_{10}\left(\frac{1}{(\pi f)^2}\right) = -50$ dB

$f = 105.4$

# Problems of FDD

- Each transceiver simultaneously transmits and receives radio signals
  - The signals transmitted and received can vary by more than 100 dB.
  - The signals in each direction need to occupy bands that are ***separated far apart*** (tens of MHz)
- A device called a **duplexer** is required to filter out any interference between the two bands.



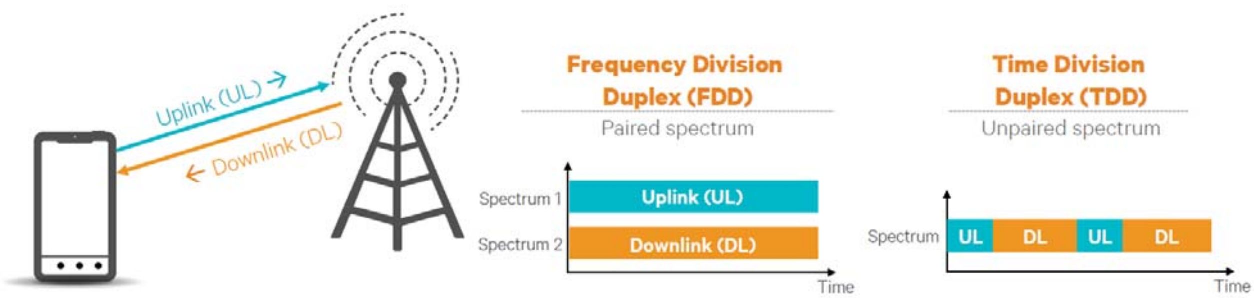

Even with filter, any practical filter is non-ideal. So, we still see the Tx power leaking into the Rx band.

[Tse and Viswanath, 2005, Ch 4, p 121]



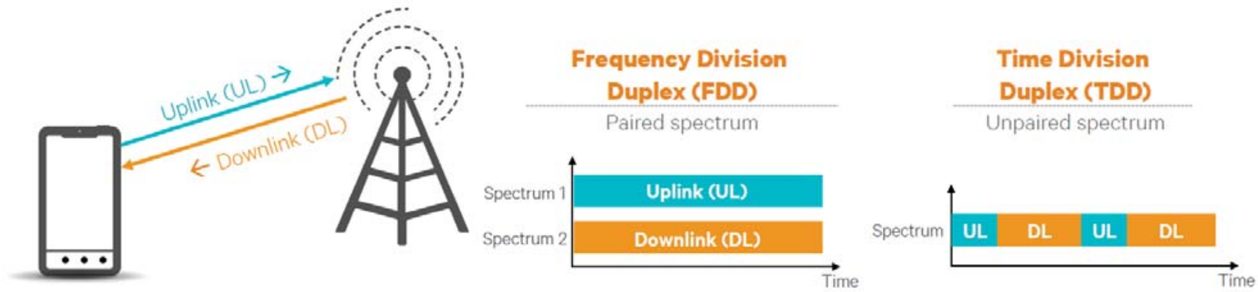
# Time Division Duplexing (TDD)

- The UL and DL data are transmitted on the **same carrier frequency** at different times. (Taking turns)
  - Use time instead of frequency to provide both forward and reverse links.
  - Each *duplex* channel has both a **forward time slot** and a **reverse time slot**.
- "Unpaired spectrum"



# Time Division Duplexing (TDD)

- If the *time separation* between the forward and reverse time slot is *small*, then the transmission and reception of data *appears* simultaneous to the users at both the subscriber unit and on the base station side.
- Used in Bluetooth and Mobile WiMAX
- LTE can be FDD or TDD.






# FDD and TDD LTE frequency bands

FDD LTE frequency band allocations

| LTE BAND NUMBER | UPLINK (MHZ) | DOWNLINK (MHz) | WIDTH OF BAND (MHZ) | DUPLEX SPACING (MHZ) | BAND GAP (MHZ) |
|---|---|---|---|---|---|
| 1 | 1920 - 1980 | 2110 - 2170 | 60 | 190 | 130 |
| 2 | 1850 - 1910 | 1930 - 1990 | 60 | 80 | 20 |
| 3 | 1710 - 1785 | 1805 -1880 | 75 | 95 | 20 |
| 4 | 1710 - 1755 | 2110 - 2155 | 45 | 400 | 355 |
| 5 | 824 - 849 | 869 - 894 | 25 | 45 | 20 |
| 6 | 830 - 840 | 875 - 885 | 10 | 35 | 25 |
| 7 | 2500 - 2570 | 2620 - 2690 | 70 | 120 | 50 |
| 8 | 880 - 915 | 925 - 960 | 35 | 45 | 10 |
| 9 | 1749.9 - 1784.9 | 1844.9 - 1879.9 | 35 | 95 | 60 |
| 10 | 1710 - 1770 | 2110 - 2170 | 60 | 400 | 340 |
| 11 | 1427.9 - 1452.9 | 1475.9 - 1500.9 | 20 | 48 | 28 |
| 12 | 698 - 716 | 728 - 746 | 18 | 30 | 12 |
| 13 | 777 - 787 | 746 - 756 | 10 | **-31** | 41 |
| 14 | 788 - 798 | 758 - 768 | 10 | **-30** | 40 |
| 15 | 1900 - 1920 | 2600 - 2620 | 20 | 700 | 680 |
| 16 | 2010 - 2025 | 2585 - 2600 | 15 | 575 | 560 |
| 17 | 704 - 716 | 734 - 746 | 12 | 30 | 18 |
| 18 | 815 - 830 | 860 - 875 | 15 | 45 | 30 |
| 19 | 830 - 845 | 875 - 890 | 15 | 45 | 30 |
| 20 | 832 - 862 | 791 - 821 | 30 | **-41** | 71 |
| 21 | 1447.9 - 1462.9 | 1495.5 - 1510.9 | 15 | 48 | 33 |
| 22 | 3410 - 3500 | 3510 - 3600 | 90 | 100 | 10 |
| 23 | 2000 - 2020 | 2180 - 2200 | 20 | 180 | 160 |
| 24 | 1625.5 - 1660.5 | 1525 - 1559 | 34 | **-101.5** | 135.5 |
| 25 | 1850 - 1915 | 1930 - 1995 | 65 | 80 | 15 |
| 26 | 814 - 849 | 859 - 894 | 30 / 40 |  | 10 |
| 27 | 807 - 824 | 852 - 869 | 17 | 45 | 28 |
| 28 | 703 - 748 | 758 - 803 | 45 | 55 | 10 |
| 29 | n/a | 717 - 728 | 11 |  |  |
| 30 | 2305 - 2315 | 2350 - 2360 | 10 | 45 | 35 |
| 31 | 452.5 - 457.5 | 462.5 - 467.5 | 5 | 10 | 5 |

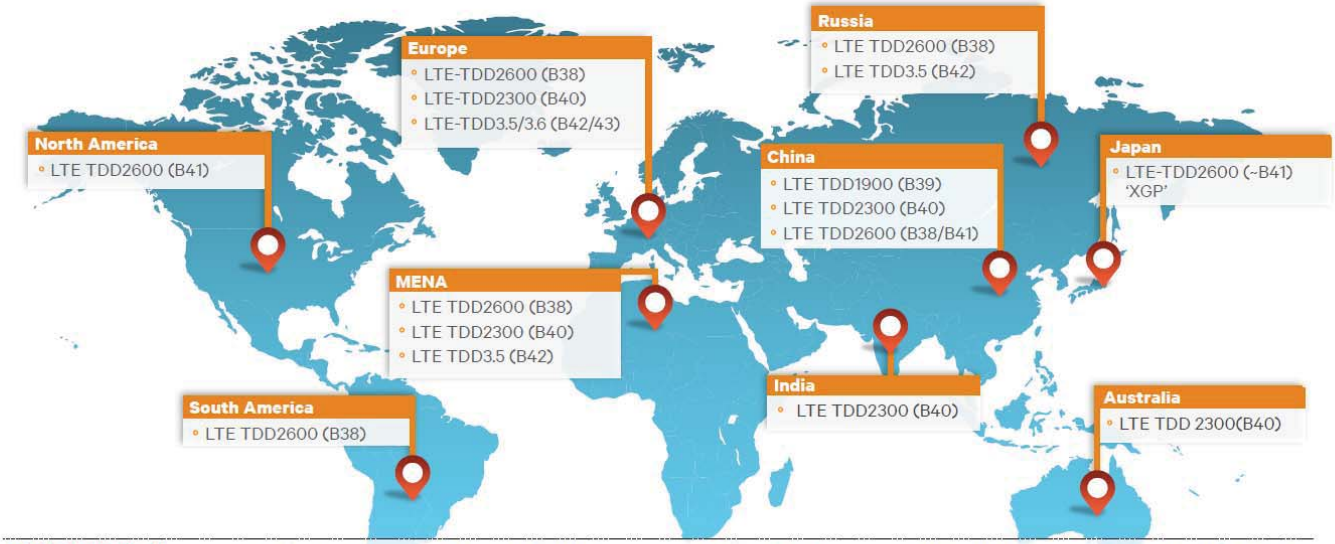
TDD LTE frequency band allocations

| LTE BAND NUMBER | ALLOCATION (MHZ) | WIDTH OF BAND (MHZ) |
|---|---|---|
| 33 | 1900 - 1920 | 20 |
| 34 | 2010 - 2025 | 15 |
| 35 | 1850 - 1910 | 60 |
| 36 | 1930 - 1990 | 60 |
| 37 | 1910 - 1930 | 20 |
| 38 | 2570 - 2620 | 50 |
| 39 | 1880 - 1920 | 40 |
| 40 | 2300 - 2400 | 100 |
| 41 | 2496 - 2690 | 194 |
| 42 | 3400 - 3600 | 200 |
| 43 | 3600 - 3800 | 200 |
| 44 | 703 - 803 | 100 |

- LTE TDD has been commercial since 2011 and is gaining global momentum.
- The initial global unpaired bands include
  - 2.3GHz (B40) used in India and
  - 2.6 GHz (B38) used Europe,
  - with variations (B41) in the U.S. and Japan.
- China is expected to launch LTE TDD in multiple global bands.

[http://www.radio-electronics.com/info/cellulartelecomms/lte-long-term-evolution/lte-frequency-spectrum.php]

# Global LTE TDD spectrum

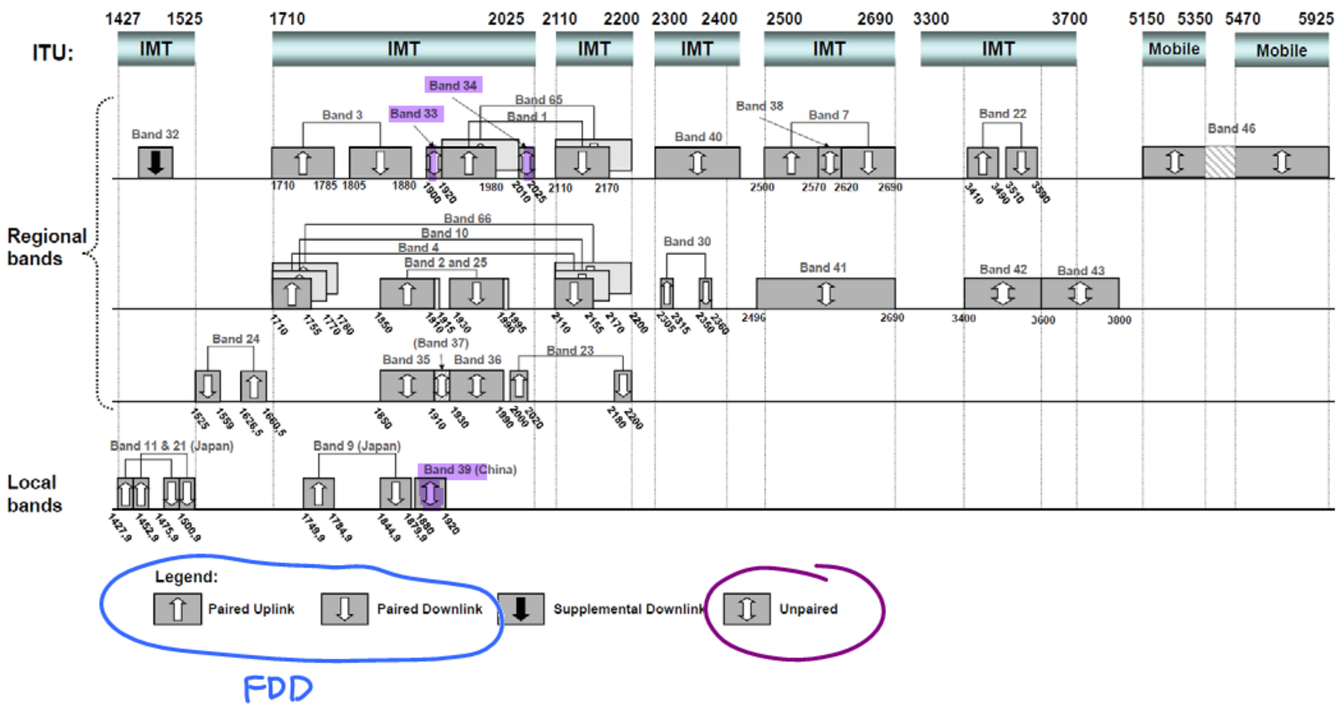



| | | | | | |
|---|---|---|---|---|---|
| Global unpaired spectrum | 1.9 GHz (B39)<br>1880 MHz to 1920 MHz | 2.3 GHz (B40)<br>2300 MHz to 2400 MHz | 2.6 GHz (B38)[1]<br>2570 MHz to 2620 MHz | 2.6 GHz (B41 )<br>2496 MHz to 2690 MHz | ~3.6 GHz (B42/43)<br>3.4 to 3.6 and 3.6 to 3.8 |
| Potential Spectrum | 40MHz | 100 MHz | 50 MHz | 194 MHz | 400 MHz |



[Qualcomm, "LTE TDD - the global solution for unpaired spectrum", September, 2014]

# Operating bands specified for LTE in 3GPP above 1 GHz

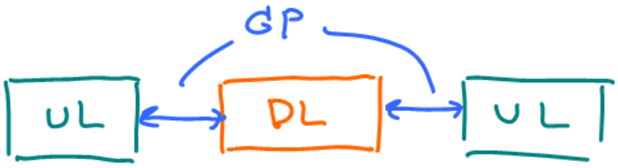





[Dahlman, Parkvall, and Skold, 2016]

# Disadvantages of TDD
# Advantages of FDD

- TDD frames need to incorporate guard periods **equal to the max round trip propagation delay** to avoid interference between uplink and downlink under worst-case conditions.




- There is a **time latency** created by TDD due to the fact that communications is not full duplex in the truest sense.

Not true duplex



# Disadvantages of FDD
# Advantages of TDD

- Duplexer is not required.
- Enable *adjustment* of the downlink/uplink ratio to efficiently support *asymmetric* DL/UL traffic.
  - With FDD, DL and UL have fixed and generally, equal DL and UL *bandwidths*.
- Ability to implement in ***unpaired spectrum***
  - FDD requires a pair of channels
  - TDD only requires a single channel for both DL and UL providing greater flexibility for adaptation to varied global spectrum allocations.
- Assure ***channel reciprocity*** for better support of link adaptation, MIMO and other closed loop advanced antenna technologies.

# Channel Reciprocity

- Usually, for better performance, to choose the coding/modulation scheme and its parameters, the transmitter needs to learn the channel state information (CSI).
- It is relatively easier for a receiver to find CSI.
  - Is the decoded message readable or gibberish?
  - Usually, this is done by the transmitter sending a preamble training sequences or pilot symbols to the receiver.
- How can a transmitter obtain CSI?
  - The corresponding receiver may convey this information via a feedback link.
    - An overhead which reduce the efficiency of the system.
      - Even worse when there are many parameters of the channel to learn.
        - For example, for MIMO, there are many antennas.
    - The information can only be used for a short time duration.
      - The channel changes due to mobility of the Tx, Rx, or objects in the environment.
  - Use channel reciprocity



# Channel Reciprocity

- The channel from point A to point B is identical to the channel from B to A if the channel is measured at the same time and same frequency.
- The channel from A to B can be estimated at A using the pilot symbols embedded in the signal sent from B.
- Using the reciprocity principle, this estimate is also an estimate for the channel from A to B.
- In FDD systems, the two directions use different frequencies. Thus, channel reciprocity does not hold.

# Chapter 4

## Multiple Access

### 4.2 FDMA and TDMA

Dr.Prapun Suksompong
prapun.com/ecs455

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# 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

# 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.



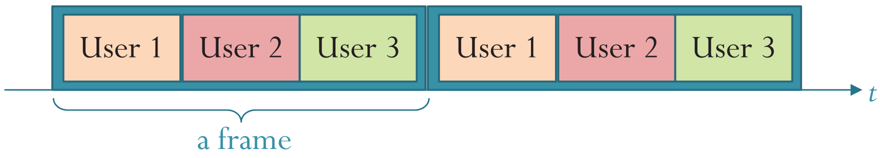
# FDMA (2)

- **Band-pass filtering** (or heterodyning) enables separate demodulation of each channel.
- 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.

[Rappaport, 2002, Ch 9, p. 449]

# Time division multiple access (TDMA)

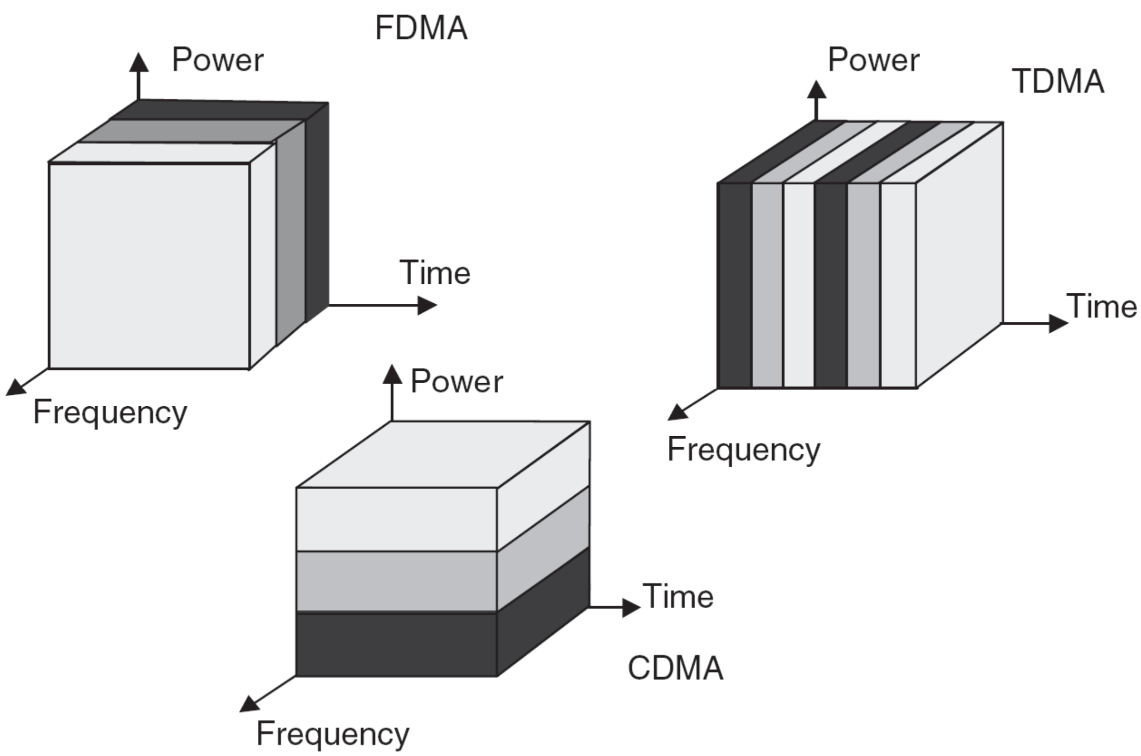
- Divide the radio spectrum into **time slots**.
- In each slot only one user is allowed to either transmit or receive.
- A channel may be thought of as a particular time slot that reoccurs every frame, where *N* time slots comprise a frame.




- 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

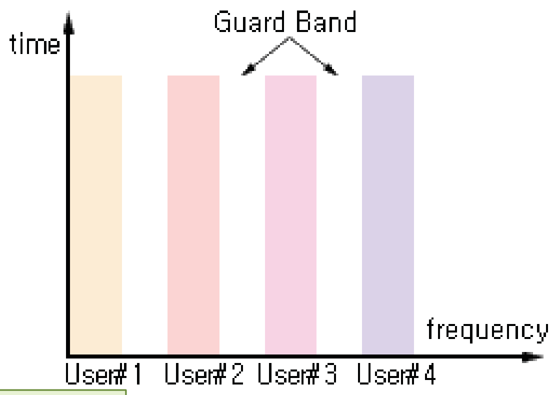


# Tradeoffs

- TDMA transmissions are slotted
  - Require the receivers to be **synchronized** for each data burst.
  - **Guard times** 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.

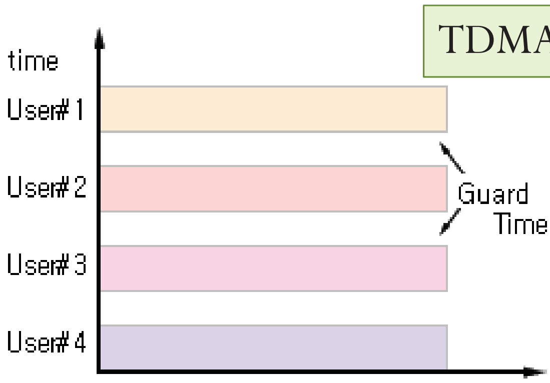


# Guard Band vs. Guard Time

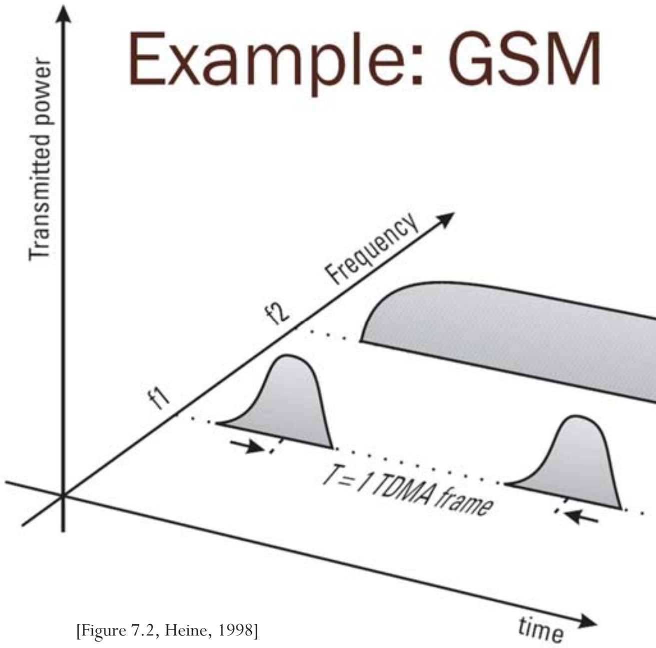



FDMA

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

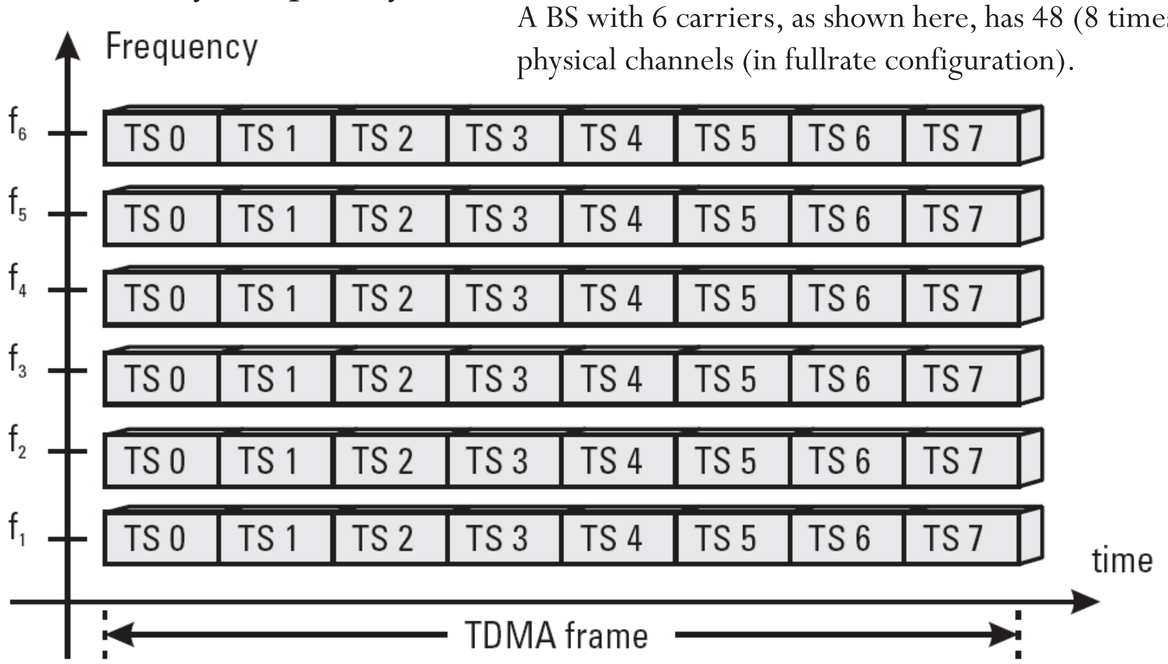
- Each narrowband channel has bandwidth 200 kHz.
- Time is divided into slots of length T =577 μs.



# The FDMA/TDMA structure of GSM

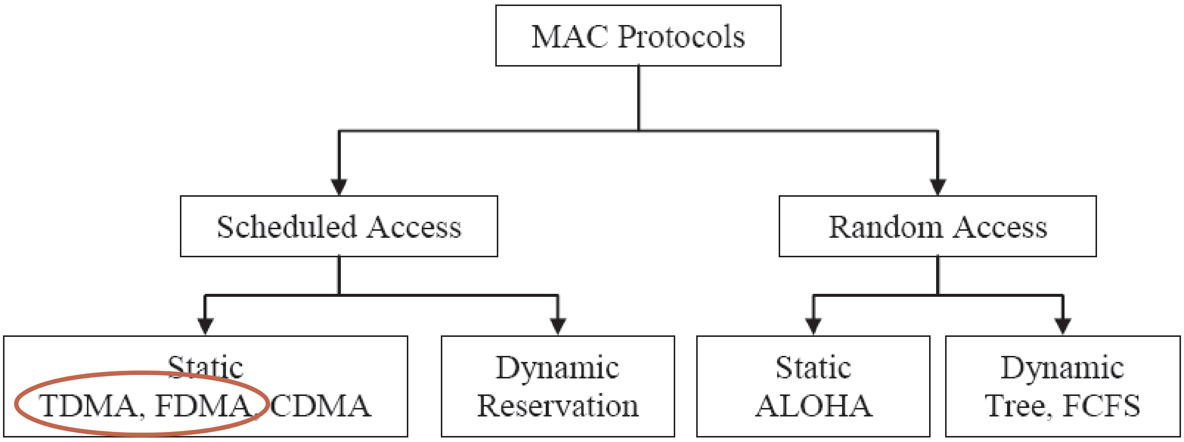
- In full-rate configuration, eight time slots (TSs) are mapped on every frequency.

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




[Figure 7.1, Heine, 1998]

# Classifications of Medium Access Control (MAC)






# Multiple Access Techniques in Cellular System

| Cellular System | Multiple Access Technique |
|---|---|
| Advanced Mobile Phone System (AMPS) | FDMA/FDD |
| Global System for Mobile (GSM) | TDMA/FDD |
| Interim Standard 95 (IS-95) | CDMA/FDD |
| W-CDMA (3GPP) | CDMA/FDD<br>CDMA/TDD |
| cdma2000 (3GPP2) | CDMA/FDD<br>CDMA/TDD |

# FDMA or TDMA?

Used exclusively for multiple access in **1G** down to individual resource units or physical channels



# FDMA or TDMA?

Transmit data in **buffer-and-burst** method

## FDMA or TDMA?

Need to use costly **bandpass filters**



## FDMA or TDMA?

Allows completely **uncoordinated** transmission in the **time domain**