ECS455: Chapter 4
Multiple Access

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1

ECS455: Chapter 4
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4.1 Duplexing: TDD and FDD

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2

Duplexing

- Allow the subscriber to send "simultaneously" information to the base station while receiving information from the base station.
  - 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)
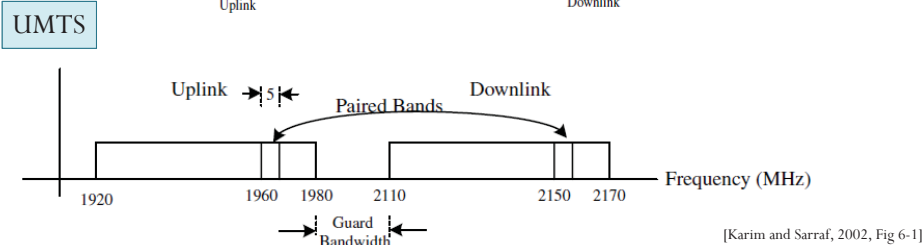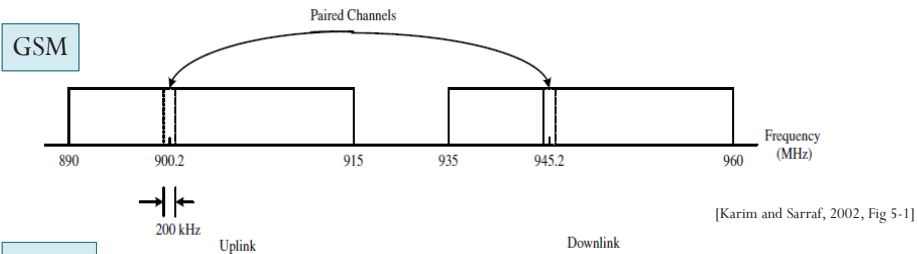 2. Time division duplexing (TDD)

[Rappaport, 2002, Ch 9]

3

Frequency Division Duplexing (FDD)

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

4

FDD Examples

Paired Channels

890 900.2 915 935 945.2 960 Frequency (MHz)

200 kHz

Uplink Downlink

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

UMTS

Uplink 5 Downlink
Paired Bands

1920 1960 1980 2110 2150 2170 Frequency (MHz)

Guard Bandwidth

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

5

Power of Sinc Function

$G(f) = \mathrm{sinc}(\pi T_0 f)$

$G^2(f) = \mathrm{sinc}^2(\pi T_0 f)$

$G^2(f) = \mathrm{sinc}^2(\pi T_0 f)$

[dB]

6

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.
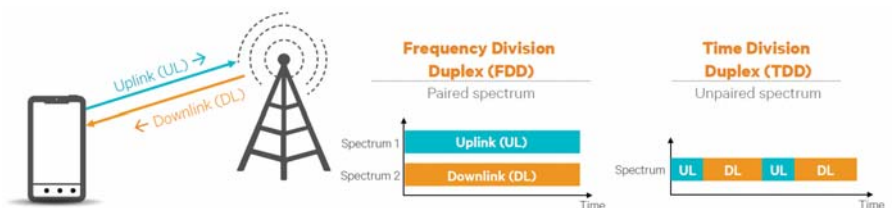
[Tse and Viswanath, 2005, Ch 4, p 121]
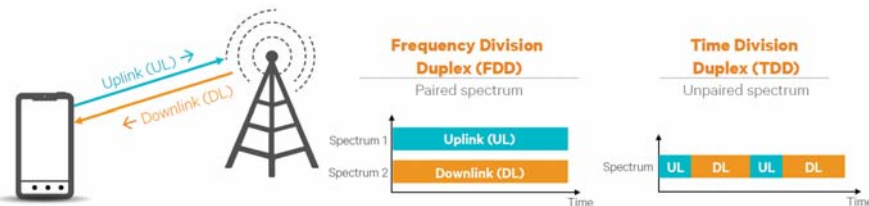
7
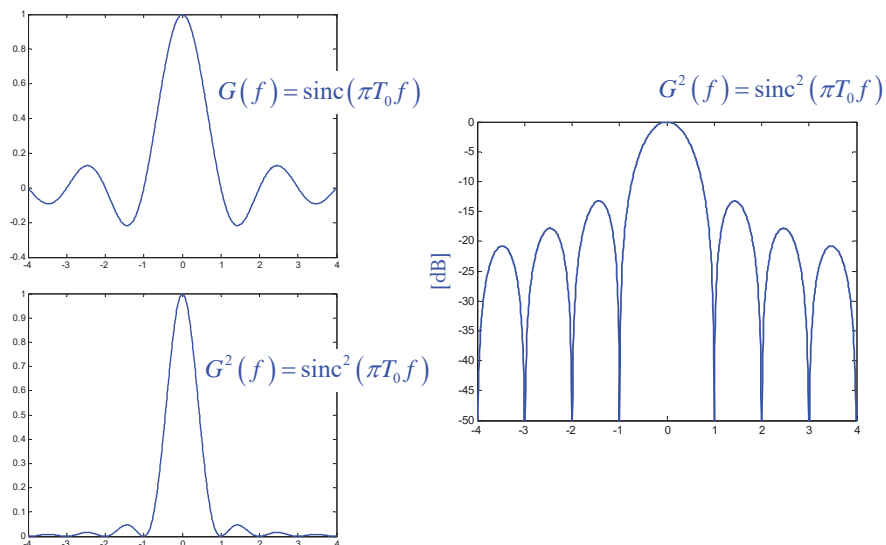
Time Division Duplexing (TDD)

- 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"

Uplink (UL) →
← Downlink (DL)

Frequency Division Duplex (FDD)
Paired spectrum

Spectrum 1 **Uplink (UL)**
Spectrum 2 **Downlink (DL)**
Time

Time Division Duplex (TDD)
Unpaired spectrum
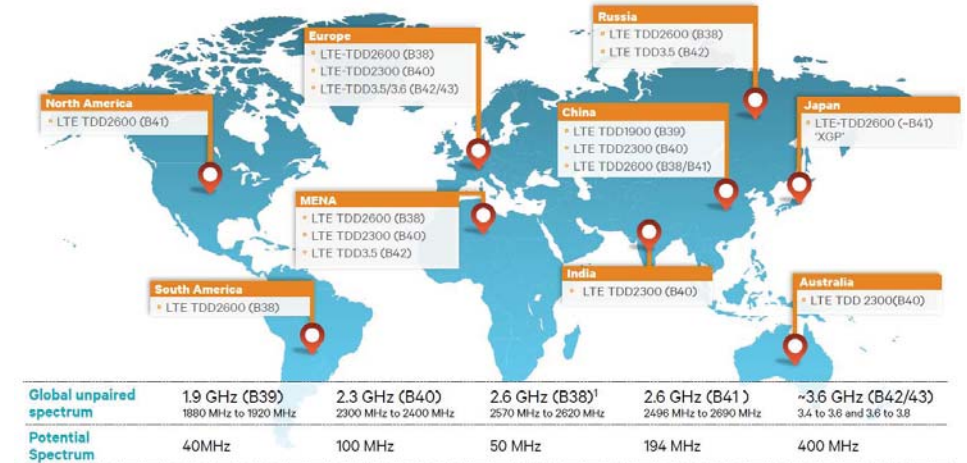
Spectrum UL DL UL DL
Time

8

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.

Global LTE TDD spectrum

Global unpaired spectrum	1.9 GHz (B39) 1880 MHz to 1920 MHz	2.3 GHz (B40) 2300 MHz to 2400 MHz	2.6 GHz (B38)[1] 2570 MHz to 2620 MHz	2.6 GHz (B41) 2496 MHz to 2690 MHz	~3.6 GHz (B42/43) 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]

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]

Operating bands specified for LTE in 3GPP above 1 GHz
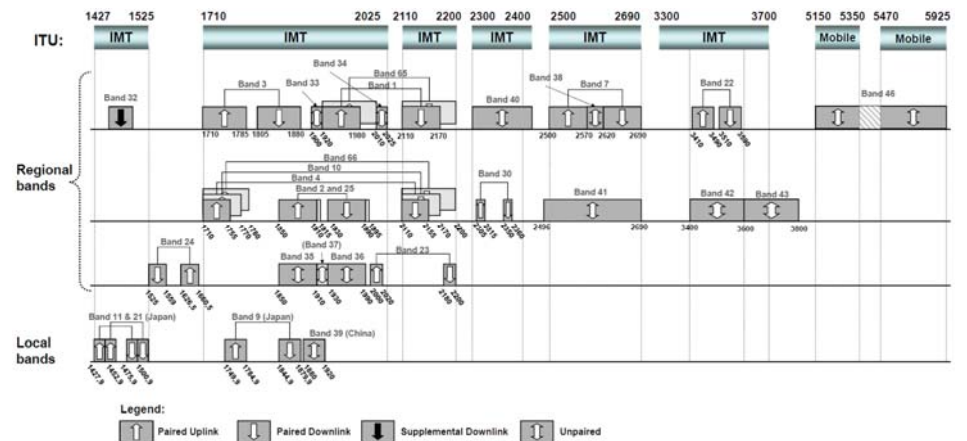
[Dahlman, Parkvall, and Skold, 2016]

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.

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

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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.
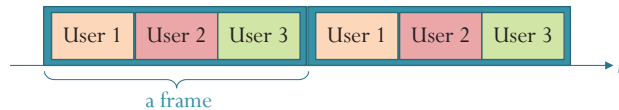
- Transmit data in a **buffer-and-burst method**
  - The transmission for any user is non-continuous.
  - Digital data and digital modulation must be used with TDMA.
  - This results in low battery consumption, since the subscriber transmitter can be turned off when not in use (which is most of the time).
- An obvious choice in the 1980s for digital mobile communications.

21

FDMA vs. TDMA

22

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**.
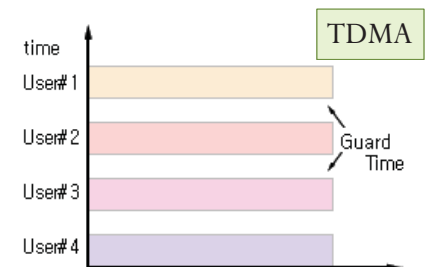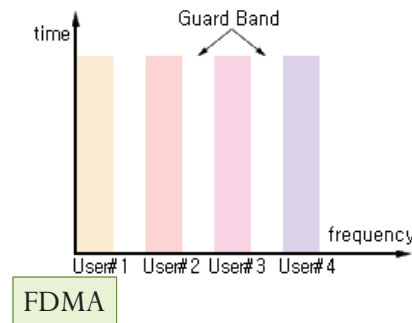 - For TDMA, no filters are required to separate individual physical channels.

23
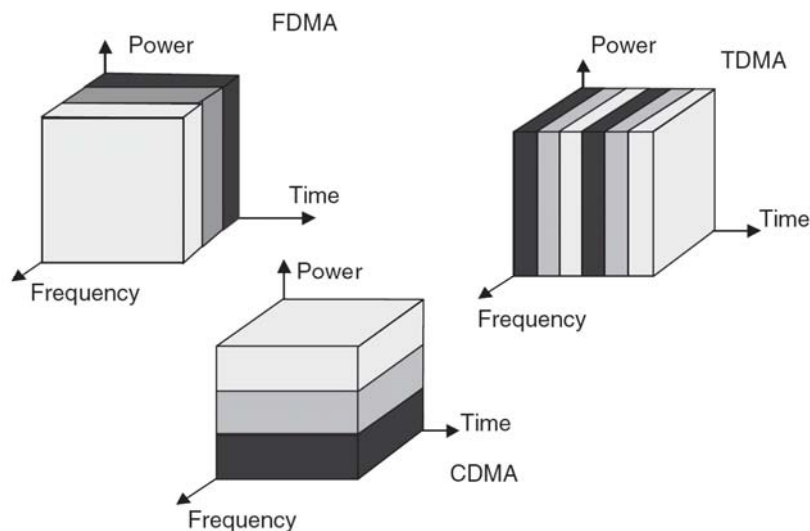
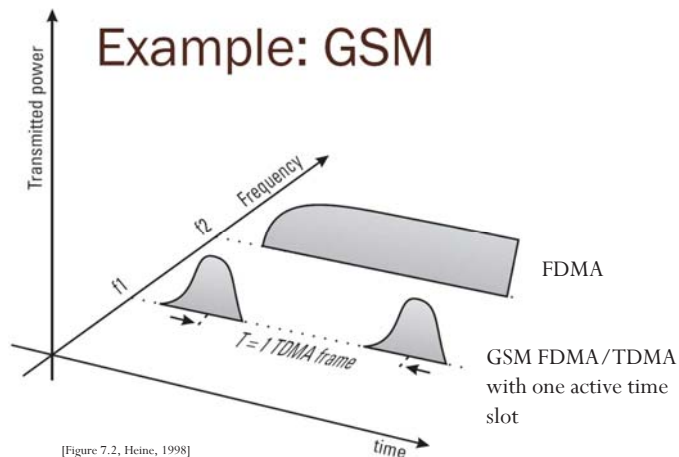## Guard Band vs. Guard Time

24

Example: GSM

FDMA

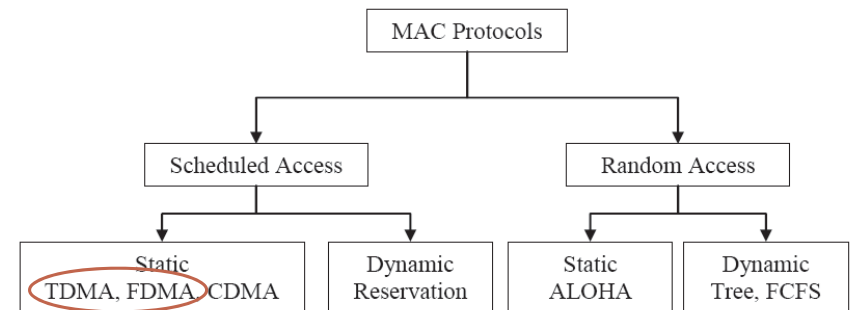GSM FDMA/TDMA with one active time slot

[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.

25

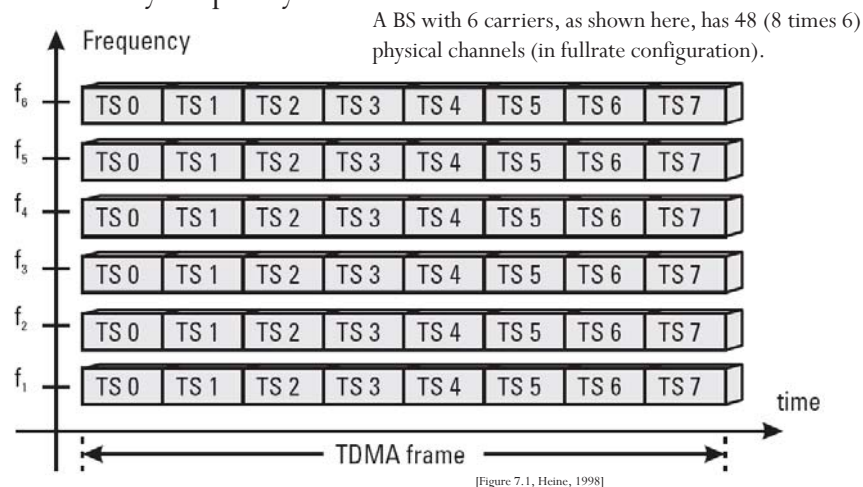## The FDMA/TDMA structure of GSM

- 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]

26

Classifications of Medium Access Control (MAC)

27

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 CDMA/TDD
cdma2000 (3GPP2)	CDMA/FDD CDMA/TDD

28