ECS455: Chapter 6

Applications

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Office Hours:
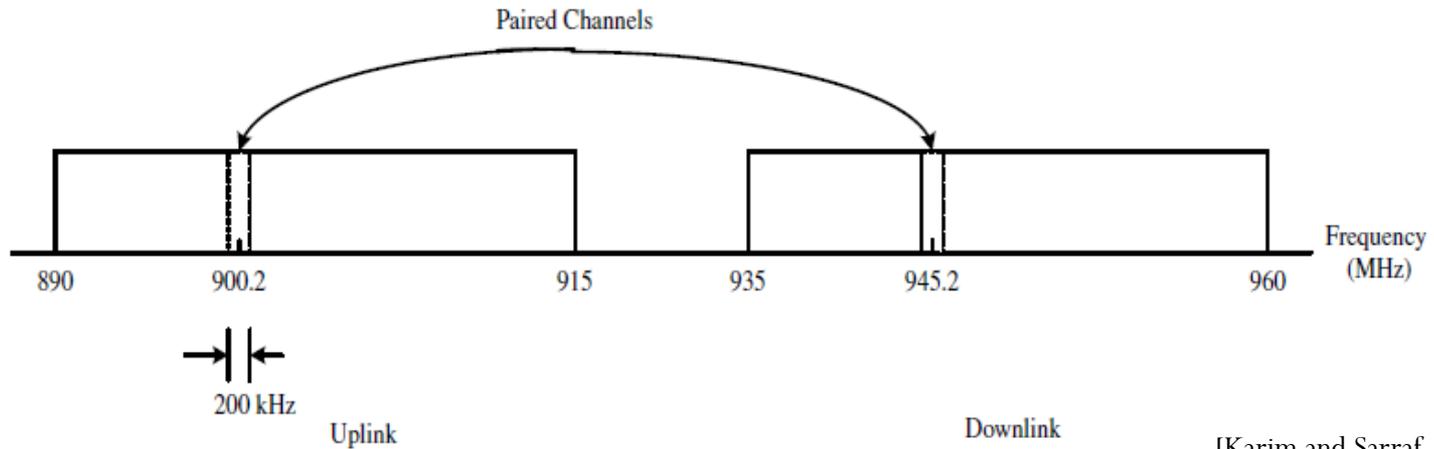**BKD 3601-7**
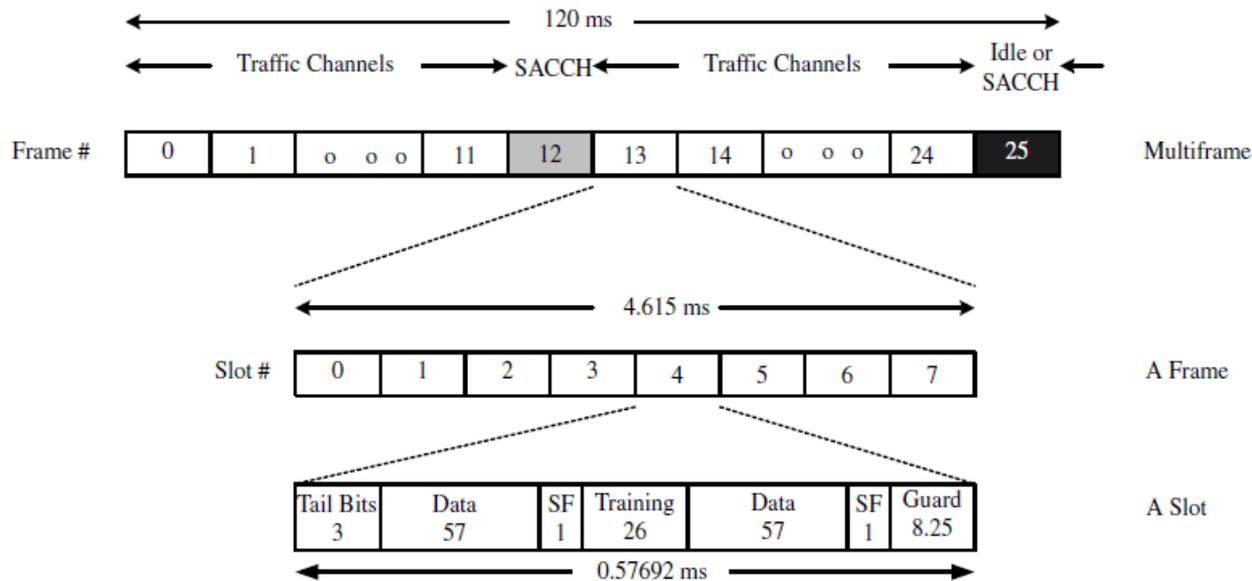**Tuesday 9:30-10:30**
Friday   14:00-16:00

Cellular History

- The **first-generation (1G)** systems introduced in the 1980s were characterized by **analog speech transmission**.
- The **second-generation (2G)** systems, developed in the 1990s, are **digital** and have data transport capabilities but only to a limited extent.
  - **GSM** supports SMSs and user data at rates only up to 9.6 kb/s.
    - Security features including (for example) the encryption of data and signaling messages on the path between the mobile phone and the BS.
    - Subscriber identity module (SIM)
      - A smart card
      - Contain the subscriber's personal details
      - Can be moved from one handset to another.
  - **IS-95B** (**cdmaOne**) provides data rates in the range of 64 to 115 kb/s in increments of 8 kb/s over a **1.25 MHz channel**.
    - Each cell uses a carrier with a bandwidth of 1.25MHz, which is divided into 64 data and signalling channels by the use of orthogonal CDMA codes.

Review: GSM (2G)

Paired Channels

Frequency (MHz)

890   900.2   915   935   945.2   960

200 kHz

Uplink   Downlink

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

120 ms

Traffic Channels → SACCH ← Traffic Channels → Idle or SACCH

| Frame # | 0 | 1 | o o o | 11 | 12 | 13 | 14 | o o o | 24 | 25 | Multiframe |

4.615 ms

| Slot # | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | A Frame |

| Tail Bits 3 | Data 57 | SF 1 | Training 26 | Data 57 | SF 1 | Guard 8.25 | A Slot |

0.57692 ms

[Karim and Sarraf, 2002, Fig 5-10]

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2.5G: GSM Enhancement

- Want to deliver *data* as well as voice.

- **General Packet Radio Service (GPRS)**

- **Enhanced Data Rates for GSM Evolution (EDGE)**

2.5G: GPRS

- **General Packet Radio Service**
- The first commercial launches for GPRS took place in 2001.
- Provide connectivity to IP networks (Internet).
- Construction of a **packet switched** core network, to run alongside the **circuit switched** network that was originally built for GSM.
- A single time slot may be shared by multiple users for transferring packet mode data
- Each slot can handle up to 20 kb/s. Each user may be allocated up to 8 slots
  - Data rates up to about 160 kb/s per user are possible.
  - A good approximation for throughput in "average" conditions is 10 Kbps per time slot. [Korhonen, 2003]
- Especially suitable for non-real-time applications, such as e-mail and Web surfing.
- Bursty data is well handled with GPRS, as it can adjust the assigned resources according to current needs.
- Not well-suited for real-time applications
  - Resource allocation in GPRS is contention based
  - Cannot guarantee an absolute maximum delay.

2.5G: EDGE

- **Enhanced Data Rates for GSM Evolution**
  - Originally this acronym stood for Enhanced Data rates for GSM Evolution, but now it translates into **Enhanced Data rates for Global Evolution**, as the EDGE idea can also be used in systems other than GSM [Korhonen, 2003]
- Support IP-based services in GSM at rates up to 384 kb/s
- Higher modulation efficiency
  - **Eight-phase shift keying (8PSK)**
    - Can only be used effectively over a short distance.
    - For wide area coverage, the old GMSK (Gaussian minimum shift key) is still needed.
- Only requires a **software upgrade** to base stations if the RF amplifiers can handle the non-constant envelope modulation with EDGE's relatively high peak-to-average power ratio (PAPR).
- EDGE is popular in North America, where the allocation of carrier frequencies has made it hard for GSM operators to upgrade to UMTS.

Motivation

Voice/SMS
~9.6Kbps

Mobile Narrow Band Internet
14.4~64Kbps

Low-QoS Mobile Multimedia Services
64~144Kbps

High-quality, Smooth and Low-delay Video, Voice, and Music Services
20~300Kbps

Mobile Broadband Internet Surfing
64~300Kbps

Abundant and High-quality New Mobile Services
300K~5Mbps

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6.1 3G (UMTS and WCDMA)

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3G

- International Mobile Telecommunications-2000 (IMT-2000)
  - A subgroup of the International Telecommunication Union (ITU)
  - Published a set of performance requirements of 3G (for both packet-switched and circuit-switched data):
    - A minimum data rate of 144 Kbps in the vehicular environment
    - A minimum data rate of 384 Kbps in the pedestrian environment
    - A minimum data rate of 2 Mbps in the fixed indoor and picocell environment
- There are several wireless standards and systems that qualify as third generation (3G) systems
  - UMTS
  - CDMA2000

UMTS

- **Universal Mobile Telecommunications System** (**UMTS**)
- The research activity on UMTS started in **Europe** at the beginning of the 1990s.
  - Even before the earliest 2G systems arrived on the market
- Designed to support wideband services with data rates up to **2Mbit/s**.
- Developed **from GSM**
  - Keep the core network more-or-less intact
  - Change the air interface to use **CDMA**
- Compatibility between UMTS and GSM:
  - Most UMTS mobiles also implement GSM, and the network can hand them over from a UMTS base station to a GSM one if they reach the edge of the UMTS coverage area.
  - However, network operators cannot implement the two systems in the same frequency band, so they are not fully compatible with each other.
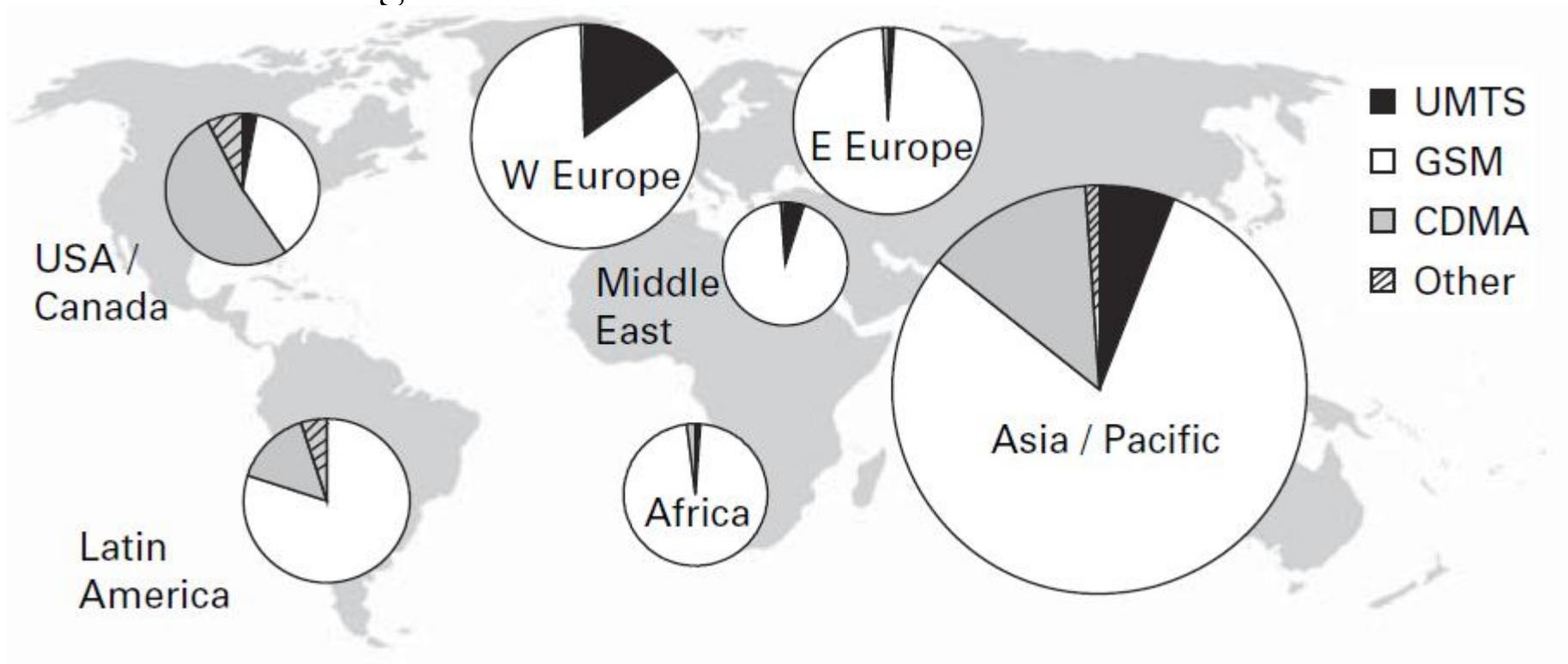
Bandwidth Comparison

Generation	Transmission Bandwidth	Standard
1G	25 and 30 kHz	
2G	200 kHz	GSM
	1.25 MHz	IS-95 (CDMA)
2.5G	1.25 MHz	CDMA2000 1X-RTT
3G	5 MHz for	*UMTS* WCDMA and CDMA2000 3X-RTT
"4G"	Up to 20 MHz	LTE and WiMAX (802.16)

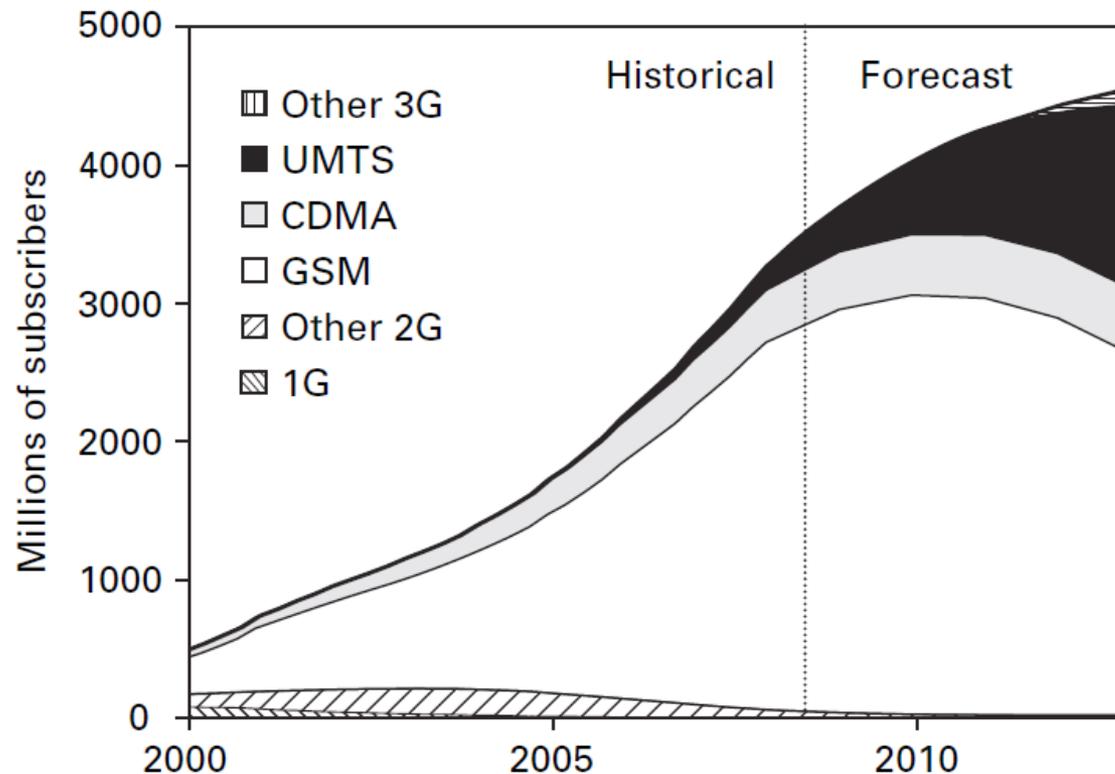Wider and wider radio frequency bands!

Market Share

- Numbers of subscribers to different mobile communication technologies in 2008.


[Cox, 2008, Fig 1.15]

Growth

- Growth in the use of different mobile telecommunication technologies, with historical data from 2000 to 2008, and forecasts from 2008 to 2013.

[Cox, 2008, Fig 1.16]

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UMTS: FDD

- UMTS = Universal Mobile Telecommunications System

- The **chip rate** for spectrum spreading is 3.84 Mc/s.

- The maximum transmitter power of the user equipment is in the range of 21 to 33 dBm (that is, 125 mW to 2 W)

$$\left(10^{21/10}\,\text{mW}\right) \quad \left(10^{33/10}\,\text{mW}\right)$$

(0 dBm or dBmW = 1 mW)
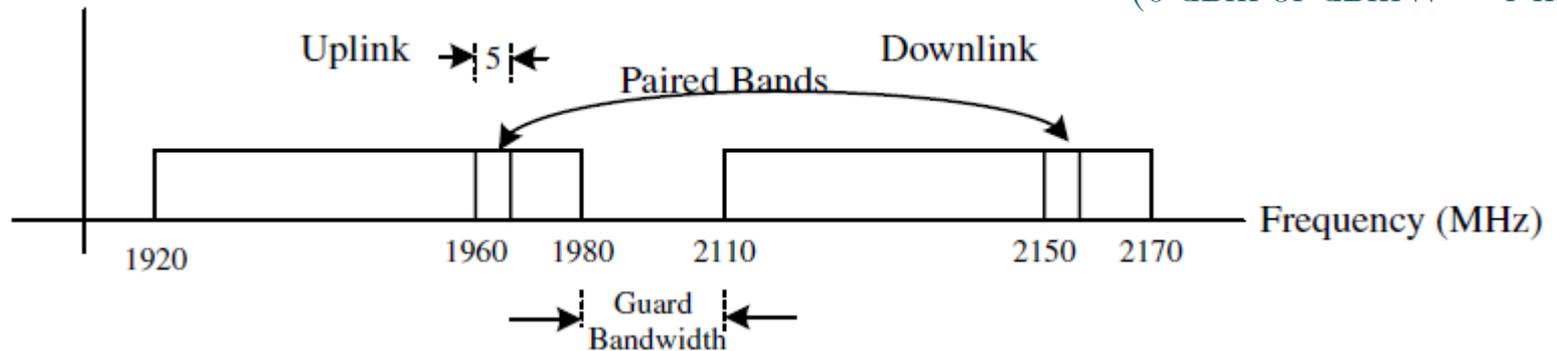

[Karim and Sarraf, 2002, Fig 6-1]

UMTS W-CDMA FDD and TDD
(UMTS Terrestrial Radio Access)

- The air interface (UTRA) of UMTS is based on CDMA

- UMTS W-CDMA **FDD**
  - Direct-sequence CDMA system
  - **5 MHz** bandwidth

- UMTS W-CDMA **TDD**
  - Also uses CDMA with a bandwidth of 5 MHz
  - The frequency band is time shared in both directions—one half of the time, it is used for transmission in the forward direction and the other half of the time in the reverse direction.

- FDD is currently much more popular
  - to the extent that we will not discuss TDD at all

cdma2000

- Another 3G mobile technology standard
- Multicarrier, direct-sequence CDMA FDD system.
- Backward-compatible with its previous 2G iteration IS-95 (cdmaOne).
- **CDMA2000 1X** (**IS-2000**)
  - also known as 1x and 1xRTT
  - 1x = Spreading Rate 1 = use the same chip rate of IS-95 (i.e., 1.2288 Mcps).
    - Same RF bandwidth as IS-95: a duplex pair of 1.25 MHz radio channels.
  - Core CDMA2000 wireless air interface standard.
  - Almost doubles the capacity of IS-95 by adding 64 more traffic channels to the forward link, orthogonal to (in quadrature with) the original set of 64.
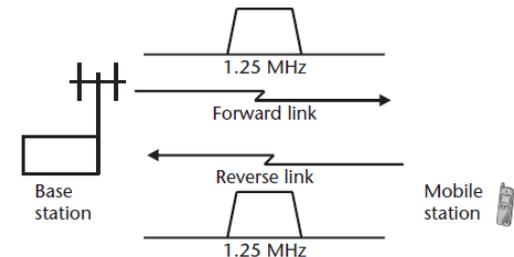
3G Spreading Codes

- In UMTS and cdma2000, signaling and user data is spread twice in succession
  - First with the channelization codes
    - Orthogonal **Walsh codes**
    - Inherently more tolerant of interference caused by multiple users.
  - Later with the scrambling codes
    - Not necessarily orthogonal
    - Built from **PN codes**
- In contrast to IS-95, the WCDMA/UMTS standard applies **variable length** orthogonal spreading codes and coherent QPSK detection for both uplink and downlink directions.

OVSF (1)

- Channelization codes used in UMTS W-CDMA and cdma2000 are **variable-length Walsh codes**, also known **as orthogonal variable spreading factor (OVSF)** codes.

- The spreading factors in UMTS may vary from 4 to 256 chips on uplink channels and from 4 to 512 chips on downlink channels.
  - In cdma2000, OVSF codes used on traffic channels may vary from 4 to 128 chips.

- **Comparison**: IS-95 uses a set of 64 fixed-length Walsh codes to spread forward physical channels. In the reverse direction, they are used for orthogonal modulation where every six symbols from the block interleaver output are modulated as one of 64 Walsh codes.
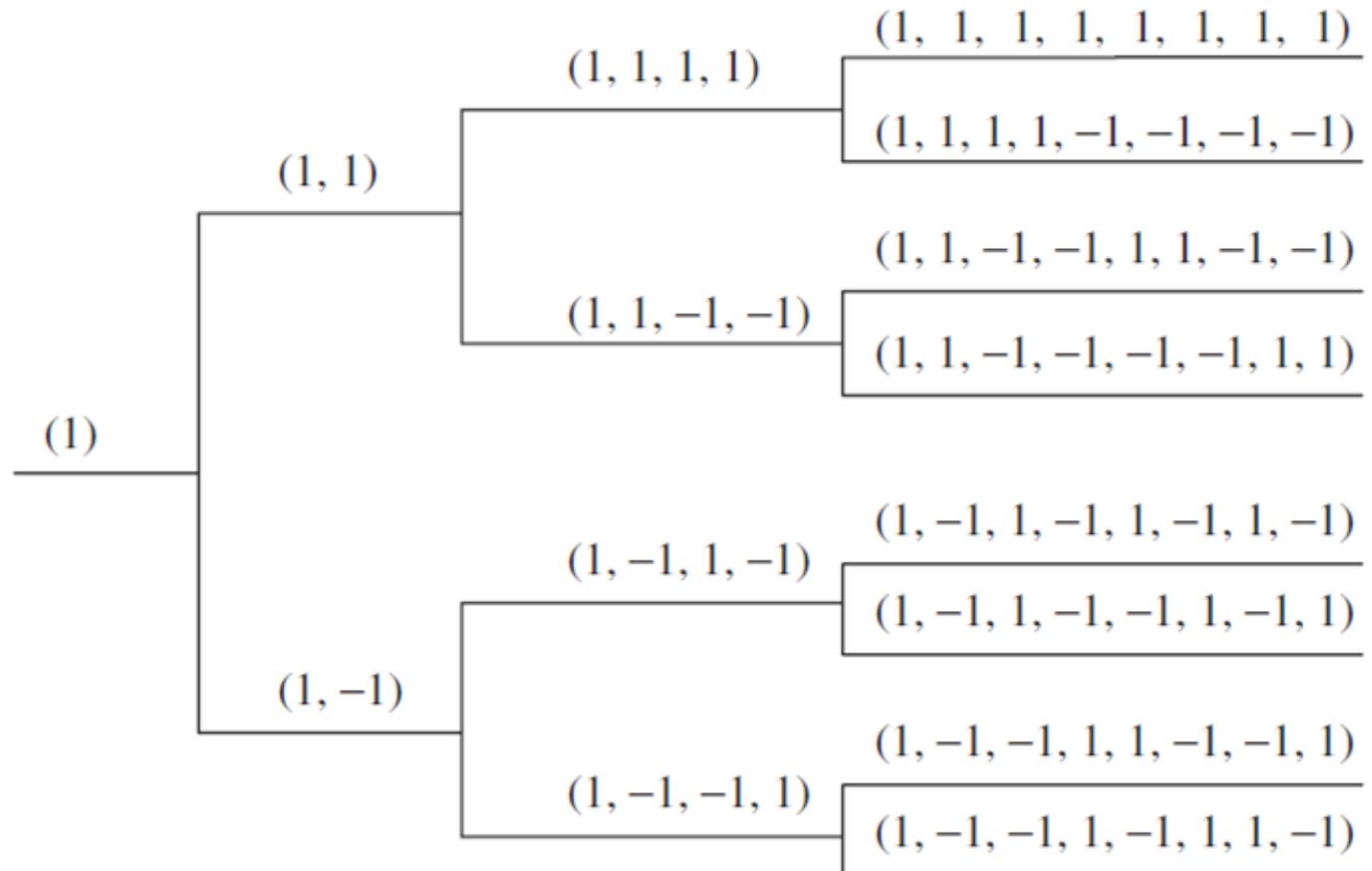
OVSF (2)

- Similar to Walsh sequences
  - Arranged and numbered in a different way
- Use a tree structure
- For each **spreading factor SF** = 1, 2, 4, . . . , which is a power of 2, there are N = SF orthogonal codes obtained by the recursion relations:

$$c_{2SF,2m} = [c_{SF,m}, c_{SF,m}], \quad m = 0, 1, \ldots, SF - 1.$$

$$c_{2SF,2m+1} = [c_{SF,m}, -c_{SF,m}], \quad m = 0, 1, \ldots, SF - 1.$$

- Different data rates are supported on a physical channel by simply changing the spreading factor of the associated code.

Tree structure for OVSF codes (1)

Rule:

(C) branches into (C, C) and $(C, -C)$

(1)

$(1, 1)$
- $(1, 1, 1, 1)$
  - $(1, 1, 1, 1, 1, 1, 1, 1)$
  - $(1, 1, 1, 1, -1, -1, -1, -1)$
- $(1, 1, -1, -1)$
  - $(1, 1, -1, -1, 1, 1, -1, -1)$
  - $(1, 1, -1, -1, -1, -1, 1, 1)$

$(1, -1)$
- $(1, -1, 1, -1)$
  - $(1, -1, 1, -1, 1, -1, 1, -1)$
  - $(1, -1, 1, -1, -1, 1, -1, 1)$
- $(1, -1, -1, 1)$
  - $(1, -1, -1, 1, 1, -1, -1, 1)$
  - $(1, -1, -1, 1, -1, 1, 1, -1)$
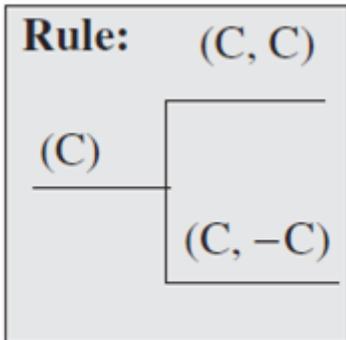
Tree structure for OVSF codes (2)

$C_{N,j}$

length of the code (SF)

$C_{1,0} = [1]$

$C_{2,0} = [1\ 1]$

$C_{2,1} = [1\ -1]$

$C_{4,0} = [1\ 1\ 1\ 1]$

$C_{4,1} = [1\ 1\ -1\ -1]$

$C_{4,2} = [1\ -1\ 1\ -1]$

$C_{4,3} = [1\ -1\ -1\ 1]$

$C_{8,0} = [1\ 1\ 1\ 1\ 1\ 1\ 1\ 1]$

$C_{8,1} = [1\ 1\ 1\ 1\ -1\ -1\ -1\ -1]$

$C_{8,2} = [1\ 1\ -1\ -1\ 1\ 1\ -1\ -1]$

$C_{8,3} = [1\ 1\ -1\ -1\ -1\ -1\ 1\ 1]$

$C_{8,4} = [1\ -1\ 1\ -1\ 1\ -1\ 1\ -1]$

$C_{8,5} = [1\ -1\ 1\ -1\ -1\ 1\ -1\ 1]$

$C_{8,6} = [1\ -1\ -1\ 1\ 1\ -1\ -1\ 1]$

$C_{8,7} = [1\ -1\ -1\ 1\ -1\ 1\ 1\ -1]$
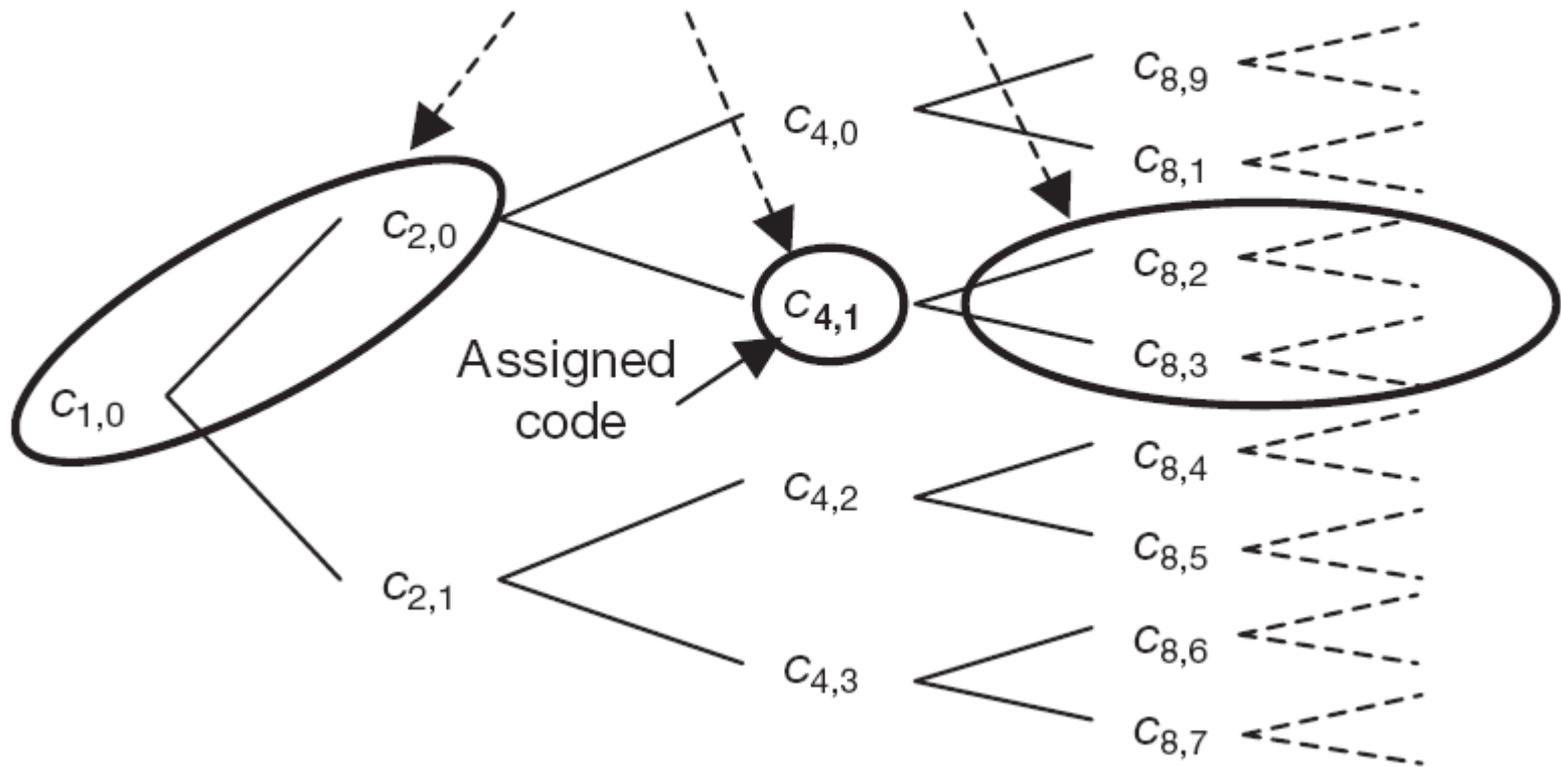
SF = 1   SF = 2   SF = 4   SF = 8
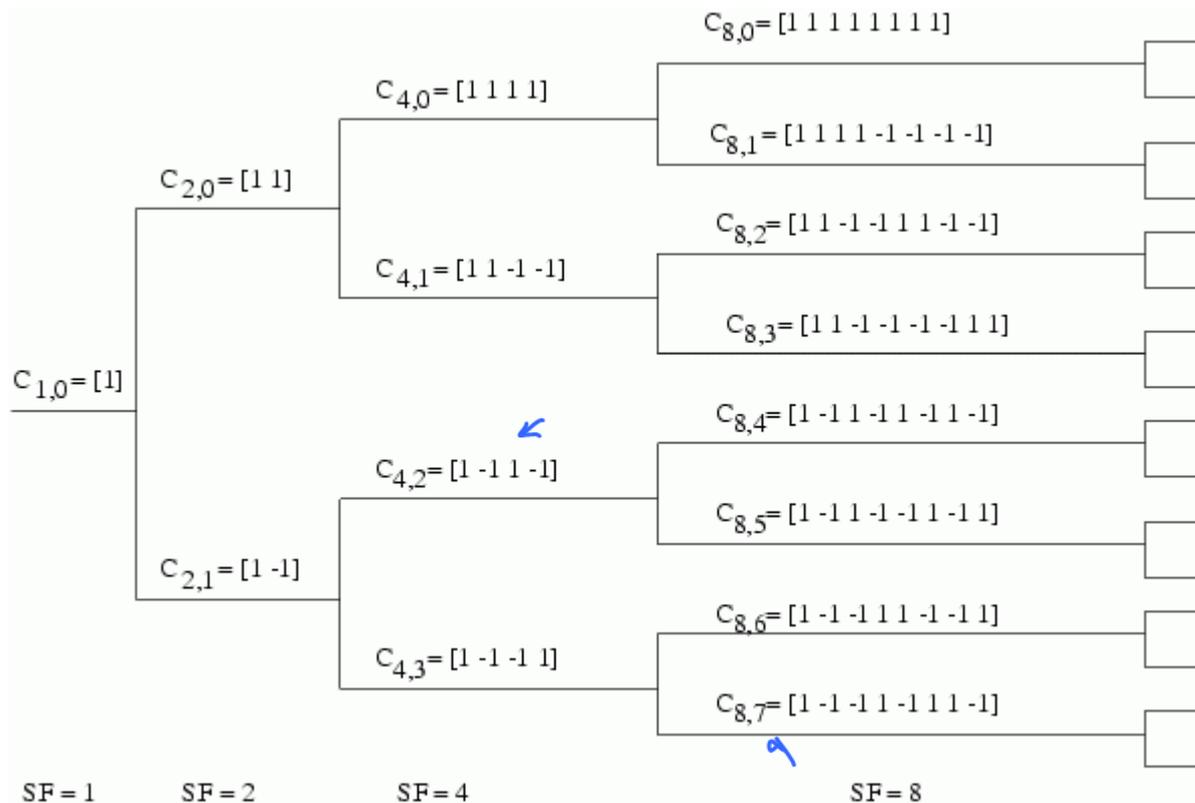
Code allocation rules (1)

- OVSF codes can be applied to realize connections with **different data rates** by varying the spreading factor.

- Smaller SF = Faster data rate

- To have connections with different data rates, need some rules (for selecting the codes) to **maintain orthogonality**

- **Code blocking property**: If a certain code is already used for one connection, neither this code nor a code that is a descendant or an ancestor of this code (on the tree) is allowed to be used for another connection

  - These codes are not orthogonal to the already allocated one.

Code allocation rules (2)

Codes not allowed to be assigned to other connections

$c_{2,0}$

$c_{1,0}$

$c_{2,1}$

$c_{4,0}$

$c_{4,1}$

Assigned code

$c_{4,2}$

$c_{4,3}$

$c_{8,9}$

$c_{8,1}$

$c_{8,2}$

$c_{8,3}$

$c_{8,4}$

$c_{8,5}$

$c_{8,6}$

$c_{8,7}$

Code allocation rules (3)

- Two OVSF codes are orthogonal if and only if neither code lies on the path from the other code to the root.

- If, for example, code $c_{4,1}$ is in use, another connection with a different data rate is not allowed to use the encircled codes.
  - Other cades can still be used.

- If, for example, the second connection has twice the data rate of the first one, it has to select the code $c_{2,1}$.
  - Within the period of one data bit of connection 1, connection 2 transmits two data bits.

OVSF: Disadvantages

- Poor autocorrelation property
  - Look, for example, at the codes $c_{SF,0}$.
- When there is no perfect synchronization, the orthogonality gets lost (high values for the cross correlation)

Scrambling Codes in UMTS

- The scrambling codes in UMTS are complex valued and may be either long or short.

- A long code has a length of 38,400 chips (that is, 10 ms) and a short code only 256 chips.

- A long code for a UMTS uplink channel is constructed with two PN codes, whose characteristic polynomials are

$$g_1(x) = x^{25} + x^3 + 1 \text{ and } g_2(x) = x^{25} + x^3 + x^2 + x + 1$$

- They are implemented as sequences PN1 and PN2 using two 25-bit shift registers.

- PN1 and PN2 are added modulo 2, and the output is mapped to a real-valued function, say, I.

- Another function Q is derived by simply delaying I by $2^{24} + 16$ chips.

- Q is multiplied by $\pm$j, where the sign changes every chip period, and then added to I to yield the long code.

HSPA

- **High Speed Packet Access (HSPA)** is a collection of two mobile telephony protocols
  - High Speed **Downlink** Packet Access (HSDPA) and
  - High Speed **Uplink** Packet Access (HSUPA)
- Extend and improve the performance of existing WCDMA protocols.
  - Use improved modulation schemes and refine the protocols by which handsets and base stations communicate.
- Many HSPA rollouts can be achieved by a **software upgrade** to existing 3G networks, giving HSPA a head start over WiMAX, which requires dedicated network infrastructure.
- There is also a further standard, Evolved HSPA (HSPA+).

Evolution of UMTS Specifications

Release	Functional freeze	Main UMTS feature of release
Rel-99	March 2000	Basic 3.84 Mcps W-CDMA (FDD & TDD)
Rel-4	March 2001	1.28 Mcps TDD (aka TD-SCDMA)
Rel-5	June 2002	HSDPA
Rel-6	March 2005	HSUPA (E-DCH)
Rel-7	December 2007	HSPA+ (64QAM downlink, MIMO, 16QAM uplink) LTE and SAE feasibility study