Mobile Communications

TCS 455

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Lecture 26

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

Announcements

- Read the following from the SIIT online lecture note system
  - Section 1.2 from [Bahai, *Multi-carrier Digital Communications: Theory And Applications Of OFDM*, 2002]
  - Theory of PN Codes from [Karim and Sarraf, *W-CDMA and cdma2000 for 3G Mobile Networks*, 2002]
  - Section 2.9 (Multi-carrier Based Access Techniques) from [Tarokh, 2009, *New Directions in Wireless Communications Research*]

Chapter 6

Applications: 3G (UMTS and WCDMA)

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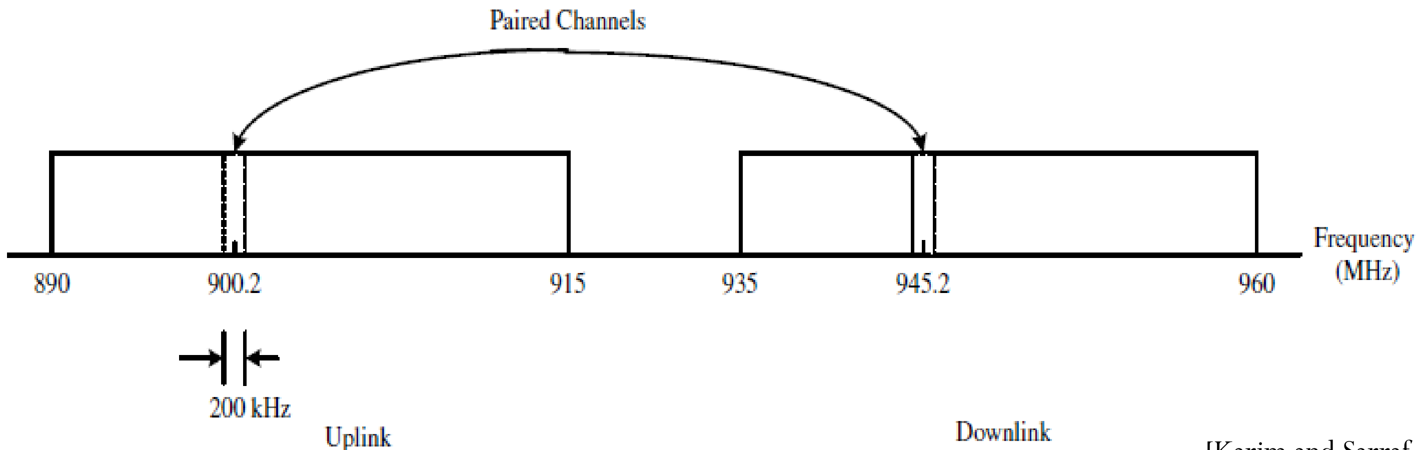
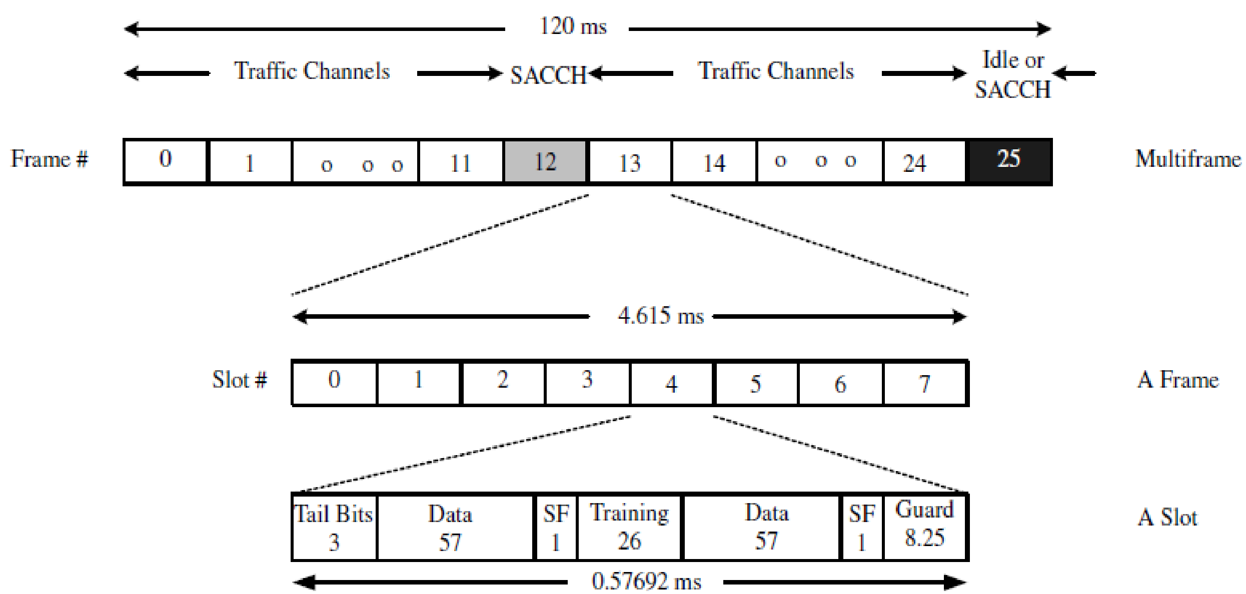
Cellular History

- The **first-generation (1G)** mobile telecommunication systems introduced in the 1980s were **analog**.
- The **second-generation (2G)** systems 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)



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



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

GSM Enhancement

- Want to deliver ***data*** as well as voice.
- **General Packet Radio Service (GPRS)**
  - 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.
- **Enhanced Data Rates for GSM Evolution (EDGE)**
  - Higher modulation efficiency
  - Support IP-based services in GSM at rates up to 384 kb/s
  - 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

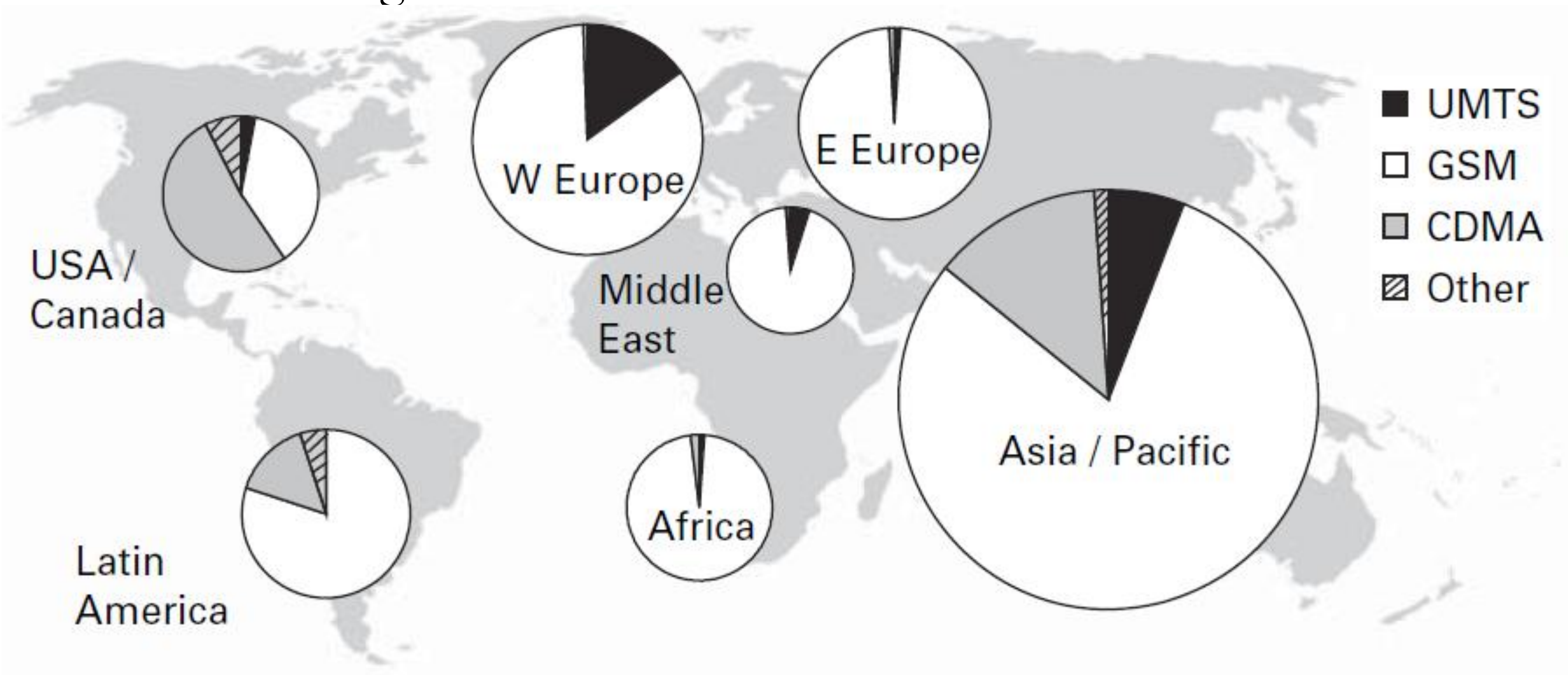
300K~5Mbps

UMTS: History

- The research activity on UMTS started in Europe at the beginning of the 1990s.
- The third-generation mobile communication systems, called International Mobile Telecommunications-2000 (IMT-2000) or Universal Mobile Telecommunications System (UMTS) in Europe, are designed to support wideband services with data rates up to 2Mbit/s.
- This system was developed from GSM
  - Keep the core network more-or-less intact
  - Change the air interface to use CDMA
- There is some compatibility between the two systems:
  - 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.

Market Share

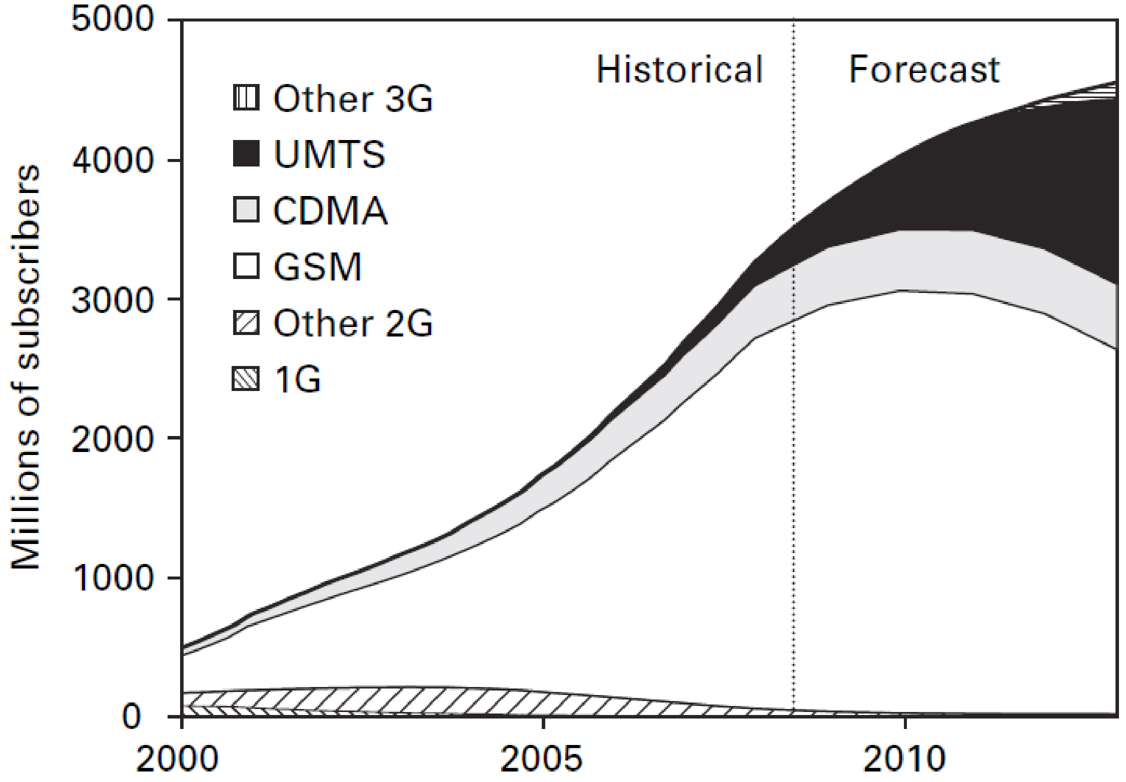
- Numbers of subscribers to different mobile communication technologies in 2008.



[Cox, 2008, Fig 1.15]

Growth

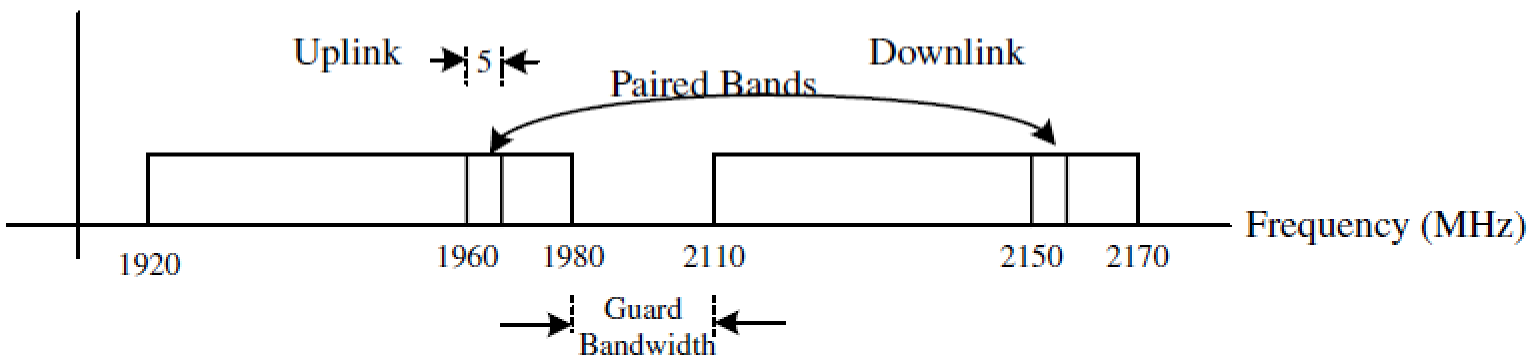
- Growth in the use of different mobile telecommunication technologies, with historical data from 2000 to 2008, and forecasts from 2008 to 2013.



[Cox, 2008, Fig 1.16]

UMTS: FDD

- Universal Mobile Telecommunications System (UMTS)
- 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)



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

Comparison

- 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 is a multicarrier, direct-sequence CDMA FDD system.

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)

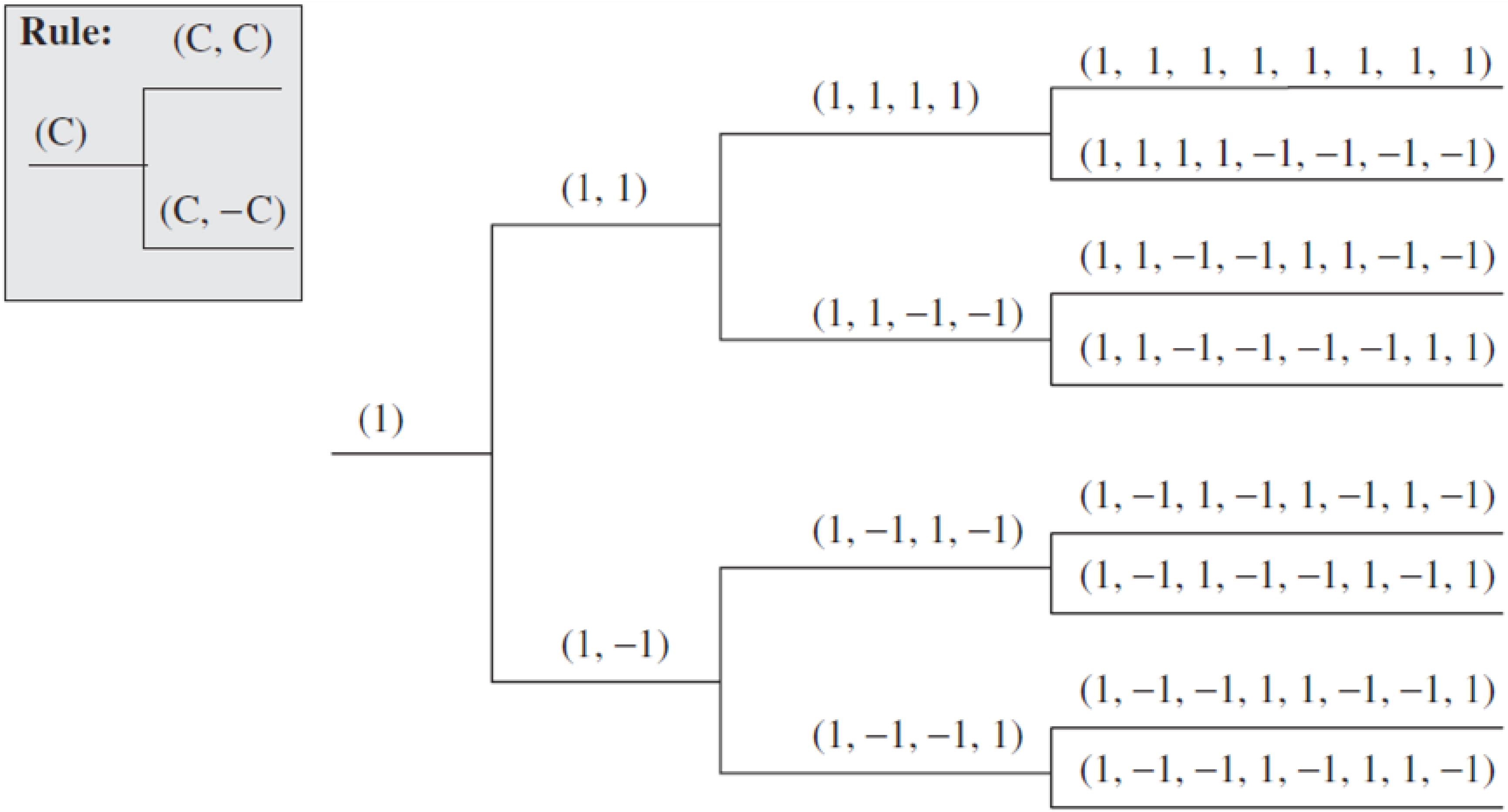
- Similar to Walsh sequences
  - Arranged and numbered in a different way
- Use a tree structure
- For each **spreading factor SF** $= 1, 2, 4, \ldots,$ which is a power of 2, there are $N =$ SF orthogonal codes obtained by the recursion relations:

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

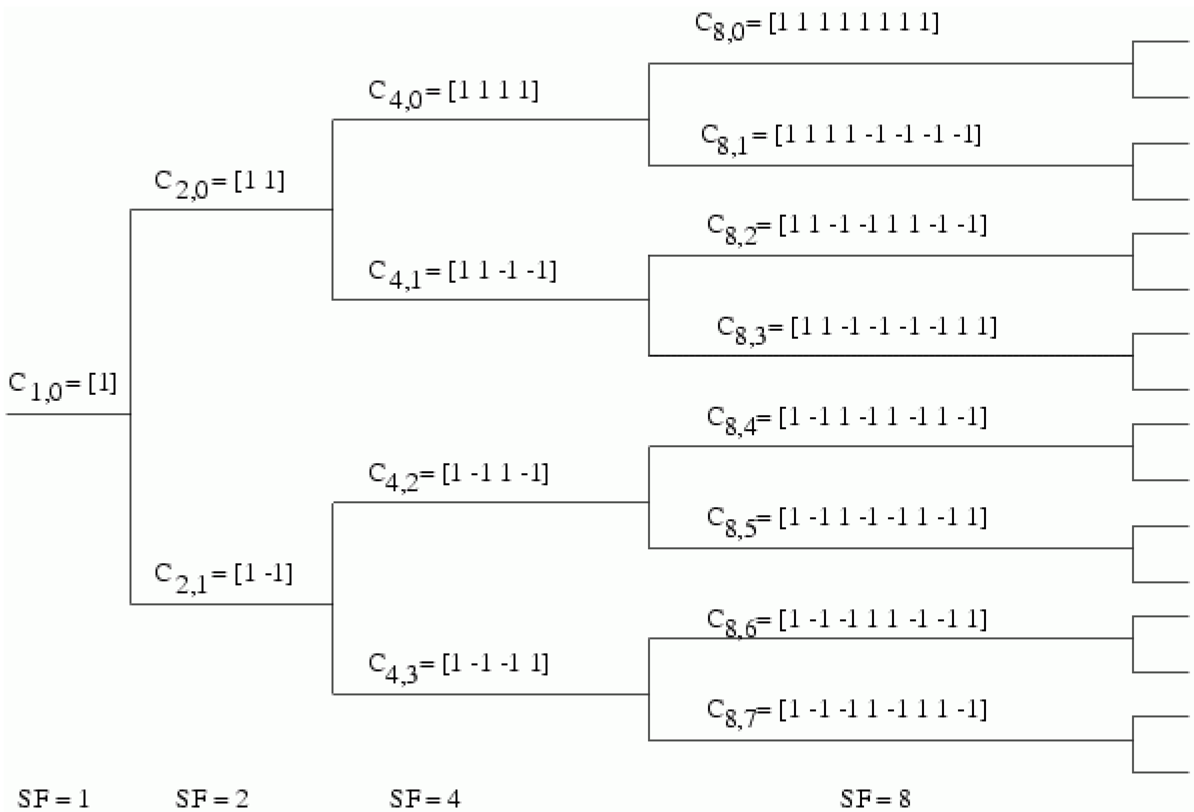
$$c_{2SF,2m+1} = [c_{SF,m}, -c_{SF,m}], \;\; m = 0, 1, \ldots, SF - 1.$$

- 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)



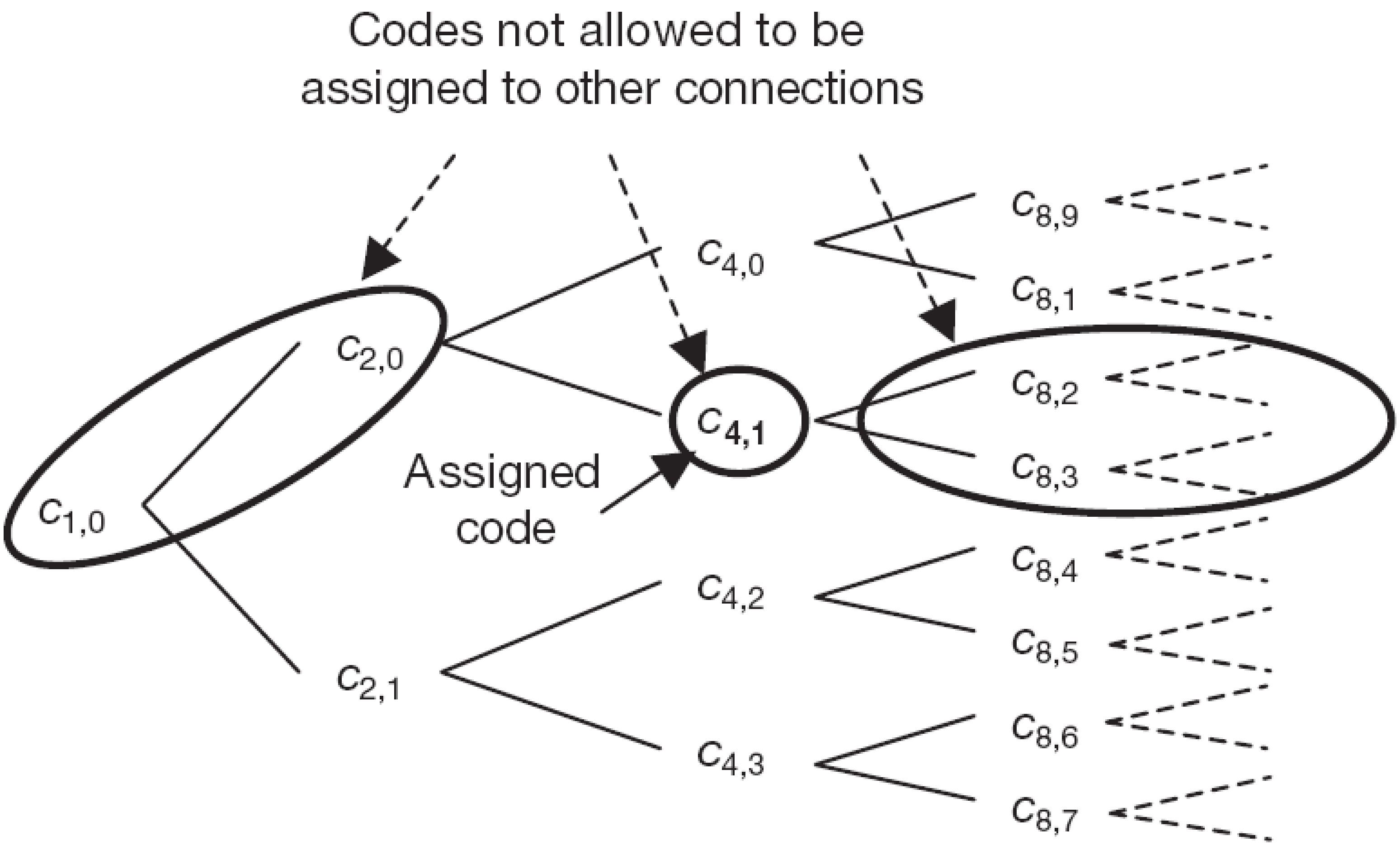
Tree structure for OVSF codes (2)



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
- 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)



[Schulze Luders, 2005, Fig 5.12]

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, but all other codes.
- 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)

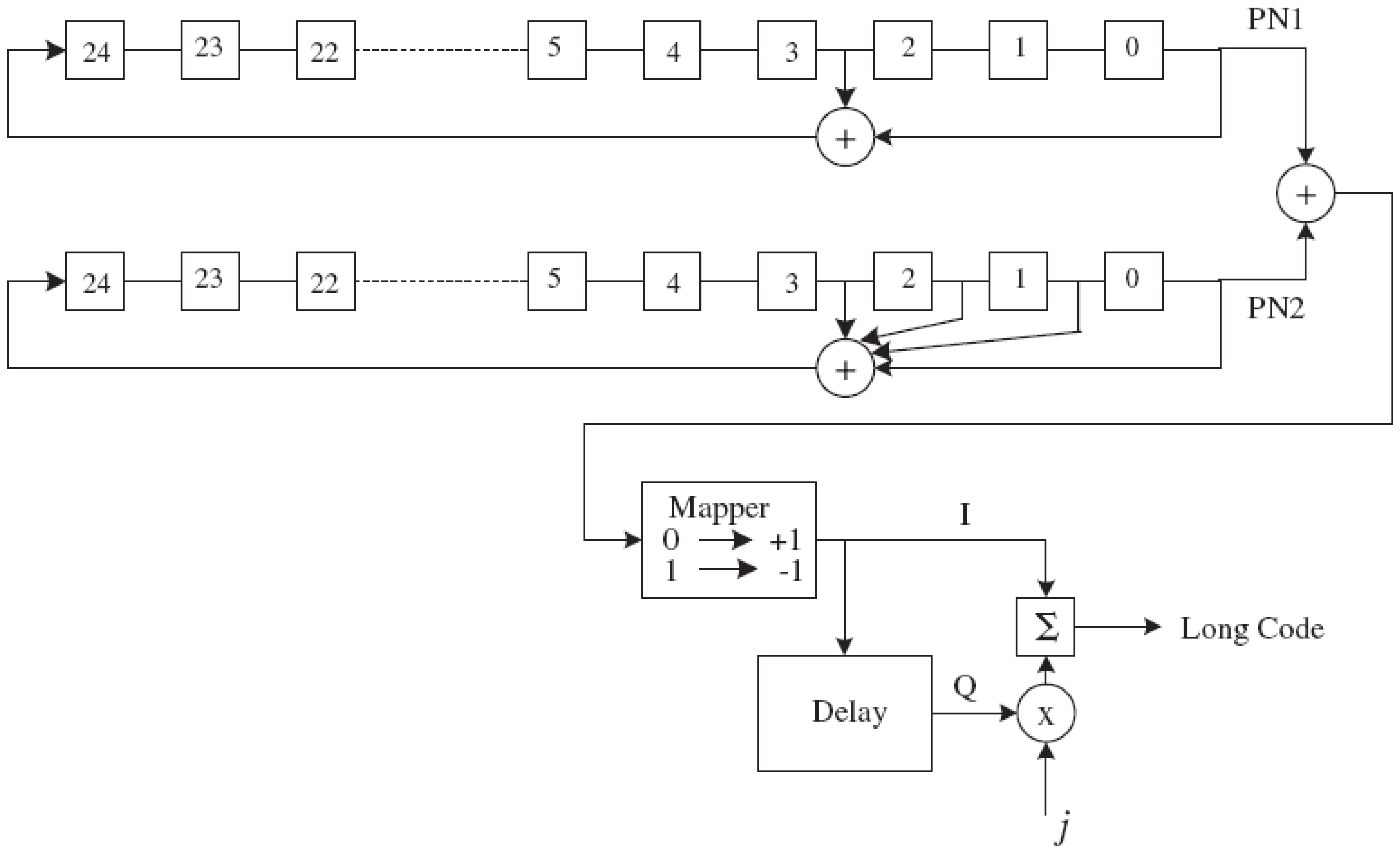
Scrambling Codes in UMTS

- 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 ±j, where the sign changes every chip period, and then added to I to yield the long code.

A long code generator for a UMTS uplink channel



[Karim and Sarraf, 2002, Fig 3-19]

Trend in BW

- Transmission bandwidths of current / future cellular wireless standards.

Generation	Standard	Transmission Bandwidth
2G	GSM	200 kHz
	IS-95 (CDMA)	1.25 MHz
3G	WCDMA	5 MHz
	cdma2000	5 MHz
3.5 ~ 4G	3GPP LTE	Up to 20 MHz
	WiMAX (IEEE 802.16)	Up to 20 MHz

[Myung, 2007, Table 2.1]

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+).