ELE 6141 : Advanced Digital Wireless Transmission

Winter 2019

Lecture 1:

— *Course Outline*

- A brief history of Mobile Telephony and Wireless Communications.
- Cellular Concept.

These days you hear a lot about 3G and 4G even in advertisements for mobile services. The G in nG refers to Generation. So, 4G for example, means the 4th generation of the mobile terminals.

The 1G or the first generation, although not called 1G at the time refers to the first offering of cellular phones in 80's. In North America, the first generation was called AMPS (Advanced Mobile Phone

System). A similar service was introduced in Europe called ETACS (European Total Access Cellular System). AMPS was deployed in 1983 and ETACS was introduced in 1985. Prior to this in 1979, a cellular system was introduced in Japan by NTT.

The common thing among these first generation services was the fact that all of them were analog, they used FM modulation and FDMA (Frequency Division Multiple Access) as their access technique.

The difference between these services was in the band of frequency they used and the bandwidth assigned to each channel. For example, AMPS used the 824-894 MHz. and each voice channel occupied 30kHz. while ETACS used 890-950 MHz. band and assigned 25 kHz. to each voice channel. Some earlier European system called

NMT-450 used 450-470 MHz. with 25 kHz. channel allocation NMT-450 (Nordic Mobile Telephone) was introduced in 1981 and a later version of it was introduced in 1986 called NMT-900 that occupied 890-900 MHz. with 12.5 kHz. voice channels.

The main application (almost the only application of the first generation Systems was <u>voice Communication</u>.

The 2G or second generation Cellular Systems were digital. The main application with 2G Systems was still <u>voice</u> with minor data Capability, e.g., Short Messaging Services (SMS).

While the first generation systems used the same <u>air interface</u>, i.e., the way to Shar the bandwidth and the Same modulation, varied Considerably in terms of modulation and Multiple Access.

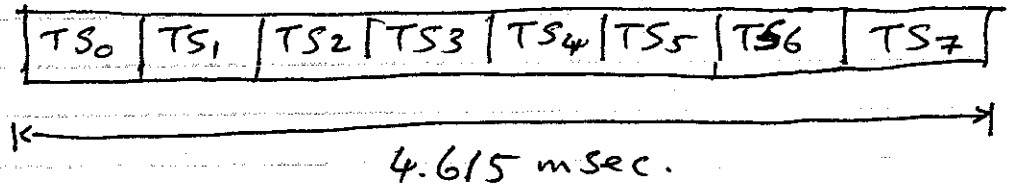
An interesting distinction between second generation mobile systems in Europe and in North America is that while in Europe a single system, i.e., GSM (Global System of Mobile) was introduced in North America several systems, namely, USDC, IS-95, CDPD as well as GSM were deployed. The irony is that the situation was completely the other way for the first generation systems. That is, in Europe, the first generation systems were different in terms of frequency band and channel bandwidth and, therefor, they were not compatible, while in North America AMPS was the only standard. It seems that Europeans learned the lesson and tried to come up with a common solution for the second generation systems, but in North America distructive competition between equipment manufacturers resulted in a variety of incompatible systems. Fortunately, later

System providers came to their senses and one by one moved to GSM. Historically, in Quebec, first FIDO started with GSM, later Rogers migrated from USDC to GSM followed by migration of Telus and Finally Bell Mobility from IS-95 (CDMA) to GSM. Of course, this must have happened at ~~the~~ The cost of unnecessary waste of money and resources.

In Brief:

GSM introduced in 1990 uses GMSK as the modulation scheme and TDMA (Time Division Multiple Access) as the Multiple Access scheme. The Channel Bandwidth is 200 kHz. This bandwidth is divided between 8 users. The division is, of Course, not in the frequency domain, but, in time domain. The time is divided into frames of duration 4.615 msec. Each frame is, in turn, divided into 8 time slots (TS). Each time slot is

assigned to a single user:



Each frame 1250 bits. So, each user is assigned $\frac{1250}{8} = 156.25$ bits every 4.615 ms. So, the rate of each user is 33.854 kbps. Out of this, a considerable part is overhead, So the maximum rate is actually 24.7* kbps. This can carry a voice channel at 13.4 kbps plus FEC (forward error correction) or data at rates 9.6 kbps, 4.8 kbps or 2.4 kbps plus extra FEC. GSM also allows half-rate transmission, e.g., speech coded at 6.5 kbps. This with additional FEC can be carried at a rate of 11.4 kbps.

* The actual rate is $24.7 * \frac{24}{26}$ since for each 24 frames two signaling frames are added.
6

Note that for communication between two entities, i.e., the base station (tower) and the mobile station (handset) two physical channels are needed: A forward channel (or downlink) from BS to MS (Mobile Station) and a return channel (uplink) between the mobile and the Base station (BS). The two channels may be either separate in frequency (this is called FDD: frequency division duplex) or time (TDD: time division duplex). In GSM the forward and return channels are separated by 45 MHz.

USDC (IS-54 and IS-136)

United States Digital Cellular (USDC) was deployed in 1991. It uses TDMA but in a 30 kHz. channel. Each channel is shared by 3 users. Modulation is $\frac{\pi}{4}$ DQPSK with a total rate of 48.6 kbps. So, each user has a raw data rate of 16.2 kbps.

The Speech Coding is at a rate of 7.95 kbps. For FEC a 7 bit CRC and rate $\frac{1}{2}$ convolutional Code is used.

US CDMA (IS-95): This system was deployed in 1993. It uses either BPSK or QPSK as the modulation scheme. The multiple access technique is Code Division Multiple Access (CDMA). In IS-95 a bandwidth of 1.25 MHz. is shared between all users. Here all users transmit all the time over the full frequency. They are distinguished from each other by their Specific Code.

2.5 G Systems:

In anticipation of 3G Systems, a few transitory systems were set up to provide high-end users with enhanced data transmission Capability. These included:

- High Speed Circuit Switched Data (HSCSD)

- GPRS: General Packet Radio Services
- EDGE: Enhanced Data rates for GSM

and

- IS-95B for CDMA in North America.

HSCD relaxed the FEC, i.e., less overhead, hence, less protection against channel errors, in order to increase the data rate from 9600 bps to 14,400 kbps. Furthermore, it allowed upto 4 time slots for a user to push the data rate to 57.6 kbps (i.e., 4 * 14.4 kbps).

GPRS: Since it is a packet switched service, it is more suitable for non real-time services such as Emails, faxes, asymmetric web browsing. Since, it is a packet network it can accomodate more users in a bursty fashion.

When all 8 time slots are allocated an

aggregate data rate of 171.2 kbps (8 x 21.4 kbps) can be achied.

EDGE:

EDGE uses 8PSK in addition to GMSK modulation. Furthermore a combination of modulation and coding schemes can be used to provide a tradeoff between quality (Bit Error Rate: BER) and data rate. This feature is called Multiple Modulation and Coding Scheme (MCS).

The adaptiveness of EDGE was its major advantage.

With 8PSK and no coding, using all 8 time slots, a user can get 547.2 kbps.

IS-95B: was the 2.5G version of North American CDMA. It assigns 8 Walsh codes to a user for a total data rate of

8×14.4 kbps = 115.2 kbps.

3G Systems

The two main standards are:

UMTS (W-CDMA) developed by 3GPP (third generation Partnership Program). 3GPP is set up by ETSI (European Telecom Standard Institute) to develop 3rd. generation System.

Universial Mobile Telecom System (UMTS) standard: UMTS: W-CDMA can provide 8 kbps to 2 Mbps on a 5 MHz. radio channel.

W-CDMA uses variable/selectable direct sequence CDMA that can exceed 16 M chips/sec. per user. It is supposed to provide at least 6 times Bandwidth efficiency of GSM.

CDMA 2000

Another standard mainly pushed by North American manufacturers was developed by 3GPP2 ~~and is~~ to be backward compatible with

IS-95.

It uses IS-95A as the building block.

Cdma 2000 1X : provides upto 307 kbps for users in packet mode. The typical throughput is 144 kbps

Cdma 2000 1XEV (also EV-DO)

EV-DO : Evolutionary - Data Only

Can provide upto 2.4 Mbps on specific channels. However, the actual data rates are much less depending on the number of users.

The ultimate cdma 2000, i.e.,

Cdma 2000 3X may combine 3 frequency bands of 1.25 MHz. to get 3.75 MHz. of bandwidth for providing peak rate of 2 Mbps similar to W-CDMA.

4G Systems:

There are two main 4G standards:

- WiMax: Word Wide Interoperability for Microwave Acces
- LTE (Long Term Evolution) developed by 3GPP.

These standards offer several Mbps and are expected to increase the download Speed to 1 Gbps.

Table 11.1 AMPS and ETACS Radio Interface Specifications

Parameter	AMPS Specification	ETACS Specification
Multiple Access	FDMA	FDMA
Duplexing	FDD	FDD
Channel Bandwidth	30 kHz	25 kHz
Traffic Channel per RF Channel	1	1
Reverse Channel Frequency	824–849 MHz	890–915 MHz
Forward Channel Frequency	869–894 MHz	935–960 MHz
Voice Modulation	FM	FM
Peak Deviation: Voice Channels Control/Wideband Data	±12 kHz ±8 kHz	±10 kHz ±6.4 kHz
Channel Coding for Data Transmission	BCH(40,28) on FC BCH(48,36) on RC	BCH(40,28) on FC BCH(48,36) on RC
Data Rate on Control/Wideband Channel	10 kbps	8 kbps
Spectral Efficiency	0.33 bps/Hz	0.33 bps/Hz
Number of Channels	832	1000

Table 11.3 GSM Air Interface Specifications Summary

Parameter	Specifications
Reverse Channel Frequency	890–915 MHz
Forward Channel Frequency	935–960 MHz
ARFCN Number	0 to 124 and 975 to 1023
Tx/Rx Frequency Spacing Tx/Rx Time Slot Spacing	45 MHz 3 Time slots
Modulation Data Rate	270.833333 kbps
Frame Period	4.615 ms
Users per Frame (Full Rate)	8
Time Slot Period	576.9 μs
Bit Period	3.692 μs
Modulation	0.3 GMSK
ARFCN Channel Spacing	200 kHz
Interleaving (max. delay)	40 ms
Voice Coder Bit Rate	13.4 kbps

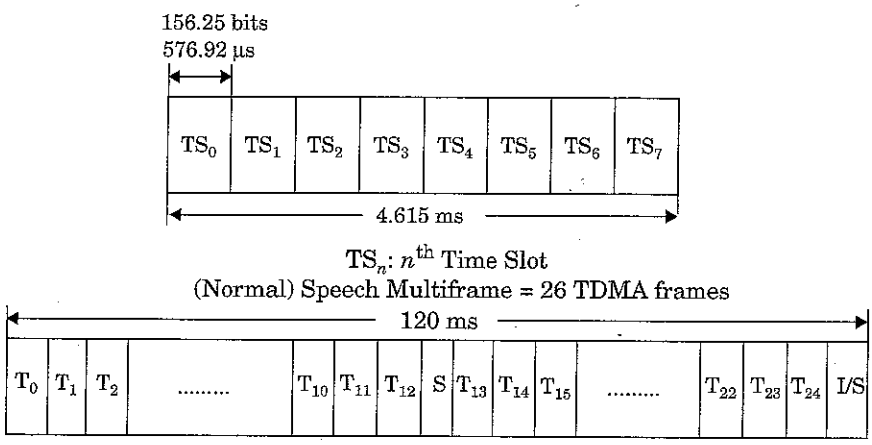
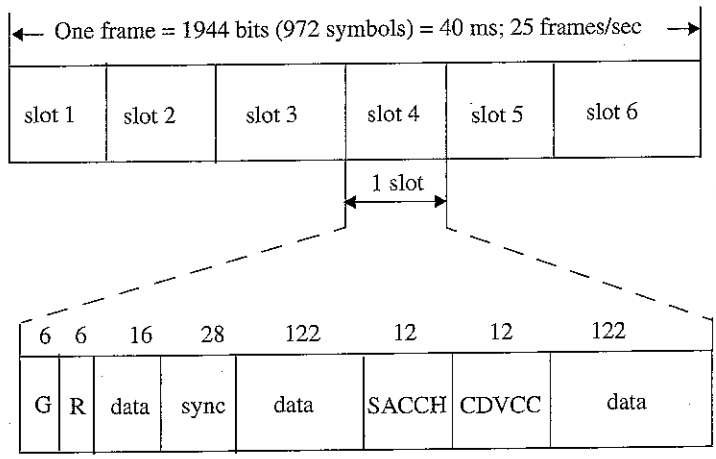


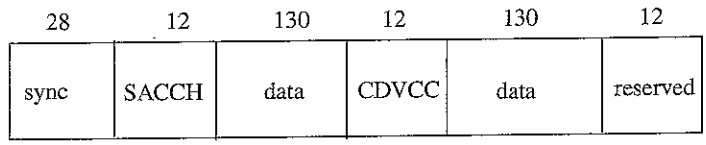
Figure 11.7 The speech dedicated control channel frame and multiframe structure.

Table 11.2 USDC Radio Interface Specifications Summary

Parameter	USDC IS-54 Specification
Multiple Access	TDMA/FDD
Modulation	$\pi/4$ DQPSK
Channel Bandwidth	30 kHz
Reverse Channel Frequency Band	824–849 MHz
Forward Channel Frequency Band	869–894 MHz
Forward and Reverse Channel Data Rate	48.6 kbps
Spectrum Efficiency	1.62 bps/Hz
Equalizer	Unspecified
Channel Coding	7 bit CRC and rate 1/2 convolutional coding of constraint length 6
Interleaving	2 slot interleaver
Users per Channel	3 (full-rate speech coder of 7.95 kbps/user) 6 (with half-rate speech coder of 3.975 kbps/user)



Mobile to Base Station Slot Format



Base Station to Mobile Slot Format

Figure 11.2 The USDC slot and frame structure on the forward and reverse link.

Table 11.4 IS-95 Forward Traffic Channel Modulation Parameters Summary (does not reflect new 13.4 kbps coder)

Parameter	Data Rate (bps)			
User data rate	**9600**	**4800**	**2400**	**1200**
Coding Rate	1/2	1/2	1/2	1/2
User Data Repetition Period	1	2	4	8
Baseband Coded Data Rate	19,200	19,200	19,200	19,200
PN Chips/Coded Data Bit	64	64	64	64
PN Chip Rate (Mcps)	1.2288	1.2288	1.2288	1.2288
PN Chips/Bit	128	256	512	1024

Table 11.6 Reverse Traffic Channel Modulation Parameters Summary (does not reflect recent 13.4 kbps coder)

Parameter	Data Rate (bps)			
User data rate	**9600**	**4800**	**2400**	**1200**
Code Rate	1/3	1/3	1/3	1/3
TX Duty Cycle (%)	100.0	50.0	25.0	12.5
Coded Data Rate (sps)	28,800	28,800	28,800	28,800
Bits per Walsh Symbol	6	6	6	6
Walsh Symbol Rate	4800	4800	4800	4800
Walsh Chip Rate (kcps)	307.2	307.2	307.2	307.2
Walsh Symbol Duration (μs)	208.33	208.33	208.33	208.33
PN Chips/Code Symbol	42.67	42.67	42.67	42.67
PN Chips/Walsh Symbol	256	256	256	256
PN Chips/Walsh Chip	4	4	4	4
PN Chip Rate (Mcps)	1.2288	1.2288	1.2288	1.2288