Introduction to GSM

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1 Introduction

This paper introduces the basic concepts of cellular handset, through a brief historical background, some details about the evolution of the GSM, and the physical layer specifications. The principles of data sampling, voice compression, digital modulation and demodulation are also detailed.

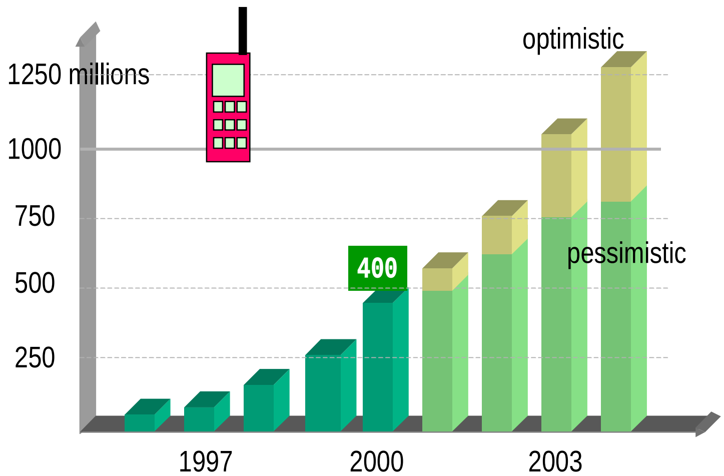


Figure 1: Number of cellular phone subscribers worldwide

The first wireless telephone has been invented by the bell labs, as early as 1940. The first analog cellular network, called AMPS (Advanced Mobile Phone System) was commercially available in 1978, in Chicago. The birth of GSM (Global System for mobiles) starts by the frequency allocation as early as 1979. Then a "Group Special Mobiles" (Early acronym for GSM) was created, leading to a standard some years later, and a commercial kick-off in 1993. In 1996 the DCS (Digital Communication System) started using a second frequency band near 1800MHz.

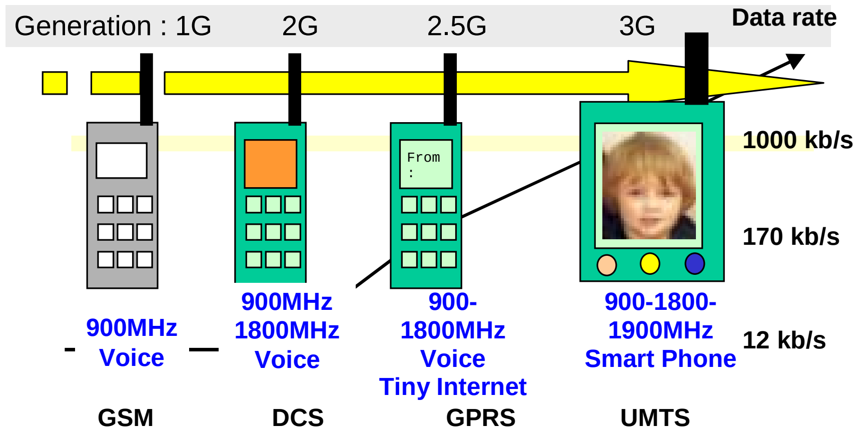


Figure 2: From GSM to UMTS

In the near future, the UMTS (Universal Mobile telephone system) will be launched, with an improved communication standard featuring real-time video, handled by an high speed protocol that will not be compatible with the GSM standard and existing infrastructure (Figure 2).

2 Specifications "Level 1"

The specification "level 1" refers to a definition proposed by the International Standard Organization (ISO) for an open system interconnection. The level 1 for the handset is a physical layer, in charge of the sound sampling, coding, modulation and transmission. In the embedded software of the handset, we also find layer 2 specifications, dealing with the data exchange protocol.

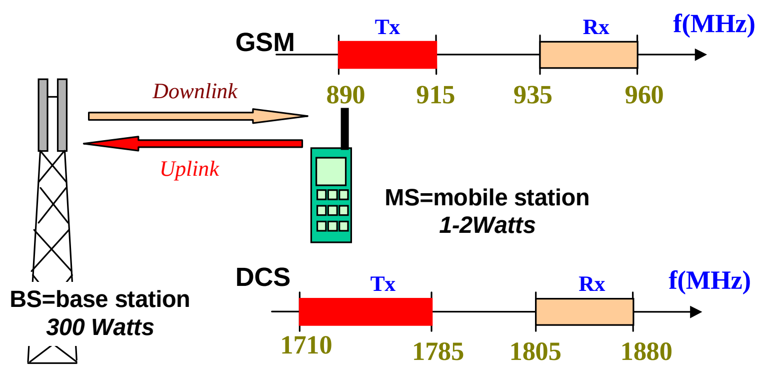


Figure 3: Frequency assignment in GSM and DCS bands

The handset is called in the GSM standard the mobile station or MS. The base station is called BS. The maximum emission power is 2 Watts for the GSM in 900MHz, 1 Watt in 1800MHz. The base station may reach 300Watts, but many efforts are undergoing to avoid the use of such power in urban environments, as base stations and mobile phone may harm human's health [1]. Figure 3 describes the frequency allocation for up and down links. A significant separation of the Tx and Rx sub-bands ease the coupling avoidance between emitter and receiver parts.

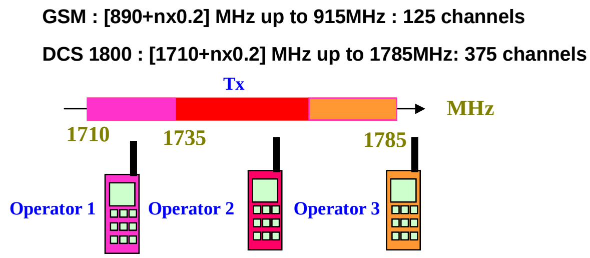


Figure 4: Network channel capacity and separation between operators

The theoretical network capacity is the number of available channels in the sub-band. As each frequency channel is 200KHz large, up to 125 channels are available for GSM and 375 channels for DCS (Figure 4). This number seams quite large. However operators buy licenses to use exclusively a portion of channels. For example, the operator 1 in the figure exploits the frequency band from 1710 to 1735MHz, that is 125 channels in DCS.

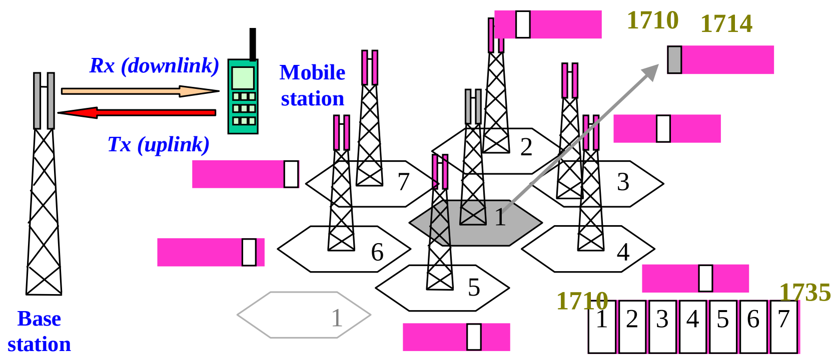


Figure 5: Sharing the frequency resource between adjacent cells

A further reduction of channels is due to the cellular structure of the network, as illustrated in figure 5. To avoid frequency conflicts, the channel resource is split into 7 portions, each portion allocated to one cell. Consequently, the number of available channels in our example is 125/7 that is 17 available channels.

3 Time Domain Multiplexing

The main novelty introduced in GSM is the time domain multiple access, a multiplexing approach with enables 8 phones to share one single frequency channel. This adds considerable complexity to the protocol, compared to a single user for each channel. Over a frame of 4.61 ms, each phone takes the lead on the channel and emits its information, during a burst of 577µs (Figure 6). See reference [2] for more detailed explanations of the protocol.

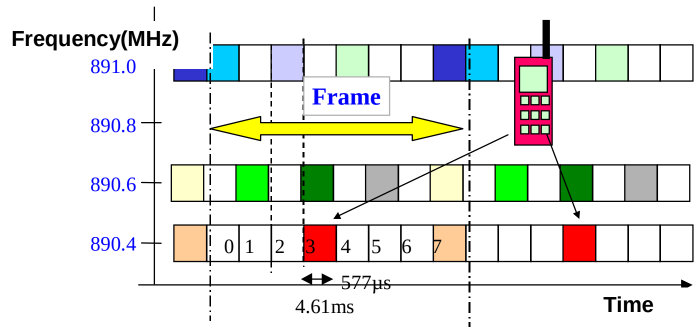


Figure 6: illustration of the time domain multiplexing (TDMA for time domain multiple access)

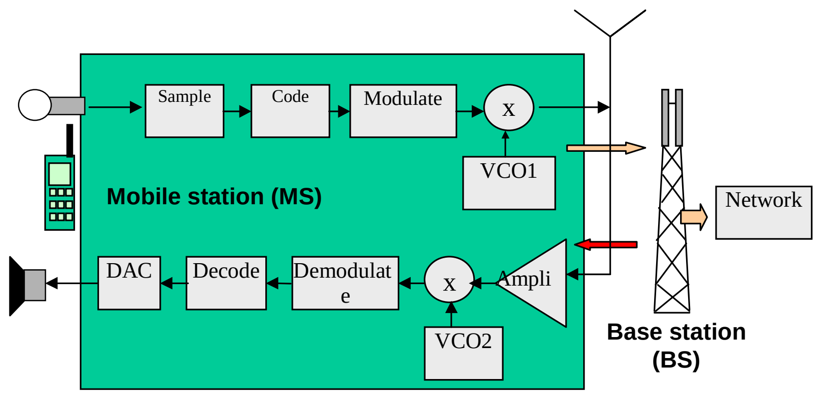


Figure 7: Block diagram of the handset

The block diagram of the mobile station is described in a very simplified way in figure 7. A microphone captures the sound, which is sampled in a numerical format, compressed, coded and modulated. A high frequency oscillator translates the modulated signal to a valid transmission frequency. The received signal (less than 1mV) is amplified before down-conversion to a low frequency, demodulation, decoding and sound reconstruction.

4 Speech sampling and compression

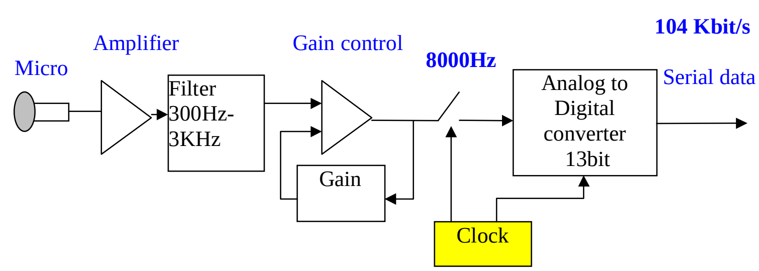


Figure 8: Schematic diagram of the speech sampling circuit

As described in figure 8, the sound captured by the microphone is filtered to remove harmonics lower than 300Hz and higher than 3000Hz. Then, a gain control stage keeps the signal envelope more or less constant, before a sampling at the rate of 8000Hz, in a 13 bits format. This leads to a rate of 104 Kbit/s. This means that a compression algorithm is mandatory to obtain an acceptable rate of 12Kb/s.

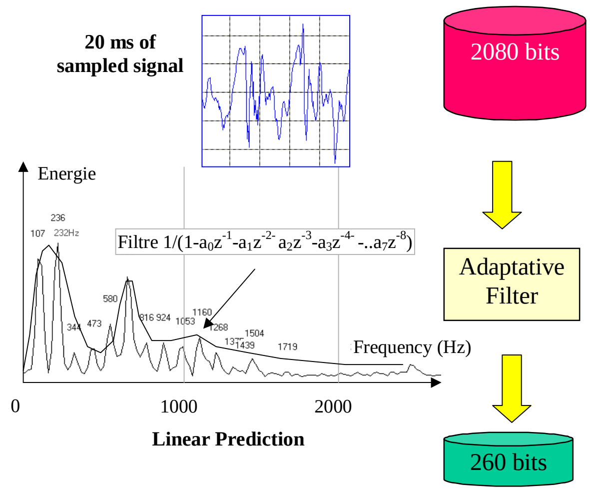
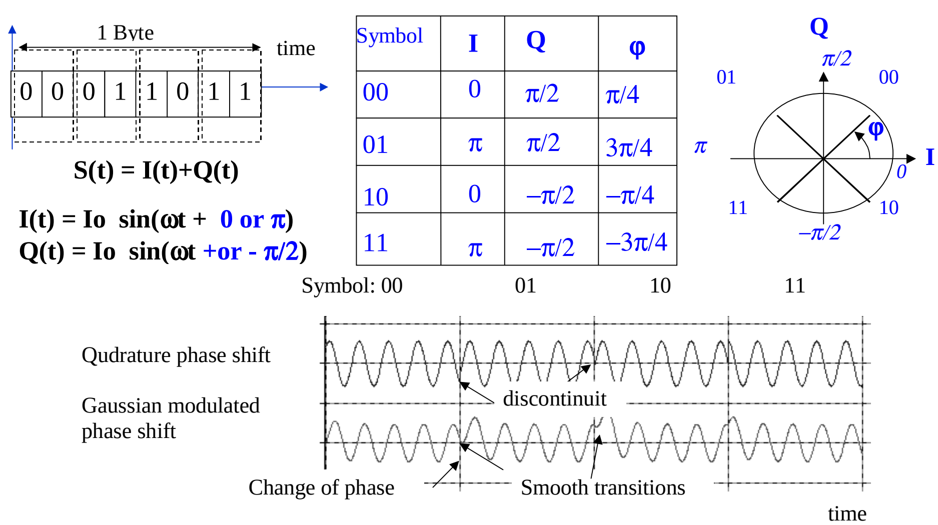


Figure 9: The GSM speech coder is based on adaptive filtering techniques

The voice coder implemented in the GSM handset splits the sound into portions of 20ms, with a time-domain aspect reported in the upper part of figure 9. The redundant periodic structure of the sound (80% of the speech), is removed by the coder. Linear prediction [3] and root mean square minimization are the mathematical basis for computing the best coefficients to approximate each portion of sound by an adaptive filter. Consequently, the filter coefficients are transmitted, not the sampled sound. This features a significant reduction of data. Low order coefficients are coded in a 6 bit format, high order coefficients in 3 bits format. See [4] for more details description of the GSM coder and decoder.

5 Modulation

The modulation used in GSM is derived from quadrature phase shift keying. Each byte of data is split into four pairs of bits (Figure 10). To each pair of bit corresponds a particular phase for I(t) and Q(t). The modulated signal is the sum of the two sinusoidal waves, with a phase shift depending on the logic symbol. The Gaussian Modulated shift has smooth transitions to avoid the spread of harmonics in the emission spectrum.



Symbol	I	Q	φ
00	0	π/2	π/4
01	π	π/2	3π/4
10	0	−π/2	−π/4
11	π	−π/2	−3π/4

Figure 10: The GSM modulation, based on phase change.

6 Demodulation

The principles for numerical demodulation of phase modulated-signals are based on the multiplication of the received signal by a sinus and cosine with the same frequency. The result shown in figure 11 is a composition of two effects: a sinusoidal wave with twice the initial frequency (removed by filtering) and steps of voltage, that are corresponding to the initial bits sent by the emitter. Half of the bits are issued from the multiplication by cosine, the other half is obtained by the multiplication by sinus. At the price of bit manipulation, the bytes are easily reconstructed (Figure 12).

$$I(t) = \cos(\omega_{gsm}t).\sin(\omega_{gsm}t+\varphi) \approx \cos(\varphi) + \text{high frequency term in } 2\ \omega_{gsm}t$$
$$Q(t) = \sin(\omega_{gsm}t).\sin(\omega_{gsm}t+\varphi) \approx \sin(\varphi) + \text{high frequency term in } 2\ \omega_{gsm}t$$

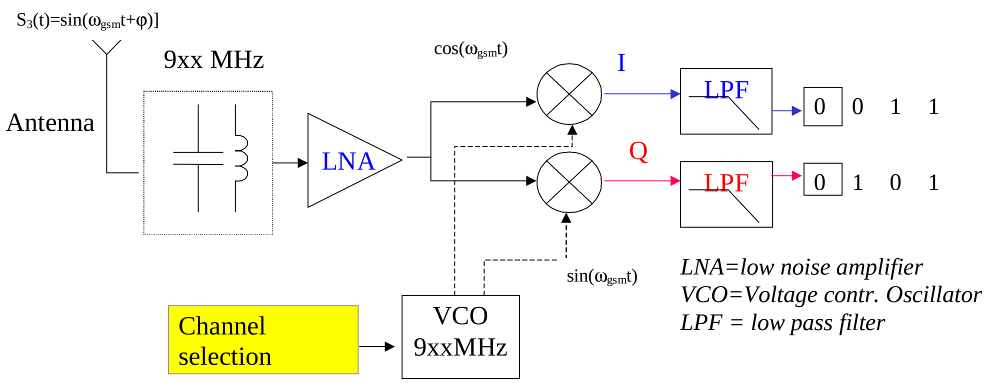


Figure 11: The GSM demodulation staged using direct down-conversion.

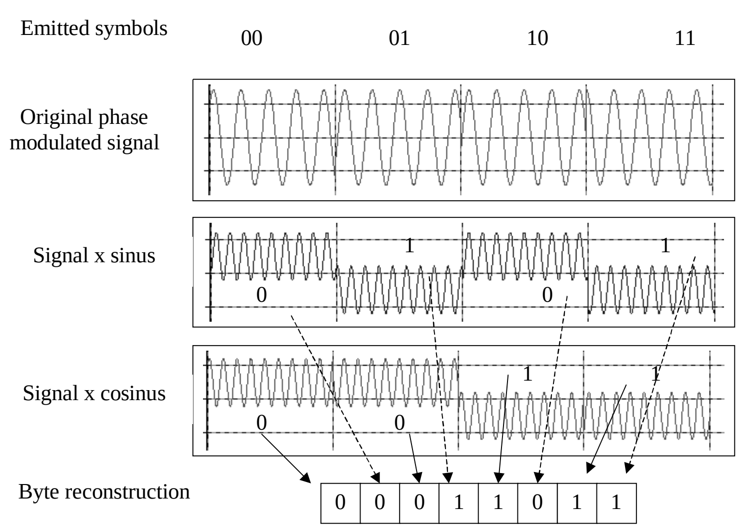


Figure 12: Byte reconstruction using cosine and sinus multiplication

7 Conclusions

The mobile phone history rapidly described in the first chapter is almost becoming a legend. The cellular phone is in constant evolution, and there are still great improvements ahead. The GSM level one has been described. The data sampling and voice compression have been introduced and illustrated. Finally, the principles of phase modulation and demodulation have been illustrated.

References

[1] Foster (2000) *Are the mobile phones safe* IEEE Spectrum, vol 37, n°8
[2] Redl, Weber, Oliphant (1996) *An Introduction to GSM*, Artech House
[3] Gold, Morgan (2000) *Speech and audio signal processing*, Wiley
[4] Steele (1996) *Mobile Radio Communications*, Wiley