DESIGN OF A DIGITAL RECEIVER FOR THE GSM CELLULAR SYSTEM

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Résumé. *L'article présent les principaux résultats de la realisation d'un recepteur digital du futur système GSM (Group Special Mobile). Dans le système GSM, l'information digital est dégradée par le multipath introduit par le radio canal mobile. Le recepteur MLSE Viterbi compense les distorsions dûes au multipath et au shift Doppler. La performance du recepteur est estimée par un simulator de canal mobile.*

Abstract. *This paper describes the main results concerning the implementation of a prototype numerical receiver of the future European Cellular System GSM (Group Special Mobile). The proposed Maximum Likelihood Sequence Estimation (MLSE) receiver based on Viterbi algorithm compensates selective distortions due to the multipath propagation and Doppler shift. The performance of this receiver is evaluated using a channel simulator suitable for mobile communications.*

1. INTRODUCTION

The Pan European cellular mobile communication system uses narrow band Time Division Multiplex Access scheme. The propagation of the electromagnetic field between the fixed station and the mobile unit is affected by many factors, including tropospheric scattering, diffraction from natural and artificial obstacles, topographic and environmental conditions. All these factors lead to the propagation conditions may significantly affect the transmission quality. In particular, the signal quality can be seriously disturbed by the time - varying intersymbol interference introduced by the multipath mobile radio channel.

Section 2 leads off with a brief review of GSM structure and then, in the Section 3, we describe the simulated mobile radio channel implemented considering the following main impairments:

- flat Gaussian noise
- Rayleigh (and Rice) fading with Doppler shift and multiple echoes as representative of different geographical areas.

The Section 4 presents the study and the implementation of an adaptive maximum likelihood Viterbi receiver for signals transmitted via intersymbol interferencee (ISI) channels.

The receiver is specifically tailored for the application with modulation index h = 0.5 and GMSK (Gaussian Minimum shift keying) modulation schemes and well suited for VLSI implementation.

The Section 5 will show the simulation results presented as BER versus a function of the energy bit/noise spectral density E_b/N_0, to evaluate the performance of a TDMA mobile radio system with the proposed MLSE receiver. Moreover the performance in terms of BER after the subsequent decoder block using the Viterbi algorithm are presented.

2. STRUCTURE AND ARCHITECTURE OF THE GSM

In this section the principal characteristics and features of the new generation of the Pan European cellular mobile communication system, called GSM (Group Special Mobile), are described in details.

The communication structure of the GSM system can be supposed as composed by the following main building blocks:

-MS : the Mobile Station;
-BS : the Base Station, to which the MS connected connected through a radio link;
-MSC: the Mobile Service Switching Centre develops the control functions of the GSM system are concentrated and which is the interface between the fixed network and the GMS network.

The MSC performs all the switching functions required for the management (set-up, clear-down, handover, etc.) of the call to/from the MS.

The main specifications proposed for the GMS system are the following:

- Digital transmission;
- Modulation scheme: Gaussian Minimum Shift Keying (GMSK) with BT = 0.3. The modulation rate is 1625/6 (270.833) kbit/s.
- Frequency bandwidths: 25+25 MHz
  890-915 MHz Mobile transmit, Base receive
  935-960 MHz Base transmit, Mobile receive
- Carrier spacing: 200 kHz, providing 125 available carriers in 25 MHz bandwidth;
- Frequency reuse : 9 groups of carriers for the cellular operation;
- Multiple access: TDMA with 8 channels per carrier.

The TDMA frame is divided in 8 time-slots, each 0.5777 ms long. Each time-slot is reserved to an user to transmit a data

packet composed of 148 bits and the structure of the time frames, time-slot and burst is shown in Fig. 1.
The time-slot is a time interval of 0.577 (=15/26) ms, comprising 156.25 bits. Its physical content is called a burst.

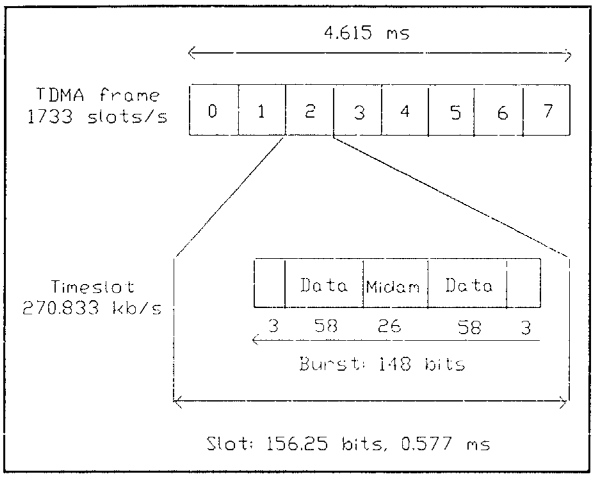

Figure 1 - *Time frames, time slots and bursts*

There are four types of burst in the system as follows:

NB	Normal burst: this is used to carry information on traffic and control channels, it contains 116 encrypted bits and includes a guard time of 8.25 bit duration.
FB	Frequency correction burst: this is used for frequency synchronisation of the MS; it is equivalent to an unmodulated carrier, shifted in frequency, with the same guard time as the normal burst; it is broadcast together with the Broadcast Control Channel (BCCH).
SB	Syncronisation burst: this is used for time synchronisation of the MS; it contains a long training sequence and carriers the information of the TDMA frame number (FN) and BS identity code; it is broadcast together with the frequency-correction burst.
AB	Access burst: this is used for random access and is characterised by a longer guard time (68.25 bits or 0.252 ms) to allow for burst transmission from a mobile that does not know the correct timing at the first access (or after handover): this allows for a distance of 35 km from BS.

When the mobile tries to connect with a base station, the FB and SB burst are used.
The MS must synchronise both in frequency and time. The BS sends signals on the BCCH to enable the MS to synchronise itself to the BS and, if necessary, correct its frequency standard to be in line with that of the BS.
Once the link between MS and BS station has been connected, the normal burst is used to transmit the information. The information to be transmitted is coded through a block and a convolutional code and, after, interleaved.

3. MOBILE RADIO CHANNEL

The propagation of the electromagnetic field between the fixed station and the mobile unit is affected by many factors, including tropospheric scattering, diffraction from natural and artificial obstacles, topographic and environmental conditions. All these factors lead to characterize the signal amplitude received at the mobile unit as fading component, due to the reflections from obstacles and the vehicle movement. Generally the assumed model for the envelope of the signal affected by this type of fading is the Rayleigh distribution or the Rice distribution.
Due to the multipath propagation, a transmitted impulse signal produces several replicas at the receiver at different time instants. Therefore, all these features give a representation in terms of time delays and Doppler shifts associated to every path which are shown as:

$$\int\int u(t-\tau)\; S(\tau,f)\; e^{j(2\pi f\tau)} df\, d\tau \qquad (1)$$

where u (t-τ) are the paths with different recieved delays τ and S(τ,f) Doppler Spectrum.
The proposed simplified model is composed by a discrete number of taps, each determined by their time delay and their average power, and by a Rayleigh amplitude varying according to a Doppler spectrum. Each taps are added as showed in Fig. 2.
In the 900 MHz band the delay spread is typically about 0.1μs on flat terrain, 2μs in urban areas and up to 5μs for hilly terrain. The maximum delay can be 0.5μs, 10μs and 20μs in the three environments respectively.

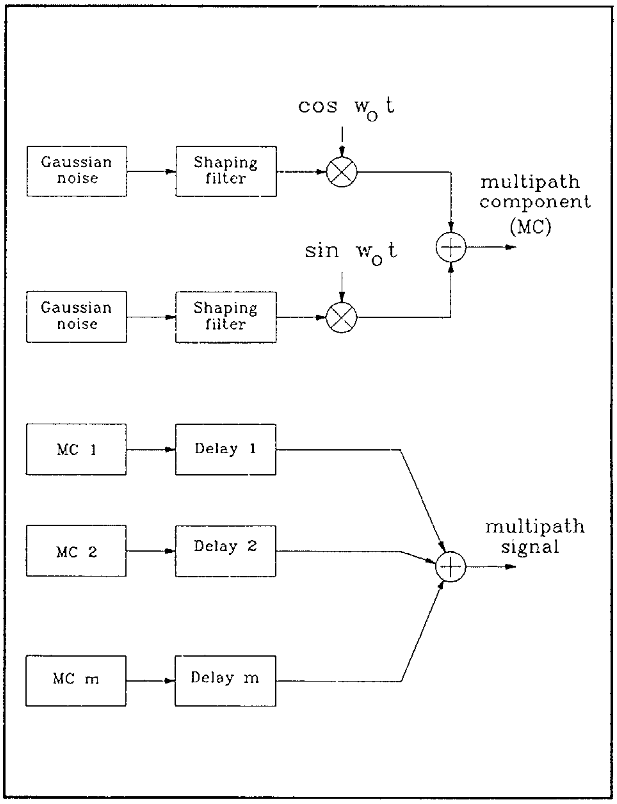

Figure 2 - *Mobile radio channel simulator*

The characteristics of the radio channel can be therefore

described by a time-varying impulse response $c(\tau, t)$, that is a function of the response delay τ at the current time t.
The shapes of the impulse responses is various in the different propagation conditions and has a relatively long duration.

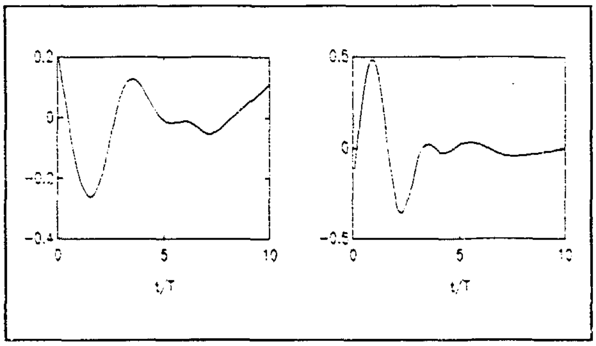

Figure 3 - *In-phase and quadrature impulse response (Urban Area 50 Km/h)*

As examples, Fig. 3 shows the equivalent lowpass impulse response of the mobile channel for the urban case.

4. A DIGITAL RECEIVER FOR THE GSM SYSTEM

In this section a prototype digital receiver of the GMS system is shortly described. In the GSM system, the reliability of the digital information is strongly degradated by multipath.
The Maximum Likelihood Sequence Estimation (MLSE) using the Viterbi algorithm seems one of the most powerful method for the equalization of channels with severe distortions.
The Gaussian Minimum Shift Keying (GMSK) modulation can be closely approximated through a linear partial-response QAM signal with the data symbols $a_i = \pm 1$, obtained from the source data symbols by differential encoding, which are phase-rotated in the complex plane by consecutive multiples of $\pi/2$.
Therefore, the transmitted signal is given by

$$s(t) = \sum_{i=-\infty}^{\infty} a_i j^i p(t-iT) \qquad (2)$$

being T the symbol interval and p(t) is a real-valued pulse shaping function.
The QAM model has been extended to cover the effect of linear transmission channels and receiver filters. The received signal r(t) can be given by:

$$r(t) = \sum_{j=-\infty}^{\infty} a_i j^i h(t-iT) \qquad (3)$$

where h(t) is the overall complex impulse response of the complete communication system, including the transmitter, the receiver and the channel response.
Applying at the received signal a derotation factor [5] $(-j^i)$ for every i, we obtain a simplified structure of the MLSE receiver.
The general structure of the digital receiver for the GSM system, which has been implemented, is shown in Fig. 4. The received signal r(t) is reported in the base band and sampled at the converter.

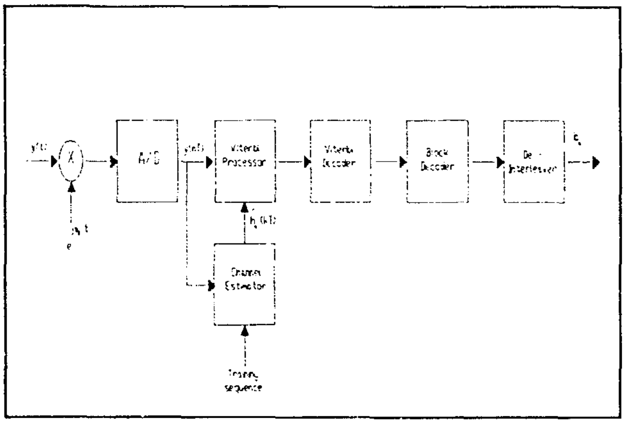

Figure 4 - *General receiver structure for the GSM system*

In order to recover the source data sequence hidden in the received signal r(t) the MLSE receiver calculates the euclidean metrics for any possible sequence $\underline{a}$ between the received signal and the reconstructed signal using estimated channel coefficients and searches the particular sequence that minimize

$$\sum_{i=1}^{N} |r(iT) - \hat{r}(iT)|^2 \qquad (4)$$

where N is the lenght of the whole data symbol sequence.
The Viterbi equalizer requires a good estimation of the actual channel impulse response.
In the GMS system, the data packet contains a pseudo- random sequence of 26 bits, termed midamble, which is known at the receiver. This sequence can be used to perform an estimate of the communication channel during the actual time- slot.
The signal samples $r_i = r(iT)$ therefore given by:

$$r_i = r(iT) = \sum_{k=-L}^{L} a_k h[(i-k)T] = \sum_{k=-L}^{L} a_k h_{i-k} \qquad (5)$$

The coefficients h_{i-k} are estimated by using the correlation properties of the midamble. To this regard, the channel estimator evaluates the correlation C_n between the samples r_i and the N symbols a_i of the midamble:

$$C_n = \frac{1}{N} \sum_{i=0}^{N-1} \sum_{k=-L}^{-L} a_k a_{i+n} h_{i-k} \qquad (6)$$

In the pratical implementation of the receiver, the system response have been assumed to span 5 symbols.
The Viterbi algorithm uses the estimated coefficients h_i to equalize and demodulate the received symbols. It uses a trellis structure with 16 states and evaluates for each path the Euclidean distance between the received sequence and the reconstructed signal using the estimated channel coefficients h_i.
The Viterbi equalizer gives at its output the sequence having the lowest Euclidean distance and a soft information on each demodulated symbol.

This soft information (3 bits) which gives an estimate of the data reliability, is used in the next block of the receiver that implements the convolutional decoding based also on the Viterbi algorithm.

5. SIMULATION RESULTS

A computer simulation program has been set up in order to evaluate the performance of a TDMA mobile radio system with the proposed MLSE receiver. The simulation program written in C language runs on VAX station to obtain the BER (bit error rate) performance of the global system.

The following assumption will be made:

- the normalized bandwidth of the premodulation filter in the GMSK transmitter is BT = 0.3 (the bit rate is 1/T= 270.833 kb/s).
- the baseband receiver filter has a 3 - dB bandwidth two - sided equal to 160 kHz
- the receiver structure includes a 16 - state Viterbi receiver and a 26 bit midamble is used to set at the receiver at the beginning of each time - slot.

The simulated channel impairments are:

- flat Gaussian noise
- Rayleigh fading with Doppler frequency shift and multiple echoes selected by the COST Propagation Group as representative of urban area (TU), rural area (RA) and hilly terrain (HT).

The results of complex echo patterns simulations is reported in Fig. 7 as BER versus E_b/N_0. It can be observed that urban channel is more selective than rural one because includes rather long echo delays.

Also it can be noticed that the bit errors are less in the midamble than in the information message since the channel estimate is evaluated on the note midamble sequence. So, the bit errors grow continuously in the two message parts towards the burst tail.

In Fig.8 is shown the BER versus E_b/N_0 after the Viterbi decoding implementing soft decision.

6. References

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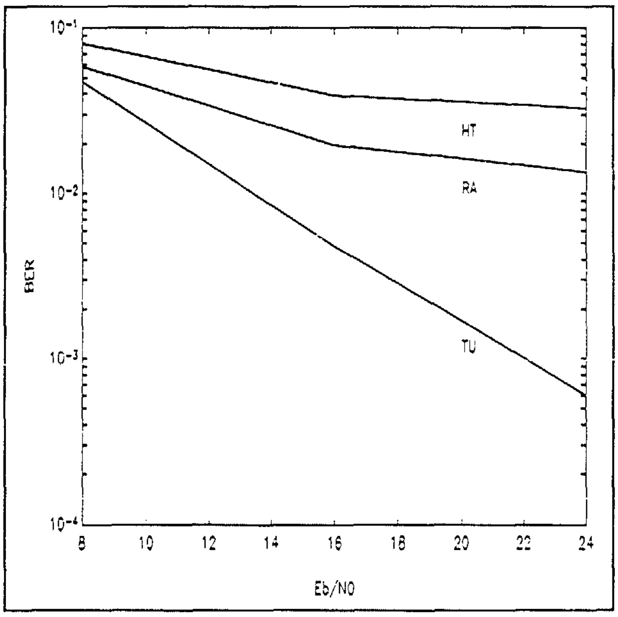

Figure 5 - *Bit error rate performance for the demodulator on TU - Urban Area, HT - Hilly Terrain, RA - Rural Area with Doppler velocity of 50 km/h, 100 km/h and 250 km/h respectively*

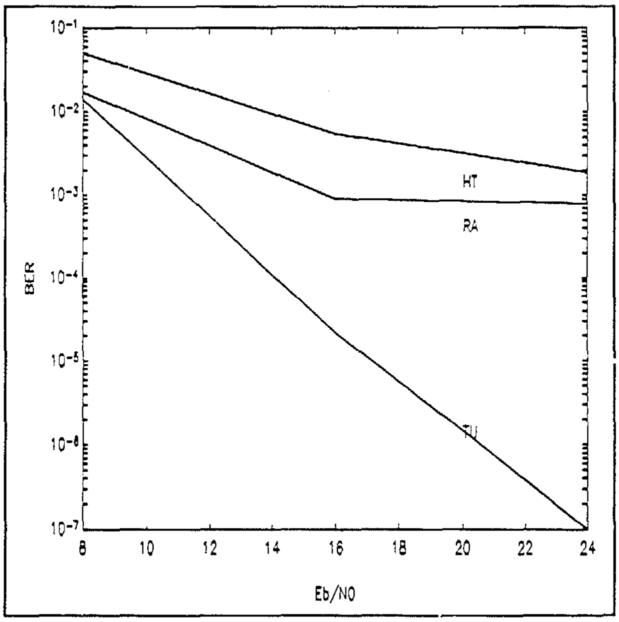

Figure 6 - *Bit error rate performance for the Viterbi decoder in the same cases as Fig.5*