SYMBOL-BY-SYMBOL MOBILE RADIO CHANNEL EQUALIZATION USING THE *K*-NN CLASSIFIER

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ABSTRACT

This paper illustrates an implementation of a GSM receiver in which channel equalization and demodulation are realised by means of the Nearest Neighbor (NN) classifier algorithm. The most important advantage in using such techniques is the significant reduction in terms of computational complexity compared with the MLSE equalizer. No explicit channel estimation need be carried out, and the whole process involves a simple symbol-by-symbol decision procedure. The performance of the proposed receiver, evaluated through a channel simulator for mobile radio communications, is compared with the results obtained by means of a 16 states Viterbi algorithm and other sub-optimal receivers. Despite the simplicity of the receiver, performance degradation is kept within the limits imposed by the GSM specifications.

1 INTRODUCTION

The degradation of the performances in a mobile radio communication system is due to physical phenomena such as multipath fading, time and Doppler delay spread, that produce Inter Symbol Interference (ISI) and time varying channel impulse response [1]. In the case of digital European Global System for Mobile communication (GSM), a TDMA protocol is used, with each TDMA frame divided into eight timeslots, 0.577 ms long, each of which is reserved for a user-transmitted data burst composed of 148 bits. Data transmission is carried out with Gaussian Minimum Shift Keying (GMSK), a Continuous Phase Modulation (CPM) scheme, with differential type precoding, BT product equal to 0.3 and a rate of 270.833 kb/s. A Maximum Likelihood Sequence Estimation (MLSE) receiver, based on the Viterbi Algorithm, is used [2 - 4]. This algorithm is well known to be optimum provided that the channel statistics are known. To this extent, adaptive channel estimation is performed by inserting known training sequences in the transmitted information [2 - 5].

As equalization can be seen as an inverse filtering problem and demodulation is substantially a mapping of received signals on an expected set of symbols, efforts have been made in the last years to treat the joint equalization-demodulation process as a classification problem [6 - 7].

In this paper we present a receiver based on an application of the classical Nearest Neighbor (NN) classification algorithm [8 - 9] that has often been applied in many pattern recognition problems. This technique is suboptimal with respect to MLSE equalizers although performances can be kept within the limits imposed by the GSM specifications. On the other hand its complexity is much lower and avoids explict recovery of the channel impulse response.

The Nearest Neighbor (NN) rule, and its extension the K-NN, belong to the so called *non parametric* classification algorithms in that they extract the information to build the knowledge about the data structure from the data set itself.

Let $X_l = \{x_1, x_2, \ldots, x_n)$ be a set of n labelled samples, i.e. a set of samples for which a decision has already been made, and let $x_i \in X_l$ be the sample nearest to that currently observed y. Then y is classifed assigning it the label associated with x_i. This is conceptually very simple and leads to fast and efficient algorithms also under the hardware implementation point of view.

The NN algorithm can be generalized to the K-NN. In this case the label associated to sample y is the one found more times among those already assigned to the K labelled samples more similar, according with the specified criterion, to the current one.

2 CHANNEL EQUALIZATION USING THE NN RULE

The GSM System uses an hybrid FDMA-TDMA channel access scheme: carrier spacing is 200kHz and each carrier conveys TDMA frames composed of eight timeslots each lasting 0.577 ms for a total frame time of 4.616 ms. The timeslots carry signalling and user traffic, following a rather complex multiplexing scheme, at a data rate of 270.833 kb/s. This rate allows for 156.25 bit periods per slot. With the only exception of the random access burst used by the mobile station when it has not yet been synchronised with the transmission frame, 148 bits are actually used for a user-transmitted data burst while 8.25 bits are indeed left empty (i.e. no transmission is performed) to compensate for fluctuations in the mobile-to-base propagation delay. The 26 central bits named *midamble* according to the GSM terminology represent a training sequence to be used for channel estimation and adaptation of the equalizer parameters. Data transmission is carried out with Gaussian Minimum Shift Keying (GMSK) modulation, a Continuous Phase Modulation (CPM) scheme, with differential type precoding and normalized bandwidth equal to 0.3 so that the correlation introduced by the modulation spans L=3 adjacent symbols.

In the applicationto mobile radio transmission, the set of labelled samples is composed by all the 26 symbols contained in the received middamble $\{m_0, m_1, ..., m_{25}\}$: these will represent the outcomes of the alterations imposed by the channel conditions on the known training sequence and will be used to perform the classification of the received information signal into the originally transmitted symbols 1 and -1.

For this purpose, as a first step the phase-quadrature alternating signal is converted to a real signal [10] and the phase information is embedded in the bit position in the burst. This is accomplished by multiplying the received middamble symbol by j^{-n}, thus obtaining a modified training sequence as $m'_n = j^{-n} m_n$.

The received signal r_i is assigned to the bit associated to the nearest sample m'_k, which minimizes the Euclidean distance between r_i and m'_k i.e.

$$\bar{r}_n = m_i \Big| \min_i \left\{ D^2 = \left| \bar{r}_n - m_i \right|^2 \right\}.$$

If the K-NN version is used, then the first K distances are evaluated and a majority voting scheme is used: the final value is simply the one that appears most often among the K m_i midamble bits.

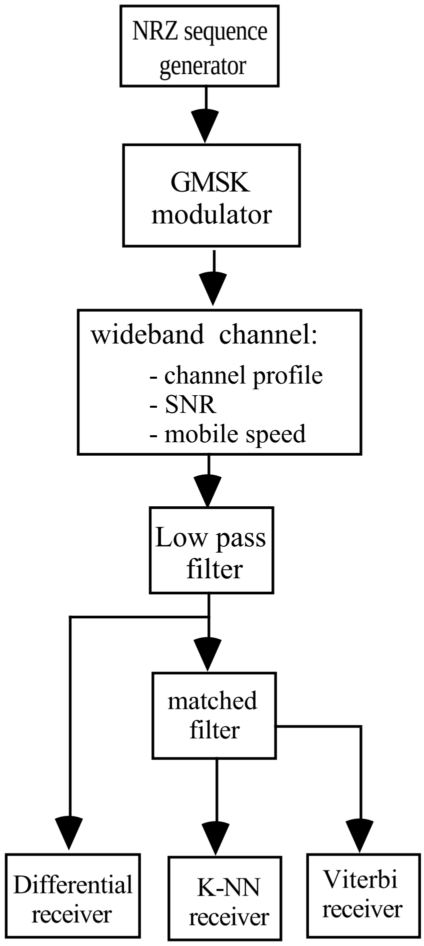

Figure 1. System model.

3 EXPERIMENTAL RESULTS

The proposed algorithm, the 16 states Viterbi demodulator traditionally used in GSM receivers and a differential receiver have been compared by means of computer simulations using the typical channel models proposed by ETSI_GSM [11]: hilly terrain (HT), urban area (UA), and rural area (RA). The transmission chain of Figure 1 has been written using the Matlab IV™ environment and validated comparing the results with those published in [3][10]. The low pass filter is a Butterworth filter with 5 taps and bandwidth equal to 0.5 times the transmission rate. To take into account the TDMA strcture of the access protocol, channel conditions are sampled every burst period. The first one is a coherent receiver and is known to be optimal in case of perfect channel knowledge. The second one is non-coherent and in its basic implementation makes a decision at every bit time without any channel estimation. In some sense, they represent two extreme solutions with the proposed algorithm being seen as somewhere in between them.

Graphs in Figures 2 to 4 show that the curves of the K-NN receiver are not much worse than the “ideal” MLSE even in very bad channel conditions while the performances of the differential demodulator are clearly unsatisfactory. In one case (the RA channel profile) the NN receiver even provides slightly better results than the MLSE one. The decay in performances with the UA and HT channels, is related to the higher delay spread of the channel and consequently to the higher ISI experienced in these cases. For K>1 one would expect this to improve the overall performances: in practice it is true only if the number of samples is large enough to allow classes to contain a dense population of samples. As this is not the case in the system under consideration, performances remain constant for low values of K and degrade when increasing K over 15 since at this point we are approaching the dimensionality of the samples space.

For comparison, we also report in Figures 5 to 7, results from two other suboptimal receiver structures derived one by simplifying the trellis diagram of the MLSE [10], the other by adding a trellis to the differential receiver [12].

It is very interesting to compare the complexities of the K-NN and MLSE receivers. First of all the K-NN does not require to explicitly extract the channel impulse response: once that the middamble has been extracted, the input signal is directly mapped into the output estimated sequence.

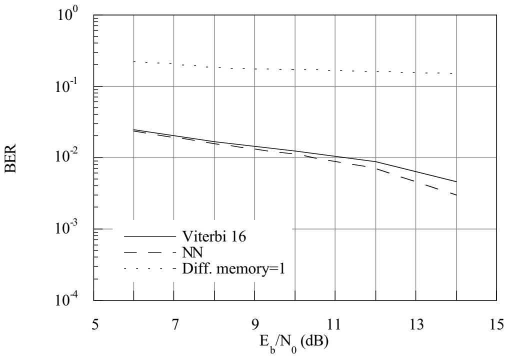

Figure 2. Performance comparison: Urban Area profile, mobile speed 50 Km/h.

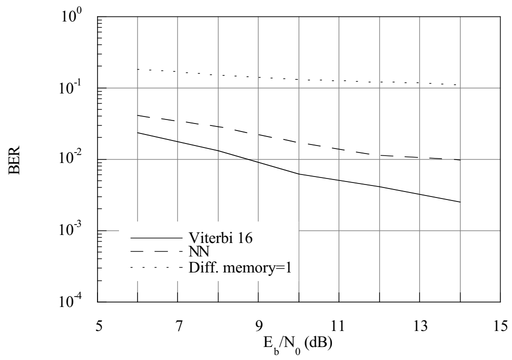

Figure 3. Performance comparison: Rural Area profile, mobile speed 250 Km/h.

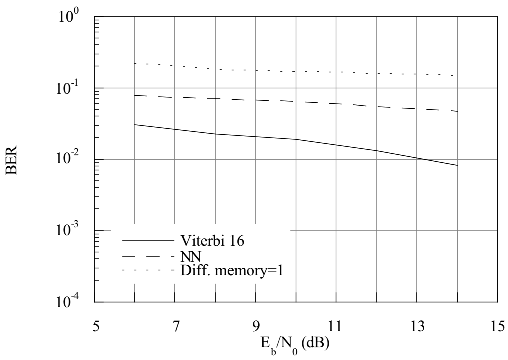

Figure 4. Performance comparison: Hilly Terrain profile, mobile speed 100 Km/h.

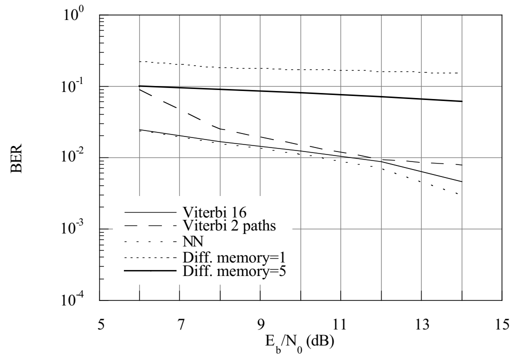

Figure 5. Comparison of different receivers for the Rural Area (RA) environment.

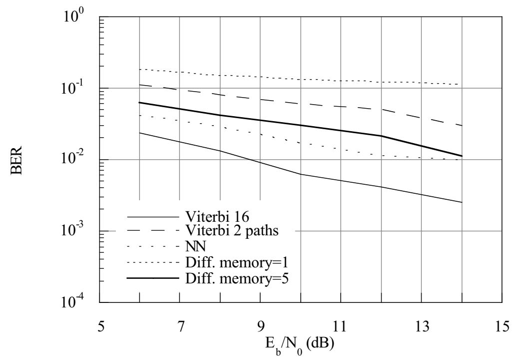

Figure 6. Comparison of different receivers for the Urban Area (UA) environment.

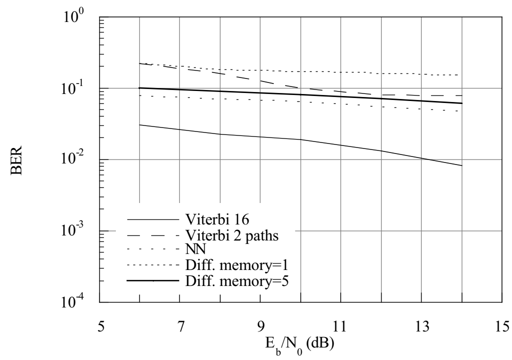

Figure 7. Comparison of different receivers for the Hilly Terrain (HT) environment.

As a second point, the proposed implementation takes decisions on the label to assign to each bit *on the fly*: this means that no additional delay is added as opposed to the Viterbi algorithm. At each step, 26 metrics are computed and not 32 as in a 16 states trellis. These metrics are simple distances and no convolution must be performed.

The computational savings are confirmed by the simulation time which is about one third than that taken by the Viterbi algorithm: only 46253 flops (as determined by the Matlab tool) opposed to the 468327 flops of the 16 states Viterbi receiver. The differential receiver in its basic version requires one order of magnitude less operations (1586 flops).

The complexity of the modified MLSE is simply the one of the MLSE scaled by the memory of the channel, while that of the modified differential is augmented by the intoduced memory an becomes comarable to the K-NN receiver for a memory of 5 symbols.

Complexity comparisons are summarized in Table I where M is the number of modulation symbols, L is the receiver memory and Γ is the length of the training sequence.

CONCLUSIONS

In this paper, an alternative approach to the equalization and demodulation process has been presented. It exploits a well known algorithm widely used in pattern analysis and image interpretation where it has proved to be effective in solving classification problems associated with characterizing features, such as those of remotely sensed images. While images exhibit spatial patterns, a sequence transmission over communication channels can be seen as producing temporal patterns. Analogies between the two problems are exploited to replace the traditional MLSE receiver employed in mobile radio communications by a nearest neighbor classification algorithm. The analysis of the two approaches shows that the trade off between implementation costs and performances may be in favour of the NN technique as it satisfies the requirements imposed by mobile radio systems such as the GSM in terms of bit error rate while its complexity is much lower than that of a MLSE signal detector.
Further studies are under consideration to add memory to the NN classifier to exploit the properties of CPM signals. This would make it an hybrid with a trellis based receiver: the issues are how much memory to add and the performance improvements to be obtained. A further research topic involves modifying the learning process to allow blind equalization.

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		Viterbi with memory L	Nearest Neighbor	Differential with memory L
Channel estimation	complex multipl additions	ΓxL ΓxL	n/a n/a	n/a n/a
metric computation	complex multipl distances	$Nx\Gamma xM^{L-1}$	$Nx\Gamma$	NxM^{L}
Decision function		minimum	minimum	threshold
Delay (symbols)		5L	none	L
Memory		$5LxM^{L-1}$	none	LxM^{L}

Table I. Operation count for different receiver structures