VITERBI ALGORITHM WITH EMBEDDED CHANNEL ESTIMATION BASED ON FUZZY INFERENCE

Lorenzo Favalli*, Alessandro Mecocci** Pietro Savazzi*

*Dipart. di Elettronica, Universita' di Pavia
via Ferrata 1
27100 Pavia, Italy
Tel.: +39 (382) 505923, fax: +39 (382) 422583
e-mail: favalli@ele.unipv.it

**Facoltà di Ingegneria, Universita' di Siena
via Roma 53
53100 Siena, Italy
Tel.: +39 (577) 263601;fax: +39 (382) 263602
e-mail: amecocci@ats.it

ABSTRACT

This paper describes a novel approach to the problem of fading channels estimation. Specifically, the proposed system makes use of fuzzy logic in the computation of the metrics for an MLSE equaliser for GMSK signals in GSM typical environments. The comparison with the traditional Viterbi algorithm is performed using the channel models specified by ETSI and shows that the proposed system performs better under all channel conditions: for the same SNR the improvement is about a half decade in BER or, conversely, the same BER can be obtained with a SNR 4dBs lower than using the adaptive Viterbi algorithm alone.

1 INTRODUCTION

In a mobile radio communication systems, continuous phase modulations (CPM) and maximum likelihood sequence estimation (MLSE) receivers are used to counteract the signal degradation due to multipath fading, time and Doppler delay spread, that produce intersymbol interference (ISI) [1]. Furthermore the channel impulse response varies with time as the user moves.

In these cases, continuous phase (CPM) modulation schemes and maximum likelihood sequence estimation receivers (MLSE) are used to overcome the mentioned impairments [2]. To optimise the decision process the channel statistics must be known. so the fundamental problem is to introduce an adaptation capability in the receiver to allow the tracking of channel variations.

In the case of the digital European Global System for Mobile communication (GSM) system, GMSK modulation is used because of its bandwidth efficiency, the correlation introduced by the modulation and channel filters spans L=5 adjacent symbols [3]. At the receiver, a $2^{(L-1)}$ =16 states Viterbi algorithm [4] is used to efficiently implement the MLSE concept. To allow channel adaptation, the information is structured in bursts of 148 bits as in Figure 1. with the 26 central bits corresponding to a known pattern (midamble). Of these 26 bits, only 16 are indeed meaningful and exhibit an autocorrelation function approaching a Dirac impulse to allow an easy identification of the channel impulse response that is then used in the evaluation of the trellis metrics.

The evaluation of the channel impulse response is in general a critical part of the system and for time varying channel conditions becomes prone to identification errors. Furthermore the capability to adapt the estimation process is obtained at the expenses of bandwidth utilization: the 26 bits introduced in the GSM burst represent over 17% of the global bandwidth and almost 23% of the user bandwidth.

To overcome this underutilization of a scarce resource, blind equalization has attracted in the years the attention of many researchers [5],[6] and [7]. Unfortunately, blind algorithms require long convergence times and this makes them unfeasible for mobile radio applications. The approach followed in this paper is slightly different in that it doesn't attempt to recover the channel behavior, but directly exploits the system memory weighting the most recent symbols in the current decision using fuzzy logic.

Fuzzy logic has been applied in various areas and mainly in control systems [8] and more recently also to channel equalisation [9]. In this paper a fuzzy estimator is used to determine the metrics to be used in a traditional Viterbi receiver such as the one used in the GSM system thus replacing the "channel estimation" block of the adaptive equaliser and incorporating the likelihood estimation function in the decoding process.

In section 2 of the paper, the system under consideration is presented and compared to the traditional MLSE receiver implemented via the Viterbi algorithm. Section 3 introduces the simulation conditions and the results comparing both the "full" receivers with memory equal to the length Intersymbol Interference and receivers with a reduced number of states.

tail bits	info bits	midamble	info bits	tail bits	guard period
3	58	26	58	3	8.25

← 148 bits →

Figure 1. The structure of the GSM information burst.

2 RECEIVER DESCRIPTION

In order to be able to apply fuzzy logic to any generic system, it is necessary to determine proper membership functions and *rules* to first transform the input variables into fuzzy variables, and then map the fuzzy variables into outputs: this process is also known as “fuzzyfication”. In our case the input variables are the complex values of the baseband signal (phasors) reconstructed at the receiver. There are five membership functions defined as Large Negative (LN), Medium Negative (MN), Zero (ZE), Medium Positive (MP) and Large Positive (LP) which are also given in Figure 2. There is a single rule stating “IF <x ∈ X> THEN <y ∈ X>" where x and y are the input and output variables and X ∈ {VN; MN; ZE; MP; VP}. This rule is applied to the estimates of the last L received symbols as in Figure 3. The results for each rule are weighted and summed in a fuzzy OR rule. The weights are determined using an exponentially decaying rule in accordance with the typical multipath intensity profile as reported in [10] with a maximum delay spread of the channel set to about 20μsec and a symbol duration of about 3.7 μsec. The sum of the weights is then normalised to one. Note that this process “sequentially” recovers the symbols without using the information provided in the middamble and thus implements a “blind” equaliser.

Once the rules have been combined to determine the fuzzy output variable, this needs to be “defuzzified” to determine the *crisp* output value. This is obtained using the *Maximum defuzzifier* rule so that the actual output is associated to the value of the fuzzy output that corresponds to the maximum membership function.

Before being fed to the classical or fuzzy Viterbi receiver, the modulated signal undergoes some pre-processing to make it more easiliy tractable.

According to [11] the GMSK signal can be approximated by a linear modulation

$$s'(t) = \sum_{k=-1}^{\infty} j^k a_k p(t-kT),$$

where $p(t)$ is a real pulse. The transmitted signal can be seen as a sequence of symbols c_n that alternate between real and imaginary values at every symbol time, with values either ±1 or ±j. In short, the c_n can be related to the information bit by the simple relationship $c_n = j^n a_n$. Due to the transmission impairments, the signal will be affected by intersymbol interference (ISI) and noise at the receiver. The approximation introduced above, justifies the following representation of the received base-band signal [11]:

$$r(t) = \sum_{k=-1}^{\infty} j^k a_k h(t-kT) + n(t),$$

$n(t)$ incorporates the additive channel noise and the approximation error $s(t) - s'(t)$ and $h(t)$ is the convolution of $p(t)$ with the complex lowpass equivalent response of

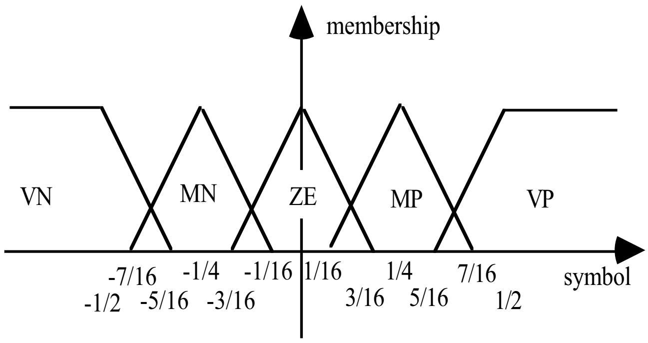

Figure 2. Fuzzy membership functions.

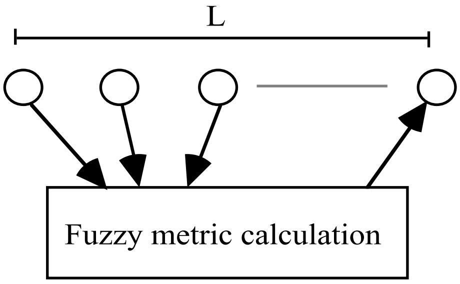

Figure 3. New metric derivation.

the transfer function of the complete system (i.e. comprising the cascade of transmitter, channel and receiver). The noise $n(t)$ is assumed to be white and gaussian, with spectral density equal to N_0. The received signal is sampled and if a finite memory L is assumed can be described as

$$r_i = r_L(iT) = \sum_{k=0}^{L-1} j^{i-k} a_{i-k} h_k + n_k .$$

The usual likelihood measure used is the minimization of the Euclidean distance D^2 between the received signal r_l and the transmitted sequence defined as

$$D^2 = \sum_{n=0}^{L_s-1} \left| r_n - \sum_{i=0}^{L-1} j^{n-i} a_{n-i} \hat{h}_i \right|$$

where $\hat{h}_i$ is the estimated coefficient of the channel impulse response, a_{n-i} is the transmitted symbol and L_s represents the length of the information burst. The traditional approach is to evaluate the $\hat{h}_i$ coefficients by correlating the received training symbols with a local prototype as

$$R_i = \sum_{n=0}^{\Gamma-1} \sum_{k=0}^{L-1} j^k m_k \bar{r}_{n+i}$$

In the case of blind receivers, this step need not be carried out with large computational savings.

3 EXPERIMENTAL RESULTS

Figures 4 to 6 describe the results for the three typical GSM test environments [12]: Urban Area (UA), Hilly Terrain (HT) and Rural Area (RA). The propagation condition are also reported in Tables I through III and the mobile speed is respectively set to 50, 100 and 250 km/h for the three environments. It should be noted that the Viterbi algorithm with metrics determined using the proposed fuzzy decision, performs better under all circumstances. Although the improvement in BER for the same SNR is not dramatical, it should be noted that conversely the same BER can be obtained with a SNR that is about 4dBs worse than with the traditional adaptive metric estimation. This is of particular significance for possible implementation in system s where the information is already coded to achieve a given error protection: in these cases, it is possible to provide a high quality of service even in severely degraded channel conditions.

Tap number	delay (μs)	Attenuation (dB)	Doppler spectrum
1	0.0	-4.0	CLASS
2	0.1	-3.0	CLASS
3	0.3	0.0	CLASS
4	0.5	-2.6	CLASS
5	0.8	-3.0	CLASS
6	1.1	-5.0	CLASS
7	1.3	-7.0	CLASS
8	1.7	-5.0	CLASS
9	2.3	-6.5	CLASS
10	3.1	-8.6	CLASS
11	3.2	-11.0	CLASS
12	5.0	-10.0	CLASS

Table I. Propagation Model for Urban Area (UA)

Tap number	delay (μs)	Attenuation (dB)	Doppler spectrum
1	0.0	-10.0	CLASS
2	0.1	-8.0	CLASS
3	0.3	-6.0	CLASS
4	0.5	-4.0	CLASS
5	0.7	0.0	CLASS
6	1.0	0.0	CLASS
7	1.3	-4.0	CLASS
8	15.0	-8.0	CLASS
9	15.2	-9.0	CLASS
10	15.7	-10.0	CLASS
11	17.2	-12.0	CLASS
12	20.0	-14.0	CLASS

Table II. Propagation Model for Hilly Terrain (HT)

Tap number	delay (μs)	Attenuation (dB)	Doppler spectrum
1	0.0	0.0	RICE
2	0.1	-4.0	CLASS
3	0.2	-8.0	CLASS
4	0.3	-12.0	CLASS
5	0.4	-16.0	CLASS
6	0.5	-20.0	CLASS

Table III. Propagation Model for Rural Area (RA)

Figures 7 to 9 provide a different view of the performance/complexity trade-off. Again for the different propagation conditions specified by the ETSI documents, the memory of the fuzzy inference engine in terms of the number of previous symbols weighed to achieve the final decision is compared to the memory of a Viterbi receiver. It is seen that the same performances can be obtained with a shorter memory thus reducing the complexity of the overall circuitry required.

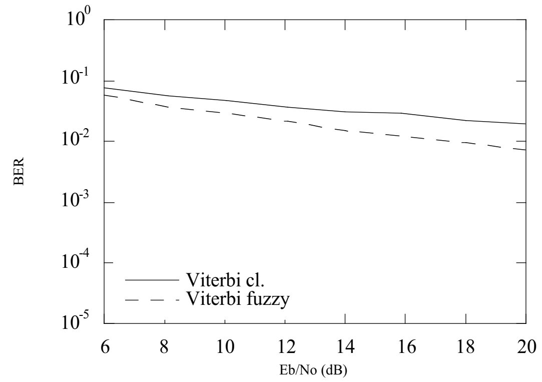

Figure 4. Results for the HT channel conditions.

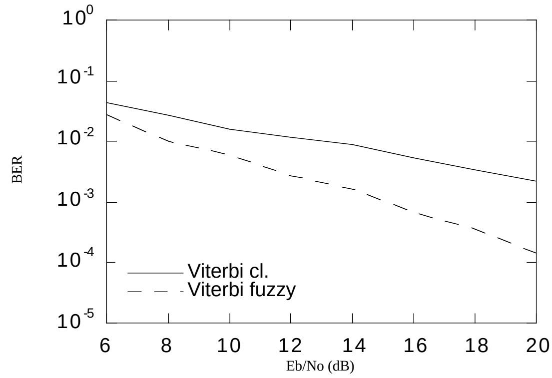

Figure 5 Results for the RA channel conditions.

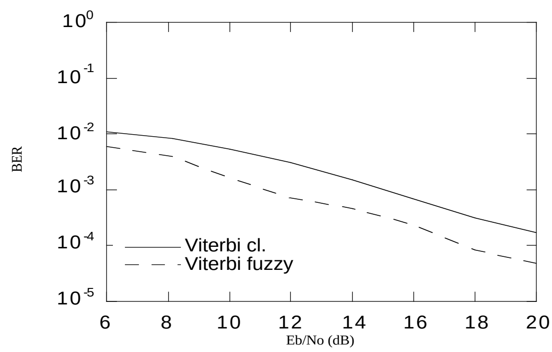

Figure 6. Results for the UA channel conditions.

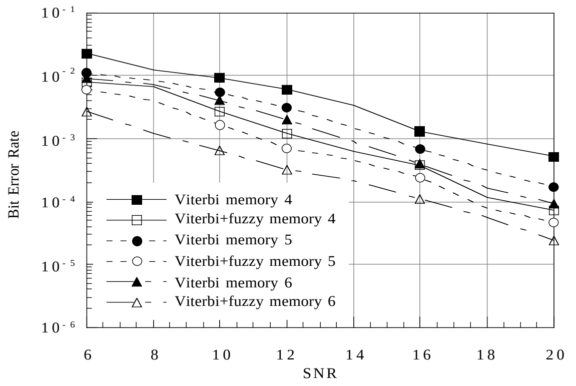

Figure 7. Comparison for different L. HT.

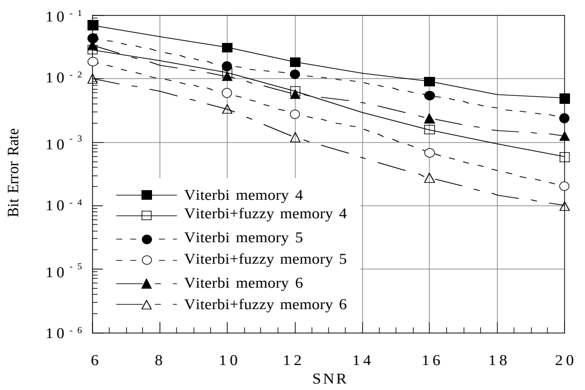

Figure 8. Comparison for different L. RA.

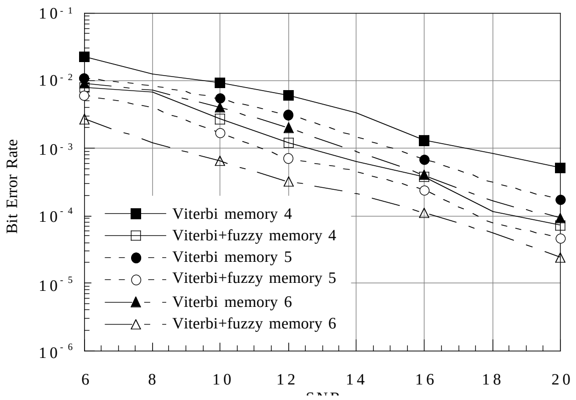

Figure 9. Comparison for different L. UA.

CONCLUSIONS

We have presented a novel approach to the problem of implementing a MLSE receiver in which the likelihood function is performed using fuzzy estimation of the alterations introduced by the channel. Although in this implementation the weights assigned to the past symbols is fixed, the results obtained show a significant improvement over the traditional approach. It is expected that a further improvement can be obtained introducing an adaptability of the system by estimating the weights to be assigned in the combination over the past L symbols. This work is currently under development. Other work that is currently being carried on is the applicability to channels in which a significant co-channel interference is present.

REFERENCES

[1] B. Sklar, "Rayleigh Fading Channels in Mobile Digital Communicatons Systems Part I: Characterization," IEEE Commun. Mag., vol. 35, no. 7, pp. 90-100, July 1997.

[2] B. Sklar, "Rayleigh Fading Channels in Mobile Digital Communicatons Systems Part II: Mitigation," IEEE Commun. Mag., vol. 35, No. 7, pp. 102-109, July 1997.

[3] K. Murota and K. Hirade, "GMSK modulation for digital mobile telephony," *IEEE Trans. Commun.*, vol. COM-29, pp. 1044-1050, July 1981.

[4] G. Benelli, G. Castellini,, E. Del Re, R. Fantacci, L. Pierucci, L. Pogliani, "Design of a digital MLSE receiver for mobile radio communications," in Proc. Int. Conf. Globecom’91, November 1991, Phoenix, pp. 1469-1473.

[5] L. Tong, “Blind sequence estimation,” *IEEE Trans. on Commun.*, vol. 43, pp. 2986-2994, Dec. 1995

[6] Y. Sato, “Amethod of self-recovering equalization for multilevel-amplitude modulation,” *IEEE Trans. on Commun.*, vol. 23, pp. 679-682, June 1975.

[7] P. Castoldi, R. Raheli, “On recursive optimal detection of linear modulations in the presence of random fading,” *European Transactions on Telecomm., Special Issue on Signal Processing in Communications*, vol 9, pp. Mar-Apr. 1998.

[8] J.M. Mendel, "Fuzzy logic systems for engineering: a tutorial," Proceedings of the IEEE, vol. 83, no. 3, March 1993, pp. 345-377.

[9] P. Sarwal, M.D. Srinath, "A fuzzy logic system for channel equalzation," IEEE Tr. on Fuzzy Systems, vol. 3, no. 2, May 1995, pp. 246-249.

[10] J.G. Proakis, "Digital communications," 3rd edition, McGraw-Hill International Editions, 1995

[11] P. A. Laurent, "Exact and approximate construction of digital phase modulations by superposition of amplitude modulated pulses (AMP)," *IEEE Trans. Commun.,* vol. COM-34, pp. 140-160, Feb. 1986.

[12] *Propagation Conditions*, ETSI/GSM Recommendation 05.05.