ON THE IMPORTANCE OF ERROR MEMORY IN UMTS RADIO CHANNEL EMULATION USING HIDDEN MARKOV MODELS (HMM)

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Abstract - The possibility to change data rate in 10 milliseconds is one of the innovative features of the Universal Mobile Telecommunications System (UMTS). This change results in a different mobile channel with different burst error characteristics that can be modelled and its effects can be emulated by Hidden Markov Models (HMM) which are computationally more efficient than waveform level models. Thus the data rate change in the wideband CDMA (WCDMA) channel supposes to change the HMM. This change from one HMM to another can be performed considering the number of errors in the last frame or not. In this paper the impact of error memory when the channel emulated by HMM change, is presented[1].

Keywords - Hidden Markov Model, WCDMA channel memory, UMTS.

I. INTRODUCTION

Markov models have been widely used for modelling different systems such as: speech and image recognition, telecommunications, and automatic control. As for wireless communications the statistics of burst errors in radio channels can be accurately modelled using a class of Markov models called Hidden Markov Model (HMM)[1][2]. The study of the HMM for real communication channels error statistics was initiated by Gilbert [3] and Elliot [4]. The Gilbert-Elliot channel is a two-state Markov channel not adequate when the channel quality varies dramatically, as it can occur in a typical multipath channel due to channel variability and high transmissions rates. The solution is to use a channel model with more than two states, as it can be a HMM. In that sense, several works have been devoted to modelling mobile propagation channels using HMM [5], [6].

Within the prevalent interest in the third generation (3G) mobile system standardisation process the packet data services integration among all the services is one of the main targets. Although data services are already present in fixed networks, i.e. Internet, and there exist several suitable protocols, the main trouble in mobile systems is the radio access, so it is important to investigate the impact of this access in the protocols used in packet mode services. At this aim, a radio access network emulator has been developed for the UMTS Terrestrial Radio Access - Frequency Division Duplex (UTRA- FDD) mode, which is based on a Wideband- Code Division Multiple Access (WCDMA) technique. A description of this emulator can be found in [7]. This emulator reproduces the lower layers of the UMTS radio interface that is: the Physical Layer, the Data Link Layer and some functionality of the Network Layer. To model the radio channel within the emulator HMMs have been used. The main advantage of using HMM in the emulator is the huge reduction in time, resources and effort with regard to a real simulation of the system.

Among the innovative features of the UMTS Radio Access, the possibility to change channel bit rate every 10 milliseconds, under Radio Resources Management (RRM) entity control, has been considered. The fact is that to change data rate at Physical Layer in 10 milliseconds turns into a change between two different HMM. This paper deals on this change, and compares whether the number of errors in the last frame before data rate change is considered or not.

The paper is organized as follows: section 2 describes the HMM basis. Next in section 3 the channel emulation in the two considered alternatives is presented. In section 4 a numerical example is shown, and finally conclusions are discussed in section 5.

II. HIDDEN MARKOV MODELS (HMM)

To outline burst errors in communications channels a class of Markov models called HMM is used. In that model the bursty error source is assumed to be in many states. In those models the observed sequence of errors is assumed to be a function of underlying Markov chain that describes a sequence of hidden channel states.

To understand the principles of the Hidden Markov Model, it is first necessary to have some knowledge of the Markov Chains [8].

A. Markov Chains

Considering a system described each time instant by a state within the set of N different states, $S_1, S_2, ..., S_N$. At discrete times, the system experiences a change of state according to a set of probabilities associated to this state. Let us define the time instants associated to state changes as t=1,2,..., and the current state at instant t as q_t.

[1] This research was supported by CICYT project TIC 2001-2222.

A full probabilistic description of such a kind of system requires specifying the current state at instant t and previous states. For a first-order Markov discrete chain, this description is simply given by the current state and the previous one:

$$P\left[q_t = S_j \middle| q_{t-1} = S_i, q_{t-2} = S_k, \ldots\right] = P\left[q_t = S_j \middle| q_{t-1} = S_i\right] \quad (1)$$

Only the processes in which the right side of equation (1) is independent of time are usually considered. Therefore, the set of state transition probabilities a_{ij} can be defined as:

$$\begin{aligned} a_{ij} &= P\left[q_t = S_j \middle| q_{t-1} = S_i\right], \qquad 1 \le i, j \le N \\ \sum_{j=1}^{N} a_{ij} &= 1 \end{aligned} \quad (2)$$

where $a_{ij} \geq 0$ since they must follow standard stochastic restrictions.

B. Hidden Markov Model

The HMM is an observable model in which the observation is a probabilistic function of the state.

The HMM is characterized by the following elements:

- N, the number of states of the model. The states are usually interconnected among them, so each state can be reached from any other. The individual states are defined as $S = \{S_1, S_2, ..., S_N\}$ and the current state at instant t as q_t.
- M, the number of different observation symbols per state. The observation symbols correspond to the physical output of the system being modelled. The individual symbols are defined as $V = \{v_1, v_2 ... v_M\}$.
- The transition probability distribution between states, $A = \{a_{ij}\}$, where:

$$a_{ij} = P\left[q_{t+1} = S_j \middle| q_t = S_i\right], \qquad 1 \le i, j \le N \quad (3)$$

- The observation symbol probability distribution in state j, $B = \{b_j(k)\}$, where

$$b_j(k) = P\left[v_k \text{ at } t \middle| q_t = S_j\right], \qquad \begin{aligned} 1 \le j \le N \\ 1 \le k \le M \end{aligned} \quad (4)$$

- The initial distribution of states, $\pi = \{\pi_i\}$, where:

$$\pi_i = P\left[q_1 = S_i\right], \qquad 1 \le i \le N \quad (5)$$

Giving appropriate values to the parameters N, M, A, B and π, the HMM can be used as a generator to produce the observation sequence $O = \{O_1, O_2, ..., O_T\}$, where O_t is one of the symbols of V, and T is the number of observations in the sequence. The procedure is as follows:

1. Choose an initial state $q_1 = S_i$ according to the initial state distribution: π.
2. Set t = 1.
3. Choose $O_t = v_k$ according to the symbol probability distribution at state S_i, i.e., $b_i(k)$.
4. Go to a new state $q_{t+1} = S_j$ according to the transition probability distribution of state S_i, i.e., a_{ij}.
5. Set t = t+1, and go back to 3 if t<T. If t=T, the procedure is finalised.

This procedure can be used as an observation generator, and also as a model by which a given observation sequence is generated by a so-designed HMM.

A complete specification of an HMM requires the two model parameters (N and M), the observed symbols and the three probability measures (A, B and π) to be specified. For convenience, to indicate the complete set of model parameters the following short notation is used:

$$\lambda = (A, B, \pi) \quad (6)$$

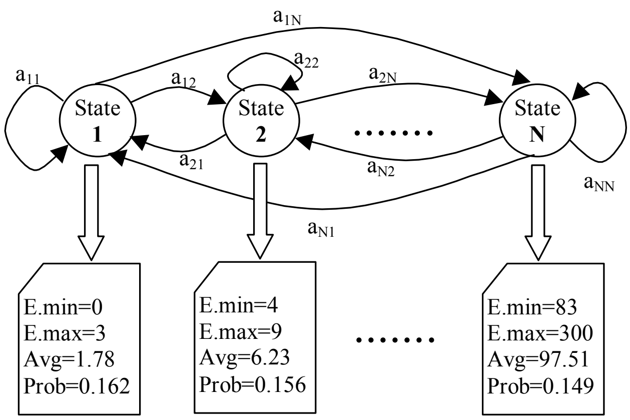
III. WCDMA CHANNEL EMULATION

In the emulation of a WCDMA channel the observation symbols correspond to the number of errors occurred in a frame or bloc, and their probability distribution is assumed to be uniform weighted by the average of errors in that state. Thus each state is defined by the minimum number of errors that can be generated in this state, the maximum number of errors, the average, and the probability to "be" in that state.

In order to obtain a better performance in the emulation the states probabilities must be as equal as possible. This implies that in the vast majority of HMMs the number of different observation symbols per state (M) is not constant within the states belonging to the same model.

A HMM diagram with numerical values is shown in Fig. 1. In this example the "state 1" has as a minimum 0 errors per frame or bloc, maximum 3 errors and average 1.78 errors per frame; the "state 2" has a minimum of 4 errors, a maximum of 3 errors and an average of 6.23 errors per frame; and so on, up to the last state which has a maximum of 300 errors, corresponding to the number of bits in a frame for this emulated channel. The transition probability distribution between states is depicted as "Transition matrix".

A statistical channel behaviour is needed to train the HMM. To that end, WCDMA channel off-line simulations have been made [9]. The simulation model implements each of the transmission chain elements, and can be considered quite accurate to a real system. It has been used to derive the channel behaviour, mainly in terms of error distribution.



Transition matrix:

a_{11}	a_{12}	....	a_{1N}
a_{21}	a_{22}	....	a_{2N}
⋮	⋮	....	⋮
a_{N1}	a_{N2}	....	a_{NN}

Fig. 1. HMM diagram

To emulate the channel using HMM provides a huge reduction in time, resources and effort with regard to a real simulation of the system. These advantages allow operating in real time. Some examples presented in [7] and [10] show that the emulator is accurate enough although there is a loss of accuracy. The validity of the HMM emulator is also presented in the mentioned references.

In order to reproduce a WCDMA channel the following parameters have been considered:

- Link direction (uplink, downlink)
- Mobile speed (3 km/h, 50 km/h or 120 km/h)
- Closed loop power control (Yes or Not)
- Spreading Factor (SF)
- Eb/No (in dB)

These parameters determine the physical channel behaviour take into account in the off-line simulations.

The nomenclature used for the radio channels emulated by HMM is the following: *LnnnVeep*, where *L* can be *D* for downlink or *U* for uplink; *nnn* indicate the spreading factor; *V* indicates the mobile speed, and can be *B* for 3 km/h, *M* for 50 km/h or *A* for 120 km/h; *ee* indicate the Eb/No in dB; and *p* indicates whether closed loop power control is considered (*s*) or not (*n*).

In Table 1 the relation between the data rate, the considered spreading factors and the frame length for the downlink is shown.

Table 1
Relation between downlink bit rate, SF and frame length.

Bit rate [kbps]	SF	Frame Length [bits]
15	512	150
30	256	300
60	128	600
120	64	1200
240	32	2400
480	16	4800
960	8	9600
1920	4	19200

A new HMM and consequently a new simulation is needed when any of these parameters change.

The three first parameters are fixed for a trial, whereas the last two can change every 10 milliseconds. The present study deals on this change and the importance to take into account the number of errors observed in the last frame before change the HMM (error memory), or not.

A. Change without error memory

In this case, once the new HMM have been selected, the state which corresponds to the first frame is calculated according to the initial state distribution: π.

If no channel change is carried out, the state which corresponds to the second frame in the new emulated channel is calculated from this state and according to the transition matrix. Otherwise the sequence starts once again according to the latest new HMM initial state distribution: π.

B. Change with error memory

In this case, once the new HMM have been selected, the state that contains the number of errors observed in the last frame in the old HMM is chosen as starting state.

From this state and according to the transition matrix the state which corresponds to the first frame in the new emulated channel is calculated. From this state and according to the transition matrix the state which corresponds to the second frame is calculated and so on, until a HMM change occurs.

IV. NUMERICAL RESULTS

In order to study the two mentioned options on an equal basis two trials have been done in parallel, one with error memory and the other without error memory. To take a decision in a given instant the two options use the same random number. So that if they select the same state into the HMM, then they generate the same number of errors since all the items are exactly the same.

In Fig. 2 a piece of one of these trials is shown. In this particular case some jumps belonging to the downlink for a mobile station going at 120 km/h and using closed loop power control are reproduced. Each row represents a different HMM, the first model emulates the first radio channel seen by the mobile station, the second model emulates the radio channel seen next, and so forth. The HMM names are in the left side rectangle. The discontinuous arrows correspond to the “with error memory” sequence, whereas the continuous arrows correspond to the “without error memory” sequence. Arrows in a model indicate the jumps between states and the number of errors emulated for a frame, while arrows between models indicate the memory considered in the change of the emulated radio channel.

Notice that in the case “with error memory” the jumps only use the initial probability state distribution, π, in the first model, whereas in the case “without error memory” they use it in each new model.

Light grey coloured states are the states seen in the “with error memory” case, and dark grey coloured states are the states seen in the “without error memory” case. Looking at jumps in the previous figure it can be proved that the observation sequence is not the same, that is, the generated errors are not exactly equal.

Nevertheless, given that the trend is similar, after some frames the probability to generate *n* errors is almost the same in the two proposed alternatives.

To show this trend, 1200 million of bits have been sent through the emulator.

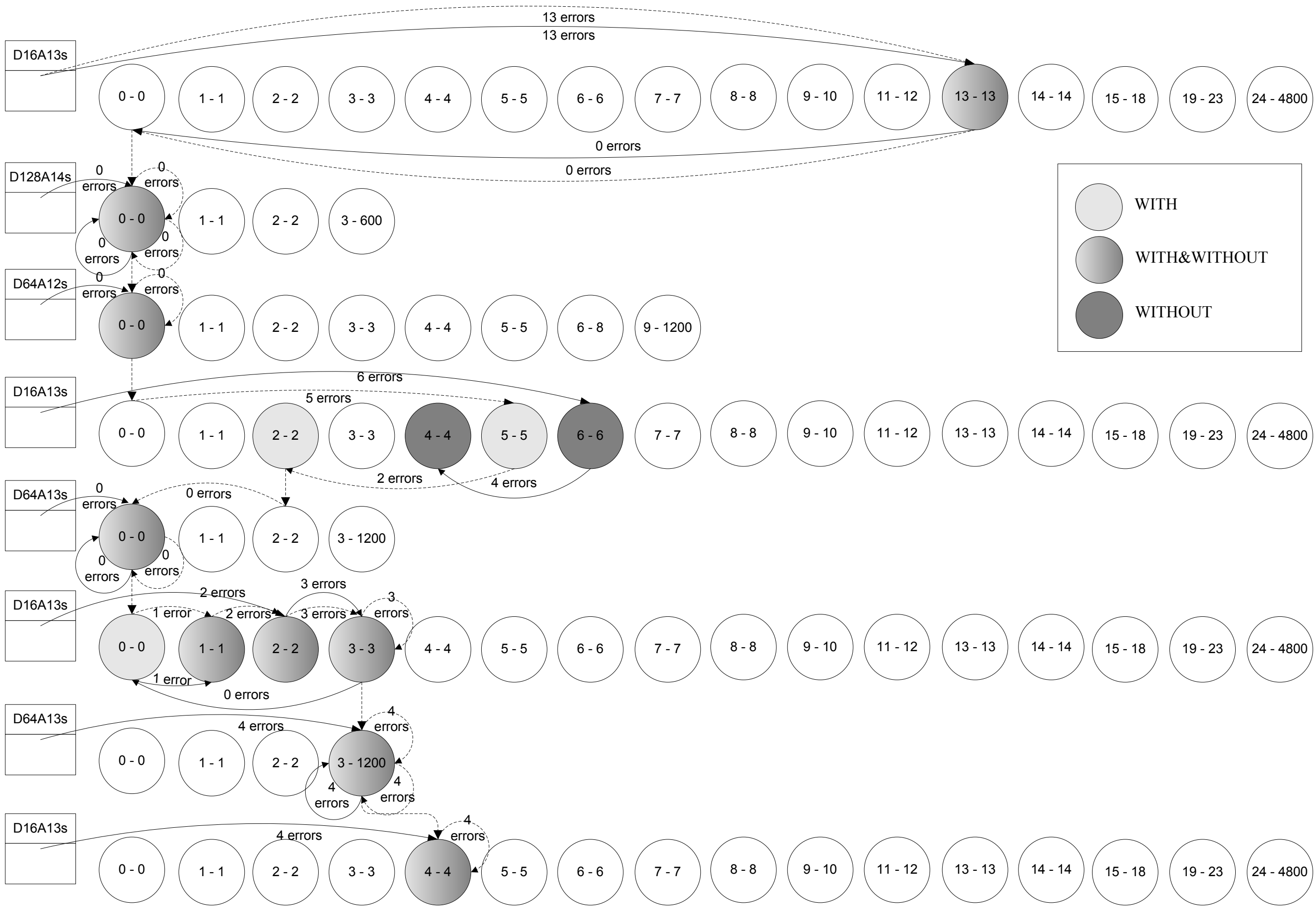


Fig. 2. HMM change with and without error memory

Fig. 3 depicts the number of events that has appeared a given number of errors per frame. As you can see from the diagram the number of errors distribution is almost equal in the two proposed cases.

After doing several trials we have come to the conclusion that errors memory between HHMs is not significant, since although the error generated instantaneous sequence is not identical, in a trial long enough the error histogram in the "without memory" case is very similar to the error histogram in the "with memory" case.

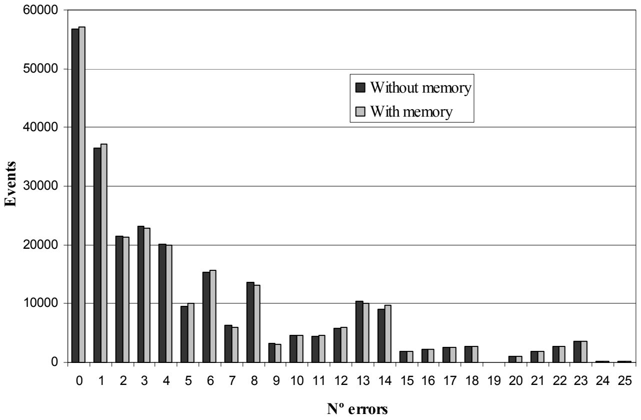


Fig. 3. Comparative diagram of error generation

V. CONCLUSION

Third generation (3G) mobile systems are designed to provide a wide range of packet oriented services to mobile users. Some of these services are already present in fixed networks, i.e. Internet, and there exist several suitable protocols for them, however radio channel introduces more errors than fixed connections and thus it is important to study data packet services over wireless connections.

In that sense, a radio access network emulator has been developed for the UTRA- FDD mode, which is based on a WCDMA technique. To reproduce the radio channel within the emulator Hidden Markov Models (HMM) have been used.

The HMM is a class of Markov model which has the bursty error source allocated in many states. The model needs to be trained with off-line simulation statistics in order to emulate a particular channel within a given environment. Although there is a lost of accuracy in radio channel emulation using HMM the emulator is accurate enough.

In order to reproduce a WCDMA channel five parameters have been considered: the link direction (uplink, downlink); the mobile speed (3 km/h, 50 km/h or 120 km/h); the use of closed loop power control (Yes or Not); the Spreading Factor (SF); and the Eb/No (in dB). A new HMM is needed when any of these parameters change.

The three first selected parameters are fixed for a trial, whereas the last two can change every 10 milliseconds, the UMTS Terrestrial Radio Access Network (UTRAN) frame duration, due to the possibility to change data rate from one frame to the next. This lead to change the used HMM at the most every 10 ms. This change can be performed considering the number of errors in the last frame before change (error memory) or not. In this paper the impact of the aforementioned error memory when the channel emulated by HMM change, has been presented.

Thus the HMM change with and without error memory have been detailed, and a numerical example has been commented. It can be seen that distributions in both cases are almost identical. So, to maintain the number of errors in last frame before change (error memory case) the HMM is not significant.

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