MARKOV CHAIN BASED MODELS COMPARISON IN IEEE 802.16E SCENARIO

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Abstract: The IEEE 802.16e is a promising technology that allows to provide wireless broadband services to a great number of mobile users. Considering this interesting scenario enriched by further presence of HAPs (High Altitude Platform) with the role of Base Stations (BSs), we have proposed a comparison between performances of a set of Markov Chain based models collected by literature. These following models: MTA (Markov-based Trace Analysis), Gilbert – Elliot, FSM (Full-State Markov) and HMM (Hidden Markov Model) are designed using packet error traces (a sequence of "1" and "0") obtained by a simulator that takes into account channel impairment effects such as path loss and Doppler effect. To compare the models performances, by each of them artificial traces are generated and then Entropy Normalized Kullback-Leibler distance, standard error and other statistical properties of random variable G (free error packets burst length) and B (corrupted packets burst length) of artificial traces are computed. The purpose of this work is to identify the model that best describes the channel error behaviour in IEEE 802.16e.

1 INTRODUCTION

In this paper we compare a set of Markov chain based models collected by literature, these models are used to describe channel error behaviour of a particular IEEE 802.16e scenario. This scenario is an HAP (High Altitude Platform), with the role of base station (BS), that provides wireless broadband service to a set of mobile users using IEEE 802.16e protocol (Amendment 4: IEEE 802.16e-03/07, IEEE 802.16e-2005). HAPs are a new technology of airships or planes that will operate in the stratosphere at an altitude of 17-22 km above the ground (De Rango et al., 2006). The IEEE 802.16e specifies a system for combined fixed and mobile BWA supporting subscriber stations moving at vehicular speeds. It should operates in these bands supporting bit rates up to 15 Mbit/s to mobile SS (Subscriber Station) with vehicular mobility up to approximately 100 km/h. Transmission between BS and mobile users is affected by impairment effects as Doppler effect and path loss, that contribute to impair the transmitted data packets. These effects is involved in a physical layer simulator realized with Matlab tool; from simulations a set of packet error traces is collected. A packet error trace is a sequence of "flags" and each one of these can take "0" value if a packet arrives to receiver side in error free manner, or "1" value if packet is received as corrupted; thus a trace describes channel error behaviour, or so we can say that it depicts the MAC – to – MAC (Medium Access Control) link; in fact in simulator transmission chain also physical layer error detection and correction instruments are involved.

Packet error traces obtained by simulations are used to calculate the parameters for the following Markov chain based models: Gilbert – Elliot (see Ebert et al., 1999), MTA (Markov-based Trace Analysis; see Konrad et al., 2001), FSM (Full State Markov; see Khayam, 2007) and HMM (Hidden Markov Model; see Rabiner, 1989). These introduced models are used to represent channel error model of IEEE 802.16e scenario, and from each of these it is possible to generate artificial packet error traces that can be used in more and more realistic simulations of network issues. In this paper we utilize artificial traces, obtained by each model, to make a performance comparison of presented models set. The paper focus is to individuate the model that best approximate the channel error behaviour; in literature, at the best of our knowledge, are not preset works that make a comparison of Markov chain based model performances applied to IEEE 802.16e. In (Khayam et al., 2003) is presented a models comparison applied to Wi-Fi scenario, and in (Konrad et al.,

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2001) models comparison is applied to GSM scenario.

In section 2 scenario with impairments effects such as path loss and Doppler effect are described; in section 3 simulation environment is presented. In section 4 Markov chain based models are introduced. In section 5 and 6 performance analysis and conclusions are respectively described.

2 SCENARIO

An HAP serves mobile users. In this architecture, IEEE 802.16SC is applied. With 802.16SC we refer the physical layer wirelessMAN-SC of IEEE 802.16 protocol. In IEEE 802.16 protocol, only one MAC layer but various physical layers are defined. ITU has licensed frequency bands for the provision of communication services via HAPs for broadband services at 28 - 31 GHz and thus this band was chosen. The wireless channel is a particular kind of channel affected by phenomena such as path loss and Doppler effect. The first is typical of each channel, the second is bound up with relative motion between the transmitter and receiver. The channel model of this scenario, used to obtain error traces, does not take into account multipath fading because this effect is negligible; see (Mohorcic et al., 2005). Regarding the path loss calculation (Spillard et al., 2005), the Free Space Path Loss (FSPL) model is considered. Doppler effect impairment is evaluated as in (Spillard et al., 2005).

3 SIMULATION ENVIRONMENT

To obtain error traces and subsequently the channel error behaviour, various simulation campaigns are needed. On the basis of previous impairment models, a simulator was realized with Matlab tool (MathWorks Inc., 2004). Table 1 contains simulation parameters. The different traces were obtained varying Doppler effect in range 1-4000 Hz that corresponds to max mobility of 150 km/h.

Table 1: Simulation parameters.

Modulation	QPSK
BW(Mhz)	20
Bit rate(Mbps)	32
Path loss (dB)	-150
Eb/N0 (dB)	22
Frequency carrier (GHz)	28
Doppler effect range (Hz)	1 - 4000

4 MARKOV CHAIN BASED MODELS

A Markov chain is a stochastic process, where if “t” is the observation instant, the process evolution from instant “t” depends only from this instant and not by previous temporal instants, in particular, in case of DTMC (Discrete Time Markov chain) the condition can be expressed with the following equation:

$$\begin{aligned} &P(X(t_{k+1}) = x_{k+1} / X(t_k) = x_k \cap X(t_{k-1}) = x_{k-1} \cap .....\\ &... \cap X(t_1) = x_1 \cap X(t_0) = x_0) =\\ &= P(X(t_{k+1}) = x_{k+1} / X(t_k) = x_k) \end{aligned} \quad (1)$$

where t_k is the selected observation instant. A generic Markov chain can be represented by a matrix *M*. This matrix is the transition probability matrix, and it is defined stochastic matrix because it must respect the property that the sum of elements of each row must be equal to one, this condition is expressed by the following equation:

$$\sum_{j=1}^{n} p_{i,j} = 1 \quad (2)$$

This paper is not intended to be a tutorial on different treated models, the attention is focused on the evaluation of their performances. To more clarity see referenced works.

5 PERFORMANCE ANALYSIS

In this section the performances of previous presented models are discussed. The parameters of each model is calculated by packet error traces obtained by simulations, thus each model describes channel error behaviour and has the capability to generate an artificial packet error trace. For each model a number (10 artificial traces) of artificial traces are obtained and to make performance models comparison, the artificial traces are statistically analyzed and compared with the simulation trace. To evaluate performances a set of statistical property are considered and applied to two different random variables elaborated by trace. The variable are B and G, the first one indicate the error burst length and the second one indicate the error free burst length. The statistical property considered to make model evaluation are the following:

- Entropy Normalized Kullback-Leibler distance: this value, indicated in the following as ENK value, is a statistical divergence measure between two probability distributions. The ENK value is a metric derived by Kullback-Leibler distance and presented in (Khayam et al., 2003). The relation (3) allows to calculate the ENK value:

$$ENK(p(x)||q(x)) = \frac{D(p(x)||q(x))}{H(p(x))} \quad (3)$$

where *H(p(x))* is the entropy value that normalizes Kullback-Leibler distance *D(p(x)||q(x))*. The first one is defined by:

$$H(p(x)) = -\sum_{x \in S} p(x)\log(p(x)) \quad (4)$$

and instead, the second one is:

$$D(p(x)||q(x)) = \sum_{x \in S} p(x)\log(p(x)/q(x)) \quad (5)$$

In relations (3) x is a random variable defined over an alphabet set *S*. Instead *p(x)* and *q(x)* are two probability distributions defined for the random variable x. The ENK value, as defined by equation (3), can be computed between two distributions. In our case we consider initially three packet error traces obtained by simulations, we call this traces as s_1, s_2 and s_3, and then compute ENK values on these traces in this way:

- ✓ ENK($S_1||S_3$): S_1 is the probability distribution of a random variable, elaborated by trace s_1. S_3instead is the probability distribution elaborated by trace s_3.
- ✓ ENK($S_2||S_3$): in analogue way S_2 and $S_3$are the probability distributions evaluated on random variable elaborated by trace s_2 and s_3 respectively.

These two values are considered as reference values for ENK values computed over distributions extracted by artificial traces. Thus for each model we generate artificial trace and compute ENK(S1||Xm) and ENK(S2||Xm), where Xm is probability distribution derived from artificial trace. This procedure is repeated for each model and then the ENK values obtained from each model is compared with the pair of values initially computed. If the ENK(S1||Xm) and ENK(S2||Xm) are smaller than reference values then the considered Markov chain based model is a good model for channel, i.e. it models channel error behaviour with good approximation. Obviously the ENK values are related to particular random variable and also the goodness of model is related to variable choice, thus we consider two random variables, and the procedure is repeated for both B and G.

- standard error: is an error measure that can be computed between two random variable distributions. Standard error is used to calculate the "distance" between artificial trace burst lengths distribution and simulation trace burst length distribution related both B and G variables. The relation (6) allows to calculate this error.

$$Er = \sqrt{\frac{(n_1+n_2)\left[\left((\sum_{x\in S} x^2)-\frac{(\sum_{x\in S} x)^2}{n_1}\right)+\left((\sum_{y\in S} y^2)-\frac{(\sum_{y\in S} y)^2}{n_2}\right)\right]}{(n_1 \cdot n_2)(n_1+n_2-2)}} \quad (6)$$

In equation (6) x and y are random variable defined over an alphabet set *S*.

- mean and standard deviation: these statistical values were calculated, as before, both on simulation traces random variables distributions and both on random variables distributions related to artificial traces generated through Markov chain based models. Table 2 contains performances evaluations obtained valuing statistical values previously described. In the first column the models are indicated and the second one contains the evaluated random variables. In first step we consider ENK calculation, in the rows labelled as simulation trace, the references values are expressed, thus if a model has ENK values smaller than reference values, it is possible summarize that the model represents a good channel behaviour approximation. Considering MTA model and B random variable, we can say that MTA is a good model because MTA ENK values are smaller than reference values and observing the ENK columns no one model has the same good results for this statistical parameter. Gilbert – Elliot model instead presents ENK values that are not smaller than reference ones, they are small but not enough; also FSM values are greater than reference values, thus FSM is not a good model for B random variable. HMM, considering B random variable, presents the best results after MTA model, although ENK($S_2||X_m$) is greater than reference one for a lot. Observing G random variable the previous considerations on MTA are not valid, in fact ENK values demonstrate that MTA is not a good model inherently the G random variable, the ENK values are excessively greater then reference ones. All the other models have good ENK($S_1||X_m$) values but no one have a good ENK($S_2||X_m$) value, although we can see that HMM model has a value that is close to reference one. The standard error column confirms the best results of MTA for B random variable, and where the other models present small errors but greater than MTA case. Also for G random variable, the standard error confirms that MTA is not a good channel behaviour approximation.

The other models, in this case, are approximately on the same floor. Mean and standard error in the sixth and last columns respectively, confirm previous consideration. It is interesting to note the excellent HMM results, this model presents values that are close to reference ones. Table results can be thus summarized: no one model presents perfect results in all cases, MTA obtains good results about B

Table 2: Model results comparasion.

MODEL	RANDOM VARIABLE	ENK		STANDARD ERROR	MEAN	STANDARD DEVIATION
		ENK(S_1||X_m)	ENK(S_2||X_m)			
MTA	G	80.4997	77.5243	6.2452	45.2416	64.4005
	B	0.0170	0.0192	0.00093	1.0232	0.1467
Gilbert - Elliot	G	15.0394	14.3310	2.0791	27.2443	25.5920
	B	0.0265	0.0371	0.0099	1.033	0.1821
FSM	G	15.9352	16.2001	2.0758	26.9829	26.5021
	B	0.0310	0.0488	0.0084	1.0322	0.1727
HMM	G	14.1402	15.2083	2.0606	27.5648	27.2898
	B	0.0237	0.0341	0.0095	1.0296	0.1713
REFERENCE VALUES						
Simulation trace	G	16.2320	13.9	/	27.6047	27.5434
	B	0.0258	0.0312	/	1.0303	0.1719

variable but deplorable results for G; the other models obtain acceptable but non excellent results both to B as in G case; among these models, HMM is preferred to others for its results, thus if we must choose a model to represent channel error behaviour of IEEE 802.16e scenario we consider HMM the best choice for its balanced results. In (Konrad et al., 2001) authors demonstrate the good results of MTA in GSM scenario, instead in (Khayam et al., 2003) authors present the validity of Gilbert – Elliot model in Wi-Fi scenario.

6 CONCLUSIONS

In this paper a Markov chain based models comparison is presented. These models, that in literature are used to describe the channel behaviour of a particular scenario, are compared in a new scenario. The best performances is obtained by MTA model inherently B random variable, and by HMM inherently G random variable, but altogether the best results is reached by HMM. This paper demonstrates that is not possible to say that a model is better than the others in absolute way, but must always relates the model to detailed scenario.

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