Radio Access Network Emulator for LTE

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Abstract— In this paper we present an LTE RAN (Radio Access Network) Emulator based on a new method for mobile channels modeling. The new method is then used to model the OFDMA Downlink of LTE (Long Term Evolution) link level performance under 16-QAM hierarchical modulation. The models have been derived for a Quality of Service (QoS) corresponding to a Block Error Rate (BLER) of 1%, which is the common value for real-time applications. The results provided by the RAN Emulator are then compared to the statistical distribution of the received sequence in a LTE link level simulation. Further, we presented an analysis of the delay in a LTE transmission with different sources.

Keywords – channel modeling, hierarchical modulation, LTE, RAN.

I. INTRODUCTION

Third-generation UMTS, based on wideband code-division multiple access (W-CDMA), has been deployed all over the world. To ensure that this system remains competitive in the future, in November 2004 3GPP began a project to define the long-term evolution of UMTS cellular technology. The specifications related to this effort are formally known as the evolved UMTS terrestrial radio access (E-UTRA) and evolved UMTS terrestrial radio access network (E-UTRAN), but are more commonly referred to by the project name LTE (Long Term Evolution). The first version of LTE is documented in Release 8 of the 3GPP specifications [2].

LTE is the next step on a clearly-charted roadmap to so-called ‘4G’ mobile systems that starts with today’s 2G and 3G networks. Building on the technical foundations of the 3GPP family of cellular systems that embraces GSM, GPRS and EDGE as well as WCDMA and now HSPA (High Speed Packet Access), LTE offers a smooth evolutionary path to higher speeds and lower latency. Coupled with the efficient use of operators’ finite spectrum assets, LTE enables an even richer, more compelling mobile service environment.

In parallel with its advanced new radio interface, to develop the full potential of LTE requires an evolution from today’s hybrid packet/circuit switched networks to a simplified, all-IP (Internet Protocol) environment. From an operator’s point of view, the pay-off is reduced delivery costs for rich, blended applications combining voice, video and data services plus simplified interworking with other fixed and wireless networks.

Technical specifications for LTE were scheduled to be completed during the first half of 2008. However, commercial deployment is not expected before 2010, although there will be many field trials before then [1]. The paper is organized as follows: In Section II a brief description of the multi-resolution with hierarchical modulation is made. Section III presents a Finite State Channel Models (FSCMs). In section III, hidden Markov models are defined and the new proposed model is described. The statistical distribution of received blocks lengths generated by the RAN Emulator and an analysis of the delay in a LTE transmission with two distinct sources are presented in Section V. Finally, in Section V a conclusion will be given.

II. MULTI-RESOLUTION WITH HIERARCHICAL MODULATIONS FOR LONG TERM EVOLUTION

In the Long Term Evolution (LTE) of UMTS the Interactive Mobile TV scenario is expected to be a popular service. By using multi-resolution with hierarchical modulations this service is expected to be broadcasted to larger groups achieving significant reduction in power transmission or increasing the average throughput. Interactivity in the uplink direction will not be affected by multi-resolution in the downlink channels, since it will be supported by dedicated uplink channels. The presence of interactivity will allow for a certain amount of link quality feedback for groups or individuals. For MBMS support within a certain cell coverage area for a given coverage target, the MCS (Modulation and Coding Scheme) of the MBMS transport channel typically has to be designed under worst-case assumptions. Apart from cell-edge users experiencing large inter-cell-interference, users with better channel conditions (closer to the base station) could receive the same service with a better quality (e.g., video resolution), as their receiving SNR would allow usage of a higher-rate MCS. Hierarchical constellations and MIMO (spatial multiplexing) are both methods that can offer multi-resolution. Any of these methods is able to provide unequal bit error protection.
In hierarchical modulation [6], which has been specified for broadcast systems like DVB-T (Digital Video Broadcast Terrestrial) or MediaFLO, we have two or more classes of bits with different error protection, to which different streams of information can be mapped.

Figure 1 - 64-QAM Hierarchical Constellation.

Considering Figure 1 [6], in a 64QAM hierarchical constellation you can code 6 bits per 64QAM symbol. In this case, the 2 most protected bits (MPB) can be demodulated for all user and the remaining 4 bits can only be demodulated by receivers with “good” reception conditions.

The first two MPBs correspond to a QPSK service embedded in the 64QAM one.

The introduction of hierarchical modulation in a broadcast cellular system requires a scalable video codec as shown in Figure 2 [4], where the base layer transmission provides the minimum quality, and one or more enhancement layers offer improved quality at increasing bit/frame rates and resolutions. This method significantly decreases the storage costs of the content provider compared to the simulcast distribution where for a single video sequence excessive video sequences must be stored at the server to enable its distribution to different customers with different terminal capabilities [4].

Besides being a potential solution for content adaptation, scalable video schemes may also allow an efficient usage of radio resources in enhanced MBMS.

Regardless of the channel conditions and user location, a given user always attempts to demodulate both the base layer and the enhancement layer carrying additional resolution. For good multi-resolution design, the basic information will be always correctly received independently of the position of any user, within the 95% coverage target. However, depending on its position inside the cell more or less blocks with additional resolution will be correctly received by the mobile user.

However, traditional hierarchical modulation suffers from serious inter-layer interference (ILI) so that the achievable rate by low-layer data stream, e.g. the base-layer data stream, is dented by the interference from high-layer signal(s). Furthermore, due to ILI and the imperfect demodulation of base-layer symbols, the demodulation error rate of higher-layer symbols increases too.

III. FINITE STATE CHANNEL MODELS (FSCMs)

FSCMs are used to denote all the elements of a communication system that lie between any two points a and b in the system, where the input entering at point a is a symbol sequence \( \{X_k\} \) and the output of the system at b is another symbol sequence related to the input sequence \( \{Y_k\} \). The relationship between the input and output sequences will be affected by the distortion and noise introduced by filters and other elements present between a and b, and the physical channel.

FSCMs fall into two categories. The first category addresses the memoryless models that can be considered as a subset of the general class, because such models have only a single state and thus no temporal correlation is assumed to exist in the transition mechanism. The second category consists of the models with memory; which are applicable to situations
where the transitions from the input symbols to the output symbols are time correlated, i.e., the probability of transition for the \( n \)th symbol is correlated with the transitions of the preceding and/or the following symbols.

The usage of FSCMs allow for a computationally more efficient simulation, contributing to several orders of magnitude savings in computational burden. The increased efficiency comes from two factors. While each individual block is simulated in detail in a waveform level model, at a rate much higher than the symbol rate (due to the spreading induced by the coding and spreading functions), there is a high level of abstraction in the finite-state model.

While memoryless channel modelling is straightforward, the modelling of channels with memory is much harder. The time correlated error generation mechanism is usually modelled by a discrete-time Markov sequence in which a state model is used to characterise the various states of the channel and a set of transition probabilities is used to capture the progression of the channel between various states. This will be described in the next section.

IV. HIDDEN MARKOV MODELS

An \( N \)-state Markov model for a discrete communication channel is defined by:

- Set of states: \{1,2,...,N\}
- State at time \( t=\mathcal{S}_t \)
- Set of state probabilities, \( \pi_i(t) = P(\mathcal{S}_t = i) \) \( i=1,2,...,N \)
- Set of state transition probabilities \( a_{ij}(t) = P(\mathcal{S}_{t+1} = j | \mathcal{S}_t = i) \) \( i,j=1,2,...,N \)
- Set of input-to-output transition probabilities for each state \( b_i(e_k) = P(e_k | \mathcal{S}_t = i) \). In the binary case, \( E=\{0,1\} \)

These parameters define a discrete-time Markov process operating at a transition rate equal to the symbol rate of the communication system, and the output of the process consists of the sequence of states \( \{\mathcal{S}_t\} \) and a sequence of error symbols \( \{E_t\} \), where \( t \) is the time index, which can be indexed over the integer set \( \{0,1,2,...\} \).

Normally, only the input and the output of the channel, and hence the error sequence can be observed, and the state sequence is “hidden” or not visible from external observations, and such a Markov model is called a hidden Markov model, or HMM.

The Markov property is defined as

\[
P(S_{t+1} \mid S_t, S_{t-1}, \ldots) = P(S_{t+1} \mid S_t, S_{t-1}, \ldots, S_{t-m})
\]

for a Markov process with memory \( m \). For a first-order Markov process,

\[
P(S_{t+1} \mid S_t, S_{t-1}, \ldots) = P(S_{t+1} \mid S_t)
\]

For channel models, a first-order Markov model is commonly used.

The general model is represented in Figure 3. Usually, for the general Markov model, the Baum-Welch algorithm is used for a Maximum Likelihood Estimate (MLE) of the parameters using iterative techniques. The use of this model is quite straightforward; the expected received sequence of blocks is obtained using a random number generator, the state transition matrix \( A \) and the input to output (I/O) transition matrix \( B \) (Figure 4).

Starting at a random state (that can be obtained through the set of state probabilities, \( \pi \)), the first random number will point to the next state described by \( A \), and the next random number will provide the output for the current state, using \( B \). Only two symbols were used \( (M=2) \), namely “0” for a correct block, and “1” for an error block.

Figure 3 – General Markov Model (top-2 state, bottom-3 state)

\[
A = \begin{bmatrix}
a_{11} & a_{12} & \ldots & a_{1N} \\
\cdot & \cdot & \ldots & \cdot \\
\cdot & \cdot & \ldots & \cdot \\
a_{N1} & \cdots & \cdots & a_{NN}
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
b_1 & b_2 & \ldots & b_M \\
\cdot & \cdot & \ldots & \cdot \\
\cdot & \cdot & \ldots & \cdot \\
b_N & \cdots & \cdots & b_M
\end{bmatrix}, \quad b_k = b(e_k)
\]

Figure 4 – State \( (A) \) and I/O \( (B) \) transition matrices, for \( N \) states and \( M \) symbols

425
The RAN Emulator was created on the proposed model in [7]. This new proposed model is represented in Figure 5, where the I/O transition matrix isn’t used; instead, each state has a discrete probability distribution function (DPDF) associated to it. At each state, a random value is used to point to a number of the corresponding DPDF, which can be a sequence of errors or non-errors. After obtaining a sequence length for the state, a transition to a different state is required. However, in this scheme, there can be no transitions between both good and bad states. Furthermore, the transition probability matrix is constructed by direct inspection of the actual number of transitions in the simulated received sequence with subsequent normalization. This new scheme’s goal is to approximate the histogram of the simulated received sequence to that of the new simulated sequence (using solely the simplified model); and, at the same, to be able to assign each state as a certain area of the received sequence histogram. This way, it’s much easier to be sensible to algorithms such hierarchical modulation, included in the LTE mode.

The definition of a state, in this case, is indicated by the number of correct/error blocks the state is allowed to have. For the study at hand, partitioning of the states was done as follows:

For Bad States:
- 2 states were defined. First state includes 80% of the total errors (starting with error sequences of length 1). Second state for the remaining 20% (long error sequences).

For Good States:
- 3 states were defined. The first state includes 10% of total correct blocks (starting with sequences of length 1); whereas the second and third states include the next 70% and 20% of the total correct blocks respectively.

Figure 6 illustrates how states are defined according to the previously discussed partition. Due to the dynamics of the channel, the throughput is changing accordingly. Scheduling also plays an important part when the system is overloaded, with each user being time-multiplexed, according to a specific scheduling algorithm. The states partitioning was performed having the hierarchical modulation and scheduling algorithms in mind.

V. SIMULATION RESULTS

To derive the channel models for all combinations of Vehicular A channel and modulation schemes (QPSK, 16-QAM, 64-QAM), an LTE link level simulator with hierarchical modulation mode was used. For each modulation scheme, BLER curves can be drawn for the various values of Es/N0, so that the required amount of power for the required BLER level is obtained.

Figure 7 portrays some BLER results taken from link level simulations. From these results, the reference Es/N0 value was taken for a BLER of 1%, so that lengthier simulations could be run for that particular point, in order to assess, with a great degree of precision, the error distribution. In this study case, 10,000 blocks were simulated.
The distribution of the blocks is separated into transmitted blocks with or without errors. After this process is completed a complete characterization of error occurrence can be made both in terms of BLER and the statistical distribution of the error block lengths. It is this sequence of blocks that is later used through the new method for channel modeling presented in previous section, to model the channel for transmissions with different hierarchical modulation schemes like 16-QAM and 64-QAM.

A. Link Level Simulations and RAN Emulator

According to the figures 8 and 9, we can say that the statistical distributions of the erroneous and non erroneous block lengths in each figure are similar.

However, it is to highlight the small difference of short sequences of non erroneous blocks, as shown in Figure 9, they only occur in two cases.

This is due to the fact that the long sequences of non erroneous blocks has a much higher probability of occurrence of that short sequences of non erroneous blocks, so whenever there was a state transition from the bad state to good state, this transitional were in fact made for good state 2, where it would generate long sequences of non erroneous blocks. On the other hand, the reason for having shorter correct sequences in the simulated received sequence could be attributed to the multipath propagation and fading or yet by the effects of turbo decoding [8].

The statistical distributions of the erroneous and non erroneous block lengths in the transmission of weak blocks, i.e., the statistical distributions represented in figure 10 and 11 are also very similar. However, the histogram generated by the emulator has a lower occurrence of short error sequences and a lower occurrence of short
correct sequences and an increase in the occurrence of long correct and error sequences. Knowing that the only way to validate the models created by new method would be to compare the statistical distribution of the error block lengths generated by the link level simulator and the generated by the new model, it was checked the accuracy of the statistical distributions of the RAN emulator.

B. System Level Simulations

The graphic of the delay in a LTE retransmission of the enhancement video layer, i.e., the weak bit blocks of the hierarchical 16QAM for two distinct sources is next presented. To obtain this graphic we used a system-level simulator, where the scheduler set was Round-Robin and the sources simulated were NRTV (Near Real Time TV) and FTP (File Transfer Protocol).

![Figure 12 – Delay vs. Geometry](image)

As can be seen in Fig. 12, when the source of transmission used is NRTV the delay is constant, while for the FTP, the variation of delay is more pronounced according to the geometry (position of the mobiles inside the cell). As showed in figure 12, FTP has a higher delay than NRTV when the users are farther from the base station, however, when users are closer to the base station, the delay in FTP begins to decline and even reaches lower values of delay than in NRTV. The most important conclusion is the delay stays always below 2ms independently of the source.

The delay is more critical in streaming applications such as NRTV than in File Download applications (FTP). LTE is able to minimize the delay and the latency independently of the source.

VI. CONCLUSIONS

In this paper we have presented a new method for mobile channels modeling. As noted in [9], it is very important to model the correlation properties of the link errors appropriately in order to meet the service quality. Thus, it was intended that the new method could create the most accurate characterization of the received sequence. The RAN emulator was based on FSCM method and knowing that the LTE is certainly a great bet for the future in mobile, so this emulator could be a useful tool as the results proved to be valid.

The results provided by the RAN emulator match our expectations, in the sense that it was made a good characterization of the errors occurrence in the channel at both the statistical distribution of received blocks lengths and in terms of BLER.

With the round robin scheduler used for retransmission of the enhancement layer, LTE is able to minimize the delay and the latency independently of the source.

REFERENCES