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Parameterized Markov Processes for Modelling the Performance of the DVB-H Physical Layer for DVB-H System Level Simulations

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Abstract: *In this article we discuss the need of system level simulations for DVB-H (Digital Video Broadcast – Handheld) to evaluate the overall system performance perceived by the users dynamically over time, including quality of service and radio resource management aspects. We also describe the main models that are needed to perform DVB-H system level simulations. Finally, we introduce parameterized 4-state Markov processes for modelling the performance of the DVB-H physical layer to obtain MPEG-2 TS packet error traces as a function of the received signal strength and terminal speed. We propose an efficient method for estimating the model parameters from measured error traces, and show the suitability of this approach.*

I. INTRODUCTION

Mobile multimedia broadcasting (i.e., delivering mass multimedia services to portable devices such as mobile phones or PDAs) is a fast emerging area with potential economic and societal impact. The most representative mass mobile multimedia service today is mobile TV, which is expected to become a key application in next generation wireless systems. Recent commercial trials all over the world reveal a strong consumer interest. The provision of digital television to mobile phones will bring new services for the consumers, which will in turn generate new business opportunities for all players of the media and telecommunications industries. Moreover, these services have the consent of the public administrations, as they clearly contribute to the Information Society development, enabling universal access to multimedia content everywhere at any moment.

The highest potential for providing mass multimedia services is presented by terrestrial digital broadcast networks specially designed for mobile services, DVB-H (Digital Video Broadcast – Handheld) being the most representative technology in Europe [1]. DVB-H is an extension of the European terrestrial digital TV standard, DVB-T (Digital Video Broadcast – Terrestrial), designed to reach handheld terminals. First commercial DVB-H services were launched in Italy last year, and during 2007 have started in Finland and Albania in Europe, in Vietnam, India and the Philippines in Asia, and it is expected that more countries will follow in 2008.

Traditional network planning for broadcast networks is based on a static approach that targets to guarantee a certain area coverage level (i.e., percentage of covered service area locations with a certain high probability at any time). However, mobile broadcasting networks require dynamic analysis over time as well as in cellular networks, since the actual Quality of Service (QoS) perceived by the users (i.e., Quality of Experience, QoE) can not be studied from average performance measures within the service area (e.g., burst error rate), as it depends on the time evolution of the transmission errors experienced by the users.

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Field measurements are obviously the most accurate way to measure the actual performance of any wireless communication system. Ideally, transmitter and receiver equipment and necessary resources to perform measurements are available, and performance analyses can be accomplished in field conditions or in a laboratory using a channel emulator. However the resource expenditure related to field measurement campaigns is often cost prohibitive, which makes simulations an essential analysis tool. Furthermore, simulations can be used to post-process measured data to provide additional information for system optimization.

Today Radio Resource Management (RRM) issues in wireless communications systems are studied using dynamic system level simulators and Monte Carlo simulations. That is, repeating the same experiment many times with different random seeds and computing the average results (the higher the number of combinations, the more accurate the results). Obviously, results must be validated with laboratory and field measurements as well. System level simulators allow estimating the overall system performance dynamically over time, including RRM and QoS aspects. In the particular case of DVB-H, it would be possible to monitor the actual QoS of a video streaming service experienced by the users when moving across the service area, investigate the optimum DVB-H transmission configuration for file delivery services, or evaluating the performance of a hybrid cellular and DVB-H IP Datacast (IPDC) system for different RRM strategies (algorithms).

In this paper we discuss the need of performing DVB-H system level simulations, and describe the joint activity between the University of Turku (Finland) and the Polytechnic University of Valencia (Spain) to develop a DVB-H system level simulator based on field measurements in a real scenario. Measurements will be performed in the DVB-T/H test network of the University of Turku. The main novelty of the work is to verify the whole chain to perform system level simulations. A related issue is to determine the degree of accuracy needed in each simulation layer to obtain a balance between simulation efficiency and accuracy. Furthermore, the simulation chain should allow identifying the limiting components of the system, and tuning the system parameters to optimize performance.

The rest of the paper is structured as follows. We first provide an example of the results that can be obtained in terms of QoE by analyzing a field measurement trace in Section 2. Then we motivate the need of system level simulations to evaluate the overall system performance experienced by the users in the service area. In Section 3 we identify and describe the main functionalities that a DVB-H system level simulator should have. We classify them in three blocks: mobility model, radio propagation model, and DVB-H performance model. In Section 4 we propose a performance model of the DVB-H physical layer based on parameterized 4-state Markov processes. Finally, we give some concluding remarks and outline future work to complete the development of the simulator.

II. EXAMPLE OF DVB-H FIELD MEASUREMENT AND QOE MEASURES

Fig. 1 shows an example of the data recorded during the DVB-H field measurement campaign performed within the Celtic Wing TV project in the city centre of the Hague (Netherlands). A DVB-H receiver and a GPS receiver were used to record synchronized reception information. In this case the measurements consisted of synchronized RSSI (Received Signal Strength Indicator), terminal position and speed, and MPEG-2 Transport Stream (TS) packet error information at the DVB-H physical layer (sampling interval 100 ms and measurement time 6 minutes). The receiver antenna was placed inside a vehicle.

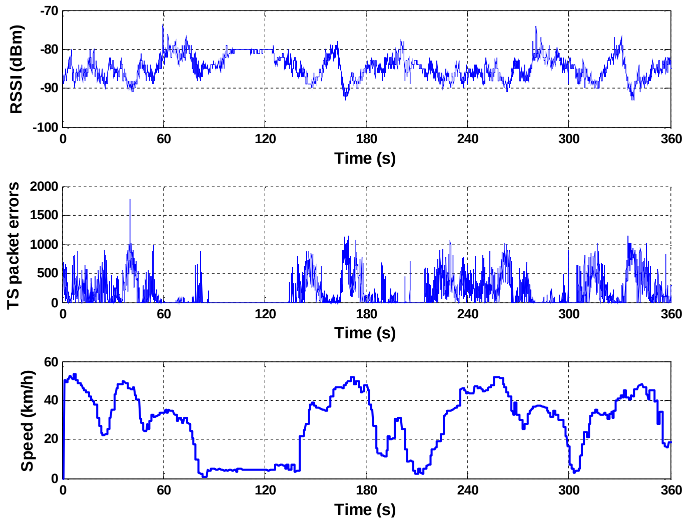

Fig. 1: Example data of DVB-H field measurement.

By recording the TS packet error trace at the physical layer it is possible, for example, to investigate the actual QoS of a streaming service perceived by a user moving across that trajectory for different DVB-H transmission configurations. Fig. 2 shows the cumulative number of erroneous seconds as a function of the service time for a 6 minutes streaming service at 256 kb/s for different MPE-FEC coding rates. MPE-FEC (Multi Protocol Encapsulation – Forward Error Correction) is the additional FEC mechanism implemented on the DVB-H link layer that was mainly introduced to cope with fast fading under mobility conditions [1]. To obtain the results we have considered the conventional MPE-FEC erasure decoding mode and 512 rows per MPE-FEC frame (burst). We have also assumed a constant IP packet size equal to 512 bytes, and that each IP packet can be played successfully without the need of any previous IP packet.

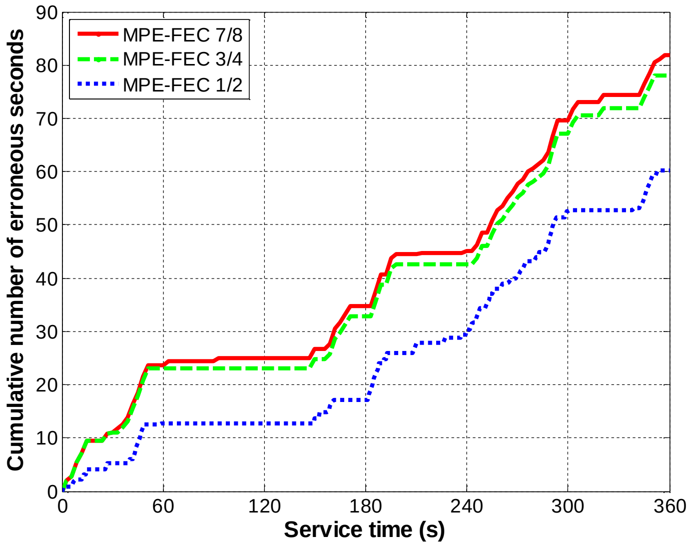

Fig. 2: Cumulative number of erroneous seconds for a 256 kb/s streaming service across the measured trajectory.

In the figure we can see the time evolution of the errors experienced by the users, as well as the actual improvement perceived by the user when varying the MPE-FEC coding rate. We can see that for this specific measurement trace there is a very slight difference between the coding rates 3/4 and 7/8 (around 4 erroneous seconds more), whereas there is a larger improvement when using a coding rate 1/2 (almost 18 erroneous seconds less than the reference case 3/4).

Other studies that could be investigated for streaming services are:

- More advanced MPE-FEC decoding methods, see [2].
- Alternative methods to deliver the information, as dividing each burst in several parts [3], transmit additional parity information in a second burst [4], or deliver the streaming service as a succession of files [5].

The main problem is that the results shown in Fig. 2 apply only for the trajectory where the measurements have been performed. In order to extract conclusions about the overall system performance experienced by the users in the service area, a considerably large number of measurements are needed. If, for example, we would like to speak in terms of percentage of satisfied users for a given QoS satisfaction criteria, at least a thousand of independent trajectories would be needed to obtain fairly accurate average results. In case we would like to obtain accurate results with a resolution of 1%, we would need up to ten thousand trajectories. If we take into account that the measurements are only useful for the specific network configuration setting employed, the need of performing dynamic system level simulations is crystal clear. Of course it will be reasonable to perform initial field measurements to verify the accuracy of the models employed in the simulations for the given scenario under study, but still the potential cost reduction is huge.

III. OVERVIEW DVB-H DYNAMIC SYSTEM LEVEL SIMULATOR

DVB-H employs a discontinuous transmission technique based on time-slicing, where data is periodically sent in bursts. Terminals synchronize to the bursts of the desired service and switch their receivers (front-end) off when bursts of other services are transmitted, reducing their power consumption and enabling the search of neighbouring cells in other frequencies. Basically, the system level simulator should provide the amount of correctly received information in each burst for each user when moving across the service area.

Three major blocks (modules) have been identified in the future DVB-H system level simulator: mobility module, the radio propagation module, and the DVB-H performance model. The mobility model moves users across the service area and provides the speed of users when receiving a burst. The radio propagation module computes the average Signal-to-Interference plus Noise Ratio (SINR) during the reception of a burst for each user. Alternatively, a coverage map of the service area can be computed. Finally, the DVB-H performance model module computes which data in the burst is correctly received for each user using the velocity and SINR information provided by the other two modules.

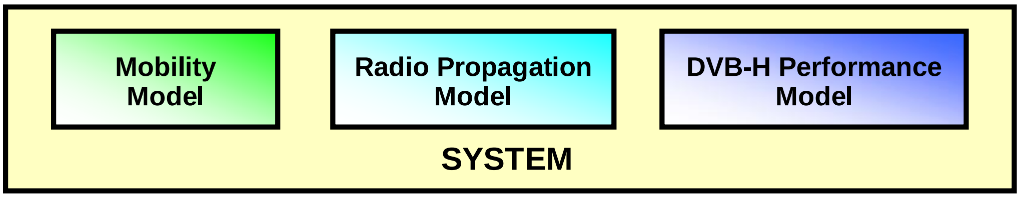

Fig. 3: DVB-H system level simulator architecture.

A. Mobility Model

The mobility model is a key element in the system model, since the results may vary a lot for different mobility patterns (trajectories and user velocities). For this reason it is important that the mobility model is based on real traffic patterns. Another important aspect is how to distribute the users initially over the service area. Typically they are distributed uniformly, unless specific information about population density is available. The mobility model is out of the scope of the joint activity between the University of Turku and the Polytechnic University of Valencia. For a good example of a mobility model extracted from realistic urban traffic conditions we refer to [6]. The model captures the users' movements with three random variables: street distance, relative change in direction when entering a new street, and average speed in the current street, and provides different distribution functions with a limited number of parameters that can be easily derived for a particular city.

B. Radio Propagation Model

The physical layer of the underlying DVB-T standard is characterized by a very rapid transition from near perfect reception to no reception at all, and it thus becomes critical to be able to define which areas are going to be covered and which are not. As a consequence, under static conditions, there will be locations where reception is not possible at all (outage areas), and locations where terminals correctly receive all bursts (covered areas). However the physical layer does not provide any time interleaving between consecutive OFDM symbols (which maximum duration is 1.12 ms), as it was initially designed for DVB-T assuming fixed reception with rooftop antennas. As a consequence mobile users may also receive the bursts partially (i.e., receive only a part of the data that constitute a burst) while being in a covered location due to fast fading or impulse interference.

The coverage performance measure in a Single Frequency Network (SFN) is the Signal-to-Interference plus Noise Ratio (SINR). It should be pointed out that the coverage estimation only provides the average received signal strength, since the fast fading due to the mobility of the terminals is considered in the DVB-H performance model described next.

The interference environment in DVB-T/H SFN differs from conventional wireless systems in the sense that all transmitters are frequency and time synchronized (typically using a GPS reference signal), which allows receivers to combine signals coming from several transmitters. Signals received within the OFDM guard interval are considered as useful and contribute totally to the useful signal, whereas signals with a time delay larger than the guard interval cause self-interference. In practice, signals arriving with a slightly longer delay than the guard interval contribute partially to the useful signal and partially to the self-interference. To determine how signals from the different transmitters contribute to the useful received signal, or cause self-interference at each location, a weighting function according to the signal delay is usually employed [7]. The weighting function provides the ratio between the useful and interfering contribution.

Obviously a prediction of the received power at each location from each transmitter in the network is also needed. When considering a real scenario the accuracy of the propagation models depend on the available cartography and its resolution (pixel size), 3D cartography being the most detailed one, including terrain height, terrain morphology and shapes of buildings.

C. DVB-H Performance Model

The DVB-H standard works with MPEG-2 packets at the physical layer (size 188 bytes), and IP packets at the link layer (typical size 1-2 KB). Each burst consists of a number of MPE sections, and each IP packet is encapsulated into a section. MPE is the adaptation protocol used to encapsulate multiple IP streams (DVB-H services) into the MPEG-2 DVB-T transport stream. At the receiver, the physical layer FEC corrects bits errors within MPEG-2 TS packets, and each packet is considered either completely received or completely lost based on a CRC (Cyclic Redundancy Check) field. MPE sections also carry a CRC field, and thus it is possible to consider them either correct or erroneous when working at the section level.

The DVB-H performance model shall then predict the amount of correctly received MPEG-2 TS packets or MPE sections in a burst. We can distinguish between a physical layer performance model (MPEG-2 TS level) and a link layer performance model (MPE section level). The section level model has the advantage of a reduced complexity, as the number of sections per burst is considerably smaller than the number of MPEG-2 packets per bust, which will speed up the system level simulations. However, some applications require working at the MPEG-2 packet level, as an erroneous section can contain several correct MPEG-2 packets [2]. Note that in the worst case one single erroneous MPEG-2 packet can cause the loss of up to two MPE sections. In practice, erroneous packets at the physical layer are usually correlated, and several consecutive packets are lost.

In this paper we have considered a physical layer performance model. The main input parameters are the following:

- Physical layer transmission mode: FFT size, Guard Interval (GI), modulation and coding rate.
- Average Signal-to-Interference plus Noise Ratio (SINR).
- Doppler frequency, directly related to the speed of the user.
- Channel model (pedestrian, vehicular, etc.).

The particular characteristics of DVB-H introduce a need for new channel models. Within the Celtic Wing TV the Typical Urban 6-paths model (TU6) was proven to be representative for DVB-H mobile reception for Doppler frequencies above 10 Hz (i.e., vehicular reception) [1]. For Doppler frequencies below 10 Hz (i.e., pedestrian indoor and outdoor reception), new channels models have been proposed [8].

In the next section we describe a DVB-H physical layer performance model based on Markov processes determined using MPEG-2 TS packet error traces from laboratory measurements with the TU6 urban channel model. More detailed derivations and justifications for the results presented in the following can be found in [9] and [10].

IV. DVB-H PHYSICAL LAYER PERFORMANCE MODEL

A. Model Structure

The DVB-H TS packet error process is modelled using a four-state aggregated Markov process with state transition probability matrix:

$$P = \begin{pmatrix} \alpha_1 & 0 & (1-\alpha_1)w_3 & (1-\alpha_1)w_4 \\ 0 & \alpha_2 & (1-\alpha_2)w_3 & (1-\alpha_2)w_4 \\ (1-\alpha_3)w_1 & (1-\alpha_3)w_2 & \alpha_3 & 0 \\ (1-\alpha_4)w_1 & (1-\alpha_4)w_2 & 0 & \alpha_4 \end{pmatrix}, \qquad (1)$$

where $0 \le \alpha_i \le 1 \forall i$, $w_1 + w_2 = 1$ and $w_3 + w_4 = 1$. States 1 and 2 are defined to output error TS packets, whereas states 3 and 4 correspond to correct reception of TS packets. A conceptual state diagram of the error model is shown in Fig. 4.

From the above, statistical properties of the model output process may be derived as given in [9] and [10]. In the following we briefly summarize relevant results. The probability of packet error in the model output process is defined as:

$$p_E = \frac{w_3}{(1-\alpha_3)\left(\sum_{k=1}^{4} \frac{w_k}{1-\alpha_k}\right)} + \frac{1-w_3}{(1-\alpha_4)\left(\sum_{k=1}^{4} \frac{w_k}{1-\alpha_k}\right)}. \qquad (2)$$

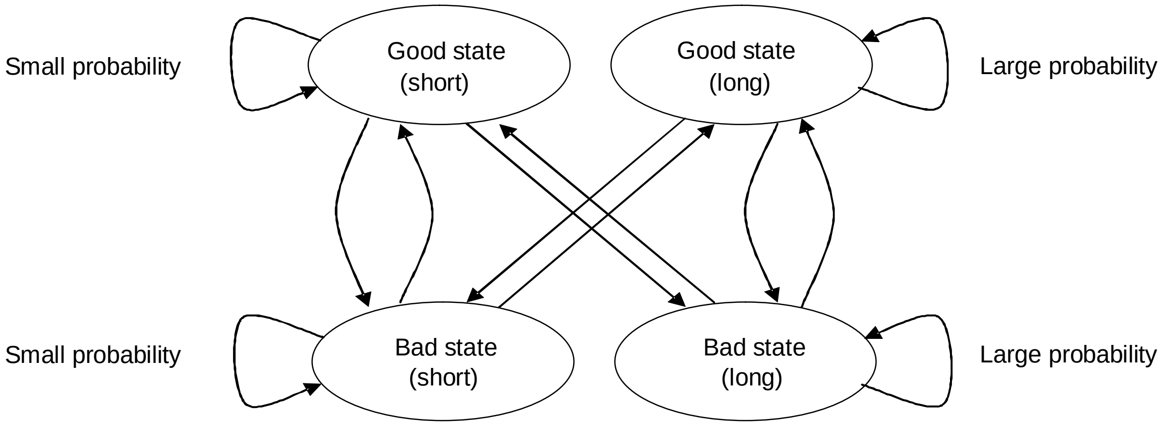

Fig. 4: Conceptual state diagram of the applied four-state error model. The good states correspond to correct reception of a TS packet, and the bad states to erroneous reception respectively. Indicated are also qualitative probabilities for staying in the states.

The mean length of sequences of correctly received packets is:

$$\mu_C = \frac{w_1}{1-\alpha_1} + \frac{(1-w_1)}{1-\alpha_2}, \tag{3}$$

the mean length of sequences of erroneously received packets:

$$\mu_E = \frac{w_3}{1-\alpha_3} + \frac{(1-w_3)}{1-\alpha_4}, \tag{4}$$

the variance of lengths of sequences of correctly received packets:

$$\sigma_C^2 = \frac{w_1\alpha_1(1-\alpha_2)^2 + w_2\alpha_2(1-\alpha_1)^2 + w_1w_2(\alpha_2-\alpha_1)^2}{(1-\alpha_1)^2(1-\alpha_2)^2}, \tag{5}$$

and finally the variance of lengths of sequences of erroneously received packets

$$\sigma_E^2 = \frac{w_3\alpha_3(1-\alpha_4)^2 + w_4\alpha_4(1-\alpha_3)^2 + w_3w_4(\alpha_4-\alpha_3)^2}{(1-\alpha_3)^2(1-\alpha_4)^2}. \tag{6}$$

Using the method of moments, we equate the above with sample error statistics obtained from measured DVB-H TS packet error traces, namely the sample frequency of packet error f_E, the sample mean error gap length and error burst lengths $\overline{L}_C, \overline{L}_E$, and the corresponding variances $S_{L_C}^2, S_{L_E}^2$. The model parameters may now be obtained by solving the following system of equations:

$$\begin{cases} p_E = f_E \\ \mu_C = \overline{L}_C \\ \mu_E = \overline{L}_E \\ \sigma_C^2 = S_{L_C}^2 \\ \sigma_E^2 = S_{L_E}^2 \end{cases}. \tag{7}$$

B. Parameterization

To obtain relationships between the above considered statistics necessary to determine the error model parameters and physical reception conditions such as the Carrier to Noise Ratio (CNR) and Doppler frequency (denoted by f_D), a set of laboratory measurements was performed with fixed DVB-H physical layer transmission parameters (16-QAM modulation, ¼ OFDM guard interval and FFT size 8K, and convolutional coding rate 1/2) using a hardware channel simulator. TS packet error measurements were performed for a range of CNR values 14-18 dB and Doppler frequencies 5-80 Hz, and the above mentioned statistics were calculated from each measurement. The statistics were then approximated as functions of the CNR and f_D using planar Least Squared Error (LSE) approximation in the logarithmic scale. Fig. 5 shows this estimation for the sample frequency of TS packet errors.

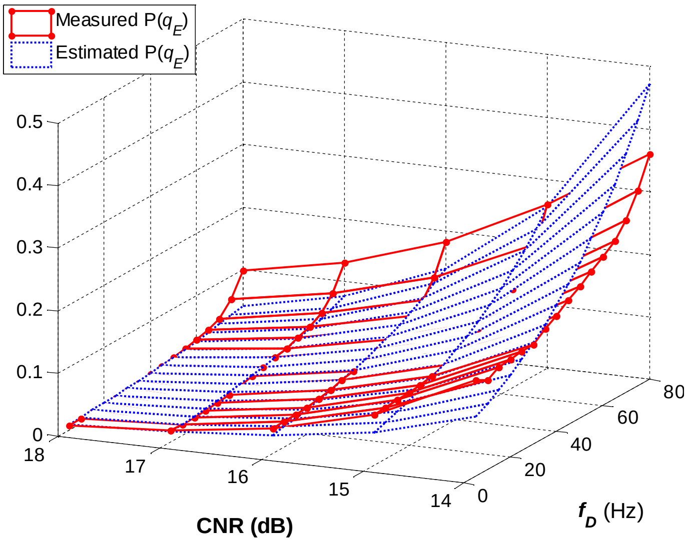

Fig. 5: Example of estimating the packet error statistics as functions of the CNR and Doppler frequency.

The above described model parameterization may be used in dynamic system simulations by assuming reception conditions to be piecewise stationary for short time intervals. For each sampling interval of the time-dependent reception conditions (CNR and f_D), the packet error model parameters are solved according to the above described LSE approximation and equations (2)–(7).

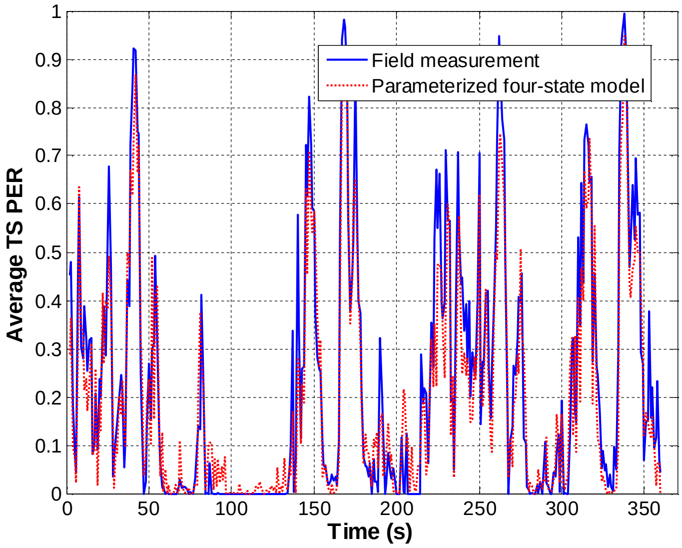

Fig. 6: Dynamic packet error simulation using measured time-dependent RSSI and vehicle speed values.

The validity of this approach is initially verified by using measured RSSI and vehicle speed values such as in the example data of Fig. 1 to obtain a TS packet error trace as suggested above. The time-dependent TS packet error rate, averaged over 1 s intervals, is then compared to the original measured TS packet error trace. Results from one simulation are shown in Fig. 6. It can be seen that the time-dependent modelled packet error rate matches the measurement well. The average packet error rate in the modelled error trace is 23.7 %, and 23.4 % in the original measurement.

V. CONCLUSIONS AND FUTURE WORK

In this paper we have motivated the need of performing dynamic system simulations in DVB-H, described the main models that are required, and proposed a parameterized 4-state Markov process to model the physical layer performance. Initial simulation results indicate that good dynamic simulation performance may be achieved using the proposed model if accurate mobility and radio propagation models are provided.

Future work includes using professional coverage planning tools and 3D cartography to obtain a coverage map to be employed in the simulations. Coverage predictions will be compared with the measurements to calibrate the propagation models. Regarding the physical layer performance model, future work includes applying the studied models also with the new pedestrian channel models suggested in the Celtic Wing TV project, and constructing models based on field measurements.

ACKNOWLEDGMENTS

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