Validation of a DVB-H Dynamic System Simulator using Field Measurements

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Abstract— **In this paper we discuss the need for dynamic system-level simulations for DVB-H (Digital Video Broadcast - Handheld), specifically to evaluate the overall system performance perceived by mobile users dynamically over time. Such simulations can be used as a complement of traditional radio coverage planning tools for analyzing quality of service and radio resource management aspects of the DVB-H network. We describe a general simulation structure and the main models required, and validate, using vehicular urban field measurements, a DVB-H physical layer performance model that enables these analyses.**

I. INTRODUCTION AND MOTIVATION

A. Background

Mobile multimedia broadcasting (i.e., delivering mass multimedia services to portable devices such as mobile phones or PDAs) is a fast emerging area with a 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 highest potential for providing mass multimedia services is presented by 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. It adopts the same physical layer as DVB-T, and adds new features at the link layer. The main technical features introduced are a discontinuous transmission technique where data is periodically sent in bursts known as time-slicing, which reduces the power consumption of terminals, and an optional Forward Error Correction (FEC) mechanism at the link layer called MPE-FEC, which ensures more robust transmissions, especially under mobility and impulsive interference conditions. In contrast to DVB-T, where content is delivered in the form of MPEG-2 packets, DVB-H is IP-based (i.e., all content is delivered in the form of IP data packets). MPE (Multi Protocol Encapsulation) is the adaptation protocol used to encapsulate multiple IP streams (DVB-H services) into the MPEG-2 DVB-T transport stream.

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 level of Quality of Service (QoS) perceived by the users cannot be studied from average performance measures within the service area (e.g., burst error rate commonly used in DVB-H network planning [2]), as it depends on the actual amount of transmission errors experienced and their time evolution.

B. Multimedia Services and QoS in DVB-H

In DVB-H systems, multimedia content can be delivered either as a streaming service or as a file delivery service to the end user [3]. For streaming services, a continuous data flow of audio, video and subtitling is transmitted and directly consumed by the users. The most representative service is mobile TV. DVB-H terminals play the information received in the last data burst until the next burst is received, in such a way that users do not notice the discontinuous transmission. If one burst is lost, the media stream is interrupted until the next burst is received. For file delivery services, a finite amount of data is delivered and stored into the terminals as a file. Some typical examples are: video clips, digital newspapers, and software download. In this case, DVB-H terminals store the information correctly received in each burst associated to the file until the complete file is available at the receiver, and accessible by applications.

For streaming services occasional data errors may be tolerated if the quality of the audio and video is enough for providing a satisfactory user experience. Typically, a 5% burst error rate is considered as the degradation point for streaming services when using MPE-FEC. This criterion is also known as MFER 5% (MPE-FEC Frame Error Rate). Another performance indicator that reflects more accurately the amount of correctly received information is the Erroneous Second Ratio (ESR), which represents the percentage of erroneous seconds during the streaming service reproduction time. Compared to the burst error rate, the ESR takes into account that it is possible to receive bursts partially, however both MFER and ESR only account for the overall transmission errors

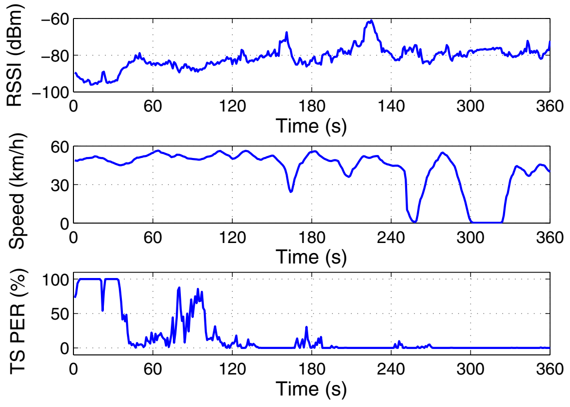

Fig. 1. Example data of vehicular urban DVB-H field measurement.

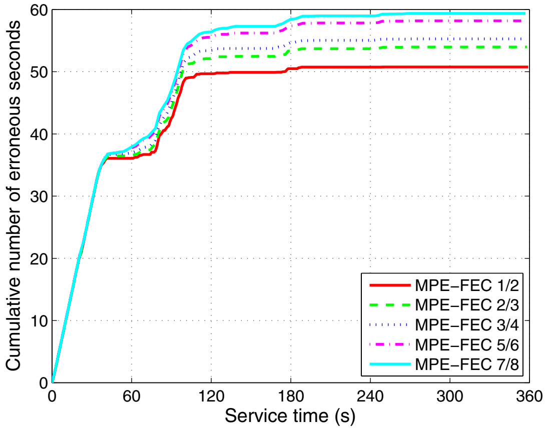

Fig. 2. Time evolution of the errors for a 256 kb/s streaming service across the measured trajectory shown in Fig. 1.

experienced by the users. One indicator that takes into account the time distribution of the errors is the ESR5(20) ratio, which represents the percentage of time intervals of 20 seconds with at most 1 erroneous second (i.e., 5% errors).

On the other side, file delivery services typically require an error-free reception of the files, as even a single bit error can corrupt the whole file and make it useless for the receiver. The main indicator in terms of QoS is thus whether the user receives the file correctly or not. In order to increase the robustness of the DVB-H file delivery, an additional FEC mechanism at the application layer (AL-FEC) using Raptor coding [4] has been adopted.

C. DVB-H Field Measurements for QoS Assessment

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. Fig. 1 shows an example of data recorded during a DVB-H field measurement campaign performed in the DVB-T/H test-bed of the University of Turku (Finland). The measurements consists 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 (100 ms sampling interval for the mobility and RSSI data).

By recording the TS packet error trace at the physical layer it is possible to reproduce the actual QoS experienced by the terminals across the measured trajectory for any type of service (streaming or file delivery) emulating the upper layers. Moreover, it is possible to investigate the effect of different DVB-H transmission configurations at the link and application layers, such as the burst size and the MPE-FEC and AL-FEC configuration parameters. Note that the measured error traces depend on the physical layer transmission mode employed, and thus the physical layer parameters are fixed.

As an example, Fig. 2 shows the cumulative number of erroneous seconds as a function of the service time for a six-minute streaming service at 256 kb/s for different MPE-FEC coding rates. 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. 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.

D. Problem Definition

The main issue with field measurement campaigns is that their resource expenditure is often cost prohibitive. Moreover, results obtained apply only for the specific receiver trajectories measured. In order to extract conclusions about the overall system performance experienced by users in a service area, a large number of measurements is needed. If, for example, we would like to consider the percentage of satisfied users for a given QoS satisfaction criteria, thousands of independent trajectories would generally be needed to obtain statistically consistent average results. If we take into account that the measurements are only useful for the specific DVB-H physical layer transmission mode and network configuration setting employed, the need of performing dynamic system level simulations becomes apparent.

In the particular case of DVB-H, with a dynamic system-level simulator it would be possible to evaluate the overall QoS perceived by the users for a given service as a function of the DVB-H transmission configuration. For example, simulations could be performed for monitoring the time evolution of the errors perceived by mobile users of a streaming service, or determining the users that successfully receive a file (and the amount of repair information needed by each user not able to decode the file). To achieve this, it is necessary to model accurately the time-variant error behavior of the receiver physical layer, and emulate the upper protocol layers based on this error information as in the example of the previous subsection. Not only should the simulation steps provide accurate results, but the results should also be obtained in a computationally efficient manner to enable simulation of large groups of users.

In this paper we discuss the need of performing dynamic DVB-H system-level simulations to evaluate the overall system performance experienced by the mobile users, and describe the simulator developed between the Polytechnic University of Valencia (Spain) and the University of Turku (Finland) within the European COST2100 action [5]. The main novelty of the work is to verify the whole simulation chain required to perform DVB-H system-level simulations, and to determine the degree of accuracy needed in each simulation layer to obtain a balance between simulation efficiency and accuracy. We identify and describe the main functionalities that a dynamic DVB-H system-level simulator should have in Section II. The main focus for this paper is on the DVB-H physical layer simulation, for which three major blocks have been found necessary: a mobility module, a DVB-H radio coverage module and a DVB-H physical layer performance model. In Section III, we validate the suitability of the proposed performance model with vehicular urban DVB-H field measurements. We also compare field measurements with simulation results produced using a DVB-H coverage map obtained with a professional radio planning tool and calibrated with measurements. Finally, we give some concluding remarks and outline future work in Section IV.

II. OVERVIEW OF THE DYNAMIC DVB-H SYSTEM LEVEL SIMULATOR

Four major blocks (modules) can be identified in a dynamic DVB-H system level simulator: a mobility module, a DVB-H radio coverage module, a DVB-H physical layer performance model, and a module to emulate the link and application layers (see Fig. 3). The mobility model moves users across the service area, and computes the speed of the users when receiving a burst. The DVB-H radio coverage module computes the average Signal-to-Interference plus Noise Ratio (SINR) during the reception of a burst for each user. For this purpose, a DVB-H coverage map of the service area can be pre-computed in order to speed up the simulation process. The DVB-H physical layer performance model computes which MPEG-2 TS packets are correctly received per burst for each user, based on the information of the time-variant reception conditions obtained from the mobility and radio coverage models. Finally, the packet error information is used in the link and application layers to compute the QoS indicators for the service under study.

The simulator can be considered a discrete-event simulator, where the only events are the reception of data bursts by the users. Network dynamics are represented as a chronological sequence of events, simulated with a slot resolution equal to the cycle time between data bursts (time at which a mobile's movement is updated, and SINR and data received in the burst parameters are computed). The position, velocity, and SINR of the users at a particular time between the receptions of two bursts are computed by interpolation.

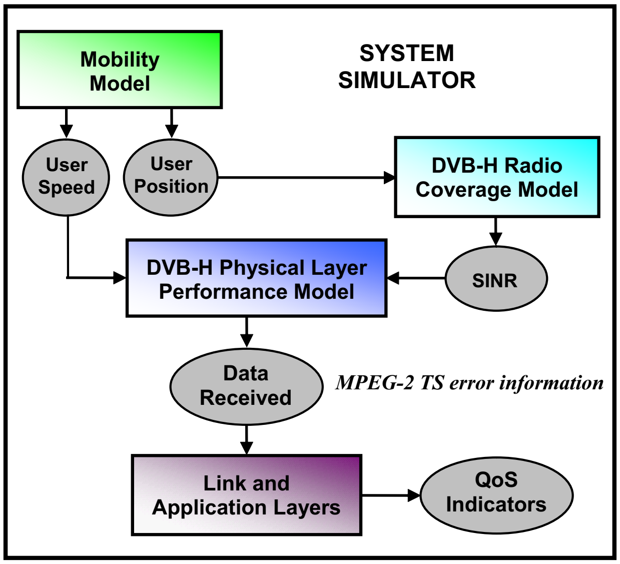

Fig. 3. DVB-H system level simulator architecture.

A. Mobility Model

Mobility models are key elements in dynamic simulators, since the simulation results may vary a lot for different mobility patterns (receiver trajectories and velocities). For this reason it is important that the mobility model is based on real traffic patterns of the scenario under study. Note that different models are needed to account for the different user cases: pedestrian (indoor and outdoor) and vehicular (urban and motorway). For a good example of a mobility model for vehicular users extracted from realistic urban traffic conditions we refer to [6].

In this paper we focus on performance analysis for the radio coverage and physical layer performance models, using measured receiver mobility information. Simulations utilizing also the mobility model are left for future work.

B. DVB-H Radio Coverage Model

The DVB-H radio coverage model is also a critical element in the simulator to determine the received signal strength corresponding to the user locations given by the mobility model. It should be pointed out that typically coverage estimation only provides the average received signal strength with a given spatial resolution. As the actual field strength can be considered a random variable, typically characterized by a lognormal distribution, it is necessary to account for the slow fading effects within each grid of the coverage map by adding an instantaneous component to the predicted mean values. For relatively low-resolution grids (500 x 500 m), a typical value for the standard deviation of this lognormal component with DVB-T/H in the UHF band is 5.5 dB, however for higher resolutions a lower value may be more realistic [1]. Furthermore, the correlation properties of the instantaneous

RSSI component must be determined according to the modeled environment.

When considering a real scenario, the accuracy of the radio propagation models, which give a prediction of the mean received power at each location in the service area from each transmission site in the network, depends on the available cartography and its resolution. Geographical data can be classified in terrain height (topography), terrain morphology (land usage or clutter class), and building heights and shapes. In order to further increase the accuracy of the results, radio propagation models can be calibrated based on field measurement campaigns. The calibration process aims to provide a zero mean and a minimum standard deviation of the error between the prediction and the measurements.

In order to compute accurately the area coverage in a DVB-H Single Frequency Network (SFN), besides the prediction of the received power at each location from each transmission site in the network, it is also necessary to determine how signals from the different sites contribute to the useful received signal or cause self-interference at each location. The coverage performance measure in an SFN is the Signal-to-Interference plus Noise Ratio (SINR). DVB-T/H SFNs differ 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 contribute to the useful signal, whereas signals with a time delay larger than the guard interval cause self-interference.

C. DVB-H Physical Layer Performance Model

The DVB-H physical layer performance model must predict which MPEG-2 TS packets or MPE sections are correctly received for each DVB-H transmission burst. This is done by applying computationally efficient finite-state models to simulate the physical layer errors in a DVB-H receiver caused by multipath propagation (fast fading) given the reception scenario and the location-dependent average signal strength provided by the radio propagation model. The main input parameters are the following:

- Physical layer transmission mode: FFT size, OFDM symbol Guard Interval (GI), modulation and coding rate.
- Channel model.
- Average Signal-to-Interference plus Noise Ratio (SINR).
- Terminal speed.

Of these, the transmission mode and the channel model can be considered fixed for any given simulation scenario. The transmission mode is mainly determined by the desired system capacity, although other parameters such as transmission robustness, maximum supported terminal velocity, and maximum distance between transmitters are also taken into account in the design process. Regarding DVB-H channel models, the Typical Urban 6-tap model (TU6) has been proved to be representative for mobile reception for Doppler frequencies above 10 Hz [1], and it is used to construct the packet error model applied in this work. For specifying the TU6 model, it is necessary to determine the maximum Doppler frequency f_D and the average Carrier-to-Noise Ratio (CNR) of the channel. Thus, relevant run-time input parameters for the physical layer model are the time-variant SINR and vehicle speed information provided by the radio coverage and mobility models, which are used to calculate the CNR and f_D as functions of time.

The maximum Doppler frequency is the maximum frequency shift of the transmitted signal experienced by a mobile terminal due to the Doppler effect. This parameter is also related to the speed of the time variant small-scale fluctuations of the received signal due to receiver mobility (i.e., fast fading). It can be computed using the receiver speed v as:

$$f_D = v \cdot \frac{f_c}{c},$$

where f_c is the carrier frequency of the transmission, and c is the speed of light. For the UHF band where DVB-H was originally designed to be deployed (470-862 MHz), Doppler frequencies above 10 Hz are associated to vehicular reception, whereas frequencies below 10 Hz are associated to pedestrian reception. For pedestrian reception, specific tapped delay line channel models for DVB-H have been proposed, which are known as PI/PO (Pedestrian Indoor/Pedestrian Outdoor) channels [2].

The Carrier-to-Noise Ratio (CNR) describes the ratio of the useful signal power to the sum of the interference and noise powers. In DVB-T/H, noise and interferences (both self-interference from the same network and external interference) are additive as interference behaves similarly to noise. DVB-T/H signals consist of thousands of carriers modulated in phase and amplitude, resembling a Gaussian noise signal, where the energy is distributed evenly over the whole RF channel. Thus, the SINR can be directly translated into CNR at the physical layer.

In short, to model the MPEG-2 TS packet error processes of DVB-H, we apply a parameterized finite-state Markov model that approximates the distributions of lengths of sequences of correctly and erroneously received packets as a function of the average SINR and the receiver speed. Estimates on the dependence between the reception conditions and the model parameters are obtained by calculating from laboratory measurements relevant packet error statistics using a given DVB-H transmission mode and TU6 channel model. Function approximation is then used to determine these statistics as functions of the CNR and maximum Doppler frequency. More detailed descriptions of the model, its parameterization and application are given in references [7], [8].

III. VALIDATION RESULTS

A. Methodology

Field measurements were performed in the DVB-H SFN test-bed of the University of Turku (Finland). The network has two transmitters operating at 610 MHz (channel 38). Field measurements were performed at various locations and transitions around the city of Turku. The total measurement time

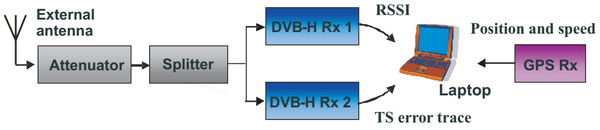

Fig. 4. DVB-H field measurement system.

TABLE I

AVERAGE ERROR RATES (IN %, OVER COMPLETE SET OF MEASUREMENTS)

Error criterion	Measured	Simulated with measured RSSI	Simulated with predicted RSSI
TS PER	3.87	4.25	4.22
IP PER	4.16	4.58	4.50
MFER	3.72	3.55	3.89
ESR	3.33	2.93	3.38
ESR5(20)	8.53	9.47	8.08

was 2 hours (corresponding to approximately $49 \cdot 10^6$ MPEG-2 TS packets), divided into 20 individual measurements of length 6 minutes each. The measurement setup is illustrated in the block diagram of Fig. 4. DVB-H transmissions were received using an external antenna placed inside a vehicle with speed ranging approximately from 0 to 60 km/h. The signal was then transferred through an attenuator and a splitter into two professional DVB-H receivers. RSSI data (with 1 dB resolution) was obtained from one receiver, and a TS packet error indicator trace from the other receiver. The RSSI and error information were then synchronized, combined with GPS data (position and speed), and stored on a laptop computer. An example of the obtained vehicular urban measurement data was presented in Fig. 1.

In the following subsection III-B, the validity of the proposed physical layer model is verified by replacing the mobility and radio coverage models with measured vehicle speed and RSSI values, respectively, and comparing the simulated TS error traces to those obtained from the measurements. It should be pointed out that for small-size networks like the one considered in this paper, self-interferences are negligible, and thus the CNR can be directly estimated from the received signal strength.

In subsection III-C we compare field measurements to simulation results obtained using a coverage map as the radio propagation model.

B. Simulations with RSSI and Velocity Measurements

Fig. 5 shows an example of measured and simulated TS Packet Error Rates (PER) over time corresponding to the measured trace shown in Fig. 1 (error rates are averaged over 1 s intervals). It can be seen that the time-variant packet error rate of the simulated error trace very closely follows the measurement. This is also true for the average packet error rate for each of the individual six-minute measurements, as can be seen in Fig. 6.

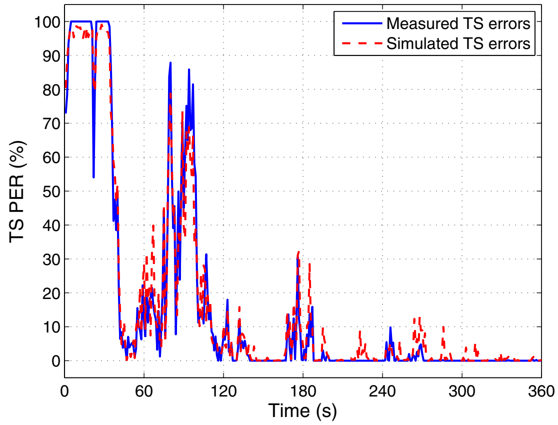

Fig. 5. Dynamic packet error simulation using measured time-dependent RSSI and vehicle speed values.

The leftmost columns in Table I show the total average error statistics for the 2 hours of measurements in terms of TS PER, IP PER (constant IP packet size 512 bytes), and MFER, ESR, and ESR5(20) for a 256 kb/s streaming service (number of rows per frame 512 and MPE-FEC coding rate 1/2), and the corresponding simulation results obtained as described above and averaged over 10 simulation runs. It can be seen that with the TS PER, IP PER and ESR5(20) error criteria, the obtained simulation results are slightly pessimistic, while with the MFER and ESR criteria the results are somewhat optimistic. This serves to emphasize the need for considering various quality of service criteria, since results obtained with different performance metrics may not be consistent. However, from these validation results it can be concluded that the overall accuracy of the considered DVB-H physical layer performance model is relatively good with measured mobility and coverage information. Possibilities for improving the simulation results can be identified for example in modifying the parameterization of the physical layer performance model. In these simulations, the parameterization was based on the TU6 channel model, which may not be the best solution for example in line-of-sight conditions.

C. RSSI Estimation from Coverage Prediction

To consider a specific use case with coverage prediction, we apply the coverage map shown in Fig. 7 for determining the predicted signal strength as a function of the trajectories measured using recorded GPS data. The coverage estimation was computed by the Finnish broadcasting service provider Digita as described within the European Celtic Wing TV project, using the CRC (Canadian Research Corporation) propagation model, terrain height, building and clutter information (pixel size 110 m) [9]. For the simulations considered in this paper the coverage map was calibrated using measurements to correspond to the received signal strength for in-vehicle reception. The mean error for the obtained coverage prediction is -0.5 dB, and the standard deviation is 7.8 dB. It should be

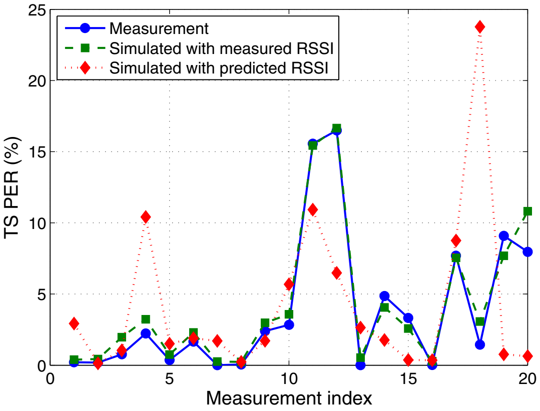

Fig. 6. Simulated average TS packet error rates compared to measured values for a sequence of six-minute measurements

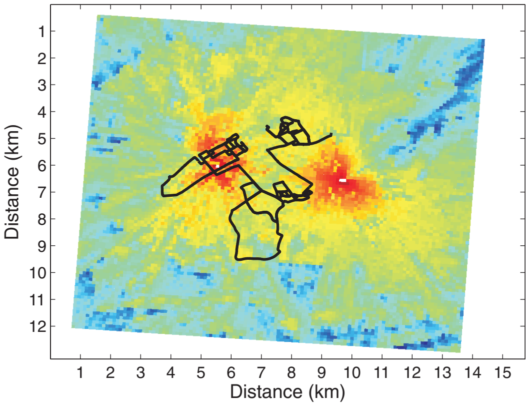

Fig. 7. Measured GPS data over coverage prediction map of the DVB-H test network in Turku, Finland.

noted that for these simulations, we use only the average RSSI provided by the coverage map. Introducing an instantaneous RSSI component as discussed in subsection II-B is left for future work.

Simulated error rates obtained using measured and predicted RSSI values are compared in Table I to field measurement results. It can be seen that in modeling this set of measurements, also the coverage prediction-based simulations produce accurate average results. It is in fact interesting to note that these results correspond to the measurements even better than the ones obtained using measured mobility and RSSI information as described in the previous subsection. This is most likely due to the RSSI estimation error present in the coverage prediction counteracting the modeling error present in the simulations of subsection III-B. This behavior may not be common for all simulation scenarios, therefore further validation studies should be performed. Furthermore, while the average error rates obtained using coverage prediction correspond very well to measurements, results for simulating short or localized receiver routes may be more inaccurate. This is illustrated in Fig. 6, where simulated and measured TS packet error rates for each of the 20 six-minute measurements are shown. Still, the accurate average error rates obtained in the case study above are a very positive result, and as such confirm the usefulness of the considered simulation models.

IV. CONCLUSIONS AND FUTURE WORK

In this paper we have motivated the need for performing dynamic system simulations with DVB-H, outlined the main models that are required, and validated the performance of critical physical layer elements of the simulator with field measurements. We found that good dynamic simulation performance is achieved using the applied performance model with accurate mobility and radio propagation estimates. The simulator was also tested by comparing field measurements with results obtained using a coverage map obtained with a professional radio propagation tool and calibrated with measurements. It was seen that the average results produced by the proposed simulator agree well with measurements.

As future work, in addition to the topics already discussed in this paper, more detailed analysis on the effect of introducing error in the receiver speed and SINR estimates will be performed and application examples for utilizing simulations of large numbers of concurrent mobile users within a transmission area will be given. Furthermore, the proposed simulator offers a working platform for developing QoS measures for streaming media services; in future work additional system performance criteria will be considered.

V. ACKNOWLEDGMENTS

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REFERENCES

[1] G. Faria, J. A. Henriksson, E. Stare, and P. Talmola, "DVB-H: Digital Broadcast Services to Handheld Devices," *Proc. of the IEEE*, vol. 94, no. 1, pp. 194-209, Jan. 2006.

[2] ETSI, TR 102 377 v1.3.1, "Digital Video Broadcasting (DVB); DVB-H Implementation Guidelines," May 2007.

[3] ETSI, TS 102 472 v1.2.1, "IP Datacast over DVB-H: Content Delivery Protocols," Dec. 2006.

[4] M. Luby, *et al.*, "Raptor Codes for Reliable Download Delivery in Wireless Broadcast Systems," *Proc. IEEE CCNC*, Las Vegas, USA, 2006.

[5] COST action 2100, "Pervasive Mobile and Ambient Wireless Communications," http://www.cost2100.org/

[6] P. I. Bratanov and E. Bonek, "Mobility Model of Vehicle-Borne Terminals in Urban Cellular Systems," *IEEE Trans. Veh. Technol.*, vol. 52, no 4, pp. 947-952, July 2003.

[7] J. Poikonen, J. Paavola, and V. Ipatov "Aggregated Renewal Markov Processes with Applications in Simulating Mobile Broadcast Systems," accepted for publication in *IEEE Trans. Veh. Technol.*, 2008.

[8] J.Poikonen, J. Paavola, and V. Ipatov, "Finite-State Models for Simulating the Packet Error Behavior of a Mobile Broadcasting System Operating in a Multi-Path Channel Environment," to be published in *Handbook of Mobile Broadcasting*, CRC Press, 2008.

[9] D. Milanesio *et al.*, "Wing TV Network Issues," Celtic Wing TV project report, May 2006. Available online: http://projects.celtic-initiative.org/WING-TV/