

Coverage Estimation for Multiburst FEC Mobile TV Services in DVB-H Systems

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Abstract—Although Digital Video Broadcast-Handheld (DVB-H) is currently considered to be a mature technology, new multiburst forward error-correction (FEC) schemes such as multiprotocol encapsulation-interburst FEC (MPE-iFEC) and application-layer FEC (AL-FEC) can be applied to mobile TV streaming services to increase the robustness of the transmission. Compared with the conventional intraburst approach MPE-FEC, multiburst encoding provides protection across several bursts rather than within a single burst because it is possible to recover from completely erroneous bursts. The robustness of the transmission can be enhanced, keeping the capacity devoted for error repair (code rate or FEC overhead) and thus increasing the number of interleaved bursts. This paper describes a methodology for estimating the coverage for multiburst FEC DVB-H mobile TV streaming services in realistic scenarios based on dynamic system-level simulations. Furthermore, it presents illustrative performance-evaluation results with field measurements, and it presents simulation results quantifying the reduction in the fading margin required to cope with fast fading and shadowing that can be achieved with multiburst FEC, compared with MPE-FEC.

Index Terms—Application-layer forward error correction (AL-FEC), coverage estimation, digital video broadcast-handheld (DVB-H), mobile TV, multiburst FEC, multiprotocol encapsulation-interburst FEC (MPE-iFEC).

I. INTRODUCTION

AFTER a slow start, terrestrial mobile broadcasting Digital Video Broadcast-Handheld (DVB-H) networks are being deployed across Europe. A key to the success of DVB-H is that it is introduced almost exclusively as a link layer on top of the European standard for digital terrestrial TV digital video broadcast-terrestrial (DVB-T), which is the most widely adopted system in the world. This way, it is possible to share the same network infrastructure (e.g., transmitters, antennas, and multiplexers).

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The main characteristic of DVB-H is its discontinuous transmission technique, which is known as *time slicing*, which reduces the power consumption of terminals and enables seamless handovers between cells with different frequencies [1]. In DVB-H, data are periodically transmitted in *bursts* with a maximum size of 2 Mb. Each burst contains information of the time difference to the next burst of the same service. Terminals synchronize to the bursts of the desired service and switch their receiver front end off when the bursts of other services are being transmitted.

Additionally, to improve the robustness of the transmission under mobility and impulsive interference conditions, DVB-H specifies an optional intraburst forward error-correction (FEC) mechanism at the link layer, which is called *MPE-FEC* [1]. When MPE-FEC is employed, each Internet Protocol (IP) datagram burst is encoded with a Reed-Solomon (RS) code at the link layer to generate repair (parity) data, which is transmitted with the source IP data to compensate for potential transmission errors. The maximum percentage of errors per burst that can be corrected is equal to the rate of parity data transmitted. For example, a code rate of 3/4 can cope with up to 25% errors. Therefore, MPE-FEC can cope with errors that represent a fraction of the burst, but it cannot recover from complete lost bursts. However, lost bursts are common in the field due to signal fading and have a major impact on the service coverage perceived by mobile users, because the service is temporarily interrupted. To recover from these errors, an FEC scheme spanning multiple bursts is required.

Although DVB-H is currently considered to be a mature technology, recent advances in *multiburst FEC* mechanisms could lead to a more cost-efficient provisioning of mobile broadcasting services [2]. FEC is a key element in wireless broadcast communication systems since any coding efficiency improvement has a positive business impact. FEC enhancements bring *link margin gains* that can be used to reduce the required infrastructure cost to provide the service over a given area or to increase the coverage area with the same infrastructure, bringing the broadcast signal to more users. The basic idea of performing a multiburst protection of the transmission is to *exploit the time diversity of the mobile channel*, increasing the time interleaving of the information. With multiburst FEC, the transmission robustness can be enhanced as a function of not only the capacity devoted for error repair but for the number of bursts jointly encoded as well. The drawbacks are that the network latency increases and that the terminal memory requirement is larger, because terminals must wait and store all bursts that are jointly encoded before decoding.

Multiburst FEC has already been standardized above the IP layer in DVB-H for file delivery services using *Raptor coding* as application-layer FEC (*AL-FEC*) [3]. However, it can be applied to mobile TV streaming services in DVB-H as well. This can be done either at the application layer with Raptor coding [4] or at the link layer with the new link-layer-protection mechanism called *MPE-iFEC* (MPE interburst FEC) [5]. Two configurations are possible: one based on Raptor codes and another based on *sliding RS encoding* (SRSE), which employs the same RS code adopted in MPE-FEC but with a sliding-window coding approach.

The gain of multiburst FEC, compared with MPE-FEC, depends on several factors, such as the code rate, the interleaving depth in the number of bursts jointly encoded, the FEC scheme employed, and the target residual error rate [2]. However, the actual gain is very difficult to quantify in real life, as it depends on the time evolution of the transmission errors experienced by the users and, hence, on the velocity and trajectory of the users. One important parameter is, for example, the coverage level perceived by the users. If it is too high, there will be no error to correct, whereas if it is too low, it will not be possible to recover any data. The gain is thus not constant across the service area, and it cannot directly be included in the link budget. Therefore, a revision of the traditional coverage estimation and network-planning methods is needed to *assess the coverage of multiburst FEC services in real scenarios* [6]. In this paper, we develop such a methodology.

Generally speaking, coverage estimation for wireless broadcast communication systems consists of predicting the service availability across a given area. In the particular case of DVB-H, the *service availability* at a certain location can be defined as the probability of correctly receiving a burst. One location is considered as well covered if the average burst error rate is below 5% [7]. However, with multiburst FEC, the service availability cannot be considered a static measure since the performance depends on the mobility of the users. For the conventional intraburst MPE-FEC scheme, coverage estimation is a semistatic process due to the reduced burst duration of a few hundreds of milliseconds. In a realistic scenario, a coverage map can easily be derived by directly mapping the signal availability in each small area (coverage map grid resolution) into the service-availability level. This cannot be done with multiburst FEC, as the probability of correctly receiving a burst depends on previous and/or future reception conditions.

This paper describes a methodology for estimating the coverage for multiburst FEC DVB-H services in realistic scenarios based on *dynamic system-level simulations*. They allow simulation of a DVB-H network over time and are able to estimate the evolution of the transmission errors experienced by the users [8]. As the multiburst FEC performance depends on the mobility and trajectory of the users, accurate received signal strength predictions, realistic mobility patterns, and DVB-H performance models such as that described in [9] are required. This paper also evaluates the potential link margin gain that can be achieved with multiburst FEC, compared with the conventional MPE-FEC intraburst mechanism. This gain can easily be interpreted in terms of network planning, as it can directly be translated into a coverage gain.

The rest of this paper is organized as follows: First, we review the main concepts behind multiburst FEC for mobile TV DVB-H streaming services and discuss implementation issues in Section II. Then, in Section III, we introduce the performance-evaluation settings and present illustrative performance-evaluation results with field measurements, as well as simulation results quantifying the reduction in the fading margin required to cope with fast fading and shadowing. Section IV is devoted to coverage estimation of multiburst FEC services in realistic scenarios. Finally, we give some concluding remarks in Section V.

II. MULTIBURST FORWARD ERROR CORRECTION IN DIGITAL VIDEO BROADCAST-HANDHELD

A. Physical-Layer Transmission Errors in DVB-H

Generally speaking, mobile users experience two types of errors at the physical layer when moving around a DVB-H network with imperfect coverage of the service area: 1) completely erroneous (lost) bursts and 2) partially received bursts. Of these, lost bursts have a major impact on the service coverage, because they are perceived as a coverage discontinuity. This situation may particularly be evident in the initial phases of the DVB-H network deployment, where mobile users experience temporary lack of coverage (outage areas) when moving across the service area. However, mobile users may experience errors in covered areas as well because of the vulnerability of the physical layer to signal fading (fast fading and shadowing) and impulse noise.

In particular, terminals can miss a burst due to temporary shadowing. This occurs due to the very rapid transition from near-perfect-reception to no-reception-at-all behavior or the underlying DVB-T standard with the received signal strength. However, this fast transition only applies for static reception conditions. The reason is that DVB-T was primarily designed for fixed rooftop reception with a very short time interleaving, because it is very vulnerable to fast fading in mobile channels and impulse noise. As a consequence, under mobility conditions, the performance degradation with fast fading enlarges the dynamic range up to 10 dB [10]. This implies that, in covered areas, mobile users may also receive only a part of a burst due to fast fading.

B. Multiburst Encoding Concept

Fig. 1 shows three different ways of transmitting the same content using intraburst FEC and multiburst FEC with the same code rate of 1/2 but different protection periods. It should be noted that each time-sliced burst contains both source IP information and FEC parity data. The IP data are obviously the same in the three cases but not in the parity data, which are computed across different IP datagram bursts. We will use the figure to illustrate the coding efficiency improvement that is achieved by jointly encoding more bursts. Although the parity data are the same in the three cases, the level of protection is different.

For the sake of simplicity and clarity, let us assume an ideal code, such that the maximum percentage of errors that can be

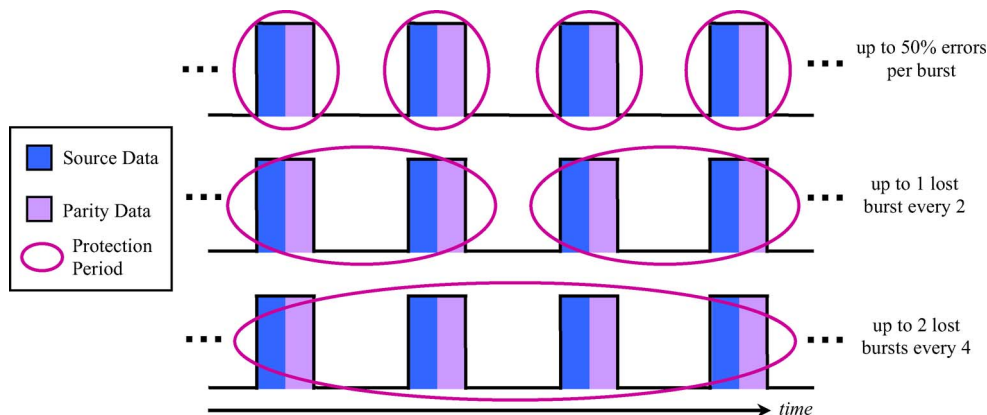


Fig. 1. Multiburst FEC concept in DVB-H and error-correction capability with 1/2 code rate.

corrected is equal to the proportion of parity data transmitted. Then, for the intraburst FEC case, if the percentage of errors in a burst exceeds 50%, the FEC decoder will fail, and only correctly received IP source packets will be available to the applications. For the cases with multiburst FEC, it can be corrected for the same percentage of errors, i.e., 50%, but across several bursts because it is possible to compensate with up to one and two completely erroneous bursts if all other bursts within the protection period are received with no errors.

Multiburst FEC can be seen as a technique to benefit from the time diversity of the mobile channel. Intuitively, the lower the statistical correlation between burst reception conditions, the higher the gain. For fully static reception conditions, there is no gain, as users receive either all content or nothing.

On the other side, mobile users experience variations in their reception conditions when moving across the service area but also due to dynamic variations in the surroundings of the receiving environment. The gain increases for higher user velocities, and for this reason, multiburst FEC is particularly suited for vehicular users. Lower gains can be expected for pedestrian users due to their reduced mobility.

In any case, the larger the number of bursts jointly encoded, the higher the interleaving and the diversity gain. However, it should be pointed out that if the code rate is not robust enough to correct the total number of errors, there may be no gain by increasing the interleaving, and the performance may even degrade. Increasing the interleaving pays off when the total amount of errors is smaller than the error-correction capability. For example, with a code rate of 7/8, only one lost burst out of eight can be recovered. The improvement is particularly evident for robust code rates.

The main drawback of multiburst FEC for streaming delivery in DVB-H is that the increase in network latency is translated into a larger zapping time between channels, which is a crucial parameter for mobile TV usability. Only specific services where a large latency is not an issue (e.g., file download services) can fully exploit the benefits of multiburst FEC with no drawbacks. For streaming services, it is necessary to establish an adequate tradeoff between the protection provided by multiburst FEC and the latency introduced in the system. Today, it is expected to be able to conceal latencies of about 10 s by implementing so-called fast zapping techniques [11].

C. Implementation Issues

Multiburst FEC can be implemented at either the link layer with MPE-iFEC or the application layer with AL-FEC. MPE-iFEC defines a generic multiburst FEC framework, which is fully compatible with the DVB-H link layer. AL-FEC could be introduced, following the FEC streaming framework defined by the IETF and already adopted by third-generation multimedia broadcast multicast services [12]. It would require minor changes in the current specifications of the content delivery protocols. It should be pointed out that the performance of Raptor coding at the application layer would practically be the same as that of MPE-iFEC and that only some implementation and signaling-specific aspects would differ.

The key advantages of Raptor codes are that they can encode large amounts of data and that they can be implemented in software with no need for additional hardware [13]. The multiburst FEC memory requirement at the terminals is not an issue, and the host memory can jointly be used with the fast memory originally dedicated for MPE-FEC. As a consequence, they can be introduced as a software update because they are backward compatible with existing networks and terminals. On the other hand, existing DVB-H terminals do not count with the necessary hardware to handle the increased memory requirements of sliding RS encoding. Nevertheless, recent advances in RS bit-level decoding using binary image extension may open the possibility of software-based implementations [14].

III. PERFORMANCE EVALUATION

A. Settings

In this paper, we consider the use of Raptor codes for DVB-H streaming services. Performance evaluation results of SRSE can be found in [15]. To account for a practical implementation of a Raptor code, a constant 1% reception overhead has been assumed (i.e., in case all source symbols are not correctly received, terminals need to receive 101% encoding symbols such that the Raptor decoder can reconstruct the original source data).

We consider a streaming service with a constant data rate of 384 kb/s. The burst size is adjusted to achieve a cycle time between bursts equal to 1 s. This value represents a good

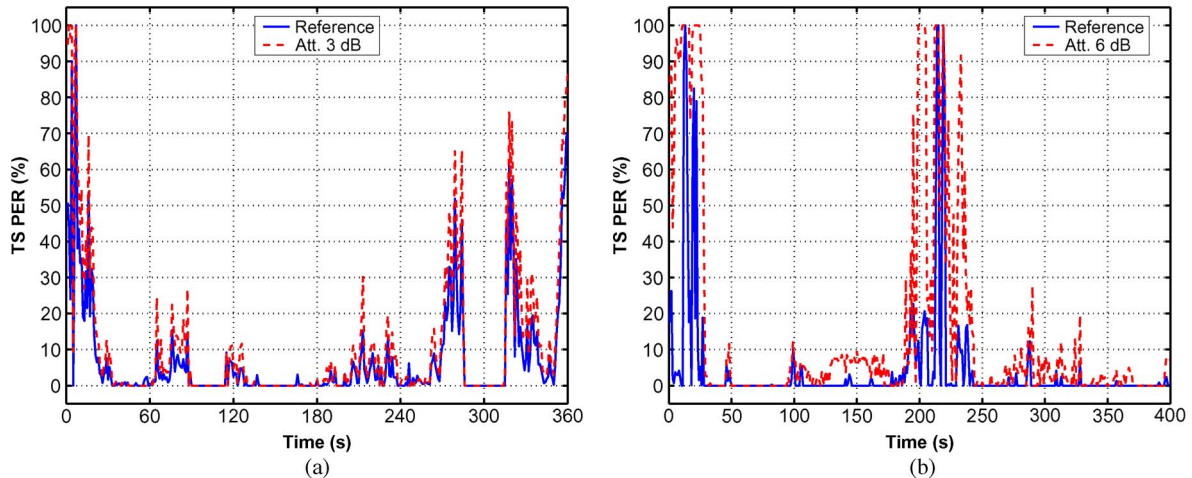


Fig. 2. Vehicular DVB-H field measurements with two receivers, with one attenuated with respect to the other. Measured MPEG-2 TS packet error rates. (a) Attenuation of 3 dB. (b) Attenuation of 6 dB.

tradeoff for power saving and zapping time in good channel conditions. The multiburst FEC latency is thus the number of bursts jointly encoded (*encoding period*) in seconds. We employ the IP packet error ratio (IP PER) of the streaming service as the performance measure to compare the robustness of different FEC schemes. Although it only accounts for the overall transmission errors, it allows an easy, objective, and fair comparison between MPE-FEC and multiburst FEC.

The physical-layer transmission mode employed in our evaluations comprises a fast Fourier transform size of 8K, orthogonal frequency-division multiplexing (OFDM) symbol guard interval of 1/4, 16-state quadrature amplitude modulation, and code rate of 1/2, which provides a channel data rate of 10 Mb/s.

In the following, we evaluate the performance of multiburst FEC with field measurements and quantify the reduction in the carrier-to-noise ratio (CNR) requirement to cope with shadowing and fast fading (*fading margin gain*).

B. Illustrative Field Measurement Results

To provide a first insight into the potential gain that can be achieved with multiburst FEC for streaming services in real scenarios, field measurements were performed in the DVB-H pilot of the Technical University of Braunschweig (Braunschweig, Germany) for vehicular reception conditions with two receivers with a common antenna but one receiver attenuated, compared with the other. This enables a comparison of the two signals with a constant offset in the received power, enabling comparison between the nonattenuated signal with intraburst FEC and the attenuated signal with multiburst FEC. Measurements consisted of MPEG-2 TS packet error information at the physical layer of the whole multiplex. Results are obtained by emulating the upper layers in software (time slicing, protocol decapsulation, and FEC mechanisms). To achieve a statistical smoothing of the results, results have been averaged within the cycle time with a burst-duration resolution. The measurement setup and the measurements performed are described in [2].

Fig. 2 shows two examples of the TS packet error rate per second recorded by the two receivers with attenuation of 3 and 6 dB. The solid line represents the reference receiver, and the dashed line represents the attenuated receiver.

Fig. 3 shows the IP packet error rate of a 384-kb/s streaming service for different multiburst FEC code rates as a function of the latency for measurements shown in Fig. 2. In the figure, it can be seen that, for the reference signals, there are a few errors, and the IP PER is about 5% for the intraburst MPE-FEC case (first marker on the left in the figures). Increasing the latency for encoding more bursts jointly improves the quality of the received service by reducing the IP PER.

For the attenuated signals, larger latencies are necessary to achieve similar residual error rates than the reference signals with MPE-FEC, particularly for the case with an attenuation of 6 dB. It should be pointed out that the gain of multiburst FEC, compared with that of MPE-FEC, for a given latency and code rate depends on the distribution of the transmission errors over time [4].

In Fig. 3(a), we can see that a 3-dB link margin gain is achieved for latencies lower than 10 s. In Fig. 3(b), we can see that a 6-dB link margin gain is achieved for latencies of 23 and 44 s, respectively, whereas it is not possible to cope with the 6-dB attenuation with code rates of 2/3 and 3/4 for latencies lower than 60 s.

C. Fading Margin Gain Simulation Results

Multiburst FEC yields a gain due to fast fading due to the improved capability for recovering from partially received bursts that MPE-FEC cannot correct as well as also a gain due to shadowing because it is possible to recover from completely erroneous bursts. The problem is that the same parity data are used to correct both types of errors, and hence, it is difficult to quantify the gain due to each type of fading.

The gain depends on the degree of spatial diversity experienced by the user along the bursts that are jointly encoded. The gain increases as the statistical correlation between reception conditions of two consecutive bursts decreases. The maximum

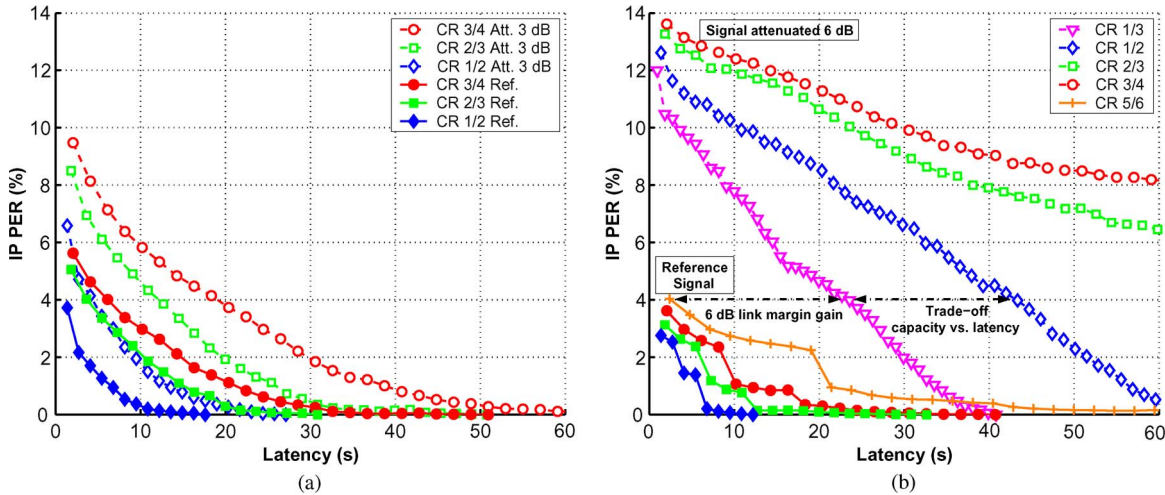


Fig. 3. IP packet error rate of a 384-kb/s streaming service versus latency. (a) Attenuation of 3 dB. (b) Attenuation of 6 dB.

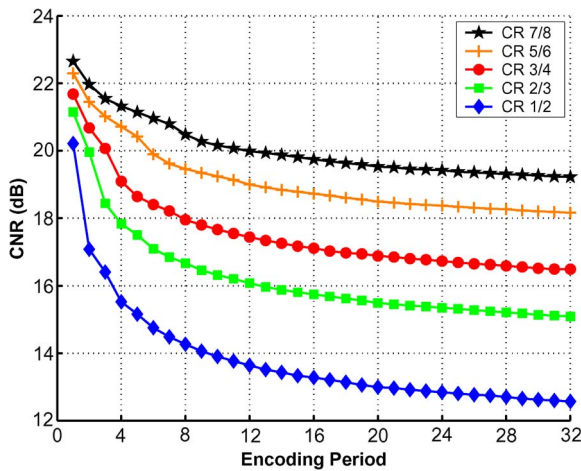


Fig. 4. Average CNR for 5% burst error rate versus encoding period (TU6 channel $f_d = 10$ Hz, uncorrelated shadowing $\sigma_l = 5.5$ dB, and $d_{\text{corr}} = 0$ m).

gain occurs when there is no correlation between reception conditions of consecutive bursts. Note that fast fading between different bursts can be considered uncorrelated, but shadowing is a spatial-correlated process [16].

We consider the simulation scenario employed in the standardization work of AL-FEC for file delivery in DVB-H [17]. Basically, it is a typical urban six-tap (TU6) channel with the average CNR varying, dynamically following a lognormal component defined by its standard deviation σ_l and correlation distance d_{corr} . The TU6 channel model is representative to model fast fading for DVB-H vehicular reception for Doppler frequencies above 10 Hz (e.g., 18 km/h at 600 MHz) [1]. The shadowing spatial correlation follows a first-order exponential model. The correlation factor between consecutive bursts depends on the shadowing correlation distance d_{corr} , the cycle time between bursts T_c , and the user velocity v , i.e.,

$$F_{\text{corr}} = e^{-v \cdot T_c / d_{\text{corr}}}. \quad (1)$$

1) *Uncorrelated Shadowing*: Fig. 4 shows the required CNR to achieve a 5% burst error rate for different code rates as a function of the number of bursts jointly encoded with

uncorrelated shadowing for 10-Hz Doppler. We can see that the potential gain is very significant and that it increases for longer interleaving and more robust code rates, as expected. Note also that very interesting gains are feasible for relatively low encoding periods, particularly for robust code rates such as 1/2 and 2/3.

In addition to the code rate and encoding period, the gain depends on several factors. In particular, the gain increases for more demanding quality criteria. In our example, gains for 1% burst error rate are larger by 1–3 dB.

The gain due to shadowing is directly proportional to the shadowing standard deviation [2]. The reason is that it determines the spread of the CNR values around the mean value, because it is a direct measure of the spatial diversity perceived by the user. The gain due to fast fading is also higher for larger Doppler because of the degradation of the performance of the physical layer.

2) *Correlated Shadowing*: As, for DVB-H streaming services, the cycle time usually ranges from 1 s to a few seconds, only vehicular users with very high speeds may experience uncorrelated shadowing between consecutive bursts. In practice, gains will be smaller than those shown in Fig. 4.

Fig. 5 shows the fading margin gain for a code rate of 1/2 as a function of the encoding period for different ratios between the moved distance by the user during the cycle time d and the shadowing correlation distance d_{corr} . In the figure, it can be seen how the gain decreases when the correlation between consecutive bursts increases. However, there is a minimum gain due to fast fading (dashed curve in the figure). If the correlation between the bursts jointly encoded is very high, there is no gain due to shadowing. It can be observed that the gain due to fast fading reaches a saturation level for an encoding period of ten bursts.

The gain due to shadowing increases as the shadowing correlation distance becomes smaller and the cycle time between bursts becomes larger. Moreover, for a given scenario and transmission configuration, the gain also depends on the velocity of the users. It should be noted that lower velocities, larger correlation distances, and shorter cycle time values can be compensated by employing a longer time interleaving.

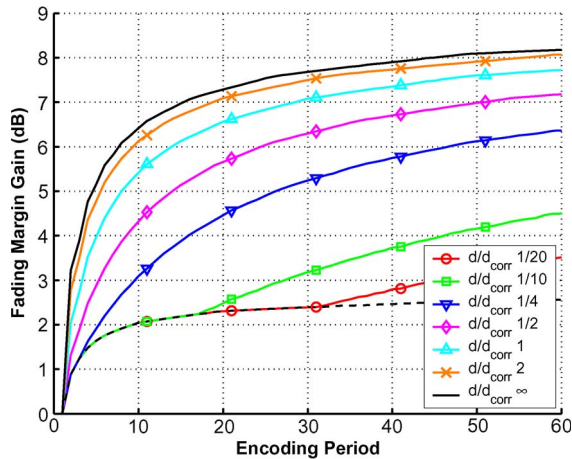


Fig. 5. Fading margin gain for 5% burst error rate versus encoding period (code rate of 1/2, TU6 channel $f_d = 10$ Hz, and correlated shadowing $\sigma_l = 5.5$ dB).

Therefore, these parameters basically determine the level of latencies required to achieve a given gain. It should be clear, however, that there is a maximum gain that is practically achieved when the receiver moves about one correlation distance between bursts.

IV. COVERAGE ESTIMATION FOR MULTIBURST FORWARD ERROR CORRECTION DIGITAL VIDEO BROADCAST-HANDHELD SERVICES

In the previous section, we have seen that multiburst FEC can significantly improve the DVB-H transmission robustness. The gain can be expressed as a reduction in the fading margin to cope with fast fading and shadowing. However, these evaluations assume a constant velocity across the bursts jointly encoded, which is not realistic, particularly for moderate and large latencies. In practice, users may become temporarily static due to traffic lights for example. For static users, the multiburst FEC gain stems from the dynamic variations in the surroundings of the receiver environment. This gain is considerably smaller than the gain obtained due to the mobility of the users, and it can be even negligible if the user stops in a spot with reduced coverage. For large latencies and high user velocities, path-loss variations may also play an important role. This is particularly cumbersome from a network planning point of view, because it implies that the gain depends on the trajectory and velocity of the users.

In this section, we present a methodology for estimating the coverage for multiburst FEC services in DVB-H networks based on dynamic system-level simulations, taking into account realistic mobility patterns. We also investigate the coverage gain in a realistic urban scenario.

A. Dynamic DVB-H System-Level Simulator

A dynamic DVB-H system-level simulator can easily be built on top of a traditional radio propagation tool employed for DVB-H network planning, adding a mobility model and a DVB-H physical-layer performance model. Fig. 6 shows a suitable modular architecture for the simulator, where four

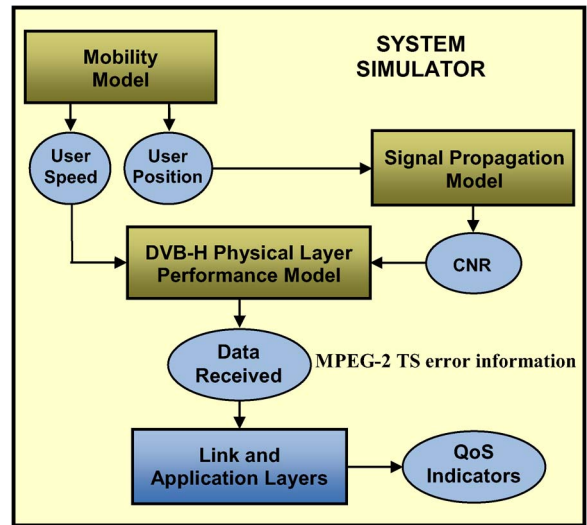


Fig. 6. DVB-H system-level simulator architecture.

major modules can be identified [8]. The mobility module moves users across the service area and computes the speed of the users when receiving a burst. The signal propagation module computes the average CNR during the reception of a burst for each user, taking into account path loss and shadowing [and possibly OFDM signal combining effects in single-frequency networks (SFNs)]. The DVB-H physical-layer performance module computes which TS packets of a burst are correctly received for each user, based on the CNR and vehicle speed information provided by the radio coverage and mobility modules [9].

B. Realistic Simulation Scenario

The simulation scenario corresponds to the DVB-H pilot network of the Technical University of Braunschweig (Braunschweig, Germany), which consists of one transmitter at 57-m height with three sector antennas operating at 554 MHz. In the simulations, the transmit power is set to 33-dBm effective radiated power for each antenna to provide partial coverage over the service area considered (2 km × 2 km).

We consider vehicular in-car users. The users' mobility has been simulated with the simulation tool Simulation for Urban MObility (SUMO) [18]. It takes into account traffic lights, turning probabilities, car densities, etc. Signal-level variations have been simulated, taking into account path loss, correlated shadowing, and fast fading. The path loss has been obtained using the macrocell propagation model proposed in [19] using terrain height and clutter data with 50-m resolution. The model was calibrated with field measurements. Shadowing is implemented by a lognormal distribution with a standard deviation of 5.5 dB and a correlation distance of 20 m. The TU6 channel model is considered to model fast fading.

C. Coverage Estimation Example

Fig. 7 shows an example of the received signal level (RSSI), velocity, and TS packet error rate at the physical layer of one simulated trajectory, as well as the service availability for multiburst FEC 1/2 and different latencies. The reference case

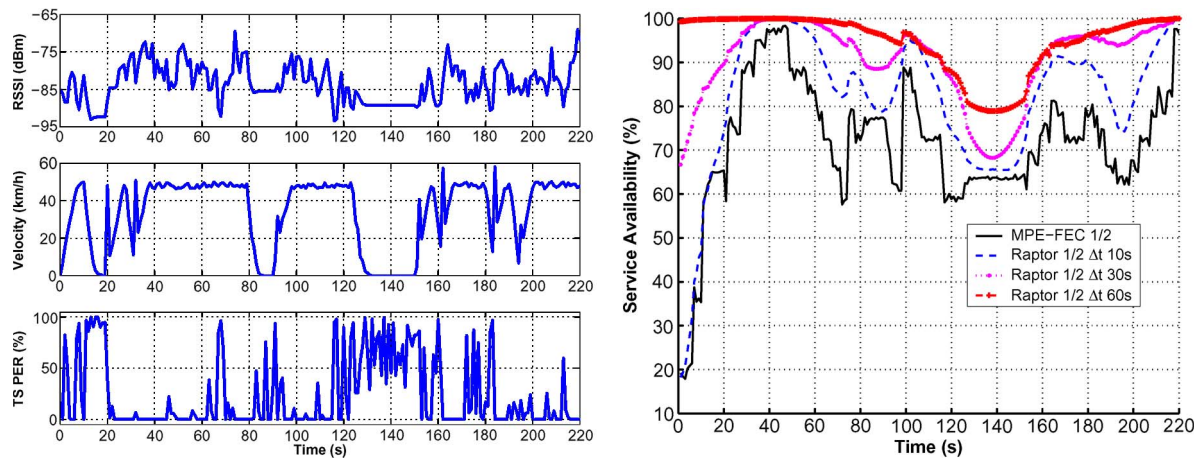


Fig. 7. Example of (left) simulated trajectory and (right) service availability with multiburst FEC.

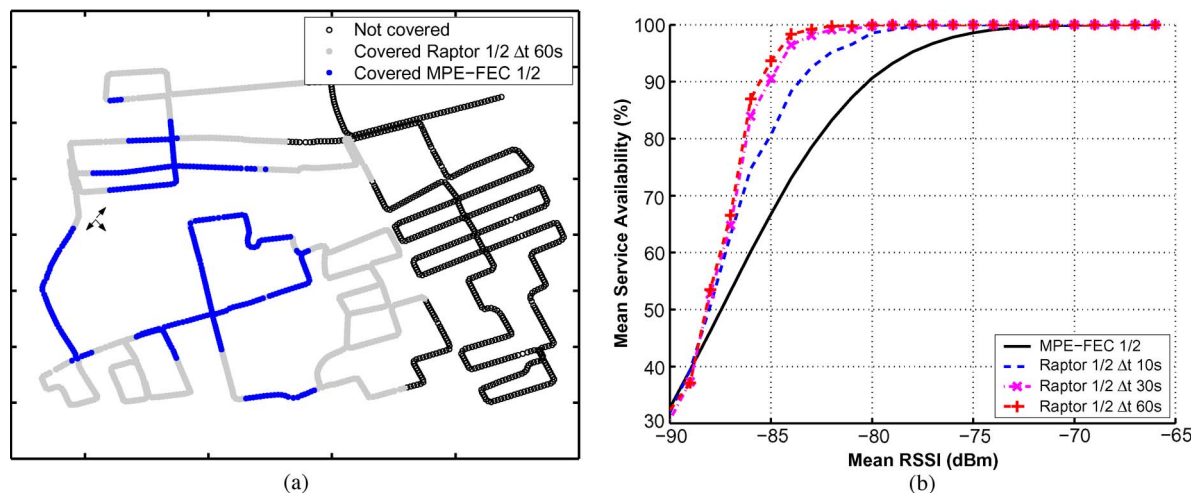


Fig. 8. Coverage estimation example with multiburst FEC (constant velocity of 36 km/h). (a) Service coverage map. (b) Service availability versus received signal level.

with MPE-FEC 1/2 is also shown for comparison. Results have been obtained by performing multiple realizations of the fading processes (shadowing and fast fading) with different random seeds.¹ That is, the velocity and the path loss remain the same, but the signal strength varies due to different shadowings. If the user stops, there is no variability due to fast fading and shadowing.

In Fig. 7, it can be seen that the code rate is robust enough such that service availability increases for larger encoding periods. However, more importantly here, the shown results can directly be translated into space, and thus, a service coverage map can be plotted. It is worth mentioning that results are valid for both forward and backward directions, but they are specific for the particular velocity trace considered. Therefore, to predict the service availability with multiburst FEC, it is

¹When modeling the wireless radio channel as three multiplicative processes with different time scales (path loss, shadowing, and fast fading) [16], the mean path loss is considered to be deterministic, whereas fading is a statistical process. To achieve statistically consistent results, 10 000 fading iterations have been performed.

necessary to accurately estimate both received signal strength and mobility pattern.

To evaluate the *service coverage* in the complete scenario under study, a trace that enters all streets has been simulated. Fig. 8(a) shows a coverage map for MPE-FEC 1/2 and for multiburst FEC 1/2 with 60-s latency for a constant speed of 36 km/h. The simulation time is about 28 min. In the figure, blue dots represent locations with service availability with MPE-FEC equal to 95% or higher, whereas gray and unfilled dots represent locations with service availability below 95%. Gray dotted locations are covered with the target probability for multiburst FEC.

To quantify the *coverage gain*, we compute the mean service availability as a function of the mean received signal strength for different encoding periods [see Fig. 8(b)]. It can be seen that, for the RSSI range considered, the service availability increases with the encoding period. The coverage gain is the reduction in the required RSSI threshold to achieve 95% service availability. For MPE-FEC, a received signal level of -78.1 dBm is necessary. For multiburst FEC with 60-s latency, the signal strength threshold is reduced down to -84.7 dBm.

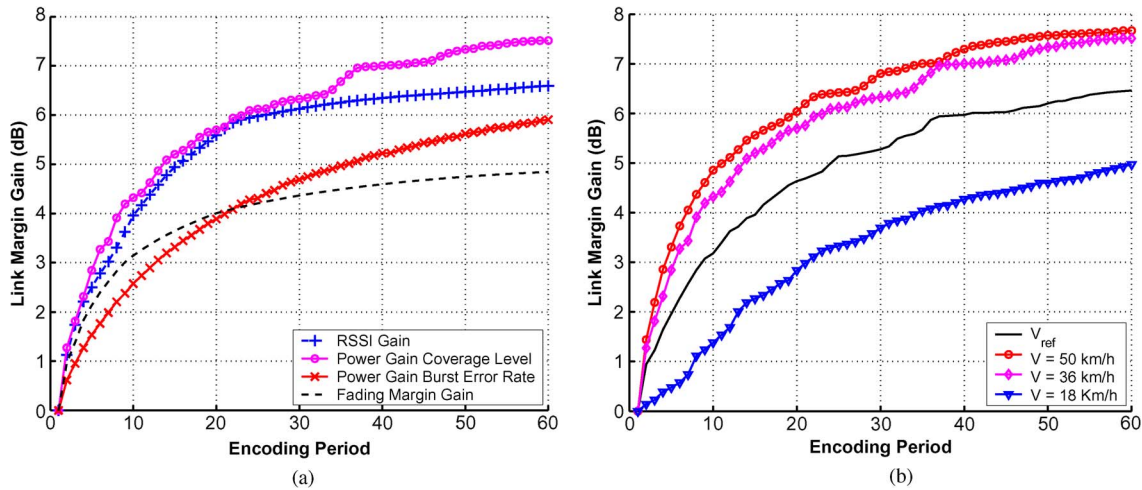


Fig. 9. Link margin gain with multiburst FEC of 1/2 versus encoding period. (a) Comparison link margin gains (constant velocity of 36 km/h). (b) Effect of variable velocity (power gain coverage level).

The difference between these RSSI values can be interpreted as a link margin gain (6.6 dB in this case).

In Fig. 8(b), we can also note that multiburst FEC yields not only a gain in coverage but a gain in service quality as well. This gain occurs in locations covered with MPE-FEC but where there is no perfect reception (i.e., locations with service availability with MPE-FEC between 95% and 100%). For example, in the figure, it can be noted that, for 10-s latency, the service availability is close to 100% when the reference case is only 90%. In this case, we have a clear gain in not only service quality but in coverage as well (about 4-dB reduction in the mean received signal level for 95% service availability).

Obviously, there is no gain in areas where there is full coverage for MPE-FEC, as there are no transmission errors to correct. In areas with very poor signal level, there is no gain either (not shown in the figure), because in this case, the total amount of errors is larger than the error-correction capability. In our example, this occurs on the right side of the scenario. Therefore, we can conclude that, for a given scenario (network infrastructure, service area, and user trajectories), multiburst FEC yields a gain in service quality in the covered locations with MPE-FEC and a coverage gain around the edge of the covered area with MPE-FEC.

D. Comparison Link Margin Gains

From a coverage estimation point of view, we have seen that, given an existing network and service area, multiburst FEC yields a link margin gain in terms of reduced received signal level threshold to achieve a target service availability. From a network-planning (dimensioning) point of view, the gain can be expressed in terms of a reduction in the transmission power required to achieve a target coverage level over the service area (e.g., 95%).

Fig. 9(a) compares both link margin gains (“RSSI gain” and “power gain coverage level”) for multiburst FEC with a code rate of 1/2 as a function of the encoding period. It can be observed that the gains are rather similar. However, gain values are larger by 1–2 dB than the fading margin gain for

5% burst error rate, considering only fast fading and shadowing (“fading margin gain” results from Section III-C2). Fig. 9(a) shows the gain in terms of the reduced transmit power required to achieve the same percentage of erroneous bursts across the trajectory (“power gain burst error rate”). The difference between the latter two curves is the path-loss variability. We can see that, for low encoding periods, the gain with path loss is smaller, whereas for large encoding periods, the gain is higher.

Multiburst FEC can cope not only against fast fading and shadowing but against path loss as well if the protection period is large enough and if the code rate is robust enough. Compared with the previous section, where only fast fading and shadowing was considered, the path-loss variability increases the time diversity of the mobile channel, and hence, the maximum potential gain that can be achieved with multiburst FEC increases. However, signal level variations due to path loss are noticeably slower than the variations due to fading. As a consequence, path loss may reduce the gain due to fading for low encoding periods, as shown in the figure. Indeed, the path loss determines the areas where there is no gain, because the signal level is either too high or too low.

For a given network, the highest gain occurs at the edge of the coverage area for the reference MPE-FEC case, as shown in Fig. 8(a). In this sense, the distribution of the outage areas within the service area becomes relevant. The case with a single transmitter is the worst scenario. Higher gains for small and moderate latencies can be expected in dense SFN scenarios, because outage areas are more uniformly distributed.

Finally, we investigate the effect of having a variable velocity with the possibility that users stop due to traffic light. We can expect the gain to be reduced, particularly if the user stops in a spot with a reduced coverage. In this case, very long latencies will be required to achieve significant gains, as the user will suffer long outage periods. Assuming a code rate of 1/2, for example, it would be, in general, necessary to consider latencies of at least twice the stop time to cope with such outages.

Fig. 9(b) shows the gain in terms of transmit power reduction for 95% coverage for different constant velocity values and for

the reference velocity provided by SUMO. The average velocity across the trajectory is 36 km/h, with a maximum velocity of 50 km/h and about 3.5-min waiting time due to traffic lights (the average waiting period lies between 20 and 30 s). Results obtained show that the gain is reduced, compared with the case of having a constant velocity, but the reduction is not very significant. In this example, the penalization of considering a variable velocity with periods without movement is lower than reducing the average velocity by half.

V. CONCLUSION

In this paper, we have presented a methodology for estimating the coverage for multiburst FEC services in DVB-H networks based on dynamic system-level simulations. This problem has not been previously addressed in the literature. Compared with the conventional intraburst MPE-FEC mechanism, multiburst FEC schemes such as MPE-iFEC and AL-FEC exploit the time diversity of the mobile channel, enhancing the FEC coding efficiency to recover from temporary transmission errors (where it is even possible to recover from lost burst). The transmission robustness can be improved by trading both system capacity and network latency. The gain increases for more robust code rates and a larger number of bursts jointly encoded, but it depends on the time evolution of the transmission errors experienced by the users and, hence, on the velocity and trajectory of the users.

Multiburst FEC requires dynamic analysis over time to take into account the mobility of the users, because the probability of correctly receiving a burst depends on previous and/or future reception conditions. The gain is not constant across the service area, and it cannot directly be included in the link budget for coverage estimation. Only for relatively short latencies and assuming a constant velocity might it be possible to express the gain as a reduction in the fading margin required to cope with fast fading and shadowing. For moderate/large latencies and high user speeds, it is necessary to accurately estimate both the received signal strength and mobility pattern (user velocity and trajectory) to predict the service coverage with multiburst FEC in a realistic scenario.

Multiburst FEC provides an improved protection against fast fading, because not only can it recover from heavily corrupted bursts that MPE-FEC cannot correct, but it can also partially cope with temporary shadowing due to its capability of recovering from lost bursts. This fading margin gain heavily depends on the shadowing correlation between the reception conditions of the bursts jointly encoded, which depends on the transmission configuration (the number of bursts jointly encoded and the cycle time between bursts), the user (velocity), and the shadowing characteristics (standard deviation and correlation distance). If the correlation is very high (e.g., for a few bursts jointly encoded, for very low user velocities, or for very short cycle time values), there is no gain due to shadowing, and the gain only stems due to fast fading. However, if the correlation is low, the gain can significantly be increased due to shadowing.

Our results show that the gain obtained by performing a multiburst protection of the transmission in an existing DVB-H

network is twofold: Not only is the area coverage enlarged, but the service quality perceived by the users is also enhanced with the same infrastructure. Moreover, we have shown that, for vehicular users, multiburst FEC can also yield an additional gain due to path loss, compared with the fading margin gains, considering fast fading and shadowing. The level of latencies required to benefit from such variability will heavily depend on the distribution of the outage areas across the service area and the positions where users stop. Very large latencies will be required if users become static in poorly covered spots. In this sense, the worst scenario is the single-transmitter case. Higher gains will, in general, hold in dense SFN scenarios, because the outage areas are usually much more uniformly distributed.

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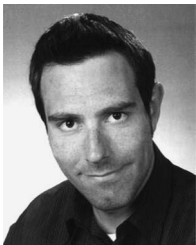
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