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Coverage Estimation for Multi-Burst Forward Error Correction in DVB-H Networks

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***Abstract*— The DVB-H system uses time slicing for transmitting data in a burst structure mainly to reduce the receiver's power consumption. Furthermore, bursts can be protected by an additional Forward Error Correction (FEC) at link layer (MPE-FEC) to increase the transmission robustness. Since MPE-FEC corrects partially lost burst, total lost of bursts cannot be recovered. An approach for increasing reception robustness for these cases has been developed employing multi-burst FEC at link or application layer. Multiple bursts will be encoded jointly in order to overcome burst errors caused by signal level variations. The approach shows high potential which can be characterized by a link margin gain. Nevertheless, the achieved gain depends on several system parameters and on the user behavior. The number of encoded bursts (encoding period), the user mobility and the received signal level have a great impact on the results. The paper deals with the coverage estimation and network gain due to multi-burst FEC for vehicular users in a realistic scenario. The results show the coverage gain depending on transmitting power and encoding period for an urban environment using simulations and measurements.**

***Index Terms*— Mobile broadcast, DVB-H, multi-burst FEC, coverage estimation**

I. INTRODUCTION

DVB-H is an extension of the European terrestrial digital TV standard, DVB-T (Digital Video Broadcast - Terrestrial) for handheld terminals [1, 2]. It adopts the DVB-T physical layer and adds new features at the link layer, being fully backwards compatible. Its main characteristic is the discontinuous transmission pattern at which data is periodically sent in bursts known as Time-Slicing. This approach reduces the average power consumption of terminals and enables seamless handovers between cells with different frequencies [3].

Additionally, it specifies an optional intra-burst Forward Error Correction (FEC) mechanism at the link layer called MPE-FEC (Multi Protocol Encapsulation FEC) in order to increase the robustness of the transmission under mobility and impulse interference conditions. With MPE-FEC the information is encoded burst by burst with a Reed-Solomon (RS) code, being possible to still recover from bursts which are partially received. However, MPE-FEC cannot recover from complete lost bursts [2].

Unfortunately, in the field mobile users typically experience spatial fading effects when moving across the service area due to multi-path propagation. These result in lost bursts due to the very rapid transition from near perfect reception to no reception at all characteristic of the underlying DVB-T standard. As a consequence lost bursts are common in the field and have a major impact in the service coverage perceived by mobile users, as the service is temporally interrupted. In order to recover from these errors, a FEC scheme including multiple bursts is required [4].

Multi-burst FEC has been already standardized above the IP layer in DVB-H for file delivery services using Raptor coding as application layer FEC (AL-FEC) [1]. But multi-burst FEC can also be applied to streaming services in DVB-H as well. In particular, the new DVB-SH (Digital Video Broadcasting – Satellite Services to Handheld Devices) standard [5] designed for the provision of mobile broadcasting services through hybrid terrestrial-satellite networks specifies a new link layer protection mechanism called MPE-iFEC (MPE inter burst FEC) [6], that defines a generic multi-burst FEC framework which is fully compatible with the DVB-H link layer. Two MPE-iFEC configurations are possible, one based on Raptor codes and another based on Sliding Reed-Solomon Encoding (SRSE), which employs the same RS code adopted in MPE-FEC but with a sliding window coding approach.

Basically, multi-burst FEC techniques increase the effective time interleaving of the information over several bursts and exploit the diversity introduced by the mobility of the users and from the dynamic variations in the environment surrounding the receiver in order to increase the FEC coding efficiency.

In this way the robustness of the transmission can be increased not only as a function of the capacity devoted for error repair, but also as a function of the number of time-interleaved bursts (further named as Encoding Period - EP). Using the same coding rate as for MPE-FEC the effective capacity remains the same. The drawbacks are larger network latencies and memory capabilities at the terminals, as they must wait and store all bursts encoded jointly before decoding and passing the information to the upper layers.

The actual gain of multi-burst FEC is difficult to quantify in real life, as it will depend on the distribution of the transmission errors over time. In this paper we investigate the coverage gain due to multi-burst FEC for DVB-H mobile TV streaming services for vehicular users in real scenarios. We investigate the gain due to fast fading, shadowing and path loss with dynamic simulations, and with field measurements. The basis of the approach will be described in Section II. Section IV deals with the simulation environment and simulation results for an urban scenario. In Section V the field measurement results will be shown. The paper will be completed with a conclusion.

II. BACKGROUND

In this section the basics of MPE-FEC and multi-burst FEC will be described.

II.A. MPE-FEC of DVB-H

As mentioned before, DVB-H employs a discontinuous transmission technique where data is periodically sent in bursts (of maximum size 2 Mb) [1]. For streaming services the terminals transform the received burst data into a continuous stream, in such a way that users do not notice the discontinuous transmission. The achieved streaming data rate depends on the burst size and the time between two bursts (cycle time).

When MPE-FEC is employed, the IP information is encoded burst by burst with a Reed-Solomon (RS) code, being possible to recover bursts if partially received. The maximum percentage of errors per burst that can be corrected is proportional to the coding rate, and for example the coding rate 3/4 can cope with up to 25% errors. MPE-FEC can only cope with very small outage periods that represent a fraction of the burst duration but it cannot recover from complete lost bursts. In this case the multimedia stream is interrupted until the next burst is received.

II.B. Multi-Burst Forward Error Correction

Compared to the conventional approach with MPE-FEC, multi-burst FEC schemes provide protection across several time-sliced bursts rather than within a single burst. In this way it is possible to correct not only partially received bursts, but also complete lost bursts. This property can be used to improve the transmission robustness for DVB-H streaming services by increasing the protection period over more time-sliced bursts. The drawbacks are an increased network latency (which is translated into a larger service access time and zapping time between channels) and larger memory capabilities in the terminals.

As an example, Figure 1 shows three different ways of transmitting the same streaming content using MPE-FEC and multi-burst FEC with the same coding rate 1/2 but different protection periods. Although the amount of parity data is the same in the three cases shown in the figure, the level of protection is different.

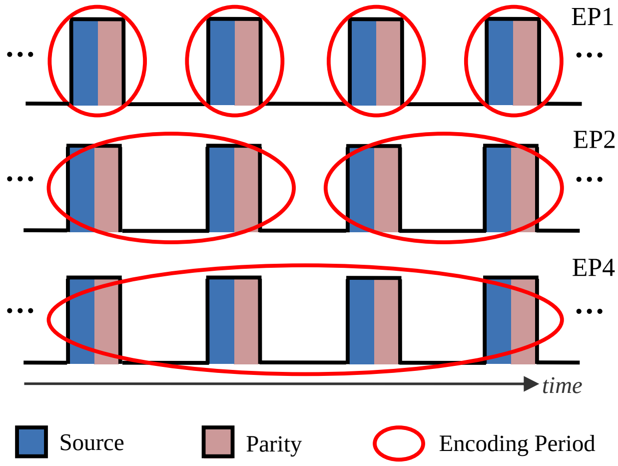

Figure 1: Multi-burst FEC concept in DVB-H with a coding rate 1/2 and with several encoding periods.

For the conventional case with MPE-FEC 1/2, if the percentage of errors in a burst exceeds 50%, the decoder will fail and the stream will be somehow interrupted. With multi-burst FEC 1/2 it can be corrected the same percentage of errors, 50% (assuming an ideal code like RS), but across several bursts. For the examples shown in Figure 1 that means that one and two completely erroneous bursts can be corrected if all other bursts within the protection period are received without any errors. It should be pointed out that if the coding rate is not robust enough to cope with all transmission errors there is no gain by increasing the time interleaving. If the MPE-FEC or multi-burst FEC decoder fails, only correctly received IP source packets will be available for playback.

The improvement of the FEC coding efficiency with multi-burst encoding is especially evident for low coding rates where a significant amount of parity data is transmitted, since if the coding rate is not robust enough to correct the total number of errors there is no gain by increasing the interleaving (e.g., with a coding rate 7/8 only one lost burst out of eight could be recovered).

Finally, it should be noted that each time-sliced burst contains both source IP information and parity data, reusing the legacy time-slice MPE burst signaling. However with multi-burst encoding the parity data is computed across several IP datagram bursts.

There are two possibilities defined in the multi-burst MPE-iFEC link layer protection mechanism of DVB-SH [6]. One alternative simply consists on encoding several consecutive IP datagram bursts jointly. This requires an encoding algorithm able to efficiently handle very large source blocks. This is the Raptor coding approach. The other alternative consists on using the same RS code defined in MPE-FEC but interleaving the information from different IP datagram bursts into one encoding matrix and distributing the generated parity data over several time-sliced bursts (sliding RS encoding approach).

III. COVERAGE ESTIMATION WITH MULTI-BURST FEC

Multi-burst FEC techniques exploit the spatial diversity introduced by the mobility of the users and the dynamic variations in the environment surrounding the receiver in order to increase the FEC coding efficiency.

The error correction capability of MPE-FEC in DVB-H depends heavily on the errors time distribution. Ideally, if the errors are uniformly distributed, it is possible to cope with MPE section error rates proportional to the coding rate employed (e.g., a coding rate 3/4 can cope with up to 25% erroneous sections). However in practice the DVB-H channel is very bursty, and long error bursts are common due to the on-off behavior of the physical layer with the received signal strength. As a consequence, the coding efficiency is reduced, being not able to correct all errors. This degradation of the coding efficiency can be ideally solved with multi-burst FEC increasing the effective time interleaving. Indeed, if a sufficiently large interleaving depth is employed, it is possible to cope with as many erroneous packets as in the best case (memoryless channel).

Another important parameter is the coverage level, since if it is too good there won’t be any error to correct, whereas if it is too bad it won’t be possible to recover any data. Increasing the time interleaving makes only sense when the total amount of errors is smaller than the error correction capability. If there are too many errors, there is no gain increasing the interleaving. For this reason multi-burst FEC techniques are especially suited for vehicular users, as they only experience temporary coverage discontinuities due to their high speed.

The coverage gain due to multi-burst FEC is very difficult to quantify in real life, as it will depend on the distribution of the transmission errors over time. Generally speaking, the gain will depend on the degree of time-spatial diversity experienced by the users along the bursts jointly encoded. The higher the diversity, the lower the statistical correlation between bursts reception conditions and the larger the gain.

The maximum gain occurs when there is no correlation between reception conditions of consecutive bursts. Fast fading between different bursts can be considered uncorrelated but shadowing is a spatial correlated process.

In order for interleaving to be effective, the interleaving depth should be large enough to essentially average out the fading statistics.

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 locations which average signal strength exceeds a given value with a target high probability). However, multi-burst FEC techniques require dynamic analysis over time, as the performance depends on the mobility and trajectory of the users. Hence, the coverage level is not a static measure, as it depends on the degree of mobility of the users.

IV. SIMULATION OF REALISTIC SCENARIOS

In real conditions the signal strength is mainly influenced by the path loss depending on the location. Fading occurs due to multipath propagation (fast fading) and shadowing by obstacles (log-normal fading). In this section it will be shown that the network gain cannot be achieved within the whole network area. As described above, the network gain depends on the velocity (Doppler), the trajectory of the users and the time distribution of the errors.

IV.A. System Model

In order to simulate realistic scenarios, besides fading models described above, mobility model and signal propagation estimations have to be used. In the following, a simulation scenario will be introduced which has been used for realistic dynamic simulations in the urban environment of the city of Braunschweig, Germany. It is based on a realistic mobility scenario, an existing DVB-H test network and a signal propagation simulation.

IV.A.1) Mobility model

For the simulation of the mobility, especially the velocity and used track, in an urban scenario, the simulation environment SUMO (Simulation for Urban MObility) [7] has been used. All streets vector information including realistic parameters for traffic lights, turning probabilities and car entering rates for an area of 2 km x 1.8 km have been developed. The output of the simulation is a collection of user traces with realistic position and velocity.

For each trace several simulation runs can be performed, including different random shadow fading processes per iteration. The quality results will be shown by using the average values of all iterations for each trace.

IV.A.2) DVB-H System Parameters

The DVB-H network used for the simulation consists of one existing transmitter with three sectors of 65° beam width in azimuths of 45°, 225° and 315°. The antennas are mounted at a height of 57 m. The 45° antenna has a down-tilt of 10°, the others 0°. The total transmitting power of 1 kW is split 55 dBm for each antenna. The UHF band with a frequency of 554 MHz is used. The total data rate for an 8 MHz channel is about 13.2 Mbit/s.

In the evaluations a streaming service with a constant data rate of 384 kb/s (typical H.264 video service with a resolution of 352 x 288 pixels CIF at 15 frames per second) is considered. A constant IP packet size equal to 512 bytes and 512 rows per burst is assumed. The number of columns per burst with MPE-FEC depends on the coding rate, but we have assumed a constant burst size of 1 Mb. This yields a cycle time of 1.4 s for coding rate 1/2.

For the simulation environment the OFDM mode 16-QAM CR 1/2 and a guard interval of 1/4 have been used.

IV.A.3) Signal level variations

The wireless channel is traditionally modeled with three different processes: path loss, slow or long-term fading (shadowing), and multipath or Rayleigh fading (fast fading). All of these processes vary as the positions of the transmitter and receiver change, and as any contributing objects between the antennas are moved.

In order to estimate the propagation loss a macro cell propagation model is used based on [8]. As input data antenna diagrams, ground height and clutter data have been used, resulting in propagation maps of a 50m resolution.

Using the position information of the traces, the appropriate path loss values can be determined. For each position, additional shadow fading value will be estimated using correlation and standard deviation parameters.

In the simulations the DVB-H physical layer performance model proposed in [10] has been used. It was developed from laboratory measurements for the Typical Urban 6-tap (TU6) channel model for the transmission mode FFT size 8K, guard interval 1/4 modulation 16-QAM and coding rate 1/2, which provides a channel data rate of 10 Mb/s at the physical layer. This channel model was proven to be representative for DVB-H mobile reception for Doppler frequencies above 10 Hz (vehicular reception), and it includes the time variant small-scale fluctuations of the received signal due to fast fading. The TU6 channel is characterized by its average Carrier-to-Noise Ratio (CNR) and maximum Doppler frequency f_d, which is calculated using the current velocity of the user.

To simulate correlated shadowing we employ the method proposed in [10], which assumes a first-order exponential model [11] where the correlation distance d_{corr} is set to 20m. The shadowing standard deviation is set to 5.5 dB.

IV.B. Simulation Results

The simulation results will be presented by means of a selected track. First a short trace of 400 seconds will be shown as an example.

IV.B.1) Single user example

Simulations have been performed for 55 generated traces with 1000 iterations each. Thereby, the velocity remains the same, but signal strength varies due to different fading processes. In Figure 2 a representative iteration is shown. The transmitting power was set to 20 dBm EIRP. Besides velocity, the received field strength including shadow fading is shown. The fast fading will be included with the TU6 model and is not shown in this plot. Furthermore, the resulting TS packet error rate is shown.

In order to estimate the quality of coverage, service availability is evaluated. It described the probability of correct reception of a burst measured over all iterations (inverse of the burst error rate). The result for the selected track is shown in Figure 3. The dotted line represents the reference case EP1 which is comparable to the traditional MPE-FEC approach using the same code rate. The solid line represents an EP of 32 bursts.

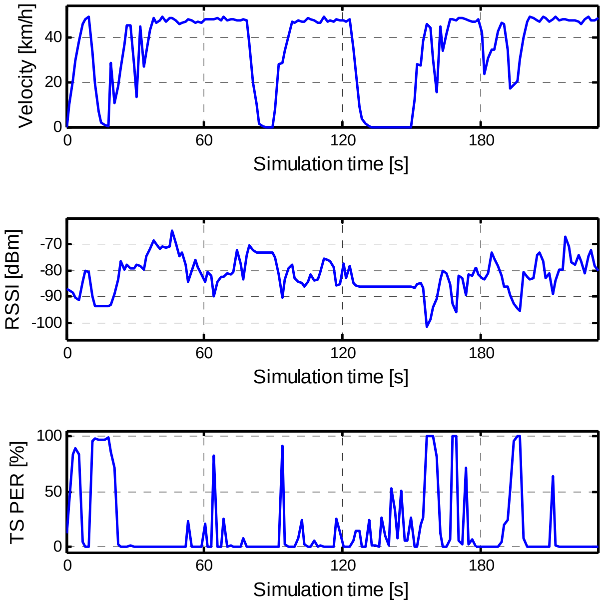

Figure 2: Information of a representative iteration of a single user's track in an urban environment. The user's velocity, received signal level and TS packet error rate are specified.

If a network planning criteria 95% service availability will be assumed, coverage can be guarantied during the whole trajectory using EP32. The fade around 140th second can be explained that the users were standing still in the simulation and therefore the bad reception conditions didn't change. As described above the more the bursts errors are concentrated over time the less is the gain. Over the whole trace, the service availability will be increased in mean from 88.5% to 99.2%. In general, due to the coding of several bursts the edges are getting smoother for higher EPs.

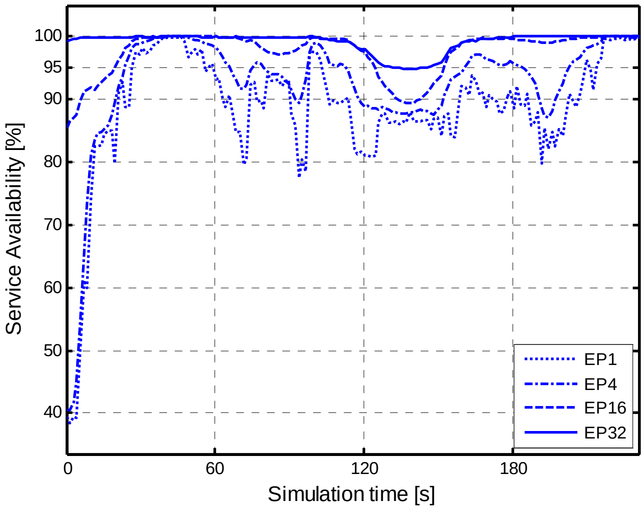

Figure 3: Burst error rate depending on the location and different encoding periods with a coding rate of 1/2.

IV.B.2) Network Gain

As indicated above the service availability as a measure for the coverage quality. If it is very high, no errors need to be corrected. On the other hand, if it is very low it is not possible to recover any data. Increasing the time interleaving (larger EP) makes only sense when the total amount of errors is smaller than the error correction capability. If there are too many errors, there is no gain increasing the interleaving. There will be two areas of gain. If the service availability for the reference case EP1 (comparable to MPE-FEC with the same coding rate) is already reaching the target threshold of e.g. 95%, an increase of the encoding period will increase quality of service (QoS). For not covered areas (coverage probability is below the threshold) coverage can be provided with an appropriate larger EP in terms of reaching the target threshold. This area can be used in order to estimate the link margin gain.

A trace has been simulated with SUMO which enters almost all streets of the above described scenario. Within the trace about 1200 bursts in 28 minutes will be received. For all users the velocity remains the same, with a mean velocity of 37 km/h. For each of the 1000 iterations different fading processes have been applied.

In Figure 4 the service availability and the network gain is shown for different EPs dependent on the mean signal level RSSI. Therefore, the average of all values for an equal RSSI value has been plotted. Using EP1 a mean received signal level of -78.8 dBm is necessary. A perfect coverage of 100% is reached with -69.2 dBm. Thus, between these two RSSI levels a gain in QoS by means of increasing the service availability will be achieved. For the highest EP length of 64 bursts and the signal strength of -84 dBm a 95% coverage will be achieved. Thus, between the specified RSSI values of EP1 and EP64 a gain in coverage will be achieved. The difference between these RSSI values can be interpreted as a link margin gain which results in this case to about 5 dB.

Furthermore, the gain value is defined as the ratio of the service availability for a selected EP compared to EP1. It is shown that for very low and very high signal level, almost no gain can be achieved. For EP64 a gain of 1.25 is achieved coverage with 95%. Thus, the achievable gain is depending on the received RSSI and therefore on the location of the user. As mentioned before, it is also influenced by the user's route and velocity.

The in Figure 4 presented values show an average representation of the whole trace. In order to evaluate the achieved coverage depending on the location a map is shown in Figure 5. The three-sectorized transmitter is depicted as well. The trace starts in the north-east heading towards western direction. A dot represents one single burst. For EP1 the gray dots have a service availability of 95% or higher. For black and not filled bursts will not be received with at least 95%. For EP64 the black bursts are additionally received with the target probability. It can be seen that the coverage depends on the trajectory. Especially in the middle-east part hollow dots occur even in areas with satisfying reception.

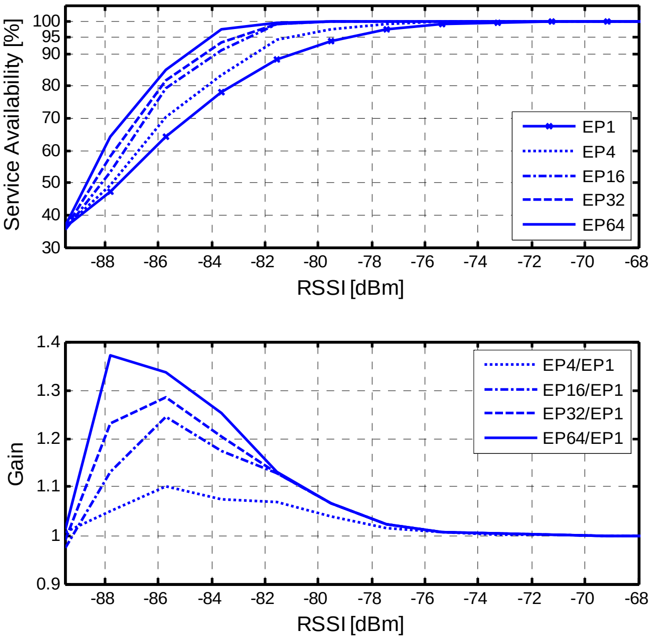

Figure 4: Service availability and network gain depending on mean signal level (RSSI) and encoding period EP.

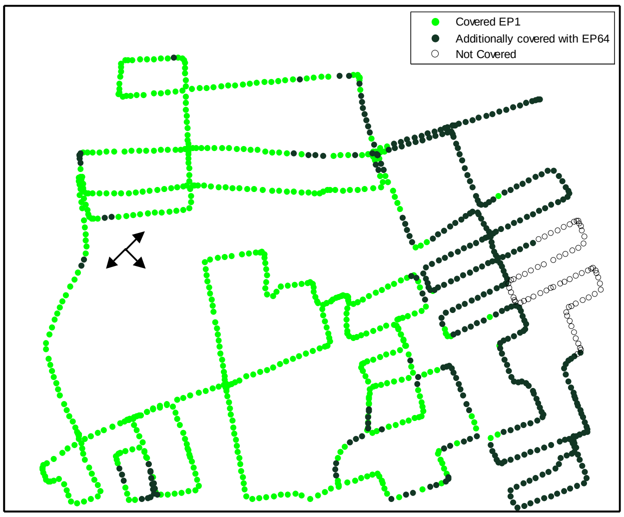

Figure 5: Coverage example with 3-sectorized transmitter. Gray dots represents coveraged bursts with EP1. Black and gray bursts are coveraged with EP64.

V. FIELD MEASUREMENT RESULTS

In order to evaluate real life performance of the multi-burst FEC approach, measurements have been performed. The DVB-H network configuration described in Section IV.A.2) has been used. Vehicular measurements of the transport stream (TS) in urban and suburban areas have been done. The higher layers have been emulated by software.

V.A. Measurement setup

For transmitting the transport stream has been equipped with a packet counter. The packet counter has been evaluated in order to gather sequences with information of received or not received TS packets marked with one or zero, respectively. The whole multiplex has been measured in capacity and time. The features time-slicing and multi-burst FEC have been emulated. Perfect codes have been assumed. Using these sequences, burst error rates can be determined for different system parameters, such as FEC coding rate and encoding period. The DVB-H physical layer transmission mode is an OFDM 8K FFT with 16-QAM CR 2/3 and Guard Interval 1/8.

The vehicle has been equipped with two antennas at the rooftop feeding two receivers. One receiver has been attenuated by 6 dB. This enables a comparison of two signals with a 6dB offset in transmitting power.

The TS packet sequence will be used in order to evaluate burst error rate depending on coding rate and encoding period of the multi-burst FEC approach. In order to get reliable results several users have been simulated having a burst starting time varied with in the cycle time.

V.B. Measurement results

In Figure 6 the result of the TS packet error rate with a one second window size is shown. The solid line represents the reference case for a 400 seconds long trace. Whereas the dash-dotted line represents the appropriate TS packet error rate with an additional attenuation of 6dB. It can be seen, that the errors patterns are bursty, which results in continuous loss of bursts.

Figure 7 shows the burst error rate averaged over the whole measured trace depending on the coding rate and encoding period. As in the simulation results, the threshold for good coverage is set to 95% service availability, which corresponds to 5% burst error rate.

For the reference case, the coverage quality has been good in order to meet the specified threshold for all coding rates and already for EP1. A further increase of EP length increases the coverage quality which represents the case where a gain in QoS is perceived.

At the case of the attenuated signal larger EP length is necessary. The burst error rate decreases for larger EPs and lower coding rates. For high coding rates of 2/3 and 3/4 many burst errors occur. As mentioned in the beginning, for a CR 2/3 a percentage of 66.6% of bursts have to be received correctly in order to decode all bursts in this encoding period. A fast decrease can be seen for CR 2/3 which represents the case when the percentage of burst errors gets below 1/3 of the EP length. Thus, 2/3 of the bursts will be received correctly and all bursts can be decoded. For the CR 3/4 case the BER increases for larger EP. In this case two blocks of burst errors will be combined in one EP due to high EP length.

There exists a trade-off between latency which is directly included in EP and coverage quality. Furthermore, a more robust coding rate can be applied in order to increase the coverage quality. In this case the overall data rate will be decreased due to smaller data sections within the burst.

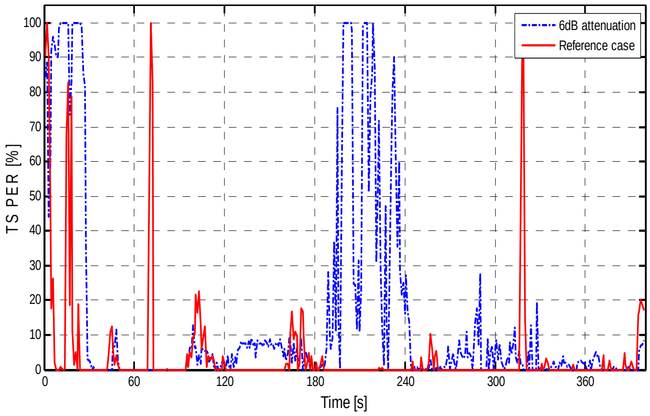

Figure 6: Transport stream packet error rate for two measured signals with a 6dB offset.

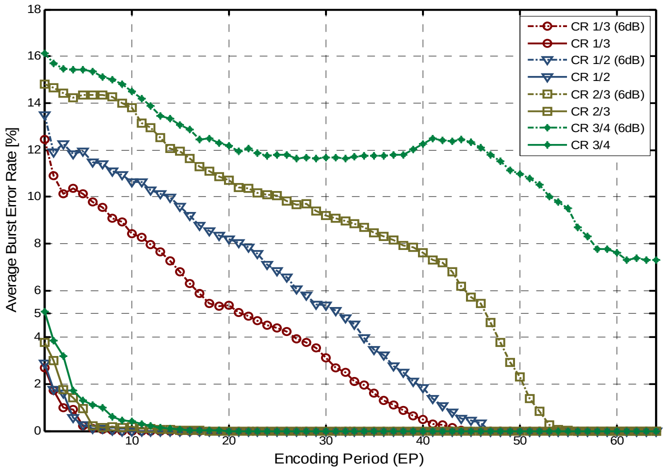

Figure 7: Average burst error rate depending on different coding rates and encoding period.

In the figure a 6dB link margin gain can be seen depending on the code rate and encoding period. For same code rate a 6 dB gain of using Multi-burst FEC can be detected if quality of attenuated case will be the same than the reference case of EP1 in the non-attenuated case. For a coding rate of 1/2 an encoding period of about EP37 the 6 dB gain can be achieved.

CONCLUSION

A multi-burst FEC approach has been used in order to increase the robustness of reception for streaming broadcast services for vehicular users in urban environments. The approach shows benefits in terms of higher service availability. Two types of gains have been observed. On the one hand QoS can be increased for already covered areas, i.e. areas where a given target probability of service availability is met. For not covered areas this target threshold can be reached and therefore coverage can be provided.

The achievable network gain has been shown by means of simulations and measurements in urban scenarios. A coverage map for a specified example has been shown. A link margin gain can be estimated out of the evaluations. The network gain depends on the trajectory, user velocity, applied coding rate and encoding period.

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