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Forward Error Correction for File Delivery in DVB-H

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***Abstract*— Reliable filecasting to vehicular users in wireless broadcast networks is a very challenging task, as an error-free transmission of the files is required. Reliability can be achieved by means of Forward Error Correction (FEC) and post-delivery file repair mechanisms. In this paper, we describe and compare the standardized FEC schemes in DVB-H (Digital Video Broadcast - Handheld) at the link and application layer, and evaluate their performance for file delivery to vehicular users. We show that by using application layer FEC it is possible to efficiently correct the errors appeared due to temporarily shadowing and fast fading, by taking advantage of the time and space diversity introduced by the bursty character of DVB-H transmissions and terminal mobility. Our results may constitute a valuable guide for operators when dimensioning their network capacity and service bandwidths, especially in the situations when vehicular users represent a large part of the customer base.**

I. INTRODUCTION

Mass mobile multimedia services to portable devices, as cell phones or PDAs, is the next big step in the wireless industry development. However, a mass-market adoption is conditioned to the provision of these services at affordable costs to the consumers. The most important bottleneck is the cost of the wireless infrastructure, which is proportional with the data rate provided to the user terminal in a system with wide coverage [1].

Terrestrial digital broadcast networks especially designed for mobile services are considered as key elements in future wireless networks, since they can efficiently distribute popular multimedia content over large areas, at significantly higher data rates than the cellular systems. The system discussed here is DVB-H (Digital Video Broadcast - Handheld), and is an extension of the European standard for terrestrial digital TV DVB-T (Digital Video Broadcast - Terrestrial), to reach handheld terminals. DVB-H reuses the same physical layer as DVB-T and adds new features at the link layer, being able to share the same network infrastructure (e.g., transmitters, multiplexes, etc.). It was initially designed to be used in UHF below 700 MHz, and it can provide capacities from 5 up to 10 Mb/s on an 8 MHz channel [2].

IP Datacast (IPDC) over DVB-H is an IP-based end-to-end broadcast system for delivery of any types of digital content and services to mobile devices. One of the key features of IPDC is the possibility to complement DVB-H with a bi-directional interactivity path offered by the cellular systems.

In IPDC systems, multimedia content is delivered either as a **streaming** service, or as a **file delivery** service, to the end user, in a time-constrained or unconstrained manner [3]. In streaming services a continuous data flow of audio, video and subtitling is delivered to the terminals, and is directly consumed by the users. In file delivery (or filecasting), services a certain amount of data is delivered and stored into the terminals in its entirety as a file, which can then be consumed immediately or at a later time.

In this article we specifically focus on file delivery services. Applications that fall within this category are: video clips, digital newspapers, software download, etc. Common to all these services is the requirement of an *error-free transmission of the files* (i.e., even a single bit error corrupts the whole file and makes it useless for the receiver).

As DVB-H only provides a unidirectional downlink channel, error correction can only be achieved by means of Forward Error Correction (FEC). FEC mechanisms rely on the transmission of *additional parity data*, that allows recovering the original data when transmission errors occur, without a need for feedback. To increase the robustness of the DVB-H transmission, while keeping compatibility with DVB-T, two optional FEC schemes have been specified on the link and application layers.

As it cannot be guaranteed that each and every user will be able to recover the file after the initial DVB-H transmission, since some users might have experienced too bad channel conditions, a post-delivery repair phase can be performed to complete the delivery of the file (via DVB-H or the cellular network) [4].

In this article, we review link and application layer forward error correction for the initial file transmission in DVB-H. We compare their performance in a dense Single Frequency Network (SFN) deployment scenario and target vehicular (portable in-car) users. Vehicular users are one of the most critical user cases in DVB-H, since terminals experience both the effects of vehicle's body attenuation, and strong fast fading impairments due to high velocity. However, it is possible to take advantage of the space diversity introduced by their mobility. We evaluate the increase in user satisfaction as

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a function of the amount of parity data transmitted under different settings; in order to clarify the impact of different parameters on the overall system performance.

The rest of the article is organized as follows: Section II highlights the way transmission errors appear in DVB-H. Section III introduces the DVB-H FEC schemes at the link and application layer. Section IV describes the main parameters that influence the performance of both FEC mechanisms for file delivery in DVB-H. Representative simulation results are presented and discussed in Section V. Finally, conclusions are summarized in Section VI.

II. TRANSMISSION ERRORS IN DVB-H

DVB-H employs a discontinuous transmission technique based on *time-slicing*, where data is periodically sent in bursts [2]. Terminals synchronize to the bursts of the desired service, and switch their receivers (front-end) off when bursts of other services are being transmitted, reducing their power consumption and enabling the search of neighboring cells in other frequencies.

The physical layer of the underlying DVB-T standard is characterized by a very rapid transition from near perfect reception to no reception at all [5]. As a consequence, under static conditions, there will be locations where reception is not possible at all (*outage areas*), and locations where terminals correctly receive all bursts (*covered areas*). However, the physical layer does not provide any time interleaving, as it was initially designed for DVB-T assuming fixed reception with rooftop antennas. Hence, in DVB-H, due to the absence of any link adaptation technique (e.g., power control or adaptive modulation), it is very likely that most of the terminals will frequently experience packet losses at the physical layer due to mobility (fast fading) or interference (e.g., impulse noise).

Typically, packet losses at the physical layer result in an even higher loss rate on the link and application layer. The DVB-H standard works with MPEG-2 packets at the physical layer (size 188 bytes), and IP packets at the link layer (typical size 1-2 kbytes). Thus, in the worst case, one single erroneous MPEG-2 packet can cause the loss of up to two IP packets. In practice, erroneous packets at the physical layer are usually correlated, and several consecutive packets are lost.

In DVB-H bursts are transmitted in the form of MPE *sections*. MPE (Multi Protocol Encapsulation) is the protocol used to encapsulate multiple IP streams (DVB-H services) into the MPEG-2 DVB-T transport stream. At the receiver, each section is considered either completely received or completely lost based on a CRC (Cyclic Redundancy Check) field [2]. If no FEC at the link or application layer is employed, each section contains an IP packet, and terminals need to receive all sections correctly to decode the burst content.

III. FORWARD ERROR CORRECTION IN DVB-H

The DVB-H standard specifies a FEC scheme at the link layer called MPE-FEC, which can be used for both streaming and filecasting services. Furthermore, Application Layer FEC (AL-FEC) in the form of Raptor coding have been recently standardized to improve the performance of MPE-FEC for file delivery [3]. It should be pointed out that DVB-H also uses FEC at the physical layer; but whereas the physical layer FEC corrects bit errors within MPEG-2 packets, the link and application layer FEC correct IP packets. The physical layer decoder will declare uncorrectable MPEG-2 packets and their associated IP packet(s) as erased, such that the link or application layer decoders see a virtual erasure channel.

A. Link Layer FEC

The MPE-FEC scheme is based on a Reed-Solomon (RS) code in conjunction with a virtual block interleaver, that allows error correction within bursts, and is typically implemented on hardware. Its objective is to compensate for the performance degradations due to fast fading in mobile channels, and to improve the tolerance to impulse interference. It increases the robustness of reception under mobility conditions, such that the service availability (i.e., burst error rate) becomes practically independent of the speed [2].

With MPE-FEC bursts contain IP packets (data sections) and RS parity information (parity sections, maximum size 1 kB). The resulting coding rate depends on the proportion of IP and parity data transmitted. The parity data is computed with a mother RS code with a coding rate 3/4. The maximum burst size is 2 Mb, of which 1.5 Mb are IP data and 0.5 Mb parity data. To allow different coding rates, the amount of IP data and parity data transmitted in a burst can be reduced by padding and puncturing. It is worth to mention that more robust coding rates than the mother code imply smaller burst sizes (e.g., a coding rate 1/2 is achieved transmitting only 0.5 Mb of IP data and 0.5 Mb of parity data).

Basically, MPE-FEC can cope with a number of erroneous sections in a burst equal to the number of parity sections transmitted (assuming the same size for data and parity sections) [5]; although more sophisticated decoding methods are possible, at the cost of higher complexity, by working with MPEG-2 packets instead of sections [6]. However, these techniques seem to be more suitable for IP packet retrieval for streaming services, as they do not provide the benefits offered by AL-FEC for file delivery.

B. Application Layer FEC

Raptor codes are a computationally efficient implementation of *fountain codes*, that achieve close to ideal performance and allows for a software implementation without the need of dedicated hardware [7]. This, in turn, allows to efficiently support a large range of file sizes.

Fountain codes are a special class of FEC codes that can generate an infinite amount of parity data on the fly (i.e., they are rateless). An ideal fountain code has the property that the source data file can be reliable reconstructed after receiving a certain amount of encoded data equal to the file size. They were originally designed to allow very efficient asynchronous file downloading over broadcast channels without the need of a feedback channel. However they have been found to be very suitable for data delivery in wireless broadcast systems

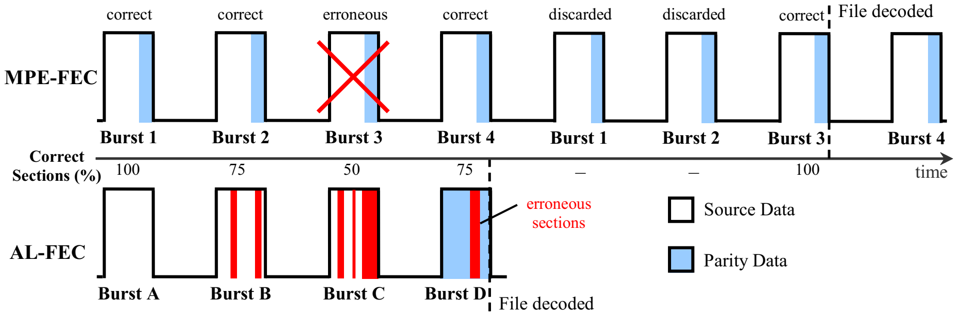

Fig. 1. Example of file delivery using MPE-FEC and AL-FEC (ideal code) in DVB-H. File size is 6 Mb. MPE-FEC coding rate is 3/4.

when working at the application layer; outperforming other FEC solutions in terms of reliability, spectrum efficiency and flexibility [8].

In the particular case of DVB-H, the key is that AL-FEC provide *protection across the entire file*, rather than across a single burst as with MPE-FEC. As a result, AL-FEC outperforms MPE-FEC when the file is spread over several bursts [9]. On the other hand, their performance is almost identical for small files that fit within a single burst. Note that this is the case for streaming services (where each burst can be seen as a unique file). For this reason AL-FEC was only standardized in DVB-H for file delivery services.

With Raptor coding, the original file is transmitted first, followed by parity data (i.e., systematic code). Obviously, if all source data is correctly received, no parity data is needed at all. Otherwise, the total amount of data that needs to be successfully received in order to recover the file is only slightly greater than the size of the file (i.e., 1-2% *reception overhead*).

IV. FILE DELIVERY IN DVB-H

A. FEC Configuration

The configuration of the FEC mechanism will depend on the service characteristics, target users, anticipated network conditions, and the amount of additional bandwidth or transmission time that can be used. Another important parameter is the cycle time between bursts.

The *FEC overhead* (i.e., amount of parity data transmitted), is ultimately the most important parameter, as on the one hand very little overhead may result in a low robust transmission not allowing most users to recover the file, and on the other hand a very robust transmission consumes resources that could be used for other services.

If AL-FEC is used, files are first partitioned into *source blocks*. The maximum recommended size is 32 Mb, to not overload the processing capacity of mobile devices [3]. The AL-FEC encoder is then applied independently to each source block. The media server has to determine a fixed FEC overhead to be transmitted, which determines the number of bursts per source block.

If MPE-FEC is used, the media server has to determine the burst coding rate and the number of times that the file is transmitted initially in a carousel (i.e., the file is transmitted repeatedly).

B. FEC Comparison Example

To illustrate the difference between MPE-FEC and AL-FEC, the delivery of a 6 Mb file is considered, as shown in Fig. 1. For the sake of simplicity, an ideal AL-FEC code has been considered. The coding rate assumed for MPE-FEC is 3/4, meaning that the file is divided into 4 bursts, and that can cope with a percentage of erroneous sections per burst up to 25%.

The major drawback of MPE-FEC for file delivery services is that *each of the unique bursts where the file is partitioned must be successfully decoded to recover the file*. If a receiver fails to recover one burst, it must wait until that burst is retransmitted. In the meantime, the terminal will discard sections/bursts already received. Note also that if one burst is completely received (i.e., all source and parity data), it cannot be used to correct errors in other bursts.

The key difference when using AL-FEC is that *all data correctly received is useful to the receiver*. Its performance only depends on the overall number of lost sections, and is not affected by the pattern of the losses.

V. PERFORMANCE EVALUATION

A. System Model

The DVB-H deployment scenario consists of an SFN in a hexagonal service area of 25 km radius. The maximum number of sites to be used is 157, and they are uniformly distributed over the service area. We assume synchronized transmitters of 1 kW EIRP (Effective Isotropic Radiated Power) at all sites. The antenna height is 35 m.

The DVB-H transmission mode considered is: FFT 4K, GI 1/4, QPSK 1/2; it provides a channel capacity of 5 Mb/s at the physical layer. Link budget values corresponding to a urban scenario at a frequency of 700 MHz have been considered. DVB-H terminals are modeled with an omni-directional antenna with -7 dBi gain and a noise figure of 6 dB. Both shadowing (characterized by a lognormal distribution with a standard deviation of 5.5 dB and a correlation distance of 70 m), and fast fading are considered. A constant vehicle entry loss of 7 dB has been assumed. The urban Okumura-Hata path loss model has been employed.

TABLE I

MOBILITY MODEL PARAMETERS.

p_0	p_{90}	p_{-90}	p_{180}	$\bar{d}$	$\bar{v}$	$\bar{v}_{mr}$	σ_v
0.695	0.2	0.1	0.005	250m	15km/h	40km/h	15km/h

In our simulations, 10^4 vehicular users are on the move according to an urban mobility model described in [10]. They are initially uniformly distributed over the service area. We compute the number of correctly received sections in each burst by each user (section size is 1 kbyte). The Carrier-to-Noise Ratio (CNR) performance model given by [11] has been used.

The mobility model captures the users' movements with three random variables: speed, relative change in direction when entering a new street, and street distance. The parameters are: direction change probabilities p_0, p_{90}, p_{-90} and p_{180}, standard deviation of direction distributions σ_φ (equal to $\pi/32$ for all four distributions), average length of major roads $\bar{d}$, variance of the length of minor city roads σ_d^2, equal to $\bar{d} \cdot \sqrt{(2/\pi)}$, mean velocities of city and major roads, $\bar{v}$ and $\bar{v}_{mr}$, velocity deviation σ_v, and percentage of cars on major roads p_{mr}. The values used in our simulations are shown in Table I. The percentage of cars in major roads is 70%.

To account for a practical implementation of an AL-FEC code, a 1% reception overhead has been assumed, as in the standardization work of Raptor codes in DVB-H.

B. Numerical Results

Fig. 2 shows the *acquisition probability* of a 30 Mb file, defined as the percentage of users that successfully receive the file, as a function of the number of sites in the SFN and for different number of transmitted bursts with MPE-FEC (coding rate 3/4) and AL-FEC. The case when there is no FEC at the link and application layers is also shown for comparison. A cycle time of 12 s has been considered.

The number of sites that provide successful burst reception by vehicular users with MPE-FEC 3/4 in 70%, 80%, 90%, 95%, and 99% of locations in the service area are also pictured, in order to help the reader in quantifying the achievable gains.

We can clearly see the significant improvement obtained with AL-FEC compared to MPE-FEC. Note how the performance of MPE-FEC with 20 bursts (i.e., one transmission of the file) is close to sending no parity at all. This is due to the increase of the number of bursts that must be correctly received to decode the file (from 15 to 20). We performed additional investigations and we observed that increasing the MPE-FEC coding rate does not improve performance at all. The reason is that it implies that the file is divided into even more bursts (e.g., for a coding rate of 1/2 the file would be divided into 60 bursts). We also observed that reducing the coding rate to 7/8 results in a very slight degradation compared to 3/4, being thus a better configuration for MPE-FEC.

The curves for MPE-FEC with 40 and 60 bursts represent the cases when the file is transmitted twice and three times respectively. We can see that the gain obtained by retransmitting the file once is considerably larger than the one obtained with the second retransmission. Once the errors become such that the MPE-FEC burst error rate becomes significant, the simply repetition of the file is not sufficient.

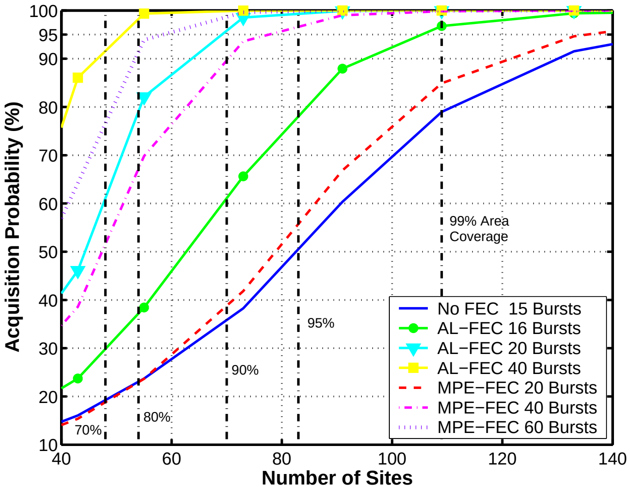

Fig. 2. Performance results for a 30 Mb file delivery service: Acquisition probability vs. Number of sites of the SFN. Cycle time is 12 s.

TABLE II

NUMBER OF SITES REQUIRED FOR 95% AND 98% ACQUISITION PROBABILITY WITH MPE-FEC 3/4 AND AL-FEC.

File Size	**Bursts**	**MPE-FEC 3/4**		**AL-FEC 3/4**	
		95%	**98%**	**95%**	**98%**
30 Mb	20	135	156	69	73
15 Mb	10	123	143	72	83
7.5 Mb	5	107	127	76	89
4.5 Mb	3	99	118	82	95
3 Mb	2	91	109	83	99
1.5 Mb	1	83	99	83	99

When using AL-FEC, an important gain is obtained with only one parity burst compared to the reference case without FEC (16 bursts). However, the gain obtained by every additional parity burst decreases as the amount of parity information transmitted increases.

Table II shows the number of sites required to achieve a 95% and 98% acquisition probability with MPE-FEC 3/4 (one transmission of the file) and AL-FEC.

We can note how the gain decreases for small files, while larger gains are obtained for more demanding user satisfaction criteria. Indeed, for files of 1.5 Mb (one single burst), AL-FEC and MPE-FEC have the same performance. Recall that this is the case for streaming services. With MPE-FEC it is simply easier to deliver small files as less bursts need to be correctly received. On the other hand, with AL-FEC, small files usually require more FEC overhead than large files since they are more vulnerable against lost bursts. We can see this effect in Fig. 3.

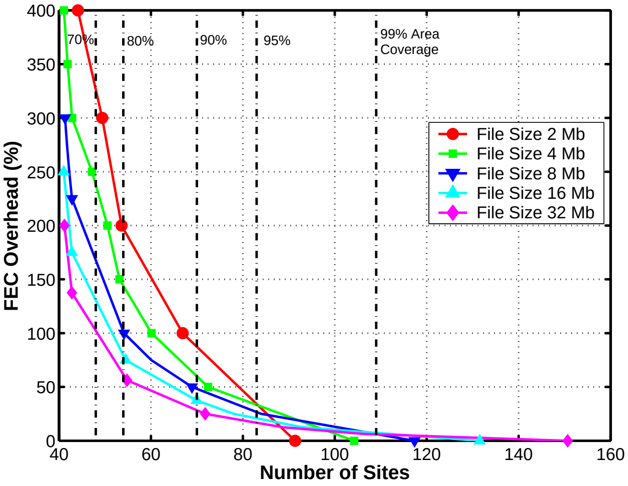

Fig. 3. FEC overhead required with AL-FEC for 95% acquisition probability vs. Number of sites of the SFN. Cycle time is 12 s.

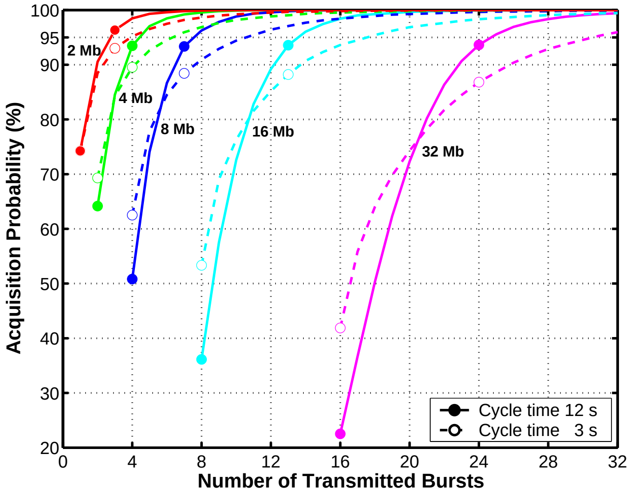

Fig. 4. Acquisition probability vs. Transmitted bursts with AL-FEC. Number of sites of the SFN is 55. The area coverage with MPE-FEC 3/4 is 82%.

Fig. 3 shows the amount of parity required using AL-FEC (relative to the file size), to achieve a 95% acquisition probability as a function of the number of sites in the SFN and the file size. We can see how it becomes increasingly more difficult to transmit larger files without (or with very little) parity information. On the other side, larger files require less overhead for moderate to large amounts of parity information transmitted (more than 15%-25% FEC overhead in our case).

Finally, we study the effect of employing a shorter cycle time. It is worth to mention that the same conclusions apply if the users' velocity is reduced. For this purpose we consider a fixed number of sites in the SFN; in particular 55 sites. This configuration provides a 82% burst error rate over the service area for vehicular users with MPE-FEC 3/4. Fig. 4 shows the acquisition probability as a function of the number of transmitted bursts with AL-FEC for different file sizes and for two cycle times values: 3 and 12 s.

The larger the time between bursts, the larger the crossed distance during the transmission of the file (keeping the velocity constant). Hence, users will experience more heterogeneous reception conditions, and it will become more difficult to deliver files with low amounts of parity data, since the probability of experiencing errors will be higher. On the other hand, it will become easier to deliver files with moderate to large amounts of parity data, as users which are temporarily affected by shadowing or fast fading may move in a better location until the next bursts are transmitted.

The use of AL-FEC is key to efficiently benefit from the spatial diversity gain due to users' mobility, as all packets correctly received are useful to the receivers. The gain brought by AL-FEC compared to MPE-FEC will thus increase for larger cycle times, user velocities, and standard deviation of the shadowing, and for smaller correlation distances of the shadowing.

VI. CONCLUSIONS

In this paper we have shown the benefits of performing forward error correction at the application layer in the initial DVB-H data transmission phase, as it provides protection across the entire file, rather than across a single burst as with link layer FEC. As a result, the time required to deliver files to subscribers is considerably reduced, and more content can be delivered with the same infrastructure. Alternatively, if the transmission time is kept constant, the area coverage for reliable reception is enlarged.

Unlike for real-time streaming services, our results show that the user satisfaction when receiving filecasting services in DVB-H networks can be very tolerant to coverage discontinuities over the service area, at the expense of an increased user perceived delay, by transmitting additional parity data.

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