Affordable Mobile TV Services in Hybrid Cellular and DVB-H Systems

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Abstract

Mobile TV services are expected to become a key application in future wireless networks. The recently proposed terrestrial digital broadcast technology, DVB-H, especially designed for mobile services, is regarded as a powerful alternative to the 3G cellular networks that already offer these services but on a point-to-point basis. Unfortunately, the cost of supporting real-time streaming and full area coverage seems to be very high compared to fixed TV services. In this article we discuss hybrid IP datacast DVB-H and 3G systems as a possible solution for providing affordable network infrastructure and services. Our approach is DVB-H centric. The 3G cellular system plays the role of providing interactivity, error reporting, and repair for the DVB-H broadcast channel. To enable an easy and efficient interworking of DVB-H and 3G, we employ forward error correction at the application layer with digital fountain coding. The main way to provide lower cost services is to avoid full DVB-H area coverage from the beginning and to perform an incremental DVB-H network deployment that follows the user demand. In this direction, to hide the discontinuity in coverage from the perception of users, we propose to take advantage of the bursty character of DVB-H transmissions and the mobility of users. This is possible by sending additional parity data, either with the DVB-H or the cellular network, in the time intervals between original service bursts. We evaluate the potential DVB-H infrastructure cost savings determined by transmitting additional parity data in DVB-H when targeting vehicular users. The implications of delivering parity data through the cellular network also are discussed. The numerical investigations show a potential for significant cost savings compared with the traditional approaches.

One of the challenges that the wireless industry faces today is to provide *affordable mobile TV services* to mobile and portable devices, such as mobile phones or PDAs. Today it is commonly accepted that mass-market demand for mobile multimedia entertainment is conditioned to the provision of these services at low cost.

After a slow deployment of 3G cellular networks, cellular operators have started to provide multimedia services, as video clips from sports events or live TV programs. However, their offers are still limited due to the inefficiency of the current unicast point-to-point (p-t-p) architecture in transmitting the same content to a large number of users. This limits the maximum number of users such systems can handle and prevents mass-market deployment, as both radio and transport network resources are physically limited. To deliver multimedia content efficiently through point-to-multipoint (p-t-m) transmissions in a cell, the 3G standard was enhanced with MBMS (multimedia broadcast multicast services) [1]. Nevertheless, MBMS offers limited capacity (approximately three channels at 256 kb/s), and thus it is unlikely that it will become a good option for mass multimedia services.

As an alternative to the 3G, terrestrial digital broadcast networks especially designed for mobile services are considered as key elements in future wireless networks, as they can broadcast multimedia content to mobile devices at high data rates over large areas. DVB-H (digital video broadcast — handheld) is an extension of the European terrestrial digital TV standard DVB-T (digital video broadcast — terrestrial) and is designed to reach handheld terminals. DVB-H reuses the same physical layer as DVB-T and adds new features at the link layer, capable of sharing 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 to 10 Mb/s on an 8 MHz channel [2].

IP datacast (IPDC) over DVB-H is an IP-based (i.e., all services are carried on top of IP) end-to-end broadcast system for delivery of all types of digital content and services to mobile devices [3]. One of the key features of IPDC is the possibility of complementing DVB-H with a bi-directional interactivity path offered by the cellular systems. The benefits of these hybrid cellular and DVB-H systems are evident. As the cellular network can provide bidirectional communication capabilities and a sophisticated billing system that broadcasting networks traditionally lack, IPDC is a platform that enables the convergence of services from broadcast and cellular domains. In this way, future mobile multimedia broadcasting services will introduce new forms of interactivity,

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customization, and personalization, generating additional revenue streams and enhancing the value of the services to the consumers.

One of the major concerns about IPDC is the cost of DVB-H network infrastructure deployment, which could lead to a price for service that is unaffordable for most users. This concern is very justified if the dimensioning of the network infrastructure is performed to support *real-time streaming services* and nearly *full area coverage*, as in traditional broadcasting. As DVB-H terminals suffer from more severe propagation conditions than DVB-T (especially for indoor and vehicular reception), reusing existing broadcasting towers for TV and radio is not enough to achieve a satisfactory DVB-H coverage. A large number of sites is then required to deploy additional DVB-H transmitters or repeaters (*gap fillers*, and forming dense single frequency networks (SFNs), which implies a larger investment in infrastructure. This penalty is particularly evident for high coverage area targets (e.g., over 90 percent of service area locations) [4].

From a business perspective, the bottleneck is quite clear: sufficiently large numbers of users are required for every site to eventually recover the investment in the infrastructure without charging unacceptable prices for the services. In areas where user density is high, high data rate and full coverage is economically justified. In areas with a scarce user population, the investment might never be recovered, meaning that only a low density of sites and a low to moderate data rate can be supported [5].

Since investment in new infrastructure is costly, the approach of reusing existing infrastructure for broadcasting and cellular systems is an interesting solution for minimizing the cost of deployment for DVB-H [6]. However, *avoiding full DVB-H area coverage for mobile and portable indoor users from the beginning* is probably the *key to providing affordable mobile TV services*. Over time, the infrastructure deployment should be incremental, following the user demand and adding capacity and transmitters only where required and when cost efficient. A progressive deployment is of special importance in the initial phases of the network rollout, when the user population is small and services are still under development.

In this article we propose a framework for affordable IPDC systems based on progressive and cost-efficient deployment of DVB-H infrastructure. Instead of building an over-dimensioned DVB-H network that supports indoor and vehicular users from the start, we propose to jointly utilize the capabilities of existing broadcasting and cellular infrastructures, and to transmit redundant parity (repair) data in order to hide the discontinuity of DVB-H coverage from the perception of the user. Our solution targets *interoperability at the network layer*, following the current trends proposed in a larger context by the Ambient Networks (EU IST-FP6) project [7]. To enable an easy and efficient implementation of the repair mechanisms, we adopt the use of application layer — forward error correction (AL-FEC) with digital fountain coding. Our approach also provides a faster time-to-market. Whereas new user equipment and servers appear on the market in a matter of months, infrastructure deployment might take years.

In our approach, the cellular system is seen not only as an interaction channel for error reporting, but also as a means to deliver parity data. User perceived reliability and coverage can be significantly enhanced by the redundancy offered by both systems, achieving an efficient use and reuse of the access networks. In particular, evolved 3G (E3G) cellular networks present a good potential for complementing DVB-H networks. This is due to the recent enhancements of the 3G standard that not only enable p-t-m transmissions with MBMS, but also high speed p-t-p connections with HSDPA (high-speed downlink packet access) [1]. Moreover, the use of the cellular systems can result in an improved radio resource utilization. In a realistic scenario, there are always some users that experience significantly worse DVB-H reception conditions than the majority (due to fading, noise, and interference), and it may be cheaper to serve them through the cellular network instead of over-dimensioning the DVB-H infrastructure.

It also is important to take advantage of the bursty transmission pattern of DVB-H together with terminal mobility. During the time period between the transmission of two bursts of data, additional repair information can be transmitted if required. Repair information can be pushed via DVB-H in another time slot (at the expense of decreased DVB-H system capacity), pushed via the cellular system with MBMS, or requested (on demand) via the cellular system with HSDPA.

In our framework the price for all these benefits is paid in the QoS (Quality of Service) domain, as *real-time streaming "everywhere" is sacrificed* in the process. The recent trend toward a personalized TV experience, with a user having the freedom to choose what to watch and when to watch it, may be of help, as real-time streaming will not be the major form of media delivery. Then, it would also be interesting to investigate the impact on the broadcasting infrastructure design and dimensioning of such a shift, from "linear TV" to a customized service, based on consumption of content that is already cached in the terminal (e.g., during idle times).

The rest of the article is organized as follows. First, we highlight the differences between streaming and file casting services in DVB-H and their implications in network dimensioning. Next, we introduce the forward error correction schemes at the link and application layer in DVB-H. We describe how error repair can be performed in a hybrid cellular and DVB-H system using AL-FEC. Then, we provide numerical examples of DVB-H infrastructure savings in terms of transmission power and number of sites, and we discuss the implications of the results we obtained. Finally, we deliver some concluding remarks and outline future research issues.

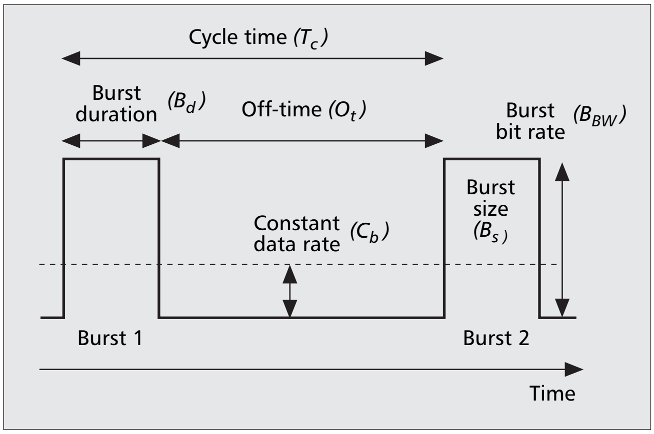
Mobile TV Services in DVB-H

In IPDC systems, multimedia content is delivered either as a **streaming** service or as a **file casting** service to the user.

In streaming services, a continuous data flow of audio, video, and subtitling is transmitted to the terminals and is directly consumed by users. Occasional data errors are tolerated. According to the nature of the transmitted content, we can distinguish between real-time services (e.g., live transmission from a sports event) and non real-time, where a delay between data delivery in the terminal and visualization of the content is accepted (e.g., video clips or soap opera episodes).

In file casting services, a finite amount of data, in its entirety, is delivered and stored in the terminals as a file, requiring an *error-free* reception of the file (i.e., even a single bit error corrupts the whole file and makes it useless for the receiver). The file can be consumed immediately or at a later time. We can distinguish between files that must be delivered within a certain time (e.g., on demand) and files that support background transfer (i.e., users are not aware of the file transmission).

DVB-H employs a discontinuous transmission technique based on *time-slicing*, where data is periodically sent in bursts, as shown in Fig. 1 [2]. Terminals synchronize to the bursts of the desired service and switch their receivers (front-end) off when bursts of other services are transmitted. This allows for a significant reduction in the average power consumption of the terminals, and enables seamless handovers.



■ Figure 1. *DVB-H discontinuous transmission technique based on time slicing. Each burst contains information of the time difference to the next burst of the same service. Terminals experience a constant data rate despite the discontinuous transmission. The maximum burst size is 2 Mb.*

For streaming services, terminals play the information received in the last data burst until the next burst is received, in such a way that users do not notice a discontinuous transmission. If one burst is lost, the media stream is interrupted until the next burst is received. The cycle time depends on the amount of IP data transmitted in the burst and the data rate of the multimedia stream. Typically, a five percent burst error rate is considered the degradation point for streaming services [2].

For file casting services, terminals store the information that was received error-free in each burst associated to the file, until the complete file is available at the receiver. Users are notified afterwards.

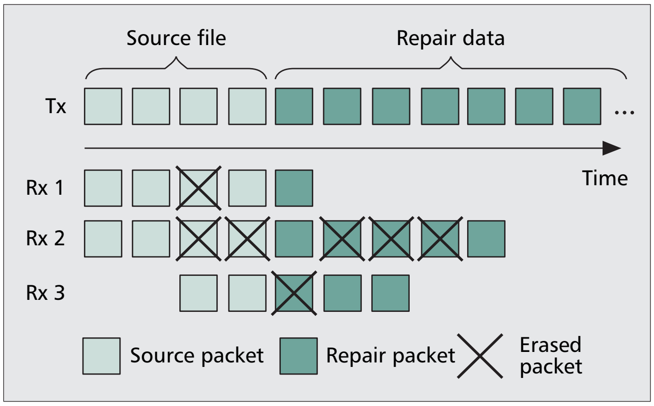
Forward Error Correction in DVB-H

As DVB-H provides only a unidirectional downlink channel, error correction can be achieved by means of forward error correction (FEC) mechanisms. FEC mechanisms protect the loss of packets on underlying levels without a requirement for feedback and rely on the transmission of additional parity data.

In general, a packet-based FEC encoder generates encoded packets out of a source data file. Let us assume the source file is k times larger than an encoding packet. The encoder generates $n \geq k$ encoding packets out of the k source packets, with (k/n) being the coding rate. If a so-called *systematic code* is applied, the first packets are the source packets, and the rest consist of additional parity packets. With any subset of r encoding packets, such that $k \leq r \leq n$, the decoder can reconstruct the source data file (i.e., it does not matter which packets are received but rather that enough packets are received correctly). The exact value of r depends on the coding scheme used.

To increase the robustness of the DVB-H transmission, while remaining compatible with DVB-T, two *optional* FEC mechanisms are specified on the link and application layers. Their goal is to recover lost IP packets. When link layer FEC (LL-FEC) is used, application layer FEC (ALFEC) is disabled, and vice versa.

The LL-FEC scheme consists of a Reed-Solomon (RS) code in conjunction with a virtual block interleaver and is typically implemented on hardware [2]. This is known as multi protocol encapsulation (MPE) FEC. With LL-FEC, each burst contains source IP data and parity data that allows error correction within bursts. This can be used for both streaming and file casting services.



■ Figure 2. *Digital fountain codes for asynchronous download over broadcast channels. An ideal fountain code has the property that the source file can be reliable reconstructed after receiving a certain amount of encoded data equal to the file size.*

On the other hand, the AL-FEC scheme is based on digital fountain coding and is standardized only for file casting services. Fountain codes are a special class of packet-based FEC codes that can generate an infinite amount of parity data on the fly (i.e., they are rateless). They were originally designed to enable efficient asynchronous file downloading over broadcast channels without the requirement of a feedback channel (Fig. 2 illustrates this concept) [8]. However, they were found to be very suitable for data delivery in wireless broadcast systems [9]. Practical implementations are LT codes and Raptor codes. Raptor codes (systematic version) were standardized in DVB-H (and also in 3G-MBMS), because they achieve close to ideal performance, and the computational complexity of their software implementation is suitable for mobile devices.

AL-FEC outperforms LL-FEC for large files that are distributed over more than one burst. The reason is that with LL-FEC, each of the unique bursts must be decoded successfully to recover the file. If a terminal misses one burst, it must wait until that burst is retransmitted. In the meantime, bursts containing data that was already received are discarded. The key difference when using AL-FEC is that *all source and parity data received correctly is useful to the receiver*, accelerating the delivery of the file. On the other hand, the performance of LL-FEC and AL-FEC 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 is standardized in DVB-H only for file casting services.

However, AL-FEC is key to providing an efficient and flexible error repair in hybrid cellular and DVB-H systems, as specific packets are not required to be retransmitted as required with LL-FEC. With AL-FEC, repair sessions consist of transmitting additional parity packets that can be used for all users.

AL-FEC for Error Repair in Hybrid Cellular and DVB-H Systems

We identify the following three alternatives for error repair of the source data using AL-FEC in a hybrid cellular and DVB-H system, which differ in the way the parity data is transmitted:

- Broadcast over the whole service area in an additional DVB-H burst
- Transmitted through the cellular system, using a dedicated connection (e.g., HSDPA)
- Cell broadcasting with the cellular system using MBMS

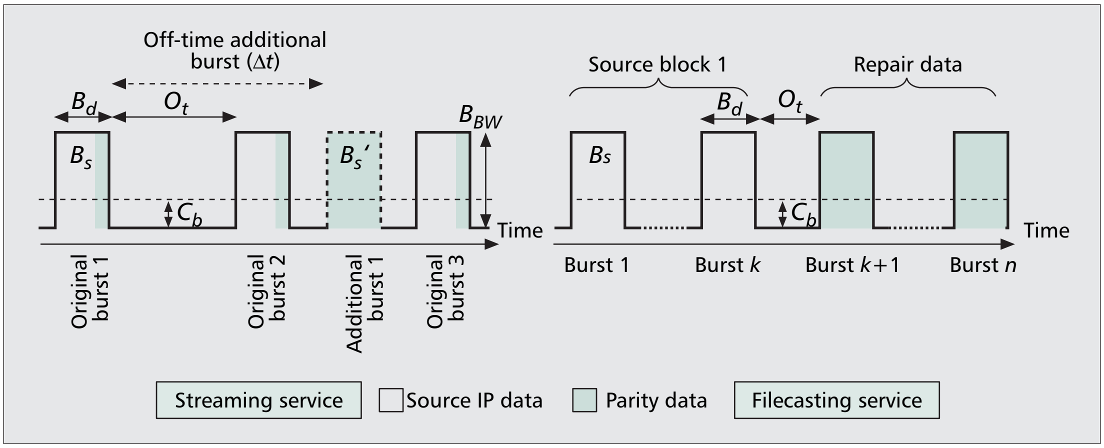


Figure 3. *AL-FEC for streaming and filecasting services in DVB-H. For streaming each original burst with unique IP data is protected with some parity data in the same burst and an additional parity data burst transmitted a few seconds afterwards. For filecasting the file is divided in source blocks that are transmitted sequentially followed by parity data.*

The capability of the cellular system to deliver parity data depends heavily on the distance between users and cellular base stations and the network load. One alternative is to deliver parity data on request. That is, terminals notify the media server about the amount of additional parity packets required. Parity information is transmitted either through dedicated p-t-p connections (HSDPA) or cell broadcasting p-t- m (MBMS), according to the number of users in a cell and the reception conditions. Another alternative is to continuously push p-t-m (MBMS) parity data in already known problematic areas, so that terminals can listen directly to the cellular transmission.

Streaming Services

One possibility is to transmit pre-scheduled additional bursts, with parity information, several seconds after the original bursts, as shown in Fig. 3. In this way, mobile terminals that fail to decode an original burst have another opportunity to recover the missing information, by synchronizing to the corresponding additional burst. This technique trades system capacity, delay, and terminal power consumption for improved mobile user satisfaction, taking advantage of the spatial diversity introduced by users' mobility. User velocity, the time between the original and additional bursts, and shadowing (slow fading) characteristics (i.e., standard deviation and correlation distance) determine the statistical correlation between reception conditions of both bursts. The lower the correlation between reception conditions, the higher the probability of successful mitigation of discontinuity of coverage. On the other hand, the power consumption of the terminals increases for each additional parity burst that is intended to be received.

Terminals that are unable to decode a burst can receive repair data through the cellular network as well, until the next burst is received. The most advantageous scenario is when a terminal misses only a few pakcets, normally due to fast fading or impulse noise. Otherwise, if most of the burst content is lost, the terminal is served in time only when a high cellular data rate is possible. If the recovery of a burst cannot be performed in time, there are two alternatives: either the burst is discarded, or the terminal waits until the burst is recovered completely (and caches the next DVB-H bursts in memory in the meantime).

It should be noted that repairing bursts for streaming services implies the introduction of a delay. When using DVB-H, the delay is equal to the time between the original and additional bursts. When using the cellular network, the delay is equal to the time required to receive the repair data that is required. The advantage is that the multimedia stream restarts, after a break, from the same point where it was interrupted. On the other hand, this may lead to a time shift between streams played in different terminals. However, for most streaming services, except for some of the live transmissions (e.g., a football game), this time shift may not be an issue at all.

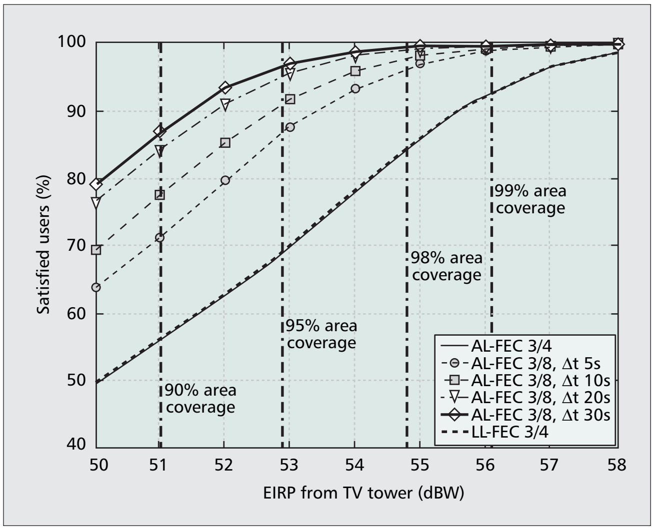
Filecasting Services

At the media server, each file is partitioned into one or more *source blocks* (maximum recommended size is 32 Mb). The AL-FEC encoder is applied independently to each source block (Fig. 3). The media server must determine a fixed parity overhead to be transmitted in DVB-H (which determines the number of bursts per source block) that is sufficient for nearly all users in the radio environment. The amount of parity that is transmitted in DVB-H depends on the anticipated network conditions, service characteristics, target users, and the amount of additional bandwidth or transmission time that can be used. A small amount of repair data might not enable most mobile users to recover the source block, but a large amount of repair data consumes resources that could be used for other services.

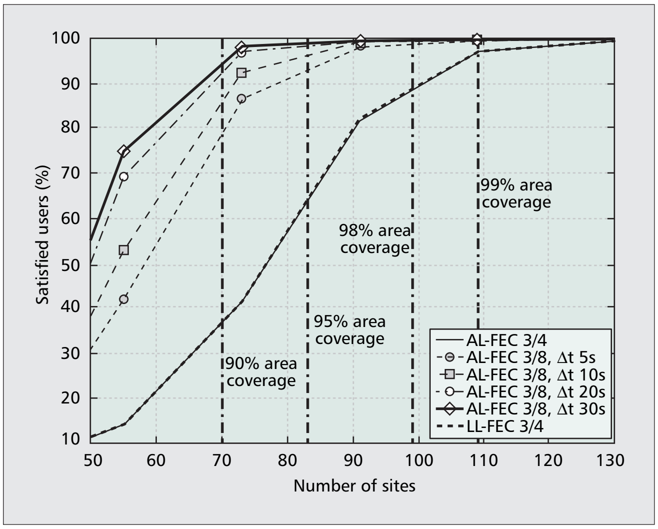
The uplink channel of the cellular system can be used, not only for notifying the media server how much of the data transmitted through DVB-H was received and to specify the number of repair packets required in a post-delivery repair phase, but also to transport quality measurements from the terminals to the server to adjust the amount of parity data to be transmitted in DVB-H.

Performance Evaluation

To illustrate the potential DVB-H infrastructure savings that can be obtained by considering a hybrid system, we investigate the transmission of a streaming service and a file casting service to vehicular (portable in-car) users. To avoid complex simulations of a hybrid DVB-H and E3G system, we consider sending parity information only with DVB-H. Then, we discuss what would happen if, instead, the cellular network is employed. We consider vehicular users because they experience both discontinuity of coverage and strong impairments due to fast fading. Moreover, they also experience an additional attenuation of the radio signal due to the body of the vehicle.



■ Figure 4. *Performance results for a 10 min. streaming service at 256 kb/s: Satisfied users vs. Transmitted power from TV tower.*



■ Figure 5. *Performance results for a 10 min. streaming service at 256 kb/s: Satisfied users vs. Number of sites of the SFN.*

System Model

We consider two DVB-H deployment scenarios in a hexagonal service area of 25 km radius, assuming that the existing broadcasting and cellular infrastructure can be reused. The first scenario consists of a network with only one transmitter mounted on a 250 m height TV tower situated in the middle of the service area. The second scenario assumes a dense SFN deployed only on cellular sites. The antenna height is 35 m, and we assume a number of 157 possible site locations uniformly distributed over the service area.

Initially, in our simulations, users are uniformly distributed over the service area and move according to an urban mobility model described in [10]. We look at the percentage of users that successfully receive the service, as a function of the EIRP (effective isotropic radiated power) from the TV tower and the number of sites in the SFN. Note that both the transmitted power from the TV tower and the number of sites are directly related to the infrastructure investment [4]. An EIRP of 30 dBW (1 kW) for the DVB-H transmitters at the cellular sites is assumed.

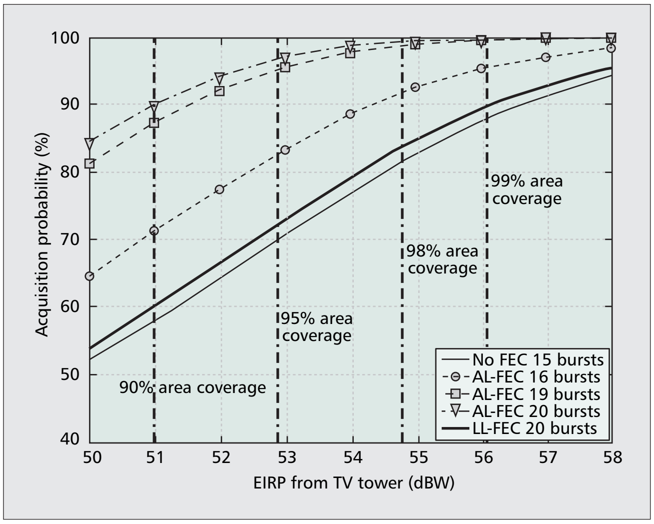
The DVB-H transmission mode considered is: FFT 4K, GI 1/4, QPSK 1/2; it provides a channel capacity of 5 Mb/s at the physical layer. Radio link budget values correspond to an urban environment at a frequency of 700 MHz. The DVB-H terminal antenna gain is –7 dBi. Both shadow fading (characterized by a lognormal distribution with a standard deviation of 5.5 dB and a correlation distance of 70 m) and fast fading are considered. More simulation settings can be found in [10], where a similar system model is used.

To account for a practical implementation of an AL-FEC code, a one percent reception overhead is assumed, as in the standardization work of Raptor coding in DVB-H.

Numerical Results — Streaming Services

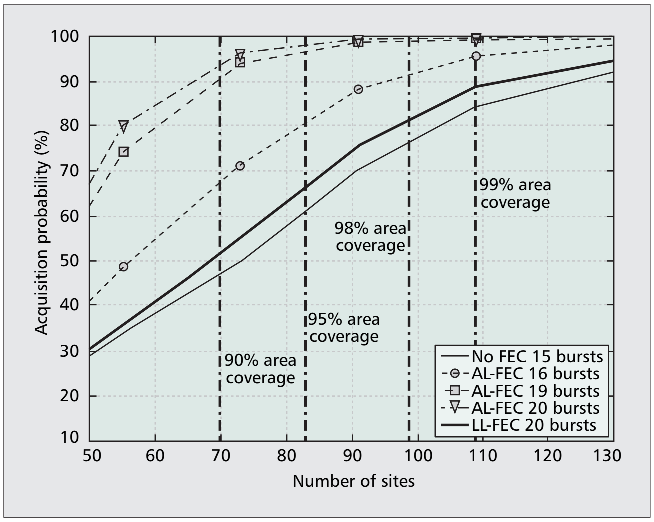
First, we evaluate the improvement in the percentage of satisfied users for streaming services when transmitting an additional parity burst Δ*t* seconds after the original bursts. The criteria for defining a *satisfied user* is that the percentage of lost bursts does not exceed five percent. According to [2], this criteria corresponds to a "good/fair" recovery of DVB-H streaming services. A 10-minute streaming service at 256 kb/s is considered. It consists of 100 bursts with a cycle time of 6 s.

Figure 4 and Fig. 5 show the percentage of satisfied users as a function of the EIRP from the TV tower and the number of sites in the SFN for different cases using AL-FEC. The FEC coding rate in the original bursts is 3/4. The curves for FEC 3/4 mean that no additional parity burst is used, and they are intended as reference. Note that AL-FEC and LL-FEC have similar performance in this case. The coding rate, 3/8, represents the situation when an additional parity burst of 2 Mb is transmitted. The EIRP values and number of sites that provide successful burst reception by vehicular users with LL-FEC 3/4 in 90, 95, 98, and 99 percent of locations in the service area are also pictured, in order to help the reader in quantifying the achievable gains.



■ Figure 6. *Performance results for a 30 Mb filecasting service: Acquisition probability vs. Transmitted power from TV tower.*

We can see the improvement in user satisfaction due to the additional burst, and how it increases with Δ*t*. As the distance crossed between the reception of the original and additional burst increases (depending on Δ*t* and user velocity), the less the correlation between reception conditions, and the higher the improvement. Under our assumptions, for Δ*t* values larger than 30 s, no further gain is visible. It should be noted that retransmitting the whole burst with LL-FEC provides similar performance. However, LL-FEC does not provide the same flexibility offered by AL-FEC, as there is no option other than retransmitting the whole burst.



■ Figure 7. *Performance results for a 30 Mb filecasting service: Acquisition probability vs. Number of sites of the SFN.*

From Fig. 4 and Fig. 5, we can see that very high area coverage levels (around 99 percent) are required to provide high quality streaming services with LL-FEC. If we target 95 percent satisfied users, for a Δt of 30 s, we can save more than 4 dB in EIRP in the single TV tower deployment and 35 sites in the SFN deployment. The corresponding area coverage is 93 percent in the TV tower case and 90 percent in the SFN case. Higher improvements in the SFN scenario are due to the more uniform distribution of the signal power over the service area compared to the single transmitter case.

Numerical Results — File Casting Services

Figure 6 shows the *acquisition probability* of a 30 Mb file, as a function of the EIRP from the TV tower, for a different number of transmitted bursts with AL-FEC. File acquisition means that the file is correctly received at the terminal. The results when using no FEC at the link and application layers (15 bursts), and when using LL-FEC (coding rate 3/4, 20 bursts), also are shown for comparison. A cycle time of 6 s is considered, as for the streaming services.

We can clearly see the significant improvement obtained with AL-FEC compared to LL-FEC. The difference in EIRP between LL-FEC and AL-FEC with 20 bursts is 5.5 dB at a 95 percent file acquisition probability. Note how the performance of LL-FEC is close to sending no parity at all. This is due to the increase in the number of bursts that must be received correctly to decode the file (from 15 to 20). When using AL-FEC, a significant gain already is noted with only one parity burst (16 bursts). However, the gain obtained by every additional parity burst decreases as the number of parity bursts increases (see the small difference between 19 and 20 bursts).

Figure 7 shows the acquisition probability as a function of the number of sites in the SFN scenario. Similar observations as in the previous figure can be noticed. In this case, almost 50 percent of the sites (from 130 down to 72) can be saved, at a 95 percent acquisition probability when using AL-FEC, compared to LL-FEC with 20 bursts.

Discussion of the Hybrid System Performance

Figures 4 to 7 show the benefits when additional parity bursts are sent through DVB-H to mobile users that missed original service bursts. The figures also show the percentage of users that actually benefit from transmitting additional bursts. Now, let us assume that parity information can be delivered through the cellular network.

For file casting, the number of parity bursts (bursts over 15, in our example) can be divided into a part that is sent through DVB-H and another that can be requested and delivered through the cellular network. Then, the curves can be interpreted as a lower bound on the hybrid system performance (under the assumption that bursts in DVB-H can be lost, but not the ones sent via the cellular network). The potential system efficiency improvement of using the cellular network for parity delivery can be seen by looking at the curves for 19 and 20 bursts. In both scenarios, less than 3 percent of the users benefit from transmitting the 20th burst through DVB-H. They could be served more efficiently through the cellular network, saving one DVB-H burst for other service.

For streaming, there is not such a direct relationship as for file casting, as the figures do not show the number of bursts recovered, thanks to the additional parity bursts. As an example of the performance improvement that can be achieved with the cellular network, we note that up to three percent of the users in the single TV tower scenario (and up to six percent in the SFN scenario), would be satisfied if only one out of the 100 bursts could be repaired with the cellular network.

Conclusions and Future Work

We discuss hybrid IP datacast cellular and DVB-H systems as an alternative to provide affordable mobile TV services. We argue that an incremental and cost-efficient deployment of the DVB-H infrastructure, where and when needed, is key. For this reason, we propose to complement the original DVB-H transmission with additional parity data at the application layer to repair errors generated by temporary shadowing and fast fading.

Our evaluations show that significant savings in transmitted power and number of sites are possible for file casting services, even with low amounts of parity data delivered through the cellular system. Important gains can be achieved for streaming services as well, at the expense of not providing real-time services everywhere, as visualization time shifts appear when burst errors occur.

Our results suggest that migrating from "linear" TV (real-time streaming) to solutions where content is transmitted during idle times and stored/cached in the terminals, could lead to more cost-efficient ways of realizing mobile TV.

Future research is needed to develop dynamic resource allocation algorithms for an efficient resource management in the hybrid system, especially in the sense of optimally choosing between different ways of delivering the parity data. Another interesting topic to investigate is how business relationships among the different parties involved affect the achievable performance of the hybrid system.

Acknowledgment

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Biographies

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