# Reliable Download Analyses for Multimedia Broadcast Multicast Services[1]

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***Abstract*- This work presents Reliable Download analyses with and without interleaving in MBMS (Multimedia Broadcast Multicast Services) under various network conditions specific to MBMS. Since MBMS download mechanism uses unidirectional multicast from one sender to a group of receivers, an application layer FEC (Forward Error Correction) is used to recover from packet losses. Our work considers Reed Solomon and Raptor FEC coding. We have done experimental work to discover Reed Solomon FEC performance under MBMS link conditions while we used analytical model for Raptor FEC under the same environment. Finally, in order to further increase the FEC performance we have applied an application layer interleaving technique to our MBMS download system that also supports progressive download and provided a performance comparison of the legacy and the interleaved download delivery.**

**The results of this study will provide guidelines to designers to fine-tune MBMS download service parameters for reliability.**

**Keywords: 3G wireless networks, MBMS, progressive download.**

## I. INTRODUCTION

The advent of new technologies in multimedia applications with a parallel progress in transport technologies has revolutionized the way that multimedia download services are provided to the masses. This revolution makes possible non-real time services such, as downloading or progressive downloading [5] of multimedia distribution in the form of multicasting or broadcasting for wireless environments. Such multicast services allow unidirectional transmission of multimedia data (e.g. text, audio, picture, video) from a single source point to a multicast group. An example of a service using the multicast download service could be a football results service that requires a subscription to receive regular updates of the game status. Similarly, with progressive download, downloadable content can be streamed sooner, after some initial startup delay. Download services are still offered today via point-to-point connections even though technological improvements have already realized the multicast counterpart of the download services. Furthermore, distributing large scale media over bandwidth-constrained networks makes this point-to-point approach inefficient. In addition to problems with scalability and network resources, download services, in which the same content is sent to a large number of receivers, require that the content be delivered reliably. Both scalability and reliability are challenging tasks even in the new content delivery platforms such as 3GPP MBMS (Multimedia Broadcast and Multicast System) [1] [3], 3GPP2 [30] BCMCS (Broadcast and Multicast System), DVB-H (Digital Video Broadcast for Handhelds) [19], and MediaFLO among others [16].

Recently, 3GPP [1] introduced support for IP multicasting services in the UMTS architecture, known as MBMS [3]. Using MBMS the download service can be offered to thousands of users asynchronously in a point-to-multipoint manner. In this study, we concentrate on the download mode of MBMS, which is based on FLUTE (File Delivery over Unidirectional Transport) protocol [2]. FLUTE is a protocol used to deliver files, particularly over unidirectional systems from one sender to many receivers. Since FLUTE uses an unreliable transport protocol, an application layer FEC is coupled with FLUTE to recover from packet losses, making for a reliable service. Download delivery of data files over FLUTE has received increased interest due to its scalability in both cellular and broadcast technologies such as MBMS and DVB-H.

There are many protocols that provide reliable multicast at the transport or application layer [14]. One class of these protocols uses negative acknowledgements (NACK-only protocols) to request the retransmission of missing packets. A second class of protocols uses positive acknowledgments (Tree based ACK protocols) to indicate multicast data packets that are successfully received. A third class of protocols uses routers in the network to assist with retransmitting lost packets. The router assisted class adds network-centric requirements while the other classes require bi-directional connectivity between sender and receivers. Asynchronous Layered Coding (ALC) [15] class protocols are important in that senders provide forward error correction with no messages from receivers or the routers of the network.

IETF (The Internet Engineering Task Force) Reliable Multicast Transport working group states that, due to a variety of applications and the orthogonal requirements of these applications, a "one size fits all" protocol is not possible [4]. FLUTE is an IETF protocol based on ALC protocol that makes

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the FLUTE well scalable and hence preferable for unidirectional systems. For file delivery, the FLUTE protocol provides capabilities to signal and map the properties of a file, including FEC coding descriptions, to ALC protocol such that receivers can decode the received files and then assign these parameters to the files. The most popular FEC codes are Raptor codes, as initially introduced by Shokrollahi in [17] and Reed Solomon codes [20]. For the MBMS system, Raptor codes have been selected due to their high performance, relative to others. Consequently, 3GPP has mandated the support of Raptor codes [18] for their terminals that uses the MBMS service. Furthermore, DVB has also decided to support Raptor codes in their terminals for IP Datacast services [19].

During the MBMS FLUTE transport, a file is partitioned into source blocks (SBs), each of which is encoded in FEC layer and then carried as a set of symbols in Multicast IP datagrams over the IP backbone to the destination network. IP datagrams are mapped to SDU (Service Data Unit) blocks and each SDU packet is mapped to RLC blocks across the UMTS core network. Each RLC block is carried as PDU packets to receivers in the Radio Access Network. This partitioning and mapping process requires allocating proper block sizes wherever they are sent throughout the route from sender to a destined multicast area. Furthermore, the sizing considerations in the IP network (IP packet size), core network (SDU and PDU size) and FEC Layers (SB size) all affect the cost of the download reliability and hence there should be a combination of the size choices that lead to a target-optimized result, such as the reliability with minimum FEC overhead.

Another technique to increase efficiency of the MBMS download delivery is the use of application layer interleaving. Interleaving can be used in digital communications systems to enhance the error correcting capabilities of FEC mechanism. Interleaving changes the transmission order of symbols in an attempt to minimize the loss of symbols belonging to the same source block. In practice, packet losses occur as error bursts. One lost packet may cause one or more consecutive packets to be lost. The interleaving mechanism can substantially reduce the negative effects of packet losses that belong to the same FEC block, thus providing an increase in download efficiency. Interleaving transmission strategy is important in that if not properly selected it may cause randomization of source blocks which prevents progressive download.

This work presents FEC performance analyses with and without interleaving in MBMS Reliable Download under various network conditions specific to MBMS. This work considers Reed Solomon and Raptor FEC coding. We have done experimental work to discover Reed Solomon FEC performance while we used an analytical model for Raptor FEC under the same MBMS network conditions. Finally, in order to further increase the FEC performance we have applied our proposed application layer interleaving technique and have provided a performance comparison of the coding techniques.

This paper is organized as follows: Section 2 describes other investigations in this arena that have been done in the past. In Section 3, a general overview of MBMS Download Delivery method provides a background on the technology. Section 4 covers issues related to the proposed MBMS system model that also support the progressive download and our interleaving method for MBMS downloads system. Section 5 provides the comparative results of several experiments for reliable download in MBMS and effects of our proposed interleaving strategy. In section 6, conclusions and future work are given.

## II. RELATED WORK

A variety of FEC codes for reliable MBMS download have been investigated. Under discussion in the 3GPP Technical Specification Group Services and System Aspects (TSG SA) were variants of Reed-Solomon codes, including one-dimensional codes with and without interleaving, and Raptor codes. These sources lack two aspects from the download optimization point of view. First, existing studies assume fixed sizing consideration in one or more layers within the IP or core network and try to explore the reliability in FEC layer. Our recommendation is MBMS download reliability should be explored by considering all sizing effects in all layers. Second, interleaving mechanism above the FEC layer is studied as random transmission of symbols across the file for the MBMS download as in [12]. However, this approach is not suitable for progressive download application, which we believe the future MBMS releases will support. Our recommendation is to use an interleaving strategy that allows senders to send symbols in a changing order and enables receivers to do progressive download with some initial startup delay.

The superiority of Raptor codes is well known, hence 3GPP selected Raptor in the MBMS specification. The use of application layer Raptor FEC has already been investigated in [21] [22]. In MBMS, FEC mechanisms have been studied on two layers, namely physical layer and application layer, in a complementary way. The tradeoff in applying one or the other or suitable combinations of the two is addressed in [22] and [23].

Interleaving in MBMS is also studied on these two layers. On the physical layer, Turbo coding with interleavers is used as a standard in 3GPP. Turbo codes emerged in 1993 [24] and have since increased its popularity in communications research. In [25] some of those works are referred and the behavior of Turbo codes for various interleaver size and structure is analyzed. Physical layer Turbo coding with interleaving in UMTS is studied in [26] [27]. In [23], tradeoffs between the assignment of physical layer resources for UMTS Turbo code and application layer resources are investigated for the MBMS download delivery service. Application Layer Interleaving for the MBMS download delivery service is experimentally studied in [12] with random interleavers. However, as stated earlier, a random interleaver is not suitable to progressive download; hence there is a need for a different interleaving strategy for a flexible MBMS download delivery.

Regarding reliability, there are many works that use FLUTE protocol with FEC. Analysis of the FLUTE performance is studied in [10] with RS FEC and data carousel reliability in which files are transported in loops and missing portions are completed in the next loop. The aim of this work is to experiment with the number of loops needed to receive the whole file for different packet loss scenarios. Although data carousel method with FEC protection could be an option for reliable download, relying on it is not suitable for newly proposed services, such as MBMS progressive download [5]. Since streaming is very resource expensive, 3GPP has been discussing new alternatives [5] [7] to the streaming that use MBMS download mode. With progressive download [6] the media can start playing right after some initial startup delay, even before the download is complete. After such a delay the user expects a smooth and successful play with no intermittent stops. However, with data carousel, once a portion is missed, the receiver has to wait for the loop that serves the missed portion. We believe that eventually progressive download support will be put into MBMS specifications. 3GPP TSG SA has investigated the MBMS download delivery method for different network conditions with RS and Raptor FEC protection. The results are summarized in [28].

Another technique that provides reliability is to use MBMS repair procedure, one of the associated delivery procedures as defined in MBMS [3], in which missing portions can be requested over ptp (point to point) or ptm (point to multipoint) connections. Again, this is not suitable for some services such as progressive download, since this procedure starts after the session ends or transmission of the object is finished.

In [12], MBMS FLUTE protocol analysis is given to show how much FEC overhead is required for reliable download under various link conditions. It expresses the reliable download probability as a function of FEC overheads for a set of cases using Raptor FEC and RS FEC in 64 kbps packet lossy UMTS network conditions. However, a single symbol length, a single IP packet size, and fixed SDU and PDU sizes are assumed and SB size information is not studied in [12].

In this work, we analyze and compare two MBMS systems with our interleaving strategy, here called Interleaved Download Delivery, and without interleaving, here called Legacy Download Delivery, under RS and Raptor FEC protection. The systems are under the conditions that are considered for MBMS.

## III. THE PROPOSED DOWNLOAD DELIVERY

This section provides the two MBMS systems: Legacy and Interleaved Download Delivery with our interleaving strategy.

The download delivery in MBMS consists of three phases Service announcement and discovery, the download delivery on MBMS download bearers, and associated delivery procedures such as file repair process. In this paper, we will focus only on the multicast download delivery of files, as the process is referred to in FLUTE [2] and ALC [15] terminology. Figure 3 and Figure 4 show sender-side downloading flow with and without interleaving that are studied in this paper. The proposed system does not require changes in MBMS receivers. In order to support progressive downloading, we assumed that repair symbols are sent just after source symbols. In Figure 3, an object is partitioned into *Z* source blocks (SB). These source blocks are further divided into *K* source symbols of equal size. Each $SB_i$ is delivered to FEC layer for encoding. The result is *N* repair symbols placed in $EB_i$ (Encoding Block) just after original source symbols. So $EB_i$ includes $K + N$ encoding symbols (ES). Each encoding symbol is uniquely identified by the couple of its Source Block Number (SBN) and Encoding Symbol ID (ESI). A group of *G* consecutive encoding symbols (ESG) starting from encoding symbol ID = j for $SB_i$ is denoted as $ESG_{i,j}$ and identified by the couple (SBN,ESI) of the first encoding symbol, here (i , j). The ESGs are packed into FLUTE payload just after the place reserved for FLUTE Payload ID that is assigned to ESG ID, here (i, j) and transported until there are no more encoding symbols to send.

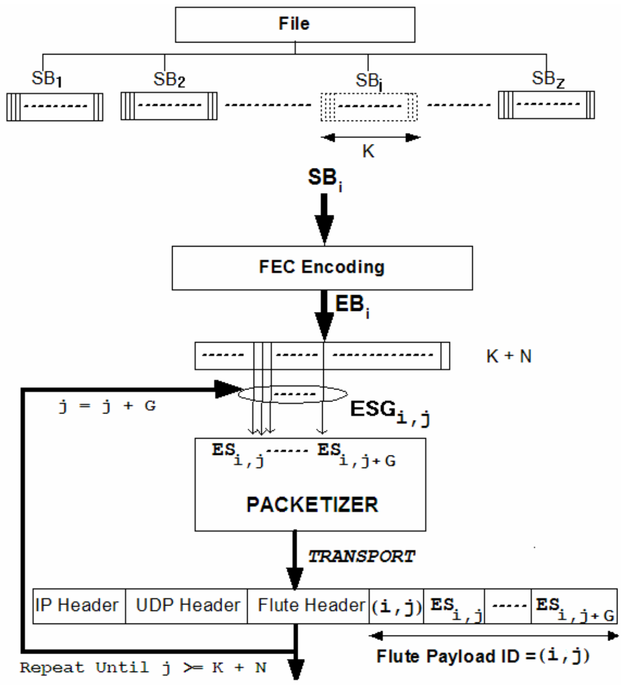


Figure 3. Download Delivery Flow without Interleaving

In Figure 4, we provided the sender-side flow of the download delivery with the SB Interleaving of block-size *b* that we considered in this paper. That is, *b* consecutive SBs constitute an interleaver-block and are sent in parallel in the order of ESIs. All encoding symbols in the interleaver-block with ESI=1 will be sent first, then all encoding symbols with ESI=2 are sent next, and so on. One more requirement of our interleaving strategy is that each FLUTE packet must include one encoding symbol at a time. So ESGs are not applicable. However, this process requires all the *b* EBs to be in memory before they are sent. So the parameter *b* and *SB* size can be used to adapt to different service conditions. Minimally the interleaver-block size should be two, otherwise interleaving cannot be applicable.

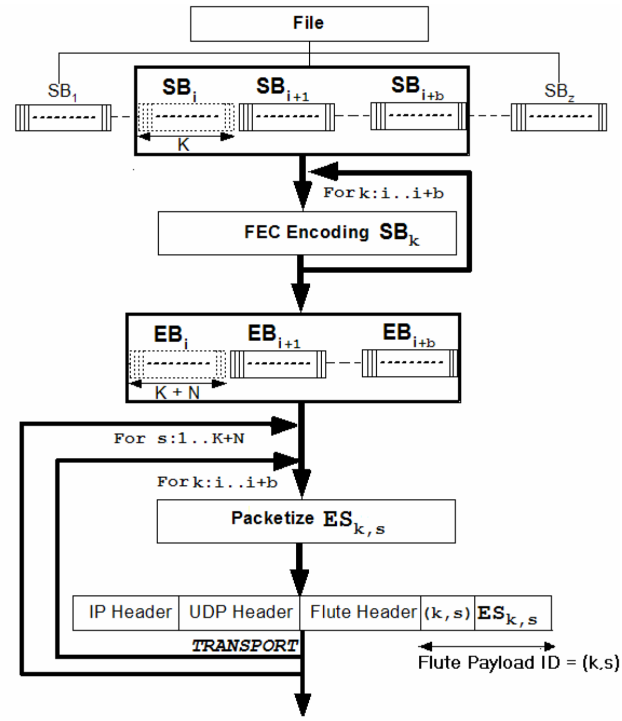


Figure 4. Download Delivery Flow with Source Block Interleaving

Adjusting the interleaver-block to a proper size is important in that a too-small size cannot distribute burst errors to a large window time, which causes the burst errors to be partly converted to randomized packet losses within the small interleaver-block. However, increasing the interleaver-block size consumes much more memory and complicates the cost of the download process. Hopefully in our work we have found a threshold point upon which increasing the interleaver-block size no longer gives benefit. In our work the best results have come with $b=3$ for MBMS link conditions and under our assumptions. This is the because of the packet loss patterns that we considered in MBMS, such that the loss of a single packet may cause a few—possibly 2 or 3—consecutive packets to be lost. Considering a fixed *b*, we have to adjust SB size accordingly so that the interleaver-block should always be filled with *b* SBs at a time. This is easily accomplished if the interleaver-block divides the number of SBs. So with the interleaving strategy that we discussed, partitioning of files into source blocks and determining the source block and symbol length will be affected by an extra parameter *b*. Since we have studied on small-scale file size we could not experimentally discover the overall aspect of the SB interleaving considering large file sizes.

In this work, we analyze and compare the two systems: Legacy Download Delivery and the proposed Interleaved Download Delivery under MBMS network conditions, and attempt to find optimum service parameters considering QoS by analyzing all the parameters jointly, such as SB size, Encoding Symbol Length, Interleaver-block size, SDU and PDU sizes across core network, and RAN.

## IV. SIMULATION ENVIRONMENT

To show the benefits of progressive download we have performed several experiments. We used the Vidiator MBMS design based on [3], [8] and [29]. The system architecture is summarized in Figure 5. We focused only on the download module. To emulate MBMS link conditions we implemented a transmission rate and packet loss control module. The MBMS link conditions are aligned with [9], [11] and [13]. Files are sent in a single loop. UTRAN bearers 64, 128, and 256 kbps are assumed.

Each simulation used the combinations of all above parameters and was repeated at least 100 times for different PDU loss patterns and different SB size, different symbol length, and different transmission rates for files 100K (small) and 512K (medium). A client was assumed to process SBs in any size for decoding in a timely manner. We assumed that there was a mapping of one IP packet to one SDU block and that each IP packet contained only one symbol of varying length.

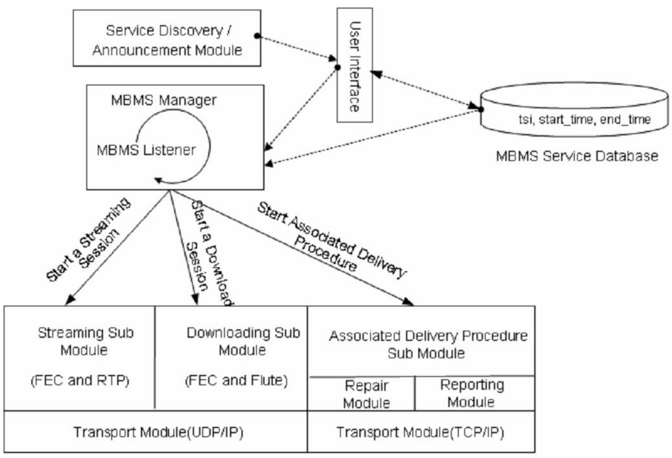


Figure 5. Vidiator MBMS prototype software modules

The symbol length for FEC is calculated as follows:

Symbol Length = S – 48, where S is the SDU size and IP\UPD\FLUTE header (44) + FEC payload ID (4) = 48 Bytes.

PDU (RLC) block sizes of 1280 B and 640 B are considered for two UTRAN bearers, 128-256 kbps and 64 kbps transmission rates respectively. The list of parameters analyzed in this study across layers is summarized in Table 1.

An algorithm to map PDU losses to SDU losses is provided in [11]. Error bursts in UMTS were generated by using the algorithm such that a single SDU loss may cause one or more PDU packet losses. We considered 1% (low), 5% (medium) and 10% PDU losses (high). Loss due to mobility such as cell handovers is not considered.

TABLE 1. PARAMETERS STUDIED ACROSS LAYERS

| Parameter | Unit | Layer | Experiment Set |
|---|---|---|---|
| File Size | Kilobyte | Application | {100,512} |
| Optimum FEC Overhead with Reliability | Percent | Application Layer | To be determined in this study |
| Gain using Interleaving | Percent | Application Layer | To be determined in this study |
| Interleaver-Block Size | Source Block | FEC | {2,3,4} |
| Symbol Length | Byte | FEC | {SDU – 48} |
| SB Size | Symbol | FEC | {10,50,80,100,120,150,180,200,230} |
| IP packet size | Byte | IP | SDU |
| SDU block size | Byte | Core Network | {400,600,800,1000,1400} |
| PDU block size (RLC block size) | Byte | RLC Radio Link layer | {640,1280} |
| PDU (RLC Link Layer) Losses | Percent | RLC Radio Link layer | {1,5,10} |

We tried to find the optimum interleaver-block size and hence made experiments for the interleaver-block size of 2, 3 and 4 source blocks. As a result we have caught best results with an interleaver-block size = 3 under both MBMS link conditions and our assumptions.

While FEC overheads and gain from interleaving for Reed Solomon are experimentally explored in this study, Raptor FEC overheads are taken from the work [12] and [19]. Since interleaving mostly deals with packet loss patterns, under the same network conditions with the same interleaving technique, we can get approximated interleaving gain for Raptor FEC protected download delivery system. So for interleaving, we derive the interleaved FEC overheads for Raptor as follows:

$$C_{InterRaptor} = C_{Raptor} * \left(1 - \frac{G_{InterRS}}{100}\right) \qquad (1)$$

Where $G_{interRS}$ indicates the gain in transmission cost with interleaving using Reed Solomon, $C_{interRaptor}$ is the Raptor FEC overhead after interleaving is applied.

## V. EXPERIMENTAL RESULTS

We combined simulation results with our approximations to compare the gain we obtained from interleaving as opposed to legacy download, both for Reed Solomon FEC and Raptor FEC in Table 2 and Table 3.

First we observe the FEC overheads for 100% reliability for various Reed Solomon SB sizes for the MBMS system without interleaving. Figure 6 and Figure 7 show our observations for transmission rates of 256 kbps, 128 kbps, and 64 kbps under 1%, 5% and 10% packet loss ratios. The SDU size is selected to be the optimum for these conditions as well as the SB to provide 100% reliability. We observed that as the SB size increases—up to approximately SB size=80 symbols—FEC overheads dramatically decreases; thereafter the decrease slows. Additionally, the small size file transport shows less deterministic behavior in terms of transmission cost required for 100% reliability. These fluctuations can be seen in Figure 6.

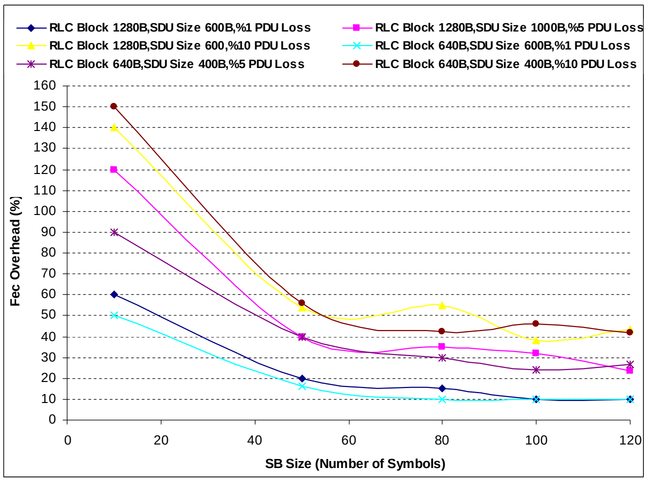


Figure 6. FEC Overhead for 100 KB file

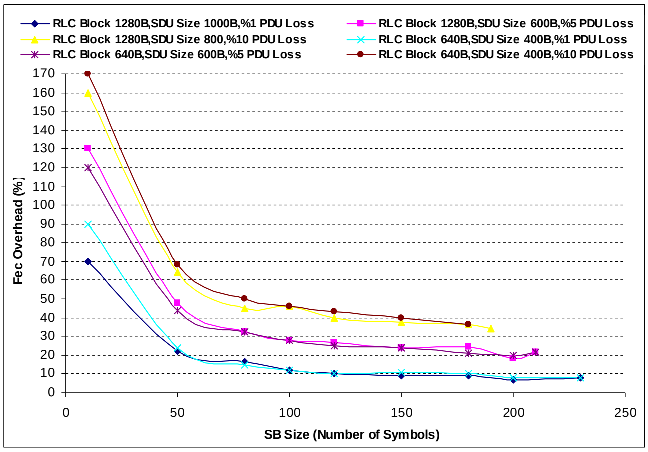


Figure 7. FEC Overhead for 512 KB file

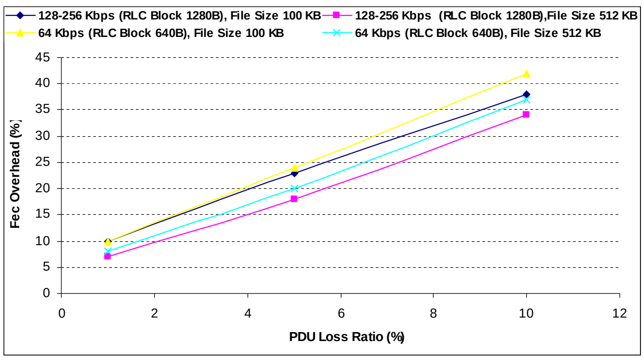


Figure 8. FEC overhead for various PDU loss ratios

Figure 8 shows the amount of FEC overhead needed as the PDU loss ratio increases. As packet loss ratio increases it is clear that transmission cost should be proportionally increased. These facts are observed in Figure 8. In the same network described by RLC block, the transport of 100 KB and 512 KB files shows almost identical behavior as the amount of losses increases.

TABLE 2. THE INTERLEAVING GAIN for MBMS at 128-256 Kbps

| File Size (KB) | PDU Loss (%) | RS FEC Overhead in Legacy Dow. Delivery (%) | Raptor FEC Overhead in Legacy Dow. Delivery (%) | RS FEC Overhead in Interleaved Dow. Delivery (%) | Raptor FEC Overhead in Interleaved Dow. Delivery (%) | Interleaving Gain (%) |
|---|---|---|---|---|---|---|
| 100 | 1 | 10 | 8 | 8 | 7 | 20 |
| 100 | 5 | 23 | 21 | 22 | 20 | 4 |
| 100 | 10 | 38 | 35 | 32 | 30 | 16 |
| 512 | 1 | 7 | 4 | 5 | 3 | 29 |
| 512 | 5 | 18 | 12 | 15 | 10 | 17 |
| 512 | 10 | 34 | 22 | 30 | 20 | 12 |

TABLE 3. THE INTERLEAVING GAIN for MBMS at 64 Kbps

| File Size(KB) | PDU Loss (%) | RS FEC Overhead in Legacy Dow. Delivery (%) | Raptor FEC Overhead in Legacy Dow. Delivery (%) | RS FEC Overhead in Interleaved Dow. Delivery (%) | Raptor FEC Overhead in Interleaved Dow. Delivery (%) | Interleaving Gain (%) |
|---|---|---|---|---|---|---|
| 100 | 1 | 10 | 8 | 7 | 6 | 30 |
| 100 | 5 | 24 | 22 | 18 | 17 | 25 |
| 100 | 10 | 42 | 39 | 30 | 29 | 29 |
| 512 | 1 | 8 | 4 | 6 | 3 | 25 |
| 512 | 5 | 20 | 14 | 17 | 12 | 15 |
| 512 | 10 | 37 | 26 | 31 | 22 | 16 |

The following is a summary of our general observations:

1. As file sizes increase, the necessary FEC transmission overhead decreases particularly for the network with RLC block = 1280 B. Generally RLC 640 B network requires more FEC overhead compared to the RLC 1280 B network
2. The gain from the interleaving can save FEC overhead up to 30%.

## VI. CONCLUSION

In this study we focused on the gain from using the application layer interleaving mechanism for the MBMS systems that supports progressive download. We analyzed and compared two MBMS download systems: a legacy download delivery and an interleaved download delivery. We analyzed parameters such as SB size, encoding symbol length, interleaver-block size, SDU and PDU sizes across core network, and RAN in order to find good service parameters.

The interleaved download delivery has provided savings in FEC transmission cost up to 30% compared to the legacy download delivery. We believe that our results will encourage more work on application layer interleaving. The results of this study will provide guidelines to designers to fine tune MBMS download service parameters for reliability and encourage new works on progressive download in MBMS.

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