Cross-layer Coordination for Efficient Contents Delivery in LTE eMBMS Traffic

Eilwoo Baik, Amit Pande and Prasant Mohapatra
Department of Computer Science
Univerisity of California, Davis
Email: {ebaik, pande, pmohapatra}@ucdavis.edu

***Abstract*—Evolved Multimedia Broadcast Multicast Services (eMBMS) in LTE standards provides Raptor code as Forward Error Correction (FEC) scheme in application layer. Hybrid automatic repeat request (HARQ) is also used to increase reliability at MAC layer for packet recovery. The two mechanisms, with no interactions between them, may either lead to more redundancy in download link (DL) network resource or meaningless drops of recovery data at application layer. In this paper, we first analyze tradeoff between two recovery mechanisms and then present a probabilistic model to find optimal Raptor encoding rate and number of HARQ retransmissions for a given network condition. This can achieve a saving of upto 13-15% in DL network resources compared to existing schemes while ensuring reliable file delivery. It was also found to reduce the transmission delay (by minimizing the number of re-transmissions). The model was evaluated using LTE-A simulation framework.**

Index terms: LTE, Raptor FEC, HARQ, eMBMS.

I. INTRODUCTION

Evolved Multimedia Broadcast and Multicast Service (eMBMS) in LTE enables a base station (eNB) to multicast or broadcast various personal and contents like TV contents and movies through P-t-M(point to multi-point) connection. The MBMS was first defined in 3GPP Release 6, and LTE-A expands it to evolved MBMS that can service the contents in the single-frequency network (SFN) with synchronized waveform from many cells simultaneously during designated service time. Contents providers are able to decrease the overhead of network and use the existing frequency efficiently by using eMBMS. [1], [2], [3], [4].

eMBMS is offered over unidirectional protocols (built over UDP) in order to enable P-t-M(point-to-multipoint) communication. To guarantee the user QoS requirements for content download service and real time streaming services, it requires some reliability mechanism in higher layers to overcome absence of feedback between content server and receivers.

The protocol in application layer of eMBMS in LTE is File Delivery over Unidirectional Transport (FLUTE) for mass media download [5], and is based on Asynchronous Layered Coding (ALC) [6]. ALC is an underlying protocol used to support massively scalable multimedia contents. It is composed of LCT (Layered Coding Transport) building blocks [7] (to offer session management); congestion control building block and FEC building block (for reliable transport). From the FEC building block, sender and receiver select the most appropriate level of error correction to be applied in the channel.

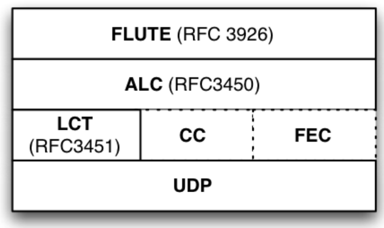


Fig. 1. Protocol stack of application layer for LTE eMBMS traffic

The protocol stack for FLUTE/ALC/LCT over UDP is shown in Figure 1. Since there is no feedback between a sender and receivers, the sender uses FEC scheme to compensate for packet losses. To meet QoS (Quality of Service), guarantee reliability and reduce radio resource utilization at the same time, IETF (Internet Engineering Task Force) has defined Raptor codes [8] as Application-Layer FEC scheme.

Raptor code is used to support reliable mass file delivery services by adding parity packets for packet losses.Moreover, the enhanced Node B(eNB) also introduces a scheme, Hybrid Automatic Repeat Query (HARQ), for reliability in MAC layer. In bad channel conditions, the HARQ protocol tries to cover up the packet error and losses with repeated transmission and combination of subsequent repeated version of the partial packet information [9].

The two protocols, Raptor code FEC and HARQ in different layers and different entities have no cooperation and interaction between them. The encoder of Raptor code will generate redundant packets for repair in application layer, and HARQ of MAC retransmits lost packets to support reliable transmission. If lower layer mechanism for reliability recover packet losses, it means that the repair packets of application layers are useless. Raptor code is called as almost "Ideal Erasure Code" because the original content can be reconstructed with very slightly greater than number of original source packets regardless of any type of packet. Unlike previous file download services, the size of file to be downloaded is expected to be of order of 100 MBs.

Even very small amount of redundancy can bring wastage of significant amount on network resources of download link(DL) in eNB and receiver side. The deployment of two protocols

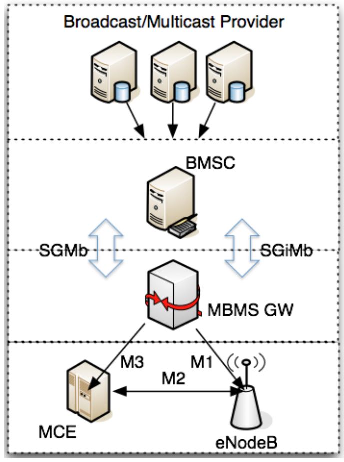


Fig. 2. Architecture of eMBMS Service

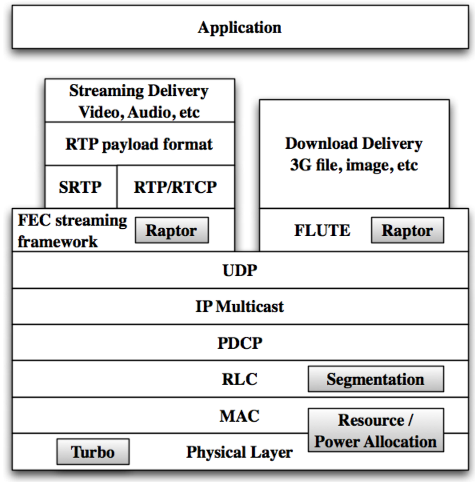


Fig. 3. Protocol Stack of eMBMS User Services [10]

without any cross-cooperation may reduce the network performance.

In this paper, we first analyze the coexistence of Raptor FEC and HARQ, in different entities of LTE network. From this approach, we design the probabilistic model to find the best trade off so that it can show better performance in saving DL network resources. For given network conditions, we find the appropriate value of Raptor and HARQ parameters for the instantaneous network channel conditions. This value of encoding parameters is then used to adaptively tune the redundancy in DL traffic with dynamic network condition. Next, we confirm and evaluate the results obtained by using simulation setup to find best matches in the given network conditions.

The advantages of the proposing transmission scheme are manifold:

1) *The signaling procedure is simple.* Different from the traditional cross-layer mechanisms with high control overhead and complicated signaling, our scheme requires only CQI feedback in each source block transmission. This is used to determine network loss rate.
2) *DL network resources are saved* by reducing the number of retransmission of HARQ in MAC layer and redundancy of Raptor code in application layer.
3) *User's QoS requirement are satisfied.* The probabilistic model chooses coding parameters which ensure reliable delivery over current channel conditions
4) The proposed coordination is *easy for commercial deployment* because changes need to be made in eNB (transmitter) and not UE (User Equipment) side. It is difficult for cellular companies to make changes to each UE (millions in number, privacy issues) than to modify software at eNB (less in number, self-owned). The implementation of protocol stack is not changed by proposed scheme, only the system parameters are changed.

The paper is organized as follows: Section II gives an overview of background and Section III gives related works. Section IV describes the probabilistic model. Experimental results are compared and validated with the proposed model in Section V. Section VI gives conclusions with directions for future work.

II. Background

A. eMBMS in LTE Network

In eMBMS service architecture, there is a packet core domain and it is compatible with EPC, EPC, 2G/GSM/3G UMTS Packet Core components(GGSN and SGSN). The EPS (Evolved Packet Service) network has other logical network components, MCE and MBMS Gateway [11], [10]. The new logical entity, Multi-cell/multicast Coordination Entity(MCE) is in charge of time allocation and frequency resources for multiple cell MBMS transmission service based on scheduling of radio resource. The MCE is logically integrated as part of of the eNB (in which case, the M2 interface becomes an internal eNB interface) as shown in Figure 2 [11]. The MBMS GW(MBMS Gateway) is the controlling point for distributing the packets to all eNBs for services area, MBMS session management such as session start and session stop. It also take charge of collecting charging information relative to the MBMS traffic for each terminal in an active MBMS session.

The entity, Broadcast Multicast Service Centre (BMSC), is already existing in 2G/3G MBMS service architecture. BMSC is responsible for providing service contents to UEs, authorization to UEs requesting activation of MBMS service and their contents, scheduling broadcast and multicast sessions, integrity/confidentiality protection of MBMS service contents, and MBMS session announcement/service management. As shown in Figure 2 [11], SGMb interface supports configuration and session establishment/termination of MBMS session, and SGiMb is for MBMS plan. The multicast management for session authorization, user session joining or leaving is also supported by the SGmb interface.

The Interface M1 is for delivering packets to eNB using IP multicast protocol, interface M2 is for radio configuration between eNB and MCE, and interface M3 is for control and session managements such as session start and session termination. There are two types of delivery in MBMS, which are download and streaming delivery. Each delivery service in MBMS is carried over the MBMS protocol stack in Figure 3 [10].

B. Overview of Raptor FEC Code

Raptor FEC is a fountain code and the latest version is Raptor Q. As a systematic code, source symbols are part of the encoding. Raptor is used in an application specific manner. For content delivery, it can encode the entire file as a block or split file as set of sub-blocks if the receiver memory is limited. For streaming service, blocks of the stream are encoded. It is also used at the MAC layer to protect all data. To give an analogy, raptor encoder produces an endless supply of water drops, which is called as fountain. Let us assume that the original source file has a size of K*L bits and each packet contains L encoded bits. The receivers within the service area collect as many packets as they need to reconstruct original content file. If the receivers receives more than K packets, it ignores other coming packets and starts reconstructing the received packets into the original packets [12].

A brief concept of Raptor code is presented in Figure 4 [13]. C indicates n codes of block with k-dimention, and (x) means a degree distribution. LT-code of distribution, (x) is process on n symbols in C(codewords) in the Figure 4. The LT codes are Fountain codes, which is close to optimal erasure codes and called as "Ideal Erasure Code" [14]. A content file is split into n symbols for source symbols of a Raptor code. The output symbols are created with the n input symbols from process of LT-code [13]. Therefore, the Raptor FEC decoder is able to decode the original data from an amount of received encoded data which is slightly bigger than the original source data, regardless of whether the received data is original source data or repair data. When Raptor codes are applied on contents, the original contents are spilt into k source blocks. And then, each source block is divided into i symbols. According to the encoding rate for redundancy, each source block is encoded independently from the next block [10], [15].

C. HARQ Action

In order to support reliability in the link layer, ARQ retransmit to recovery lost or corrupted data. It is a control scheme for data-link layer where a receiver requests the sender to resend data which has error or has been corrupted while delivery in the air. The receiver can detect presence of error in the received

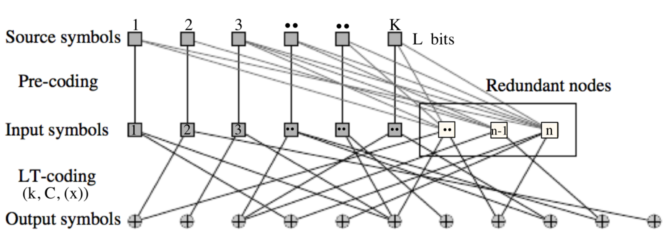


Fig. 4. Input symbols are created through Pre-coding with Source symbols, which create input symbols including redundant symbols. An appropriate LT-code make output symbols to be delivered to the receivers [13]

data by using CRC (Cyclic Redundancy check) code that is attached to each and every information block. After verifying CRC, the receiver will sends either a acknowledgement (ACK) or a negative acknowledgement (NACK) for the reception of the data block. General type of ARQ scheme is stop-and-wait (SAW). The other schemes are go-back-N and selective retransmission. The SAW scheme is the simplest way to implement but it is not efficient in the channel environment of high propagation delay. The ARQ replace the lost or corrupted packet with newly received one, while HARQ stores the received packet in the buffer and it replaces erroneous parts with new one or combines retransmitted packet, which is referred to as soft-combination. There are two ways for combining: CC (chase combining) and IR (incremental redundancy) [16]. In CC, the same information in the packet is retransmitted, while IR contains different information at every retransmission times so that with additional information, it can obtain the original packet rather merely requesting another packet for the error or loss [17].

III. Related Works

Efforts of HARQ for reliability in link layer means meaningless redundancy of Raptor code. If HARQ perfectly recover packet error or losses, it leads to waste of DL network resources due to repair packets of Raptor code. [18], [19] consider Raptor code based HARQ in unicast scenario where the sender decides the suitable Raptor redundancy at each HARQ transmission according to past Channel Quality Index values. In [20], unicast scheme can be applied into multicast/broadcast scenario with consideration on channel state information of UEs, which decreases the number of encoded packets to delivery so that the receivers reconstruct an original content.

Unlike above schemes, in case of LTE eMBMS protocol stack Raptor codes are used in application layer, exist in eBMSC while HARQ retransmissions exist in physical layer and deployed in transmission nodes (evolved Node B or eNB). These nodes (eBMSC and eNB) are connected via high speed Evolved Packet Core (LTE-EPC) and can possibly coordinate with each other.

Wang et al. [21], [22] propose a novel scheme to handle this redundancy : (1) Reduce overhead of Raptor code; (2) Decrease the number of retransmissions in HARQ. The authors propose a the conditional HARQ feedback policy to manage HARQ retransmission, called as threshold based feedback(TBF). The suggested scheme is that a UE does not always delivery back to NACK. Only when the RPER (residual packet error rate) is larger than a specified threshold, t, the user sends NACK to eNB. Secondly the optimal threshold t is derived according to the QoS requirements, the number of Raptor repair packets and physical channel condition. TBF has following advantages: (1) The signaling is very simple as only one parameter needs to be transmitted once in the source block transmission. (2) Multicast/Broadcast performance on throughput can be improved by decreasing the number of retransmission in HARQ and (3) user's QoS requirement is satisfied. On the other hand, this scheme is difficult to

TABLE I
DEFINITION OF TERMS FOR MODELING

Definition	*Term*
Packet loss rate	p_{PLR}
Residual packet loss rate (after HARQ)	$\widehat{p}$
Number of source packet	N_t
Number of original source packet	N_0
Encoding rate of raptor code	E_r
Overhead of HARQ	Ov_{HARQ}
Overhead of RAPTOR	Ov_{Raptor}

deploy in an existing commercial setup because it alters parameters at User Equipment (UE) side which are millions in number and may have personal issues. Moreover, the cross layer coordination proposed in this approach adjusts HARQ threshold based on Raptor code and CQI values instead of considering all these values together.

In this work, we use a joint model - considering both HARQ and Raptor parameters to build a more efficient solution to address this problem. We mathematically derive the optimal number of HARQ and encoding rate of Raptor code at a given channel condition, instead of a heuristic based approach - leading to significant improvements in performance, as described in latter sections.

IV. PROBABILISTIC MODEL

We use the terminology in LTE-A eMBMS group (LTE-Advanced enhanced Multicast Broadcast Multimedia Services) to derive the model. However, this works for a generic case also. A user equipment (such as cell phone or Tablet) is abbreviated as UE while the transmitting station is called as eNB (or evolved Node B).

Let p_{PLR} be the packet loss rate. This value gives the probability that a certain packet transmitted in the air from eNB will be lost before reaching UE. For each packet delivery, the probability for a reachable case is (1-p_{PLR}). If the packet doesn't reach the UE, HARQ will send the lost packet again over the same channel. In n^{th} retransmission, the probability for reachable case is again (1-p_{PLR}) and the probability for non-reachable case or failure is p_{PLR}. In this case, the probabilities of success and failure in second retransmission are p_{PLR}(1-p_{PLR}) and p^2_{PLR}. For third retransmission, the probabilities will be p^2_{PLR}(1-p_{PLR}) and P^3_{PLR} respectively.

The traversal of a packet over wireless channel can be viewed as a Bernoulli random variable with success rate $p = 1 - p_{PLR}$. The probability distribution of the number X of Bernoulli trials needed to get one success, supported on the set 1, 2, 3 ... is given by a Geometric distribution.

$$\text{Pr } (X = k) = (1 - p)^{k-1} p \tag{1}$$

$$\text{Pr } (X = k) = p^{k-1}_{PLR} (1 - p_{PLR}) \tag{2}$$

where Pr($X = k$) gives the probability of successful transmission in k_{th} transmission.

On the application layer, Raptor codes are used to provide redundancy in transmission so that the decoder can reconstruct the correct packets even with some transmission losses.

Let the original total number of transmitted source packets be N_t and the number of received packet be N_r. N_o stands for the number of original source symbols and E_r for encoding rate which indicate amount of Raptor FEC repair symbols.

$$N_t = N_o(1 + E_r/100) \tag{3}$$

The probability that a packet reaches destination in upto n HARQ retransmissions is given by:

$$\widehat{p} = \text{Pr } (X = 1) + \text{ Pr } (X = 2) ... + \text{ Pr } (X = n) \tag{4}$$

$$= (1 - p_{PLR}) + p(1 - p_{PLR}) + p^{n-1}(1 - p_{PLR}) \tag{5}$$

$$\Rightarrow \widehat{p} = (1 - p_{PLR}) \sum_{k=1}^{n} p^k_{PLR} = (1 - p^n_{PLR}) \tag{6}$$

The conditional probability that a user correctly decodes packets at the end of period given v Raptor packets are received is computed as:

$$\begin{aligned} \text{Pr(success}/v) &= \binom{\lfloor N_t E_r \rfloor}{v} \left(1 - 2^{-E_r(N_t(1-\widehat{p})+v))}\right) \\ &\times \; u\left(N_t(1-\widehat{p})+v\right) \widehat{p}^{N_t E_r - v}(1-\widehat{p})^v \end{aligned} \tag{7}$$

$$\begin{aligned} \text{Pr(success)} &= \sum_{v=0}^{N_t E_r} \text{Pr(success}/v) \\ &= \sum_{v=0}^{N_t E_r} \binom{\lfloor N_t E_r \rfloor}{v} \left(1 - 2^{-N_0 E_r(1+\widehat{p}(1+E_r))}\right) \\ &\times \; u\left(N_t(1-\widehat{p})+v\right) \widehat{p}^{N_t E_r - v}(1-\widehat{p})^v \end{aligned} \tag{8}$$

where u() is the unit step function. The exponential term vanishes quickly when number of received packets is slightly larger than transmitted packets, the step function becomes 1 [23]. For Raptor codes, the reconstruction is successful when received packets are greater than source packets (N_0). The relationship between received packets and source packets can thus be simplified as follows:

$$N_r = N_t \times \widehat{p} = N_t(1 - p^n_{PLR}); \tag{9}$$

From equations 3 and 9, we obtain the following result:

$$N_r = N_o(1 - p^n_{PLR})(1 + E_r/100); \tag{10}$$

The inequality $N_r \geq N_o$ must hold true for proper reconstruction of received packets.

Overhead in packet delivery due to retransmission of HARQ is calculated as the sum of probability of losses in first n transmissions:

$$Ov_{HARQ} = p_{PLR} + p^2_{PLR} + ... + p^n_{PLR} \tag{11}$$

$$Ov_{HARQ} = p_{PLR} \sum_{k=1}^{n} p^{k-1}_{PLR} \tag{12}$$

$$Ov_{HARQ} = \frac{p_{PLR}(1 - p^n_{PLR})}{1 - p_{PLR}} \tag{13}$$

The overhead (in network transmissions) due to Raptor is calculated as the difference between the redundancy added

TABLE II
PARAMETERS IN SIMULATION(1)

Parameters	*Value*
Mass File Size	100 MB
Source Symbol Size	1024B
Repair Symbol Size	1024B
Max Encoding Rate	1/2 (50%)
No. of Symbols per FLUTE Packet	1
Number of Nodes	1
Max HARQ Rx. Time	4
Max MPDU Drop Probability	1.0
Rx. Improvement Factor	1.0
LTE 20MHz FDD	1.0
Base Frequency	1920MHz
Bandwidth	20MHz

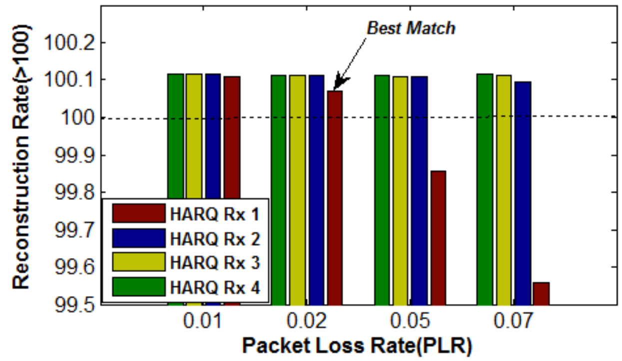


Fig. 6. Simulation of Encoding Rate 0.1% with HARQ Rx.

by Raptor codes and the net packet loss rate after n HARQ transmissions:

$$Ov_{Raptor} = E_r/100 - p^{n+1} \tag{14}$$

The net overhead due to co-existence of Raptor and HARQ can be summed as follows:

$$Ov = Ov_{Raptor} + Ov_{HARQ} \tag{15}$$

$$Ov = E_r/100 - p_{PLR}^{n+1} + \frac{p_{PLR}(1 - p_{PLR}^{n})}{1 - p_{PLR}} \tag{16}$$

$$Ov = \frac{Er}{100} + \frac{1}{100}\left(p_{PLR} - 2p_{PLR}^{n+1} + p_{PLR}^{n+2}\right) \tag{17}$$

The equation 17 needs to be minimized with respect to n and E_r for a given channel loss rate. The Raptor decoder in a receiver side is able to start decoding if it receives the source block from any set of packets which amount is slightly greater than the number of source packets. This property of Raptor FEC is used for finding match of two variables for encoding rate in Raptor FEC and the number of HARQ retransmissions at each packet loss rates.

V. SIMULATION RESULTS

We first defined a probabilistic model to understand the overhead caused by HARQ and Raptor FEC on network throughput. Based on this model, we find the best matching of Raptor encoding rate and HARQ retransmission rates in order to save DL network resources between mobile user and eNB. In this section, we first compare the results of our probabilistic model with simulation results. We use the OPNET network simulator [24] to model the LTE network while we use the Raptor FEC code by using the academic license provided by Qualcomm. [25] to support our research.

TABLE III
PROBABILISTIC MODEL FOR ENCODING RATE 0.1%

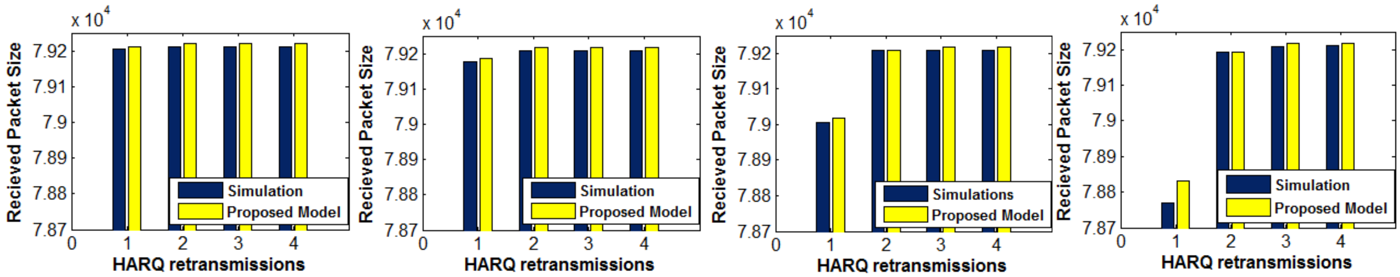
P_{plr}	HARQ Rx.#1	HARQ Rx.#2	HARQ Rx.#3	HARQ Rx.#4
1%	S	S	S	S
2%	$S*$	S	S	S
5%	F	S	S	S
7%	F	S	S	S

Based on this calculation, we compare this equation with simulation result as shown in Figure 5. The parameters used in OPNET LTE model, for eMBMS case are reported in Table II. The amount of original packets is 79220 bytes, destined to a user equipment (UE). There are one content server and $10 \sim 15$ UEs in a single cell. The collected data and simulation results are analyzed in Matlab. The packet in the simulation is injected as uniform distributed, not as bursty pattern. In Figure 5, the simulation shows the same pattern to the probabilistic model. There is a very slightly difference between them in real measured figures. The simulation can have "Border effect" which means very slight margin can happen in at the very closely end of the simulation time. The differences, however, are very small so that it can be ignored and it is even much smaller than the range of the encoding rate to be added. The simulation results validate the probabilistic model. Figure 5 shows each difference between result of the proposed model and simulation in the given conditions. Our model shows the result is dramatically close to the the result of the simulation in the condition.

A. Simulation results at fixed encoding rate

First, in order to evaluate the accuracy of the probabilistic model, the simulation are performed with fixed encoding rate, and the HARQ retransmissions and packet loss rate are changed.

Table III shows result of whether the receiver can be successful for receiving enough packets for successful decoding using probabilistic model. The fixed condition of Raptor FEC encoding rate is 0.1% and the other parameters are same as in Table II. The values of Table III are S (Success) and F (Failure), which means whether a receiver will be successful for receiving enough packets for correct reconstruction of received data. The mark, * means the optimal value in the given condition. The results of the probabilistic model shows that encoding rate 0.1% at 1% packet loss rate can guarantee enough packets for decoding in a receiver, regardless of HARQ retransmissions. 2% of packet loss rate can also be recovered. However, the encoding rate 0.1% was not be able to recover 5% of packet loss rate with only one retransmission of HARQ. Simulation results in Figure 6 shows 0.1% encoding rate can



(a) 0.01% Loss (b) 0.02% Loss (c) 0.05% Loss (d) 0.07% Loss

Fig. 5. Comparing the simulation results with results proposed using probabilistic model.

TABLE IV
PROPOSED MODEL FOR PACKET LOSS RATE 0.1 / 0.3

E_r	p_{PLR} = 0.1				p_{PLR} = 0.3			
	#1	#2	#3	#4	#1	#2	#3	#4
0.5%	F	S	S	S	F	F	S^*	S
1.0%	S^*	S	S	S	F	F	S	S
2.0%	S	S	S	S	F	S	S	S
5.0%	S	S	S	S	F	S	S	S
10%	S	S	S	S	S	S	S	S

recover up to 2% packet loss rate, but it requires more HARQ retransmissions for coping with packet loss rates 5% and 7%.

In Figure 6, the points under 100% of Y axis value indicate that the receiver fails to reconstruct the original file.

B. Performance in worse conditions

In this section, we cover examples of bad network conditions (10% and 30% loss rate). First we simulate each case of packet loss rate of 10% and 30% and then validate the simulation results from results of the proposed model in Table IV.

In figures of 7 and 8, the zero point in Y-axis is the deadline to reconstruct received packets into the original content. All points over 0 in the figures are successful case to reconstruct original symbols. Each point indicate a match of retransmission of HARQ and encoding rate. If match point is below 0, a receiver is not able to reconstruct the original content. As the match point goes far from the 0 point, more DL network resources are wasted. In the case of 10% of packet loss rate, Figure 7 shows that the best combination of HARQ retransmission and encoding rate is HARQ #1 and E_r 1% respectively, marked as dotted circle. This point is the closest point from the reconstruction deadline but not less than zero. Table IV validates the result in the case of 10% packet loss (S is successful transmission while F indicates a failure where receiver fails to reconstruct).

Figure 8 shows the case of packet loss rate of 30%. In order to cover the 30% packet loss, the 3 times of HARQ retransmission and 0.5% encoding rate of Raptor code is the most efficient match for transmission. Lower encoding rate with higher number of retransmission is more efficient than higher encoding rate with lower retransmission. The option of 2% encoding rate with #2 retransmission can be

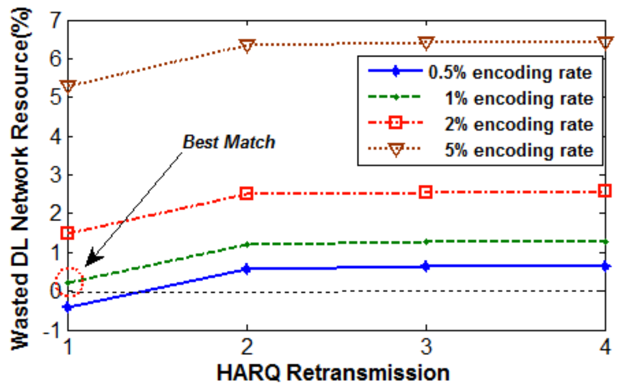


Fig. 7. Wasted DL Network resource at 0.1 loss rate

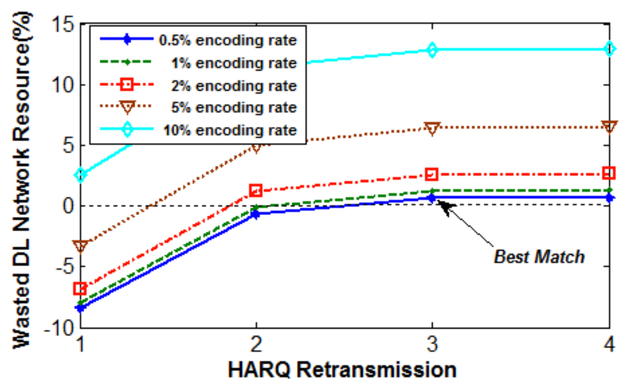


Fig. 8. Wasted DL Network resource at 0.3 loss rate

possible match, but the lower encoding rate 0.5% with #3 retransmission is chosen in order to use the minimum DL network resources to delivery to various and hugh number of users. From the possible matches to cover each packet loss, the proposed model can save unto 13% of DL network resources comparing the worst case.

C. Comparison with existing works

In this section, we compare simulation result of the proposed model with two other schemes. One is the full feedback HARQ and the other is threshold based feedback (TBF) [23]. The main behavior of TBF is that UEs do not report NACK to the sender (eNB), but conditionally feedback when packet

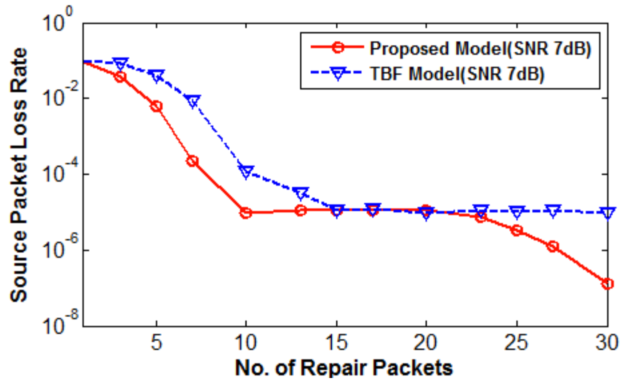


Fig. 9. Plot of source packet loss rate with number of repair packets at 7 dB

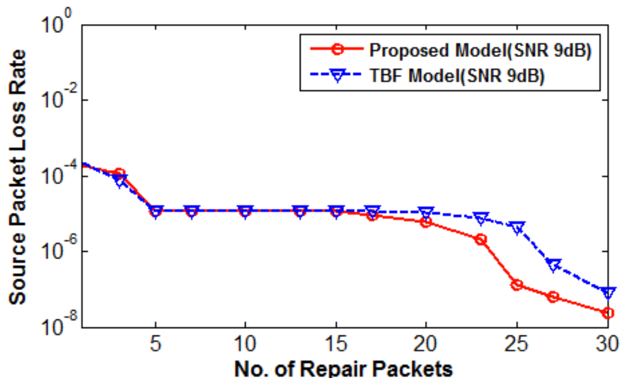


Fig. 10. Plot of source packet loss rate with number of repair packets at 9 dB

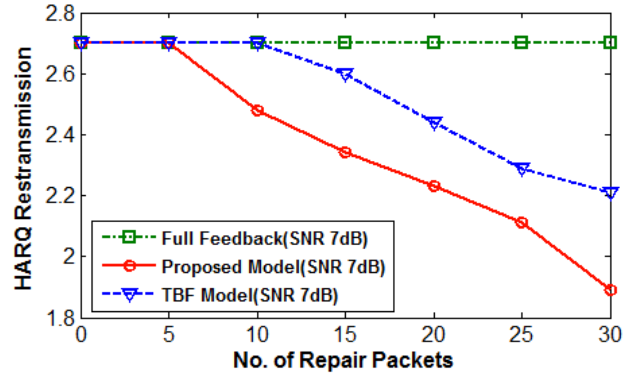


Fig. 11. Plot of average number of retransmissions with number of repair packets at 7 db, 100 source packets

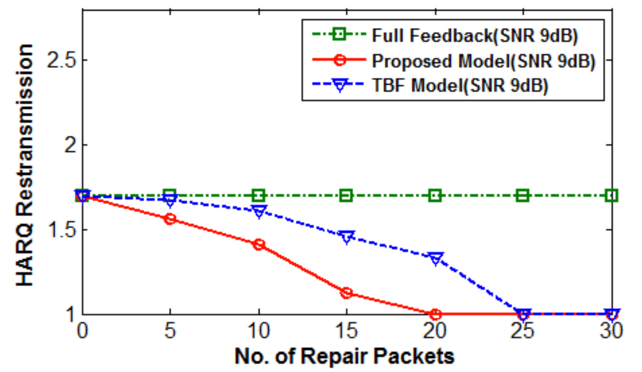


Fig. 12. Plot of average number of retransmissions with number of repair packets at 9 db, 100 source packets

loss and error rate is greater than the threshold point which is already calculated with given information of number of source symbols and repair symbols. For comparison of two models, the network parameters chosen are reported in Table V and the other fundamental conditions are from II.

As we increase the number of repair packets in Figure 9, both models (ours and proposed) show decrease in source packet loss and reach to the QoS target. The proposed scheme already reaches to the QoS target around 10 repair packets while TBF needs around 15 packets. With 30 repair packets, the proposed model can reach less than 10^{-6} of source packet loss rate. Due to the properties of raptor code, our proposed model begin to reconstruct the original source content when UEs receive enough packet to reconstruct. The channel condition (SNR) was set to 7db.

In Figure 10 the channel conditions are improved to 9 db. In this case, both (TBF and proposed model) are able to meet QoS requirements with around only 5 repair packets. Overall, our proposed model outperforms TBF in terms of source packet loss rate as a function of repair packets. After 17 repair packets, the proposed model sharply starts to go down and comes close to under 10^{-7} of source packet loss with 30 repair packets. The higher the channel condition and signal-to-noise ratio(SNR) is, the smaller number of repair packet is required. That is, in good channel condition, the repair packets are unnecessary for UEs to rebuild the original source content. In eMBMS, the channel quality condition for multiple UEs is considered and the lowest CQI is selected.

Figures 11 and 12 plot the number of transmission with the number of repair packets at SNR 7dB and 9dB. In this case, we also compare with full feedback HARQ of eMBMS. the model of full feedback of HARQ has fixed number of retransmissions irrespective of number of Raptor packets used. Regardless of the number of repair packets, there is no variance in the model of full feedback. The full feedback model requires over two retransmission at SNR 7dB and over one and half retransmission at 9dB. If channel condition is better, naturally number of retransmission is decreased but, the the number of repair

TABLE V
PARAMETERS IN SIMULATION(2)

Parameter	*Value*
Content(Source Block) Size	50 KB
Source Symbol Size	512B
Repair Symbol Size	512B
Symbol Size	512B
No. of source symbols to be transmitted	100, 200
Max Encoding Rate	30%
Number of Nodes	10-15
QoS Target	10^{-5}

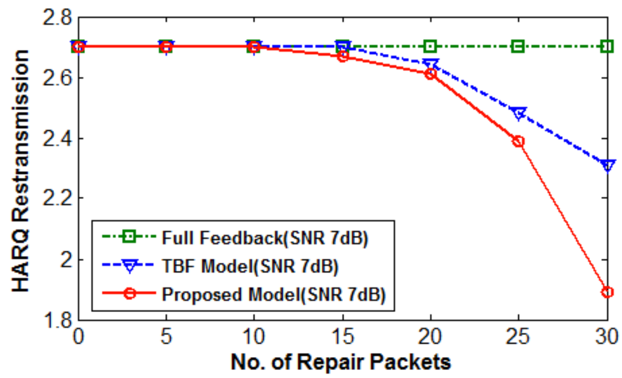


Fig. 13. Plot of average number of retransmissions with number of repair packets at 7 db, 200 source packets

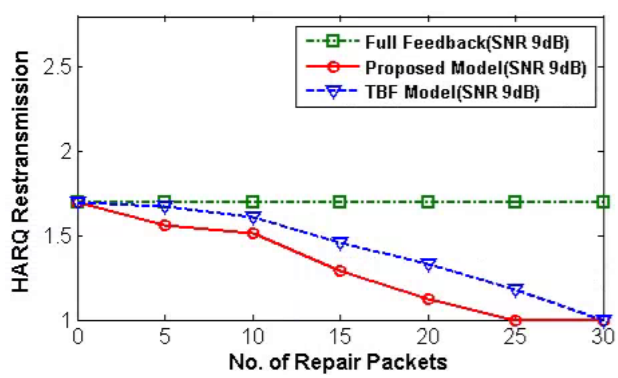


Fig. 14. Plot of average number of retransmissions with number of repair packets at 9 db, 200 source packets

packets does not affect the number of retransmission of the full feedback scheme. The original full feedback scheme wastes a number of repair packets of Raptor FEC. TBF can decrease the number of repair packets with more retransmission but, it still requires more than two retransmission at 7dB with 30% of overhead of original content.

The proposed model can show better performance in different channel conditions. With 30 repair packets, only less than 2 transmission times are required to reconstruct the original source packets. TBF can decrease the number of repair packet but it requires more retransmissions and repair packets than our proposed model because threshold-based scheme require more processes if the threshold is greater than the target of packet error and packet losses. With around 20% repair packets, it needs only one retransmission for reconstruction in our model.

Figure 13 and 14 show the cases of doubled source packets at 7dB and 9dB. The full feedback also show same pattern regardless of the number of repair packet. The main difference between those figures is that the more repair packet are applied, the bigger the differences between those models are. Moreover, with the more repair packets, the proposed model can reduce the number of retransmissions than the other models. At SNR 7dB, our model can decrease the number of retransmission to under 2 with 30 repair packets for reconstruction of 200 source packets. With the 30 repair packets, the proposed model can show under 1 retransmission in good channel condition at SNR 9dB in Figure 14.

In 3GPP LTE and subsequent standards, it takes 8ms before retransmitting a packet. A receiver waits for 4 time slots before transmitting an ACK or a NACK. It also needs 1ms to send ACK or NACK for the response. And then, the sender, eNodeB requires 3ms to process the corresponding response (frame) when it receive reply, including time of scheduling decisions. Thus, total 8ms is required for the entire duration from sending to receiving ACK/NACK by eNB [26]. The total delay is the sum of time required for transmissions and retransmissions. Figure 15 gives a comparative analysis of improvements in transmission delay using our scheme as against TBF and naive scheme. The number of source packets was kept to 10,000 and the time is measured in seconds. It can be observed that our model reduces the delay in all channel conditions, achieving significant improvements for poor channel conditions. The TBF scheme performs closely to ours, however it takes slightly more time. In high rate of loss and error, the delay values of proposed model are similar to TBF but the the required number of packets is less than TBF model and naive HARQ. In order for successful transmission with TBF, it needs more repair packets than our scheme leasing to higher values of encoding rate (E_r).

VI. Conclusion and Future Works

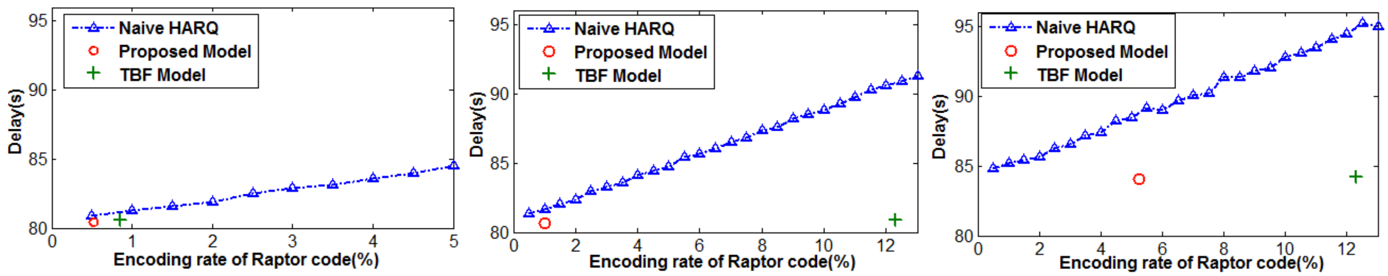
In this paper, we analyze the overhead of DL network resource for mass file delivery service in LTE network due to coexistence of Raptor FEC and HARQ mechanism. We derive a probabilistic model to find the appropriate matches of encoding rate of Raptor FEC and the number of HARQ retransmissions. Based on this approach with the proposed model, we confirm and evaluate the accuracy of the proposed model by simulations. Finally we compare our model with the existing work and original full feedback HARQ with raptor code and it shows better performance. Future work includes incorporation of the cross-layer network parameters and video encoder parameters into the model and implementation on real testbeds. In the case of original HARQ, it process the packet error and loss without consideration of Raptor code so that it shows the linear overhead in proportion to the increment of repair packets.

References

[1] A. Soares, A. Correia, J. Silva, and N. Souto, “Ue counting mechanism for mbms considering ptm macro diversity combining support in umts networks,” in *Spread Spectrum Techniques and Applications, 2006 IEEE Ninth International Symposium on*, aug. 2006, pp. 361 –365.

[2] H. Jenkac, G. Liebl, T. Stockhammer, and W. Xu, “Retransmission strategies for mbms over geran,” in *Wireless Communications and Networking Conference, 2005 IEEE*, vol. 3, march 2005, pp. 1773 – 1779 Vol. 3.

[3] V. Vartiainen and J. Kurjenniemi, “Point-to-multipoint multimedia broadcast multicast service (mbms) performance over hsdpa,” in *Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. IEEE 18th International Symposium on*, sept. 2007, pp. 1 –5.



(a) Packet Loss and Error 0.05%   (b) Packet Loss and Error 1%   (c) Packet Loss and Error 5%

Fig. 15. Improvements in transmission delay using our model as compared to naive scheme and TBF. The input file size was fixed at 10,000 packets. The HARQ parameter (max HARQ retransmissions) for Our approach and TBF was determined by the models and kept at 3 for Naive scheme.

[4] K. Aho, T. Ristaniemi, J. Kurjenniemi, and V. Haikola, "Performance enhancement of multimedia broadcast multicast service (mbms) with receive diversity," in *Networking, 2007. ICN '07. Sixth International Conference on*, april 2007, p. 86.

[5] T. Paila, M. Luby, R. Lehtonen, V. Roca, and R. Walsh, "Flute-file delivery over unidirectional transport," *IETF, RFC3926, Tech. Rep*, 2004.

[6] M. Luby, J. Gemmell, L. Vicisano, L. Rizzo, and J. Crowcroft, "Asynchronous layered coding (alc) protocol instantiation," *Request For Comments*, vol. 3450.

[7] M. Luby, L. Vicisano, J. Gemmell, L. Rizzo, M. Handley, and J. Crowcroft, "Rfc 3451 layered coding transport (lct) building block," *Network Working Group*, 2002.

[8] M. Luby, A. Shokrollahi, M. Watson, and T. Stockhammer, "Raptor forward error correction scheme for object delivery," *Internet Engineering Task Force (IETF), Tech. Rep. RFC*, vol. 5053, 2007.

[9] P. Kosut and J. Polec, "Investigation into optimum go-back-n arq strategy of bruneel and moeneclaey," *Electronics Letters*, vol. 36, no. 4, pp. 381–382, 2002.

[10] *3GPP TS 26.346 V9.3.0, Technical Specification Group Services and System Aspects; Multimedia Broadcast/Multicast Service (MBMS); Protocols and codecs*, Dec. 2010.

[11] *3GPP TS 23.246 V8 2.0, Technical specification group services and system aspects; multimedia broadcast/multicast service (mbms); architecture and functional description*, Jun. 2008.

[12] D. MacKay, *Information theory, inference, and learning algorithms*. Cambridge Univ Pr, 2003.

[13] O. Etesami and A. Shokrollahi, "Raptor codes on binary memoryless symmetric channels," *Information Theory, IEEE Transactions on*, vol. 52, no. 5, pp. 2033–2051, 2006.

[14] M. Luby, "Lt codes," in *Foundations of Computer Science, 2002. Proceedings. The 43rd Annual IEEE Symposium on*, 2002, pp. 271 – 280.

[15] M. Luby, M. Watson, T. Gasiba, T. Stockhammer, and W. Xu, "Raptor codes for reliable download delivery in wireless broadcast systems," in *Consumer Communications and Networking Conference, 2006. CCNC 2006. 3rd IEEE*, vol. 1. IEEE, 2006, pp. 192–197.

[16] D. Chase, "Code combining–a maximum-likelihood decoding approach for combining an arbitrary number of noisy packets," *Communications, IEEE Transactions on*, vol. 33, no. 5, pp. 385–393, 2002.

[17] M. El Bahri, H. Boujernaa, and M. Siala, "Performance comparison of type i, ii and iii hybrid arq schemes over awgn channels," in *Industrial Technology, 2004. IEEE ICIT'04. 2004 IEEE International Conference on*, vol. 3. IEEE, 2005, pp. 1417–1421.

[18] E. Soljanin, N. Varnica, and P. Whiting, "Incremental redundancy hybrid arq with ldpc and raptor codes," *IEEE Trans. Inform. Theory*, 2005.

[19] E. Soijanin, N. Varnica, and P. Whiting, "Punctured vs rateless codes for hybrid arq," in *Information Theory Workshop, 2006. ITW'06 Punta del Este. IEEE*. IEEE, 2006, pp. 155–159.

[20] P. Casari, M. Rossi, and M. Zorzi, "Towards optimal broadcasting policies for harq based on fountain codes in underwater networks," in *Wireless on Demand Network Systems and Services, 2008. WONS 2008. Fifth Annual Conference on*. IEEE, 2008, pp. 11–19.

[21] X. Wang, Y. Wang, and Y. Zhang, "A novel transmission policy for reliable embms download delivery," in *Wireless Communications and Networking Conference (WCNC), 2010 IEEE*. IEEE, pp. 1–6.

[22] X. Wang and Y. Zhang, "Efficient streaming delivery in embms with harq and raptor," 2011.

[23] X. Wang, Y. Wang, and Y. Zhang, "A novel transmission policy for reliable embms download delivery," in *Wireless Communications and Networking Conference (WCNC), 2010 IEEE*. IEEE, 2010, pp. 1–6.

[24] [Online]. Available: http://www.opnet.com/LTE/index.html

[25] [Online]. Available: http://www.qualcomm.com/

[26] *3GPP, "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures TS36213-870(Release 8)"*, ed, 2009.