CRT-based AL-FEC and Its Application on Streaming over the WiMAX Networks for High-Speed Rail Reception

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Abstract—**In recent years, Application-Layer Forward Error Correction (AL-FEC), especially rateless AL-FEC, receives a lot of attention due to its superior performance in both transmission and computation efficiency. Rateless AL-FEC (e.g., Raptor code or LT code) can protect large data block with the overhead somewhat close to ideal codes. In the meantime, its data processing rates of both encoding and decoding are quite efficient even in software implementations (probably reaching Gbps throughput on a modern PC). Due to its properties, rateless AL-FEC is suggested to be used to protect packet erasure for wireless communications or the environments where retransmissions are infeasible. However, we found that conventional rateless AL-FEC may not be the best candidate when considering streaming over WiMAX networks for high speed rail reception in Taiwan. To facilitate streaming service delivery for high-speed rail reception, we proposed a new AL-FEC scheme based on Chinese Remainder Theorem (CRT). The scheme supports greater symbol size than conventional ideal codes and requires less overhead than conventional rateless codes, making the proposed AL-FEC scheme more feasible to harsh bandwidth-limited networks.**

Keywords-AL-FEC; Forward Error Correction; high-speed rail communications; streaming services

I. INTRODUCTION

In recent years, Application Layer Forward Error Correction (AL-FEC) is commonly known as an effective solution for reliable data transmission (e.g., video streaming or file delivery over erasure channels). The data to be encoded by using AL-FEC are partitioned into multiple source blocks, each of which is composed of k source symbols to form an independent encoding domain. After being encoded, the source symbols in a block can be used to generate limited or unlimited numbers of repair symbols such that any $k(1+\varepsilon)$ out of all the source and repair symbols can be used to recover the original source block, where ε is the decoder overhead. Since the source data can be recovered based on extra repair symbols, AL-FEC is especially suitable for the applications where retransmission is inefficient (e.g., multicast or broadcast services) or data transmission is prone to loss (e.g., video streaming over wireless networks). Another advantage of AL-FEC is its superior encoding and decoding performance. Even in software implementations, the AL-FEC schemes based on XOR operations (e.g., Raptor codes) can reach high throughput for both encoding and decoding operations (e.g., in Gbps level) on a commodity personal computer [1].

Currently, AL-FEC is mainly standardized by IETF working groups (e.g., RMT WG or FEC Framework WG) for different use cases and applications. Until now, there are four fully-specified FEC schemes standardized by IETF: Raptor codes [2], Reed Solomon codes over GF(2^m) where m = 2~16 [3], Low-Density Parity-Check (LDPC) Staircase Codes, and LDPC Triangle Codes [4]. To the best of our knowledge, Raptor code seems to be the most attractive AL-FEC scheme because of its relatively low computational complexity when considering large source block or large symbol size.

In our previous works [5], we have evaluated the performance of a mobile TV streaming service over a WiMAX emulation network that can emulate 300 Km/h high-mobility WiMAX reception in order to demonstrate its potential performance over the Taiwan High Speed Rail (THSR). In the emulation environment, when the emulated speed reaches 300 Km/h (i.e., the normal maximum operation speed of THSR), we observe that packet losses are still occurred even when enabling the reliability control mechanisms in both the physical layer and MAC layer of WiMAX networks. Therefore, an AL-FEC scheme (i.e., systematic Raptor codes) is introduced to increase the capability of error resilience of the mobile TV streaming service. The experiment results show that given a reasonable transmission overhead of AL-FEC (about 20% to 25% overhead), error-free video streaming can be achieved for high-speed rail reception.

However, we found that Raptor code is not always advantageous over other AL-FEC schemes (e.g., the category of ideal AL-FEC codes whose decoder overhead ε is equal to 0) especially in bandwidth-limited, harsh wireless environments, such as WiMAX network reception over THSR trains. In such environments, the extra overhead incurred by Raptor codes may significantly reduce the network bandwidth available for service delivery. For the case of ITRI/THSR trial WiMAX network, the measured peak TCP throughput provided by the WiMAX network is about 11.5 Mbps, which is in fact shared by all the WiFi users inside a THSR train since the WiMAX network connection is served as a backhaul to Internet for all the WiFi users. Here we can further estimate the number of such users inside a THSR train. All the trains currently in service for THSR are of the same Japanese Shinkansen 700T model, where each train has 990 available seats. According to the statistic data released by the THSR Company, the average seat occupation rate is 55% in 2010, and 37.4% of the THSR passengers are business travelers. According to a survey done in U. K. [6], about 78% business travelers are willing to use WiFi-based Internet access services over a train. Consequently, we can infer that the 11.5 Mbps available WiMAX network bandwidth will be shared by about 158 potential users in average. Furthermore, three live mobile TV services for offering DVB-T live programs, each of which consuming 1 Mbps bandwidth, are planned to be delivered to each THSR train via the WiMAX network. Since live mobile TV services will further reduce the available WiMAX network bandwidth for end users, ideal AL-FEC schemes, which require less decoder overhead as well as transmission overhead, are preferred to protecting mobile TV streaming service delivery.

In terms of fully-specified AL-FEC schemes standardized by IETF, only Reed-Solomon codes belong to the category of ideal codes, but the codes only support small symbol size (e.g., 2~16 bits) and are considered as computation inefficiency when using larger symbol size. Generally, most known ideal codes also suffer from the same computation issues.

In this paper, we propose a new AL-FEC scheme based on the previous decomposable CRT-based FEC scheme [7]. The proposed scheme is a balance between ideal block codes (e.g., Reed Solomon codes) and rateless codes (e.g., Raptor codes). The proposed scheme supports larger symbol size than conventional ideal codes and requires less decoder overhead than rateless codes. Besides that, the emulation results show that the proposed scheme outperforms than other AL-FEC schemes when applied to mobile TV streaming over WiMAX networks for high speed rail reception.

The rest of this paper is organized as follows. In Section II, we introduce some background knowledge and related works. Then, we present our proposed CRT-based AL-FEC scheme in Section III. The performance issues of the proposed scheme are analyzed in Section IV. In Section V, we show how to apply our AL-FEC scheme to protect streaming service delivery. The emulation results of using the proposed scheme to protect mobile TV streaming for high-speed rail reception are described and analyzed in Section VI. Finally, we conclude our works in Section VII.

II. BACKGROUND AND RELATED WORKS

First of all, the notation throughout the rest of the paper are defined in TABLE I.

A. Decomposable Non-systematic CRT-based FEC Scheme

Since the proposed AL-FEC scheme is based on CRT and our previous CRT-based FEC scheme, we introduce them as follows. First, we show the fundamentals of CRT.

Theorem 1 (Chinese Remainder Theorem). Let m_1, m_2, …, m_k be pairwise relatively prime integers. The congruence system

$$x \equiv a_1 \bmod m_1$$
$$\vdots$$
$$x \equiv a_k \bmod m_k$$

can determine a unique solution x modulo M where $M = m_1m_2\ldots m_k$. The solution is derived by $x = a_1M_1y_1 + a_2M_2y_2 + \cdots + a_kM_ky_k$, where $M_i = M/m_i$ and $1 \equiv M_iy_i \bmod m_i$.

Next, we review our previous non-systematic CRT-based FEC codes [7] extended from Chinese Remaindering codes [8][9][10]. The code we call F-CR code is an ideal FEC scheme. Better yet, the code supports symbol decomposition, which means that an encoding symbol can be further decomposed into smaller sub-symbols. Since the property of decomposition may not be significant to AL-FEC, we do not introduce this property in this paper.

Data Representation The data D in a source block is represented as a positive integer whose value is smaller than kl bits (i.e., the data D consisting of k l-bit source symbols).

Encoding The k source symbols are encoded to t encoding symbols.

1. Choose t l-bit moduli $m_1, m_2, \ldots, m_t$ satisfying $m_1 < m_2 < \cdots < m_t$, where $\gcd(m_i, m_j)$ =1 for $i \neq j$. We ensure that the value of the data D is smaller than the value of K ($K=\prod_{i=1}^{k} m_i$) such that the value of the data D is smaller than the product of any k out of t moduli $m_1, m_2, \ldots, m_t$.
2. Let $y_i = D \bmod m_i, i = 1,2,\ldots,t$ be the t encoding symbols.

Decoding If a receiver receives enough encoding symbols such that the product of the corresponding moduli of these symbols is greater than or equal to the value of K, the value of D can be uniquely determined by CRT; that is, the data in the source block can be recovered.

B. Streaming Service Delivery Based on AL-FEC

As mentioned above, FEC schemes are commonly used for protecting data delivery (e.g., video streaming or file delivery) over erasure channels. Considering the case in DVB-H, multi-layer FEC mechanisms are employed to protect IP-based service data delivery [11]. The physical layer FEC of DVB-H is inherited from DVB-T and based on both Reed Solomon codes and convolution codes. The Link-layer FEC of DVB-H (or called MPE-FEC) is based on interleaved Reed Solomon codes. The application layer FEC of DVB-H is based on rateless FEC codes (i.e., systematic Raptor codes). Besides

TABLE I NOTATION

Natation	Statement
k	The number of source symbols in a source block.
t	The number of encoding symbols where $t = k(1 + \delta)$.
δ	The proportion of total redundancy sent to receivers (i.e., transmission overhead).
ε	The proportion of redundancy required to reconstruct the source block (i.e., decoder overhead).
l	The length of a symbol in bits.

DVB-H, 3GPP MBMS (Multimedia Broadcast / Multicast Service) also employs rateless AL-FEC for its RTP streaming service [12]. In general, the FEC mechanisms in both physical layer and link layer are ideal codes and have heavier computational overhead when protecting a large block of data. Therefore, these codes are usually implemented in hardware and mainly used for protecting small blocks of data in lower layers. On the contrary, rateless AL-FEC is usually much more computationally efficient for protecting larger blocks of data. Its decoder overhead is also quite close to ideal codes (usually about or less than 5% overhead). Due to its efficiency, rateless AL-FEC (e.g., fountain codes, LT codes, or Raptor codes) is usually employed to provide extra protection against data loss in higher layers.

Ahmad *et al*. [13][14] proposed a framework based on rateless codes and receiver feedback to protect video streaming. More specifically, the sender encodes the streaming data by using rateless codes and sends the corresponding encoding symbols to a receiver until the sender receives an acknowledgement from the receiver for confirming the completion of the transmission of a source block. The encoding symbols are sent in separated bursts based on different time intervals and transmission rates.

The studies on DVB-H [11][15][16] use rateless codes to protect the data transmitted in multiple DVB-H bursts. More specifically, the data to be delivered in multiple bursts are treated as the data in a source block and are jointly encoded. Since both the FEC protection period is extended and the required decoder overhead is reduced, such mechanisms can support better error resilience against packet loss. Besides DVB-H, AL-FEC is also studied for being applied to video streaming services over cellular networks [17][18] and WiMAX networks [19].

C. Comparison of Conventional AL-FEC schemes

For an FEC scheme, k source symbols in a source block are encoded into limited or unlimited encoding symbols such that any $k(1+\epsilon)$ of all the encoding symbols can be used to recover the original k source symbols. FEC schemes can be further categorized into erasure correcting codes (e.g., Reed Solomon codes) and rateless codes (e.g., Raptor codes).

Erasure correcting codes are conventional FEC schemes, e.g., Reed Solomon codes [20] and LDPC codes [21]. In comparison with rateless codes, erasure correcting codes have fixed code rates (or information rates) and have better recovery property in terms of the decoder overhead for successful decoding (i.e., $\epsilon = 0$). The main disadvantage of erasure correcting codes is their high computational complexities, rendering them impractical to support a large source block or a large symbol size.

Another category of FEC codes is rateless codes. The codes are called rateless codes because the code rates are not fixed. Given a source block, a theoretically unlimited number of encoding symbols can be generated. In comparison with erasure correcting codes, the codes are much more computationally efficient. For example, in LT codes, each encoding symbol is only the exclusive-or of a subset of the source symbols. Better yet, the decoder overheads of rateless codes are also close to ideal codes (more precisely, ϵ close to 0). Hence, they are more suitable for the case of using a large source block or a large symbol size. Fountain codes [22], LT codes [23] and Raptor codes [24] belong to this category.

RFC 5052 [25] has specified the requirements of an FEC scheme standardized by IETF. Until now, there are four fully-specified FEC schemes: Raptor codes [2], Reed Solomon codes over GF(2^m) where m = 2~16 [3], LDPC Staircase Codes, and LDPC Triangle Codes [4]. Raptor code appears to be the most attractive AL-FEC scheme because of its low computational overhead and its low decoder overhead when considering a large source block or a large symbol size. In addition, RaptorQ codes [26] that improved Raptor codes recently become the next fully-specified FEC scheme after the standardization procedure was done in IETF.

III. Systematic CRT-based AL-FEC Scheme

Our previous work [7] proposed an FEC scheme that does not fit the requirements of AL-FEC because the scheme does not support systematic representation where all source symbols are also the encoding symbols. That is, the first k of t encoding symbols are the same as the k source symbols. Systematic representation is beneficial to service delivery in an erasure channel because a subset of source symbols can still be available even when the decoding procedure has failed. To revise our previous work to fit the requirements of AL-FEC, we proposed a new construction which is still based on CRT but enables systematic representation. The details of the code are as follows:

Data Representation We assume that the data D whose value is smaller than kl bits are partitioned into k l-bit integers $d_1, d_2, \ldots, d_k$.

Encoding The encoding supporting systematic representation requires using the decoding in original non-systematic construction. In the decoding, the inputted encoding symbols are the k source symbols (i.e., $d_1, d_2, \ldots, d_k$).

1. Choose t (l+1)-bit moduli $m_{1,}m_2, \ldots, m_t$ and compute K as the same as non-systematic encoding.
2. Compute $\widehat{D}$ mod K satisfying $d_i \equiv \widehat{D} \bmod m_i$, for i = 1, 2, …, k by using CRT. Likewise, the value of $\widehat{D}$ is smaller than the product of any k out of t moduli $m_{1,}m_2, \ldots, m_t$.
3. Compute the remaining t-k encoding symbols $y_i = \widehat{D} \bmod m_i$, for i=k+1, k+2, …, t. The final encoding symbols are $d_1, d_2, \ldots, d_k, y_{k+1}, \ldots, y_t$.

Decoding The decoder first recovers the value of $\widehat{D}$, and then recovers the source symbols as well as the value of D.

1. If a receiver receives enough encoding symbols such that the product of the corresponding moduli of these symbols is greater than or equal to the value of K, the value of $\widehat{D}$ can be uniquely determined by using CRT.
2. The k source symbols can be derived from the value of $\widehat{D}$ by computing $\widehat{D}$'s first k remainders modulo m_i as $d_i = \widehat{D} \bmod m_i$ for i=1, 2, …, k, and then the value of D can be reconstructed.

As we can see, the newly proposed CRT-based FEC scheme is an AL-FEC scheme because of the support of systematic representation.

IV. Performance Issues on CRT-based AL-FEC

In this section, we evaluate the computation overhead and decoder overhead of the proposed AL-FEC scheme in order to demonstrate that the proposed scheme supports larger symbol size than conventional ideal codes and requires less decoder overhead than conventional rateless codes.

A. Computation Overhead

To measure the performance gain of the proposed AL-FEC scheme, we implement the proposed scheme in C programming language on a workstation with Intel Xeon 2.80GHz CPU and 4GB main memory. Both of the encoder and decoder are built by the GNU MP library of version 4.3.2 on GNU/Linux operating system. We measure the encoding and decoding throughput of the proposed scheme for different symbol size as shown in TABLE II. As we can see, the throughput of encoding is close to the throughput of decoding, and the smaller the symbol size l, the higher the encoding and decoding throughput are. Besides, the decoding throughputs in some configurations are fast enough to support the bandwidth throughput in THSR.

B. Decoder Overhead

Here we discuss the decoder overhead of the proposed AL-FEC scheme for successful decoding (i.e., ε). For the proposed AL-FEC scheme, any k out of t encoding symbols can recover the data D, but the sizes of the encoding symbols can be either l or $l + 1$ bits. More specifically, the sizes of the first k encoding symbols (i.e., source symbols) are l bits, whereas the sizes of the remaining $t - k$ symbols (e.g., repair symbols) are $l + 1$ bit. Therefore, the largest decoder overhead to recover the data D can be estimated as $(t - k)/kl = \delta/l$. As we can see, in most settings, the overhead is as small as the overhead in the ideal code. For example, if δ is 15%, the decoder overhead is at most 0.47% for 32-bit symbol size, and at most 0.23% for 64-bit symbol size.

V. FEC Framework for CRT-Based AL-FEC

The design of the IETF FEC framework [27] is to protect the delivery of a streaming service by using any AL-FEC scheme satisfying the requirements defined in the IETF RFC 5052 [25]. For employing an AL-FEC scheme to protect the delivery of a streaming service, the streaming packets to be delivered are partitioned into several source blocks based on the decision of the streaming server, and each source block is encoded by the AL-FEC scheme independently. In a source block, k source symbols are formed by rearranging the streaming packets, and then the source symbols are encoded by the AL-FEC encoder to generate (t-k) extra repair symbols, so that the total amount of encoding symbols is t. Since the decoding procedure in the streaming client is based on the received encoding symbols, the encoding symbols are delivered to the streaming client in two different ways. Instead of delivering the source symbols directly, the original streaming packets are delivered to the streaming client. In contrast, the repair symbols are delivered to the streaming client by encapsulating one or several whole repair symbols into a repair packet. In order to identify the encoding symbols, the repair packet header should contain at least the encoding symbol ID of the first repair symbol carried in the repair packet. Similarly, for each streaming packet to be delivered, the encoding symbol ID of the first corresponding source symbol is also carried in the streaming packet.

TABLE II The Throughput of Encoding and Decoding of the proposed AL-FEC for Different Symbol Sizes When k=1024 and $\delta = 0.05$

***l* [bits]**	**Encoding** [Mbps]	**Decoding** [Mbps]
32	19.39	21.59
64	16.44	19.26
128	11.84	13.39
256	8.23	9.25
512	6.54	7.34
1024	5.05	5.74
2048	3.72	4.26
4096	3.05	3.57

Then, here we specified the required details in order to apply the CRT-based AL-FEC scheme to protect a streaming service by using the FEC framework defined by IETF. First, an instance of the CRT-based AL-FEC scheme can be defined by the parameters (k, l) (i.e., the block size and the symbol size). The encoding modulus of an encoding symbol can be identified by an encoding symbol ID (e.g., the value of 1 to k denoting source symbols and the value of k+1 to t denoting the remaining repair symbols), such that the corresponding modulus can be specified based on the encoding symbol ID. Second, the corresponding t relatively-prime moduli for each practical AL-FEC setting (k, l) should be prepared in both a streaming server and a streaming client before the packet delivery of a streaming service begins. Since the generation of these moduli is quite time-consuming, both the streaming server and the streaming client have to possess and store all the moduli in advance. As a result, given the encoding symbol ID, the value of the corresponding encoding modulus can be retrieved efficiently.

VI. Performance Emulation Results for High-Speed Rail Streaming Services

For showing the effect of using the CRT-based AL-FEC scheme to protect the delivery of a streaming service over WiMAX networks for high speed rail reception, we provide the performance emulation results for using both the CRT-based AL-FEC scheme and the Raptor AL-FEC scheme defined in IETF RFC 5053 [2].

The emulation is done over a cable-based IEEE 802.16e mobile WiMAX network, and a channel emulator is placed between the Alvarion WiMAX BS (Base Station) and the WiMAX MS (Mobile Station) in order to emulate the WiMAX network reception over a 300 Km/hr high-speed rail train. The detailed parameters employed in the high-mobility WiMAX emulation network are shown in TABLE III.

Besides, the streaming service delivered over the high-mobility WiMAX emulation network is augmented by the IETF FEC Framework [27], using either the CRT-based AL-FEC scheme or the Raptor AL-FEC scheme. The average

TABLE III THE PARAMETERS OF THE MOBILE WIMAX NETWORK FOR EMULATING 300 KM/HR HIGH-SPEED RAIL RECEPTION

Parameter	**Value**
WiMAX MS Model	AWB RG231
Channelization	10 MHz
WiMAX AMC	Disabled
DL Modulation and Coding	16 QAM 3/4, Repetition 0
UL Modulation and Coding	QPSK 1/2, Repetition 6
HARQ	Enabled
Carrier Frequency	2.5 GHz
MIMO	Disabled
WiMAX BS Power	36 dBm
Channel Emulator Model	Spirent SR5500
Channel Model	VA120

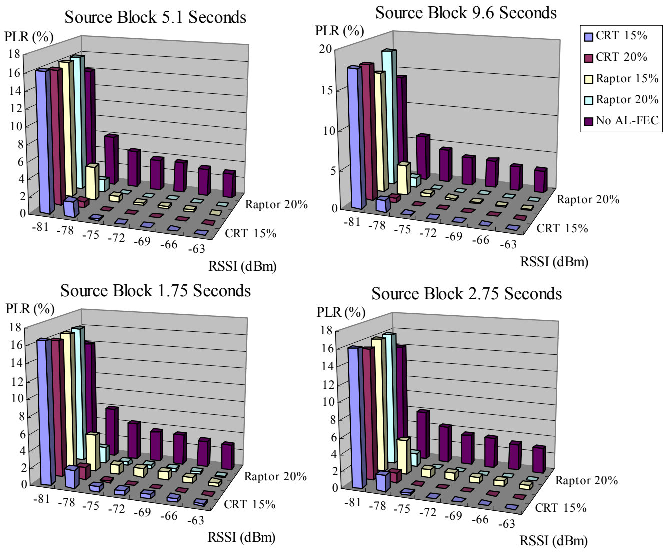

Figure 1. The RTP Packet Loss Rate (PLR) of the streaming service for 300 Km/hr WiMAX network reception (CRT overhead 15% ~ 20%, Raptor overhead 15% ~ 20%)

bandwidth consumed by the streaming service is 350 Kbps (without the AL-FEC repair packet flow). The audio and video codes employed are the AAC (Advanced Audio Coding) and H.264 AVC (Advanced Video Coding) codec set provided by MainConcept.

Fig. 1 depicts the RTP PLR (Packet Loss Rate) of delivering the streaming service over the high-mobility WiMAX emulation network. Here the AL-FEC transmission overheads employed for both the CRT-based AL-FEC scheme and the Raptor AL-FEC scheme are 15% and 20%. In addition, four different protection periods of an AL-FEC source block are selected for emulation: 1.75 seconds, 2.75 seconds, 5.1 seconds, and 9.6 seconds. Basically, the protection period setting longer than 10 seconds is not an acceptable setting for streaming services due to the long client-side service initialization delay and service switch delay. The symbol size of the CRT-based AL-FEC scheme is 4 bytes (using interleaving to support a larger source block), and the symbol size of Raptor code is 336 byte. For revealing further details, the real values of the RTP PLR in Fig. 1 for using CRT-based AL-FEC scheme and Raptor AL-FEC scheme are also listed in TABLE IV and TABLE V, respectively.

TABLE IV THE DETAILED RTP PLR VALUES FOR CRT-BASED AL-FEC

RSSI / CRT	**-81 dBm**	**-78 dBm**	**-75 dBm**	**-72 dBm**	**-69 dBm**	**-66 dBm**	**-63 dBm**
9.6 seconds SB, 15% Overhead	17.73 %	1.56 %	0.1%	0%	0%	0%	0%
9.6 seconds SB, 20% Overhead	17.6 %	0.69 %	0%	0%	0%	0%	0%
5.1 seconds SB, 15% Overhead	16.22 %	1.81 %	0.16 %	0%	0%	0%	0%
5.1 seconds SB, 20% Overhead	15.81 %	0. 79%	0%	0%	0%	0%	0%
2.75 seconds SB, 15% Overhead	16.06 %	1.94 %	0.17 %	0%	0%	0%	0%
2.75 seconds SB, 20% Overhead	15.47 %	1.12 %	0%	0%	0%	0%	0%
1.75 seconds SB, 15% Overhead	16.56 %	2.13 %	0.6%	0.52 %	0.49 %	0.39 %	0.24 %
1.75 seconds SB, 20% Overhead	16.05 %	1.48 %	0.17 %	0%	0%	0%	0%

TABLE V THE DETAILED RTP PLR VALUES FOR RAPTOR AL-FEC

RSSI / Raptor	**-81 dBm**	**-78 dBm**	**-75 dBm**	**-72 dBm**	**-69 dBm**	**-66 dBm**	**-63 dBm**
9.6 seconds SB, 15% Overhead	15.91 %	3.96 %	0.51 %	0.26 %	0.21 %	0.13 %	0.04 %
9.6 seconds SB, 20% Overhead	18.18 %	1.26 %	0%	0%	0%	0%	0%
5.1 seconds SB, 15% Overhead	16.11 %	3.96 %	0.79 %	0.35 %	0.26 %	0.21 %	0.11 %
5.1 seconds SB, 20% Overhead	16.25 %	1.47 %	0%	0%	0%	0%	0%
2.75 seconds SB, 15% Overhead	16.03 %	4.17 %	0.93 %	0.89 %	0.71 %	0.64 %	0.52 %
2.75 seconds SB, 20% Overhead	16.07 %	1.56 %	0.11 %	0%	0%	0%	0%
1.75 seconds SB, 15% Overhead	16.32 %	4.42 %	1.07 %	1.05 %	1%	0.7%	0.46 %
1.75 seconds SB, 20% Overhead	16.42 %	1.95 %	0.51 %	0.39 %	0.37 %	0.31 %	0.19 %

From Fig. 1, we can observe that if 15% AL-FEC overhead is employed, using CRT-based AL-FEC scheme can enable error-free streaming service delivery once RSSI >= -72 dBm and protection period >= 2.75 seconds. In contrast, error-free streaming service delivery is not possible if Raptor code is employed with the same AL-FEC overhead setting. In addition, we also find that if we slightly increase the employed overhead of CRT-based AL-FEC scheme from 15% to 16%, error-free streaming service delivery is observed since -75 dBm RSSI under the following protection period settings: 2.75 seconds, 5.1 seconds, and 9.6 seconds. This is quite similar to the case of using Raptor AL-FEC scheme with 20% AL-FEC overhead. Hence, about 4% AL-FEC overhead can be reduced if we use CRT-based AL-FEC scheme instead of the Raptor AL-FEC scheme.

Hence, CRT-based AL-FEC scheme is quite suitable for streaming over the WiMAX networks for high-speed rail reception because high-mobility can effectively reduce the available bandwidth provided by a WiMAX BS, and such limited bandwidth even has to be shared by all the passengers inside a high-speed train. However, in comparison to the Raptor AL-FEC scheme, the disadvantage of CRT-based AL-FEC scheme is its higher computational complexity because Raptor AL-FEC can offer very high encoding and decoding throughput [1]. Nevertheless, as shown in TABLE II, the encoding and decoding throughput of CRT-based AL-FEC is still good enough to enable us to deliver three 1Mbps live mobile TV streaming services (in SD resolution) over the THSR mobile WiMAX network. For example, only 4.6% CPU consumption is required for decoding a 1 Mbps streaming service protected by CRT-based AL-FEC scheme (32-bit symbol size selected and over a 2.8 GHz CPU using only single thread). In addition, CRT-based AL-FEC scheme is in fact easy to be parallelized for exploiting the modern multi-core processors for personal computers and handheld devices. We will show the potential of parallelizing the CRT-based AL-FEC scheme in the future publications.

VII. CONCLUSION

In this paper, we proposed a new AL-FEC scheme based on CRT. The code is extended from our previous non-systematic FEC scheme. The proposed AL-FEC scheme supports greater symbol size than conventional ideal codes and requires less decoder overhead than conventional rateless codes. Finally, we also demonstrate that employing the proposed AL-FEC scheme for streaming service delivery is quite suitable for the scenario of high-speed rail reception over a mobile WiMAX network.

In the future, we want to improve the throughput of the proposed AL-FEC scheme further by parallel computation and pre-computation.

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