Online AL-FEC protection over Mobile Unicast Services

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***Abstract*—Forward error correction (FEC) is a method for error control of data transmission adopted in several mobile multicast standards. FEC is a feedback free error recovery method where the sender introduces redundant data in advance with the source data enabling the recipient to recover from different arbitrary packet losses. Recently, the adoption of FEC error control method has been boosted by the introduction of powerful Application Layer FEC (AL-FEC) codes i.e., RaptorQ codes. Furthermore, several works have emerged aiming to address the efficient application of AL-FEC protection introducing deterministic or randomized online algorithms. The investigation of AL-FEC application as primary or auxiliary error protection method over mobile multicast environments is a well investigated field. However, the opportunity of utilizing the AL-FEC over mobile unicast services as the only method for error control, replacing common feedback based methods that are now considered to be obsolete, is not yet examined. In this work we provide an analysis on the feasibility of AL-FEC protection over unicast delivery utilizing online algorithms on the application of AL-FEC codes with exceptional recovery performance.**

***Keywords*-forward error correction, RaptorQ codes, online algorithms, mobile unicast services**

I. Introduction

Forward error correction (FEC) is a method for error control of data transmission adopted in several mobile multicast standards. In multicast delivery, the FEC encoding significantly reduces the effect of independent losses at different receivers, while achieving a reduction in the rate of packet loss according to the introduced redundancy by the FEC encoder, resulting in large mitigation to the costly need of lost packets retransmission. Based on the above, several mobile multicast standards recommend the use of FEC on application layer, and more specifically, Raptor codes family [1] are adopted due to their high performance. However, FEC protection comes with its own cost since controlling the introduced redundancy is not a trivial issue. The multicast sender should decide on the redundancy will introduce to the transmission so as to ensure that the multicast recipients will be able to recover independent data losses while, at the same time the redundant information should be adapted to the current reception conditions to avoid resources wastage. Based on this, the efficient application of AL-FEC protection can be achieved by a multicast transmitter enabled to adapt the introduced AL-FEC redundancy according to the current reception conditions. The design of an algorithm adapting the introduced AL-FEC transmission overhead can be reduced in the basis of an online problem.

In general, online algorithms [2] are used to confront problems where the input of the algorithm is not available in advance. Subsequently, online algorithms have to generate output without knowledge of the entire input since input information arrives in the future and is not accessible at present. The effectiveness of online algorithms is evaluated using competitive analysis. The main concept of competitiveness is to compare the output generated by an online algorithm to the output produced by an optimal offline algorithm which knows the entire request sequence in advance and can serve it with minimum cost.

Online algorithms are utilized in many research fields of mobile networks as the work presented in [3], where the frequency assignment problem is examined through distributed online algorithms. Furthermore, the authors of [4] introduced a competitive online algorithm in terms of energy efficiency and delay in scheduling problems over wireless multicast environments. The work presented in [5] proposes a data selection policy where, in the concept of competitive analysis, the decision of transmitting source data, retransmitting a packet or transmitting a redundant codeword is investigated. Finally, the authors of this paper introduced in [6] an online framework for the utilization of online algorithms on the efficient application of AL-FEC protection problem over mobile multicast networks evaluating the first attempt of a naive randomized online algorithm for the stated AL-FEC policy online problem. The same authors presented in [7] a deterministic online algorithm based on a weights assignment procedure and also presented an adaptive variation of this online algorithm in [8].

It is clear that significant work has been done on the application of online algortihms for the AL-FEC error control over mobile multicast networks in the context of competitive analysis. In this work we concentrate on the application of AL-FEC codes as the primary method for error correction over mobile unicast services aiming to replace common error control methods. Since the reliability control of unicast services over mobile networks is underspecified and protocol dependent, we study several online schemes on the efficient deployment of AL-FEC protection and we investigate the performance and the feasibility of AL-FEC protection over mobile unicast services.

The rest of this paper is organized as follows: In Section II we provide an in-brief description of the protocols providing reliability in mobile unicast services and in Section III we present the proposed strategy on the AL-FEC protection deployment over mobile unicast transmission environments. In Section IV we analyze the performance of the proposed scheme and concluding in Section V, we provide a discussion on the advantages of the presented error protection online schemes and we propose some possible future steps that could follow and extend the presented work.

II. Reliable Unicast Mobile Delivery

The 3GPP packet-switched streaming service (PSS) [9] is a standard for media streaming to mobile terminals that provides a complete streaming and download framework for commercial content. The main protocols of 3GPP PSS include the Real-Time Streaming Protocol (RTSP) for session control, the Session Description Protocol (SDP) for presentation descriptions, and the Real-time Transport Protocol (RTP) for media transport. 3GPP PSS recommends the implementation of RTP retransmissions that enable repairs due to packet losses. RTSP may use either an unreliable datagram protocol (UDP), a reliable datagram protocol (RDP) or a reliable stream protocol such as TCP as it implements application-level reliability. Retransmission of lost packets is an obvious mean by which losses can be repaired. However, it is typical that in some applications, this error control method cannot always perform well. In addition to the possibly high latency, there is a high bandwidth overhead introduced to the use of retransmission. Not only are the same data sent multiple times, but additional control traffic is necessary to realize the request for the retransmission. It has been shown that, under certain circumstances, the overhead of requesting retransmission for most packets may be such that the use of a FEC is more acceptable and efficient.

The newer member in Raptor codes family is known as RaptorQ code [10]. RaptorQ is also a fountain and systematic FEC code. RaptorQ is a significantly more efficient AL-FEC code than the older Raptor code, in terms of superior flexibility and higher protection and coding efficiency. The encoding process of RaptorQ code is mostly identical with that of Raptor code but, RaptorQ code introduces certain design selections that ensure superior performance compared with that of Raptor code.

Concerning the performance of RaptorQ, the key property of a Raptor codes member is the probability of a successful decode as a function of the received symbols similar to that of the standardized Raptor code described above. The decoding failure probability of RaptorQ code can be modeled by (1) [11]:

$$p_{f_{RQ}} = \begin{cases} 1 & \text{if } n < k \\ 0.01 \times 0.01^{n-k} & \text{if } n \geq k \end{cases} \quad (1)$$

In (1), $p_{f_{RQ}}(n,k)$ denotes the probability of a failed decode of a RaptorQ protected block with k source symbols if n encoding symbols has been received.

III. Online Algorithms on AL-FEC

Several approaches have emerged for the efficient application of AL-FEC protection utilizing randomized and deterministic online algorithms.

The randomized Algorithm 1 of [6] processes a sequence of packets selecting equiprobably a value from a fair range, which denotes the introduced transmission overhead, when a source block is formed. Subsequently, the introduced transmission overhead is computed according to the random choice of the random variable. The competitive ratio for the algorithm of [6] is:

$$c = 1.275 \cdot (1 - p)$$

Algorithm 1 Randomized AL-FEC Algorithm of [6]

```
procedure (pkt, sbl)
    sbn ← ⌊pkt.uid/sbl⌋
    if pkt.uid mod sbl ≠ 0 then
        pkt.sbn ← sbn
    else
        pkt.sbn ← sbn
        select equiprobably a value i from the set {0.05 :
0.01 : 0.5}
        transmission overhead ← ⌈sbl * i⌉
    end if
end procedure
```

Algorithm 2 Weighted AL-FEC Online Algorithm of [7]

```
procedure (pkt, sbl, t)
    pkt.w ← log2(pkt.uid)/log2(sbl)
    if pkt.w ≤ t then
        count ← count + 1
    end if
    if pkt.id mod sbl = 0 then
        transmission overhead ← count/sbl
    end if
end procedure
```

The online Algorithm 2 presented in [7] is based on weights assignment in each processed AL-FEC packet. The algorithm takes as input each processed packet and assigns a weight to the packet according to its unique id i.e., the number of packets included in each FEC source block and the size of the source block each packet belongs to. Thereafter, the algorithm determines if the processed packet will be included in the introduced redundancy comparing the assigned packet's weight with a selected threshold. The value of the threshold determines the required robustness of the AL-FEC protection. Finally, the algorithm examines if the processed packet is the last packet of the current FEC source block in order to compute the transmission overhead will introduce to the multicast transmission.

The competitive ratio for this deterministic online algorithm of [7] is:

$$c = (1 + sbl^{t-1})(1 - p)$$

Finally, in [8] is presented the deterministic online Algorithm 3 that extends the online scheme of [7] and comes to enhance its performance, introducing an adaptive variation based on the outcome of previous multicast deliveries of the transmitted object. The proposed adaptive algorithm takes as input a sequence of symbols, assuming one symbol per packet, the length of the source blocks that will be produced and a quantity that represents a threshold. The value of this quantity determines the User Equipments (UEs) coverage that the algorithm should achieve.

The competitive ratio for this deterministic online algorithm is equal to the competitive ratio achieved by the online algorithm of [7] but seems to be more efficient in practice due to its adaptation nature.

Algorithm 3 Adaptive Weighted AL-FEC Algorithm of [8]

procedure $(symbols, sbl, targetThreshold)$
    $compute\ factor$
    if $factor \leq targetThreshold$ **then**
        $threshold \leftarrow threshold - (0.05 * threshold)$
    else
        $threshold \leftarrow threshold + (0.05 * (1 - threshold))$
    end if
    $count \leftarrow 0$
    for all symbols **do**
        $symbol.w \leftarrow log_2(symbol.uid)/log_2(sbl)$
        if $symbol.w \leq threshold$ **then**
            $count \leftarrow count + 1$
        end if
        if $symbol.uid \bmod sbl = 0$ **then**
            transmission overhead $\leftarrow count/sbl$
        end if
    end for
end procedure

IV. Performance Evaluation

A. Network Model

In this section we present the network model and the assumptions we utilize on this work.

The transmission environment we introduce refers to a typical streaming environment to mobile users. A bunch of data are transmitted to a fraction of mobile users through unicast unreliable radio channel. The transmitted data considered to be a continuous object, as in a streaming delivery session, are encapsulated in RTP/UDP flows, where a source injects packets into the network.

On the AL-FEC protection mechanism, we consider the application of the newly introduced RaptorQ FEC scheme. The sender introduces redundant information within the source data in order to enable receivers to overcome independent packet losses and successfully reconstruct the transmitted data. On the AL-FEC encoding, the transmitted object is partitioned in one or several source blocks. Each FEC source block consists of k source symbols with k depending on the selection of the encoding parameters. The size of a FEC source block is denoted as source block length (sbl). Through the RaptorQ encoding, for each FEC source block, a certain amount of redundant symbols, also called repair symbols, are generated according to the desired amount of protection introduced by the multicast source. A unique ID is assigned on each resulting encoding symbol, which can be a source or a repair symbol, in order to identify the type of the symbol according to the assigned value. At the receiver side, a multicast client is able to determine, for each FEC source block, which source symbols should have been received but have not and is also able to determine the number of encoding symbols it has received.

In this work, we assume the transmission of a packet sequence with independent packet loss masks applied to each mobile receiver according to an examined packet loss rate. In each packet sequence, each packet is denoted by the triplet $\{uid, sbn, r_{il}\}$ where:

- uid: is a unique ID identifying each AL-FEC resulting packet
- sbn: is the number of the FEC source block the examined packet is organized to
- r_{il}: defines if the examined packet was not received by the receiver i with the boolean l set to 0 if packet was not received

The behavior of the network is modeled as a loss transcript, consisting of the values of the boolean variables r_{il}. In more detail, in the general mobile network model we consider, the values r_{il} may be set arbitrarily, allowing for bursty periods of loss which need not to be correlated across the receivers. More precisely, the packet loss pattern applied to the sequence of transmitted packets is denoted by p, which is the average network packet loss rate taking values in the range $[0, 1]$. At each receiver, a packet loss mask is applied independently based on the value of p. Furthermore, we have to denote that the packet erasures are randomly distributed at each receiver.

At each receiver the AL-FEC decoding process is modeled according to the decoding failure probability of (1) in order to denote the examined AL-FEC source block as successfully reconstructed or not. On the decoding process, we assume that a sufficient threshold for the failure probability of a recovered source block is 10^{-2} or less as proposed in [12].

B. Evaluation Scope & Setup

The scope of this work, as already described in previous Sections, is to examine the feasibility of utilizing FEC protection at the application layer as the primary and only error correction method in evolved unicast mobile environments. This option is boosted by the emergence of the powerful RaptorQ FEC codes that came to mitigate the major drawback of the predecessor Raptor codes i.e., the reception overhead. This option is boosted by the practically zero reception overhead of the RaptorQ code since it requires zero encoding symbols to have been received further of the number of source symbols in order to achieve decoding failure probability of 10^{-2}, a safe threshold for practically zero failure probability.

For the evaluation testbed of this work, we compare the protection performance achieved between two basic error control scenarios. The first scenario assumes that the unicast flows are protected entirely by a retransmission based scheme where a mobile user is able to indicate which data should have been received but haven't and request retransmission of missing data. The retransmission of lost data is provided through a point-to-point channel. For the second evaluated scenario we assume that the exclusive error protection scheme utilized for the reliable provision of RTP/UDP flows is a FEC scheme based on RaptorQ codes. For this case we evaluate the application of FEC through the three novel deterministic and randomized online algorithms that were previously described. The main concern of the presented evaluation is the impacts of the amount of packets exchanged between the unicast source and mobile clients, for the successful reception of the transmitted content. We provide simulation results for the performance of those two error protection schemes over several network scenarios.

C. Number of Packets

In the first part of the provided simulation results we illustrate the total amount of data exchanged in the mobile network for different values of simulated packet loss rate. In more detail, in Fig. 1 we present the total number of packets exchanged in a mobile network of 100 UEs that receive an object of 1024 packets over unreliable unicast bearers evaluating the average packet loss rate in the range of 1% to 20%. For the feedback-based error recovery case, we assume that each UE requests the retransmission of the lost packets untill all the required packets have been successfully received. For the evaluation of the FEC- based error control cases, we assume that the transmitted object is partitioned in 4 source blocks each one of length 256 symbols. The results for the randomized online AL-FEC algorithm refer to the average number of packets after 10 consecutive simulations for each evaluated value of packet loss rate. The setup for the weighted online AL-FEC algorithm assumes that the selected value of the threshold t is 0.7 while for the adaptive weighted online AL-FEC algorithm the selected value of $targetThreshold$ is again 0.7 and the provided results refer to the simulation of 10 consecutive transmission rounds in order the algorithm to reach a converged state.

Regarding the case of the retransmission-based error recovery, we can observe that the total number of packets exchanged in the network increases in proportion to the packet loss rate increase. Obviously, as the average packet loss rate of the network increases, the number of retransmitted packets and as a consequence the total amount of transmitted data increases too. Furthermore, as long as the network packet loss rate increases the number of established retransmission session for each particular UE increases too. Analyzing the

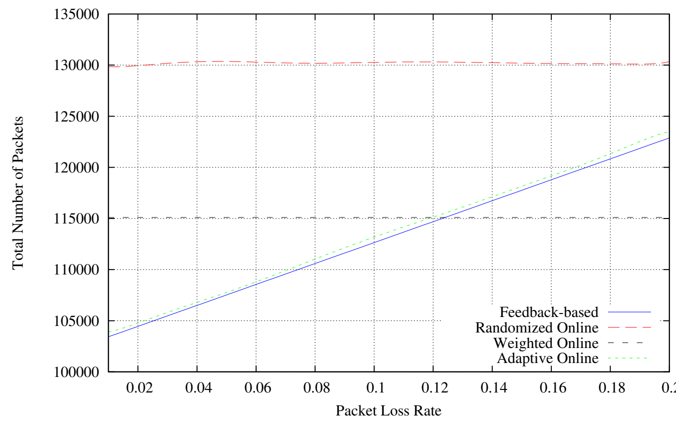

Fig. 1: Total Number of Packets vs. Packet Loss Rate

curves of the utilization of the evaluated online algorithms for the application of RaptorQ FEC as the primary error protection method, regarding the randomized online algorithm we can immediately remark that the algorithm just introduces random amount of overhead in the transmission. For the case of the deterministic weighted online algorithm, we observe that the algorithm introduces a constant amount of transmission overhead for all of the evaluated values of packet loss rate. This is something anticipated since, the online algorithm adapts the introduced transmission based on the size of the length of the AL-FEC source blocks the transmitted object is partitioned to and since it is a feedback-free scheme cannot make any adaptation on the packet loss rate conditions. On the other hand, the last online algorithm, the adaptive weighted algorithm, which is an extension of the previously described online scheme, we observe that is able to adapt the AL-FEC transmission overhead to the packet loss rate. Based on this, we can remark that the adaptive online scheme can operate very close to the retransmission-based scheme in the context of transmitted packets with respect to the requested value for the percentage of the "recovered" UEs.

D. Source Block Length

In this subsection we provide simulation results for the performance of the evaluated online AL-FEC schemes over different values of AL-FEC source block length. In Fig. 2 we present how the total number of packets varies when the length of the formed AL-FEC source block increases. For this evaluation we simulate the transmission of an object of size 8192 packets to 100 mobile UEs over unicast bearers. The evaluated average packet loss rate is fixed at 5% and the evaluated values of the source block length are 512, 1024, 2048, 4096 and 8192. Again we assume that the threshold t for the weighted online AL-FEC algorithm is 0.7 and the same lies for the setup of the adaptive weighted online AL-FEC algorithm simulating 10 consecutive transmission rounds.

Regarding the behavior of the retransmission-based case, the constant number of transmitted packets is anticipated

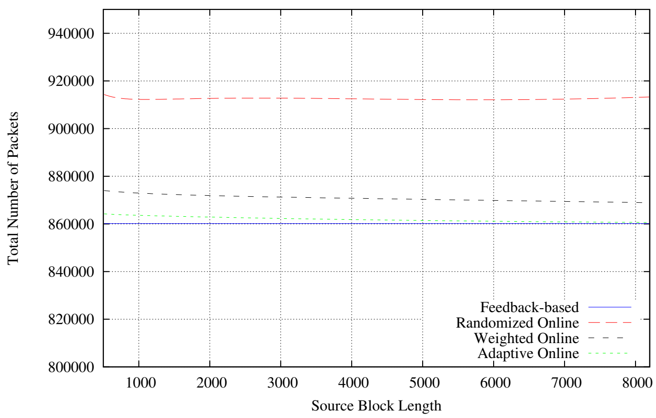

Fig. 2: Total Number of Packets vs. Source Block Length

for this error recovery method since there is no AL-FEC encoding applied on the transmitted object and therefore the data are not partitioned in source blocks. For the case of the randomized online algorithm the increase of the source block length cannot have any impacts on the introduced amount of AL-FEC redundancy. The interesting part of the presented results refers to the performance achieved by the two weighted deterministic online algorithms. We can immediately observe that the weighted online algorithm achieves improved performance in terms of the amount of data transmitted as the source block length increases. This behavior directly implies from the operation concept of the weighted online algorithm as well as from the performance properties of the RaptorQ FEC code. Moreover, we can remark that the adaptive online algorithm combines its adaptation nature with the weight assignment process based on the source block length and is able to reach the performance of the retransmission-based method as the size of the source block increases.

V. Conclusions & Future Work

In this work we have investigated the feasibility of the application of AL-FEC codes as the basic and the only error control method over unicast mobile delivery. We have examined the performance of three different online algorithms, randomized and deterministic, aiming on the efficient application of AL-FEC application against the performance of the common method of error control, i.e., a retransmission-based scheme. At first we have presented the evaluated online algorithms and we have analyzed their operational concepts. Thereafter, we have introduced the network model under which we have conducted the presented evaluation and, thereafter we have provided and analyzed simulation results for the performance achieved by the evaluated error control schemes in terms of the total amount of data transmitted in the network.

Regarding the outcome of the conducted simulations, the most interested results came up from the performance achieved by the adaptive weighted online algorithm. This deterministic scheme is able to adapt the introduced AL-FEC transmission overhead based on the length of the source block the transmitted object is partitioned too as well as the reception conditions of the network. This fact implies that the adaptive weighted online algorithm is able to exploit the performance properties of the utilized RaptorQ FEC code, in conjunction with the advantages of the adaptation of the introduced AL-FEC overhead to the packet loss conditions of each recipient. Based on the simulation results, we were able to verify that this online scheme is able to operate close enough to the performance of a retransmission-based error recovery method. Furthermore, we have to remark that with a careful selection of the AL-FEC encoding properties the online scheme can achieve almost the same performance with the feedback-based method.

Some possible future steps that can follow this work are a more comprehensive evaluation of the online schemes for the AL-FEC application considering also other network parameters and settings. Furthermore, the design of more sophisticated and dedicated on unicast environments online algorithms for the AL-FEC policy online problem could be beneficial for the efficient application of AL-FEC protection over mobile unicast services.

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