Evolving AL-FEC application towards 5G NGMN

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***Abstract*—The fifth generation of mobile technology (5G) is positioned to address the demands and business contexts of 2020 and beyond. Therefore, in 5G, there is a need to push the envelope of performance to provide, where needed, for example, much greater throughput, much lower latency, ultra-high reliability, much higher connectivity density, and higher mobility range. A crucial point in the effective provisioning of 5G Next Generation Mobile Networks (NGMN) lies in the efficient error control and in more details in the utilization of Forward Error Correction (FEC) codes on the application layer. 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. Furthermore, several works have emerged aiming to address the efficient application of AL-FEC protection introducing deterministic or randomized online algorithms. In this work we propose a novel AL-FEC scheme based on online algorithms forced by the well stated AL-FEC policy online problem. We present an algorithm which exploits feedback capabilities of the mobile users regarding the outcome of a transmission, and adapts the introduced protection respectively. Moreover, we provide an extensive analysis of the proposed AL-FEC algorithm accompanied by a performance evaluation against common error protection schemes.**

***Keywords*-forward error correction, next generation mobile network, online algorithms, mobile multicast services**

I. Introduction

Forward error correction (FEC) is a method of obtaining error control in data transmission in which the source (transmitter) sends redundant data and the destination (receiver) recognizes only the portion of the data that contains no apparent errors. FEC does not require handshaking between the source and the destination hence, it can be used for broadcasting of data to many destinations simultaneously from a single source.

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 [1] 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. Online problems assume that complete knowledge of the entire input is not available to an algorithm and the input is revealed in parts, with an online algorithm responding to each new input upon arrival. In some problems, where the application of deterministic solutions lacks of applicability, a randomized online algorithm [2] is the simplest available algorithm and some times the most efficient solution. 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. The competitive ratio of an online algorithm A is defined with respect to an adversary. In general, the adversary generates a sequence σ and the online algorithm A has to serve σ. When constructing the sequence σ, the adversary always knows the description of the online algorithm A. Formally, given a sequence σ, $A(\sigma)$ denotes the cost of the online algorithm A and $OPT(\sigma)$ denotes the cost of the optimal offline algorithm. An online algorithm A is called c-competitive if there exists a constant α such that $A(\sigma) - c \cdot OPT(\sigma) \leq \alpha$.

Many active research fields of communication networks utilize online algorithms. The authors of [3] proposed an online algorithm on maximizing the throughput of multihop radio networks, in the context of energy constraints and the design of routing algorithms. Additionally, in [4] online algorithms are applied over multicast routing problems over energy-constrained ad-hoc networks. In the work presented in [5], the frequency assignment problem is examined through distributed online algorithms. Moreover, the authors of [6] introduced a competitive online algorithm in terms of energy efficiency and delay in scheduling problems over wireless multicast environments. In the work of [7] a data selection policy was presented where, under 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 described in [8] an online framework for the utilization of online algorithms on the efficient application of AL-FEC protection stating the online AL-FEC policy problem over mobile multicast networks. Also they presented the first naive attempt of a randomized online algorithm for the online problem. The same authors presented in [9] a deterministic online algorithm based on a weight assignment process, and finally in [10] they presented an adaptive variation of the weighted online algorithm.

In this work we concentrate on the application of FEC codes as the primary method for error correction on the application layer over next generation mobile networks. Since the reliability control of multicast services over mobile networks is under specified and protocol dependent, we study a new adaptive online algorithm for the efficient deployment of AL-FEC protection which exploits reporting capabilities of multicast protocols. Moreover, we investigate the performance of such AL-FEC protection scheme over next generation mobile multicast networks.

The rest of this paper is organized as follows: In Section II we provide an in-brief description of the multicast delivery advances over 5G mobile networks and in Section III we present the most recent and valuable FEC codes. In Section IV we present the proposed algorithm on the AL-FEC protection deployment and in Section V we analyze the performance of the proposed scheme. Concluding in Section VI, we provide a discussion on the advantages of the proposed online error protection scheme and we refer to some possible future steps that could follow and extend the presented work.

II. Multicast Delivery on 5G NGMN

Multimedia services are driving the evolution of mobile communications systems with increasing demands in terms of network capacity and Quality of Service (QoS). Today video traffic amounts to more than 50% of mobile traffic and it is foreseen to become more than 70% by 2019.

Broadcasting and multicasting are the most efficient ways to deliver the same multimedia content to a wide audience. Using common resources to transmit the information makes an efficient use of the radio spectrum, which is one of the goals towards the evolution of Fifth Generation of Mobile Communications (5G).

In this context, there is the need to develop novel technologies to enhance multimedia broadcasting so as to cope with the new requirements and trends of future mobile networks. In this scenario, multimedia services will coexist with other emerging ecosystems, such us the Internet of Things (IoT), Machine-Type Communications (MTC) including vehicular networks, or Device-to-Device (D2D) communications. Therefore, the new solutions must be designed taking into account this global context. Advances are required at all levels of the protocol stack, spanning from concepts related to modulation and coding, radio resource management, network and transport protocols, and applications.

III. Reliability Control with Forward Error Correction Codes

Fountain Codes are a new class of codes designed and ideally suited for reliable transmission of data over an erasure channel with unknown erasure probability [11]. The new RaptorQ code [12] is a significantly more efficient AL-FEC code than its predecessor Raptor code. It provides superior flexibility and improved error protection and coding efficiency. The encoding process of RaptorQ code is mostly identical with that of Raptor code. However, RaptorQ code introduces certain design that ensure higher performance compared with the older Raptor code.

The decoding failure probability of RaptorQ code can be modeled by (1) [13]:

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

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 have been received.

IV. Online AL-FEC Protection

A. Online Model

The transmission environment we introduce refers to a typical multicast streaming delivery environment to mobile users. A bunch of data are transmitted to a fraction of mobile users through a multicast unreliable radio channel. The transmitted data, considered to be a continuous object, 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 RaptorQ FEC scheme. 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 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 with the behavior of the network being modeled as a loss transcript. 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 within the range $0, 1$.

At each receiver the AL-FEC decoding process is modeled according to the decoding failure probability in order to denote the examined AL-FEC source block as successfully reconstructed or not. A sufficient threshold for the failure probability of a recovered source block is 10^{-2} or less as proposed in [14].

B. Optimal Offline Algorithm

The scheme that can ensure the optimal selection of the transmission overhead is a multicast source that selects the introduced redundancy to a value close to the average packet loss rate of the network as defined in [15] given the recovery properties of the utilized AL-FEC code. In the present analysis the multicast sender can exploit the exceptional recovery properties of RaptorQ code. RaptorQ provides a practically zero reception overhead since, as described in (1), can achieve the specified threshold of the decoding failure probability requiring to receive no more additional encoding symbols than the number of the transmitted source symbols. Subsequently, the optimal AL-FEC selection policy can introduce as many repair symbols as the average number of lost symbols in the multicast users. Based on this, the number of repair symbols r the optimal offline algorithm will introduce in each source block of size sbl symbols is calculated as follows: $r = (sbl+r) \cdot p$. Consequently, the cost of the optimal AL-FEC policy algorithm can be computed as: $OPT = sbl + r$.

C. Mean Transmission Overhead (MTO) Online Algorithm

The proposed online MTO algorithm operation is based on transmission rounds. The algorithm adapts the selected AL-FEC transmission overhead based on the outcome of previous deliveries of the transmitted object and the attribute UE coverage which indicates the amount of UEs after which the multicast delivery is considered as sufficient protected. At each round of multicast transmission, the MTO algorithm computes at first the ideal transmission overhead, i.e. the transmission overhead which had to be introduced in order to achieve the target UE coverage, exploiting its knowledge on the outcome of the AL-FEC protected delivery individually on each UE. Afterwards, it updates the mean transmission overhead with the computed value of the ideal transmission overhead from the previous round. Finally, the current AL-FEC transmission overhead is updated with the mean transmission overhead value.

For the purposes of the presented algorithm, we suppose that the multicast source can monitor and log the outcome of each multicast delivery. To clarify this assumption, we mention that several mobile multicast standards define a post-delivery procedure to provide extra features (e.g. delivery reporting, file repair capabilities) for the multicast delivery. Based on this, a multicast UE is able to determine, for each AL-FEC source block of each transmission object, which source symbols should have been received but have not and is also able to determine the number of symbols it has received. Therefore, a multicast source is able to maintain extensive information for the outcome of each content delivery to the mutlicast UEs.

Regarding the cost of the proposed MTO online algorithm, let denote r' the amount of source symbols that the algorithm will introduce in a transmission according to the computed value of mean transmission overhead. Hence, the cost of the MTO algorithm can be computed as: $ALG = sbl + r'$.

V. Performance Evaluation

A. Source Block Length

In this first section of the provided evaluation results we compare the performance of the proposed MTO online algorithm with the performance of the fixed AL-FEC policy approach and a feedback-based protection scheme in respect of the amount of satisfied UEs. A UE is considered as satisfied if it was able to reconstruct the original object. In Fig.1 we present simulation results regarding the percent of satisfied UEs for different values of AL-FEC source block size. The evaluated source block size resides in the range of 2048 to 65536 symbols per source block. For this evaluation the average packet loss rate of the multicast transmission is fixed to 5%, the amount of UEs participating in the multicast delivery is 100 and the transmitted object is of size 65536

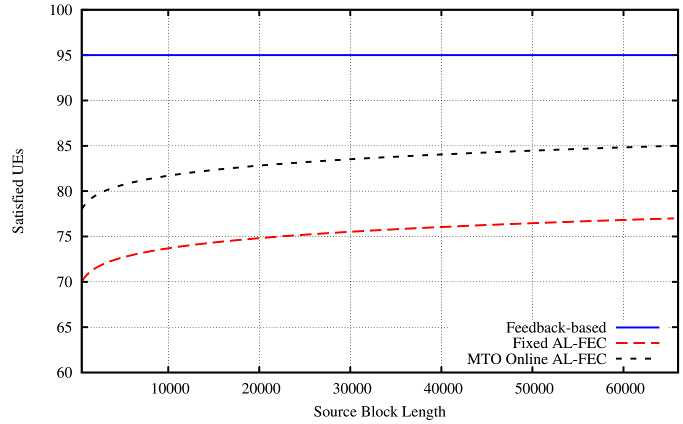

Fig. 1: Satisfied UEs vs. Source Block Length

symbols. The target UEs coverage for this evaluation is set to 90%.

As expected there is no impact of the source block length to the feedback-based approach since no AL-FEC encoding is applied to this scenario. It is also anticipated that the feedback-based error recovery scheme will present superior performance regarding the amount of UEs that successfully received the transmitted entity. However, as next simulation results subsections indicate, this performance comes on its own cost. For the two schemes that utilize AL-FEC protection, the fixed policy and the MTO approaches, we can immediately remark the gain on the recovery performance by the increase of the source block length. This behavior directly implies from the performance properties of the RaptorQ AL-FEC code where the decoding performance is increased while the amount of source blocks protected together within one source block is increased. Due to the increased spreading of protection across the whole protected object, the RaptorQ code can operate more efficient as the source block length increase. Apart from this fact, it is expected that the gain trend on the amount of satisfied UEs will be identical between the MTO algorithm and the fixed AL-FEC policy. Since the reception conditions are not altered for each simulation instance and the MTO algorithm operation is based on the adaptation of the transmission overhead according to previous transmission rounds variations on the reception conditions the simulation results are expected.

B. Packet Loss Rate

In this part we analyze how the packet loss rate of the network affects the performance of the MTO algorithm. In Fig.2 we present the achieved performance on the satisfied UEs for different values of packet loss rate against the fixed AL-FEC overhead policy and the feedback-based error protection scheme. The average packet loss rate evaluated values reside on the range of 1% to 20% simulating the multicast delivery of an object of 4096 packets to 100 UEs. We assume

Algorithm 1 Mean Transmission Overhead Algorithm

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1: procedure (ueCoverage)
2:     currentIdealOverhead ← computeIdealOverhead(ueCoverage)
3:     meanOverhead ← updateMeanOverhead(currentIdealOverhead)
4:     transmissionOverhead ← meanOverhead
5: end procedure
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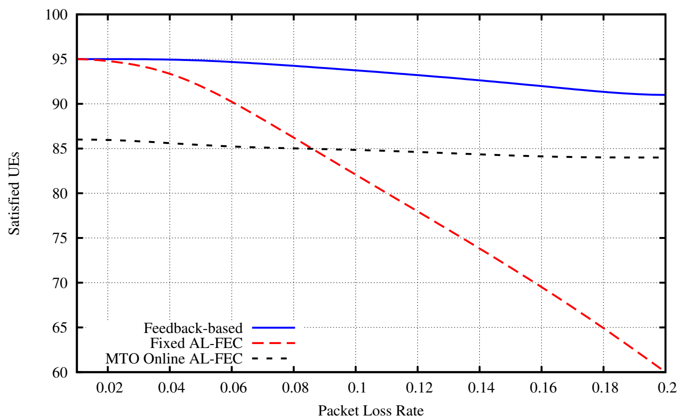

Fig. 2: Satisfied UEs vs. Packet Loss Rate

AL-FEC source blocks of size 4096 symbols and one packet per symbol. As a result the object is transmitted within one AL-FEC source block.

We can again denote that the performance of the feedback-based approach is superior compared to the AL-FEC protection. Only for small values of average packet loss rate the achieved performance is equal to the AL-FEC fixed policy approach. Of course, this fact lies on the fixed value of introduced AL-FEC overhead for the fixed policy approach which is selected in higher value compared to the average packet loss rate, which leads on high network resource waste. Another remark for the performance of the feedback-based protection is that it presents a slightly reduced performance as the packet loss rate increases. This is expected, since for high values of packet loss rate more UEs will be in bad reception conditions and will be finally dropped. It is true, that the fixed AL-FEC overhead policy can initially, for small values of average packet loss rate, achieve a high amount of satisfied UEs, but this performance is ephemeral as depicted in the curve trend. We can denote that after the value of packet loss rate exceeds the 5% the performance of the fixed overhead policy is dramatically reduced and reaches UEs coverage 25% lower from the performance of the MTO algorithm for 20% of packet loss rate. This reduction is expected as the packet loss rate increases, since the fixed overhead policy approach is not able to adapt the amount of introduced protection to the variations of the reception conditions. On the performance of the proposed MTO online algorithm we can immediately remark that the algorithm is able to achieve an almost constant performance on the UEs coverage. For high values of average packet loss rate the performance of the algorithm is slightly reduced, but this is again expected as in the case of the feedback-based approach where UEs are dropped. Moreover, the achieved coverage is lower compared to the feedback-based protection. However, this behavior is related to the selected UE coverage attribute of the algorithm with the outcome of these simulation results be the ability of the MTO algorithm to adapt on reception conditions variations.

C. Resources Utilization

For this last part of the simulation results, in Fig.3 we examine the impact of the three evaluated protection schemes on the network resources utilization in the context of the total number of packets exchanged during a multicast delivery against growing values of simulated average packet loss rate. Again, the evaluated packet loss rate is within the range of 1% to 20%. For this evaluation we simulate the transmission of an object of 4096 packets to 100 mobile UEs. Regarding the applied AL-FEC protection we utilize source block size of 4096 symbols. At this point, it is important to clarify once more that for the AL-FEC protection application each packet is mapped to exactly one AL-FEC source symbol. Hence, the transmitted object is carried over one single source block. Regarding, the feedback-based protection scheme, we have to note that each UE provides, through unicast bearers, feedback to the multicast source for the packets that need to be retransmitted. Afterwards, during a repair transmission phase, the multicast source transmits the packets to the appropriate UEs through unicast bearers.

We can immediately remark the constant number of packets introduced from the fixed AL-FEC overhead protection scheme for any value of simulated average packet loss rate. This is the expected behavior for this protection scheme since, according to the policy of this approach a constant number of redundant symbols are introduced to the transmission irrespective of the network reception conditions or any other parameter, a fact which makes this protection scheme non feasible. Furthermore, the superior protection of the feedback-based protection scheme comes on its own cost regarding network resources utilization. In comparison with the MTO algorithm, the feedback-based scheme presents significant higher amount of packets exchanged in the network for all of the simulated values of packet loss rate. Especially, when the average packet loss rate exceeds 10%, we can remark that this scheme adds more than 50% of additional traffic on

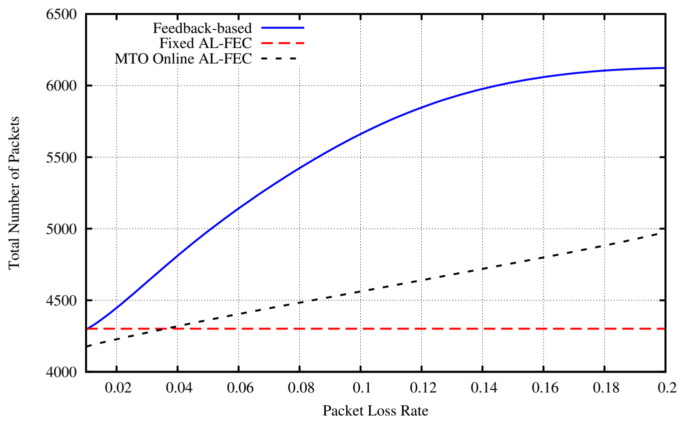

Fig. 3: Total Number of Packets vs. Packet Loss Rate

the network. Another note for the behavior of the feedback-based scheme is that after 12% of average packet loss rate the increase on the total number of packets is getting less steep since a significant amount of UEs are dropped and they are not participate in the retransmission phase. Finally,regarding the performance of the MTO algorithm we can notice that the total number of transmitted packets follow the trend of the average network packet loss rate, according to the adaptation nature of the algorithm. Furthermore, in all cases the MTO algorithm is more efficient than the feedback-based protection scheme in terms of resources utilization. Despite, the fact that the MTO algorithm cannot reach the performance of the feedback-based scheme on error recovery as depicted in Fig. 2, the gain it offers on resources utilization is by far higher compared to the error protection shortcomings it presents.

VI. Conclusions & Future Work

In this work we have presented a new AL-FEC online algorithm named MTO. The algorithm adapts the selected AL-FEC transmission overhead based on the outcome of previous deliveries. Since the reduction of the AL-FEC application over mobile networks to an online problem was newly introduced we have grasped the opportunity to design a new online algorithm and examine the impacts of this algorithm for the application of AL-FEC protection against a common feedback-based error control method and a fixed AL-FEC overhead policy.

We have described and state the proposed online algorithm MTO and we have analyzed its operational concept. Thereafter, we have introduced the network model under which we have conducted the algorithm evaluation, which refers to a typical mobile network where data are transmitted to mobile users through unreliable channels. Afterwards, we have presented simulation results for the performance achieved by the newly introduced MTO algorithm.

Regarding the outcome of the conducted simulations, we were able to verify that the proposed online scheme is able to operate close enough to the performance of a retransmission-based error recovery method or even overcome it under conditions. Furthermore, regarding the trade-off between network resources utilization and introduced error protection, the MTO algorithm is the most efficient scheme between the evaluated ones, with respect to the achieved protection in conjunction with the load it introduces to the network.

Possible future steps that can follow this work are the performance improvement of the proposed online MTO algorithm, and the design of more sophisticated online schemes for the AL-FEC policy online problem which could further boost the efficient application of AL-FEC protection over mobile services.

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