Inter-Packet Symbol Approach To Reed-Solomon FEC Codes For RTP-Multimedia Stream Protection

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***Abstract*—This paper presents an alternative Forward Error Correction scheme, based on Reed-Solomon codes, with the aim of protecting the transmission of RTP-multimedia streams: the inter-packet symbol approach. This scheme is based on an alternative bit structure that allocates each symbol of the Reed-Solomon code in several RTP-media packets. This characteristic permits to exploit better the recovery capability of Reed-Solomon codes against bursty packet losses.**

The performance of our approach has been studied in terms of encoding/decoding time versus recovery capability, and compared with other proposed schemes in the literature. The theoretical analysis has shown that our approach allows the use of a lower size of the Galois Fields compared to other solutions. This lower size results in a decrease of the required encoding/decoding time while keeping a comparable recovery capability. Finally, experimental results have been carried out to assess the performance of our approach compared to other schemes in a simulated environment, where models for wireless and wireline channels have been considered.

***Keywords*-Multimedia Communications, Wireless Networks, Real Time Protocol, Forward Error Correction, Reed-Solomon codes.**

I. INTRODUCTION

Nowadays time sensitive audiovisual communications are moving to IP networks due to the fact that packet switching networks allow lower costs and improve efficiency, thanks to the sharing of the communication channel. Voice over IP (VoIP), Television over IP (IPTV) and Video Conferences are the most popular audiovisual real time services that make use of IP networks with a deep expansion in wireless area [1].

Nevertheless, IP network transmission characteristics, due to congestions and errors, unreliable packets delivery (erasure channel) and delays are difficult to control. IP is commonly used with the transport level protocols TCP (Transmission Control Protocol) and UDP (User Datagram Protocol). The choice between TCP and UDP depends on offered service. In the case of time sensitive applications and real time services, UDP is a preferable solution because it allows lower delays, although it does not guarantee retransmission of lost packets nor the order of received packets.

In multimedia streaming context it is common to use Real time Transport Protocol (RTP), RFC 3550 [2], that works at the application layer and, in turn, is encapsulated in UDP. RTP provides several tools that help the handling of the packets transmission, such as payload type identification, sequence numbering, or timestamping.

Since neither UDP nor RTP include error control at packet level, it is usually necessary to introduce additional protection mechanisms that add robustness to the communication. In that sense RFC 5109 [3] proposes a protection based on Forward Error Correction (FEC) [4] techniques for RTP transmissions. FEC codes consist in the generation of redundancy that can be used to recover lost or corrupted information. FEC techniques are usually preferred to other error control methods such as Automatic Repeat reQuest (ARQ) schemes in time-sensitive communications, as no extra delay is added due to the use of retransmissions [5].

According to RFC 5109 it is possible to generate a FEC-RTP stream employing schemes based on parity codes (simple or interleaved), Low-Density Parity-Check (LDPC) codes, Reed-Solomon codes, etc. [6]. In this paper, we focus on Reed-Solomon codes since they are particularly appealing for erasure channels and specifically for bursty packets losses, as the case of wireless networks. Reed-Solomon codes belong to the class of Maximum Distance Separable (MDS) codes, that is, they offer the best recovery capability for a block code. Nevertheless, their application can be constrained by a remarkable computational complexity in the case that a large size of the Galois Fields is used [4] [6].

In this work we present an alternative approach to handle Reed-Solomon codes within an RTP protection scheme compatible with the RFC 5109: the inter-packet symbol approach. This scheme is based on the well known interleaving technique (e.g. in [5] and [6]) that allows an alternative bit structure that allocates each symbol of the Reed-Solomon code in several RTP-media packets. The novelty consists in applying this technique to Reed-Solomon erasure codes for RTP-media stream. That permits to better exploit the recovery capability of Reed-Solomon codes against bursty packet losses. Our approach allows the use of a smaller size of the Galois Fields compared to other solutions. This lower size results in a decrease of encoding/decoding time while keeping a comparable recovery capability.

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The paper is organized as follows: in Section II we describe the fundamentals characteristics and parameters of Reed-Solomon codes and describe our protection scheme in detail; in Section III an analysis of the performance in terms of encoding time of FEC-based schemes is carried out; in Section IV we assess the performance of the proposed scheme through experimental results; finally in Section V we present our conclusions.

II. REED-SOLOMON FEC-RTP

A. Reed-Solomon Codes

Reed-Solomon (RS) codes [7] are block codes that belong to the Maximum Distance Separable codes family. Block codes are defined by the parameters k, number of symbols of a data word, and n, number of symbols of a codeword. Let $(d_0, d_1, ..., d_{k-1})$ be a data word. A codeword is the result of the application of the code to a data word. In case the code is systematic, the codeword is formed by appending the resulting $r = n - k$ redundancy (or parity) symbols to the data word: $(d_0, d_1, ..., d_{k-1}, r_k, r_{k+1}, ..., r_{n-1})$ where r_i denotes parity symbols. Therefore, provided that the code word has been correctly received, the use of systematic codes simplifies the decoding of the data word, since just a direct extraction from the codeword is required.

Reed-Solomon codes are linear no-binary cyclic codes, formed by sequences of m-bits symbols, that belong to (2^m) extended Galois fields, where m takes values greater than two. RS code parameters n and k are chosen so as to (1) and (2) are fulfilled:

$$n = 2^m - 1 \tag{1}$$

$$k = 2^m - 1 - 2t \tag{2}$$

where $2t$ equals the redundancy r of the code. The recovery capability of a MDS code depends on whether the positions of erroneous symbols are known (erasure codes) or not (error detection and correction codes). In the first case, a maximum of r erroneous symbols can be recovered, whereas in the latter only $t = r/2$ symbols can be detected and corrected.

B. Protection Scheme Description

RTP, specified in RFC 3550 [2], is an application layer protocol that defines a packet format suitable for transmitting audio and video data over IP networks. It is commonly used on top of UDP and provides tools such as payload type identification, sequence numbering, or timestamping, which are useful for transmission management and monitoring. Nevertheless, RTP by itself does not provide any additional error protection mechanism.

In order to provide robustness for the RTP transmissions, RFC 5109 describes an approach that allows the application of FEC on a multimedia RTP stream. More specifically, for a given FEC code of parameters (n, k), the packetized multimedia stream (RTP-media packets) is divided into k-packet groups and the FEC code is applied to each group. The outcome of the FEC code is packetized in turn, in $n-k$ RTP packets (FEC-RTP packets) resulting in a new RTP stream that can be used at the reception side to recover lost RTP-media packets.

RFC 5109 firstly defines how to combine the fields of an RTP packet in order to generate a bit sequence suitable for the application of the FEC code (see Fig.1). We will refer to this output bit sequence as an *information string*. Therefore, from a group of k RTP-media packets, a set of k information strings are formed. Then, the selected FEC code is applied to them resulting in a new set of $n-k$ *parity strings*. Finally, RFC 5109 specifies how to generate RTP-FEC packets out of the parity strings. Several FEC codes can be used according to this scheme. For instance, RFC 5109 includes examples of the application of simple XOR based codes.

In the literature, several works have attempted to apply Reed-Solomon codes to improve the robustness compared to other simpler codes. Reference [8] considers a real-time Internet video context and applies an RS code orthogonally across k data packets (see Fig. 2), producing $n-k$ redundant packets. In [6], a performance analysis of several FEC schemes, including RS codes, for real time applications is presented. All FEC proposed schemes generate $n - k$ redundant packets from each group of k data packets. Moreover, a new draft [9] has been proposed to the Internet Engineering Task Force (IETF) in order to apply RS codes according to the RFC 5109 proposed scheme.

The use of RS codes requires to work with symbols of m bits. Therefore it is necessary to specify how the symbols are placed in the information strings. The protection scheme proposed in [6] [8] [9] suggests that each information string is divided into groups of m bits forming RS symbols (see Fig. 2). We refer to this scheme as an *intra-packet symbol* approach. In this case, for a given RS code of parameters (m, n, k) ($RS(m, n, k)$), where m is usually 8, k RTP-media packets are needed to generate $n - k$ parity packets. Thus, this approach can recover up to $n-k$ lost packets out of each group of n transmitted packets. Note that RTP transmission results in an erasure code scenario since the location of packet losses is known. The recovery capability of the RS code is mainly controlled by the value of m according to (1) and (2). In the case of intra-packet symbol approach, the most common value of m reported in research literature is

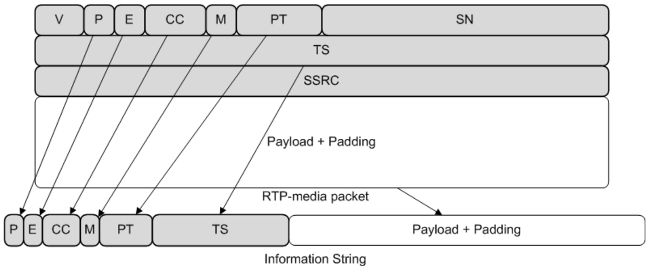


Figure 1. String generation from a RTP-media packet.

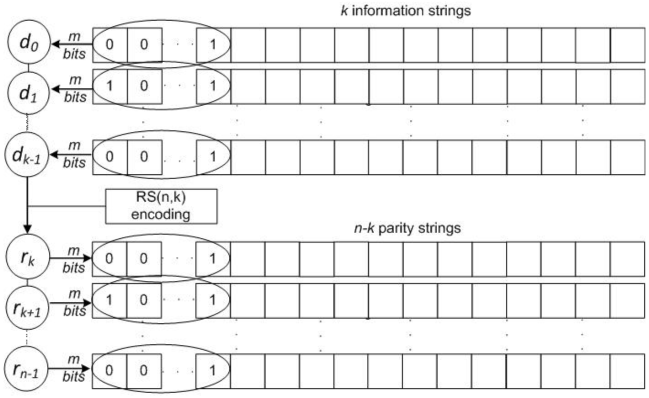


Figure 2. Symbols generation in intra-packets symbol approach.

$m = 8$ as a tradeoff between computational complexity and recovery power.

Previous works, such as [10], have pointed out that RS codes suffer from computational complexity ([6] [4]) and the encoding/decoding time depends directly on the value of m, as we will discuss in Section III. For this reason in this paper we argue that an alternative approach to the application of RS codes to the information strings can be more convenient. Our approach allocates a given RS symbol along several information strings. This enables the use of lower values of m with a comparable recovery capability to that of the intra-packet symbol scheme with higher values of m.

The main idea of this work is allocating RS symbols along several information strings as Fig. 3 shows. For this purpose, we work with groups of $k \cdot m$ RTP-media packets resulting in a matrix (information string matrix) of $k \cdot m$ information strings. Then we consider that the m bits of each Reed-Solomon symbol are spread over different rows of the information string matrix. For this reason we call our scheme *inter-packet symbol* approach. Once the entire data word is generated, $(d_0, ..., d_{k-1})$, it is encoded by the RS(m, n, k) code as specified before, resulting in a code word of n symbols. The first k symbols correspond to those of the data word, and the remaining $n - k$ represents the redundancy coefficients as described in Fig. 4.

The redundancy coefficients $(r_k, ..., r_{n-1})$ are rearranged in a redundancy matrix of $(n - k) \cdot m$ rows as shows Fig. 5. Each row of this matrix represents a parity string, which is used to generate the corresponding FEC-RTP packet according to RFC 5109. Therefore, the outcome of protecting $k \cdot m$ RTP-media packets is a total of $(n - k) \cdot m$ FEC-RTP packets.

This protection scheme permits to exploit better the recovery capability of Reed-Solomon codes against bursty packet losses, since a packet loss does not affect an entire symbol but only one of its bits. Indeed, the recovery capability of this approach can be up to $(n - k) \cdot m$, in the best case, and $(n - k) \cdot m - m + 1$, in the certain case. Therefore, the inter-packet symbol approach can reach similar recovery performance to that of the intra-packet symbol with a lower value of m, thus requiring less computational complexity. In the next section we estimate and compare the encoding time of both approaches.

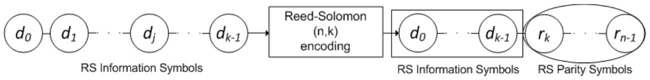


Figure 4. Encoding process for a data word.

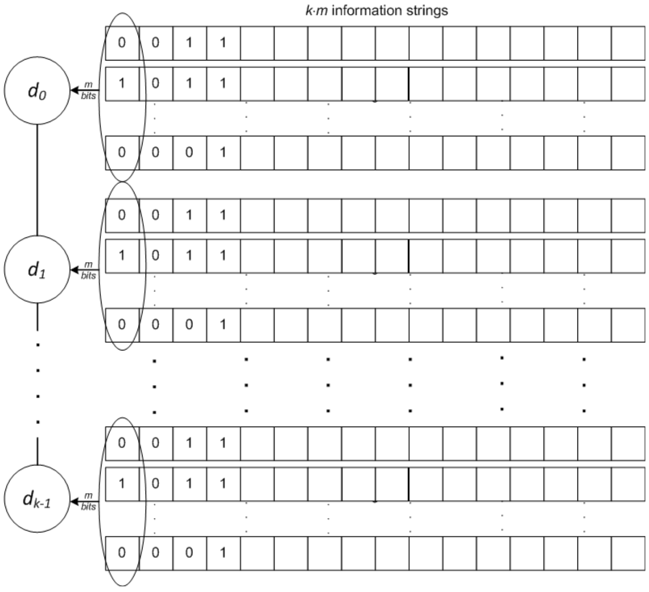


Figure 3. Symbols generation in inter-packet symbol approach.

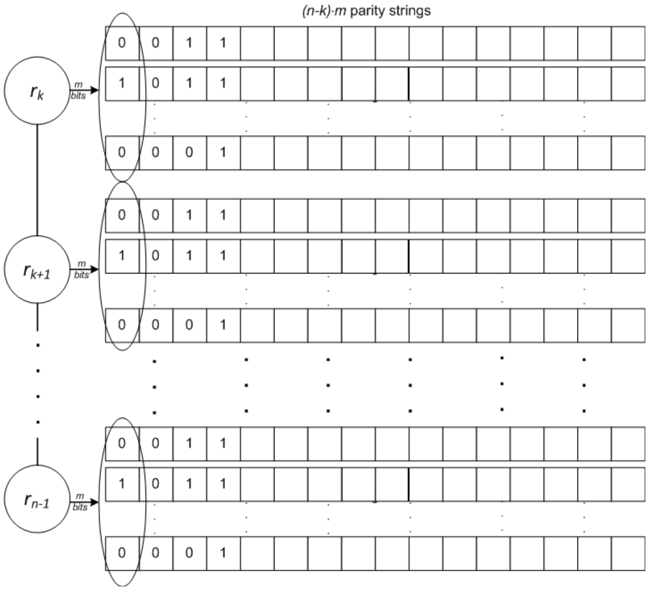


Figure 5. Generation of FEC-strings in inter-packet symbol approch.

III. PERFORMANCE ANALYSIS OF FEC-BASED SCHEMES

In this section we present a characterization of the computational complexity required by the intra-packet and inter-packet symbol approaches. Based on the models on time devoted to encoding/decoding a data word proposed in [10], we characterize the time required by both approaches to encode/decode a full media stream.

A. Encoding time of a single data word

For a given a systematic code of parameters (n, k), each data word has to be used in the FEC code $n-k$ times in order to generate $n-k$ redundant symbols. Moreover, according to [10], the time to produce a single information symbol depends also on the size of the data word, k. The bigger k is, the more time is needed to compute the parity symbols. Thus the encoding time of a data word, t_e, can be expressed as a function of k and $n-k$, as (3) shows:

$$t_e = (n-k) \cdot k / C_e \tag{3}$$

where C_e is a constant that reflects the speed of the encoding system.

On the other hand, decoding time for a code word depends on the number of missing transmitted symbols. So, considering the additional costs deriving from encoding matrix inversion, we can write the decoding time of a single symbol as:

$$t_d = (n-k) / C_d \tag{4}$$

where the constant C_d is related to the speed of the decoding system. For a given FEC code, C_d can be considered smaller than its corresponding C_e, because of the decoding computational cost which includes the inversion of the encoding matrix: this means the decoding time for a single symbol is higher than the encoding time. Therefore, in order to avoid a redundant analysis, in the following sections we only consider the encoding time to study the performance of our approach.

B. Encoding time of entire media sequence

Let consider M as the total number of RTP-media packets needed to stream a given media content, and L, the number of bits of each information string.

In case of intra-packet symbol scheme, information strings are grouped in sets of k strings. In each set, the encoding operation on data words is applied L/m times, taking into account that each symbol in the data word consists of m bits within each information string. Therefore, the number of times the encoding operations are applied for a whole content, N_o^{intra}, is expressed by the following equation (5):

$$N_o^{intra} = \frac{M}{k} \cdot \frac{L}{m} \tag{5}$$

Regarding the inter-packet symbol approach, RTP-media packets are organized in groups of $k \cdot m$ packets that generate $k \cdot m$ information strings. In this case, in each set of strings, the encoding operation on data words is applied L times, since the m bits of each symbol are spread over m different information strings (see Fig. 3). Therefore, the number of times the encoding operations are applied for a whole content, N_o^{inter}, is expressed as (6):

$$N_o^{inter} = \frac{M}{km} \cdot L \tag{6}$$

As can be observed N_o^{intra} follows the same equation as N_o^{inter}.

Finally, we can compute the total encoding time for a media sequence from (3), (5), and (6):

$$t_e^{tot} = \frac{ML}{C_e} \cdot \frac{n-k}{m} \tag{7}$$

As can be seen in (7), the encoding time of an entire packetized media content follows the same expression for both schemes and it only depends on the parameters of the chosen RS code (n, k). Nevertheless, given a predetermined recovery capability that the protection scheme has to fulfill, the inter-packet approach is more efficient in terms of computational cost thanks to the alternative distribution of the symbol bits along the information string. Table I shows the different values given to the RS parameters that have been used to compare both approaches. Note that the recovery capability is conditioned by the number of resulting parity packets. Therefore we have selected those RS configurations that use comparable number of redundant packets and code rate. As a consequence, both schemes will require a similar number of input media packets to generate the FEC stream.

Fig. 6, 7 and 8 show the total encoding time as a function of the number of generated redundancy packets (r_{pck}) in normalized time units.: $Normalized\ t_e^{tot} = (n-k)/m$.

We can observe that for a given recovery capability, the encoding time of the inter-packet symbol scheme is lower than that of the intra-packet symbol approach. This occurs since the inter-packet symbol approach requires a lower value of m to fulfill a specific recovery capability. Note that the number of redundant packets in our scheme is $r_{pck} = (n-k) \cdot m$ ($(n-k) \cdot m - m + 1$ certain

Table I

PARAMETERS m AND n FOR INTRA-PACKET AND INTER-PACKET APPROACH. m AND n HAVE BEEN CHOSEN SO AS TO THE NUMBER OF REDUNDANT PACKETS ARE COMPARABLE IN BOTH SCHEMES.

Inter-Packet Approach	**Intra-Packet Approach**	**Parity Packets**
$m = 4$ bits per symbol $n \cdot m = 60$ total packets	$m = 6$ bits per symbol $n = 63$ total packets	$r_{pck} \in [6, 26]$
$m = 5$ bits per symbol $n \cdot m = 155$ total packets	$m = 7$ bits per symbol $n = 127$ total packets	$r_{pck} \in [5, 51]$
$m = 6$ bits per symbol $n \cdot m = 378$ total packets	$m = 8$ bits per symbol $n = 255$ total packets	$r_{pck} \in [7, 102]$

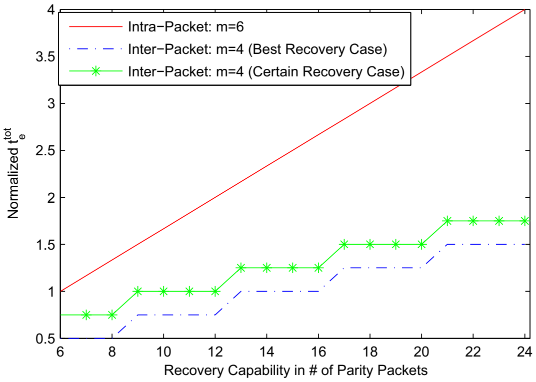


Figure 6. Encoding time of an entire video in two different schemes: Intra-Packet m=6, Inter-Packet m=4.

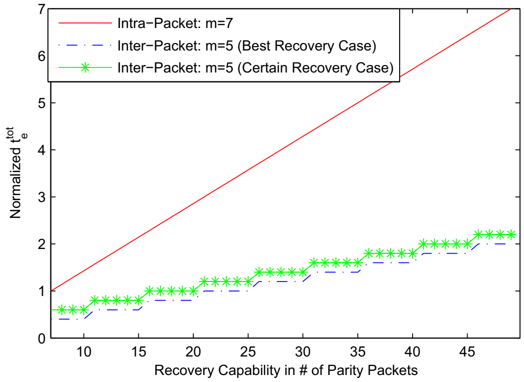


Figure 7. Encoding time of an entire video in two different schemes: Intra-Packet m=7, Inter-Packet m=5.

recovery capability) whereas in the intra packet symbol is $r_{pck} = (n - k)$.

IV. SIMULATION RESULTS

The recovery capability of the inter-packet symbol approach depends on how bursts affect each group of packets since each packet contains a single bit of a symbol. Therefore, a lower bound can be computed being the maximum length of a burst of lost packets that the inter-packet symbol approach can certainly recover (the certain case). Nevertheless, in case the burst is aligned with a packet that corresponds to the beginning of a symbol (the best case), the maximum length of the burst that can be recovered is higher than that of the certain case. Therefore, an RS code following our approach can recover error bursts of length ranging from $((n - k) \cdot m - m + 1)$ packets in the certain case up to $((n - k) \cdot m)$ packets in the best case.

In order to assess the effectiveness of our approach within a communication system, we have compared two RS codes in a simulated environment. The m parameters of both protection schemes are $m = 4$ in case of inter-packet symbol approach and $m = 6$ in case of intra-packet symbol scheme. Besides, the code rate has been fixed to $k/n = 40\%$ for both approaches. The recovery characteristics of both RS codes are summarized in Table II.

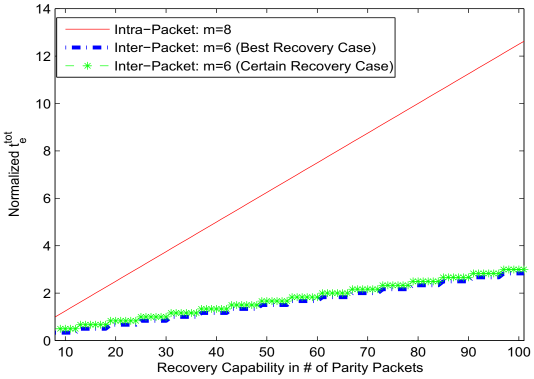


Figure 8. Encoding time of an entire video in two different schemes: Intra-Packet m=8, Inter-Packet m=6.

Table II
RECOVERY CAPABILITY FOR INTRA-PACKET AND INTER-PACKET APPROACH.

Intra-Packet Approach	**Inter-Packet Approach**	
	best case	***certain case***
24 packets	24 packets	21 packets

We have carried out different experiments simulating the transmission of an RTP-media stream together with its corresponding RTP-FEC stream. The input to our system is an MPEG2-TS video movie. The transmission channel is simulated through a simplified Gilbert-Elliot model according to [11]. Table III shows the parameters of the channel models considered. The average burst length has been set close to the maximum recovery capability of the RS codes and close to the typical average burst length for wireless networks (about 20 packets for 802.11g [12]).

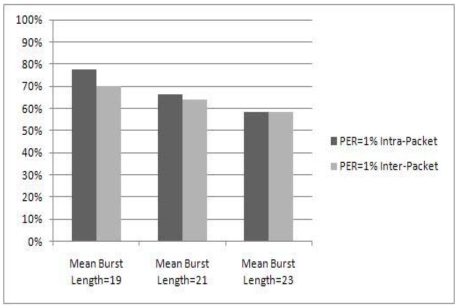
Fig. 9 shows the ratio of recovered packets with respect to the number of lost packets. As can be observed, the inter-packet symbol approach provides similar results in all the experiments to those of the intra-packet symbol scheme. Moreover, the results of the inter-packet approach are closer to those of the intra-packet approach as the average burst length increases.

V. CONCLUSION

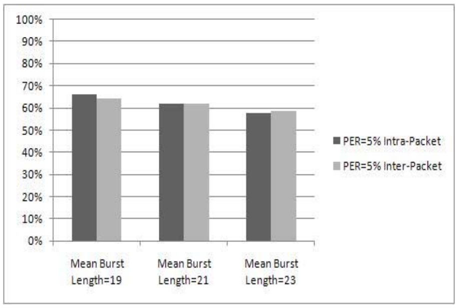
In this paper we have introduced a novel approach to handle Reed-Solomon codes within a protection scheme intended for RTP transmission of multimedia contents: the

Table III
PARAMETERS OF COMMUNICATION CHANNEL.

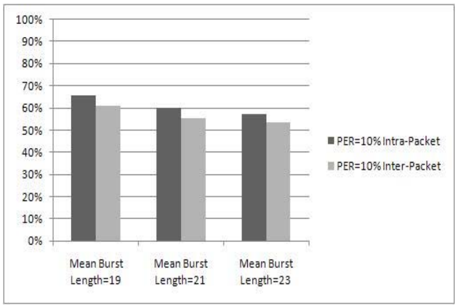
Packet Error Rate (PER)	**Average Burst Length (packets)**
1%	19
	21
	23
5%	19
	21
	23
10%	19
	21
	23



(a) PER=1%.



(b) PER=5%.



(c) PER=10%.

Figure 9. Percentage of recovered packets obtained by the inter-packet and intra-packet approaches for the different channel models specified in Table III.

inter-packet symbol approach. This scheme is based on an alternative bit structure that allocates each symbol of the RS code along several RTP-media packets. This characteristic permits to exploit better the recovery capability of Reed-Solomon codes against bursty packet losses, since a packet loss does not affect an entire symbol but only one of its bits. Moreover, the inter-packet symbol approach is compatible with the RFC 5109.

We have analyzed the performance of our approach in terms of computational complexity versus recovery capability, and compared with other proposed schemes in the literature that follow an intra-packet symbol approach. The theoretical analysis has shown that our approach allows the use of a smaller size of the Galois Fields size compared to other solutions. This lower size results in a decrease of the required computational cost while keeping a comparable recovery capability. This result has been finally assessed through experimental tests in which both schemes have been used to protect an RTP-media transmission in a simulated wireless environment.

ACKNOWLEDGMENT

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