Evaluation of Error Control Mechanisms for 802.11b Multicast Transmissions

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Abstract— **This article first presents several packet loss profiles collected during 802.11b multicast transmissions carried out under variable reception conditions (mobile and fixed receivers). Then, an original approach consisting in mapping *a posteriori* some error control mechanisms over these observations is presented. This approach allows to evaluate the performance of these mechanisms according to their parameters and various channel properties. It is shown in particular that relatively simple mechanisms based on retransmissions and/or error correcting codes of small length achieve very good performance in this context (92% of the best performance).**

I. INTRODUCTION

Wireless networks have become a very popular way to exchange data. As a major example, the 802.11 family of protocols for wireless LANs is now largely deployed, for instance in offices or in hotspots like hotels, airports or conference locations. However, due to the fragile nature of wireless communications over the radio channel, those communications suffer from relatively high packet loss rates at the link level. The problem is even worse when considering multicast transmissions where different receivers naturally experience heterogeneous packet loss profiles. Offering reliable communications over such multicast wireless networks is quite a challenge.

The various 802.11 MAC layers handle packet losses but only for unicast transmissions; in multicast neither acknowledgements nor retransmissions occur [1] and reliability must be provided by higher layers.

A number of mechanisms have been proposed for terrestrial multicast transmissions (e.g. over the MBONE) and can be globally reconsidered [2]. Two essential types of mechanisms ensuring packets transmission reliability can be distinguished: reactive mechanisms using Automatic Repeat reQuest (ARQ), and proactive mechanisms based on Forward Error Correction (FEC) codes. These mechanisms are often combined (Hybrid ARQ mechanisms) by using acknowledgments to adjust the quantity of redundancy of FEC codes (see e.g. [3]). However these works often make very strong assumptions on the loss profiles: each receiver experiences uniformly distributed losses, and independently from each other. Those models have been used to evaluate the above mechanisms and conclude that hybrid mechanisms rapidly outperform other mechanisms. Another approach is to reliability mechanisms is to observe real traffic and evaluate reliability mechanisms against real traffic [7].

Although a number of models have been proposed to weaken the uniform loss assumption, e.g. based on Markov chains, little work has been done to weaken the independent losses assumption [5], [6]. Yet, the selection of the most appropriate error control mechanism is closely tied to the type of errors that affect the transmission channel. In a wireless LAN multicast context, errors result in packet losses which can be characterized not only by a mere packet error rate, but also by the correlation of losses in both space and time: spatial correlation measures the probability that a packet is lost by more than one receiver, while temporal correlation measures the burstiness of losses experienced by a given receiver.

The present work describes a method based on the collection of real traces and on trace-based simulation allowing to take into account all the above parameters upon evaluation of error control mechanisms. We will show that a fair re-evaluation of the performance of classical mechanisms can be done on the basis of our work. Section II describes how traces were collected and characterized in terms of temporal and spatial correlation. Section III evaluates a set of classical error control mechanisms against the collected traces. The impact of spatial and temporal correlations on the observed results is showed. The performance of small length FEC codes is then evaluated. We conclude with Section IV.

II. PACKET LOSSES MEASUREMENTS

In a wireless multicast context, packet losses can be characterized by the following parameters:

- the **packet loss rate**: on 802.11b links with infrastructure, this rate is extremely variable according to the position, the movement and the distance between the receiver and the access point;
- the temporal distribution of packet losses, or **temporal correlation**: this parameter indicates whether, for a given receiver, packet losses are grouped or distributed in a uniform way;
- the correlation of packet losses among the receivers, or **spatial correlation**: this parameter, specific to multicast transmissions, indicates if the losses observed by a receiver are independent of the losses observed by the other receivers.

These three parameters are absolutely necessary to evaluate an error control mechanisms. The packet loss rate reflects the global transmission quality. The temporal correlation allows the adjustment of the parameters k and n of a FEC code.

Indeed, for a fixed packet loss rate, a code will be able to correct isolated losses quasi-perfectly, but could be completely ineffective with grouped losses. The spatial correlation is also important: if a packet is lost by a large proportion of receivers, retransmitting this packet is useful for all of them; if the packet is lost by a small proportion of receivers, retransmitting is only useful for a few receivers.

This remainder of this section presents experimental packet losses measurements in an 802.11b infrastructure mode network, with various mobility and reception conditions. The collected traces are analyzed and the importance of the observed spatial and temporal correlation is pointed out.

A. Experimental Platform

A platform of wireless tests was installed in order to collect IP multicast packets loss measurements. It relies on an 802.11b infrastructure mode network, which comprises one access point, nine nodes with an 802.11b interface, and one node with an Ethernet interface, directly connected to the access point. Various types of 802.11b interfaces (PCI, USB and PCMCIA) and material architectures (PC, laptop PC, Pocket PC) were used.

First, a series of 5 experiments was carried out during which all the nodes remained motionless. The nodes were placed at various places, with a distance approximately 2 to 20 meters and a separation of 0 to 4 walls from the access point. In a second series of 6 experiments, 4 of the nodes were mobile: each one was carried by an operator walking without a specified trajectory while always remaining in the range of the access point. In each experiment, the fixed node `wifisender` transmits a 90-second long multicast MPEG/RTP video stream, which consisted of 300 to 1400 bytes packets with a mean bandwidth of 500kbps, to 9 wireless receivers (`wifi-recv-`n, $n \in \{1, \dots, 9\}$) and one Ethernet receiver (`eth-recv`). One of these nodes, `wifi-recv-6`, is an IPaq Pocket PC.

Thus, each experiment made it possible to record the sequence numbers of the RTP packets actually received by each receiver. No acknowledgment nor retransmission being performed in the MAC layer for multicast packets [1], each received RTP packet was transmitted only once at the MAC level. Assuming that no packet is lost on Ethernet, `eth-recv` allows the measurement of MAC losses over the uplink between the transmitter and the access point, the wireless receivers allowing to measure the additional MAC losses over the downlink.

B. Captured Traces

Figure 1 gives the traces of one of the experiments with four mobile stations (`wifi-recv-2`, `wifi-recv-4`, `wifi-recv-5` and `wifi-recv-6`). Only the traces for stations with a 802.11b interface are shown here. The displayed experiment is representative of the others, as we will see later.

The x-axis corresponds to the sequence of transmitted packets and the y-axis illustrates the length of packet loss bursts for each station. The percentage given after the station name is the packet loss rate observed for this station in this experiment. Lines are separated by a height representing 10 consecutive losses, and large peaks have been cut off. The receiving stations listed on the left are ranked from the closest to the farthest, except for `wifi-recv-1` which is close to the access points but loses many packets. Receiver `eth-recv` loses no packet in this experiment and is not displayed here to simplify the picture.

The experiments show that practically no data is lost on the uplink, and that many losses are observed on the downlink. The peaks observed for each individual receiver of Figure 1 denote temporal correlation. Spatial correlation can be observed too when peaks occur for the same packets, as in e.g. experiment #11 for packets around #7100.

	Temporal correlation		Spatial correlation	
Experiment	μ_T	σ_T	μ_S	σ_S
1	1.56	2.57	1.01	1.27
2	1.53	2.93	1.05	1.50
3	1.62	2.91	1.13	1.23
4	1.65	2.99	1.33	1.19
5	1.67	3.05	1.08	1.42
6	1.52	2.97	0.92	1.42
7	1.63	7.87	0.99	1.26
8	1.61	3.33	1.12	1.15
9	1.59	3.62	0.84	1.16
10	1.44	2.98	0.72	1.15
11	1.73	3.82	1.11	1.69

TABLE I

SPATIAL AND TEMPORAL CORRELATIONS

C. Trace Analysis

For each receiver, the temporal correlation can be characterized by the length of the burst losses and by the length of periods without loss. The average and the standard deviation of the burst lengths, averaged for all receivers of a given experiment, are respectively denoted by μ_T and σ_T. The spatial correlation can be characterized by the size of the set of receivers losing a given packet. This size was computed for each packet transmitted. Spatial correlation is globally evaluated by the computation of the average μ_S and the standard deviation σ_S of this size for each experiment.

The results concerning the temporal and spatial correlations for the 11 experiments are given in Table I. These results show that the variation of both spatial and temporal correlation is very important, and we will see that it has a strong impact on the performance of error control mechanisms. In particular, having long burst lengths or having large groups of losers affects the performance of FEC-based mechanisms. The effects of spatial and temporal correlation on performance will be quantitatively demonstrated in Section III-B.

D. Traces Derivation

To interpret the values of of μ_T, σ_T, μ_S and σ_S in Table I, the real traces were modified in order to remove temporal and/or spatial correlations.

To remove only the temporal correlation of a given experiment, the transmission order of the packets was changed using

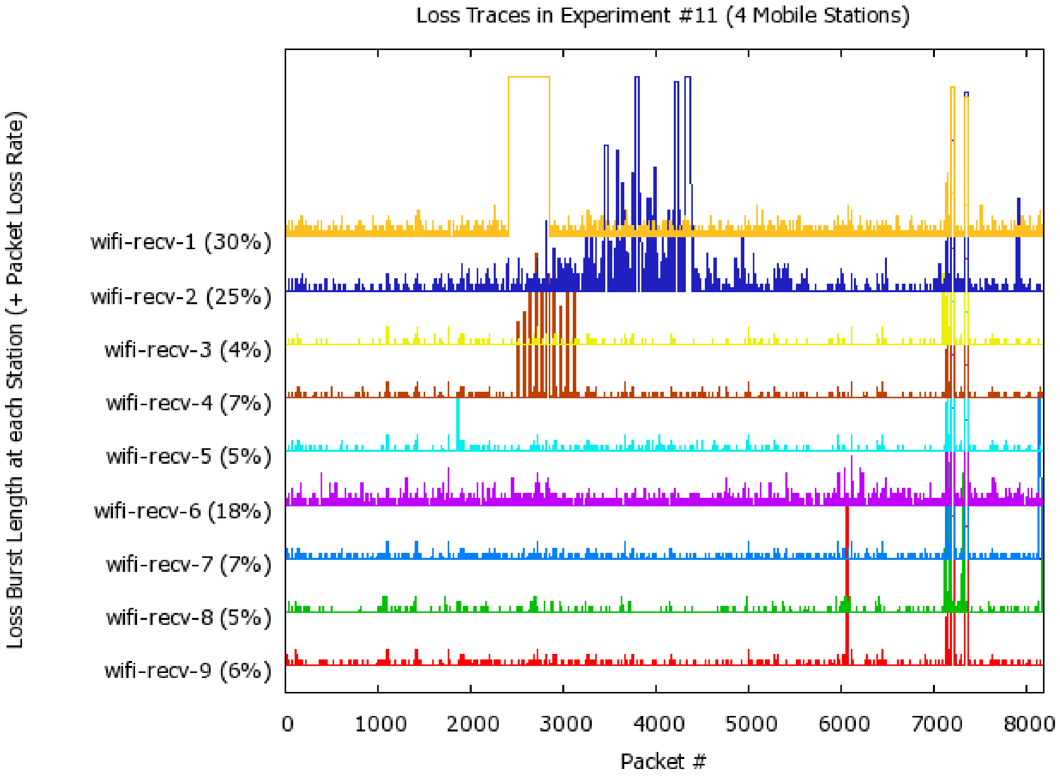

Fig. 1. Traces of packet losses with fixed and mobiles stations

permutations. The same permutations were applied to all the traces, so that the spatial correlation was not modified.

To remove only the spatial correlation of a given experiment, independent circular shifts were applied to each receiver trace. The independence of shifts allowed the spatial correlation to be removed while keeping the temporal correlation (i.e. the length of the burst losses) constant.

To remove both temporal and spatial correlations while keeping the packet loss rate observed by each receiver, losses were generated according to a random uniform independent law with a packet loss rate corresponding to the observed one.

The last trace derivation also removed both temporal and spatial correlations and consisted in evaluating the global packet loss rate observed for the set of the receivers of a given experiment and generating random uniform independent losses with the global packet loss rate.

The results presented in Table II show that the proposed derivations effectively remove spatial and/or temporal correlations: when a correlation is removed, the corresponding values are close to the uniform case.

III. SIMULATING ERROR CONTROL MECHANISMS

In this section the performance of representative error control mechanisms in the wireless multicast transmission context is evaluated. These mechanisms comprise an ARQ-like reactive mechanism, a FEC-based proactive mechanism, and a hybrid ARQ mechanism [3]. Note that we did not seek to evaluate the most advanced mechanisms found in the literature. Our goal was simply to evaluate the various mechanisms *potential* by evaluating them at their best. It is observed that using real traces, these mechanisms exhibit unexpectedly close performance results.

A. Proposed Methodology

Section II has pointed out the importance of temporal and spatial correlations, and the difference observed between real traces and uniformly generated traces. We thus decided to evaluate error control mechanisms with real traces rather than with traces generated by the models proposed in e.g. [6] or [7]. *Reliable* multicast transmission mechanisms are studied here.

The main idea of the simulations proposed here is to evaluate on a fixed trace the number of information packets that would have been received by all receivers using a given mechanism. For each receiver, a trace of packet losses has been captured with only information packets (see Sections II-A and II-B). We use the exact same traces with the assumption that information and/or redundancy packets that would have been sent using any of the error control mechanisms below would have experienced the same losses.

Of course error control mechanisms imply the use of acknowledgement packets (positive, negative, selective, etc.) on the return channel. We make some classical simplifying assumptions: the return channel is error-free, and the considered stream is slow enough so that receivers have the time

	Experiment #6				Experiment #11			
	μ_T	σ_T	μ_S	σ_S	μ_T	σ_T	μ_S	σ_S
Real traces	1.52	2.97	0.92	1.42	1.73	3.82	1.11	1.69
Traces without temporal correlation	1.13	0.36	0.92	1.42	1.17	0.44	1.11	1.69
Traces without spatial correlation	1.52	2.97	0.92	0.86	1.73	3.82	1.11	0.95
Uniform independent losses (original receiver's rate)	1.11	0.30	0.92	0.86	1.14	0.36	1.11	0.95
Uniform independent losses (common global rate)	1.12	0.37	1.02	0.96	1.14	0.40	1.24	1.05

TABLE II

TEMPORAL AND SPATIAL CORRELATIONS FOR SELECTED EXPERIMENTS

to transmit their acknowledgments before the transmission of the next packet. Moreover, we assume that the transmission of acknowledgements does not change the sequence of losses among information or redundancy packets.

On the other hand, the strong points of this approach are numerous. First, the comparisons of the mechanisms are done exactly on the same traces. Moreover, tests are easy to run, thus allowing very fine evaluations of the various parameters. Finally, additional simulations can be carried out to evaluate the chosen mechanisms against derived traces (see Section II-D).

The first considered mechanism is an *ARQ*-like mechanism. Each transmitted packet must be received by all of the receivers. Hence, it is retransmitted in multicast mode until all the receivers have received it.

We then simulate a *FEC*-like mechanism. The transmitted packets result from a preliminary phase of coding which generates $n - k$ redundancy packets based on a block of k information packets. The sender transmits n consecutive packets for each block. If all receivers receive k packets or more among these n, the block is considered to be received and we count k correctly received packets. We assume here that a MDS code is used, which is optimal in terms of correcting ability for a given block. If a receiver gets less than k packets, the block cannot be decoded and no packet is counted (counting the received packets corresponds to the type II hybrid ARQ described hereafter). The block is retransmitted until it can be decoded by all the receivers; stopping after a number of unsuccessful retransmissions does not achieve a reliable multicast transmission. Note that we chose n (and therefore k) values smaller or equal to 256 in order to keep these parameters realistic. Greater values would lead the use of less powerful codes (can not work with byte values), and would also force the receiver to wait more before decoding, which is non optimal as far as delay and jitter are concerned.

Lastly, we simulate a *type II hybrid ARQ*-like mechanism, which associates MDS coding and ARQ as follows: a block of packets to be transmitted is divided into k information packets, the sender then transmits these k packets consecutively. After that, each receiver sends an acknowledgment specifying the number of lost packets $r_i, i \in \{1, \ldots, 10\}$, among the k initially sent. The sender calculates the maximum $r_{\max}$ of these values, encodes $r_{\max}$ new redundancy packets and then transmits them. The process is repeated until all of the receivers have received at least k packets. Here again we chose values of k smaller or equal to 256.

B. Simulation Results and Discussion

For each mechanism and for each set of traces, we compute the percentage of *information* packets received or decoded by *all* receivers. In the case of FEC simulations, the result given corresponds to the (k, n) couple achieving the best performance. In the case of type II hybrid ARQ simulations, the result corresponds to the k value achieving the best performance.

The results of these simulations are presented in Figure 2 for all experiments. In all the cases, the hybrid ARQ mechanism is the most efficient in terms of the received over transmitted packets ratio. This result is not surprising since this mechanism combines the advantages of FEC (a single redundant packet can be used to recover distinct losses in different receivers) and ARQ (adaptive number of retransmissions). This result confirms the others results in this domain [2], [4]. More surprising is the unexpectedly small difference of performance between hybrid ARQ and both FEC and ARQ mechanisms. This similarity of performance was confirmed by additional simulations taking into account the best 7 or the worse 3 receivers.

C. Simulating with Derived Traces

This difference in appreciation can be explained by the uniform independent packet loss model they used, in which case they demonstrate a clear superiority of FEC-based mechanisms. To confirm this explanation, we have evaluated these mechanisms on the derived traces, i.e. modified in order to remove the different correlations (see Section II-D). The results are presented on Figure 3 for experiment #11.

One can observe some strong differences between the performance of the mechanisms on the real channels and on the uniform independent ones. Globally, we can state that, in all cases, hybrid ARQ obtains better performance, but when spatial and temporal correlations are not taken into account, FEC-based mechanisms are overestimated while ARQ-based mechanisms are often underestimated: here the FEC-based performance jumps from approximately 4000 to 6500 packets decoded. Another important point is that channel models do not have the same impact on all mechanisms: the ARQ based only jumps from 4000 to 4200 packets received between real traces and uniform independent derived traces. These results show that the evaluation of error control mechanisms cannot be based on the uniform independent assumption.

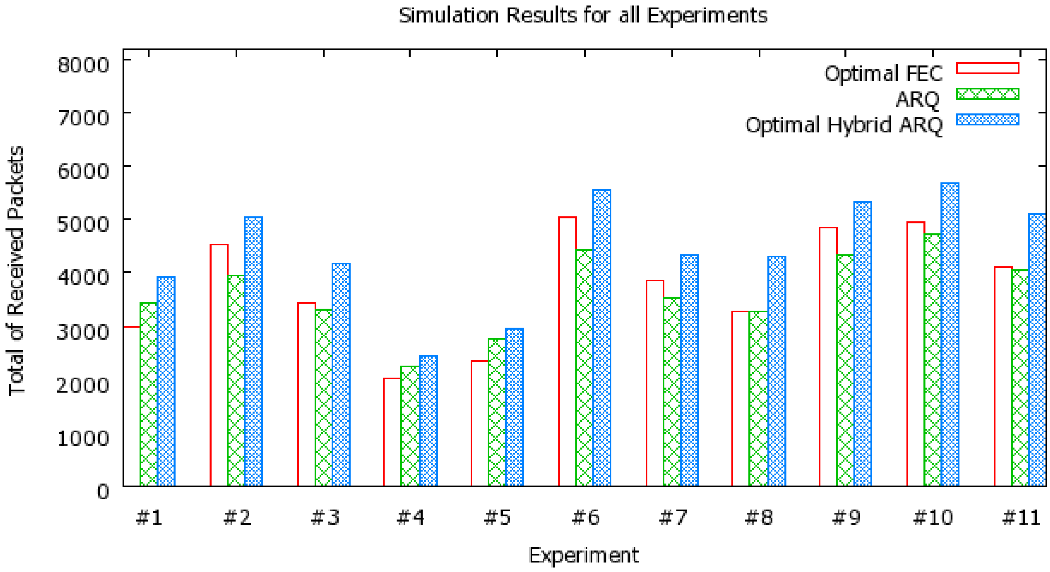

Fig. 2. Results of the simulations of the error control mechanisms for all experiments

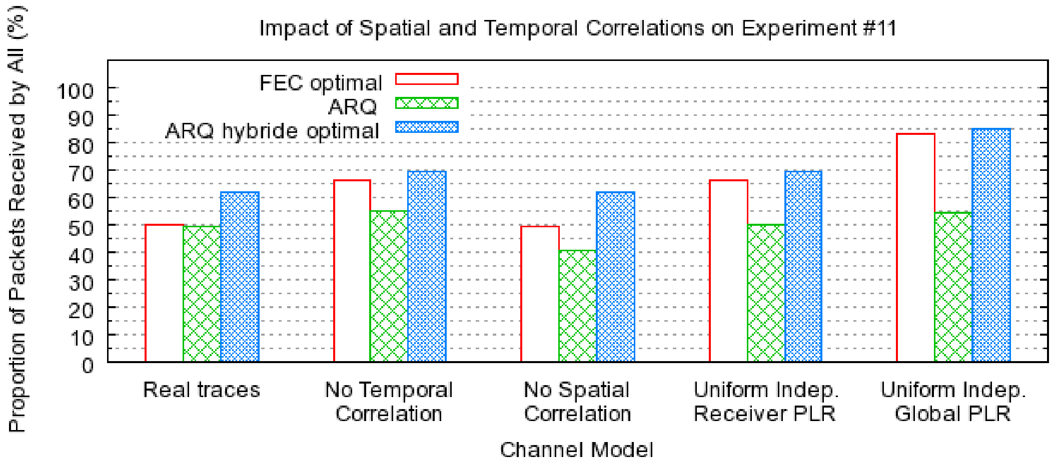

Fig. 3. Impact of the channel model on the performance of mechanisms

These observations remain valid for all other derived traces and associated channel models. The performance of FEC on the temporally uncorrelated traces is still too high (1200 packets more than on real traces), although the spatial correlation has been removed. Meanwhile, ARQ-based mechanisms receive ”only” 500 packets more than on real traces. This difference in over-performance comes from the better performance of FEC in the absence of temporal bursts.

The performance of all mechanisms on the uniformly derived traces where each receiver keeps its real loss rate are similar to their performance on temporally uncorrelated traces. The comparison with real traces leads to the same conclusions as above.

Considering spatially uncorrelated traces, we observe different performance for all mechanisms compared to real traces, but to a smaller extent than with temporal uncorrelation. Temporal bursts are still present but they are not synchronized anymore, which decreases even more the performance of FEC-based mechanisms. ARQ performance decreases because spatial bursts could be recovered with a small number of retransmissions.

This leads to the conclusion that temporal correlation has a strong impact on the performance of error control mechanisms on a real channel, and that spatial correlation has an impact too, but to a smaller extent.

D. Evaluating Hybrid ARQ Type II Performance

The results in Section III-B show that on a real channel, ARQ-based mechanisms have a better than expected performance. In this section, the parameters of the FEC code

Exp.	$k_{\max}$	$k_{\max}$ perf.	$k = 64$	$k = 32$	$k = 16$
#1	245	48,36	98,8	98,7	97,3
#2	245	62,02	97	95	92,4
#3	161	50,76	97,3	96,3	94,1
#4	244	29,48	98,9	98,9	99
#5	247	36,42	99,1	99	98,6
#6	198	67,74	98,8	97,2	94,8
#7	206	56,91	98,6	96,5	94,5
#8	220	51,34	96,5	94,7	92,4
#9	221	65,35	97,9	96,7	94,4
#10	203	69,40	98,9	97,3	94,6
#11	218	61,78	97,1	95,4	92,7

TABLE III

PERFORMANCE OF HYBRID ARQ WITH SHORT LENGTH CODES

used in a hybrid-ARQ mechanisms are studied in detail. Indeed, the ARQ mechanism can be considered as a hybrid ARQ mechanisms with a code of length 1. The relatively good performance of ARQ compared to hybrid ARQ with long length codes (up to 1024 in our simulations) has lead us to evaluate the performance level of short length codes in a hybrid ARQ mode. Indeed, as confirmed by energy consumption measurements of different FEC processing on a Pocket PC (not shown here), short length codes are easier to manipulate (coding/decoding speed, energy consumption, memory use). Table III presents the performance of short codes (3 last columns) relatively to the best code. The k value corresponding to the best code of length ≤ 256 is given in the second column and its performance in terms of the proportion of useful packets is given in the third column.

These results show a rather good performance of short length codes, which stand at least within 92% of the best performance. This is a very interesting result since short length codes are fast to decode, can be implemented on almost any platform since they do not require a lot of memory, and do not imply a large delay before delivery of the decoded information to the above layer.

IV. CONCLUSION

We collected traces of a real multicast traffic over a wireless network, then applied to these traces error control mechanisms in order to evaluate them with realistic packet loss profiles.

The importance of both spatial and temporal correlations in the collected traces has been observed, and their influence on the performance of representative error control mechanisms has been clearly demonstrated. The performance results obtained lead us to establish the superiority of error control mechanisms based on hybrid FEC-ARQ mechanisms for wireless multicast communications. However, as a good behavior of retransmission-based mechanisms over a real wireless channel was also observed, the performance of hybrid ARQ mechanisms with *short length* codes was also investigated. This solution proves satisfying and thus appears to be a really good compromise between the error control performance and the ease of use (energy consumption, coding/decoding speed, memory use) by mobile devices with limited capacities.

We now intend to improve the precision of the method we used by also simulating the transmission of various types of acknowledgment (positive, negative, selective, in point-to-point or in multicast). Moreover, we plan to integrate real-time constraints inherent to some multimedia transmissions within this method.

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REFERENCES

[1] ANSI/IEEE Std 802.11, “Wireless LAN MAC and PHY Specifications,” 1999.

[2] L. Rizzo and L. Vicisano, “RMDP: an FEC-based Reliable Multicast Protocol for Wireless Environments,” *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 2, no. 2, pp. 23–31, 1998.

[3] S. Lin and D. Costello, *Error Control Coding: Fundamentals and Applications*. Prentice-Hall, Englewood Cliffs, NJ, 1983.

[4] P. Chumchu and A. Seneviratne, “Adaptive Packet Level Redundancy Mechanisms for Reliable Mobile Multicast: Proposed Architecture and Performance Analysis,” in *The First International Conference on Information Techology & Applications (ICITA 2002)*, 2002.

[5] P. McKinley, C. Tang, and A. Mani, “A Study of Adaptive Forward Error Correction for Wireless Collaborative Computing,” *IEEE Transactions on Parallel and Distributed Systems*, vol. 13, pp. 936–947, September 2002.

[6] C. Tang and P. McKinley, “Modeling Multicast Packet Losses in Wireless LANs,” in *The Sixth ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM 2003)*, 2003.

[7] G. Nguyen, R. Katz, and B. Noble, “A Trace-Based Approach for Modeling Wireless Channel Behaviour,” in *The 1996 Winter Simulation Conference*, 1996.