A Novel Approach to ARQ Error Control Mechanisms for Wireless LANs Communications

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Abstract

Communications in high-speed wireless mobile networks have to deal with large varying transmission and service requirement conditions, often needing complex radio modulations and concatenated error control functions. For the latter, it is usual to implement Forward Error Correction and Automatic Repeat reQuest (ARQ) mechanisms in, respectively, the Physical (PHY) and the Data Link Control (DLC) layers. Even so, the communication requirements of medium/high quality real-time services may be hard to meet under hostile transmission conditions. In this paper an analysis on some improvements over current ARQ error control schemes is presented, envisaging more efficient communications in high-speed wireless LANs. It will be shown that high performance ARQ schemes can be used at the DLC layer of wireless LANs by carrying critical control information in more robust physical modes. Performance comparisons for current and proposed ARQ schemes, and some protocol implementation aspects, are the main focuses of analysis.

1. Introduction

Error control is one of the most important functions in a modern digital communication system. The two classical ways to implement such control are the Forward Error Correction (FEC) and the Automatic Repeat reQuest (ARQ) mechanisms. The choice for one of both methods is traditionally related with the kind of application in terms of delay tolerance, application error sensitivity and the availability of a feedback channel. FEC is normally used for delay-constrained communications such as real-time audio and video services; ARQ is more suitable for delay-tolerable communications such as typical data services.

Wireless mobile digital communications are strongly affected by errors caused by the joint effects of fading and multipath signal propagation. Fading effects are felt only at minor percentages of time, but multipath effects can be more persistent, depending on the mobile terminal location. When too many errors occur one says the radio channel is in a *bad* condition; otherwise the radio channel is considered to be in a *good* condition.

For these fading and multipath environments, a FEC type mechanism represents a lack of efficiency since FEC doesn't adapt to variable error channel conditions: either a waste of bandwidth may occur when the radio channel is in a good condition, or insufficient error protection may exist when it gets bad.

An ARQ mechanism is by far more adaptable to the variable radio channel conditions than FEC. Nevertheless, in the presence of a low-speed short-range wireless network, or in a high-speed long-range radio link, an ARQ mechanism presents prohibitive time delays for delay-constrained communications, such as those carrying real-time audio and video. This limitation is mainly due to the cumulative delays originated by the packet framing, packet transmission, protocol execution and propagation time from transmitter to receiver, making the allowable number of retransmissions almost null.

With the recent and on-going development of high bit rate Wireless Local Area Networks (WLANs) standards [1, 2], intended for short-range communications and to be operated at frequencies around 5 GHz [3], the ARQ mechanisms are, again, being strongly considered even for delay-constrained applications.

From a protocol layering perspective, in these WLANs the FEC mechanism is mainly used in the wireless PHY layer and associated with an Orthogonal Frequency Division Multiplexing (OFDM) modulation scheme [4]. The functions related with the time frame structure and respective access are carried out in the wireless Medium Access Control (MAC) sublayer. ARQ mechanisms may finally be used in the wireless Logical Link Control (LLC) sublayer, to further improve the communication link quality. Figure 1 shows the wireless specific layers within a typical user plane protocol reference model.

In fact, as radio link speed increases and distance between transmitter and receiver points decreases, the sum of packet transmission delay and propagation delay becomes small enough to consider ARQ as a viable solution for the error protection of real-time communications. Proof of this is the publication of several recent works supporting this idea [5, 6]. This approach will enable scenarios with real-time multimedia terminals using Wireless LANs both in infrastructure and ad hoc modes. A representation example is shown in Figure 2.

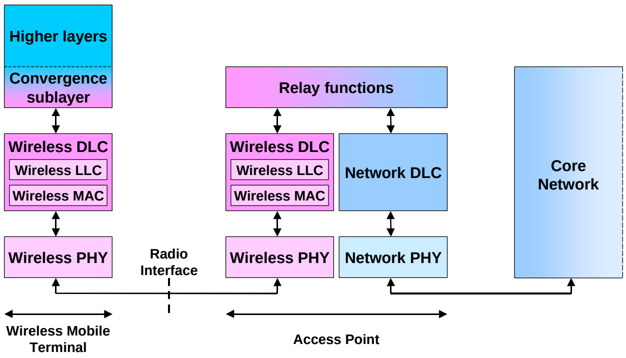


Figure 1. Wireless LANs User Plane Protocol Reference Model.

Perhaps even more important than publications is the recent adoption by ETSI/BRAN Project of a basic set of error control modes for its High Performance Local Area Network Type 2 (HIPERLAN/2) standard, implemented in the DLC layer [7]. These so-called "acknowledged", "repetition" and "unacknowledged" modes differ mostly in reliability terms. Their application depends also on the connection type (unicast, multicast or broadcast). Anyway, intrinsically or through some extra mechanism, all of them have means to achieve low latency transmissions.

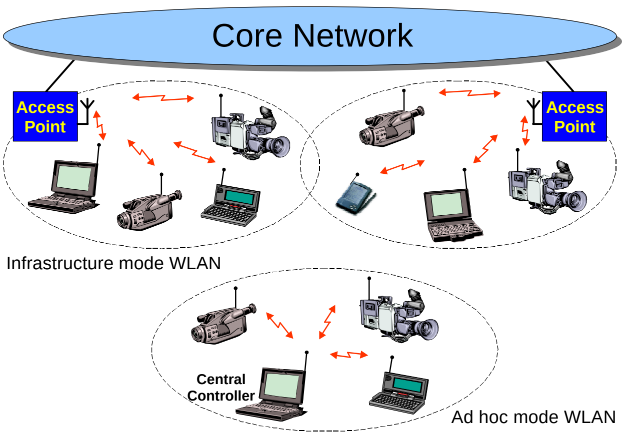


Figure 2. Multimedia terminals using Wireless LANs.

For unicast connections the acknowledged mode is the main error control mode and is based on ARQ mechanisms in order to provide more reliable transmissions. But even in this mode and to deal with time expired packets that belong to delay-constrained applications, a packet discard mechanism is provided [8, 9]. In this way a low latency transmission is guaranteed.

The HIPERLAN/2 DLC User Protocol Data Unit (U-PDU) format, which has a total of 432 bits (54 octets), is depicted in Figure 3. Some fields of the U-PDU are reserved to implement the necessary error control functions for the user data.

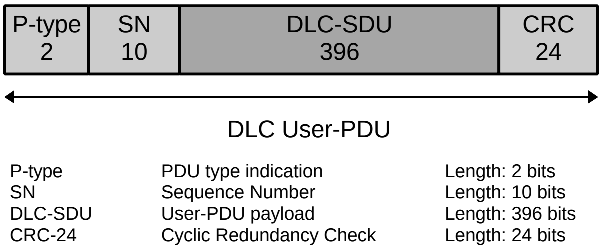


Figure 3. HIPERLAN/2 DLC User-PDU format.

Fields for error control functions are the 10-bit Sequence Number (SN) field and the 24-bit Cyclic Redundancy Check (CRC-24) field. The SN field allows the identification and alignment of correctly received U-PDUs and is to be used later on in positive acknowledgment messages. The CRC-24 field is used for error detection covering the whole PDU.

In spite of the general satisfactory performance that can be achieved with the acknowledged/ARQ mechanism (eventually enough for low quality real-time audio/video services), there is still room for some improvements both in terms of efficiency, lower delay and lower packet dropping.

These improvements, even obtained at the expense of more complex protocols, can definitely push the up-coming wireless LANs techniques to meet the more quality demanding (semi-) professional applications.

For this type of applications the impact of terminal cost is less sensitive than for pure personal communications. On the contrary, very low packet loss, low delay and high useful bit rate are major requirements when aiming higher quality standards.

The work presented in this paper has evolved from the current general acknowledged error control mode defined for HIPERLAN/2.

The paper organization is as follows: in section 2 a review of ARQ schemes is presented; in section 3 the Hybrid ARQ suggested improvements are described; in section 4 it is given information about the simulation system model; section 5 shows the simulation results; the paper ends with conclusions and references.

2. A review of ARQ schemes

ARQ is a mechanism developed for error free data communications where the received packets with undetected (or presumably corrected) errors are "positive acknowledged" to the transmitter. This one is then responsible for the retransmission of corrupted packets, no matter how long it takes.

The way the acknowledged messages and retransmitted packets interact with the normal packet flow has originated three methods known as Stop-and-Wait (SW), Go-Back-N (GBN) and Selective-Repeat (SR).

In spite of requiring a higher protocol execution complexity the selective-repeat strategy is by far the more efficient. Hereafter, it is assumed that all ARQ mechanisms use a SR strategy.

Besides these ARQ packet flow strategies, another important aspect to take into account is the coding strategy used in packets and the corresponding retransmissions. In fact, the plain error detection and "plain copy" packet retransmission can be improved by the so-called Hybrid ARQ (HARQ) schemes (a combination of FEC and ARQ). Among these schemes the extra complexity can vary within a certain extent depending on the added functionalities and how they are implemented. The final goal is always a general performance increase.

Table 1 summarizes the more common ARQ schemes.

Table 1. ARQ schemes.

ARQ scheme	Functionality
Pure detection	Detection and packet retransmission
Type I Hybrid	Detection/correction and packet retransmission
Type II Hybrid	Detection and redundancy retransmission
Type III Hybrid	Detection/correction and redundancy retransmission

Conventional pure detection ARQ uses a CRC code to achieve the largest detection capability; but since a single bit error is enough to force a retransmission, it may be advantageous to use a correcting code instead of an only detecting CRC. In this case the ARQ scheme is named Type I Hybrid ARQ.

It is also possible to concatenate two codes in order to improve the global ARQ throughput. From the transmitter point of view the first code applied to the information word is the outer code being the second the inner code.

Type II and Type III Hybrid ARQs normally use concatenated coding with a half-rate outer code [10]. A half-rate code means that the number of parity check bits (n-k) is equal to the number of information bits (k) in each n-bit codeword, resulting in a k/n ratio of 1/2. Codewords are computed on the data delivered from higher layers but, within each DLC U-PDU payload, only one of the parts (information or parity) is inserted. Figure 4 shows an example of a transmitter-receiver setup for a Type II/III HARQ communication.

Type II uses a correction code and a CRC for the outer and inner coding respectively. Type III uses correction codes for both outer and inner coding. To distinguish between “information” and “parity” packets a type indication field is also necessary; hereinafter this field is called “Info/Parity indication”.

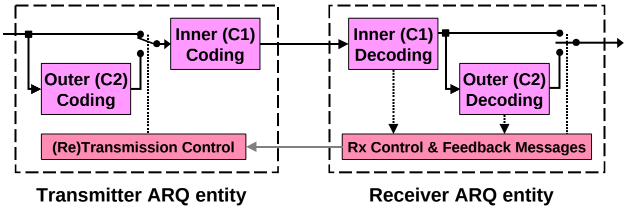


Figure 4. Transmitter-receiver setup for Type II/III Hybrid ARQ schemes.

The main problem of Type II/III HARQs is how to provide the receiver with the correct data, concerning the very important packet control information (SN and Info/Parity indication), when transmission conditions are bad. In fact, when a received packet is detected as containing errors, the packet control information within it can not be considered reliable because the errors may have occurred exactly within that zone.

3. Hybrid ARQ improvements

As described above more complex and higher performance but more "problematic" ARQ schemes are feasible other than just allowing error detection and "plain copy" packet retransmission. In this paper two new ways to improve the Type II/III HARQ schemes are presented.

One is the implementation, at the receiver ARQ entity, of a saving and a combination mechanism applied to the (re) transmitted packet payloads. For each packet (i.e., with the same SN), this mechanism enables the existence of multiple copies for the information and redundancy parts, guaranteeing the testing of more codewords for each copy arrival.

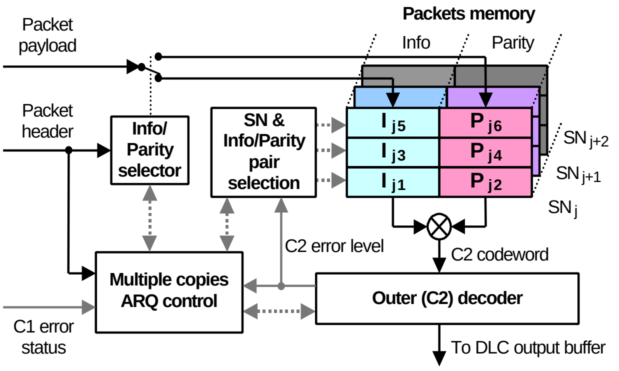
The other proposed improvement is the provision of a method that conveys the essential packet control information to the receiver in a safer way. This guarantees the fundamental condition for the operation of more powerful Type II/III HARQ schemes, which is the correct knowledge of SN and “Info/Parity indication”, even under a considerable number of errors in the main stream.

Some protocol implementation aspects and performance comparisons for all these ARQ models are the central focus of the analysis presented in this paper.

Although specially considered for wireless mobile environments, this analysis suggests that other environments, subject to errors and packet losses, can also benefit from the application of these improvements, particularly when applied to real-time audio/video services (e.g., internet telephone links).

3.1. Type II/III Hybrid ARQs with multiple copies combination

This new implementation is characterized by the existence of M (even) memories for each packet (i.e., for packets having the same SN). M/2 memories are used to save "information" packets; the other M/2 memories are used to save "parity" check packets. Figure 5 shows a possible multiple copies combination setup for M=6.



K-th arrival	Pair selection order	K-th arrival	Pair selection order
K=1 (I)	not applicable	K=7 (I)	Ij1-Pj6, Ij1-Pj4, Ij1-Pj2
K=2 (P)	Ij1-Pj2	K=8 (P)	Ij1-Pj2, Ij5-Pj2, Ij3-Pj2
K=3 (I)	Ij3-Pj2	K=9 (I)	Ij3-Pj2, Ij3-Pj6, Ij3-Pj4
K=4 (P)	Ij3-Pj4, Ij1-Pj4	K=10 (P)	Ij3-Pj4, Ij1-Pj4, Ij5-Pj4
K=5 (I)	Ij5-Pj4, Ij5-Pj2	K=11 (I)	Ij5-Pj4, Ij5-Pj2, Ij5-Pj6
K=6 (P)	Ij5-Pj6, Ij3-Pj6, Ij1-Pj6	K=12 (P) :	Ij5-Pj6, Ij3-Pj6, Ij1-Pj6 :

Figure 5. Multiple copies combination for Type II/III HARQ schemes (M=6).

The rationale behind this mechanism is that every received copy of a packet (even with unrecovered errors) contains large parts with correct information.

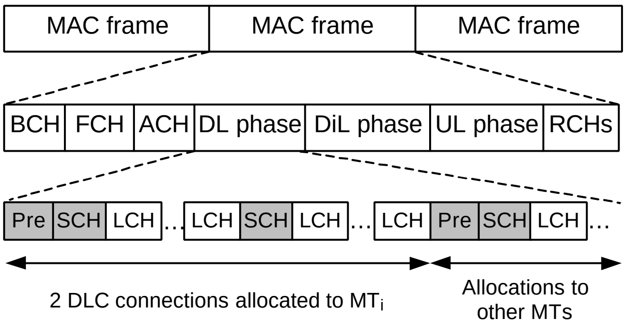
Hence, when the inner code states an unrecovered error, it passes the received packet payload to this second level of decoding. Having several copies memorized, it is possible to combine more “information” and “parity” parts. In this way, for each packet retransmission arrival, more codewords are fed to the outer decoder, improving its success rate.

A typical Type II/III HARQ uses only two memories (M=2) for each packet. Simulation results for M=2, M=4 and M=6 will be shown.

3.2. Protecting packet control information

When composing the HIPERLAN/2 MAC frame, the 54 octets User-PDUs (Figure 3) from a DLC connection are mapped into a same sized transport format named Long transport Channel (LCH). Shorter ARQ acknowledgements and some other link control messages are mapped into a 9 octets transport format named Short transport Channel (SCH).

Figure 6 shows the HIPERLAN/2 MAC frame structure and corresponding ordering of the different transport channel formats.



BCH - Broadcast CHannel
FCH - Frame CHannel
ACH - Access feedback CHannel
DL - Down Link
DiL - Direct Link
UL - Up Link
RCH - Random CHannel
Pre - Physical Layer Preamble
SCH - Short transport CHannel (9 octets)
LCH - Long transport CHannel (54 octets)

Figure 6. HIPERLAN/2 MAC frame structure.

LCH and SCH transport formats can use more than one physical mode. These modes, as specified by HIPERLAN/2 [11], are shown in Table 2. IEEE 802.11a standard physical modes are (almost) identical [3].

Table 2. HIPERLAN/2 physical modes.

Modulation	Coding rate	Nominal bit rate (Mbit/s)	Transport channels
BPSK	1/2	6	BCH. FCH, ACH, SCH, LCH, RCH
BPSK	3/4	9	SCH, LCH
QPSK	1/2	12	LCH
QPSK	3/4	18	SCH, LCH
16QAM	9/16	27	LCH
16QAM	3/4	36	LCH
64QAM	3/4	54	LCH

In order to efficiently use the available bandwidth, normally DLC U-PDUs use the LCH in the high bit rate physical modes. The tradeoff is a higher vulnerability to errors. Short feedback messages, such as an ARQ positive acknowledgement containing a sequence numbers list, carry higher sensitive information. Corresponding transport in SCH are conveyed through slower but more reliable physical modes.

With the adoption of the packet structure shown in Figure 3, a straightforward implementation of Type II/III HARQ schemes would imply that SN field and Info/Parity indication (this one probably embedded in PDU-type field) are transported within User-PDUs, jeopardizing its normal operation.

In this paper it is proposed that, for each DLC connection (DLCC), that information is condensed into a “forwarding direction packet list” and transported in one or more SCHs aside with corresponding LCHs containing the U-PDUs. Figure 7 shows these “forwarding direction lists”, within a MAC frame structure, using SCHs allocated to the respective DLCCs.

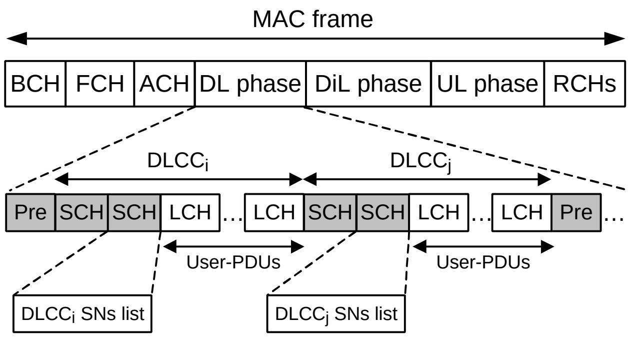


Figure 7. Transport of "forwarding direction" SN lists for each DLCC.

In this way, the packet control information has a significant increase in its protection, hence guaranteeing the normal operation of Type II/III HARQ schemes.

The DLCC SN lists can use the same method as the one specified for HIPERLAN/2 ARQ acknowledgement messages, which also use SCHs. Those messages, containing Bitmap Blocks, can carry acknowledgement status (positive or negative) for 24 packets, divided into 3 blocks of 8 contiguous SNs and a positive acknowledgement for all packets below a certain SN (cumulative acknowledgement). Adopting this method up to 24 semi-contiguous packet SNs can be listed, not excluding a mixed situation where a list with a SN-start and a SN-end can be used for contiguous SNs.

For each DLCC, and considering respective SCH and LCH sizes, the introduced overhead depends on the ratio between the number of SCHs (Nr_{SCH}), used to transport the list, and the number of LCHs (Nr_{LCH}). Nominal bit rates of the different SCH/LCH physical modes have also to be considered in this calculus. The overhead (OH) formula is then set by:

$$OH_{SNlist} = (Nr_{SCH}/Nr_{LCH})\times(9/54)\times(Rate_{LCH}/Rate_{SCH})$$

As an example, consider a frame where a certain DLC connection has 8 plus 16 contiguous User-PDUs and is using the 54 Mbit/s physical mode. Suppose also that the SCH containing the SN list is using the 18 Mbit/s physical mode. In this case the overhead is $(1/24)\times(9/54)\times(54/18) = 0{,}02083$.

Overhead values tend to rise when there is a decrease in SCH/LCH bit rates ratio and/or SN lists do not map so well into the Bitmap Blocks. This last situation is more likely to occur when packet retransmissions start to increase in consequence of a degradation of transmission conditions. But, as the performance of Type II/III HARQs is justly more significant in those conditions, even bigger overheads (<10%) are still small when compared with real advantages.

For good transmission conditions, where performance differences among ARQ schemes are almost null, the forward direction SN list may be suspended, to appear only when the radio channel gets bad. Hence, it is a saved resource that can be used in another way.

4. Simulation system model

In order to compare the various classic ARQ solutions with the proposed alternative solutions, a system model was developed with a graphical simulation tool. The model includes the main connections and components of a typical wireless communication system. Figure 8 shows the relevant system model entities used in the simulation model and the proposed DLC main data units.

For each simulated connection the channel capacity (expressed here in number of time slots within MAC frames) is assumed constant.

This last assumption is in line with centralized controlled systems, like HIPERLAN/2, both in infrastructure and ad hoc modes. In that system, it is possible to get a fixed capacity agreement between an Access Point/Central Controller (AP/CC) and a Mobile Terminal (MT). This negotiation is done during the connection setup or during a connection modify process.

This type of capacity negotiation is particularly advantageous when constant data rate traffic is foreseen between both points (for both symmetrical and asymmetrical connections), and/or an extra capacity is needed to guarantee available bandwidth for retransmissions. This is best applied to audio/video (semi) professional applications where perceived Quality of Service (QoS) is more important than general efficiency.

4.1. PDU formats

As the HIPERLAN/2 User-PDU shown in Figure 3 contains 432 bits, with 24 of them reserved for the CRC function, a search for BCH (n,k) codes containing approximately the same number of information (k) and redundancy (n-k) bits was performed, not forgetting the correcting capability (t bit errors).

Two shortened code options were analyzed. The first one is the BCH (432,405) code with 27 parity-check bits and a correction capability of t=3 errors; the second is the BCH (432,414) code with 18 parity-check bits and a correction capability of t=2.

Since the second code offers somewhat limited error correction/detection capability the first one was chosen. This is the main (inner) code used to detect errors in user PDUs arriving to the DLC layer.

Detected errors may be accepted as corrected if their number is equal to or less than a certain programmable corrective action threshold, hereafter called λ ($\lambda \leq t$).

In error correcting block codes, such as BCH, it is possible to trade between corrective action (λ) and detection range (l). The relation of these two figures with the correcting capability (t) is set by equation:

$$2t=\lambda+l \qquad (\lambda \leq t \leq l)$$

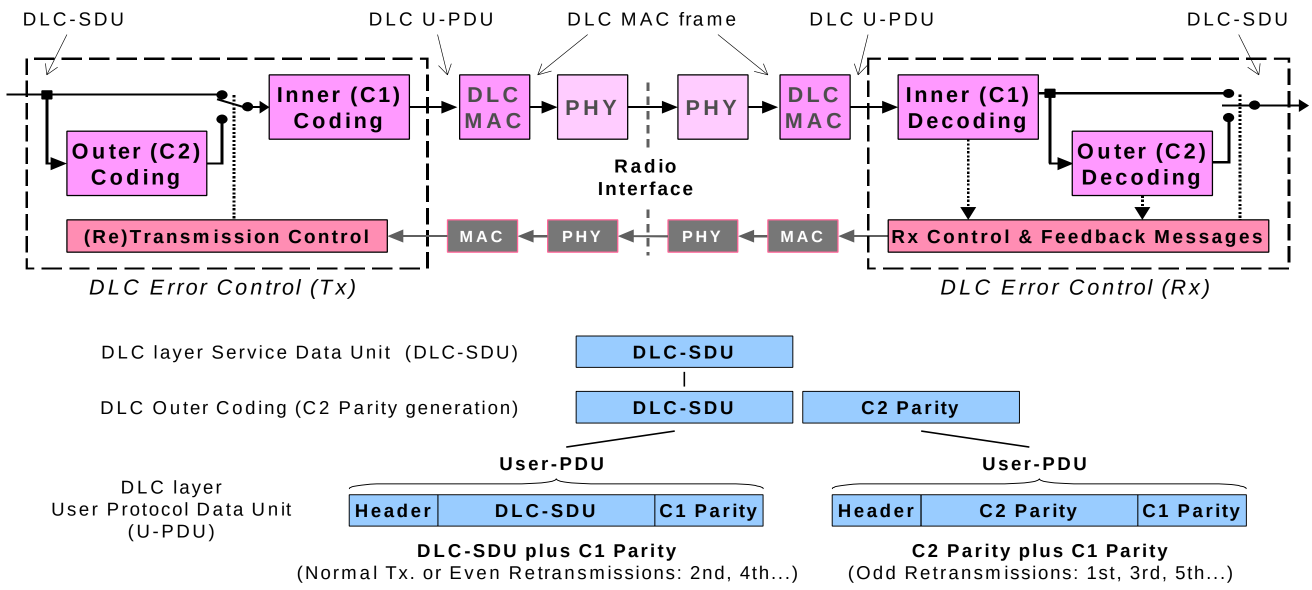


Figure 8. System model entities and DLC main data units.

The relationship with the minimum Hamming distance (d) of the code can be devised from the well known formula d≥2t+1:

$$d \geq \lambda + l + 1 \qquad (\lambda \leq t \leq l)$$

The λ corrective action threshold is applicable both to inner and outer codes. Hereafter, the subscripts 1 and 2 will refer to DLC inner and outer codes, respectively.

For the inner code, if λ_1 is set to zero that means that the code will be only used to detect errors, hence the ARQ is a Pure detection and retransmission type. If λ_1 is set such as $1 \leq \lambda_1 \leq t_1$ then a Type I HARQ scheme is actually used.

For Type II/III HARQ schemes the BCH (432,405) code acts as the DLC inner code but a DLC half rate outer code has also to be chosen. In this last code, for each codeword, only one of the parts (information or redundancy) is inserted in the user PDU payload.

In HIPERLAN/2 the size of that payload is 396 bits. Checking of primitive BCH codes with more than 396 bits in the information part and an approximate size in the redundancy part leads to the BCH (1023,628) code with 395 redundant bits and a correction capability of t=43. Shortening this code in 233 bits changes it to the required half rate format, more precisely a (790,395) code. Even not equal in the payload size (difference of 1 bit) this code is enough to make the intended performance comparisons.

In conclusion, the information part of the inner code (405 bits) is obtained from the sum of those 395 bits (payload) plus 10 bits for the packet control information. These 10 bits are composed by PDU type and SN fields when testing Pure detection and Type I HARQ schemes. When evaluating the novel implementation strategy of Type II/III HARQ schemes the same 10 bits are fulfilled with corresponding PDU type, Info/Parity indication and header protection fields. Figure 9 shows the DLC User-PDU format adopted for the simulator in this last case.

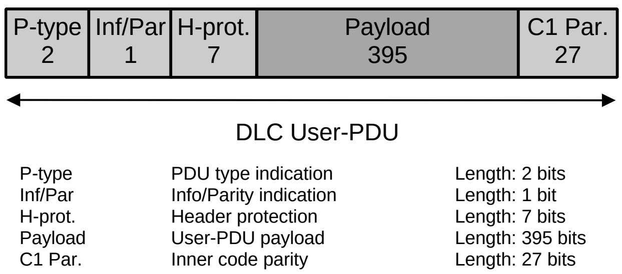


Figure 9. Simulator model DLC User-PDU format.

4.2. Radio channel models

Up to now two channel models are being used in the simulations: the memoryless Additive White Gaussian Noise (AWGN) channel, characterized by a random error Poisson process, and the Gilbert-Elliott (GE) memory channel [12, 13], characterized by a two state Markov chain.

In this last model, the two states are normally called the “Good” and the “Bad” state. A different channel bit error rate (BER_{bad} and BER_{good}) and a corresponding static probability (P_{bad} and P_{good}) characterize each one.

In the GE channel model the parameterization choices are much larger than in the AWGN channel.

4.3. Simulation runs

During each simulation run the transmitter has to transfer a predetermined number of packets to the receiver. To get a performance curve with a certain set of model parameters, the main parameter to vary is the channel BER (BERc) when using the AWGN model, or the corresponding average BER when using the GE model.

The computed performance metrics are:

- connection global efficiency,
- average number of packet retransmissions,
- residual packet error rate, and,
- residual bit error rate.

5. Simulation results

Simulations were run not only with 432-bit packets but also with smaller packets. The structure of these ones is set using the same common guidelines. The half rate outer codes are derived from the primitive BCH codes applying minimum shortening. Subsequent BCH inner codes are chosen to have the same correcting capability of 3 bits. The resulting codes are shown in Table 3.

Table 3. Packet lengths and respective BCH coding.

Packet length	BCH inner code (n_1, k_1, t_1)	BCH outer code (n_2, k_2, t_2)
94	(94, 73, 3)	(126, 63, 10)
158	(158, 134, 3)	(248, 124, 18)
289	(289, 262, 3)	(504, 252, 30)
432	(432, 405, 3)	(790, 395, 43)

The efficiency curves shown are based in the number of retransmissions and k_1/n_1 ratio (different ARQ schemes have the same size packet headers).

5.1.AWGN memoryless channel results

In the AWGN channel model BERc was specified to range from 10^{-4} to a maximum of 10^{-1}.

In the following they are shown several comparisons among discussed ARQ schemes, namely:

- Pure ARQ versus Type I HARQ,
- Pure ARQ versus Type II HARQ,
- Type I versus Type III HARQs, and,
- Type II/III HARQs with and without multiple copies combination.

Figure 10 shows a comparison between Pure detection (λ_1=0) and Type I Hybrid (1≤λ_1<t_1) ARQs, for two packet sizes, in the presence of a discrete memoryless channel. It is shown that, when using detection/correction codes such as BCH, Type I HARQ performs always better than pure detection.

In that figure, as expected, curves λ_1=2, λ_1=1 and λ_1=0 present for any BERc a decreasing efficiency value. But

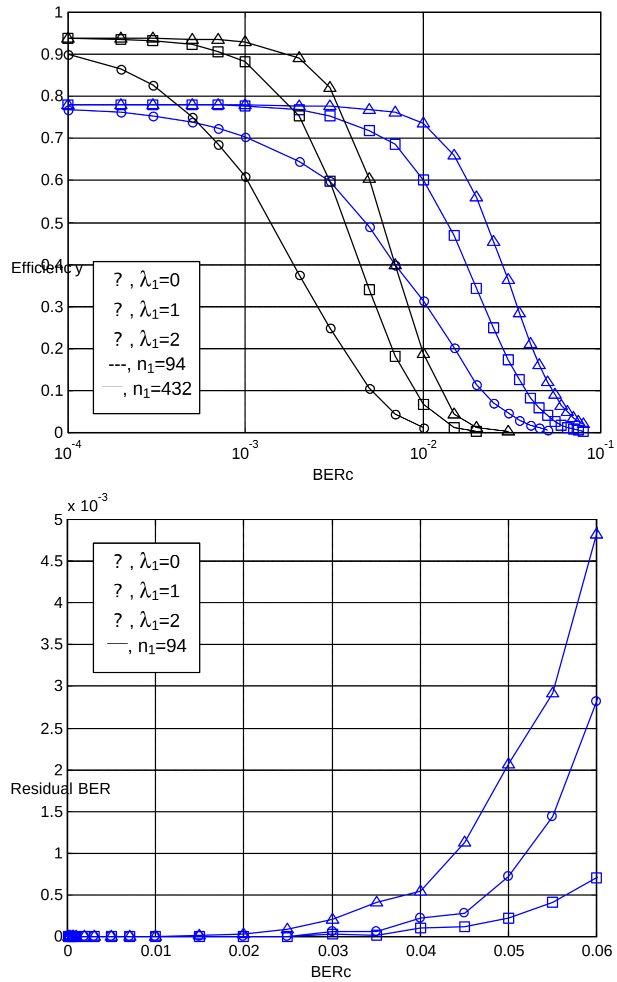


Figure 10. Efficiency and residual BER for Pure detection (l$_1$=0) and Type I Hybrid (1£l$_1$<t$_1$) ARQ schemes.

for residual BER, due to undetected errors, the same decreasing behavior has a change between λ_1=1 and λ_1=0 curves.

Indeed, λ_1=1 curve do not only presents lower residual BER values than λ_1=2 but also lower than λ_1=0. This is explained by the fact that when BERc is high a great part of packets have errors. If λ_1=0 (hence not performing any correction) the only chances for packets to get through is when arrives a “clean” copy or when an undetected error occurs. As there is a significant increase in the number of retransmissions, the chances for the code to fall in an undetected error situation also increases. As shown in Figure 10, this leads to a higher residual BER curve in λ_1=0 than in λ_1=1.

For this case, and analyzing both efficiency and residual BER, a λ_1=1 value is the best choice. For following examples, using also inner codes with t_1=3, it will be seen that a λ_1=1 value represents always a very good compromise.

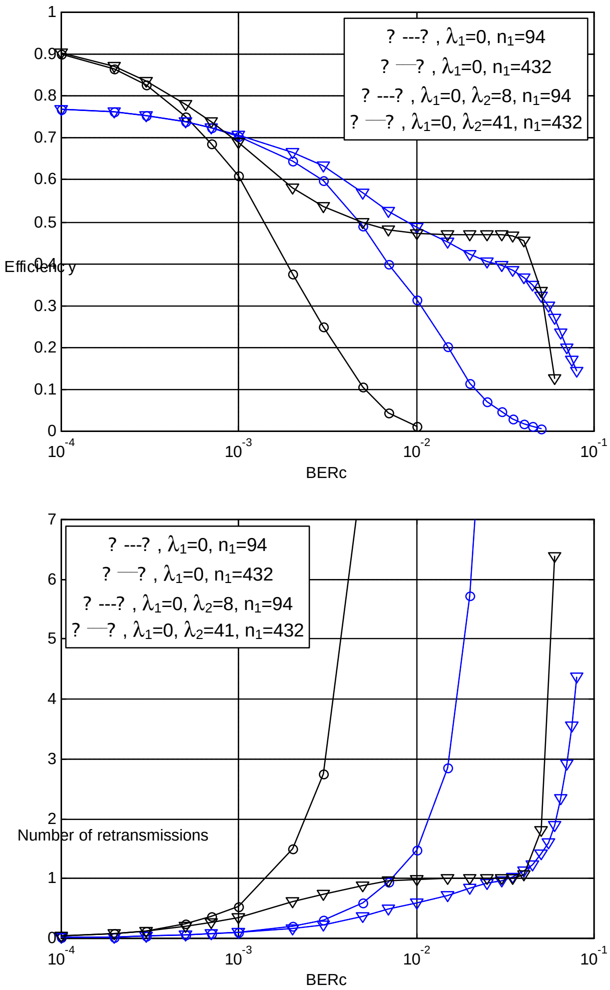


Figure 11. Efficiency and average number of retransmissions for Pure detection (l_1=0) and Type II Hybrid (l_1=0, l_2<t_2) ARQ schemes.

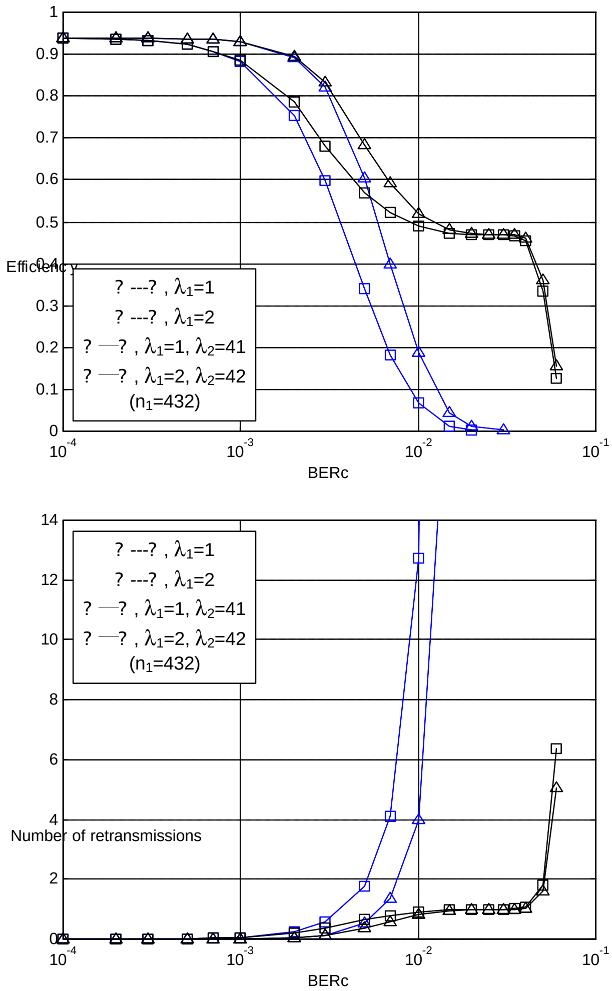


Figure 12. Efficiency and average number of retransmissions for Type I (1£l_1<t_1) and Type III (1£l_1<t_1, l_2<t_2) Hybrid ARQ schemes.

Figure 11 shows a comparison between Pure detection (λ_1=0) and Type II Hybrid (λ_1=0, λ_2<t_2) ARQs for 432-bit and 94-bit packet sizes. As expected, Type II HARQ clearly outperforms the Pure detection scheme, showing the characteristic of only requiring about one retransmission for a large extension of high BERc values (more noticed in the larger packet size), until it breaks down.

Figures 12 and 13 show the same kind of comparisons but for Type I (1≤λ_1<t_1) and Type III (1≤λ_1<t_1, λ_2<t_2). HARQs. As in previous case, Type I is clearly outperformed by Type III scheme. For this last, it was found that best compromises, in terms of efficiency and residual BER, are achieved with λ_1=1 and λ_2=t_2-2.

Figure 14 shows a comparison made with a Type III HARQ (λ_1=1) for 2, 4 and 6-memory multiple copies combination and using two consecutive outer coding corrective action (λ_2) thresholds.

For each λ_2 situation, when the channel BER is high, the difference in the number of retransmissions between the 2 and 4-memory cases is of some significance, increasing a little bit when the 2 and 6-memory cases are compared.

For the example given, the curve corresponding to λ_2=29 and 2-memory, is “caught” by the 6-memory and λ_2=28 curve. This means that is possible to achieve a much lower residual BER maintaining the same average number of retransmissions. If a memory saving is necessary, the 4-memory solution appears always as a good compromise.

5.2. GE memory channel preliminary results

For the GE model only a very preliminary set of simulations were yet performed. Values of BER_{bad}/BER_{good}=10 and 100 were chosen and several

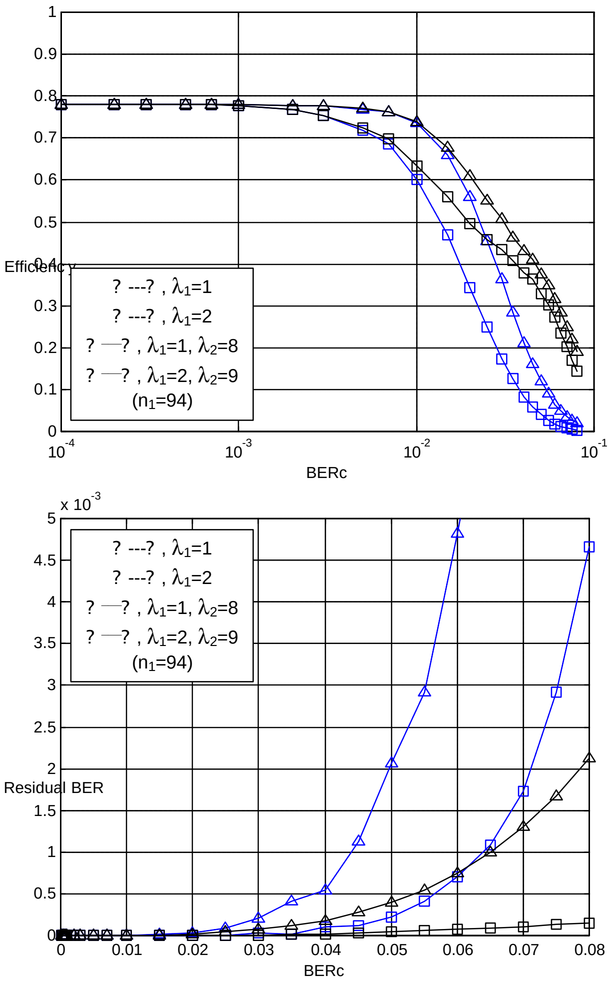


Figure 13. Efficiency and residual BER for Type I (1£l$_1$<t$_1$) and Type III (1£l$_1$<t$_1$, l$_2$<t$_2$) Hybrid ARQ schemes.

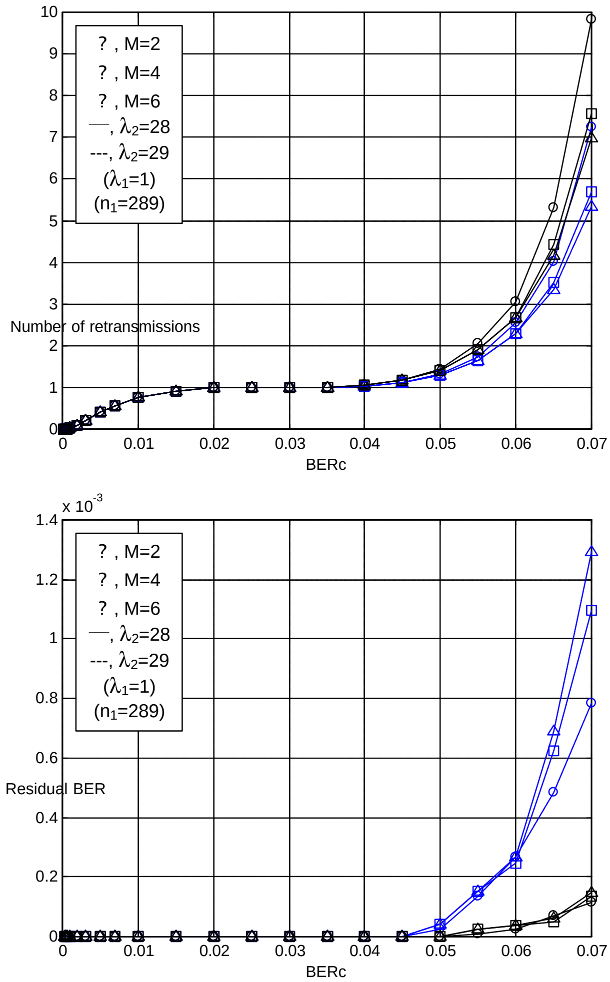


Figure 14. Number of retransmissions and residual BER for a Type III HARQ with 2, 4 and 6-memory multiple copies combination.

probabilities (P_{bad}) of being in the "Bad" state were also selected.

Figures 15 and 16 show some of these results. Herein BERc is the weighted average BER calculated over BER_{bad} and BER_{good}, that is:

$$BERc=(BER_{bad}\times P_{bad})+(BER_{good}\times P_{good})$$

Up to now, results indicate that even in less favorable memory channels Type II/III HARQ schemes still perform considerably better than Pure and Type I Hybrid ARQs.

6. Conclusions

When thinking on high performance wireless mobile communications, it is obvious that none of the two usual ARQ schemes (Pure detection and Type I Hybrid) is sufficient to timely combat the errors induced by the combined effects of channel fading and multipath signal propagation. These schemes require a considerable number of retransmissions almost proportional to the channel bit error rate.

In order to guarantee the normal operation of Type II/III HARQ schemes, it is now proposed to convey the important packet control information into the more reliable physical modes already defined for the 5GHz WLANs. The packet control information is mainly composed of a "forwarding direction" SN packet list and in this way its protection is significantly increased.

Some results, based on this method, were shown for the ARQ schemes under discussion when in presence of radio channels characterized by high BERs. An M-memory packet copies combination associated with Type II/III HARQ schemes is also proposed and results shown.

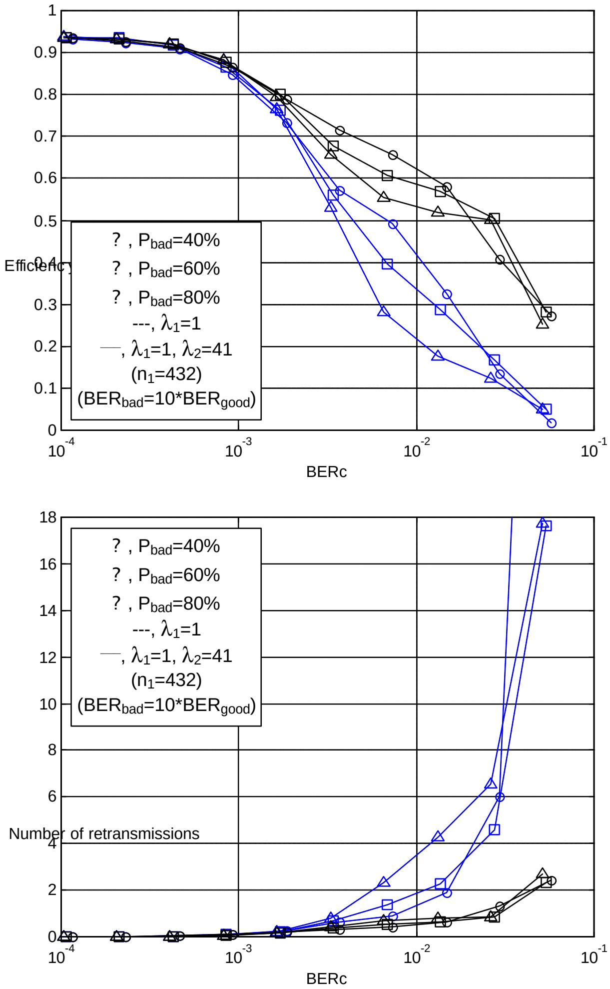


Figure 15. Type I versus Type III HARQ schemes for P_{bad}=40, 60 and 80% of time and BER_{bad}=10BER_{good}.

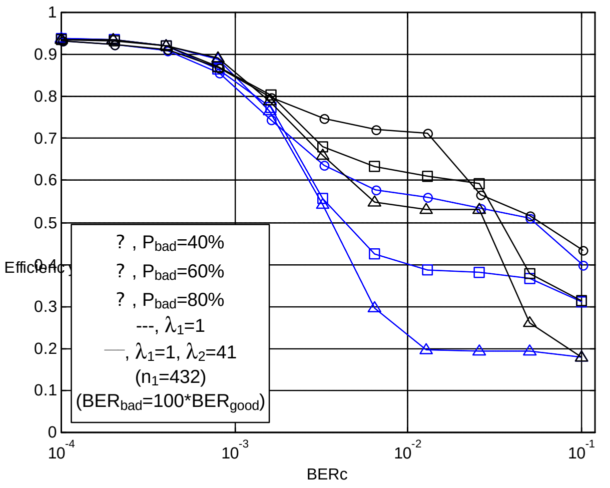


Figure 16. Same as Figure 15 with P_{bad}=40, 60 and 80% of time and BER_{bad}=100BER_{good}.

In conclusion: it should be stressed that the provision of a special SN protection mechanism is not only important for Type II/III HARQ but also for normal ARQ, if a packet delay aware scheme is to be implemented. In fact, differentiated treatment for errored copies of the same packet can only be done in the presence of a correct knowledge of the corresponding packet sequence number.

7. References

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