A Receiver-Oriented Approach for Efficient Link-Level Mobile Data Integrity

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Abstract: The transmission of data on wireless links requires some means of preserving data integrity in spite of the higher error rates expected in a typical radio environment. Both the use of an appropriate Forward Error Correction (FEC) coding and a suitable Automatic Repeat Request (ARQ) protocol are considered for non time critical services [1]. Their use is reconsidered in view of the large number of simultaneously active logical connections or “sessions” in typical 3rd generation wireless data applications such as web browsing from a wireless IP terminal which may lead to storage, bandwidth and processing requirements exceeding the size and power restrictions of the receiver. The proposed framework for realization of a receiver-efficient selective-repeat mechanism with minimal overhead in combination with forward error-correction is described and quantitative guidelines are presented.

I INTRODUCTION

In [2] strategies for a combined FEC/ARQ system have been proposed, based on bounding the number of retransmissions to meet the delay requirements of wireless ATM connections and by choosing an FEC coding rate based on ATM delay requirements (maxCTD). In this paper we are concerned with delay tolerant packet data and with increasing efficiency in terms of receiver complexity. If delay is not a constraint, the use of an unlimited number of retransmissions would make FEC superfluous. The IEEE 802.11 wireless LAN standard for instance does not require FEC coding. However, in a mobile data environment with time and space varying radio channels this may not be an option, since efficiency of the ARQ may decrease rapidly, because a large amount of the available bandwidth is consumed for retransmissions in a slow fading situation.

The approach proposed in this paper has the following goals: to include for FEC coding for mobile data by finding a trade-off between the complexity of ARQ and FEC and the complexity of the hardware and processing needed at the receiver for decoding the error correction protocols.

II RECEIVER-ORIENTED REQUIREMENTS

Future radio interfaces of up to 25 MBit/s with increased the latency of the links require larger buffers at the receiver side. The large number of simultaneously active logical connections or “sessions” in typical wireless data retrieval applications such as wireless IP makes it however impractical to save long sequences of state informations for the individual sessions due to the size and power restrictions of the receiver. A typical scenario is web browsing from a wireless data terminal, in which the data traffic is biased in the downlink direction. At the base station receiver on the other hand, the burden comes from the number of terminals in the served radio cell. An important design goal of the data link and transmission layers of wireless data systems is to compensate the time and spatial varying nature of the wireless channels. The combination of Forward Error Correction (FEC) coding and a suitable Automatic Repeat Request (ARQ) can yield residual packet loss rates comparable with fixed connections. However, such a combined solution might not be economical in terms of bandwidth, size, or power consumption needed.

In the following a strategy for a receiver-oriented link level error control with respect to receiver complexity is presented.

III FRAMEWORK FOR A RECEIVER-ORIENTED APPROACH

The receiver-oriented efficiency is based on three main ideas: reduce storage, reduce bandwidth and reduce processing overhead. At the ARQ protocol level the approach should allow to minimize the retransmitted amount of data and to achieve throughput and bandwidth efficiency. At the FEC coding level, the strategy will require a trade-off between performance and complexity of the decoder which will have a direct impact on power consumption. Finally, based on the loss tolerance parameters of a session and to the fading scenario, FEC and ARQ can be used in combination or individually to restore the integrity of the data.

In a fast fading situation, the BER burst has a duration of the order of a packet transmission [4] and retransmission will be able to cope with it, without having to increase the redundancy at the FEC level. In a slow fading or shadowing environment, the channel BER is increased for the equivalent of the transmission time of a large number of packets, and some coding at the FEC level is needed to avoid thrashing of the retransmission requests which lead to inefficiency of the ARQ protocol. It is also important to note that by increasing the FEC redundancy the effective “usable” bandwidth of the link will be reduced which in turn will have an impact on the MAC-level scheduling at the transmitter side.
A. A “Light Weight” Selective Retransmission Protocol

The logical model of an arbitrary ARQ protocol is shown in Figure 1. In order to allow room (bandwidth, processing power, etc.) for an eventual FEC coder, a “light weight” ARQ is proposed. Each packet header contains a sequence number and a flag to mark retransmitted packets. The actual format on the radio interface will have to be integrated with the MAC layer concept [5].

On the reverse control channel retransmit messages containing negative acknowledgments are sent, which introduce a smaller load than positive acknowledgments for every successfully transferred packet. An important factor for achieving high data rates is the possibility to group several NACKs in one retransmit message. There are two levels of error detection: detection of errored packets, which have to be discarded at the receiver, and detection of lost packets. For lost retransmissions and lost retransmission requests two different time-out mechanisms are used, which are in the following called relative and absolute time-out respectively. The relative time-out indicates the loss of either a retransmission request or of a retransmitted cell. It triggers the generation of a new retransmission request for the same packet. The absolute time-out is used to limit the number of retransmissions and ensure the stability of the protocol. This is important to avoid buffer overflow in periods of very high loss. The time-out values can be used to adapt the protocol to the momentary link quality, the forward cell rate and the application requirements. An important part of the “light weight” concept is the very small per packet overhead, which reserves only 4 bit for the sequence number. This leads to a wrapping of the sequence counter every 16 packets and introduces several serious problems to the ARQ mechanism. A misinterpretation of retransmission requests at the sender is avoided or at least diminished by a special feature of the proposed protocol, which is called sequence number range extension.

The sender as well as the receiver continuously track the sequence numbers and count the number of wraps. This allows both entities to internally identify cells by the value of the wrap counter and the value of the sequence number.

B. Receiver-oriented alternatives for FEC coding

As mentioned in the introduction, since in packet data delay is usually not a constraint, the option of using an unlimited number of retransmissions makes FEC superfluous. This has the advantage of simplifying receiver design and minimizing bandwidth overhead, however in slow fading or shadowing scenarios, unlimited ARQ will put a high burden on the “usable” bandwidth. The approach therefore is to limit in any case the number of re-transmissions, and to either mitigate the high channel BER problem by using some form of FEC coding or by leaving it to the higher layers to deal with the residual packet loss rate. The decision on which to choose will depend a lot on the receiver architecture including the question if the higher software layers support more advanced protocols.

IV GUIDELINES FOR A PRACTICAL APPROACH

The approach proposed in this paper is to design FEC coding for mobile data by finding a trade-off between the complexity of ARQ and the complexity of the hardware and processing needed at the receiver for decoding the FEC. For this we provide design guidelines based on the residual packet loss rate with limited retransmissions, the required FEC code rate for a given packet loss target in combination with ARQ, and the complexity of different decoder implementations. The following charts have been produced for a TDMA based MAC protocol. If perfect ARQ protocol is assumed, i.e. a protocol, which delivers the correct cell sequence for all error cases, the achieved throughput can be used as a performance measure. Fig. 2 shows the throughput h versus the channel bit error rate without any FEC coding.

![Fig. 1. ARQ Mechanism](image1)

![Fig. 2. ARQ Throughput vs. Channel BER without FEC](image2)
In the proposed approach (as in many real protocol implementation) the number of retransmissions will be limited. In this case the residual packet loss becomes the performance parameter.

The residual packet loss in Fig. 3 shows the higher number of protocol errors for higher forward channel rates and 2 allowed retransmissions.

The effect of packet loss on the reverse channel is displayed in Figure 4. The simulated residual cell loss rate is plotted versus the maximum number of retransmissions for a packet loss rate of about 0.1. The graph also shows the theoretical curves for the geometric distribution.

To evaluate the advantage of combining ARQ with FEC, we analyzed in [2] a selective-repeat ARQ system in combination with a Reed-Solomon FEC code. For completeness reasons, Fig. 5 gives the evaluation of required FEC code rate for limited retransmission versus the channel BER for a given packet loss rate of 1e-06 as derived in [2]. The 3 curves correspond to no ARQ, 1 retransmission and 3 retransmissions at maximum. To evaluate what is the complexity of the receiver when implementing the FEC decoder, we derived the number of gates needed for different Reed Solomon decoder implementations as shown in Fig. 6

V CONCLUSIONS

Theoretically, if delay is not a constraint, the use of an unlimited number of retransmissions would make FEC superfluous. However, in a mobile data environment with time and space varying radio channels this may not be an option, since efficiency of the ARQ may decrease rapidly in a slow fading situation. The approach proposed in this paper is to allow for FEC coding of mobile data by finding a trade-off between the complexity of ARQ and FEC and the complexity of the hardware and processing needed at the receiver for decoding the error correction protocols. For this we provide design guidelines based on the residual packet loss rate with limited retransmissions, the required FEC code rate for a given packet loss target in combination with ARQ, and the complexity of different decoder implementations.
REFERENCES


