Performance Analysis of ARQ Schemes for UTRA TDD Ad Hoc Mode

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ABSTRACT

Inter-Vehicle Communication (IVC) has become a research challenge of major importance during the last few years. Within the FleetNet Project a novel inter-vehicle mobile ad hoc network will be developed to interconnect vehicles and roadside gateways via a mobile Internet.

The FleetNet system will be based on UMTS Terrestrial Radio Access Time Division Duplex (UTRA TDD). Among others, major services supported by FleetNet will be *road traffic telematics* and *mission critical services*, like emergency notifications and services for cooperative driver assistance. This services put very high requirements on the constrained air interface and the used protocols.

Within this work we will provide an outlook of the proposed Automatic Repeat Request (ARQ) method standardized for UTRA TDD. We calculate both analytically and simulative the usability in terms of performance overhead of two basic ARQ schemes: SR and GBN, for the UTRA TDD Ad hoc Mode in the FleetNet Project.

KEYWORDS

Inter-Vehicle Communication (IVC), Ad Hoc Networks, Automatic Repeat Request (ARQ), UTRA TDD

I INTRODUCTION

In digital communication, a mean to combat errors is the retransmission of faulty received information, e.g. by means of the Automatic Repeat Request (ARQ) protocol [2] One goal of these type of protocols is to guarantee a reliable data transfer.

Three different basic schemes used in fixed as well as in wireless systems are Stop-and-Wait (SW), Go-back-n (GBN) and Selective-Repeat (SR). Different to cellular networks, which are coordinated by a base station, in ad hoc networks a decentralized MAC scheme is most suited. In cellular networks, long connection times are available, large sliding windows and sequence numbers are used. In the case of highly dynamic ad hoc networks, the ARQ shouldn't be controlled by a central instance, but it is equally distributed between communicating stations. Furthermore, it can be expected that the communication will not take part between one and several stations like in a cellular system, but between arbitrary stations in a peer-to-peer fashion. This will also impact the ARQ scheme in every station, which has to handle several links to different stations at the same time (and not only to one base station like in a cellular system).

Existing ad hoc networks like IEEE802.11 [3] and Bluetooth [4] implement a Stop-and-Wait mechanism with positive acknowledgments (ACK) in IEEE802.11 and negative unnumbered ACKs in the case of Bluetooth. Both systems dispose of a random access scheme to access the network, which demands fast ACKs of sent packets. Traffic characteristics in FleetNet, which are characterized by large packet trains between peer stations and collision free reservation requests for packet transmissions, make fast ACKs not essential, not to mention all delay insensitive applications mentioned in the introduction Therefore GBN and SR schemes can be used and an improvemed error control performance can be achieved.

The rest of the work is organized as follows. First we will study the boundary conditions required for ARQ within the FleetNet Project [1]. A description of the UTRA TDD ad hoc mode will follows. Then we will describe the analytical and simulative environment where we have tested the efficiency of GBN and SR schemes. Next the performance results will presented, and we will conclude with a summary and conclusion.

II CHALLENGES ON ARQ IN FLEETNET

After giving an introduction of general ARQ schemes, we will present the typical conditions which FleetNet posses. A general scenario of the FleetNet is presented in Figure 1.

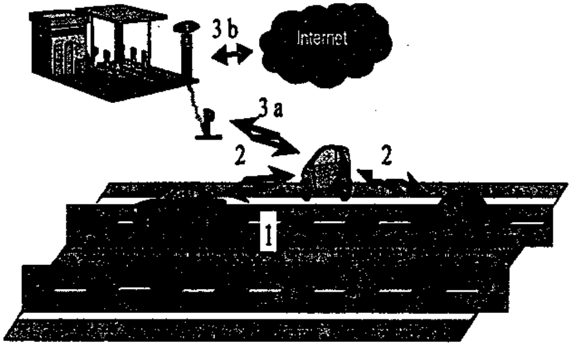

Figure 1: FleetNet Communication Scenarios.

One typical communication relation is the direct exchange of information between arbitrary vehicles (1). This is needed for Cooperative Driver Assistance. FleetNet supports multihop operation (2) and manages information processing without centralized instances. User communication and information services, e.g., for 3a), marketing along the road, 3b) Internet access, and mobile office will enhance the passengers comfort.

As the basis for the FleetNet air-interface, UTRA TDD low-chip rate has been chosen. As UTRA TDD is basically a

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technology for cellular mobile networks, most of the protocol layers – like MAC and RRM – have to be modified or newly defined to support the depicted challenges. To provide different service classes with different requirements on Quality of Service (QoS) the FleetNet MAC will provide different schemes of reservation of transmit capacity [1]. Besides permanently assigned parts of transmit capacity for high-priority services, resources can be dynamically reserved for services with lower priority. Each UTRA TDD radio frame of 10 ms duration is sub-divided in the LCR option in two subframes with 7 time slots each. Following the first time slot an additional special time slot for synchronization is inserted, which is marked in red in Figure 2 Each of the following time slots have the same length and structure as the first time slot and comprise two data parts that are separated by a midamble and a guard period (G).

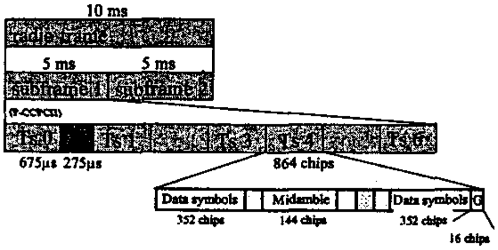

Figure 2: UTRA TDD LCR frame structure

For the ad hoc mode of UTRA TDD the implementation of ARQ should be as close as possible to the UTRA TDD standard. But regarding the limited bandwidth under changing topologies the ARQ scheme should work with as less as possible overhead and should be adaptive to changing network conditions. Applying ARQ will – of course – increase transmission overhead. Though it has been shown the superior behaviour of SR in the literature [6]-[8], it is worth mentioning that SR results in the largest protocol overhead. Especially, for large window sizes, the signalling of corrupted packets might result in large protocol overhead compared to, e.g., GBN. However, the increased overhead comes with an decrease of the number of required re-transmission ending up in most of the cases in an improved throughput and delay performance.

Because of the special MAC scheme used in UTRA TDD ad hoc, the performance of the ARQ scheme differs from the one proposed in the standard. In UTRA TDD ad hoc it is proposed that every station keeps a special part of the available resources permanently reserved, the so-called Circuit Switched Broadcast Channel (CSBC). This constantly reserved capacity can advantageously be used as reverse channel for acknowledgements. Hence, there might be a trade-off in the required signalling effort and efficiency for SR and GBN, which might prioritize the selection of the one or the other protocol depending on the distribution of the channel errors and the error probability.

FleetNet nodes will have to frequently exchange user data and control information for self-organization of the network because transmission conditions and states of other nodes change continuously. These information will include Neighbourhood Tables where every station transmits its own knowledge about the channel status, reservation messages, and under particular traffic circumstances, periodical broadcasts of security relevant messages. It is foreseen that all these information will be transmitted inside the CSBC. Large messages from higher layers will be segmented and will cause large packet trains. Some of these messages have to be transmitted in a very short time. This maybe an argument against ARQ in IVC systems. But with frame sizes of 10 ms re-transmissions can be realized in very short times and there are plenty of applications that can be supported under these conditions, including chats between passengers or downloads from the Internet like e-mails. Moreover, it has been already shown that ARQ is meaningful in IVC systems [8].

In a realistic approach, the existence of an available reverse channel to acknowledge sent packets is not assured. It is determined that after a mean waiting time of 20 ms (2 TDD frames) [3], the station's CSBC is available, thus, the station can use this for sending the ARQ message. But the sum of the aforementioned expected messages leaves place only for short ARQ signalling reports inside the CSBC, as they arise with SW and GBN. Longer ARQ messages, as required in SR (e.g. [999] using a UTRA-TDD standard bitmap super-field with 3 octets, each bit representing a data packet, will require 44 bits of the total number of 210 bits available in the CSBC) demand an additional reverse channel. But this depends certainly on the number of packets which have to be acknowledged, i.e. on the protocol window size. Larger protocol window sizes mean, as well, larger delays from the high layer's point of view.

If a reverse channel exists, and it is available earlier than the CSBC, ARQ messages can use it. If the reverse channel comes later, two possibilities exist: first, to use the CSBC and second, to wait for the reverse channel. Therefore the decision depends on the available space inside the CSBC.

In high traffic load situations, the average delay to get a reverse channel will increase, because the probability to get free slots decreases. This situation represents the worst-case scenario for our investigations.

III DESCRIPTION OF THE ANALYTICAL AND SIMULATIVE ENVIRONMENT

In this section an analytical and simulative investigation of the well-known ARQ protocols Selective-Repeat and Go-Back-N under the boundary conditions of the UTRA TDD ad hoc mode is performed. The efficiency of both protocols in terms of protocol overhead have been compared in a single-user case scenario, i.e. only one user is allowed to have an active connection.

Analytical Setup

We begin with the description of the analytical evaluations. Following boundary conditions have been assumed:

- Slots for ARQ signaling will be reserved only when necessary.
- Slot granularity, i.e. overhead efficiency has been calculated as the quotient between the total number of error free received data slots and the total number of sent slots: data, retransmissions and ARQ messages.

- Partial bitmap signaling mechanism as defined in the UTRA-TDD standard [9] is used. Maximal 128 packets can be acknowledged within a single slot. Working with large window sizes, up to 256, would not be allowed in the case of Selective Repeat because of the UTRA-TDD conform signaling mechanism, whose requirements would exceed the available capacity of one channel, which is 210 net bits.
- Only one error occurs in the frame. For a certain packet error rate, e.g. 0.1% it would mean that only one packet of 1000 total sent packets is corrupted.

The scenario has been separated in two cases: a) where the one user reserves only one additional slot every frame for data transmission, and b) where the user occupies the whole frame resulting in the maximum possible throughput, as shown in Figure 3.

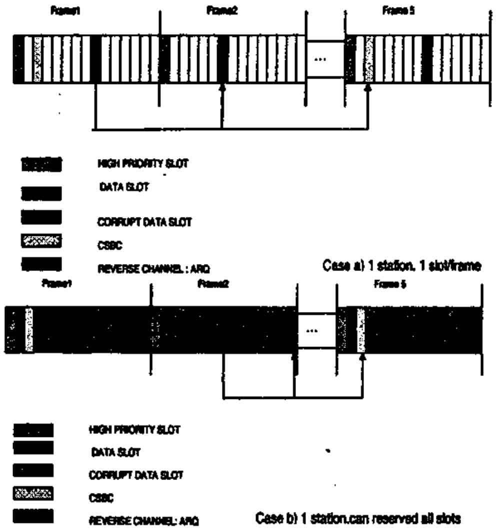

Figure 3 : Single user scenario case a) and b)

We derivate the following formulas to calculate the overhead efficiency of SR and GBN for the case a):

$$S_{SR} = \begin{cases} \dfrac{L-1-\left(\dfrac{L}{WindowSize}+\max\left(1,\dfrac{WindowSize}{BitmapSize}\right)\right)}{L} & , if\,PER \sim= 0\% \\[2ex] \dfrac{L-\left(\dfrac{L}{WindowSize}\right)}{L} & , if\,PER = 0\% \end{cases}$$

$$S_{GBN} = \begin{cases} \dfrac{L-N_{following}-\left(\dfrac{L}{WindowSize}+1\right)}{L} & , if\,PER \sim= 0\% \\[2ex] \dfrac{L-\left(\dfrac{L}{WindowSize}\right)}{L} & , if\,PER = 0\% \end{cases}$$

where:

- L being the number of frames which have to be taken into account in order to talk about a certain PER (PER=1/ total number of sent packets) if only one error emerges, i.e. the mean number of frames in which an erroneous packet occurs, and
- $N_{following}$ being all sent packets that following the corrupt packet until the ARQ message is received , will have to be retransmitted.

As mentioned earlier, slots for ARQ signaling will be reserved only when necessary. This implies that the number of slots reserved for ARQ depends directly on the window sizes. For a fixed number of packets sent, the number of ARQ messages will increase with shorter window sizes since the reception window will be filled more often. With the Selective-Repeat protocol it will be necessary to sent $(\dfrac{L}{windowsize}+1)$ ARQ messages, which corresponds to the same number of slots (slot granularity).

The factor $\dfrac{Windowsize}{BitmapSize}$ comes from the fact that we have supposed that one ARQ message (equal to one slot) can only contain one Bitmap Super field , that can acknowledge only 128 packets. If we work with window sizes larger than 128, more than one slot would be necessary to acknowledge a full window.

Following the discussion, we derivate the formulas for the case b) resulting in:

$$S_{SR} = \begin{cases} \dfrac{N_{data}*L-1-\left(\dfrac{L}{WindowSize}+\max\left(1,\dfrac{WindowSize}{BitmapSize}\right)\right)}{N_{data}*L} & , if\,PER \sim= 0\% \\[2ex] \dfrac{N_{data}*L-\left(\dfrac{L}{WindowSi}\right)}{N_{data}*L} & , if\,PER \sim= 0\% \end{cases}$$

$$S_{GBN} = \begin{cases} \dfrac{N_{data}*L-N_{following}-\left(\dfrac{L}{WindowSize}+1\right)}{N_{data}*L} & , if\,PER \sim= 0\% \\[2ex] \dfrac{N_{data}*L-\left(\dfrac{L}{WindowSi}\right)}{N_{data}*L} & , if\,PER = 0\% \end{cases}$$

where:

- L and $N_{following}$ being the same as in case a), and
- N_{data} refers to the number of slots per frame that the active single user can be used for data transmission, i.e. 14 slots.

Simulative Setup

An SDL-based simulation environment has been set up to further investigate the best suited ARQ scheme for FleetNet. The ARQ protocol variable *transmission and reception window sizes* and the *packet error rate* serve as parameters.

The frame structure considered consists of a frame with duration of T=10 ms comprising N=14 slots (N_{high}=1 slot is permanently reserved for high priority services). The network is modeled with a fully meshed topology and a population of M stations. In our simulation setup, no velocity is assumed.

Uncorrelated channel errors are considered, but as a first approximation the reverse channel is supposed error free. No capture-effect is taken into account. All stations have identical message arrival statistic that follow a stationary Poisson process with rate λ.

And finally, only one packet, either data or ARQ can be served within one channel. Each station has a limited buffering capacity of 100 packets. Additionally, one channel for the CSBC is provided for each station in every superframe, i.e. 4 TDD frames.

In next section we will present our results and major findings.

IV PERFORMANCE RESULTS

The analytical results are depicted in Figures 4, 5, 6, and 7 respectively.

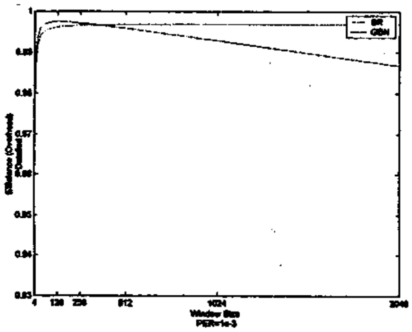

Figure 4 : Efficiency comparison, packet error rate 10e-3. Single user case a) the user can reserve only one slot per frame

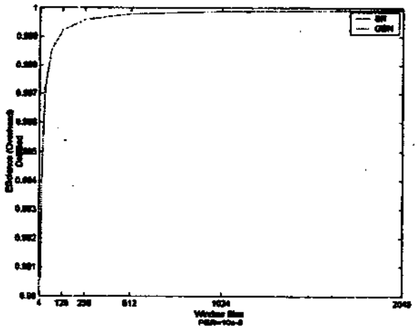

Figure 5 : Efficiency comparison, packet error rate 10e-6. Single user case a) the user can reserve only one slot per frame

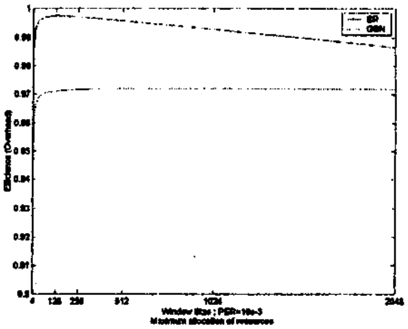

Figure 6 :Efficiency Comparison, packet error rate 10e-3. Single user case b) the user can reserved all slots in the frame.

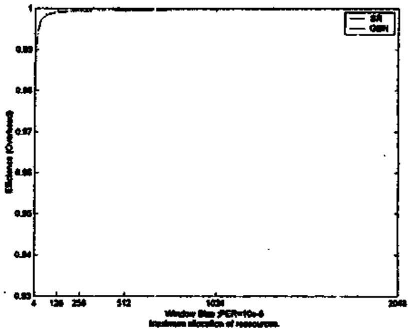

Figure 7: Efficiency comparison, packet error rate 10e-5 Single user case a) every user can reserved all slots per frame.

The simulative results are depicted in Figures 8, 9, 10 and 11 respectively.

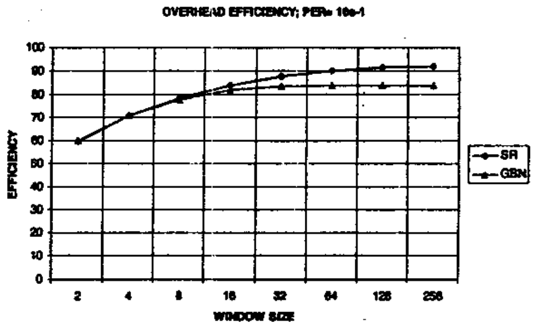

Figure 8 : Efficiency comparison, packet error rate 10e-1 . Single user case b) every user can reserve 1 slot per frame.

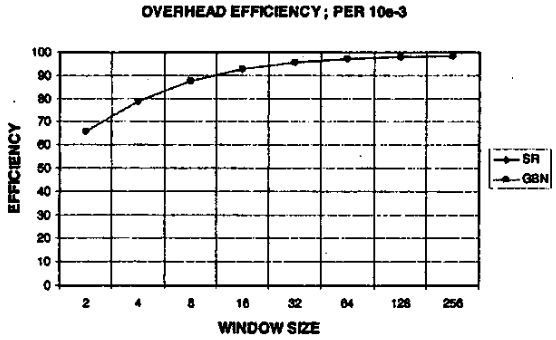

Figure 9: Efficiency comparison, packet error rate 10e-3. Single user case b) user can reserve 1 slot per frame.

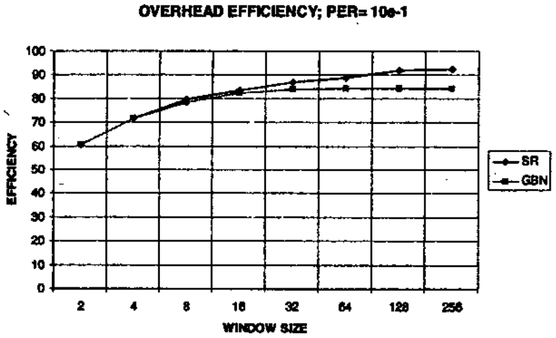

Figure 10: Efficiency comparison, packet error rate 10e-1. Single user case b) user can reserve all slots per frame.

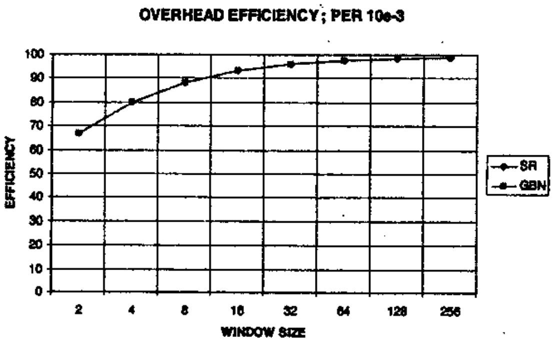

Figure 11: Efficiency comparison, packet error rate 10e-3. Single user case b) every user can reserve all slots per frame.

First we analyze the results obtained through analytical evaluation, which correspond to Figures 4-7. In **Figure 4** we appreciate that for window sizes ≤ 256 the efficiency of Selective-Repeat is slightly better than in the Go-back-N case. With window sizes ≥ 256, due to the partial Bitmap signaling mechanism, an ARQ message does not fit anymore inside one single channel but occupies more than one slot, i.e. an increase in overhead appears. Therefore the overhead efficiency of the SR protocol decreases with larger window sizes. The GBN schema shows in contrast a constant efficiency, since an ARQ message fits always inside a single slot independent of the window size and a reverse channel is assumed to be available always when it is necessary, thus the number of packets that have to be retransmitted ($N_{following}$) is also independent of the window size. The small advantage of SR over GBN disappears as the PER decreases, up to being almost null for a PER=10e-6 (see **Figure** 5).

The GBN protocol rejects at the receiver all packets received after an erroneous one. These packets together with the corrupt packet ($N_{following}$) must be retransmitted. In the scenario where the single user can occupy the full frame a larger number of packets must be retransmitted after a corrupt one. That is why a difference between the efficiency of both ARQ schemas is more perceptible in Figure 6. But the difference is still very fine. The worst case for $N_{following}$ happens when the ARQ message has to be shipped within the CSBC, which is available after a mean waiting time of two TDD frames, therefore in average 21 packets must be retransmitted (we suppose that the one error in the frame occurs in the middle of the frame). SR mantains the same efficiency as in the scenarion a). With decreasing PER both protocols tend to show equivalent performance, as we appreciate in Figure 7.

Therefore, after the analytical results have been presented the ARQ protocol which better performs for FleetNet seems to be the Go-back-N. It offers almost the same efficiency as Selective-Repeat plus an additional flexibility and protocol simplicity.

Now we analyze the results obtained through the simulative evaluation which correspond to Figures 8-11. The obtained absolute overhead efficiency is lower than in the ideal analytical case because additional overhead due to the resource reservation mechanism emerges, but of the same order of magnitude. Both protocols show very similar overhead efficiency for the expected packet error rates, i.e. below 10e-3 in both simulated scenarios (Figure 9 and **Figure** 11). The improvement of SR over GBN decreases with lower PER. This effect is due to the lower error occurrence, where fewer packets have to be retransmitted in the GBN schema. The efficiency in both ARQ schemas increases as expected with larger window sizes, because the overhead in terms of number of ARQ messages that have to be transmitted decreases. Notice that we have simulated only for window sizes ≤ 256. However, in Figures 8 and 10, i.e. for PER = 10e-1, we see that the improvement of SR over GBN grows with larger window sizes, the reason is that in the GBN case the efficiency remains constant up window size 64. This is because the number of ARQ messages sent remains in the same order of magnitude as the number of erroneous received packets for WS≥ 64 while in the SR case the number of ARQ messages sent does depend exclusively on the window size and is halved each time the window size grows one step. For window sizes ≤ 64, the number of GBN ARQ messages is larger as the number of erroneous received packets because the reception window can be still filled up with error free packets and then trigger additional ARQ messages.

In the single user scenario b) the user is allowed to occupy up to 14 slots per frame for data transmission, i.e. the total transmission capacity in a frame (high priority slots have been accounted). However, with the simulated traffic load the user occupies maximal 3 slots per frame, but usually 1 or 2 slots. This makes clear because the results are nearly similar to the ones for the case of minimum allocation of resources, as shown in figures 8 and 9. A bigger difference in the overhead efficiency like in the analytical scenario can not be seen here because the number of packets that have to be retransmitted is not as significant as it was supposed for the analytical case.

V SUMMARY AND CONCLUSION

In this paper we analyse the suitability of different ARQ methods for the Ad hoc Mode of UTRA TDD deployed within the FleetNet Project. The methods we have studied are the Go-Back-N and Selective Repeat.

We restrict our analysis to a scenario where only one user is active. Two cases have been analysed and simulated: case a) where the one user reserves only one additional slot every frame for data transmission, and case b) where the user occupies the whole frame resulting in the maximum possible throughput. As a major result of this work, the Go-Back-N approach is proposed as the suitable ARQ protocol for the FleetNet Project because its overhead efficiency is comparable to the one of SR and besides offers more implementation simplicity and flexibility. GBN ARQ messages could always be sent inside a CSBC and as well be piggybacked inside a data packet.

We expect that the influence of the ARQ schema on the average message delay is only minor, since if large packets are sent, the stations in both schemes have to wait until an erroneous packets occurs. Simulative analysis is actually being conducted to confirm our expectations and will be presented in a further document.

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