

Reservation Conflicts in a Novel Air Interface for Ad Hoc Networks based on UTRA TDD

M. Meincke, K. Jobmann

University of Hannover
Hannover, Germany
meincke@ant.uni-hannover.de
jobmann@ant.uni-hannover.de

M. Lott

Siemens AG,
Munich, Germany
Matthias.Lott@siemens.com

Abstract — Inter Vehicle Communication (IVC) has become a major topic during the last few years. Within the FleetNet project a novel mobile ad hoc network will be developed - based on the UMTS Terrestrial Radio Access Time Division Duplex (UTRA TDD) air interface - to interconnect vehicles and vehicles with roadside gateways via a mobile Internet. This paper focuses on the possibilities of reservation conflicts in the proposed protocol exploring multiple frequency channels, and outlines the impact on transmission delay and protocol efficiency. Intelligent algorithms to avoid these conflicts are proposed and are evaluated by means of simulations.

Keywords — Wireless ad hoc networks, UTRA TDD, FDMA, medium access control, inter-vehicle communication, reservation conflicts

I INTRODUCTION

Inter Vehicle Communication (IVC) has become a major topic during the last few years. Within the FleetNet* project [1] a novel mobile ad hoc network will be developed to interconnect vehicles and vehicles with roadside gateways via a mobile Internet based on UMTS Terrestrial Radio Access Time Division Duplex (UTRA TDD). Major services, supported by FleetNet will be road traffic telematics and mission critical services like emergency notifications and services for cooperative driver assistance, which put very high demands on the air interface and the used protocols. As a basis for the air interface, UTRA TDD has been chosen to provide the entire range of FleetNet applications. Since UTRA TDD is based on an infrastructure, a new UTRA TDD ad hoc mode for FleetNet has been proposed in [3], which was extended in [4] to explore more than one frequency. Both protocols are based on a reservation procedure. This paper will focus on possible resource allocation problems, esp. reservation conflicts in the proposed protocol exploring multiple frequencies, its impacts on transmission delay and protocol efficiency and how conflicts can be avoided.

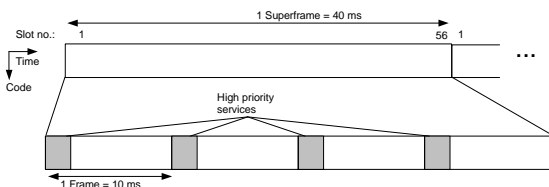


Figure 1. Superframe structure for the UTRA TDD ad hoc mode

II FLEETNET PROTOCOLS FOR THE AIR-INTERFACE

In the single frequency approach (as described in [3]) the available UTRA TDD frame is divided into a first part for high priority services and into a second part for on-demand dynamic reservations. Four TDD frames together form a superframe structure (cf. Figure 1) and each station is able to reserve one fixed slot per superframe out of 56 slots, which is used for the Circuit Switched Broadcast Channel (CSBC). The CSBC is reserved in every following superframe by means of reservation (R)-ALOHA and is basically used for signaling purposes, esp. for reservation of additional capacity by means of in-band signaling. Reserved slots are sensed and will be respected by the neighboring stations. Packets transmitted in the same slot in subsequent frames can be described as packet train. When no packets have to be transmitted the slot is released and the train ends. The release of a slot is indicated by signaling it with the last packet (release flag).

The procedure to reserve additional capacity is based on the knowledge which channels (time slots) are available, i.e. which are free of interference, and which are used (reserved) by other stations. This knowledge will usually be gained by a) measuring the radio channel, and b) receiving reservation packets from neighboring stations. Measuring the signal strength (RSSI, Received Signal Strength Indicator) of each time slot, a station can detect the status of each slot. If the RSSI is below a predefined threshold Th_{detec} , the channel is expected to be unused; if it is above Th_{detec} but below a second threshold Th_{decode} , it is used. If the signal strength is above Th_{decode} the transmitted data can be decoded and we can obtain additional knowledge about that channel.

$$\text{channel free: } RSSI < Th_{detec} \quad (1)$$

$$\text{channel used: } Th_{detec} \leq RSSI < Th_{decode} \quad (2)$$

$$\text{channel decodable: } Th_{decode} \leq RSSI \quad (3)$$

If a station is able to decode a channel, it can obtain the IDs of the communicating stations, detect reservation messages and release flags, i.e. it can forecast the usage status in the following superframe. This forecast is needed if a station wants to reserve additional resources without disturbing foreign transmissions. However, even without decoding messages the future reservation of slots can be anticipated because of the frame and slot structure and the condition that used slots are automatically reserved in the next frame (principle of R-ALOHA). This is a fundamental advantage of reservation-

*Partly funded by the German Ministry of Education and Research, BMBF

based MAC schemes using a frame/slot structure compared to asynchronous schemes that use random-access, e.g. CSMA.

III EXPLORATION OF MULTIPLE FREQUENCY CHANNELS

The decentralized Frequency Division Multiple Access (dFDMA) procedure supports the exploitation of an arbitrary number of frequencies in ad hoc networks. As described in [4], the dFDMA concept logically subdivides time into two different phases: the *exchange phase (EX-Phase)* and the *arbitrary transmission phase (AT-Phase)*. During the EX-Phase, a station listens and transmits on a predefined frequency – the coordination frequency, f_{coord} – and can announce reservation requests, exchange signaling information to run the protocol and manage the radio resources. During the AT-phase, the station is allowed to arbitrarily explore all available frequencies f_i . In addition, the station has to measure and test the available resource units that it is currently using and that it might use at a later time for transmission or reception. Since all frequencies in parallel to the coordination frequency cannot be used by stations that have only one transceiver and that are in the EX-Phase, different frequency patterns are introduced that define concurrent EX- and AT-Phases. The phases of the frequency patterns are equidistant in time. An example for three frequency patterns is shown in Figure 2.

The reservation procedure in dFDMA basically works the same way as in the single frequency approach. A more detailed description can be found in [4]. In the dFDMA approach – if we are only able to use a single transceiver – a station can only work on one frequency at a single point of time. But as a station can choose out of all available frequencies (in this report, we assume three) in the AT-Phase and has to work on the predefined coordination frequency f_{coord} in the EX-Phase, it is not able to gain full knowledge about the channel status on all frequencies by scanning only within one superframe.

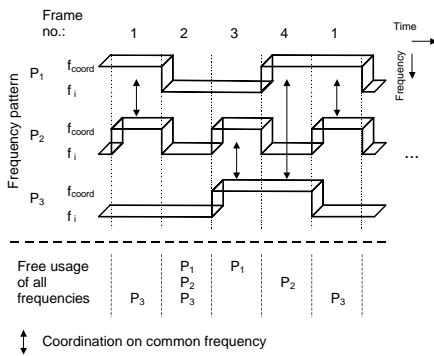


Figure 2: Selection of frequencies in dFDMA, based on frequency patterns

IV RESOURCE ALLOCATION CHALLENGES

In the dFDMA approach, three types of resource allocation problems can occur: a) *reservation conflicts*, b) *unresolvable reservations* and c) *release latency*.

A Reservation Conflicts

Even in a fully meshed network with no hidden stations reservation conflicts may occur. During the EX-Phase, each station has two CSBC slots in every superframe to transmit reservation messages for slots in a following frame on an arbitrary frequency. In every frame, stations belonging to the same frequency pattern and stations belonging to one other pattern (e.g. station S_1 and S_k in pattern P1 and P2 in frame no. 1) are able to overhear the reservations (cf. Figure 3). Stations belonging to the third frequency pattern (e.g. station S_m in pattern P3 in frame no. 1) are not aware of the reservation since they operate on a different frequency to explore all channels at every time. These stations might propose the same slot in their reservation messages (e.g. in the previous superframe in frame no. 3), which results in a reservation conflict and might cause data packet collisions in a following frame (in the example in frame no. 2). We can distinguish two different possibilities of reservation conflicts:

- i.) conflicts due to a reservation of slots on an arbitrary frequency f_i in the AT-phase (excluding f_{coord}),
- ii.) conflicts due to a reservation of slots on f_{coord} for data transmissions in the EX-Phase.

For i.) it can be seen in Figure 3 that reservation conflicts can only occur, if slots in frame 2 of the superframe are reserved, because it is the only frame where more than one station belonging to different frequency patterns is able to transmit on an arbitrary frequency f_i . As explained above, the reservation conflict occurs only if the same slots for frame 2 are reserved by a station of P3 in frame 3 (or 4) and a station of P1 (or P2) in frame 1.

For ii.) it can be seen, that reservation conflicts could also occur in any other frame. E.g., if S_k reserves a slot on f_{coord} in frame 4 using its CSBC in frame 3, there is a potential reservation conflict if the slot in the frame is placed behind the CSBC of S_1 in frame 4, because S_1 could reserve the same slot on f_{coord} in frame 4 itself, see Figure 3.

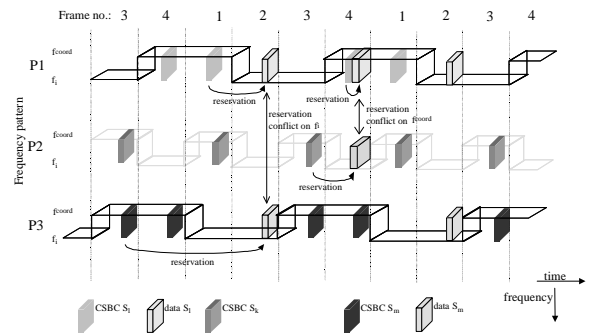


Figure 3: Reservation conflicts

B Unresolvable Reservations

If two stations reserve channels for a transmission to a single receiver, and they reserve the same slot on different frequencies, the receiver is not able to receive both transmissions. Due to the time needed for a frequency turnaround, even consecutive slots on different frequencies cannot be served by the receiver¹. This could lead to a significant decrease in throughput of the protocol.

C Release Latency

Channels, once reserved via a CSBC reservation message are implicitly reserved during following superframes by means of R-ALOHA, i.e. the reservation is valid in every superframe until it is released by a piggybacked release-flag, and is then not used again in the next superframe. This mechanism may lead to the problem, that stations operating on a different frequency at release time will realize the clearance of the channel deferredly. This will increase the average delay and reduce the maximum achievable load because stations regard channels as still reserved, esp. if they do not measure that frequency in the next superframe.

V SOLUTIONS

Some of the depicted problems can be avoided by intelligent reservation algorithms. Others, esp. in the dFDMA approach, result from the fact that a station cannot listen to all frequencies at the same time, and needs additional mechanisms.

A Reservation Conflicts

Reservation conflicts can be avoided, if we repeat reservations for slots in frame 2 in the second EX-Phase, e.g. station S_k has to repeat the reservation (first sent in frame 3, cf. Figure 3) in frame 1 so that S_l can overhear it. This will increase overhead needed for the reservation procedure. The repetition of reservations will not resolve conflicts in all cases. In Figure 4 a situation is depicted where at least one collision occurs before the conflict can be resolved: if S_m and S_k reserve in frame 4, respectively frame 1 the same slot in frame 2, each of them did not overhear the other's reservation. The first possible time to repeat the reservation is frame 3, where one of the stations, S_k or S_m will cancel its reservation to resolve this conflict.

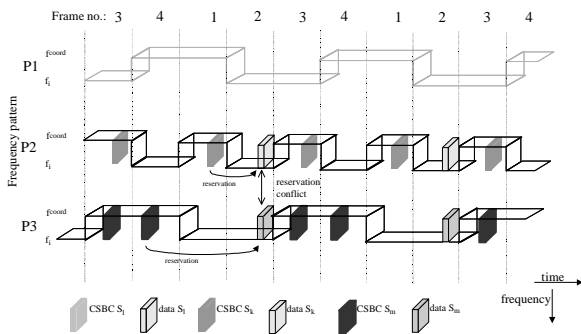


Figure 4: Reservation repetition

¹ We assume no transceiver turn-around time in the following.

Nevertheless, if we force a station to repeat the reservation before it uses the respective slot in frame 2, a reservation conflict can be precluded. The only drawback is a potential increased delay if the repetition has to be transmitted a second time after frame 2 because of an unfavorable schedule of the EX-phases.

B Unresolvable Reservations and Release Latency

To avoid unresolvable reservations a sending station has to have full knowledge about the channel usage of the intended receiver, even if it uses the same pattern. Stations have to gain knowledge on the usage status of each channel inside the system. Thus, if a station receives a reservation for a slot it already regards as reserved, it will save the new information even if the old one is still valid for the sender because the sender did not realize the conflict.

The release latency problem is even harder to resolve. Within the protocol release messages are transmitted piggybacked on the last packet of a packet train. If this packet is transmitted within the EX-Phase, i.e. inside a CSBC, we have a higher probability that this message is overheard by other stations. But if the message is transported within the AT-Phase it is overheard only by stations receiving this message by chance.

If every station transmits its own knowledge about the channel status inside its CSBC in terms of a neighborhood table or channel status indicator (CSI), we can improve the system performance. The transmission of CSI tables can also help to solve the hidden station problem. If a station broadcasts its knowledge about used channels, stations in the vicinity will benefit from that. The deferred release messages could be avoided by spreading CSI tables, too, because a station can gain information of released data channels from another station which decoded the release message (flag).

VI SIMULATION SYSTEM

For the purpose of performance analysis an event-driven simulation environment has been build. It is based on SDL (Specification and Description Language). All protocol elements for the evaluation are incorporated in the simulator and are described in SDL.

In this section a simulative investigation of the described resource allocation problems and the proposed solutions is performed and the results are presented. In the following a frame with duration of $T = 10$ ms comprising $N = 13$ slots is considered ($N_{\text{high}} = 1$ slot is permanently reserved for high priority services) and 3 frequencies are used. Further, the term channel is used for a slot on one of the three frequencies. As a starting point and to understand the basic principles of the schemes, the topology is modeled as fully meshed network with a population of $M = 18$ stations. No velocity is assumed. No channel errors are considered. Simultaneous transmissions of more than one station per channel result in collisions. No capture-effect is taken into account. In the simplified model a channel is either free of interference or reserved. In the latter case it is unserviceable for any other station since a fully meshed network is assumed. All stations have identical message arrival statistic that follow a stationary Poisson

process with rate I . One packet can be served within one channel. Each station has a limited buffering capacity of 100 packets. One channel for the CSBC is provided for each station in every EX-Phase of the superframe where a superframe contains $n_{SF}=4$ frames, i.e. two CSBC channels per superframe are available for each station. If the two CSBC channels per superframe are not sufficient for the offered load, the reservation procedure tries to reserve up to 10 additional data channels per station, where within one CSBC up to 3 channels are reservable at once, which leads to a maximum of 6 reservable channels per superframe. The simulation environment does not perform any link layer acknowledgements or retransmissions, i.e. if collisions occur or transmissions cannot be received on a channel because the receiver is currently working on a different frequency the packet is lost.

VII SIMULATION RESULTS

The following graphs represent the results of 4 simulated scenarios:

1. *central*: the system is equipped with a central reservation table, i.e. all stations are fully informed about the slot status;
2. *decentral*: all stations have their own reservation table; they gather the information only by overhearing reservations and ongoing data transmissions;
3. *repetition*: like decentral, but for reservations regarding slots in frame 2 of the superframe the protocol performs a repetition of reservations in the next CSBC;
4. *tables*: like *decentral*, but each station transmits a reservation table with each packet on the CSBC, where all slots are listed the station is receiving on in the next superframe.

First we have a look on the resulting packet loss as function of the load normalized to the max. possible capacity of one frequency channel (cf. Figure 5). In the *central* scenario no packets are lost (we assume no channel errors) and no reservation conflicts occur because the stations are fully informed about the channel allocations. Due to the depicted problems of reservation conflicts and unresolvable reservations, the packet loss increases in the other scenarios.

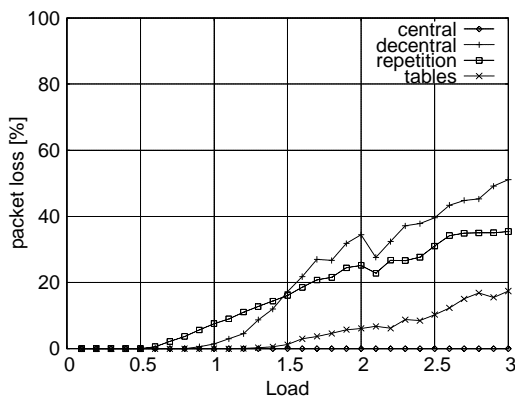


Figure 5: packet loss

The *decentral* approach performs worst, because no conflict resolution methods are applied. The spreading of reservation *tables* performs better than *repetition* of reservations. The reason becomes more clear, if we look at the two possibilities of packet losses: *collisions* and *unresolvable reservations*, which are depicted in Figures 6 and 7.

In the *decentral* scenario packet loss is mainly caused by collisions due to reservation conflicts. These collisions can be combated by *repetition* of reservation messages and by spreading of reservation *tables*. The repetition significantly reduces the collision rate, but the spreading of reservation *tables* performs better. This is because the repetition is sender-based, but collisions happen at the receiver. If the receiver resolves the conflict by sending a table where it successfully receives on, conflicts can be resolved earlier. The rest of the packet losses are caused by unresolvable reservations, depicted in Figure 7. The *repetition* of reservation messages does not reduce the number of unresolvable reservations, they are increased instead. If reservations are repeated more stations regard them and may have the wrong information if the reservation is cancelled afterwards. Even the spreading of reservation *tables* does not fully combat this problem, because between two table transmissions the situation can change due to further reservations of other stations or own reservation cancellations. This information may not be available at the sender.

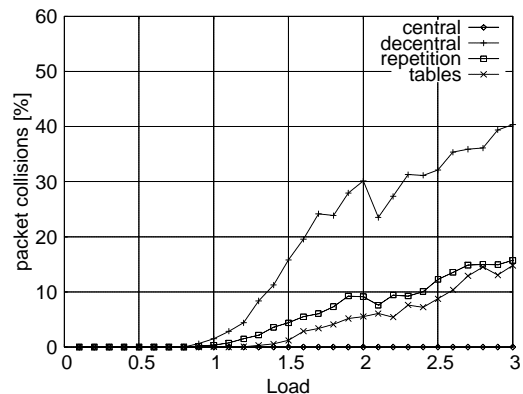


Figure 6: packet collisions

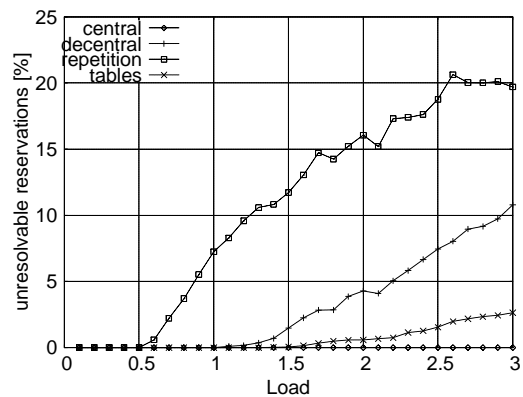


Figure 7: unresolvable reservations

In an enhanced version of the protocol reservation conflicts and unresolvable reservations will be further combated by reservation acknowledgements and link layer retransmissions. This will reduce the packet losses but increase the mean message delay. Additionally, reservation tables can be added providing information on which channels a sender is transmitting. This will have the same effect like a repetition of reservations but – if the whole reservation still fits into one CSBC – without occupying a whole additional slot.

In Figure 8 the resulting mean message delay as function of the load normalized to the max. possible capacity of one frequency channel is shown. Compared to the *central* scenario, the mean delay increases because of the additional overhead in the protocol. Here the *repetition* of reservation performs worst, because capacity is used for the repetition, which can be used for data transmission in the other scenarios. Due to performed reservation cancellations the delay slightly increases in the case of the *table* scenario.

The maximum throughput of the *repetition* and *tables* scenario is comparable to the *central* scenario. In the *decentral* scenario the maximum throughput performs best, but this is due to the fact that only transmitted packets are counted for the statistical calculation. If more packets are lost, the throughput is smaller than the offered load and packets with high delay will be dropped. This improves the delay performance close to saturation of the system on cost of increased packet losses.

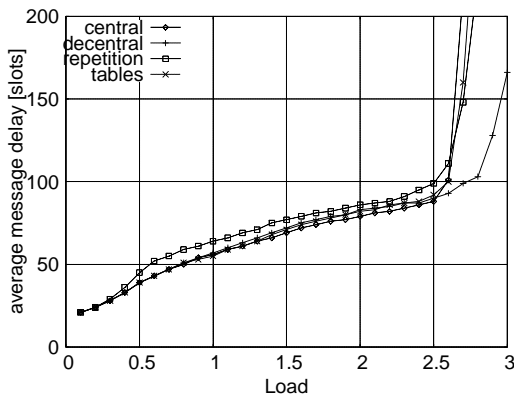


Figure 8: Mean delay

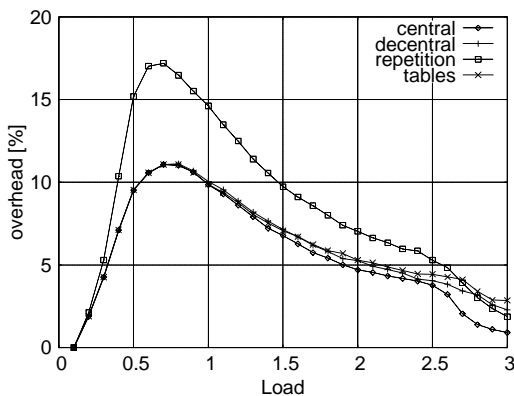


Figure 9: reservation overhead

Finally we consider the protocol overhead, i.e. how many percent of the transmitted packets are reservation messages. Figure 9 shows the results. The *repetition* of reservation cost about 50% more overhead than the spreading of reservation *tables*, because every reservation is transmitted twice. This relation remains true as long as reservation tables can be piggybacked with data or reservation messages inside the CSBC. When tables grow they need more capacity and the overhead grows, too.

VIII SUMMARY AND CONCLUSION

In this paper we focused on a new air interface for ad hoc networks using a novel reservation procedure in a multiple frequency environment. We showed, that due to the use of FDMA in ad hoc networks reservations may lead to conflicts and, consequently to collisions. It has been shown that the conflicts have an impact on the efficiency of the proposed protocols with respect to increased delay and packet losses.

To solve these reservation conflicts, different algorithms have been proposed and evaluated by means of event-driven simulations. It has been shown that the spreading of reservation tables outperforms the repetition of reservations, although not all conflicts can be avoided. Besides reservation acknowledgements and link layer retransmissions the combination of information on slots used for receiving (as proposed in this paper) and sending in the reservation table could further reduce the amount of conflicts.

If mobility is introduced into the scenarios, resource allocation problems due to hidden stations will become much more relevant, but it is foreseen to combat them with the same methods as proposed for the multi-frequency operation in this paper.

REFERENCES

- [1] H. Hartenstein, et al., "Position-Aware Ad Hoc Wireless Networks for Inter-Vehicle Communications: the FleetNet Project", in *Proc. ACM MobiHOC 2001*, Long Beach, USA, Oct. 2001.
- [2] M. Chiani, R. Verdone, "A TDD-TCDMA Radio Interface at Millimetre Waves for ITS Applications", *IEEE VTC'99 fall*, Amsterdam, Netherlands, 19.-22.Sept., 1999, pp.770-774.
- [3] M. Lott, R. Halfmann, E. Schulz, M. Radimirsch, "Medium access and radio resource management for ad hoc networks based on UTRA TDD", in *Proc. ACM MobiHOC 2001*, Long Beach, USA, Oct. 2001.
- [4] M. Lott, R. Halfmann, M. Meincke, "A Frequency Agile Air-Interface for Inter-Vehicle Communication", *Proc. ICT 2003*, Papeete/Tahiti, February 2003.