Wireless Adhoc Networks for Inter-Vehicle Communication

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Future enhancements in automobile technology will cope – besides traditional aspects, like security and driving conditions or comfort aspects of passengers – especially with the ability of vehicles to communicate. The aspirated enhancements in the ability of communication of vehicles should not only focus on the use of existing wireless (cellular) networks, but should also concentrate on totally new concepts for inter-vehicle communication. The following paper will give an overview of ongoing research activities at the Institute of Communications Engineering in the industrial project FleetNet, dealing inside the emerging field of wireless ad hoc networks.

1 Introduction

The project FleetNet[1] brings together two emerging technologies – mobile ad hoc networking and the Internet - by building up a mobile Internet for communication with and among vehicles. FleetNet integrates the application area of Intelligent Transportation Systems (ITS) into the Internet. Communication in ITS is based upon wireless Inter-Vehicle Communication (IVC) [Ha01] and has been found to be an attractive area of research many years ago, e.g. within the framework of PROMETHEUS [Wa92]. Current research on ITS concentrates on network architectures where an infrastructure exists to connect vehicles with each other and with the Internet (DRIVE [Wa92], COMCAR [Er02]).

The FleetNet air-interface will be based on UMTS Terrestrial Radio Access Time Division Duplex (UTRA TDD) and will provide a wide range of FleetNet applications [An00]. However, because UTRA TDD is a cellular communication system with centralized organization, its air-interface has to be changed and adopted towards an ad hoc mode to make it a suitable system for FleetNet.

After introducing the FleetNet philosophy [FEL01] and depicting the basic application classes [FHB01], the basic modifications of the protocol stack of FleetNet towards a mobile ad hoc network for Inter-Vehicle Communication, are introduced in this paper. It will be shortly depicted what has to be changed at the UTRA TDD air-interface with respect to the medium access control and radio resource management. To provide performance measurements of the proposed protocols, an SDL-based simulation environment will be introduced and first results will be outlined. With respect to one of the most emerging application classes – the Cooperative Driver Assistant Applications – special forwarding strategies will be introduced, to distribute e.g. Emergency Notifications in case of accidents etc. without flooding the entire network.

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2 FleetNet, an ad hoc network for Inter-Vehicle Communication

Figure 1 shows a simple FleetNet scenario, where vehicles can communicate with each other, with stationary FleetNet gateways and with the Internet (using the gateways).

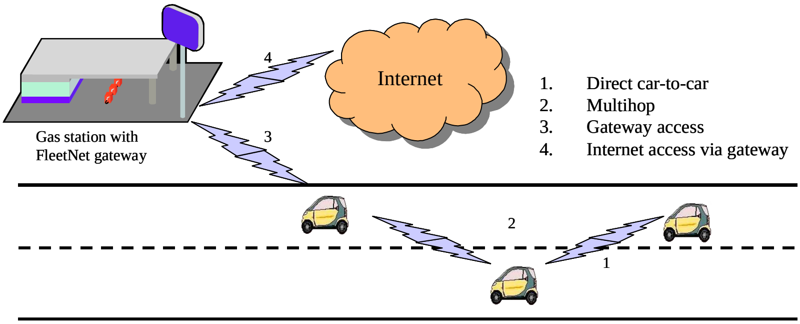

Figure 1: A simple FleetNet scenario

FleetNet will support three application classes, as follows:

- Cooperative Driver Assistance Applications will mainly distribute sensor data or other status information among vehicles. One major application will be Emergency Notifications, for example messages containing information about emergency braking.
- Decentralized Floating Car Data Services (dFCD) will exploit position-awareness for data distribution to collect and combine data from vehicles and broadcast 'drawn conclusions' among surrounding vehicles.
- User Communication and Information Services (Internet access) will provide all kinds of possible applications, which run on top of Internet protocols like TCP/IP or UDP/IP.

3 The FleetNet air interface

Within the projects work the UMTS Terrestrial Radio Access Time Division Duplex (UTRA TDD) mode has been identified to be best suited as the FleetNet air-interface for various reasons [Lo01]. One argument is the availability of an unlicensed frequency band at 2010 - 2020 MHz in Europe, as well as the high flexibility of UTRA TDD owing to its frame and slot structure. It provides asymmetric data flows, high transmission ranges, supports high velocities and enables the operation of circuit-switched and packet-switched traffic with QoS support in parallel. Because of its code division multiple access (CDMA) component it provides a high data rate up to 2 Mbit/s with a high granularity. Last but no least, it has been shown in [CV99] that UTRA-TDD is appropriate for ITS applications and operation in an ad hoc network.
The air-interface to be developed has to cope with high dynamics and rapid topology changes [RML02]. To overcome the centralized control of the wireless medium access, which incorporates a lot of difficulties in dynamic systems like FleetNet, several changes at the Data Link Control (DLC) layer become necessary. A second item to be changed is

the Radio Resource Management (RRM) that is controlled by the base station in UTRA TDD, which is now omitted and has to be distributed among all stations of the ad hoc network.
The resulting task is to define appropriate protocols for the Data Link Control (DLC) - including the Logical Link Control (LLC) and Medium Access Control (MAC).

4 Basic changes to the DLC for an UTRA TDD ad hoc mode

The requirement to operate in an ad hoc environment leads to a number of enhancements and extensions of the DLC Layer of UTRA TDD [Lo01]. The frame structure of UTRA TDD is basically maintained, i.e. the frame duration is 10ms and comprises 14 slots in the aspired Low Chip-Rate mode (LCR). To avoid the need of a central instance for resource control the resource management is assumed to be spread among all participating nodes of the network.
In accordance to the distributed RRM, the medium access control (MAC) is organized in a totally decentralized fashion, whereas each station takes over the resource management by itself, only considering the current situation of transmission requests, adjacent stations and interference.
For the MAC the approach described in [Lo01] is foreseen. In this approach only one station is allowed to transmit in one slot at the same time. This is to avoid the so-called near-far-problem and keeps the power control mechanisms simple. In the proposed ad hoc mode of UTRA TDD a combination of frequency, slot and code will provide a transmission resource used for a connection. With this concept, up to the number of parallel codes that are supported- in case of UTRA TDD this number is 16 - can be simultaneously reached by one station (cf. Figure 2).

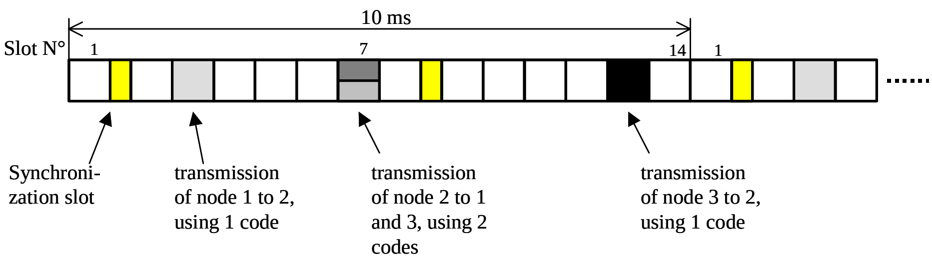

Figure 2: Example for code assignment to connections

One major challenge for the ad hoc mode is the radio resource management (RRM). It covers the reservation of capacity, the operation of channels, and the release of reserved capacity. Reservation of transmit capacity is a basic requirement for the provision of QoS.
In the ad hoc mode of UTRA TDD, transmit capacity is provided by a combination of codes, slots, and frequency. To provide the use of high priority services, an adjustable part of the capacity in terms of slots in a frame, is constantly reserved. The remaining part can be dynamically assigned and temporarily reserved by different stations for several services with lower priority, cf. Figure 3.

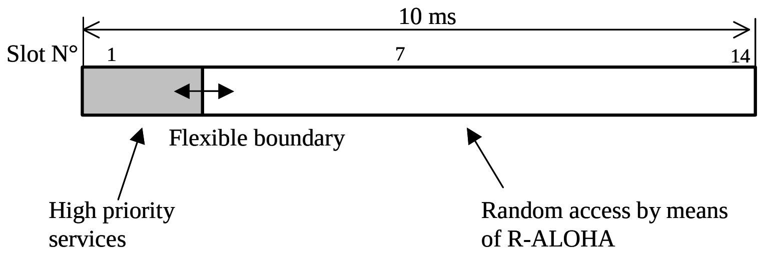

Figure 3: Organization of the frame

For the reservation mechanism a distributed access schemes has to be used. To keep it simple, the access is granted by means of Reservation ALOHA (R-ALOHA), where reserved slots are used in subsequent frames as long as packets have to be transmitted [La80][Ta83]. The reservation of the next slot is indicated by piggyback signaling. To avoid the collisions during the reservation attempts in R-ALOHA, each node can reserve a circuit-switched broadcast connection (CSBC, Circuit-Switched Broadcast Channel) that is primarily used for signaling purposes. If this connection does not provide enough capacity, it is used to transmit a reservation request for additional capacity. This capacity is only used as long as packets have to be transmitted and is released after successful transmission. This will lead into a large amount of unused capacity. Therefore a 40ms superframe (4 normal frames) is introduced, see Figure 4. For each node the CSBC will exist only once inside this superframe.

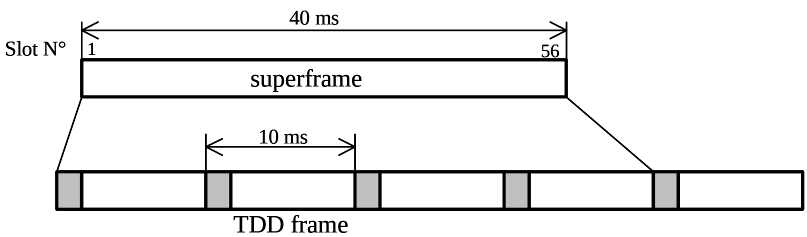

Figure 4: Superframe structure for the UTRA TDD ad hoc mode comprising 4 frames

5 Protocol performance simulations

For the purpose of performance analysis of the proposed protocol, an event-driven simulation environment has been built. 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.

5.1 The simulation environment

The simulator consists of a number of generic parts, such as the simulation manager and the radio channel, and provides a framework for the implementation of the actual protocol and system, respectively, that shall be simulated.

The simulator structure for the FleetNet simulator is given in Figure 5 and the structure of the protocol package (FleetNet Module) is given in Figure 6.

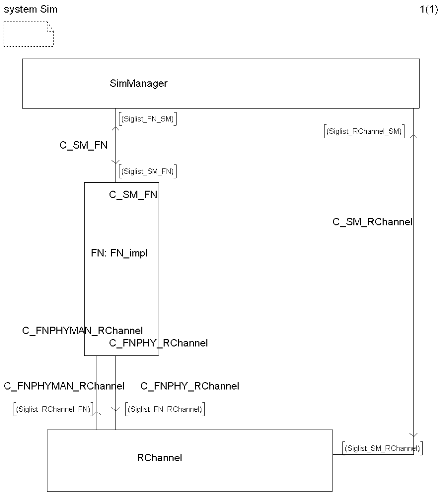

Figure 5: The structure of the simulator

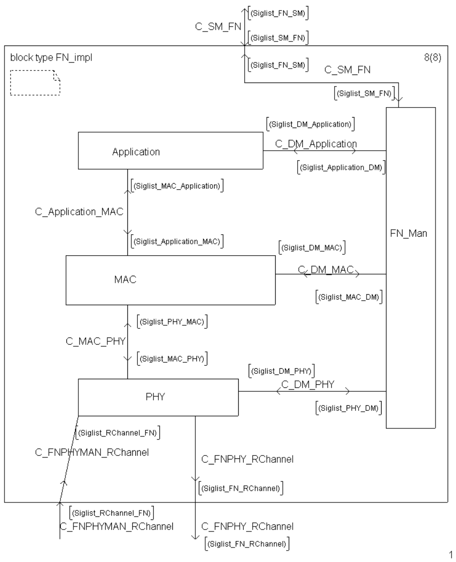

Figure 6: The FleetNet Module

The simulator provides a horizontal structure with a number of blocks representing the layers of the FleetNet reference model, a simulation manager, a radio channel and a device manager (FN_Manager). The simulation manager and the radio channel are generic to keep the structure adaptive for different systems.

The Simulation Manager (SimManager)

The simulation manager shall provide a generic framework for the implementation of a radio network simulator for a certain system. It contains some generic functions to control the simulation, basically the initialization process, which provides the routines for initialization. Moreover, it reads some parameters, i.e. it allows to determine the generation and removal of devices where the time to generate or to remove a device is given in the instruction.

The Radio Channel (RChannel)

The radio channel covers the special characteristics of the channel we deal with inside FleetNet. Implemented functions are:

- interference measurement for Dynamic Channel Allocation (DCA),
- calculation of path loss and interference and
- indication of simultaneously used codes.

Within a first step the radio channel is implemented in a very simple way. All nodes are within radio range and the interference is measured by a yes/no decision, i.e. if two or more nodes transmit within the same slot there is a collision and the packet is discarded.

In further versions, more detailed channel models will be implemented with respect to path loss and interference conditions.

The FleetNet Manager (FN_Man)

The FleetNet-Manager block is responsible for transferring the signals from the simulation manager to the different layers and vice-versa. Therefore, most signals are converted to suitable signals for the specific blocks. Additionally it contains the device manager, which is responsible for the handling of any devices. Especially it contains functions for mobility, i.e. the movement of devices. In the first step the simulation will work without movement. But in further versions, detailed movement models – based on realistic traffic simulations – will be added to simulate the proposed protocols under realistic traffic scenarios.

The Physical Layer (PHY)

The Physical Layer will be based on the UTRA-TDD physical layer. Implemented functions will be:

- burst generation out of higher layer PDUs and transmission to the radio channel,
- generation of bit errors based on path loss and interference reported by the radio channel,
- transmission of received bursts to higher layers and
- Forward Error Correction (FEC).

The generation of a bit error rate (BER) will not be done by detailed simulations, but will be extracted out of BER-curves. Within this first implementation the physical layer is basically empty – it just hands through the packets between the DLC layer and the radio channel.

The Medium Access Control Layer (MAC)

The proposed MAC-protocol depicted in earlier sections of this paper is implemented with the following presumptions:

- the amount of nodes is smaller than the amount of time-slots within one superframe (but the total amount of active nodes may vary),
- all nodes have at least one reserved time-slot, i.e. they establish a circuit-switched broadcast connection which they never quit. The number of the used slot (the CSBC) will be determined by an initialization file, i.e. there is no contention for the initial time slot,
- in case of a higher amount of data, additional time slots will be reserved and released afterwards,
- no information for self-organization will be included and
- only unicast traffic will be simulated.

The Application Layer

The application layer hosts mainly the traffic sources. Implemented sources are Constant Bit-Rate (CBR) and poisson sources. Both types create traffic with a constant packet length. The length of the packet will suit the length of a UTRA-TDD time-slot. In the case of poisson sources, the inter-arrival time of the created packets are negative-exponentially distributed, but the packet length is still constant.

5.2 Simulation results

Based on the simulation environment described in the previous section, the performance of the proposed protocols should be estimated. In the following a frame with duration of 10ms comprising 14 slots is considered (1 slot is permanently reserved for high priority services). For the generation of first results (cf. 5.1) the topology is modeled as fully meshed network, no velocity is assumed, no channel errors and no interference is considered. Simultaneous transmission of more than one station results in collisions. All stations have identical message arrival statistic that follow a stationary Poisson process. One packet can be served within one slot. Each station has a limited buffering capacity of 200 packets. One slot for the CSBC is provided for each station in every superframe where a superframe contains 4 frames.
The SDL-based simulations returned the resulting message delays for the proposed protocol, shown in Figure 7 and Figure 8.

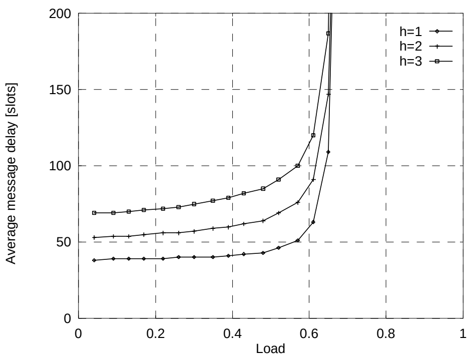

Figure 7: Average message delay with 15 stations

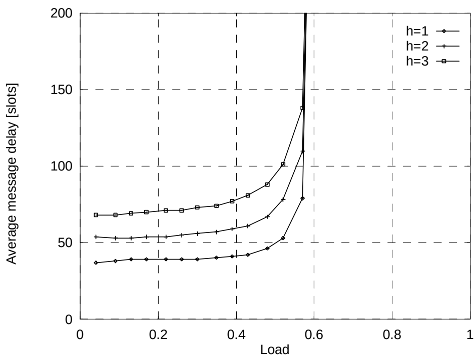

Figure 8: Average message delay with 20 stations

The mean delay has been derived for 15 and 20 stations for different numbers of fragments per packet *h*. As long as the traffic load is below saturation, the mean delay is almost constant. The value is defined by the time until the slot for the CSBC is available for reservation. For a message length of *h=1* we retrieve message delays of a nearly constant average value of approximately 25ms, i.e. 1 frame and 1 superframe. With bigger message lengths the delay increases linear, but remains constant until saturation.
In the simulation with 15 nodes, approximately 28% of the capacity is reserved for in-band-signaling, so the max. throughput is limited at approximately 72% of the available capacity. If we simulate with 20 stations, the max. throughput decreases to approximately 60%, because more capacity is reserved for the CSBC.
In the above simulations, the CSBC was used for signaling only. If we use the CSBC for data transmission also, we retrieve the following results, depicted in Figure 10 and Figure 11.

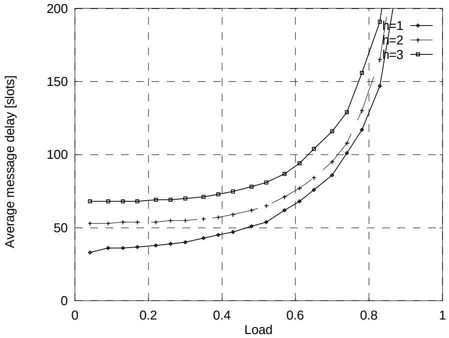

Figure 10: Average message delay with 15 stations using the CSBC for data

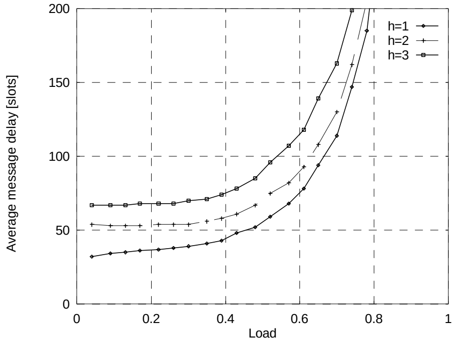

Figure 11: Average message delay with 20 stations using the CSBC for data

The reachable capacity increased to approximately 85%, and 80% in case of 20 stations respectively. This is because of the additional capacity in the CSBC every fourth frame. On the other hand the message delay seams to increase for higher loads. After a careful consideration of the depicted graph, we see that the gradient of the graph is smaller for higher loads, but not the real delay. The reason for the lower gradient is the fact, that the transmission buffers are charging slower due to the additional capacity of the CSBC and so the throughput increases.

It has to be kept in mind that this implementation of the simulation environment is in an early state and a lot of restrictions were made. In the real protocol, the CSBCs are not reserved infinitely, but released after a period of time and re-established to take into account changes in topology. This will lead to collisions during CSBC reservation process and a reduction in throughput.

From the results it can be concluded that with the MAC scheme proposed for FleetNet the demands of the FleetNet applications can be fulfilled since a constant delay can be guaranteed that depends only on the capacity reserved for the CSBC but not on the load. Furthermore, prioritization of services can be supported by means of allocating a different number of slots to the CSBC.

6 Forwarding strategies for security relevant information

By enabling multi-hop vehicle-to-vehicle communication it will be possible to improve safety through an extended range of awareness of a vehicle and its driver. The safety task benefits from the fact that vehicles will be enabled to quickly distribute collected sensor data to surrounding vehicles allowing them to take appropriate actions: e.g. in an emergency situation when vehicles have to brake hard, following vehicles can be informed immediately and independently of ‘line-of-sight’ conditions.

As an example of potentially dangerous traffic situations an equipped vehicle identifies itself as crashed by vehicular sensors that detect events like airbag ignition. In this case it can report the accident instantly to nearby vehicles by sending an Emergency Notification. If the notification reaches a vehicle for which the warning is relevant, the driver can be informed earlier by the system.

The algorithm proposed in this paper allows us to enlarge the area in which a vehicle is able to receive Emergency Notifications without flooding the whole network.

In this application the vehicles are provided with radio equipment allowing them to contact other equipped vehicles in their surrounding area. No fixed infrastructure to support communication is assumed and the resulting ad hoc network requires no additional infrastructure at the road side. The vehicles use omni directional antennas implying that a sender can transmit to multiple hosts simultaneously.
Many vehicles do or will soon utilize navigation systems like the Global Positioning System (GPS). Thus, it is assumed that equipped vehicles know their location more or less accurately, which is necessary to make the algorithm work.
In the following section the forwarding rules are described. When a road accident has happened, the crashed vehicle wants to inform other vehicles that are approaching the hazardous area. Our aim in using the forwarding rules is to disseminate messages quickly and efficiently in a local area around the initiating vehicle.
Two different road types are considered: a divided highway and a national road, which can be seen as a highway without divider and with fewer number of lanes (cf. Figure 13).

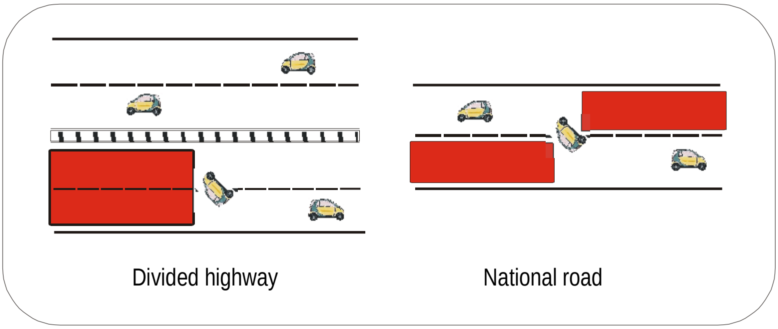

Figure 13: Considered road types

For the road model of the divided highway, the 'Zone of Relevance' covers the region behind the accident on the side of the highway where the accident happened. On divided highways, an accident usually does not harm vehicles in the other driving direction. In the second road type, the national road, the vehicle having an accident can affect both driving directions. Hence, all vehicles approaching the position of the accident are part of the 'Zone of Relevance` .
Predominantly the 'Transmission Range' of a vehicle depends on its antenna's transmission power, antenna's height and on the propagation channel characteristics. It defines the limit of antennas' radio coverage area. In this paper it is assumed that vehicles use omni-directional antennas, i.e., its radio coverage area extends homogeneously in a circle with center the sender vehicle and with radius the transmission range (in this paper a constant transmission range of 1000 m is assumed). Under normal circumstances a vehicle sending data packets can reach all other vehicles within its transmission area simultaneously.
'Information range' is a definition related to one message, and tells us how far from the source of the message the message's information has arrived at all. If using a multi-hop strategy, usually, the Information Range of a message should be larger than the Transmission Range of the source vehicle (cf. Figure 14). On the other hand, e.g. in case of

very high interference level in the channel, the vehicles may be able to receive the signal but it could be impossible for them to decode the message.

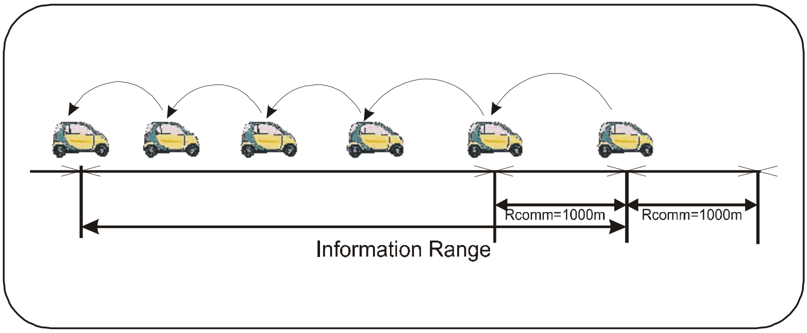

Figure 14: Transmission Range vs. Information Range

The algorithm proposed in this paper aims to extend the Information Range of messages under normal circumstances of channel interference level. That is achieved by multihopping the message between the equipped vehicles. A strategy need to be defined in order to prevent packets from being forwarded infinitely. Many protocols define a maximum number of hops, so that, if the number of hops made by the packet exceeds a given threshold, the system discards the packet. In this work, this strategy is not used, but a different based on the importance of the message for the recipient. Every message has a determined importance for the vehicle that receives it. A vehicle that receives a message will only discard it, if its relevance is zero. There is a probability that the chain of multi-hopped information is disrupted. A disruption occurs if there is no further equipped vehicle within the Transmission Range that could propagate the traffic message in the desired direction.

Within the forwarding algorithm it can be differentiated between two different sorts of messages:

- Emergency Notifications, triggered by the vehicle which causes the emergency (e.g. crash). It is assumed that a vehicle in an emergency situation will be able to send at least once the corresponding Emergency Notification. It is considered a high-priority service for the system and there is a permanently part of the transmission capacity reserved.
- Forwarding Messages, originated by the algorithm’s multihopping strategy. Resources for these messages have to be dynamically reserved.

First step of the algorithm is to determine if the received message is new for the receiving vehicle, otherwise it is already known.

An Emergency Notification (EN) message with counter = 0, is always new for the receiving vehicle, in case we assume the worst case where the crashed vehicle is able to send the EN only once. A Forwarded Message (FM) can be new or already known for the receiving vehicle, it has to look in its list of recently received message to discover it. In case of the crashed vehicle is able to continue its transmission it will send the Emergency Notification periodically, therefore vehicles can receive repetitions of the EN.

A vehicle receiving an EN, estimates its start forwarding probability e.g. depending on its distance to the accident point, and will try to resend the EN with a certain probability.

If the vehicle decides not to resend the EN, it doesn't forget about its forwarding task. The vehicle reaches a “wait for forward” state, where it will periodically try to resend the message in case that no confirmation message from other vehicles are received. If a forwarded message (concerning the same event that the vehicle tries to propagate) is received, the received FM is considered as an acknowledgement (ACK). The aim of this behavior is to give the algorithm more resistance against disruptions of the communication chain and to avoid unnecessary flooding of the network. In case that the vehicle does not receive any other forwarded message concerning the EN, e.g. only this vehicle was within Transmission Range of the crashed vehicle, it is guaranteed that the vehicle tries to resend the EN until the relevance of the EN is zero.
If the vehicle decides to forward, afterwards it doesn't forget neither about its forwarding task. The vehicle reaches a “wait for acknowledgement” state. In this state, if no Forwarded Message concerning the same event is received, it will initiate to resend again the message periodically, because the vehicle can be sure that its message was received by other vehicles and the dissemination process goes on. The number of periodical transmissions is unlimited. The vehicle stops periodical forwarding of the message if its importance becomes zero. The aim of this behavior is again giving the algorithm more resistance against disruptions of the communication channel. The last informed vehicle doesn't quit its forwarding task until it is guaranteed that another vehicle can go on with the dissemination work.
After the forwarding decision is made, the behavior of the vehicle is identical as already explained. In case of forwarding, the vehicle enters the “wait for acknowledgment state”, and in case of not forwarding the vehicle enters the “wait for forward state” In any case, receiving an ACK (from other vehicles) concerning the message the vehicle tries to disseminate means that the forwarding task of the vehicle is, for the moment, not necessary anymore.
The algorithm makes sure that not every vehicle which receives the message resends it. Only those whose relevance in the dissemination process is highest will resend it. This is controlled by multiple dependences of the forwarding probability. Other vehicles will wait and observe the progression of the spread process. Thanks to the existence of more than one resending attempt within the forwarding algorithm, they would have periodically the chance of forwarding till its participation in the algorithm is necessary. This behavior aims to avoid the flooding of the network with unnecessary messages.
The algorithm does not end for a vehicle until the importance of the Emergency Notification becomes zero.

7 Summary

In this paper we gave an overview of ongoing research activities at the Institute of Communications Engineering in the industrial project FleetNet, dealing inside the emerging field of wireless ad hoc networks. We presented classes of applications using the communication system and outlined their basic requirements. We depicted the necessary enhancements of the Data Link Control Layer of UTRA TDD to provide an ad hoc mode with decentralized Medium Access Control and Radio Resource Management. With help of a developed event-based simulation environment – implemented in the Specification and Description Language (SDL) – we showed first performance measurements of the proposed MAC protocol extensions. From the first results it can be concluded that with the MAC scheme proposed for FleetNet the demands of the FleetNet applications can be fulfilled since a constant delay can be guaranteed that depends only on the capacity reserved for the CSBC but not on the load. Furthermore, prioritization of services can be supported by means of allocating different numbers of slots to the CSBC. As an example for an important FleetNet service we introduced the forwarding of Emergency Notifications without flooding the whole network. We described a first algorithm, which computes forwarding probabilities for each received EN, based on message importance and current position in relation of the source of the message.

8 References

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