On the Dynamics of Ad Hoc Networks for Inter Vehicle Communications (IVC)

M. Rudack[1], M. Meincke[1], M. Lott[2]
[1]Institute of Communications Engineering – University of Hanover
Appelstr. 9A, 30167 Hannover, Germany
{rudack, meincke}@ant.uni-hannover.de
[2]Information and Communication Mobile, Siemens AG, Munich, Germany
Matthias.Lott@icn.siemens.de

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 roadside gateways via a mobile Internet. In this paper we focus on the impacts of vehicular traffic dynamics on protocols for ad hoc networks. Based on analytical distributions of vehicular traffic theory and on realistic traffic scenarios we develop requirements and dependencies of the developed protocols for ad hoc networks.

KEYWORDS

Inter Vehicle Communication (IVC), Ad Hoc Networks, UTRA TDD, Vehicular Traffic Theory, Traffic Dynamics, Medium Access Control (MAC)

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 roadside gateways via a mobile Internet. Major services, supported by FleetNet will be road traffic telematics and communication for business and entertainment purposes. Especially, mission critical services like emergency notifications and services for co-operative driver assistance put very high demands on the air interface and the used protocols. High relative velocities up to 500 km/h between oncoming vehicles in a highway scenario will lead to frequent topology changes, i.e. a very high network dynamic. This high dynamics will cause much effort in developing appropriate protocols.

Intelligent Transportation Systems (ITS) have been found to be an attractive area of research many years ago, e.g. within the framework of PROMETHEUS [2]. Current research on ITS concentrates on network architectures where an infrastructure exists to connect vehicles with each other and with the Internet (DRIVE [2], COMCAR [3], etc.).

Within this work we will describe and analyse the grade of topology changes in freeway environments and its impact on the protocols of FleetNet, which will be introduced in Section II. In this paper we will concentrate on the protocols of the data link control (DLC) layer. However, impacts on the required routing protocols will be sketched but not discussed in detail (for further information on activities on routing with FleetNet cf. [4]). To receive estimations on traffic dynamics and protocol activities in FleetNet, we will introduce the classic traffic theory in Section III and present some analytical and simulative results in Section IV.

II FLEETNET PROTOCOLS FOR THE AIR-INTERFACE

Mobile ad hoc networks do not depend on a given infrastructure. Thus, communicating devices cannot rely on access points or base stations acting as central controllers. They have to build the network in a self-organizing way. FleetNet has to use a decentralised Medium Access Control (MAC) protocol together with a Radio Resource Management (RRM) scheme that is suitable for a scenario with frequent topology changes. Because of high dynamics in the IVC scenario it seems not to be recommendable to select a centralised MAC scheme with master-slave communication to avoid protocol overhead for changes of the master role in case of topology changes.

As the basis for the FleetNet air interface, UTRA TDD low-chip rate has been chosen for various reasons [5]. Because of its code division multiple access (CDMA) component together with its frame and slot structure (MAC frame of 10ms), UTRA TDD offers a high flexibility for asymmetric data transfer and granularity. It offers a communication range over 1km and supports high velocities. It has been shown in [6] that UTRA TDD is suitable for Intelligent Transportation System (ITS) applications and operation in ad hoc networks. As UTRA TDD is basically a 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. Besides permanently assigned parts of transmit capacity for high-priority services, resources can be dynamically reserved for services with lower priority. For the latter reservations, an R-ALOHA scheme [7] is foreseen to constantly assign a small portion of the available resources as a Circuit Switched Broadcast Channel (CSBC). This CSBC can be either used for transmission of small data packages, or for signalling purposes to reserve additional resources.

In Figure 1 the reservation of new resources is depicted when a new packet arrives.

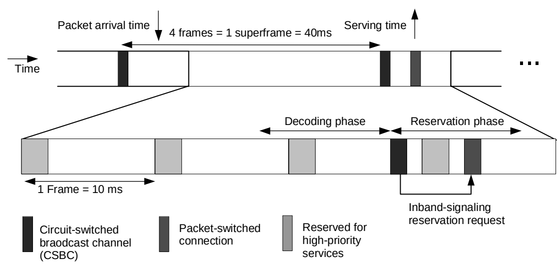

Figure 1: Reservation of transmit capacity by means of in band-signalling

In case there have been no resources reserved so far, except one slot every fourth frame for the CSBC, an inband-signalling request is initiated within the CSBC. Within this request one free slot is reserved within the next frame. By decoding the reservation request, the addressed station is aware of the slot to be decoded and all other stations will mark the respective slot to be reserved. Thus, this slot can be used in this and the following frames without contention and collisions can be precluded. Since a reservation will refer to the next frame only, the respective station has to decode only all slots in the preceding frame to avoid reservation conflicts.

A significant parameter for this kind of medium access is the grade of topology changes. The dynamics will have impacts on various parts of the protocols. Statistical investigations on the traffic dynamics shall give realistic estimations on possible communication durations and speed of topology changes depending on distributions of velocities and traffic densities. These distributions will have impact both on reservation procedures within the MAC protocol and on means of RRM, e.g. Power Control (PC) and Dynamic Channel Allocation (DCA). One of the basic tasks of the RRM protocol will be the self-organization of the network which will be handled in a distributed manner. To achieve the self-organization RRM signalling packets will be transmitted by each device periodically – the so called beacon. Besides data identifying the node, i.e. its position, speed, etc., the beacon will contain information on used resources, measurement data of interference and other information supporting the self-organization of the network. Additionally, control information from the routing protocol can be included in the beacon as well.

The investigation of the dynamic of topology changes by means of vehicular traffic theory shall answer two main questions: First, if it is sensible or not to reserve resources for a certain period of time, and second what update rates for signalling purposes to maintain the self-organization of the network have to be considered. The latter question will depend – amongst other things – on the path loss situation and its impact on the RRM.

III VEHICULAR TRAFFIC THEORY

In the classical vehicular traffic theory (e.g.[8],[9]) freeway traffic is described by three elementary parameters: traffic density ρ_{veh} in [veh/km], traffic flow q in [veh/s] and net time gap τ in [s]. These quantities can be related together by their average values [10] as shown in Equation 1. Herein l_m is the average length of vehicles, d_m the average distance between vehicles and v_m the average speed in [m/s] of vehicles:

$$d_m = \frac{1000}{\rho_{veh}} - l_m \qquad \tau_m = \frac{d_m}{v_m} = \frac{1}{v_m} \cdot \left(\frac{1000}{\rho_{veh}} - l_m \right) \qquad q = \frac{1}{\tau_m} = v_m \cdot \left(\frac{1}{\frac{1000}{\rho_{veh}} - l_m} \right) \tag{1}$$

From Equation 1 we can calculate a possible maximum velocity v_p, if the average time gap τ_m and traffic density ρ_{veh} are given. Real average velocities, the so-called average free velocities $v_{m,free}$, are always below this limit or equal to this limit:

$$v_{m,free} \le v_p = \frac{1}{\tau_m} \cdot \left(\frac{1000}{\rho_{veh}} - l_m \right) . \tag{2}$$

If traffic density is low vehicles are assumed to drive with their free velocity $v_{m,free}$. Additional vehicles do not diminish the average driven velocity $v_{m,free}$, but only v_p. Thus additional vehicles result in an increase of the traffic flow q and shorter time gaps τ_m. This traffic state is called undisturbed traffic. If traffic density becomes higher, so that it isn't longer possible to drive by $v_{m,free}$, the driven velocity will reduce to v_p and the traffic state is called disturbed traffic.

After introducing these vehicular traffic theory fundamentals we want to have a look on the statistical distributions of velocity, time gaps and distances. These quantities are described by random variables v, τ and d.

The value of velocity is assumed generally as normal distributed [8]. Therefore, to the probability density function (pdf) and the probability distribution function (PDF) of velocity applies

$$p_v = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(v-\mu)^2}{2\cdot\sigma^2}} \quad \text{and} \quad P(v \le V) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^V e^{-\frac{(v-\mu)^2}{2\cdot\sigma^2}} dv \ , \tag{3}$$

whereby μ and σ^2 are average value and variance of velocity according to the usual notation. Later publications suggest more advanced distributions for the pdf of vehicles' velocity, e.g. [10]. These distributions include cars and trucks in one model. But for the easier use we remain with the older distributions to get a first and illustrative approximation of FleetNet dynamics.

The PDF cannot be solved analytically. Thus, the following results are obtained by numerical computation with MAPLE V. In a first step a realistic distribution for the velocity is to be found. To the PDF applies $P(v \le \mu - \sigma) = 15{,}87\%$ and $P(v \le \mu + \sigma) = 84{,}13\%$, i.e. approximately 15% of the vehicles deviate more downward or above from the average speed than the value of the standard deviation is. At traffic-technical analyses one operates simplifying with boundaries of 15% and 85% ($V_{15} = \mu - \sigma$ und $V_{85} = \mu + \sigma$). The quantity V_{15} indicates the velocity, which 15% of the drivers do not exceed. Their size characterizes the slow drivers. V_{85} is the velocity that is exceeded by 15% of the drivers (high-speed drivers) [8]. The definition of the velocity, that characterizes the high-speed drivers, can be used for the calculation of the standard deviation of velocity in reverse.

In the following we assume that the vehicles drive with an average speed of 130km/h on a motorway with low traffic density (undisturbed traffic), whereby vehicles with a speed of 170km/h are considered as fast driving. From this results the variance σ^2 of velocity of 1489,5(km/h)^2 which means a standard deviation of $\sigma = 38{,}6$km/h. As an approximation we chose $\sigma = V_{85} - \mu = 0{,}3*\mu$. To keep the analyses more clearly we proceed with the values presented in Table 1, with which also the figures were calculated.

μ [km/h]	V_{85} [km/h]	σ [km/h]
30	≈ 40	9
50	65	15
70	≈ 90	21
90	≈ 120	27
110	≈ 145	33
130	≈ 170	39
150	195	45

Table 1: Typical values of velocity distributions

According to classical vehicular traffic theory literature, cars are assumed to have Poisson distributed arrivals. This leads to time gaps between cars that are distributed with pdf and PDF [9]

$$p_\tau(\tau) = q \cdot e^{-q\cdot\tau} \quad \text{and} \quad P_\tau(\tau > T) = e^{-q\cdot T} \ , \tag{4}$$

respectively, wherein q is the traffic flow in vehicles per second. With the distribution of the time gap between vehicles (Equation 4) we obtain the pdf of vehicles' distance d

$$p_d(d) = \frac{q}{v_m} \cdot e^{-q\cdot\frac{d}{v_m}} = \frac{\rho_{veh}}{1000} \cdot e^{-\frac{\rho_{veh}}{1000}\cdot d} \ . \tag{5}$$

To keep mathematics simple we neglected l_m in Equation 5.

In this chapter the number of freeway lanes N_{lane} is neglected. Traffic parameters are assumed to be measured for one direction of freeway traffic, not dividing single lanes. Regarding the real distance between two vehicles on different lanes, we have introduced an error by our simplification that is caused by the vertical shift of n lanes of width w. The correct distance d' can easily be calculated as

$$d' = \sqrt{d^2 + (n \cdot w)^2} \ . \tag{6}$$

Furthermore, it is assumed that there is always enough room for vehicles to overtake without changing speed or disturbing other vehicles in another way. This assumption limits the possible traffic density.

IV ANALYTICAL INVESTIGATION OF TOPOLOGY DYNAMICS

Based on classical vehicular traffic theory, we try to answer the questions depicted in Section II. In this paper the following basic communication scenarios are considered:

- For the two cases of a) only one considered driving direction and b) oncoming traffic, the possible communication durations between two vehicles are calculated. This gives an idea if the topology is approximately stable during a period of time that is long enough to make e.g. resource reservations reasonable.
- The dynamics of topology changes that are caused by vehicles joining or leaving communication and detection radii is analysed.
- The number of time slots of the FleetNet MAC-frame that are necessary to react on topology changes or increase of interference and path loss is calculated.

A. *Communication Duration*

In the following two scenarios it is to be examined, how long a vehicle is within detection or communication radius of another vehicle. The detection radius defines the area where a transmission of any station can be detected, whereas the communication radius defines the area where a signal can be decoded with high probability. We proceed with the assumption of undisturbed traffic. Velocity of both vehicles is constant, whereby the value of velocity is assumed generally as normal distributed.

a) All vehicles are driving in the same direction:

The probability of a velocity difference Δv between two vehicles in same driving direction amounts to $P(\Delta v) = P(v_2 - v_1)$, wherein v_1 and v_2 are normal distributed random variables according to Equation 3. Thus, Δv is also a normal distributed random variable with $\mu_{\Delta v} = \mu_2 - \mu_1$ and $\sigma^2_{\Delta v} = \sigma^2_1 + \sigma^2_2$. To the distance d between vehicles as a function of the relative velocity Δv and the time t applies $d(t) = \Delta v \cdot t$.

Thus, d is also a normal distributed random variable. The velocity difference Δv can be negative. That can be interpreted in the following way:

1. The reference vehicle is approaching another vehicle from behind ($\Delta v > 0$).
2. The reference vehicle is overtaken by another vehicle ($\Delta v < 0$).

In practise, both cases are identical, of course. The further view can be limited thus to $\Delta v > 0$, from which it follows that pdf and PDF within the range of $\Delta v > 0$ are to be multiplied by two. The distance between two cars changes from $d = -R_{comm}$ to $d = R_{comm}$, while they are able to communicate, wherein R_{comm} is the communication radius. Thus, the distance passed, while communication is possible, is $d = 2*R_{comm}$. We can now calculate the probability distribution function (PDF) of communication duration as

$$p_t(t) = \frac{4 \cdot R_{comm}}{\sigma_{\Delta v}\sqrt{2\pi}} \cdot \frac{1}{t^2} \cdot e^{-\frac{\left(\frac{2 \cdot R_{comm}}{t} - \mu_{\Delta v}\right)^2}{2 \cdot \sigma_{\Delta v}^2}} \quad \text{for } t \geq 0 . \tag{7}$$

Figure 2 shows pdf and PDF of possible communication durations t_{comm} that are resulting from the values presented in Table 1. For the communication range a value of R_{comm} = 1000m is assumed.

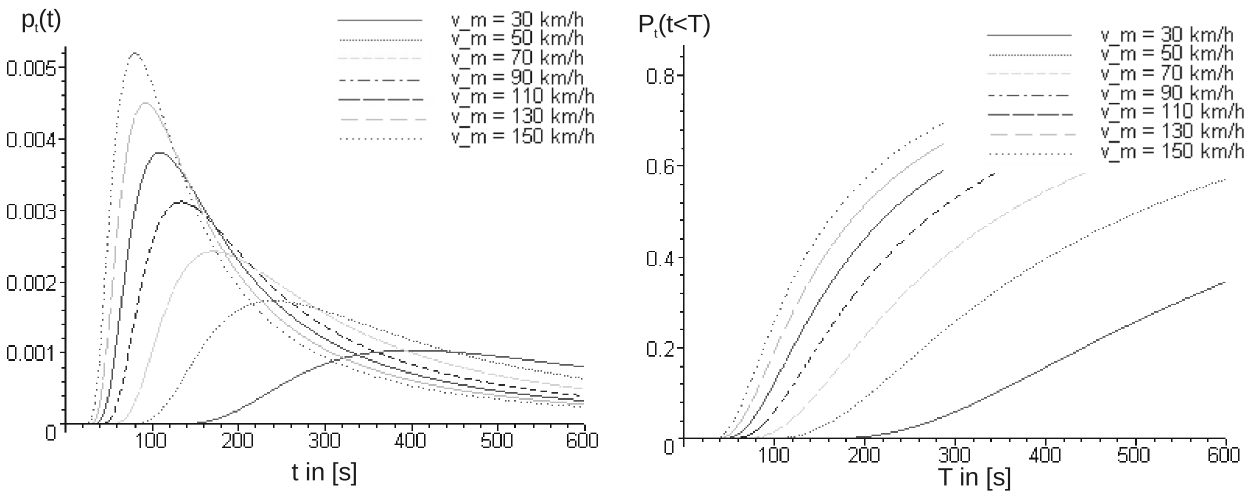

Figure 2: pdf and PDF of communication duration t_{comm}

b) Oncoming Traffic:

For the oncoming traffic scenario similar equations can be inferred. The probability of a velocity difference Δv_{on} between two vehicles in same driving direction amounts to $P(\Delta v_{on}) = P(v_2 + v_1)$ with $\mu_{\Delta v,on} = \mu_2 + \mu_1$ and $\sigma^2_{\Delta v,on} = \sigma^2_1 + \sigma^2_2$. To calculate communication durations, one simply has to substitute Δv by Δv_{on} in Equation **7**. From this we obtain pdf and PDF shown in Figure 3.

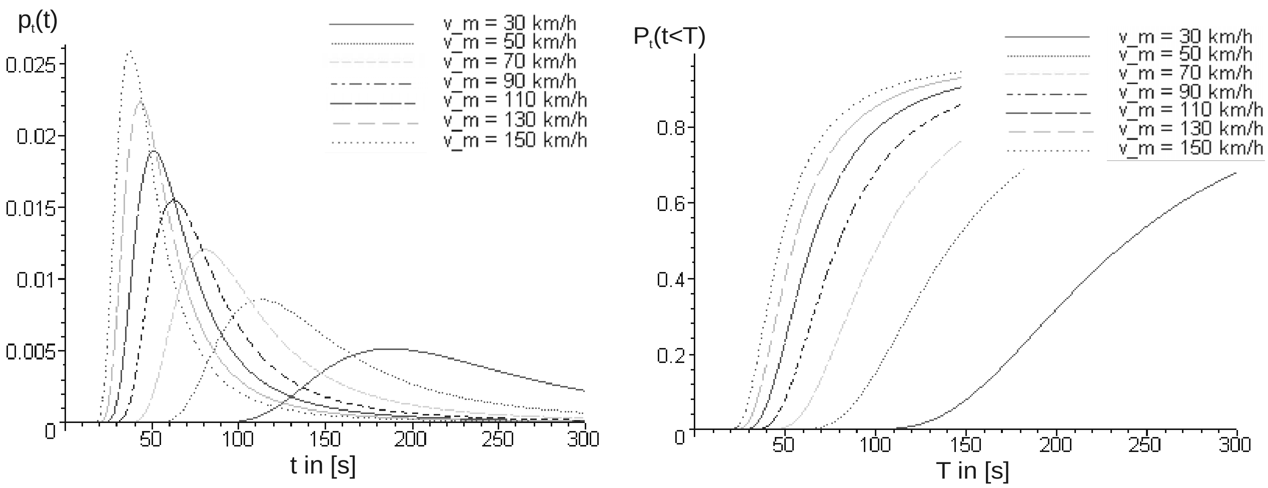

Figure 3. pdf and PDF of communication duration $t_{comm,on}$

With increasing speed the duration decreases as expected. Depending on the relative speed it can be seen that communication duration can differ extremely. But even in the case of oncoming traffic and a high average velocity of 130km/h the probability to have a communication duration less than thirty seconds is about 0.1. Typical duration exceed 141 sec for a relative speed of 30km/h and 28 sec for 150km/h in 95% of the cases if oncoming traffic is considered. This means, we have a high probability to have communication periods with more than 3000 MAC-frames, which makes reservations reasonable from our simple scenario.

B. Frequency of Topology Changes

In the following the dynamics of topology changes, which are caused by vehicles joining or leaving communication and detection radii, is analysed. Results on how many stations are leaving and entering the communication or detection range within a period of time are presented. The calculation of joining or leaving probabilities is based on the distributions of time gaps between vehicles.

We start our analysis with considering only one driving direction. One vehicle is considered as a reference vehicle and assumed to be in the centre of the detection range. Relative velocities are calculated with reference to this vehicle. Let us now consider the point of time when one vehicle is just joining the detection radius of the reference vehicle. Thus, this vehicle has exactly the distance R_{detec} from the reference vehicle. In Figure 4 we can see one car ("2") joining the detection range of another ("P").

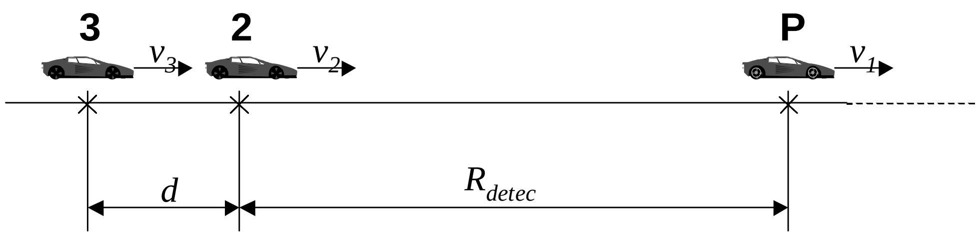

Figure 4. Vehicle joining R_{detec}

The next following car ("3") has got a distance d from car 2. Distance between two cars has got the pdf

$$p_d(d) = \frac{\rho_{veh}}{1000} \cdot e^{\frac{\rho_{veh}}{1000} \cdot d} \quad , \tag{8}$$

according to Equation 5. Let us now assume that "P" a parked vehicle or a gateway station with $v_1 = 0$. In this case car 3 has to pass the distance d before it joins the detection range of "P". The point at R_{detec} where cars join the detection range of "P" we can consider as a fixed observation point. This leads to pdf and PDF of the time gap τ between two vehicles joining the detection range, which simply is

$$p_\tau(\tau) = \frac{\rho_{veh} \cdot \Delta v}{1000} \cdot e^{-\frac{\rho_{veh}}{1000} \cdot \Delta v \cdot \tau} \qquad \text{and} \qquad P_\tau(\tau \le T) = e^{-\frac{\rho_{veh}}{1000} \cdot \Delta v \cdot T} \tag{9}$$

according to Equation 4.

Equation 8 can be generalized for a moving vehicle P with $v_1 > 0$. Then we have to work with a moving coordinate system and a moving observation point at R_{detec}. Velocity differences between “P” and the approaching vehicles substitute for velocities in Equation 8.

We now have to determine a meaningful value for T. Let us assume that a reservation should be valid for the transmission of an IP-packet of size 1500 Bytes, which is a quite usual value. Within the period of the IP-packet transmission the topology must not change because otherwise the resources cannot be guaranteed. The IP-packet has to be segmented over several MAC-frames each of which contains at least one time slot with about 100 Bytes of user data. Thus, the network topology should remain unchanged during the period of 15 MAC-frames, which means a period of 150ms. Furthermore let us assume, one fragment of the IP-packet is erroneous and has to be resend after a negative acknowledgement. Adding some time for the reservation procedure we need a time period of approximately T = 200ms during which the topology has to be stable.

In Table 2 we present some numerical results for the PDF of the time gaps τ between to vehicles joining the detection range. Rows 1 and 2 with Δv = 130km/h and Δv = 100km/h represent cars passing a parking vehicle or a gateway station, whereas rows 3 to 5 show numerical values for velocity differences between two vehicles that have the same driving direction.

	$P(\tau \leq 200\text{ms})$		
Δv [km/h]	**ρ_{veh} = 75 veh/km**	**ρ_{veh} = 20 veh/km**	**ρ_{veh} = 6 veh/km**
130	0,41822	0,13450	0,04241
100	0,34076	0,10516	0,03278
30	0,11750	0,03278	0,00995
20	0,07996	0,02198	0,00664
10	0,04081	0,01105	0,00333

Table 2. Numerical results for $P(\tau \leq T)$ with T = 200ms

Table 3 shows the average time gap τ_{avrg} between two vehicles joining the detection range, which is

$$\tau_{avrg} = \frac{1}{q} = \frac{1000}{\rho_{veh} \cdot \Delta v}, \tag{10}$$

	τ_{avrg} [s]		
Δv [km/h]	**ρ_{veh} = 75 veh/km**	**ρ_{veh} = 20 veh/km**	**ρ_{veh} = 6 veh/km**
130	0,36923	1,38462	4,61538
100	0,48	1,8	6
30	1,6	6	20
20	2,4	9	30
10	4,8	18	60

Table 3: Numerical results for τ_{avrg}

Even in the worst case, where vehicles pass parking cars or fixed gateways with velocities of 130 km/h (row 1 in Table 2) in high traffic densities the topology remains stable in nearly 60%. If we consider 'normal' traffic scenarios (rows 3 to 5 in Table 2) the probabilities for a stable topology vary between 90 and ~100%; in other words – as shown in Table 3 - the topology remains absolutely stable for 1.6 seconds in the case of high traffic density and higher relative velocities to up to 60 seconds in case of lower densities and lower relative velocities.

As depicted in Section II, regarding the protocols for the air interface, we can assume that every node has reserved a CSBC, i.e. within a 40ms superframe approximately 52 nodes can have such a CSBC reserved (1 time slot per frame is permanently reserved for high-priority services). If we would have a high probability, that up to 52 nodes reach the communication range of the reference vehicle within 40ms, we would have a real problem doing reservations, switching to different time slots and distributing status information. The results show that we are quite far away from this worst case. On the other hand, if we look from the point of a meaningful undisturbed communication range, we have a manageable situation if merely one node reaches the communication range. Here the probability, that this reaching node occupies a reserved resource is very low. As we can see from the tables above, the probabilities to have a stable topology are quite high in the depicted scenarios.

C. Impacts of Path Loss on RRM

In this section we present the calculation of the number of time slots of the FleetNet MAC-frame that are necessary to react on changing propagation conditions like increasing path loss. Basis of the scenario is the assumption that a change of 10dB in the receiver input level requires the transmission of a RRM message as a reaction on the change of network state. E.g. power control information or a change of the used time slot has to be communicated. A RRM message is assumed to occupy one time slot. The 10dB limit is based on some early considerations of joint detection. Path loss is assumed to be caused be changing distances between vehicles. The first question to be answered is on the distance that has to be covered to cause a network reaction and if there will be enough time to communicate the change of network status to other mobile stations. The relation between covered distance and received input level is given by Equation 11

$$\Delta P_e = 10 \cdot \log_{10} \frac{d_2^\gamma}{d_1^\gamma} = 10 \cdot \gamma \cdot \left(\log_{10} d_2 - \log_{10} d_1 \right) . \tag{11}$$

With the assumption of ΔP_e = 10dB follows

$$d_2 = d_1 \cdot \sqrt[\gamma]{10} = 2{,}15 \cdot d_1 \ \text{ with } \ \gamma = 3 . \tag{12}$$

Thus, a decrease of 10dB in the received input level corresponds to doubling of vehicles' distance. Accordingly, an increase of 10dB corresponds to a reduction of distance to the half. The absorption coefficient is set to γ = 3, which is between the two extremes γ = 2 (line of sight) and γ = 5 (high absorption in municipal environment) and seems to be a realistic value for our freeway scenario [11].

To continue our considerations freeway traffic is assumed with the vehicles having an initial distance R. If the vehicles are departing, the distance $d = R$ is covered, before the received input level is reduced by 10dB. If they are approaching, the distance is $d = R / 2$. Thus, the number F of MAC-frames that passed during the time $T_{10\text{dB}}$ of the 10dB decrease is given by

$$F = \frac{T_{10dB}}{T_{MAC}} = \frac{R}{\Delta v \cdot T_{MAC}} \qquad \text{for departing cars and}$$
$$F = \frac{T_{10dB}}{T_{MAC}} = \frac{R}{2 \cdot \Delta v \cdot T_{MAC}} \qquad \text{for approaching cars.} \tag{13}$$

In Equation 13 Δv is the relative speed of two vehicles and T_{MAC} is the frame duration of the FleetNet-MAC-frame, which is T_{MAC} = 10ms. The initial distance R of the two considered cars has a major influence on the number of usable MAC-frames.

To get a very simple estimation of how often network reactions have to be communicated, consider Figure 5.

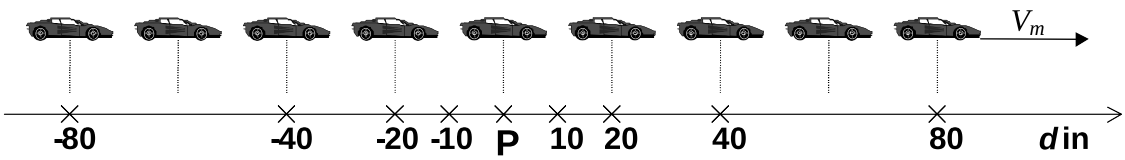

Figure 5: Communication distances during crossing a parked vehicle

We assume that in the area of d = [-10m, 10m] no network reactions have to be communicated. This assumption is just to keep calculations simple and is not based on network physics. If a car is departing from the parked vehicle “P” then it has to send a message at d = 10m the first time, followed up by a message each time the distance is doubled. The last network reaction happens, when the departing car is leaving the detection range. This communication pattern is repeated with every car that is passing. We now have to analyse how often cars pass those “communication points” at 10m, 20m, etc.

We describe the traffic stream by a chain of equidistant cars with gaps of $d_m = \varphi*1000/\rho_{veh}$. Here the ratio φ of FleetNet equipped vehicles is introduced to take into account only vehicles with FleetNet equipment. Distance between cars is passed in the time $\tau_m = d_m/v_\mathrm{m}$. Thus, after every time t_m the chain of cars looks the same. This means that every time τ_m one car of the chain is passing one of the communication points. The communication points directly neighboured to the parked vehicle are lying very close together, so the distance between them is passed in less than τ_m. To correct this we simply assume that the communication points at 10m and 20m are passed within τ_m. Therefore the number of network reactions within τ_m has to be increased by one. Now we only have to calculate the number of communication points N_{CP} within the detection range to get an estimation of necessary network reactions. The position of the communication points can be determined by $d_n = 10\text{m} \cdot 2^n$. From this follows

$$N_{CP} = \left\lfloor \log_2 \frac{R_{detec}}{10\text{m}} \right\rfloor \tag{14}$$

and for the number of network reactions per second

$$N_{R,dep} = \frac{1 + N_{CP} + 1}{\tau_m} = \frac{(N_{CP} + 2) \cdot \rho_{veh} \cdot v_m}{1000 \cdot \varphi} \ . \tag{15}$$

We can argue on the same way for approaching traffic and obtain $N_{R,app} = N_{R,dep}$ and therefore

$$N_{R,ges} = \frac{(N_{CP} + 2) \cdot \rho_{veh} \cdot v_m}{500 \cdot \varphi} \text{ in [1/s].} \tag{16}$$

If we relate Equation 16 to the duration T_{MAC} of a MAC-frame, we obtain the number c_{MAC} of MAC-Frames during which one network reaction has to be communicated:

$$c_{MAC} = \frac{1}{T_{MAC} \cdot N_{R,ges}} = \frac{500 \cdot \varphi}{T_{MAC} \cdot (N_{CP} + 2) \cdot \rho_{veh} \cdot v_m} \ . \tag{17}$$

Numerical results obtained by Equation 17 are presented in Table 4:

	c_{MAC}	
ρ_{veh} **[veh/km]**	v_m **= 130km/h;** R_{detec} **= 2000m;** φ **= 0,5**	v_m **= 30km/h;** R_{detec} **= 2000m;** φ **= 0,5**
6	128,2	555,6
12	64,1	277,8
25	30,8	133,3
75	10,3	44,4

Table 4: Number of MAC-frames c_{MAC} between RRM messages

The values presented in Table 4 show, that even in scenarios with high traffic densities and relatively high velocities, the number of available MAC frames is sufficient to react on increasing or decreasing path loss, e.g. allocating a more suitable time slot, solving a collision, etc.

V Summary and Conclusion

In this paper we focused on the impacts of vehicular traffic dynamics on protocols for ad hoc networks. Based on analytical distributions of vehicular traffic theory and on realistic traffic scenarios we developed requirements and dependencies of the developed protocols for ad hoc networks.

In Section IV.A we investigated possible communication durations between two vehicles for the two cases of a) only one considered driving direction and b) oncoming traffic. We showed, that even with oncoming traffic and high relative velocities, we have a high probability to have communication periods with more than 3000 MAC-frames, which makes reservations reasonable from our simple scenario.

In Section IV.B we analysed the dynamics of topology changes that are caused by vehicles joining or leaving communication and detection radii. In 'normal' traffic scenarios the probabilities for a stable topology vary between 90 and ~100% and the topology remains absolutely stable up to 60 seconds in case of lower densities and lower relative velocities. Even in cases of high traffic densities and high relative velocities the topology remains stable in nearly 60% which should be not too hard to handle.

In Section IV.C we calculated the number of time slots of the FleetNet MAC-frame that are necessary to react on topology changes or increase of interference based on a changing path loss. The values presented show, that even in scenarios with high traffic densities and relatively high velocities, the number of available MAC frames is sufficient.

Although, running an ad hoc network in a inter vehicle communication scenario seems to be very challenging, regarding the very high dynamics and frequent topology changes, the use of UTRA TDD as the air interface for FleetNet gives us enough flexibility to handle theses dynamics. The presented calculations and distributions are suitable to adapt the developed protocols to realistic traffic scenarios in freeway environments.

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] J. Walker, “DRIVE, PROMETHEUS and GSM”, in Mobile Radio Technology, Marketing and Management (COMEX 92) Conference Proceedings, London, UK, 1992.

[3] Ericsson, “Communication and Mobility by Cellular Advanced Radio”, ComCar project web site, www.comcar.de (2/12/2002).

[4] Mauve, M., Widmer, J., Hartenstein, H., „A Survey on Position-Based Routing in Mobile Ad-Hoc Networks”, IEEE Network, v 15, no. 6, November/December 2001, p 30-39

[5] 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.

[6] 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.

[7] Lam, S.S., „Packet Broadcast Networks – A Performance Analysis of the R-ALOHA Protocol”, IEEE Trans. on Computers, vol.C-29, no.7, July 1980, pp.596-603

[8] W. Schnabel, D. Lohse: “Grundlagen der Straßenverkehrstechnik und der Verkehrsplanung”, Bd. 1, 2. Aufl., Verlag für Bauwesen, Berlin, 1997.

[9] W. Leutzbach: “Introduction to the Theory of Traffic Flow”, Springer, Berlin, 1988

[10] D. Vollmer, A. Hiller: “Problemorientierte Verkehrsmodellierung auf Bundesautobahnen”, internal report, FleetNet, 2001

[11] B.H. Walke: “Mobile Radio Networks: Networking and Protocols”, Wiley, Chichester, 2000