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

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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, specifically the medium access, which supports QoS by means of resource reservation. 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. From the results it can be concluded that the proposed modified MAC scheme based on UTRA TDD can cope with typical network topology changes as expected for vehicular environments.

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

I INTRODUCTION

Intelligent Transportation Systems (ITS) have been found to be an attractive area of research many years ago, e.g. within the framework of PROMETHEUS [1]. Current research on ITS concentrates on network architectures where an infrastructure exists to connect vehicles with each other and with the Internet (DRIVE [1], COMCAR [2], etc.). ITS are heavily based on Inter Vehicle Communication (IVC), which are most efficiently served by ad hoc networks, and which have become a major topic during the last few years. Within the FleetNet project[1] [3] 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.

Besides routing one key challenge is the selection of appropriate medium access control (MAC) schemes that can cope with network dynamics. At the same time these protocols have to serve different applications that are distinguished by their QoS requirements. Typical applications which can be built upon the FleetNet network target to improve driving safety, to enable collection and distribution of traffic-related information, and to increase the comfort of traveling in a vehicle. The applications range from emergency warning, e.g. in the case of accidents, decentralized Floating Car Data (dFCD) services [4], to more advanced applications, like co-operative driving [5]. Furthermore, Internet applications such as mail, chat or server applications can be provided directly between running vehicles and access to the Internet can be offered by fixed gateways along the road that can be financed by, e.g., the commercial information push services.

To serve these different applications it is proposed to modify the UMTS Terrestrial Radio Access Time Division Duplex (UTRA TDD) air-interface towards an ad hoc system. In combination with resource reservations schemes it is expected to serve different QoS requirements. However, it remains to be answered whether reservation mechanisms that rely on a frame-based structure can cope with rapid topology changes.

Within this work we will describe and analyze 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, which comprises the MAC sub 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. [6]). To receive estimations on traffic dynamics and protocol activities in FleetNet, we will introduce the classic vehicular traffic theory in Section III and present some analytical results in Section IV.

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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 decentralized 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 recommendable to select a centralized 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 [7]. 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 [8] 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 [9] 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 signaling purposes to e.g. reserve additional resources.

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

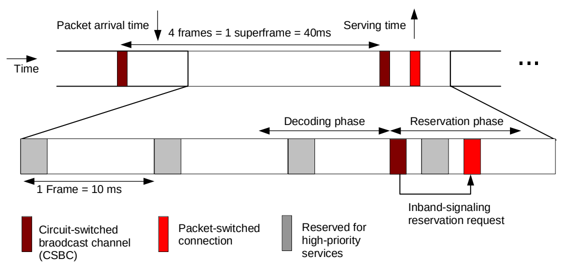

Figure 1: Reservation of transmit capacity by means of inband-signaling

In case there have been no resources reserved so far, except one slot every fourth frame for the CSBC, an inband-signaling 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 within radio range 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 signaling 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 have to be considered for signaling purposes to maintain the self-organization of the network.

III VEHICULAR TRAFFIC THEORY

In the classical vehicular traffic theory (e.g. [10], [11]) 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 [12] as shown in Equations 1-3. Herein l_m is the average (mean) length of vehicles, d_m the average distance between vehicles and v_m the average speed in [m/s] of vehicles and ρ_{veh} the traffic density on the considered freeway section:

$$d_m = \frac{1000}{\rho_{veh}} - l_m; \qquad (1)$$

$$\tau_m = \frac{d_m}{v_m} = \frac{1}{v_m}\left(\frac{1000}{\rho_{veh}} - l_m\right) \text{ and} \qquad (2)$$

$$q_m = \frac{1}{\tau_m} = v_m\left(\frac{1}{\frac{1000}{\rho_{veh}} - l_m}\right) \qquad (3)$$

In Equations 2 and 3 the mean time gap τ_m and mean traffic flow q_m are calculated for given values of v_m and ρ_{veh}.

Otherwise, if a minimum time gap τ_{min} and a traffic density ρ_{veh} are given, one can calculate a velocity parameter v_p. This value can be interpreted as a parameter of the route and it represents a possible maximum velocity on this route. Take as an example a traffic density of 10 veh/km, an average vehicle length of 5m and a minimum allowed time gap of 1.2sec. Then the possible maximum velocity amounts to 285km/h.

As one can see, real average velocities, the so-called average free velocities $v_{m,free}$, are always below or equal to this limit:

$$v_{m,free} \le v_p = \frac{1}{\tau_{\min}}\left(\frac{1000}{\rho_{veh}} - l_m\right) \quad (4)$$

If traffic density is low, vehicles are assumed to drive with their free velocity $v_{m,free}$. Additional vehicles do not diminish the average driving 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 velocity is generally assumed to be normal distributed [10]. Therefore, to the probability density function (pdf) and the probability distribution function (PDF) of velocity applies

$$p_v = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(v-\mu)^2}{2\cdot\sigma^2}}; \quad (5)$$

$$P(v \le V) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^V e^{-\frac{(v-\mu)^2}{2\cdot\sigma^2}} dv \quad (6)$$

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. [12]. These distributions include vehicles 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) [10]. 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 $1489{,}5(\text{km/h})^2$ 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 analysis more clear we use the values presented in Table 1 with which also the figures were calculated.

Table 1: Typical values of velocity distributions

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

According to classical vehicular traffic theory, vehicles are assumed to have Poisson distributed arrivals. This leads to time gaps between vehicles that are distributed according to the following pdf and PDF [11],

$$p_\tau(\tau) = qe^{-q\cdot\tau} \text{ and } P_\tau(\tau > T) = e^{-q\cdot T}, \quad (7)$$

respectively, wherein q is the traffic flow in vehicles per second.

To derive the distance d between two vehicles from this, consider Figure 2 where two vehicles are shown at times t_1 and t_2. The vehicles are assumed to drive with velocities v_1 and v_2, respectively.

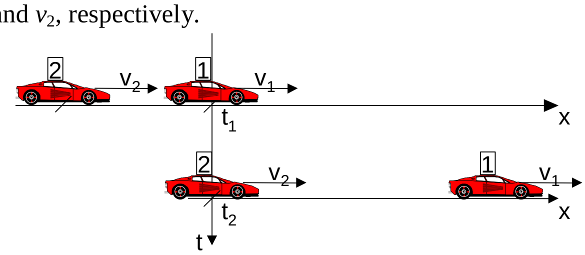

Figure 2: Derivation of distances between two vehicles based on known time gaps

If velocity v_2 is constant, we get

$$d = v_2 \cdot (t_2 - t_1) = v_2 \cdot \tau \quad (8)$$

for vehicles' distance. With the distribution of the time gap between vehicles (equation 7) we obtain the pdf of vehicles' distance d

$$p_d(d) = p_\tau\left(\tau = \frac{d}{v_2}\right)\cdot\left|\frac{d\tau}{dd}\right| = \frac{q}{v_2}\cdot e^{-q\cdot\frac{d}{v_2}} \quad . \qquad (9)$$

In equation 9 we can substitute q by use of equation 3:

$$p_d(d) = \frac{q}{v_m}e^{-q\cdot\frac{d}{v_m}} = \frac{\rho_{veh}}{1000}e^{-\cdot\frac{\rho_{veh}}{1000}\cdot d} \quad . \qquad (10)$$

To keep mathematics simple we neglected l_m in Equation 10. Furthermore we assumed $v_m = v_2$.

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

$$d' = \sqrt{d^2 + (nw)^2} \quad . \qquad (11)$$

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 formulated in Section II. In this paper the following basic communication scenarios are considered:

A. 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 whether the topology is approximately stable during a period of time that is long enough to make e.g. resource reservations reasonable.

B. The dynamics of topology changes that are caused by vehicles joining or leaving communication and detection radii is analyzed, to estimate the time for an almost stable topology.

A Communication Duration

In the following two scenarios it is examined, how long a vehicle is within the detection or the 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 all vehicles is constant, whereby the value of velocity is assumed generally as normal distributed.

A.1 All vehicles are driving in the same direction:

The probability of a velocity difference $\Delta v = v_2 - v_1$ 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 equations 5 and 6. 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 $d(t) = \Delta v \cdot t$. According to [13] each linear transformation of a normal distribution results again in a normal distribution. 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 practice, both cases are identical, of course. Thus, further calculation can be limited 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 vehicles 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

$$p_t(t) = \frac{4\cdot R_{comm}}{\sigma_{\Delta v}\sqrt{2\pi}}\cdot\frac{1}{t^2}\cdot e^{-\frac{\left(\frac{2\cdot R_{comm}}{t}-\mu_{\Delta v}\right)^2}{2\cdot\sigma^2_{\Delta v}}} \quad \text{for } t \geq 0 \,. \qquad (12)$$

Figure 3 and Figure 4 show the PDFs of possible communication durations t_{comm} that are resulting from the values presented in Table 1. For the communication ranges values of R_{comm} = 250m and R_{comm} = 1000m are assumed.

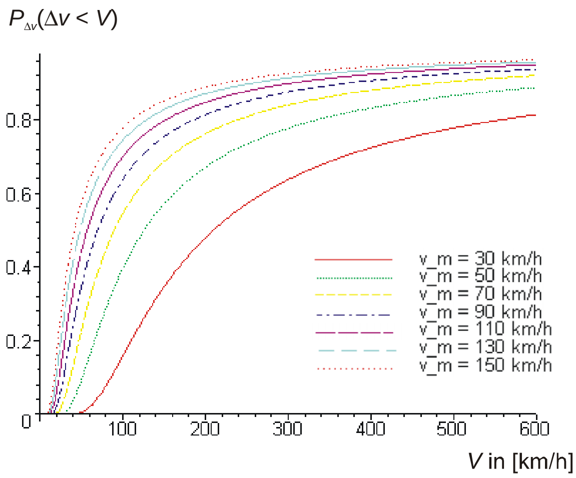

Figure 3: PDF of communication duration t_{comm}, R_{comm} = 250m

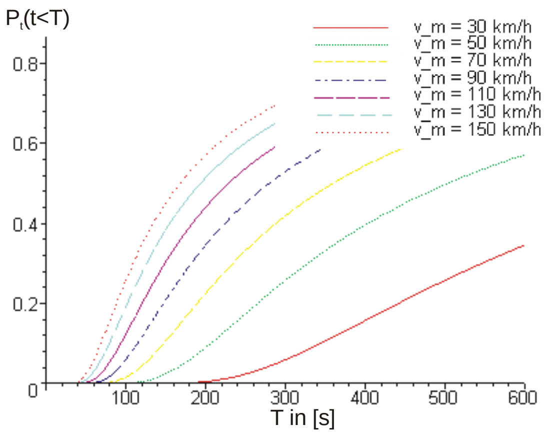

Figure 4: PDF of communication duration t_{comm}, R_{comm} = 1000m

A.2 Oncoming Traffic:

For the oncoming traffic scenario similar equations can be inferred. In this case we get simpler equations because we needn't face with negative velocity differences. 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 12. From this we obtain the PDFs shown in Figure 5 and Figure 6.

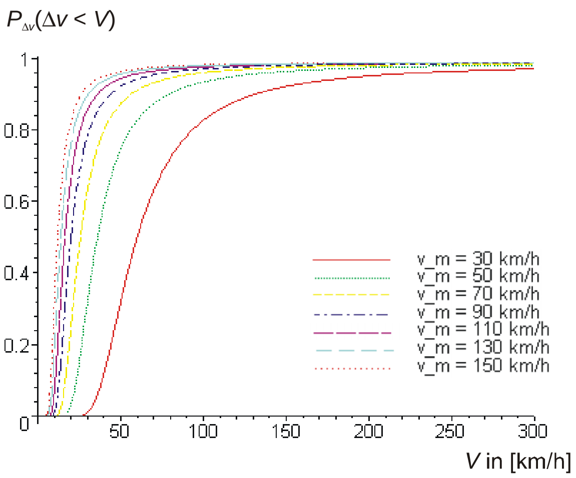

Figure 5. PDF of communication duration $t_{comm,on}$, R_{comm} = 250m

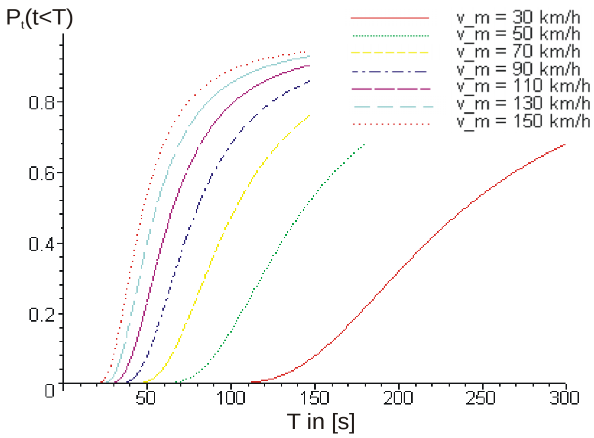

Figure 6. PDF of communication duration $t_{comm,on}$, R_{comm} = 1000m

Table 2 gives some exemplary values of possible communication durations for v_m = 130km/h. Vehicles are considered as driving with a constant velocity that has a normal distributed level.

Table 2: Exemplary PDF values for t_{comm} and $t_{comm,on}$

	$P(t_{comm} \leq T)$		$P(t_{comm,on} \leq T)$	
T in [s]	R_{comm} = 250m	R_{comm} = 1000m	R_{comm} = 250m	R_{comm} = 1000m
10			0.1823	≈0
15	$0.154*10^{-7}$	≈0	0.5719	$0.5*10^{-9}$
30	0.2767	$0.135*10^{-4}$	0.8978	0.0231
60	0.5865	0.0296	0.9651	0.5719
120	0.7856	0.2767	0.9815	0.8978
300	0.9134	0.6635	0.9877	0.9727

With increasing speed the duration decreases as expected. Depending on the relative speed it can be seen that communication duration can differ extremely.

In case of R_{comm} = 250m – which is a usual value for an IEEE 802.11 radio interface – and oncoming traffic there is a significant probability of nearly 20 percent to have communication duration less than 10 seconds. Typical duration exceed 35 sec for v_m = 30km/h and 7 sec for v_m = 150km/h in 95% of the cases.

In case of R_{comm} = 1000m and oncoming traffic the probability to have a communication duration less than thirty seconds is about 0.02. Typical duration exceed 141 sec for v_m = 30km/h and 28 sec for v_m = 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.

Besides answering the question if reservations make sense, comparing both communication radii, shows that R_{comm}=1000m supports significantly higher communication durations. The probability to have communication durations shorter than 30 sec is about 0.02 in case of R_{comm} = 1000m, whereas it is nearly 90 percent for R_{comm} = 250m. This leads to the conclusion, that, although reservation is also reasonable for a communication radius of 250m, a larger communications radius is preferable if services with higher communication durations (e.g. internet gateway access or online gaming between passengers) are to be supported.

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 analyzed. 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 center 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 7 we can see one vehicle ("2") joining the detection range of another ("P").

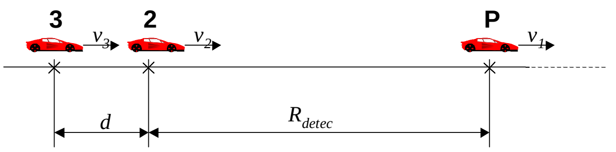

Figure 7. Vehicle joining R_{detec}

The next following vehicle ("3") has a distance d from vehicle 2. Distribution of the distances between two vehicles are defined by the pdf

$$p_d(d) = \frac{\rho_{veh}}{1000} e^{\frac{\rho_{veh}}{1000} \cdot d}, \tag{13}$$

according to Equation 10. Let us now assume that "P" is a parked vehicle or a gateway station with $v_1 = 0$. In this case vehicle 3 has to pass the distance d before it joins the detection range of "P". The point at R_{detec} where vehicles 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

$$p_\tau(\tau) = \frac{\rho_{veh}\Delta v}{1000} e^{-\frac{\rho_{veh}}{1000} \cdot \Delta v \cdot \tau} \text{ and} \tag{14}$$

$$P_\tau(\tau \le T) = e^{-\frac{\rho_{veh}}{1000} \cdot \Delta v \cdot T} \tag{15}$$

according to Equation 7.

Equation 13 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 13.

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

$$\tau_{avrg} = \frac{1}{q} = \frac{1000}{\rho_{veh}\Delta v}, \tag{16}$$

Table 3: Numerical results for τ_{avrg}

	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

If we consider only one driving direction (as shown in rows 3 to 5 in Table 3) the topology remains 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. Rows 1 and 2 in Table 3 show the situation if we consider vehicles passing e.g. a gateway station or other parked vehicles. Here the topology remains stable for up to 6 seconds.

We now have to determine a meaningful value for T, which is the time that the topology should remain unchanged. 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 reserved resources for this transmission cannot be guaranteed. The IP-packet has to be segmented over several MAC-frames each of which is assumed to contain 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 resent 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 4 we present some numerical results for the probability of the time gaps τ between two vehicles joining the detection range being smaller than the allowed max. time T. Rows 1 and 2 with Δv = 130km/h and Δv = 100km/h represent vehicles 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.

Table 4: Numerical results for $P(\tau \leq T)$ with T = 200ms

	$P(\tau \leq 200ms)$		
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

Even in the worst case, where vehicles pass parking vehicles or fixed gateways with velocities of 130 km/h (row 1 in Table 4) in high traffic densities the topology remains stable in nearly 60%. If we consider 'normal' traffic scenarios (rows 3 to 5 in Table 4) the probabilities for a stable topology vary between 90 and ~100%.

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 (it is assumed that 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 view 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.

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 analyzed 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 stable for 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.

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.

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