Forwarding of Emergency Notifications in One-dimensional Networks

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Abstract. Inter-Vehicle Communication introduces some challenges to the standard performance of ad-hoc networks. In particular, high speeds and one-dimensionality of road scenarios are different to other ad-hoc communication scenarios. Within the FleetNet project, one of the first services to be implemented will be the dissemination of safety related messages, so called Emergency Notifications. Such messages are only released in case of an emergency when an immediate and automatic reaction of the surrounding vehicles is required to prevent critical situations and further accidents. This chapter introduces the reader in the world of Inter-Vehicle Ad-hoc Networks and in particular in different forwarding strategies proposed for distribution of safety related messages using such networks.

1 Introduction

Driving a car is one of the most dangerous human activities. The innovation progress of car engineering has contributed in the last decades to proportionate a high standard of passive safety and comfort in modern cars.

Passive safety systems can ensure the survival of the driver in traffic accidents only in case of low velocities. Intelligent Transportation Systems (ITS) have been proposed with the aim of using advanced technologies to improve safety and efficiency of transportation systems.

One of the main features of such systems is the use of wireless communication among vehicles, called Inter-Vehicle Communication (IVC). Floating car data such as speed, acceleration and braking conditions are transmitted. Human visual attention is very limited and a driver has only incomplete knowledge about exact positions and velocities of surrounding vehicles. Thus, accidents, congestions and other traffic associated problems are the consequence of the inability of drivers to evaluate complex traffic situations correctly and instantly. Reactions to dangerous situations using Inter-Vehicle Communication are predicted to be faster and more reliable than human reactions, since advance warning is given, and action to avoid accidents can be taken.

This chapter introduces the reader in forwarding strategies proposed for distribution of safety related messages as a part of an Intelligent Transportation System.

2 Multi-hop Forwarding Strategies

Emergency Notifications show high requirements with respect to end-to-end delay but have small bandwidth requirements. Since the functionality of Emergency Notifications depends largely upon the reliability and delay of their data transmission, an instant and exclusive access to the shared physical medium is crucial. For that reason, a predefined part of the channel may be reserved for the data transmission of Emergency Notifications only. The goal of this section is the development of a forwarding strategy for the dissemination of these Emergency Notifications.

2.1 Challenges of Message Propagation

Challenges of message propagations regarding safety related messages like Emergency Notifications depend on their underlying scenarios. In the following we have chosen a so called "worst case scenario" which means there was only one message sent by a car in case of an accident of that car. As we can see later a different approach makes no sense for investigations described in this section. However, each vehicle with ad hoc network capabilities should be reached by a notification just demanding a minimal count of repetitions. Furthermore, despite having no infrastructure of any kind information about an accident should remain in its geographical area over a certain time. The aim of these requirements is to disseminate information about the accident quickly and efficiently to any vehicle affected by the dangerous situation.

In case of first receiving an Emergency Notification a vehicle has to wait a given time with its repetition of the message, based on the algorithm described in Sect. 2.3. In addition to this time the vehicle will only attempt to forward a notification if a random condition reaches a defined value in order to spreed repetitions of different cars more properly. To ensure that the proposed algorithm works properly we have to examine, how long a vehicle will be within the detection radius of another vehicle and whether this time will be greater or less the sum of waiting times of a vehicle mentioned above.

There are studies in technical literature about possible communication durations between vehicles, e.g. [1]. The scenario supposed by this study presents undisturbed traffic conditions as well as constant velocity of both vehicles, whereby velocity is assumed generally as normally distributed. In the following we present some theoretical considerations extracted from [1] in order to introduce the reader with some important aspects of the classical vehicular traffic theory.

Possible communication durations between vehicles depend on their relative velocity. With higher relative velocity time vehicles have to communicate with each other is getting shorter. Therefore, the worst case scenario is communication between oncoming vehicles. As it will be explained later that kind of communication is necessary for the supposed algorithm in order to avoid dissemination disruptions. It can be shown that relative velocity between vehicles increases when average speed of these vehicles become higher. Thus, the worst case scenario consists of vehicles with a high average velocity of about 130 km/h, e.g. a highway scenario at day. Theoretical examinations start with statistical distribution of velocities. In classical velocity theory values of velocities are generally assumed as normal distributed [2]. Therefore, the probability density function (pdf) of velocity applies to:

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

where according to usual notation μ and σ^2 are average value and variance of velocity respectively. Thus, probability distribution function (PDF) results as:

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

Table 1. Typical values of velocity distributions

Scenario	μ [km/h]	σ [km/h]
	30	9
	50	15
day (road)	70	21
	90	27
night (highway)	105	30
day (highway)	130	39
	150	45

Considering two vehicles driving the same direction with v_1 and v_2 as there velocities respectively, where v_1 and v_2 are normal distributed random variables. $P(\Delta v) = P(v_2 - v_1)$ represents the probability of the velocity difference Δv between these vehicles. According to statistical theory Δv is a normal distributed random variable with $\mu_{\Delta v} = \mu_2 - \mu_1$ and $\sigma^2_{\Delta v} = \sigma_1^2 + \sigma_2^2$. The belonging PDF was calculated for $\Delta v > 0$ only.

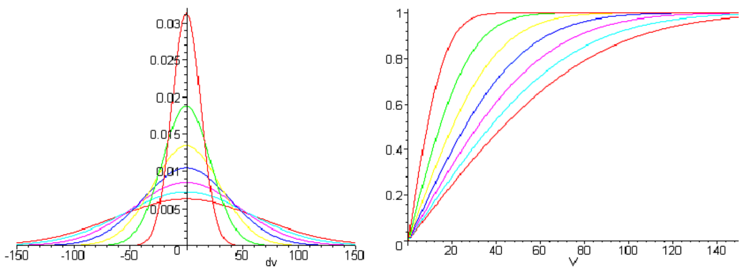

Fig. 1. pdf and PDF of velocity differences Δv

Figure 1 depicts pdf and PDF of Δv using different values of average velocities of the two vehicles and the condition $\mu_2 = \mu_1$. Therefore, pdf is axially symmetric, whereby the highest curves in Fig. 1 in both diagrams correspond to the first value in Tab. 1. Table 2 shows some exemplary values for the PDF of Δv for $V_{\text{avg}} = 70\,\text{km/h}$, $V_{\text{avg}} = 105\,\text{km/h}$ and $V_{\text{avg}} = 130\,\text{km/h}$. These velocities correspond to the day road scenario and the night and day highway scenarios of Table 1 respectively. The table confirms the assumption that with higher average velocity the relative velocity between two randomly chosen vehicles is getting higher, too. It can be seen that, e.g. in the road scenario that a probability of relative velocity larger than 50 km/h of vehicles driving the same direction is relatively small with approximately 10 %.

Table 2. Exemplary PDF values for Δv

	$P(\Delta v \leq V)$		
V [km/h]	$V_{\text{avg}} = 70\,\text{km/h}$	$V_{\text{avg}} = 105\,\text{km/h}$	$V_{\text{avg}} = 130\,\text{km/h}$
10	0,2637	0,1696	0,1439
20	0,4993	0,3317	0,28311
50	0,9077	0,7159	0,6353
80	0,9984	0,9532	0,8564
100	0,9993	0,9679	0,9302

The distance d between two randomly chosen vehicles can be calculated using relative velocity Δv and time $t: d(t) = \Delta v \cdot t$. Thus, d is also a normal distributed random variable. Δv may be positive as well as negative. This can be interpreted as follows:

1. the reference vehicle is overtaking a vehicle ($\Delta v > 0$),
2. the reference vehicle is overtaken by a vehicle ($\Delta v < 0$).

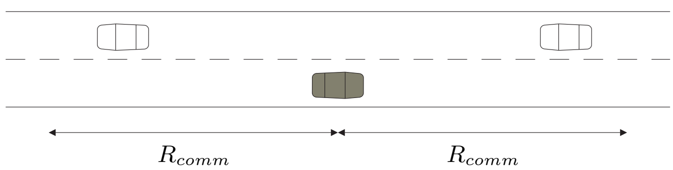

Fig. 2. Communication Range R_{comm}

Both cases are identical in practice. Thus, calculations can be limited to $\Delta v > 0$ in case of multiplying pdf and PDF by two. While two vehicles are able to communicate the distance between these vehicles changes from $d = R_{comm}$ to $d = -R_{comm}$, from the reference vehicle's point of view where R_{comm} is the communication range as shown in Fig. 2. Thus, the distance passed while communication is possible is $d = 2 \cdot R_{comm}$. Using the condition $\Delta v > 0$ the probability distribution function (PDF) of communication duration can now calculated as:

$$p_t(t) = \frac{4 \cdot R_{comm}}{\sigma_{\Delta v}\sqrt{2\pi}} \cdot \frac{1}{t^2} \cdot \mathrm{e}^{-\frac{\left(\frac{2 \cdot R_{comm}}{t} \cdot \mu_{\Delta v}\right)^2}{2 \cdot \sigma_{\Delta v}^2}} \quad \text{for} \quad t \geq 0 \quad . \tag{3}$$

Figure 3 shows pdf and PDF of possible communication durations Δt_{comm}, $R_{comm} = 1000\,\mathrm{m}$ and with traffic of same direction for different average velocities as presented in Table 1. In opposite to Fig. 1 this time the first value in Table 1 is presented by the lowest curves in both diagrams.

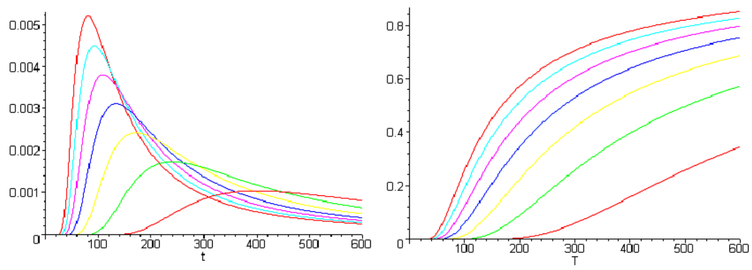

Fig. 3. pdf and PDF for Δt_{comm} (same traffic direction)

Considering two vehicles with velocities v_1 and v_2 respectively, where v_1 and v_2 are normal distributed random variables. $P(\Delta v_{opp}) = P(v_2 + v_1)$ represents the probability of the velocity difference Δv_{opp} between these vehicles. According to statistical theory Δv_{opp} is a normal distributed random variable with $\mu_{\Delta v_{opp}} = \mu_2 + \mu_1$ and $\sigma^2_{\Delta v_{opp}} = \sigma_1^2 + \sigma_2^2$. PDF and pdf as represented in Fig. 4 correspond to the average speed and variance values of Table 1.

To calculate communication durations considering oncoming traffic Δv has to be substituted by Δv_{opp} in (3). Figure 5 shows pdf and PDF for Δt_{comm}, $R_{comm} = 1000\,\mathrm{m}$ and traffic with opposite directions for different average velocities as presented in Table 1 whereas Table 3 shows exemplary PDF values for Δv_{opp} and $V_{\mathrm{avg}} = 130\,\mathrm{km/h}$ only, due to it represents the worst case scenario mentioned above.

If speed increases communication duration decreases as expected. For our purpose it is sufficient to prove that vehicles performing the forwarding algorithm have enough time to communicate with each other in the worst case scenario. Table 4 shows some exemplary values of possible communication durations for $R_{comm} = 1000\,\mathrm{m}$ and $V_{\mathrm{avg}} = 130\,\mathrm{km/h}$.

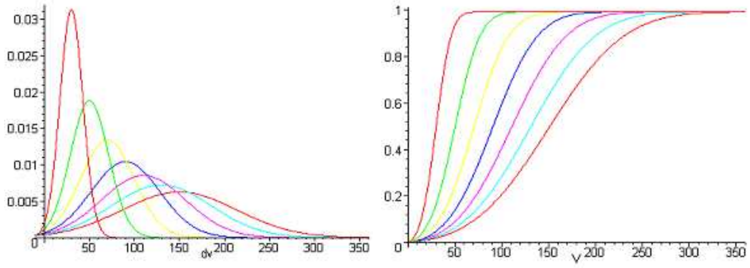

Fig. 4. pdf and PDF of velocity differences Δv_{opp}

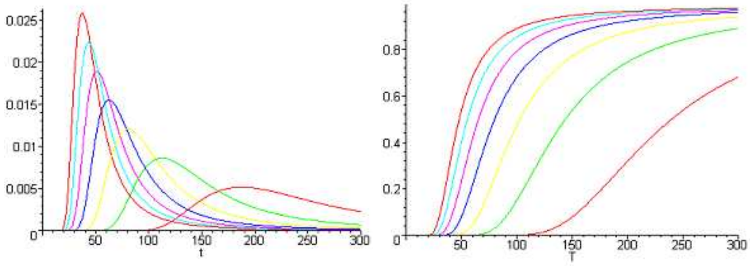

Fig. 5. pdf and PDF for Δt_{comm} (oncoming traffic)

Table 3. Exemplary PDF values for Δv_{opp}

$P(\Delta v_{opp} \leq V)$	
V [km/h]	$V_{\mathrm{avg}} = 130$ km/h
10	0,2637
20	0,4993
50	0,9077
80	0,9984
100	0,9993

Table 4. Exemplary values of possible communication durations

T [s]	$P(t \leq T)$	$P(t_{opp} \leq T)$
10	≈ 0	≈ 0
15	≈ 0	$0,5 \cdot 10^{-9}$
30	$0,135263 \cdot 10^{-4}$	0,023054
60	0,029577	0,571938
120	0,276658	0,897809
300	0,663459	0,972690
> 300	0,336541	0,027310

Depending on relative speed it can be seen that communication durations can differ widely. However, despite having oncoming traffic and high average velocity of 130 km/h the probability to have a communication duration less than thirty seconds is about 2 %. That means there is a high probability of communication durations large enough for our goals even in case of the worst case scenario.

After determining expected communication durations between vehicles we have to estimate the maximum time interval that can be used between periodically transmitted important messages. This can be calculated as follows: We consider a configuration like in Fig. 6 with two vehicles, A and B. In succession of its accident vehicle A starts sending Emergency Notifications at time t_{acc} in order to inform other vehicles about the dangerous situation where vehicle B is still out of communication range of A and therefore unable to receive the transmitted message ($t_{acc} < t_{R_{comm}}$). Vehicle B drives toward A and should be warned at least when it reaches the point where the distance between vehicle A and itself is right large enough in order to ensure a reliable reaction of the driver to the accident.

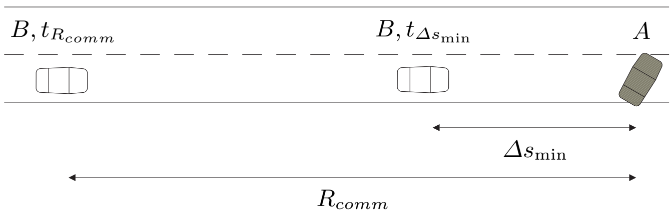

Fig. 6. Maximum time interval between periodically transmitted messages

On the assumptions that vehicle B drives with a velocity of $v = 200$ km/h toward the accident point, a total reaction duration of human and machine of $\Delta t_{react} = 1.4$ s and a maximum deceleration of $-a = 5\,\mathrm{m/s^2}$ the minimum braking difference $\Delta s_{\min}$ can be calculated using (4) to 387 m. In case of a velocity of $v = 130$ km/h the minimum braking difference decreases to 181 m.

$$\Delta s_{\min} = -\frac{v^2}{2a} + v \cdot \Delta t_{react} \tag{4}$$

To calculate the maximum duration between repetitions we have just to consider the difference between time $t_{R_{comm}}$ where vehicle B reaches the communication range of A and time $t_{\Delta s_{\min}}$ where vehicle B reaches the minimum braking difference. Using (5) a duration of about $\Delta t_{\max,200} = 11$ s corresponds to $v = 200$ km/h and $\Delta t_{\max,130} = 22.7$ s to $v = 130$ km/h respectively.

$$\Delta t_{\max} = t_{\Delta s_{\min}} - t_{R_{comm}} = \frac{R_{comm} - \Delta s_{\min}}{v} \tag{5}$$

As Table 5 shows a maximum deceleration of $-a = 5\,\mathrm{m/s^2}$ is less than we can expect normally. This value as well as the high speed of $v = 200\,\mathrm{km/h}$ was chosen to get an additionally amount of safety.

Table 5. Exemplary values of possible decelerations $-a$

	$-a\,[\frac{m}{s^2}]$
ice	1.0
snow	1.5
snow-chain on ice	2.0
bad way	4.0
wet lane	4.5
wet asphalt	5.5
dry lane	6.5
ABS	7.5
very good lane	8.0

After these reflections we want to concentrate on designing the proposed forwarding algorithm. During the first time the success of the algorithm depends on the existence of at least one additionally equipped vehicle within direct communication range of the car damaged in the accident that can start the forwarding process. There are three possible situations we have now to investigate:

1. Because of the accident the transmitter of the vehicle was destroyed before sending at least one Emergency Notification.
2. The vehicle was able to send just one complete message before its transmitter was destroyed.
3. The transmitter is able to keep sending Emergency Notifications periodically because it was not destroyed by the accident.

Item 1 does not need any further investigation because of the algorithm does not apply. Item 3 represents the opposite to Item 1 due to vehicles driving toward the accident point will be warned by the car damaged in the accident itself. Thus, applying the algorithm in order to avoid dangerous situations to other vehicles caused by the accident will be useful but not really necessary. Therefore, special interest has to apply to Item 2, the worst case scenario. We have to consider three different situations (the zone concept will be explained in detail in Sec. 2.2):

1. Only vehicles belonging to the Hazardous Zone are involved in the forwarding process.
2. Only vehicles belonging to the Opposite Zone are involved in the forwarding process.
3. Vehicles belonging to both zones are involved in the forwarding process.

We aim to determine whether the algorithm works only with the participation of Hazardous Zone traffic, thus the Emergency Notification is in fact relevant only for these vehicles or otherwise the participation of Opposite Zone vehicles is necessary for the success of the dissemination of Emergency Notifications. For each situation it is supposed that the radio equipment of the crashed vehicle is able to send the Emergency Notification only once so that the worst case scenario applies as described above.

At first we calculate for each situation the probability that at least one equipped vehicle on the studied zone receives the Emergency Notification. It will be made under different circumstances of system penetration rate and traffic densities. Hence, our next objective is to determine the formula which proportionate such probability. Statistical theory describes the probability distribution of net time gaps through the Poisson distribution. The general expression of this distribution shows (6):

$$P(X = k) = \frac{\lambda^k}{k!} \cdot \mathrm{e}^{-\lambda} \quad . \tag{6}$$

Based on the Poisson Distribution Model for net time gaps between vehicles the probability to find exactly k equipped vehicles in an area of length L [m] with a traffic density of ρ [veh/km/lane] can be calculated using (7) and (8) where N means the number of lanes while F stands for penetration rate of equipped vehicles:

$$P(X = k) = \frac{n^k}{k!} \cdot \mathrm{e}^{-n} \quad \text{with} \tag{7}$$

$$n = L \cdot \rho \cdot N \cdot F \quad . \tag{8}$$

For our purposes $L_{\max}$ corresponds to $2 \cdot R_{comm}$ as the reader can already suppose remembering considerations made in previous sections about the distance where communication between two vehicles is possible.

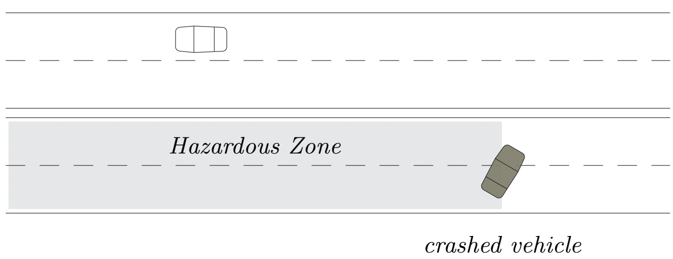

Fig. 7. Hazardous Zone

In the particular case of "at least one vehicle" the Poisson Probability Distribution as described above is equivalent to the Exponential Probability Distribution [3, 4]. This supposes a simplification of the mathematical calculation effort.

The basic formula that will be used for the evaluation of the algorithm success shows (9). It provides the probability to find at least one equipped vehicle in an area L:

$$P(X < L) = 1 - \mathrm{e}^{-(L \cdot \rho \cdot N \cdot F)} \quad . \tag{9}$$

In this case the probability to find at least one vehicle in the Hazardous Zones part of the communication area of the crashed vehicle as shown in Fig. 7 that could initiate the spread process of an Emergency Notification is depicted in Fig. 8 in dependence of penetration rate. Using $L = R_{comm} = 1000\,\mathrm{m}$, $N = 2$ and (9) the calculation corresponds to one driving direction of a highway scenario. As expected the probability increases with higher penetration rate as well as with higher traffic density.

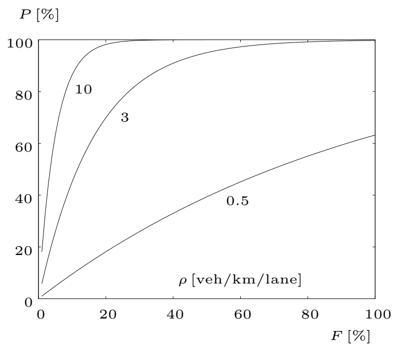

Fig. 8. First hop probability using Hazardous Zone traffic only

At the beginning an ad hoc network has to deal with relative low penetration rates. With a penetration rate of, e.g. only 2 % the probability to find at least one vehicle is very small, approximately 2 % in the night scenario with low traffic density which is considered as a worst case scenario for our purposes. The probability increases to almost 12 % in the night scenario with average traffic density and at day time with average traffic density conditions it reaches almost 33 %. The penetration rate should be higher than 40 % in order to obtain the same probability, 33 %, in the worst case scenario (night plus lower traffic density). By average traffic densities at day time the probability is about 86 % with a penetration rate of only 10 %, with 20 % of penetration rate the probability reaches the maximum value. At night time it would be necessary to have a penetration rate higher than 50 % to ensure the reception of an Emergency Notification by a vehicle on the Hazardous Zone.

After determining the probability to find at least one vehicle in the Hazardous Zone we calculate now the same probability for the Opposite Zone as shown in Fig. 9 that could initiate the spread process of an Emergency Notification in

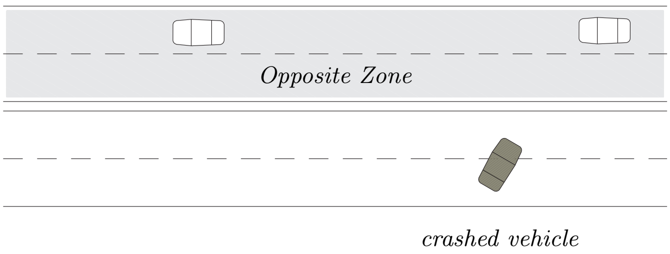

Fig. 9. Opposite Zone

dependence of penetration rate. Using $L = 2 \cdot R_{comm} = 2000\,\mathrm{m}$, $N = 2$ and (9) the calculation corresponds to the entire opposite driving direction within communication range of the car damaged by the accident in a highway scenario. Figure 10 depicts the probability of information propagation over one car within the Opposite Zone for different values of traffic density corresponding to the night and day scenarios respectively. As expected again the probability increases with higher penetration rate as well as with higher traffic density.

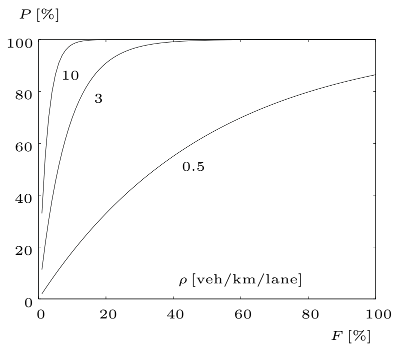

Fig. 10. First hop probability using Opposite Zone traffic only

In the night scenario with lower traffic density and a very low penetration rate of only 2 %, the probability to find at least one vehicle is also very small but higher than in the case of a car within the hazardous zone, approximately 4 %. The probability increases to almost 22 % in the night scenario with average traffic density as well as 55 % at day time. The penetration rate should be higher than 40 % in order to obtain the same probability in the worst case scenario (night plus lower traffic density). By average traffic densities at day time the probability is again 40 % with a penetration rate of, this time, only 5 %, with

10 % of penetration rate the probability almost reaches the maximum value. At night time a penetration rate higher than 40 % would be necessary to ensure the reception of an Emergency Notification by a vehicle on the Opposite Zone.

At last we calculate the combined probability for Hazardous and Opposite Zone. Using $L = (1 + 2) \cdot R_{comm} = 3000\,\text{m}$, $N = 2$ and (9) the calculation corresponds to one driving direction of the highway scenario and the entire opposite driving direction within communication range of the car damaged by the accident of the same scenario. Figure 11 depicts the probability of information propagation over one car within these zones for different values of traffic density corresponding to the night and day scenarios respectively. As in the cases before the probability increases with higher penetration rate as well as with higher traffic density.

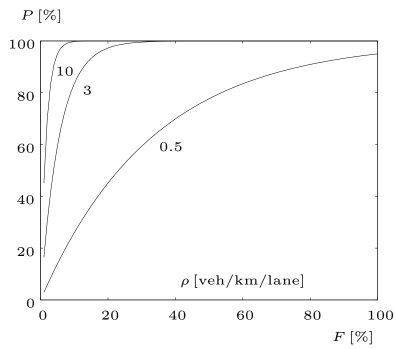

Fig. 11. First hop probability using Hazardous and Opposite Zone traffic

In the night scenario with lower traffic density and a very low penetration rate of only 2 %, the probability to find at least one vehicle is still small but higher than in the cases described above, approximately 6 %. The probability increases to 30 % in the night scenario with average traffic density as well as 70 % at day time. The penetration rate should be higher than 40 % in order to obtain the same probability in the worst case scenario (night plus lower traffic density). By average traffic densities at day time the probability is almost 95 % with a penetration rate of only 5 %, with 10 % of penetration rate the probability almost reaches the maximum value. At night time a penetration rate higher than 25 % would be necessary to ensure the reception of an Emergency Notification by a vehicle on the Hazardous or Opposite Zone.

In the following results for the probability of information propagation over multiple hops are depicted with participation of Hazardous Zone traffic only. Two scenarios are considered, a highway scenario with average night traffic conditions ($\rho = 3\,\text{veh/km/lane}$) and the same highway scenario with average day traffic conditions ($\rho = 10\,\text{veh/km/lane}$). The probability is calculated for different values of penetration rate. An important conclusion to be extracted from these results is a limit for the penetration rate which can ensure a high probability to propagate an Emergency Notification along a relevant zone of the message with participation of Hazardous Zone traffic only. In fact, only vehicles which belong to this traffic zone are direct affected by an accident and therefore should take the higher responsibility in the propagation process. Participation of vehicles within the other two traffic zones is foreseen in the algorithm in case of adverse dissemination conditions (low traffic density, low penetration rate) in order to avoid disruptions of the communication chain.

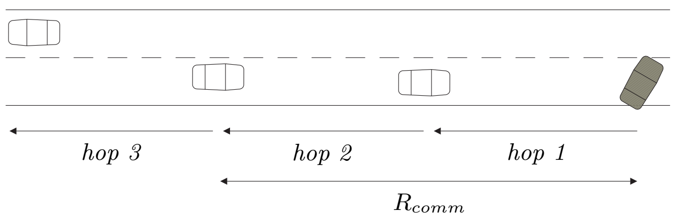

Fig. 12. Gain of information range

In the next figures the abscissa axis illustrates the gain of information range. We have studied a simplified scenario as depicted in Fig. 12 where each new hop of a message represents a gain of information range of 500 m, i.e., half of maximum transmission range. Gain "0" corresponds with the first hop probability already shown in Fig. 8. For each hop it is assumed that the receiving vehicle places 500 m away from the transmitting vehicle, this value is taken as the smallest distance which ensures a relative high usage of a messages forwarding as shown in Fig. 20.

Figure 13 shows results obtained for the night scenario while Fig. 14 shows results for the highway scenario at day time.

In the night scenario with average traffic densities the penetration rate that ensures a high propagation of information is about 50 % using Hazardous Zone traffic only. With this penetration rate the algorithm ensures a dissemination of the message over 7 km, which corresponds to 14 hops with a probability of 50 % and over 3.5 km (7 hops) with a probability of 70 %.

In the day scenario with average traffic conditions the algorithm deals with a higher traffic density. Thus, the penetration rate limit which already ensures a high probability of information propagation is only 20 %. With this penetration rate the algorithm ensures a dissemination of a message over 7 km, which corresponds to 14 hops, with a probability of almost 80 %.

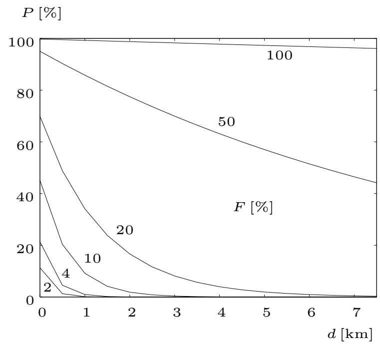

Fig. 13. Probability of information propagation over multiple hops (night)

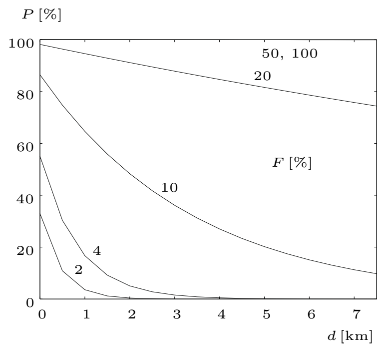

Fig. 14. Probability of information propagation over multiple hops (day)

2.2 Traffic Zones

After discussing the question under which circumstances communication among vehicles will be successful regarding time in Sec. 2.1 the following section will now deal with special qualities relating to space conditions.

The algorithm proposed in this work allows us to enlarge the area within the Zone of Relevance of the accident in which a vehicle could receive an Emergency Notification. A definition of the Zone of Relevance concept shows Fig. 15. In this application vehicles are provided with a radio equipment allowing them to contact with other equipped vehicles in their surrounding area. No fixed infrastructure to support the 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. Furthermore, to make the algorithm work, vehicles need to be aware of their current locations. Taking the driving direction into account, a vehicle can distinguish more reliably whether it is approaching a special point or not as well as if it employs a digital road map it may improve its ability to classify a given situation.

In case of an accident vehicles driving toward or already into the hazardous area should be warned by the crashed vehicle. The goal is to disseminate information about the accident quickly and efficiently to any vehicle affected by the dangerous situation.

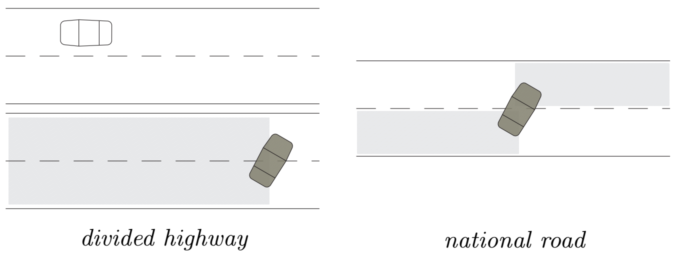

Fig. 15. Relevance Zone and road types

Two different road types are considered: A divided highway and a national road that can be seen as a highway without of any kind of physical divider and with fewer number of lanes. For the road model of a divided highway the Zone of Relevance covers the region behind the accident on the side of the highway where the accidents happens. On divided highways an accident usually does not harm vehicles of the other driving direction. In case of the second road type, the national road, vehicles having an accident can affect both driving directions.

Hence, all vehicles approaching the position of the accident are part of the Relevance Zone. For our forwarding strategy we suppose to divide a road into three different zones related to the point of accident:

1. Vehicles belonging to the Hazardous Zone drive toward the point of accident. They can be involved in the accident directly because there is no physical divider between these cars and the accident.
2. Vehicles belonging to the Opposite Zone drive away from the point of accident in general. If there is a physical divider on the road the Opposite Zone covers the entire opposite driving direction. Thus, in this case there are vehicles that drive toward the point of accident as well. Vehicles within this zone can play a very important role in the dissemination process, helping to avoid disruptions of the communication chain in case of long net time gaps between equipped vehicles.
3. Vehicles belonging to the Neutral Zone drive always away from the point of accident. The concept Neutral Zone is used because vehicles within this area are not affected by the accident directly. However, their participation in the dissemination mechanisms may be necessary under special traffic conditions, e.g., a very low traffic density or system penetration rate.

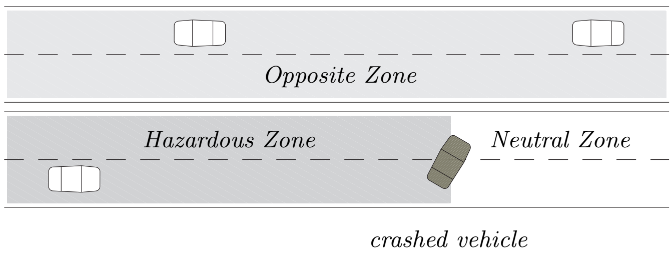

Fig. 16. Traffic Zones in a highway scenario with physical divider

Figure 16 shows the classification of road lanes and traffic into different zones of a divided highway. If there is no divider like in Fig. 17 the Neutral Zone disappears due to the inability of assigning a vehicle that caused an accident to a certain driving direction.

As it can be seen by comparing Fig. 15 with Fig. 16 and Fig. 17 respectively Relevance Zone and Hazardous Zone cover the same area because vehicles in theses zones are always affected by an accident directly. Both terms represent different concepts. While Hazardous Zone stands for the traffic's point of view Relevance Zone means the communication's point of view.

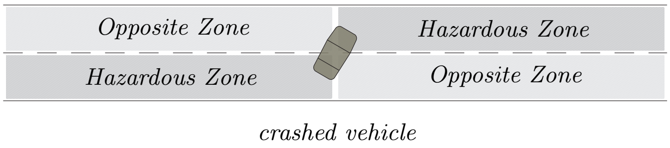

Fig. 17. Traffic Zones in a national road scenario without physical divider

2.3 Rules and States – the Forwarding Algorithm

Before discussing the proposed forwarding algorithm, the main goal of this section, we want to discuss the concept "Transmission Range" vs. "Information Range" shortly because of their relevance for the algorithm.

Predominantly the Transmission Range of a vehicle depends on its antenna's transmission power, antenna's height and on the propagation channel characteristics. The size of an area covered by a radio system directly depends on these factors. As already mentioned before it is assumed vehicles use omni directional antennas, i.e., their radio coverage areas extend homogeneously in a circle with the respective transmitting vehicle as center and its transmission range as radius. Under normal circumstances, a vehicle sending one data packet can reach all vehicles within its transmission area simultaneously. Information Range is a definition related to one message and tells us how far from the source of a message has arrived the information of this message at all. When using a multi-hopping strategy the Information Range of a message should be larger than the Transmission Range of the initiating vehicle as shown in Fig. 18. However, under conditions of a very high interference level vehicles may receive a signal but it could be impossible for them to decode the message. In this case Information Range is smaller than Transmission Range.

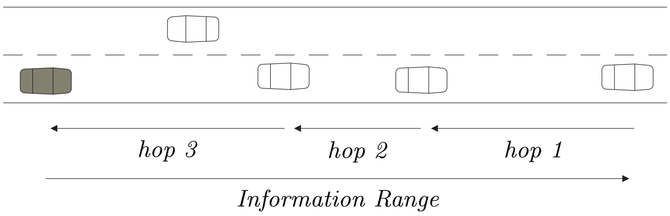

Fig. 18. Information Range

The proposed algorithm aims to extend the Information Range of a message under normal circumstances of a channel interference level. That is achieved by multi-hopping a message among equipped vehicles. First, a strategy has to be defined in order to prevent a message from being forwarded infinitely. Many protocols define a maximum number of hops so that if the number of hops made by a message or packet exceeds a given threshold the system discards the packet. In this work this strategy is not used, but another based on the importance of a message for the recipient and the usage of a message repetition for the dissemination process. The importance of a message depends on its content as well as on the distance to its place of origin. Therefore, a function can be defined in order to describe the importance i of a message in dependence on a distance d, e.g. $i(d_{acc})$ in case of an accident for an Emergency Notification, as shown in Fig. 19. D_{RZ} means the distance between accident and the end of the Relevance Zone whereas $\Delta s_{\min}$ stands for the minimum braking difference as described in Sec. 2.1. A vehicle discards a received message only when its importance reaches the value "0".

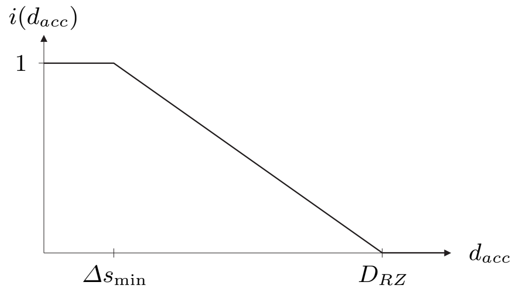

Fig. 19. Importance of a message

Like in case of the importance of a message a function can be defined that describes the usage u of a message repetition in dependence on the distance between a receiving vehicle $n+1$ and a transmitting vehicle n. As Fig. 20 shows $u(d_{n,n+1})$ depends not on the place of origin of the message but only on the distance $d_{n,n+1}$ between the vehicles. R_{comm} stands for communication range as shown in Fig. 2.

The algorithm distinguishes between two kinds of messages:

1. An "Emergency Notification" initiated by a vehicle damaged in an accident. As already discussed in Sec. 2.1 it is assumed that the vehicle was able to send at least one complete message.
2. A "Forwarded Message" sent by a vehicle involved in the dissemination process of the Emergency Notification.

In a first step the algorithm determines whether the received message is currently unknown for the vehicle or not. Due to multi-hopping it is more likely to receive transmissions of the same message which have to be discarded. In order

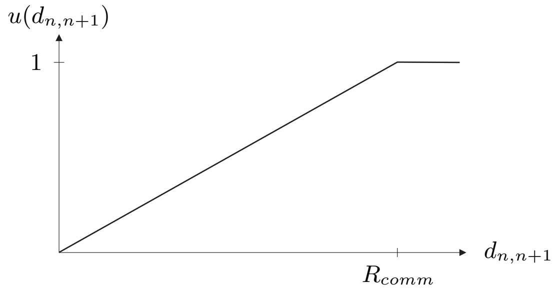

Fig. 20. Usage of a message repetition

to determine whether a message is already known each vehicle implements a list of recently received messages. This list stores only one copy of each received message. Already known messages just remain in the list until its importance reaches the value "0" while unknown messages are added to the list. An Emergency Notification with an internal counter $I_{count} = 0$ was always sent by the vehicle damaged in the accident due to it is the original message whereas an Emergency Notification with $I_{count} \geq 1$ is in fact a Forwarded Message that was sent by a vehicle involved in the forwarding process. An Emergency Notification with $I_{count} = 0$ may be received more than once. In this case the radio equipment of the vehicle that caused the accident was not destroyed and therefore still capable of keeping sending the message periodically.

When a vehicle receives a new Emergency Notification the forwarding algorithm determines the probability of resending the received message. The probability of forwarding a received message depends on a list of factors:

1. To which driving zone the vehicle belongs. The more dangerous its position is the higher is the probability of forwarding a message. Thus, vehicles within the Hazardous Zone have a higher forwarding probability than vehicles within any other zones. The Opposite Zone has the next higher probability for its vehicles whereas the lowest forwarding probability corresponds to vehicles of the Neutral Zone.
2. The distance d_{acc} between vehicle and accident point.
3. The distance $d_{n,n+1}$ between receiving vehicle $n+1$ and forwarding vehicle n in case of a Forwarded Message.

If the vehicle decides not to resend the Emergency Notification it puts the message on its internal stack. Thus, it is still able to forward the message later. The vehicle reaches a "Wait for Forward" state where it tries to resend a message periodically as long as no confirmation messages from other vehicles are received. When a Forwarded Message about the same event that the vehicle tries to propagate is received the received message is considered as an acknowledgment. The aim of this behavior is to give the algorithm more resistance against disruptions of the communication chain as well as to avoid unnecessary overflooding of the underlying radio network. In case of not receiving any other Forwarded Message about the Emergency Notification, which could happen if only this vehicle was within transmission range of the crashed vehicle, it is still guaranteed that the vehicle tries to resend the Emergency Notification until the relevance of the message reaches the value "0".

State 1. Wait for Forward
Reached when an Emergency Notification was received. A decision whether to forward or not will be made after 3 s:

In case of "yes":

- if the Emergency Notification was not forwarded send message and go to "Wait for Acknowledge" state, if "channel not free" try again after 1 s;
- if the Emergency Notification was already forwarded make a new decision after 6 s.

In case of "no":

- if the Emergency Notification was not forwarded make a new decision after 3 s;
- if the Emergency Notification was already forwarded make a new decision after 6 s.

In case of "cancel":

- discard message and delete it from stack.

If the vehicle decides to forward the message it reaches a "Wait for Acknowledge" state. Like in "Wait for Forward" state as long as no confirmation messages from other vehicles are received, that ensures the vehicle that the dissemination process goes on, it will initiate to resend again the message periodically. In general the number of periodical transmissions is unlimited. The vehicle stops with the periodically forwarding of the message when importance becomes "0". Again, the aim of this behavior is to give the algorithm more resistance against disruptions of the communication chain. The last informed vehicle does not leave its forwarding task until the relevance of the message reaches the value "0" or it is sure another vehicle goes on with the dissemination process.

State 2. Wait for Acknowledge
Reached when a received Emergency Notification was forwarded. A decision whether to repeat or not will be made after 6 s:

In case of "repeat":

- send message again, if "channel not free" try again after 1 s and
- remain in "Wait for Acknowledge" state, make a new decision after 6 s.

In case of "acknowledged":

– discard message and delete it from stack.

As described in Sec. 2.1 the maximum duration between periodical repetitions of Emergency Notifications in case of $v = 200\,\mathrm{km/h}$ corresponds to $\Delta t_{\max,200} = 11\,\mathrm{s}$. We have chosen a maximum duration value of $\Delta t_{\max} = 6\,\mathrm{s}$ in order to get an additional amount of safety.

After finishing the forwarding task the behavior of the vehicle is identical as before. In case of forwarding a message the vehicle enters the Wait for Acknowledge state again and in case of not forwarding the vehicle enters the Wait for Forward state. Receiving an acknowledge from other vehicles about the message the vehicle tries to disseminate means in both cases that the forwarding task of the vehicle is for the moment no more necessary for the global performance of the algorithm.

Controlled by multiple dependencies of the forwarding probability the algorithm determines that not each vehicle that receives a message resends it automatically but only those whose relevance in the dissemination process is the highest. Other vehicles wait and observe the progression of the spread process. Thanks to the existence of more than one resending attempt within the forwarding algorithm and in case of their participation become necessary, they get a chance of forwarding the message by themselves periodically. This performance aims again to avoid overflooding of the underlying radio network with unnecessary messages.

Messages containing safety relevant information are most important to vehicles belonging to the Hazardous Zone. Thus, forwarding of such messages should be done by these vehicles first. However, as described in Sec. 2.1 a participation of vehicles belonging to other zones still remains necessary at least in cases of low penetration rate or low traffic density.

2.4 Traffic Models

Inter-vehicle communication represents a distinctive case for ad hoc networks, characterized by high speed and "one-dimensionality" of their scenarios. By modeling of vehicles movements it can be assumed for small traffic densities that cars are moving independently of each other. At high traffic densities the complex interactions among neighboring vehicles make modeling of such a dynamical system a challenge.

For low density scenarios basic traffic models are usually built by specifying probability distributions for vehicle speeds and net time gaps. These net time gaps provide a safety-related measurement of distances and are typically measured in seconds. However, for our purposes, it is more interesting to know the distance between vehicles in meters. In this way, the probability for a vehicle to reach at least one other equipped vehicle within a distance d was modeled by an exponential distribution [5]:

$$P(x < d) = 1 - \mathrm{e}^{-\frac{d}{d_a}} \quad , \tag{10}$$

where d_a is the average effective distance between two equipped vehicles. The value of d_a depends on the average velocity V_{avg}, the net time gap Δt, the number of lanes N and the penetration rate F:

$$d_a = \frac{V_{\text{avg}} \cdot \Delta t}{N \cdot F} \quad . \tag{11}$$

For a more accurate modeling, in particular for high density scenarios, some microscopic traffic simulation models have been proposed and analysed for their appropriateness within the framework, e.g. Psycho-physical models [5], Car-following models [6], Velocity-density models [7], Cellular Automaton Based models [8] or Drive-based models [9]. These models, in their basic versions, model the speed or acceleration with what a vehicle must perform in order to keep constant the distance between it and the leading vehicle.

The cellular automaton approach was selected for simulations introduced in Sec. 3, because it provides sufficient accuracy for low computational costs. For the sake of simplicity, we do not model complex maneuvers like lane changes or overtaking. Cellular automata are discrete models that are consist of an infinite, regular grid of cells, each in one of a finite number of states. The grid can be in any finite number of dimensions. Time is also discrete, and the state of a cell at time $t + 1$ is a function of the state of a finite number of cells at time t. In order to describe a road using a cellular automaton cells are defined as 7.5 m long. This corresponds to the space required by a vehicle in traffic jam. Each cell may be empty or engaged by exactly one vehicle. Vehicles are characterized by their current velocity v. The velocity can be one of the allowed integer values $v = 0, 1, 2, \ldots, v_{\max}$. In a simple case $v_{\max}$ corresponds to a speed limit and is therefore equal for all vehicles. If a vehicle is present in the cell it may be advanced to another cell using a simple rule set. A typical configuration of a cellular automaton is shown by Fig. 21.

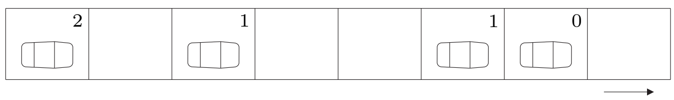

Fig. 21. Configuration at time t

The state of the road at time $t + 1$ can now be obtained from that at time t by applying the following rules to all cars at the same time:

Step 1. Acceleration
If speed v_n of vehicle n is less than the maximum speed $v_{\max}$, increase vehicle's speed by one cell per time step: $v_n \rightarrow \min\{v_n + 1, v_{\max}\}$.

Step 2. Braking
If speed v_n of vehicle n is greater than the number of empty cells d_n in front of it, set vehicle's speed to the number of empty cells: $v_n \to \min\{v_n, d_n\}$.

Step 3. Randomization
If speed v_n of vehicle n is greater than zero, decrease vehicle's speed by one cell per time step with a probability of p: $v_n = f(p) \to \max\{v_n - 1, 0\}$.

Step 4. Driving
Move vehicle n forward the number of cells given by vehicle's speed v_n: $x_n \to x_n + v_n$.

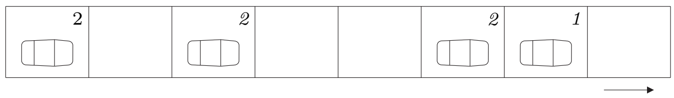

Fig. 22. Acceleration

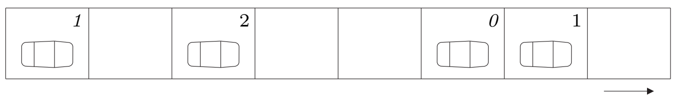

Fig. 23. Braking

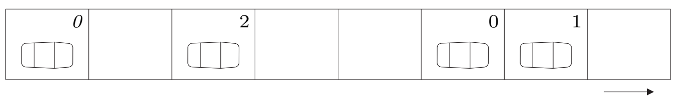

Fig. 24. Randomization

The applying of a minimal rule set is shown by Fig. 21 to Fig. 25. Minimal rule set means there is no negligible rule within the set. Thus, a realistic behavior with fewer rules is not possible where realistic behavior stands for spontaneous appearance of traffic jam and the right form of the fundamental diagram, i.e.

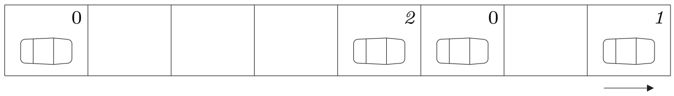

Fig. 25. Driving = configuration at time $t + 1$

the correlation between traffic density and traffic flow. Even the change of the order in the update procedure leads to a completely different behavior. In case of low traffic densities traffic flow is proportional to traffic density because of the lack of interaction among the vehicles. In case of increasing traffic densities interaction among vehicles becomes more important. Thus, the characteristic of the correlation between density and flow is getting more and more non linear. Finally, interaction among vehicles becomes dominant so that traffic flow decreases while traffic density still increases.

3 Car-to-Car Forwarding: Performance Analysis

After introducing the reader with the basic concepts related to this work in the sections before we want to show now some results obtained by our simulations.

3.1 Results by Using Different Zone Concepts

In the following we present simulation results obtained by using the parameter presented in Table 6. Vehicles of all three zones are involved in the forwarding process. The term "forwarding" stands for the number of first repetitions of a message by the vehicles whereas "repeating" means that vehicles had to repeat transmissions more than once due to the lack of an acknowledgment. A third value "max" shows the maximum number of the internal message counter I_{count} as explained in Sec. 2.3, i.e. "max" stands for the highest length of a repetition chain and therefore for the maximum number of hops of a message that occurred in a simulation.

Although the simulations introduced below cover a range from 1 veh/km/lane to 30 veh/km/lane there are three values of traffic flow indicated by special scenarios as described in Sec. 2.1 that we want to spend a little bit more attention:

1. The "Night Scenario" is defined by a traffic flow of about 3 veh/km/lane. In this scenario the probability to reach another vehicle with just one sent message is very low due to the low probability of having at least one equipped vehicle within communication range of the initiating vehicle at sending time t_{acc}.
2. The "Day Scenario" is defined by a traffic flow of about 10 veh/km/lane. In this scenario the probability to reach at least one other vehicle with just one sent message should be reasonably high.

Table 6. Parameter for long time simulations

Parameter	Value
Number of vehicles	1200 (600/lane)
Simulation duration	3600 s
Number of lanes	2
Road length	10 km (1333 cells)
Length of Relevance Zone $D_{RZ,HZ}$	4.5 km (600 cells)
Length of Relevance Zone $D_{RZ,NZ}$	1.125 km (150 cells)
Communication range R_{comm}	1 km (133 cells)
Guaranteed receiving of EN	0.5 km (67 cells)
Initial speed	108 km/h
Maximum speed $v_{\max}$	162 km/h
Penetration rate F	variable
Number of sent EN	1 (worst case scenario)
Cell of accident	99
Time of accident t_{acc}	20 s
Time to wait until forwarding	3 s
Time to wait until repeating	6 s
Time to wait if “channel not free”	1 s

3. Like the other scenarios the “High Traffic Flow Scenario” is defined by a traffic flow of about 18 veh/km/lane. In this scenario the probability to reach at least one other vehicle with just one sent message should be almost “1”.

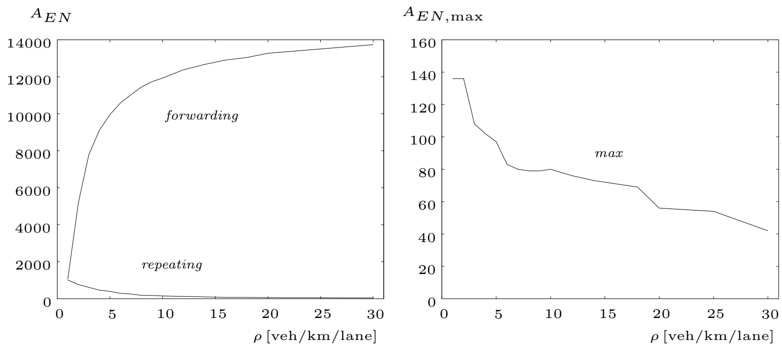

Fig. 26. 100 % Penetration rate

As it can be seen in Fig. 26 there are no problems that could be expected if the penetration rate equals to 100 %. There are a large number of “forwarding” repetitions of different vehicles even in case of low traffic density, e.g. 1052 repetitions and a traffic density of 1 veh/km/lane. The number of multiple transmitted messages, as explained above they are marked by the term “repeating”, are about in the same size. If traffic flow increases the number of “forwarding” messages increases as well while the number of “repeating” messages decreases very fast due to the fact that with higher traffic densities it is no longer necessary by a vehicle to transmit a Forwarded Message more than once in order to get an acknowledgement by another vehicle (proportion forwarding : repeating equals to 13572 : 45 in case of 30 veh/km/lane). Despite using a conservative set of rules for message repetition as introduced in Sec. 2.3, there is still a large number of repeated messages in case of high traffic flow, e.g. 40 messages/min/km. Thus, rule settings have to be a focus on further investigations to reduce this large number of repetitions.

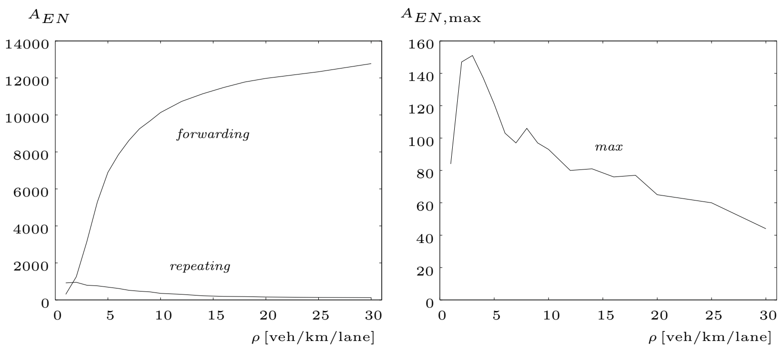

Fig. 27. 50 % Penetration rate

Figure 26 right shows the number of maximum hops made by a message. As mentioned above in case of forwarding a message the internal counter of this message is incremented by the forwarding vehicle before transmitting: $I_{count} \rightarrow I_{count} + 1$. A counter value of “0” indicates an original message sent by, e.g. a car involved in an accident whereas a value of “1” identifies a first repetition of this message by a vehicle that received the original message. A third vehicle that receives this first repetition increases I_{count} to “2” and so on. Thus, Fig. 26 right shows $I_{count,\max}$ obtained by given traffic flows respectively. It can be seen that the length of repetition chains decreases with increasing traffic flow and therefore reaches its maximum under low traffic conditions.

There are no significant differences between 100 % and 50 % penetration rate except for low traffic. For the first time vehicles require multiple repetitions of a message in order to accomplish their forwarding tasks.

Figure 27 shows that the maximum value of “max” shifts to higher traffic flows. As it can be seen below this behavior continues when penetration rate decreasing goes on.

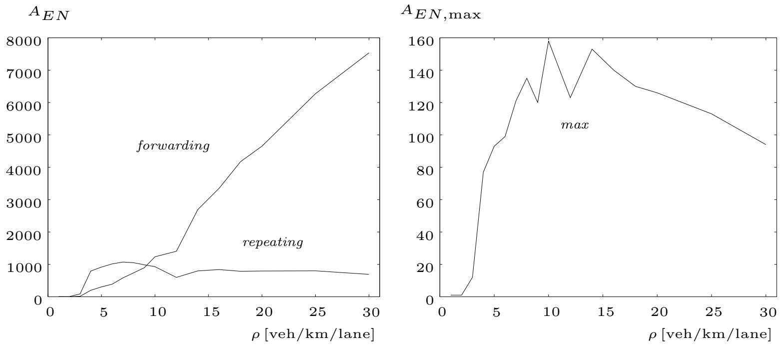

Fig. 28. 10 % Penetration rate

At a rate of 10 % we are first within a realistic range of penetration rate in the foreseeable future. It can be seen that vehicles require multiple repetitions of messages in order to accomplish their forwarding tasks. Until to a traffic flow of about 9 veh/km/lane the part of multiple repetitions outbalanced the part of single repetitions clearly.

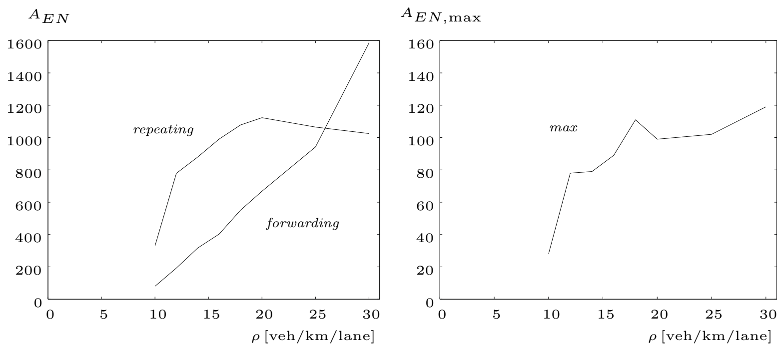

Fig. 29. 4 % Penetration rate

As the graph in Fig. 28 shows there is an optimum regarding maximum length of repetition chain in the range of 10 to 12 vehicles per km and lane.

In the range of less than 10 % penetration rate, e.g. as shown in Fig. 29 and Fig. 30 for 4 % and 2 % respectively, vehicles are no longer able to proceed their forwarding tasks until penetration rates reach values like in the day scenario.

As mentioned above in case of only 2 % penetration rate vehicles are no longer able find an appropriate successor in the forwarding process until traffic

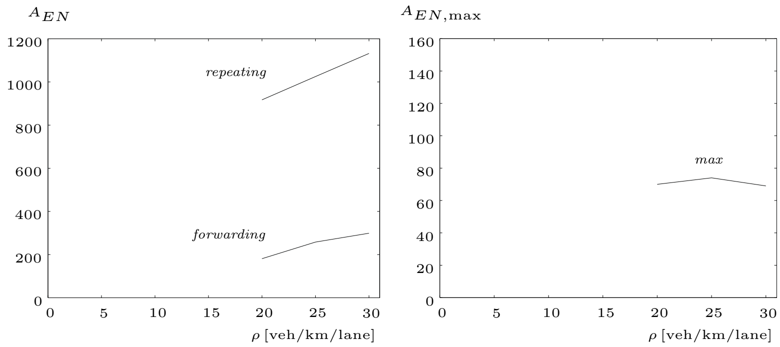

Fig. 30. 2 % Penetration rate

flow increases dramatically. Even in these cases multiple repetitions occurring much more than single repetitions.

3.2 Message Distribution

In the following we want to consider the distribution of Forwarded Messages sent by a vehicle in dependence on the position of this vehicle. The position corresponds to a cell number as described in Sec. 2.4. In the diagrams above points are used to identify the number of messages whereas a line is used for belonging average values calculated using a sliding window of 10 cells, for some example combinations of penetration rate and traffic flow. The initiating Emergency Notification is always transmitted at cell 99. Due to vehicles drive in a circle, cell 0 is successor of cell 1333. As shown in Sec. 3.1 used penetration rates are unrealistic high. However, these rates are chosen in order to describe the behavior of vehicles in the forwarding process more clearly.

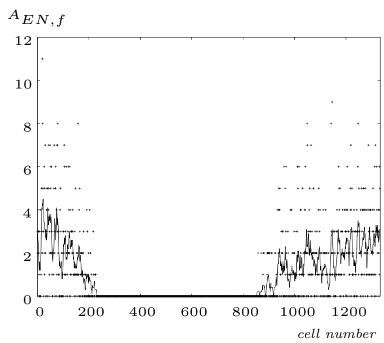

Fig. 31. 10 % Penetration rate, 10 veh/km/lane

As it can be seen in Fig. 31 and Fig. 32 respectively the behavior of vehicles that repeating a received message is already visible. Starting at cell 800 the number of forwarded messages increases continuously.

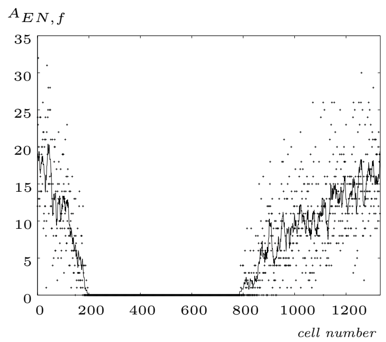

Fig. 32. 10 % Penetration rate, 30 veh/km/lane

The maximum value of repeated messages is located in front of the accident as expected in order to inform vehicles that driving toward this position right on time.

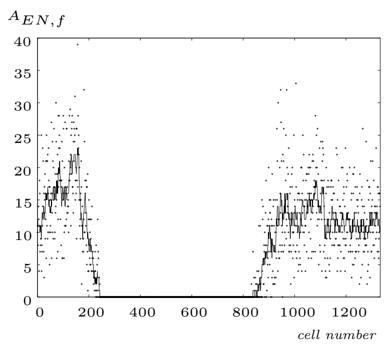

Fig. 33. 100 % Penetration rate, 4 veh/km/lane

Increases the number of single repetitions, e.g. in case of a higher level of equipped vehicles as shown in Fig. 33, vehicles involved in the forwarding process changes their behavior apparently.

While in case of 100 % penetration rate and a traffic flow of 4 veh/km/lane transmitted messages are distributed continuously over all cells within the Relevance Zone this proportion changes when message density increases as shown

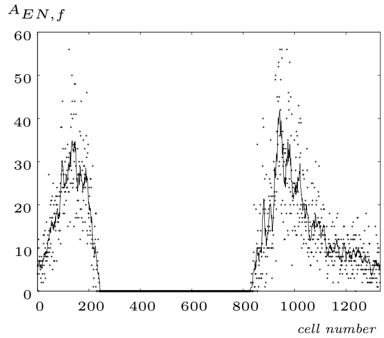

Fig. 34. 100 % Penetration rate, 10 veh/km/lane

in Fig. 34 and Fig. 35. In these cases the maximum value of forwarded messages shifts toward the end of the Relevance Zone.

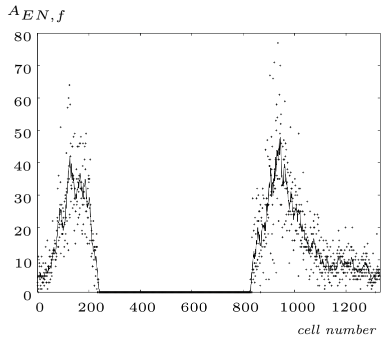

Fig. 35. 100 % Penetration rate, 18 veh/km/lane

As it can be seen in the figures above there is still a demand of optimizing the behavior of vehicles involved in the forwarding process regarding the large number of transmitted messages as well as the distribution of messages over all positions.

3.3 First Repetition Probability

Having discussed the number of forwarded messages and their distribution we want now simulate the probability to find at least one equipped vehicle within the communication range of a randomly chosen vehicle. This probability was already calculated in Sec. 2.1 using a simple approach. In case of the worst case scenario described in the same section this question is very important due to it corresponds to the decision whether the forwarding process may start or not at all. In contrast to this fact vehicles following in the repetition chain can repeat a received message as often as necessary because of, e.g. they are not affected by an accident like an initiating vehicle may be. Thus, the probability to find at least one equipped vehicle does not matter for these vehicles. The simulation results introduced below are obtained by using the parameters presented in Table 7.

Table 7. Parameter for short time simulations

Parameter	Value
Number of vehicles	1200 (600/lane)
Simulation duration	120 s
Number of lanes	2
Road length	10 km (1333 cells)
Communication range R_{comm}	1 km (133 cells)
Guaranteed receiving of EN	0.5 km (67 cells)
Initial speed	108 km/h
Maximum speed $v_{\max}$	162 km/h
Penetration rate F	variable
Number of sent EN	1 (worst case scenario)
Cell of accident	variable
Time of accident t_{acc}	90 s

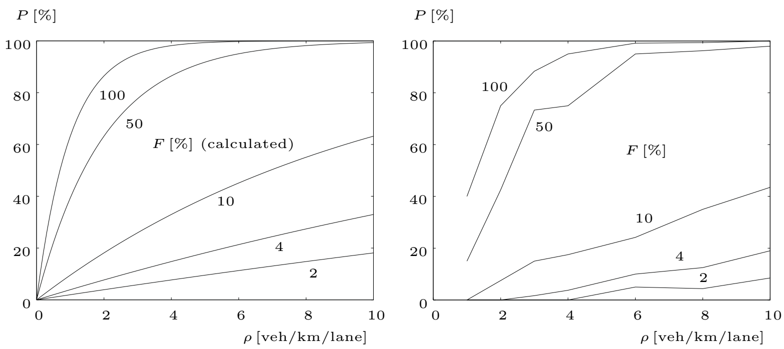

Fig. 36. Forwarding by vehicles of Hazardous Zone only

Figure 36 shows results where vehicles of the Hazardous Zone are involved in the forwarding process only. It can be seen that for low penetration rate receiving of the original message even in case of a high traffic density of 10 veh/km/lane is still insufficient. On the other hand using, at least for a start up phase, unrealistic high values of penetration rate but a low traffic flow value of 3 veh/km/lane results in a probability of about 70 % for a successful first forwarding task. The results obtained in the short time simulations approve the assumption as discussed in Sec. 2.1 that taking the forwarding process by vehicles of the Hazardous Zone only leads to disadvantageous values of forwarding probability.

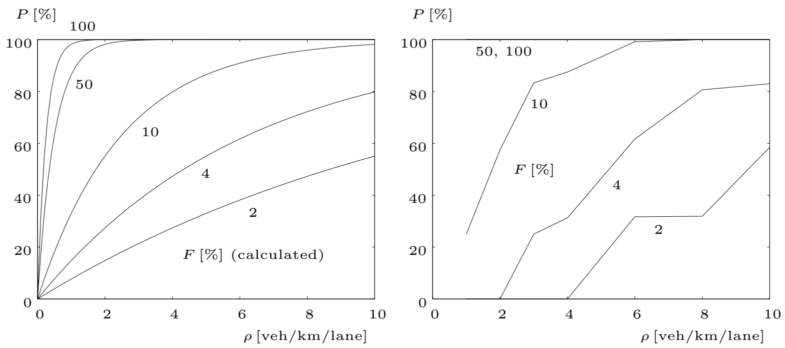

Fig. 37. Forwarding by vehicles of all three zones

Results obtained by using all available equipped vehicles to take part of the forwarding process are shown in Fig. 37. In comparison to the scenario of using vehicles of the Hazardous Zone only there can be observed significant improvements for all penetration rates. In case of traffic flow values greater or equal 50 % the probability of a successful receiving of the original message corresponds to almost 100 % even in case of a low traffic flow of 1 veh/km/lane. Furthermore, having realistic penetration rates, except in case of 2 %, and a traffic flow of at least 6 veh/km/lane sufficient values for receiving of an original message are already very likely.

3.4 Fastest Direct Sequence Forwarding and Information Coverage

Having discussed the question of forwarding messages in general as well as the probability to find at least one equipped vehicle within the communication range of a randomly chosen vehicle in the sections before it can be considered additionally the question how fast a message may be transfered from the place of its origin to the end of the Relevance Zone. As a required condition in this case all messages involved in the task of information transport have to belong to the same repetition chain. This "Fastest Direct Sequence Forwarding" is important for extending the underlying forwarding algorithm from 1- to n-dimensionality.

In opposite to the first part of this section we want to consider in the second part the question how long information contained in a certain message may remain in a geographical area like a Relevance Zone without using of any kind of fixed infrastructure at the road side. What the term "Information Coverage" of a certain zone stands for is depicted in Fig. 38. Two vehicles are shown that repeat a received message at the same time independently of each other. Thus, they provide an area with information much larger than the area covered by the communication range of just one vehicle. Due to the almost periodically appearance of such message repetitions in similar configurations information about events can remain in their respective target areas over time even when vehicles which carried the information before leave these areas.

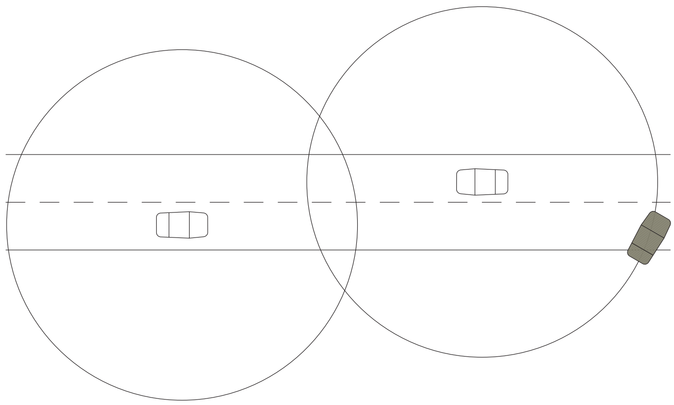

Fig. 38. Information Coverage

As it could be seen in different simulations a successful forwarding of messages using Fastest Direct Sequence Forwarding only is possible but not very likely. Providing of an area with information about an event is the much easier task even in cases of disadvantageous conditions.

4 Conclusions

The goal of the work introduced in this chapter was the development of an algorithm for the propagation of Emergency Notifications, i.e., messages released automatically by vehicles in emergency situations, like airbag ignition or hard braking. The algorithm is based on a multi-hopping strategy. In this work, the area of interest for a message dissemination was called Relevance Zone of a message. The algorithm is based on the division of different traffic zones and on some concepts like message importance and usage of a message repetition. In ad-hoc networks resource management techniques are very important due to the limitation of resources. Thus, the proposed algorithm aims to disseminate an Emergency Notification quickly among vehicles of the Relevance Zone as well as minimizing the hazard of overflooding the underlying radio network.

The goal of these multiple dependencies of the forwarding probability is to ensure that vehicles forward messages only in case of high benefits for the dissemination process. Vehicles on the Hazardous Zone take the highest responsibility in the dissemination process, due to their belonging to the Relevance Zone. Vehicles on the other traffic zones help to avoid disruptions of the propagation chain under adverse circumstances of low traffic density or low penetration rate.

Future work related with this work should be directed in the enlargement of the scenarios of this study. In this work straight roadways are considered only, further extensions of the dissemination algorithm should include road intersections as well as complex maneuvering of vehicles like possible change of direction or overtaking. In this work scenarios and vehicular traffic theory concepts were maximal simplified in order to obtain a first evaluation of the possible performance of the algorithm.

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