Evaluation of Typical Road Telematics Scenarios on a Freeway

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Abstract

Besides typical applications in vehicular environments, the Internet access for vehicles using inter-vehicle communication systems will become very important in the future. However, the communication characteristics of such systems are completely different compared to communication in the Internet. In order to evaluate the performance of the Internet access, an abstract communication model of the inter-vehicle communication system is necessary. In this paper, we propose emulations of such network models for two "typical" communication scenarios on a freeway: a freeway with a high traffic flow and a congested freeway. Based on these models, we evaluate the performance of TCP and a web application in both scenarios. This evaluation allows an estimation of the communication performance vehicular applications can expect for the communication with the Internet.

1 Introduction

Communication in vehicular environments becomes more and more important for the future development in the automotive domain. An example is the FleetNet project, which aims at the development and promotion of an inter-vehicle communication (IVC) system [1]. The FleetNet IVC system is based on multi-hop ad hoc radio networks, which enables the local exchange of information without any infrastructure components like access points or base stations. Moreover, the multi-hop capability of the IVC ad hoc network virtually increases the radio transmission range of a vehicle by using intermediate vehicles as relaying nodes. Thereby, a location-based ad hoc routing protocol is responsible to forward the data via intermediate vehicles to the targeted vehicle [2].

The IVC system can be also used to communicate with hosts in the Internet using so-called Internet gateways (IGWs) installed on the roadside. Internet gateways are integrated seamlessly into the IVC network, i.e. they appear as common (but stationary) vehicles in the vehicular ad hoc network. The gateways are also connected to the Internet to provide Internet access for a restricted geographical area, which is called coverage area further on. Within this area, the vehicles are able to discover the IGWs and they can use them for Internet access. The Internet integration of such an IVC network requires additional communication architectures and protocols. For the example of FleetNet, the Internet integration of the IVC system is described in [3]. This way, a vehicle is able to retrieve information from the Internet, such as updated traveling information, weather conditions, or personal information services of the passengers like e-mail and WWW.

The performance of such applications highly depends on the performance of the communication system and the communication protocols being deployed. The communication characteristics of vehicular ad hoc networks are completely different compared to wireless and wired local area networks. The characteristics not only depend on the mobility of the vehicles, but also on the communication environment. However, a general performance evaluation of the Internet access is not possible, because it is not possible to specify one scenario representing all typical communication situations on the road. In [4], we proposed and evaluated models for a crossway in a city and an empty freeway at night. This paper introduces two more complex communication models for a vehicle in two freeway scenarios: A freeway with high traffic flow and a congested freeway. Furthermore, the performance of TCP and an Internet application are evaluated in both models. In the remaining paper, sections 2 and 3 describe mobility patterns of the two freeway scenarios. The mobility patterns are evaluated in section 4. Finally, section 5 concludes this paper and gives an outlook on our future activities in this area.

2 Freeway with High Traffic Flow

Our first scenario describes a freeway with high traffic flow as illustrated in figure 1. The modeled freeway has three lanes per direction. The features and assumptions of this scenario are the following:

- The traffic flow on the freeway is high and slightly disturbed owing to overtaking maneuvers of slower vehicles like trucks.
- The mobility of the vehicles is quite high and different between the individual lanes, because vehicles on the left lane will drive at higher speeds than, e.g. trucks on the right lane.
- As a result of the different vehicle's speeds on a freeway, faster vehicles often overtake slower ones. Therefore the reconfiguration rate of the inter-vehicle ad hoc network will be high due to topology changes.
- The freeway segment is supplied by two IGWs mounted beside the road, which provide Internet access for the vehicles. The coverage areas of the IGWs do not overlap each other, thus no communication is possible in an area between them.

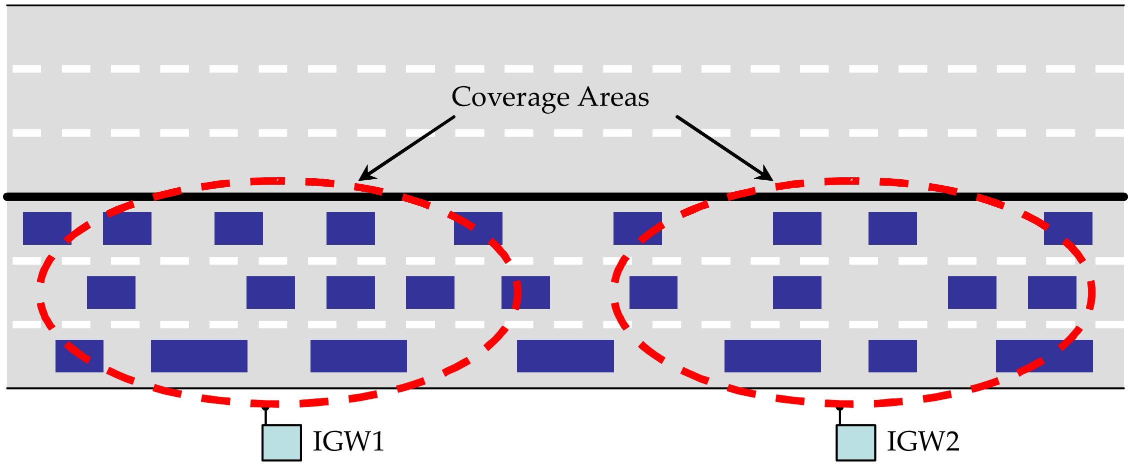

Figure 1: Freeway with high traffic flow

The freeway traffic is characterized by many different kinds of vehicles like cars, trucks or semitrailer trucks. Hence, the length of the vehicles on the right lane is likely higher than on the middle or left lane, because trucks dominate the right lane, whereas the other lanes are mainly occupied by cars or small transporters. According to [5] the average length of cars (including small busses) is 4.5 m in Germany. This value is well suited for describing the vehicles on the middle and left lane. The average length of the other kinds of vehicles can be determined by considering those maximum permissible lengths of 12 m, which are defined in [6]. Assuming trucks to have a share of 10% on the total traffic, the average length of vehicles on the right lane is about 6.3 m. Combining those values results in an average length per vehicle l_{veh} of 5.3 m for all lanes [7]. Furthermore, the average distance Δx between two neighbored vehicles can be assumed to be 25 m. We assume the diameter of the IGWs' coverage area S_{geo} to be 2000 m with a vehicle's radio transmission range of r = 100 m. Notice that the radio transmission range depends on the number of vehicles taking part in the IVC system. The penetration p of communicating vehicles was assumed with 15%. We used parameters from the FleetNet link layer performance [8] to model the inter-vehicle communication. The maximum net link layer bandwidth of a single IGW is $bw_{net} = 588$ kbit/s. Hence, an average IP packet of 20 kbyte is spread on 390 link layer frames of 420 bit length. The expected delay is 40 ms per link at the worst case with an assumed jitter of ±20%. In FleetNet, the data link frame error rate can be supposed to be 10^{-4}. This results in an IP packet error rate of up to $err = 390 \cdot 10^{-4} = 3.9\%$ per link and an IP packet loss probability against a vehicle's distance to the IGW in hops of $loss(hops) = 1 - (1 - err)^{hops} = 1 - 0.961^{hops}$.

2.1 Macro Mobility Observations

Based on these micro mobility parameters, we derived some macro mobility statistics. An important characteristic is the traffic density. According to [7], the traffic flow on a freeway is colloquial designated as "high", if the traffic density ρ exceeds 30 vehicles/km (per lane). In this example we assumed the average density with $\rho = 30$ vehicles/km on all lanes. Obviously, the traffic density on the right lane of a real freeway will be lower than on the other lanes, because this lane is mainly occupied by longer vehicles, which in addition might observe a higher safe distance than the drivers of cars. In order to simplify the model, we assumed an equal distribution of the vehicles on all lanes. This way, the result shows that the assumption for $\Delta x = 25$ m is a suitable distance: Under these conditions, the total number of communicating vehicles in the coverage area of an IGW is $n_{veh} = S_{geo} \cdot 3\text{lanes} \cdot 30\ \text{vehicles/km} \cdot 15\% = 27$ vehicles with the assumed penetration of 15%. Together with the equal distribution of the vehicles on the lanes, the average distance between two neighbored communicating vehicles is S_{geo} / 27 vehicles ≈ 74 m/vehicles. The other way round, there are $(2 \cdot \text{r}) / 74 = 2.7$ communicating vehicles in the radio transmission diameter of each communicating vehicle. This way, packet duplication may occur, because a node has more than one forwarding node in its immediate communication range [2]. In this example, a duplication rate of $dup = 1\%$ per link was assumed. Thus, the overall duplication probability dependent on the number of hops is $dup(hops) = 1 - (1 - dup)^{hops} = 1 - 0.99^{hops}$.

Another important parameter is the estimated available bandwidth for Internet access. For simplicity reasons, we assume all vehicles to access the Internet simultaneously and not to communicate locally except for the forwarding of IP packets to or from the IGW. Thus, the available bandwidth is basically determined by the last hop to the IGW, because all vehicles have to share this hop for Internet access. The available net bandwidth is slightly reduced due to overhead caused by the service discovery protocol to discover the IGW in S_{geo}, which can be estimated to be 6.512 kbit/s [9]. Based on this information, we can determine the available bandwidth *bw* per vehicle, assuming that all vehicles share the bandwidth fairly:

$bw = (bw_{net} - \text{overhead}) / n_{veh} = 21.57$ kbit/s

2.2 Mobility Model of one Vehicle

An evaluation additionally requires a mobility model for one vehicle *v* traveling on the freeway. In this example, we will examine a freeway segment of 5 km length. The coverage area of each IGW is 2000 m with a coverage gap of 1000 m between the coverage areas of IGW1 and IGW2 as depicted in figure 1. When *v* enters the coverage area of IGW1, it is able to communicate with the Internet via relaying vehicles driving ahead. From the border of the coverage area, $(S_{geo} / 2) / (74 \text{ m/hop}) = 14$ hops are needed to communicate with the IGW, assuming that all lanes are equally used by vehicles. For simplicity reasons, this scenario distinguishes two cases. The first case represents a truck that drives smoothly on the right lane. In the second case a vehicle on the left lane is modeled, driving at higher speed and overtaking other vehicles.

2.2.1 Vehicle on the right lane

The traffic on the right lane is usually very smooth. The vehicles drive at an almost constant speed of 85 km/h. The reduction of the number of hops is dominated by the influence of approaching the IGW. If a faster vehicle on any of the other lanes forwards data packets of vehicle *v* in the direction of the IGW, it may occur that this vehicle leaves the radio transmission range of the slower vehicle on the right lane. Thus, the Internet access becomes temporarily unavailable for *v*, if no other vehicle is available to forward the data. This does not only interrupt the communication of *v* but also of all other vehicles that use *v* as a forwarding hop towards the IGW. For simplicity reasons, we assume that all lanes are equally used by communicating vehicles. Since the communication range of *v* is larger than the average distance between two communication vehicles, it is supposed that in most situations a communication path between *v* and the IGW exists. A reduction of the number of hops will occur every $74 \text{ m} / 85 \text{ km/h} \approx 3$ s. As already mentioned above, a vehicle needs 14 hops to communicate with the IGW from the border of the coverage area.

Figure 2 illustrates the behavior for the observed vehicle. At time t_0, the vehicle reaches the gateway's coverage area and is able to access the Internet. The number of hops is decremented periodically every 3 s until t_1, when the connection is lost for a short period of 1 s, because other communicating vehicles are not able to forward the data packets towards the IGW. This model only considers vehicles moving in the same direction to forward data packets, while vehicles in the oncoming traffic are neglected. At t_2, v communicates directly with the IGW. As long as the vehicle is located in the gateway's radio transmission diameter of $2 \cdot r = 200$ m, both delay and packet losses will be minimal. This period takes 200 m / 85 km/h ≈ 9 s. After that, the number of hops increases every 3 s. At t_3, the Internet access becomes unavailable again for 2 s, because the connection to a forwarding vehicle is lost. The next event occurs at time t_4, when v leaves the coverage area of the IGW after 14 hops and therefore no further communication is possible.

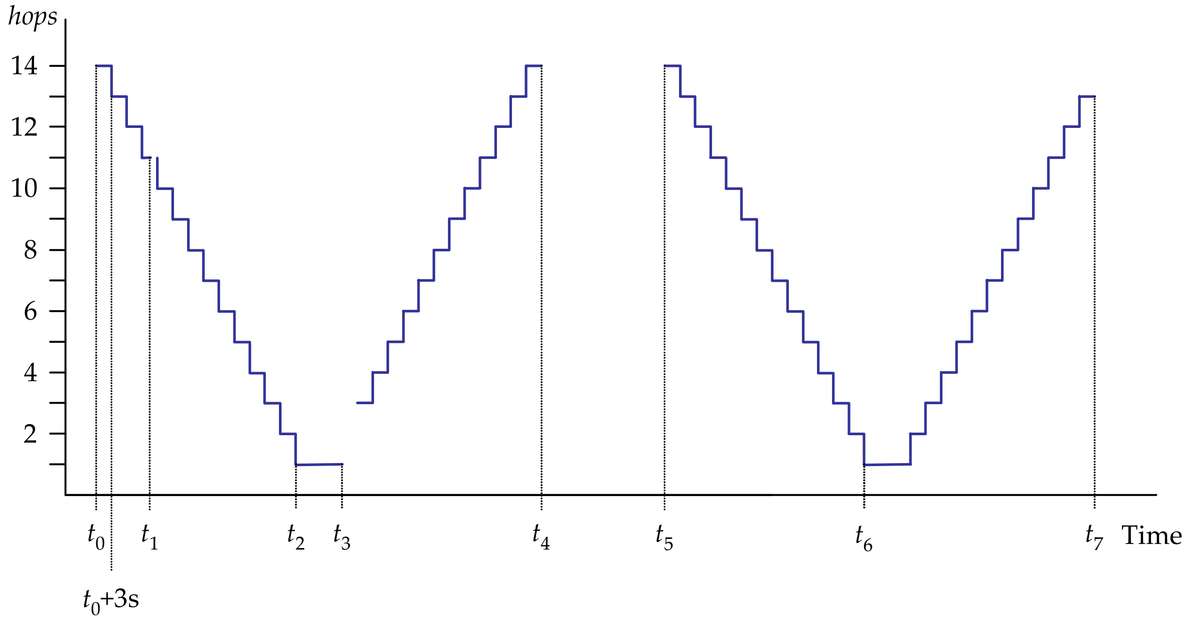

Figure 2: Effect of vehicle's movement on the number of hops (right lane)

The second IGW becomes accessible at t_5. Here, a similar behavior than at the first IGW can be observed: The distance to the IGW is decremented periodically every 3 s. At t_6, v drives into the direct radio transmission range of the second IGW and, thus, has again Internet access for a period of 9s. Finally, the connection to the second IGW is assumed to be lost at t_7, because no communication path to a following vehicle is available. The connection cannot be re-established until the examined vehicle leaves the coverage area of the second gateway.

2.2.2 Vehicle on the left lane

The second case of this scenario represents a vehicle *w* driving on the left lane of the freeway. Therefore, *w* drives at a much higher speed, which is assumed to be 120 km/h on average. A velocity of 100 km/h can be considered for vehicles on the middle lane, which corresponds to measurements in [7]. Hence, the duration of Internet access is much shorter than for vehicles on the right lane. Additionally, a vehicle on the left lane will overtake vehicles on other lanes. If the overtaken vehicle is used as next hop for the data packets, an additional reduction of the number of hops occurs. Similar to the vehicles on the right lane, it is assumed that *w* has rather continuous access to the Internet. The distance of the vehicle (in hops) to the IGW is decremented every 74 m / 120 km/h ≈ 2.2 s. Actually, this period will vary between 3 s and 2.2 s, because vehicles on other lanes will be used to forward IP packets. In this example we assume a reduction every 2.5 s for simplicity reasons. Again, only vehicles moving in the same direction forward data packets towards the IGW.

The reduction period will be shorter if the vehicle overtakes its "forwarding" vehicle. To simplify matters, only overtaking maneuvers of *w* are considered. Assuming the distance to the next-hop-vehicle to be 74 m when selecting it, the overtaking maneuver will take 74 m / (120 – 100) km/h ≈ 13.3 s, if this vehicles drives on the middle lane and 74 m / (120 – 85) km/h ≈ 7.6 s if it is located on the right lane due to the higher speed difference

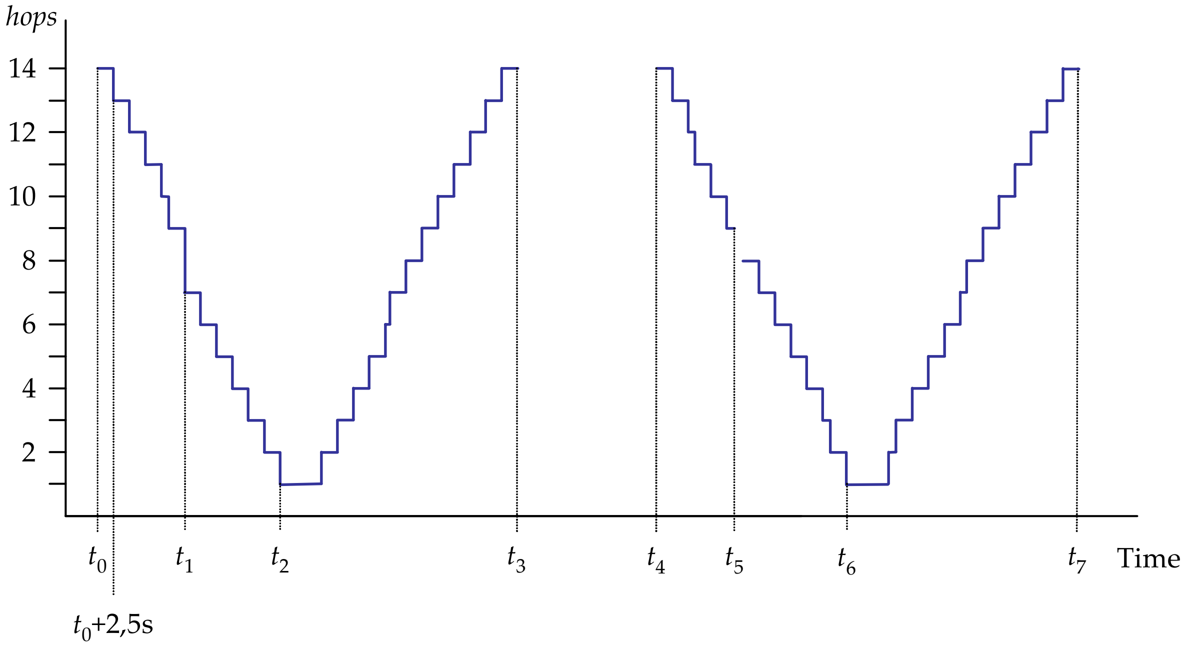

Figure 3: Effect of vehicle's movement on the number of hops (left lane)

The distance (in hops) between *w* and the IGW against the time is shown in figure 3. It can be assumed that the change of the number of hops is quite irregular due to the overtaking maneuvers. At t_0 the vehicle enters the coverage area of the first IGW, and the IP packets from *w* pass 14 hops to the IGW. The number of hops is reduced every 2.5 s while approaching the gateway. At t_1 the number of hops is decremented by two, because an assumed overtaking maneuver overlaps the reduction. At t_2, *w* reaches the transmission range of the first IGW. It can directly communicate with the IGW for a period of 200 m / 120 km/h ≈ 6s. Afterwards, the number of hops increases again when leaving the radio transmission range. From now on, following vehicles forward the IP packets of *w*. At t_3, *w* reaches the border of the IGW's coverage area and, thus, becomes disconnected from the Internet. At time t_4, the procedure starts anew like at the first IGW. The next event occurs at t_5, where the connection will be lost for 1s, because no other communicating vehicle is within reach during this period. Direct communication to the gateway gets possible at time t_6. This period lasts 6 s as derived above. Afterwards, the number of hops increases until t_7. Here, the geographical distance between the second IGW and vehicle exceeds 1000 m and *w* leaves and becomes disconnected from the Internet.

3 Congested Freeway

Another typical situation on a freeway is a congestion. Figure 4 depicts a congested freeway, which consists of three lanes per direction. The situation can be characterized by the following assumptions:

- The congestion on the freeway occurs in one direction.
- The vehicles on the congested freeway do not move. Hence, the structure of the inter-vehicle ad hoc network does not change over time and connections to the IGW remain over a long period. Furthermore, the transmission characteristics do not change.
- The Internet access is provided by a single IGW. Therefore, all communicating vehicles have to share the bandwidth of this gateway.

Like in the previous model, the average length of a vehicle l_{veh} on a German freeway is 5.3 m and the average distance Δx between two consecutive vehicles is 2 m [5]. The diameter of the IGW's geographical coverage area S_{geo} is reduced to 800 m, which is rather short compared to the other freeway scenario. However, this configuration proved as suitable as derived below. In addition, the radio transmission range *r* is reduced to 50 m in order to minimize the interference in the IVC caused by the higher traffic density. The remaining micro mobility parameters are chosen like in the previous scenario: bw_{net} = 588 kbit/s, $delay$ = 40ms per link with a jitter of ±20%, err = 3.9%, and a penetration of 15%.

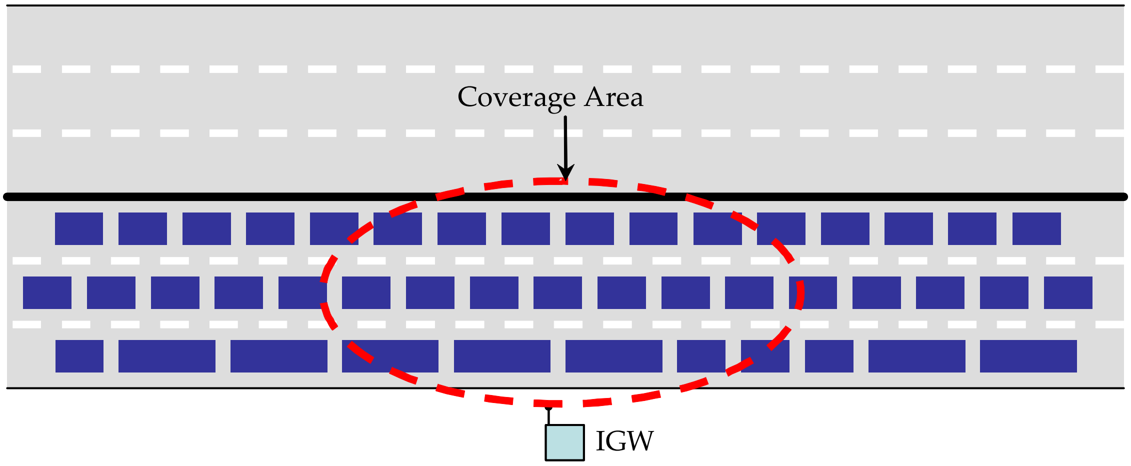

Figure 4: A Congested Freeway

3.1 Macro Mobility Observations

Based on these values, we can determine the macro mobility statistics as known from the previous scenario. According to [7], congestion occurs if the traffic density per lane ρ reaches a maximum $\rho_{max} \approx 140$ vehicles/km per lane. This value agrees with the assumption for Δx. In this model, the congestion covers all three lanes of the freeway. Hence, the total number of communicating vehicles located in the coverage area of the IGW is $n_{veh} = S_{geo} \cdot 3$ lanes · 140 vehicles/km · 15% ≈ 50 vehicles, which have to share the available of this IGW. Based on this value and the assumption that all of those vehicles are equally distributed over the coverage area of the IGW, it is feasible to find out the average distance between to neighbored communicating vehicles. This distance is S_{geo} / 50 vehicles = 16 m. Out of this it follows, that on average there are $(2 \cdot r)$ / 16 m ≈ 6.3 communicating vehicles within the radio transmission diameter of a communicating vehicle. This justifies, the reduction of the transmission range to 50 m and the reduction of S_{geo} as mentioned above. Otherwise, the number of vehicles that share the IGW simultaneously would be significantly higher. Moreover, a higher number of IP packet duplicates would appear because of the vehicles in the immediate communication range would increase as well.

Since FleetNet uses a location-based routing protocol, this protocol may cause duplicate IP packets when forwarding IP packets over several hops. This duplication cannot be modeled exactly, because it basically depends on the routing protocol being deployed. In this example, we assume a duplication rate of $dup = 2\%$ per link. The total duplication rate is, thus, determined by $dup(hops) = 1 - (1 - dup)^{hops} = 1 - 0.98^{hops}$.

Again, the overhead for the discovery of the gateway reduces the available net bandwidth. In this model, the overhead sums up to 12.848 kbit/s [9]. Like in the previous example, we assume that all vehicles access the Internet simultaneously. Thus, the available bandwidth bw per vehicle is:

$bw = (bw_{net} - \text{overhead}) / n_{veh} = 11.503$ kbit/s

3.2 Mobility Model for one Vehicle

In contrast to the previous scenario, vehicles do not move in a congestion. Therefore, the network topology is static and does not change over time. The individual transmission delay and link quality depends on the position of a vehicle within the congestion. Hence, this communication model considers the data transmissions of vehicles at different distances to the IGW.

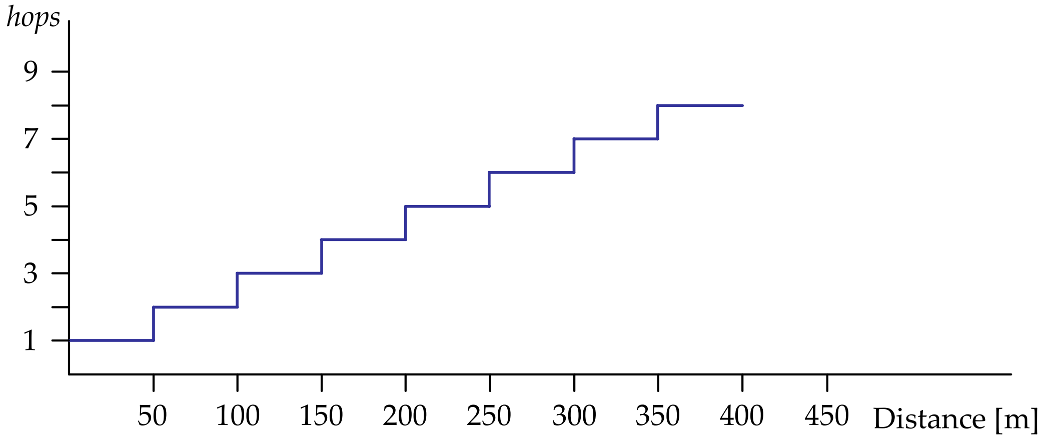

Figure 5: Idealized distance against the vehicle's position

Our model represents a freeway segment of 2 km length. Figure 5 shows the dependency of the number of hops against the distance of a vehicle to the IGW. The representation in figure 5 is idealized and assumes that all vehicles are distributed equally in the coverage area of the IGW. Additionally, it is considered only the situation when a data packet is always forwarded to the vehicle in the radio transmission range that is closest to the IGW. In the worst case, a vehicle at the border of the coverage area needs S_{geo} / 16 m = 25 hops to communicate with the IGW when all vehicles are distributed equally. In this case, the vehicle will suffer from a packet error rate of 22.22% and an average packet delay of 1 s.

4 Performance Evaluation

In order to evaluate communication in the proposed road scenarios, we connected three Linux-based hosts as illustrated in figure 6. The IP traffic between ‘sender’ and ‘receiver’ is routed via host ‘nistnet’. On this router, we installed the NISTNet network emulator [10] to emulate the necessary network characteristics such as bandwidth, delay, jitter, packet drops, and duplications. NISTNet implements a statistical network emulator, i.e. jitter, packet losses and duplicates occur statistically. Hence, several measurements under identical emulations typically generate different results. The measurements themselves were performed with a maximum transfer unit of 1500 byte. In order to emulate the time-variant communication characteristics for the two road scenarios, we controlled NISTNet by a shell script that reconfigures the network characteristics over time.

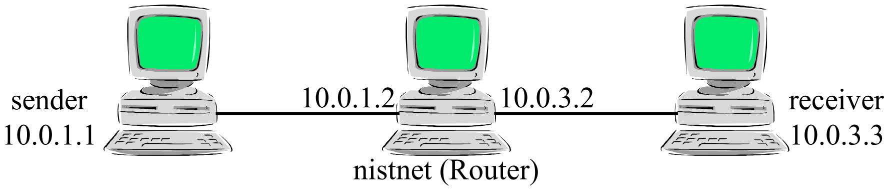

Figure 6: Testbed configuration

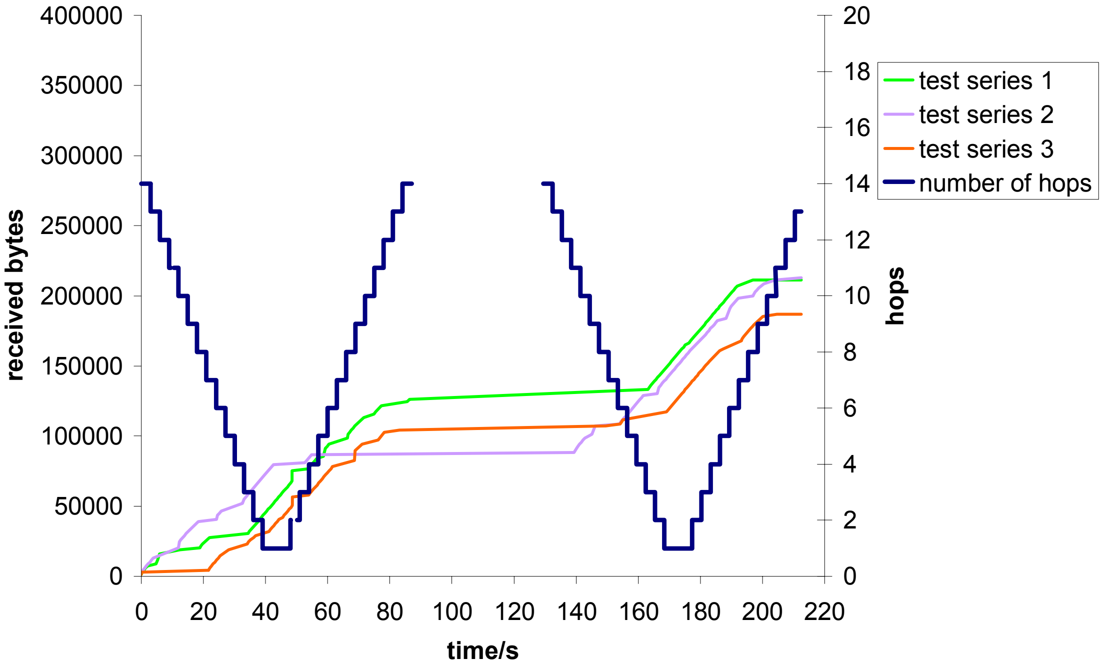

Figure 7: TCP throughput (right lane of freeway)

4.1 TCP Performance

In the first measurement, we tried to analyze the throughput of TCP in the two scenarios. For each scenario, we ran three test series with the same set of parameters. Figure 7 shows the results of three test series for a vehicle moving on the right lane of the freeway. Additionally, we show the vehicle's distance (in hops) to the IGW in the graph to illustrate the dependencies of the TCP throughput on the number of hops between vehicle and IGW.

As described in section 2, the vehicle passed two IGWs whose coverage areas did not overlap. It can be seen that during the phase of approaching the first gateway only very few packets were received. This is due to the faster changes in the network conditions and the high packet loss rates of up to 42.704% at higher distances to the IGW. Moreover, the TCP throughput varied heavily in this segment. After the vehicle reached the coverage area of the second IGW at 129.4 s, it took on average about 15.96 s until TCP continued its transmission. The differences between the three test series can be explained by statistical deviations used in NISTNet. Altogether, the average measured data rate of a vehicle moving on the right lane of the modeled freeway was $T_{mean,right}$ = 1629.483 kbit / 212.4 s = 7.672 kbit/s.

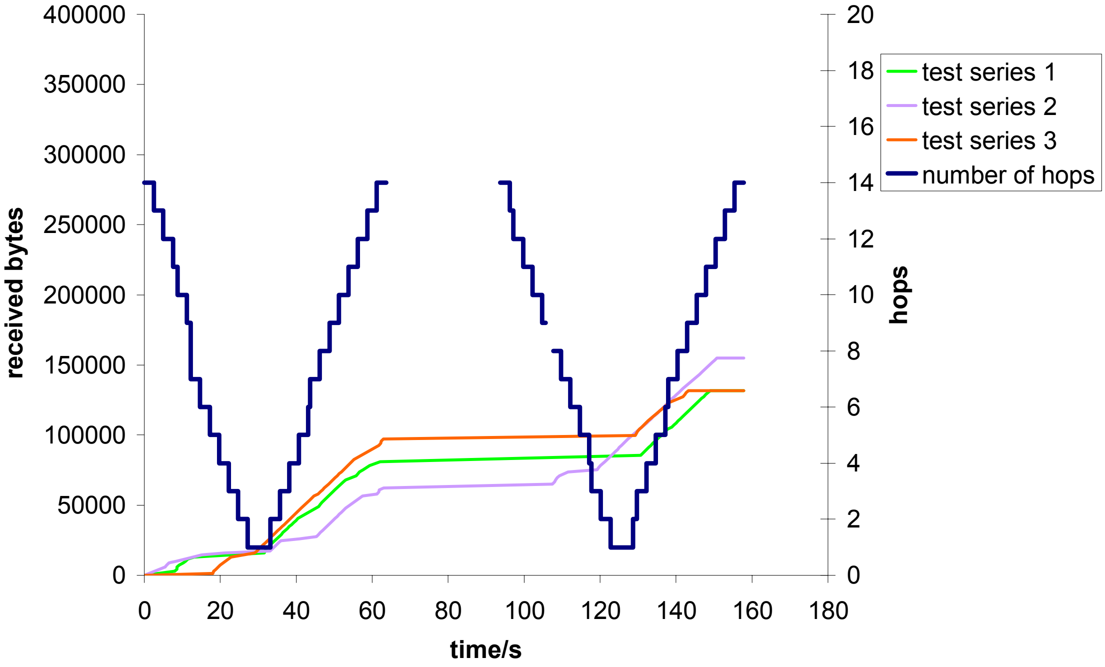

Figure 8: TCP throughput (left lane of freeway)

The results of the vehicle on the left lane are depicted in figure 8. The curve progression is quite similar to the results of the right lane. Again, only very few packets were received after the first IGW became accessible. After the vehicle discovered the second gateway, it took on average 28.8 s until new IP packets arrived at the IGW. This period was significantly longer than on the right lane due to faster changes in the network conditions and the interruption of the connection between 105.7 s and 107.7 s. However, the measured average data rate for a vehicle on the left lane is only slightly lower than on the right lane: $T_{mean,left}$ = 1115.925 kbit / 157.9 s = 7.067 kbit/s.

The congestion scenario lacks on any mobility that might affect the network conditions. Hence, we analyzed the TCP throughput of vehicles at different distances (in hops) to the IGW. The graph in figure 9 shows the results for vehicles at distances from one hop to ten hops. It is expected that the higher the number of hops between IGW and vehicle the lower the amount of data that arrives at the receiver within the same period of time. Except for some test series, figure 9 shows this behavior. The deviations might be a consequence of the statistical determination of the packet loss rate and the delay in the NISTNet network emulator. Obviously, a vehicle's throughput depends strongly only its distance (in hops) to the IGW in a congestion. The difference of the throughput amounts to approximately 5.148 kbit/s when comparing the throughput of a vehicle that has direct access to the IGW and a vehicle at a distance of ten hops. The curve progression is very unsteady. The high packet loss rate and delay especially at higher distances (in hops), become clear by the sharp curve progressions.

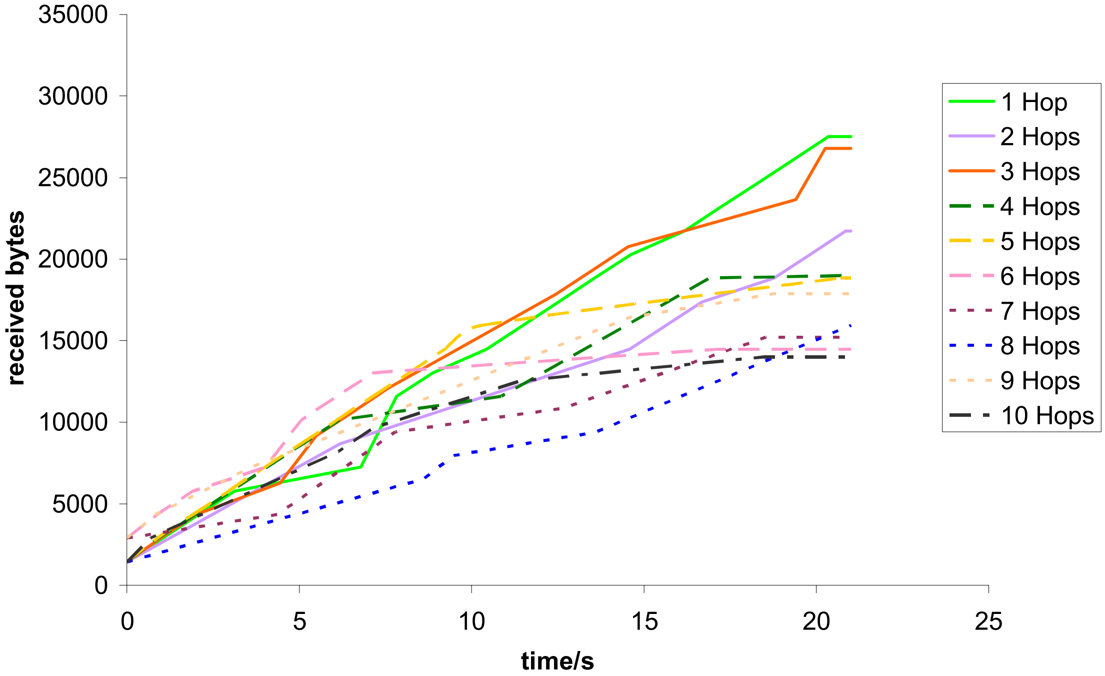

Figure 9: TCP throughput (congestion)

The average throughputs for vehicles that need a specific number of hops are summarized in table 1.

# Hops	Overall throughput [kbit/s]
1	10.480
2	8.274
3	10.205
4	7.238
5	7.171
6	5.516
7	5.792
8	6.803
9	6.068
10	5.332

Table 1: Measured TCP throughputs (congestion)

4.2 Performance of a typical Internet Application

Besides the analysis of the TCP throughput, we also examined the performance of a typical Internet application. According to [11], the main part of the Internet traffic is caused by the Hypertext Transfer Protocol (HTTP), which is used by World Wide Web (WWW) applications. Hence, we measured the times for transferring a web page between a vehicle and the IGW. For that, the ‘receiver’ ran a web server and a web browser on ‘sender’ requested web pages from this server. Of course, the WWW contains manifold web pages whose structure and characteristics may differ significantly. Web pages may, e.g., contain pictures of various sizes or animations that affect the time needed to fetch a page from the server. We therefore compared three web pages of different size and characteristics. The small web page contained only text and no further embedded objects like pictures. The size of the HTML file was 2.89 kbyte. The medium web page embedded five pictures and had a total size for all objects of 47.5 kbyte. Finally, the large web page was structured by several frames. In addition, 14 pictures were embedded. Thus, the total size of this page was 86.8 kbyte.

The load times for a vehicle on the right lane of a freeway are depicted in figure 10. Obviously, the measured time periods for downloading a web page depend clearly on its characteristics and size. The figure illustrates two kinds of measurements. They where taken while the vehicle approaches the IGW and moves away from it respectively. Again, the distance (in hops) of the vehicle against the time is shown as well.

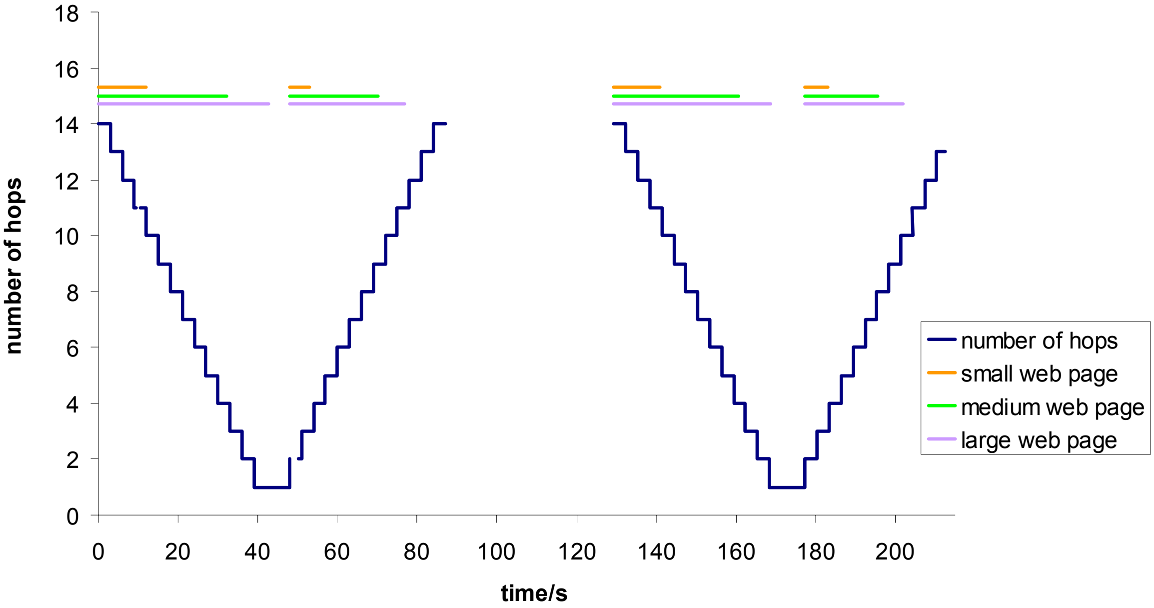

Figure 10: Load times (freeway right lane)

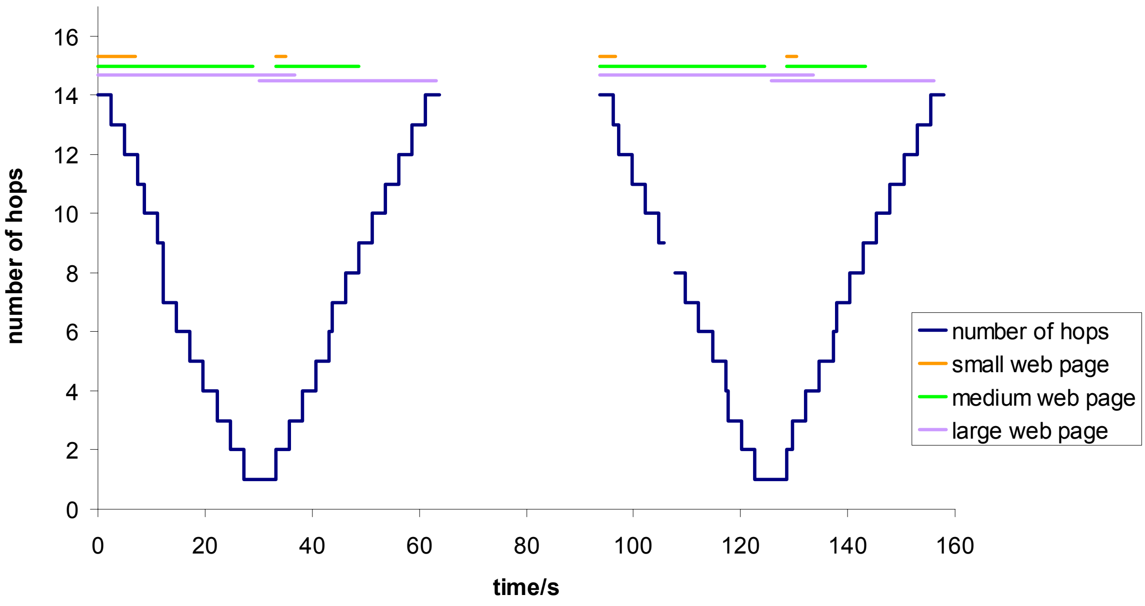

Figure 11: Load Times (freeway left lane)

The download of the small web page took on average 11.782 s while approaching to the IGW. Medium-sized web pages required a time period of 32.286 s at the first and 31.138 s at the second IGW. For the large page, 42.588 s and 39.369 s were needed respectively to fetch the page from ‘receiver’. This way, it was not possible to load the large website completely before the vehicle has direct access to the IGW. When a vehicle passed the gateway and moves away from it, the measured load times were much shorter due to the better conditions when the page was requested. Fetching the small page took 4.926 s at the first IGW and 5.809 s at the second IGW. The delivery of the medium-sized web page lasted 22.082 s and 18.212 s respectively. The large web page required a time period between 24.499 s and 28.719 s. As a result, only two web pages similar to the large test page could be fetched from a web server while the vehicle had access to the IGW.

The measured load times for a vehicle on the left lane are slightly lower than on the right lane. Figure 11 shows the results. While approaching the IGW it took between 2.832 s and 7.015 s to fetch the small web page. For the medium-sized page, 28.877 s and 30.798 s were needed respectively. Downloading the large page lasted 38.333 s on average. When the vehicle moved away from the IGW, loading the small page took about 1.8845 s. The delivery of the medium-size page took between 14.483 s and 15.425 s.

As shown in figure 11, the load time measurement of the large web pages when moving away from the IGW started earlier than the other measurements, because its was not possible to fetch the page from 'receiver' until the vehicle became disconnected form the IGW. This is owing to the faster speed of the vehicle on the left lane compared to the vehicle on the right lane. Nevertheless, the load times amounted to 35.022 s at the first IGW and 33.310 s at the second IGW.

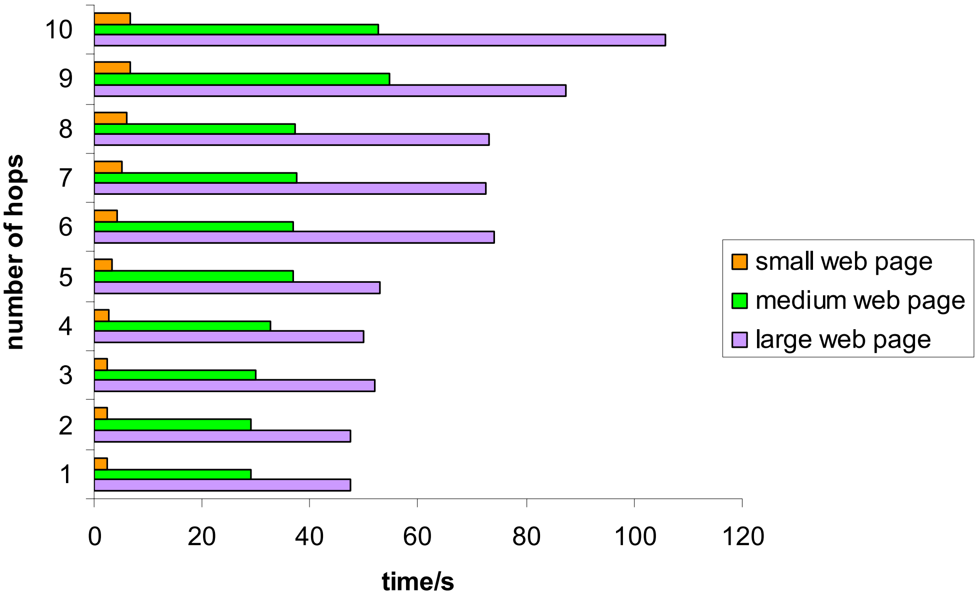

Figure 12: Load Times (congested freeway)

The WWW performance in the congestion scenario is again determined by the distance of the vehicle (in hops) to the IGW. The bar chart in figure 12 presents the results. As expected, the time needed to fetch a web page from the web server decreases with a lower distance (in hops) to the IGW. The results clearly show that vehicles at a high distance to the IGW suffer from high download times due to high delays and many packet losses. The download of the large web page took 105.73 s on average at a distance of ten hops, while the whole page was downloaded by the vehicle within a period of 47.306 s when the vehicle had direct access to the IGW. Thus, the delivery of the web pages to a vehicle at a distance of ten hops to the gateway took more than twice as long as to a vehicle that was able to communicate with the IGW directly. The medium-sized web page was loaded after 52.588 s at a distance of ten hops and 29.011 s at a distance of one hop respectively. The small page needed 6.67 s and 2.285 s at these distances.

5 Conclusions

The communication characteristics of vehicular ad hoc networks are completely different compared to wireless and wired local area networks. They not only depend on the mobility but also on the traffic scenario. In this paper, we introduce two time-variant communication models of “typical” freeway scenarios: the left and right lane of a freeway with a high traffic flow, and a congested freeway. We used these models to evaluate the performance of Internet access via gateways along the road. The results of the measurements shows that the performance of the inter-vehicle communication system depends strongly on the number of vehicles using the services of a gateway simultaneously. Another important factor is the distance (in hops) between a vehicle and the gateway. Especially the results of the congestion scenario show the dependency between the distance and the communication performance from a vehicle to the gateway. Moreover, disconnections from the Internet have a high impact on the TCP throughput, which is illustrated in the results of the freeway with a high traffic flow scenario: Particularly after the vehicle reconnects to the second IGW, it takes a long period of time until TCP continues the transmission of data packets.

Further work will include the emulation of more road traffic scenarios. Additionally, possible options to improve the performance of Internet access in these scenarios might be examined. Especially the reaction of TCP to packet losses on the communication path to the IGW and its behavior after a vehicle reconnects to an IGW needs to be adjusted in order to improve the utilization of the available resources from the inter-vehicle communication system.

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