Simulation and Evaluation of Typical Road Telematics Scenarios

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***Abstract*—Besides typical road applications, inter-vehicle communication systems can be also used for Internet access. 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 network model of the inter-vehicle communication system is necessary. In this paper, we propose the emulation of such a network model for two "typical" road communication scenarios. Based on these models, we evaluate the performance of TCP and a web application in the scenarios.**

***Index terms*—Vehicular Ad Hoc Networking, Modeling.**

I. INTRODUCTION

Communication in vehicular environments becomes more and more important for the future development in the automotive domain. An example is FleetNet, which aims at the development and promotion of an inter-vehicular communication (IVC) system [1]. The FleetNet IVC system is based on ad hoc radio networks enabling multi-hop communication between vehicles using intermediate vehicles as relaying nodes. The IVC system can also be used to communicate with hosts in the Internet using Internet gateways (IGWs) installed on the roadside. The communication protocols used for the Internet integration of the vehicular ad hoc network are described in [2].

However, the evaluation of an Internet integration approach requires the simulation of IVC network characteristics in typical situations on the road. In this paper, we examine two typical road scenarios: a crossway in a city, and a freeway at night. We therefore studied the typical behavior of vehicles and derived a time variant network model for the Internet access. Such a model can be easily simulated with existing tools allowing for an evaluation of the performance of transport protocols like TCP in such scenarios.

In the remaining paper, sct. II and III describe the two models, which are evaluated in sct. IV. We do not discuss any related work, because it basically observes mobility patterns and their simulation. Finally, sct. V concludes the paper.

II. CROSSWAY SCENARIO

Our modeled crossway combines four street segments as illustrated in fig. 1. A traffic light controls the traffic flow for each street segment. The IGW for Internet access is installed on one corner of the crossway. While the traffic lights are red, the "red phase," the vehicles on the respective street segment do not move. If the light switches to green, the "green phase," the vehicles will start moving to pass the crossway. This scenario has the following characteristics and assumptions:

1. During the red phase, there is no movement of the vehicles on one street segment.
2. The movement of vehicles during the green phase is very smooth. Vehicles drive at low speeds and typically do not overtake each other. Hence, the reconfiguration rate of the IVC system is rather low.
3. Internet access is provided by only one IGW, which covers the whole crossway. Hence, all vehicles have to share the available bandwidth of the IGW. When leaving the coverage area, the vehicles will not perform a handoff.

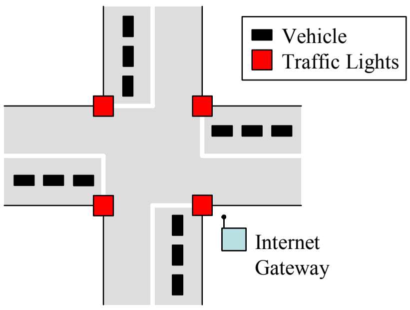

Fig. 1. Crossway scenario

The traffic in a city mainly consists of cars and small busses with an average length l = 4.5 m and an average distance D_x between two vehicles of 2 m [3]. For simplicity reasons, this scenario assumes that all vehicles on the street segment start to move at the same time when the traffic light switches to green. The diameter of the IGW's coverage area S_{geo} indicates the area in which the IGW can be used by vehicles via multi-hop communication. In this example, we chose $S_{geo} = 800$ m with a radio transmission range of 100 m. Notice that the radio transmission range depends on the number of vehicles taking part in the IVC system. The penetration rate of communicating vehicles was assumed with 8 %. In order to model the inter-vehicle communication, we used parameters from the link layer performance of FleetNet [4] with a max. net link layer bandwidth of 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 (worst case) with an assumed delay of ±10 %. In FleetNet, the frame error rate of the data link layer can be supposed to be 10^{-4}, resulting in an IP packet error rate of up to $err = 390 \cdot 10^{-4} = 3.9$ % per link. With these assumptions, the IP packet loss probability against the #hops a vehicle is away from the IGW is

$$loss(hops) = 1 - (1 - err)^{hops} = 1 - 0.961^{hops}$$

A. Macro Mobility Observations

With the help of these micro mobility parameters, it is possible to derive some macro mobility statistics. An important parameter is the traffic density, which is $\rho = 1/(l + D_x) = 154$ veh./km per lane. As the traffic lights are typically green for two street segments at the same time, we can assume six lanes to be used by vehicles at the same time. With the assumed penetration of 8 %, the total number of communicating vehicles in the coverage area of the IGW is $n_{veh} = (S_{geo}/2) \cdot 6 \text{ lanes} \cdot \rho \cdot 8\ \% = 30$ veh.

If we assume an equal distribution of the vehicles in this area, there are five communicating vehicles on each lane, and the average distance between these vehicles is 400 m/5 hops = 80 m. Hence, the transmission range of 100 m is enough to make inter-vehicle communication possible.

Another important parameter is the (estimated) available bandwidth for the Internet access. For simplification reasons, we assume that all vehicles access the Internet at the same time and do not communicate locally except for the forwarding of IP traffic in the direction of the IGW. Because of these preconditions, the available bandwidth is basically determined by the last hop to the IGW, because all vehicles have to share this hop for Internet access. A small share of the available net bandwidth is needed for the overhead caused by the service discovery protocol to identify the IGW in S_{geo} [5]. The IGW sends 2 advertisements/s, which are forwarded by all communicating vehicles within the coverage area of the IGW. As a result, the overhead caused by the service discovery protocol is 14.96 kbit/s [5].

Based on this parameter, it is possible to determine the available bandwidth *bw* per vehicle, if all vehicles access the Internet simultaneously (assuming a fair sharing of *bw* among the vehicles):

$$bw = (link\ bw - \text{overhead}) / \#\text{veh.} = 19.1 \text{ kbit/s}$$

B. Movement of one Vehicle

An evaluation additionally requires a mobility model for one vehicle *v* passing the crossway. At first, *v* will receive the service advertisements of the IGW when entering the IGW's coverage area. After that, *v* is able to communicate with the Internet via vehicles driving ahead. As mentioned above, the initial distance between the IGW and a vehicle at the border of the coverage area is 5 hops. For simplicity reasons, this scenario supposes that IP traffic is only forwarded by vehicles on the same direction and not by vehicles on the oncoming lane. This way, the initial transmission delay for *v* is $5 \cdot 40$ ms = 200 ms with a jitter of ±10 %. If the traffic lights switch to green, the vehicles start up and pass slowly the traffic lights. Thereby, the average speed of the vehicles is supposed to be 15 km/h.

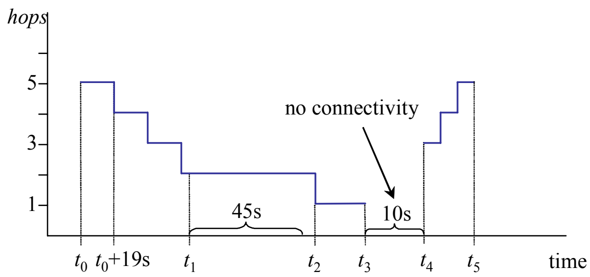

Fig. 2. Model of vehicular movement

While *v* approaches the IGW, the number of hops will be decremented every 80 m, i.e. after 80 m/15 km/h ≈ 19 s, as illustrated in fig. 2. At t_1, the traffic light switches to red. Hence, the vehicles do not move the next 45 s. After the movement continued, *v* enters the IGW's radio transmission range at t_2 and passes the crossway at t_3. Therefore, it speeds up to 30 km/h, i.e. *v* is 36 s in the radio transmission range of the IGW. Afterwards, *v* looses the connection to the IGW, because we assume that the succeeding communicating vehicle turns off and comes out of *v*'s transmission range. Hence, communication will not be possible for 10 s. At t_4, other following vehicles move into the radio transmission range of the examined vehicle and again provide access to the Internet by forwarding data packets in the direction of the IGW. Finally, the connection is lost after 5 hops at t_5, when the vehicle leaves S_{geo}.

III. Freeway at Night

The second scenario represents an almost empty freeway at night. Fig. 3 depicts such a freeway, which consists of three lanes per direction. Internet access is provided by three Internet Gateways IGW1, IGW2, and IGW3. The basic characteristics and assumptions for this scenario are:

- Due to the low traffic density, vehicles are traveling at high speeds. Hence, the connection to an IGW is of short-term nature.
- The distance between IGW1 and IGW2 is larger than the diameter of the IGW's coverage area. For this reason, no communication is possible in a small area between these IGWs.
- The radio transmission areas of IGW2 and IGW3 overlap each other. Hence, a handoff is required to continue communications.

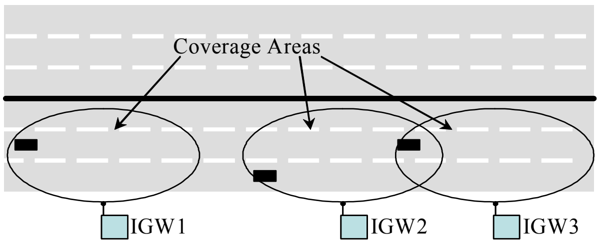

Fig. 3. A freeway at night

At night, the freeway will be likely used by cars or small busses. Hence, the average length of these vehicles is $l = 4.5$ m [3]. Due to the sparse traffic, the distance D_x between two neighbored vehicles is assumed with 333 m. The diameter S_{geo} of the coverage area of an IGW is supposed to be 2000 m, which is in accordance to the max. radio transmission range of 1000 m in FleetNet [4]. As only few vehicles are traveling on the freeway, the radio transmission range r of the vehicles is also set to this max. value of 1000 m. The penetration rate p of communicating vehicles is likely higher than in the crossway scenario, because there might be more of better-equipped cars and trucks on the freeway. We therefore assume a penetration of 15 % to be suitable.

Like in the crossway scenario, there will be an available net bandwidth of 588 kbit/s and a transmission delay of 40 ms per link. The packet error rate in this scenario varies while the vehicle passes the coverage areas of the IGWs. This is due to the fact that the error rate depends on the distance to the IGW and the radio wave propagation. In order to determine the exact packet error rate, propagation models and the data coding have to be considered. However, this scenario assumes a constant packet error rate of 3,9 % for simplicity reasons. Thus, the overall loss probability depending on the number of hops is determined by $loss(hops) = 1 - 0.961^{hops}$.

The jitter is assumed to be lower as compared to the crossway scenario, because a vehicle always has direct access when communicating with the IGW and do not need to forward any data packets of other vehicles. Hence, a jitter of ±5 % seems to be a suitable value.

A. Macro Mobility Observations

Based on these micro mobility parameters, it is possible to derive some macro mobility statistics. In this example, the traffic density per lane is assumed to be $\rho = 1$ veh./km, which reflects the sparse utilization of the freeway. With $S_{geo} = 2000$ m, the total number of communicating vehicles within the coverage area of one IGW is determined by

$$n_{veh} = S_{geo} \cdot 3 \text{ lanes} \cdot \rho \cdot 15\,\% = 0.9 \text{ veh.}$$

Hence, there is no more than one communicating vehicle driving through the coverage area of an IGW. This way, each vehicle has the full available bandwidth while connected to an IGW. The bandwidth is slightly reduced by the service discovery protocol for the IGW. Like in the crossway scenario we assume a frequency of two advertisements per second, resulting in an overhead of 3.52 kbit/s [5]. Hence, the average available bandwidth for a vehicle traveling through the coverage area of IGW1 is given by

$$bw = net\ bw - overhead = 584.48 \text{ kbit/s}$$

This value is only valid for vehicles traveling in the transmission range of a single IGW. However, there is also a small area between IGW2 and IGW3 where a vehicle has direct access to both gateways. Although a vehicle can only have a connection to one of the IGW's, service advertisements from both need to be forwarded. Hence, the available bandwidth for this area is:

$$bw_{2\text{-}3} = net\ bw - 2 \cdot overhead = 580.96 \text{ kbit/s}$$

Because of having no other communicating vehicles within the transmission range of a vehicle, communication with an IGW is only possible if this gateway can be accessed directly. This is why the number of hops and therefore the delay for a connection is always constant as long as the IGW is available. This way, duplicates can be neglected as no inter-vehicle communication takes place.

B. Mobility Model for one Vehicle

On an empty freeway, drivers are able to travel at high speeds. According to [7], the average speed of vehicles at low traffic density is 150 km/h. Based on the observations in the previous section, fig. 4 shows the variation of the number of hops against the time for a vehicle v passing the three IGWs.

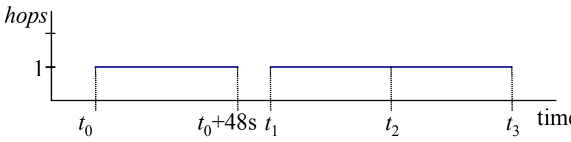

Fig. 4. Vehicular Movement on a freeway at night

In this scenario, we assume a freeway segment of 6 km. The distance between IGW1 and IGW2 is supposed to be 2500 m. Thus, the coverage areas of both gateways are separated. The distance between IGW2 and IGW3 is 1500 m, which means, that the transmission ranges of the gateways overlap each other for a distance of 500 m.

IGW1 gets accessible at time t_0. v will be able to communicate with this gateway over a distance of 2000 m, which corresponds to $2r$. At a speed of 150 km/h, the connection to this gateway will be lost after 2000 m / 150 km/h = 48 s. At time t_0+48s there is no other IGW available and no further communication is possible for v. For simplicity reasons, the possibility of using the oncoming traffic to get access to an IGW is neglected.

The next event occurs at t_1 when v enters the transmission range of IGW2. As the transmission areas of IGW2 and IGW3 overlap each other, the connection of v with the second IGW can be handed off to IGW3. In FleetNet, this handoff is realized with a modified Mobile IP [2]. According to [8], the handoff latency can be assumed as $t_{HO\text{-}lat}$ = 24 ms. In this time, we assume that no communication will be possible due to the hard handoff. This corresponds to the assumption that during the handoff procedure v first releases the connection to IGW2 and afterwards connects to IGW3 including the location update of its Home Agent. Afterwards, v will be able to continue its communications. In this example, the handoff occurs at t_2. At this time, v is located in the middle of both IGWs. When it leaves the transmission range of IGW3 at t_3, the connection breaks down.

IV. Performance Evaluation

In order to evaluate communication in the proposed road scenarios, we connected three Linux-based hosts as illustrated in fig. 5. The IP traffic between 'sender' and 'receiver' is routed via host 'nistnet'. On this router, we installed NISTNet [9] to emulate the necessary network characteristics such as bandwidth, delay, jitter, packet drops, and duplications. 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 emulator over time.

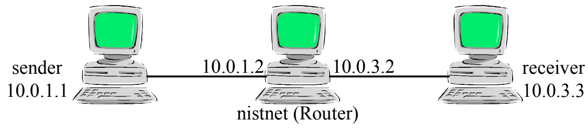

Fig. 5. Testbed configuration

A. TCP Performance

In the first measurement, we tried to find out the throughput of TCP in the two scenarios. We ran our tests for three times, which is marked by 'test series' 1 to 3. Fig. 6 shows the results of the three measurements for the crossway scenario. Additionally, we plotted the number of hops in the graph to illustrate the dependencies on the number of hops between vehicle and IGW. Especially in the beginning when the hops decrease, the TCP throughput varies heavily. However, between 50 s and 150 s the curve progression is quite smooth, although we used a jitter of ±10 % and an IP packet error rate of 3.9 % (cf. sct. II). Another important observation is the difference between the three measurements, which can be explained by the statistical deviations used in NISTNet. Especially in the beginning, the throughput performance differs significantly between the three measurements.

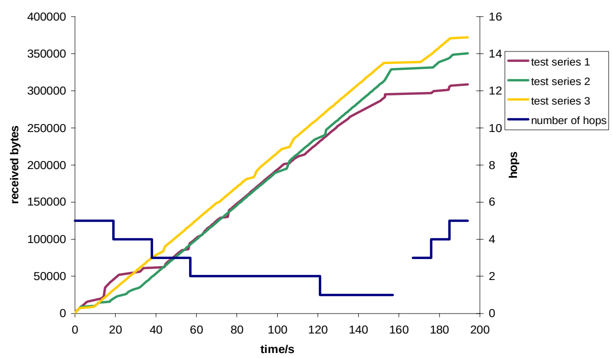

Fig. 6. TCP throughput (crossway)

As described in sct. II, the IGW is not available between 157 s and 167 s. After the reconnection to the IGW, it takes about 9.5 s until TCP continues its transmission. Altogether, the average throughput T_{mean} in this scenario is

$$T_{mean} = 2749.269 \text{ kbit/s} / 194 \text{ s} = 14.171 \text{ kbit/s}$$

Compared to the crossway scenario, the curve progression in the freeway scenario is much smoother (cf. fig. 7). In addition, there are fewer divergences between the three test series. This effect can be explained with the steady conditions in this scenario, which only models communication over one hop distance. Another interesting observation in this scenario is that the effect of the handoff between IGW2 and IGW3 has a minor impact to the TCP throughput. The overall measured average throughput for this scenario is

$$T_{mean} = 40914.688 \text{ kbit/s} / 156 \text{ s} = 262.233 \text{ kbit/s}$$

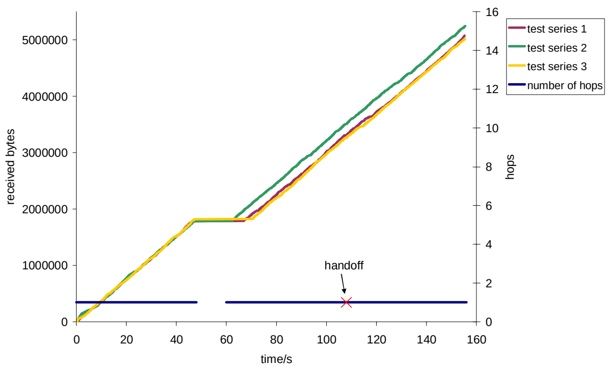

Fig. 7. TCP throughput (freeway)

B. Performance of a Typical Internet Application

In addition to the TCP throughput, we measured the times for transferring a web page from ‘receiver’ to ‘sender’. We therefore compared three web pages of different size: small (2.98 kbyte, text-only), medium (47.5 kbyte, text and some pictures), and large (86.6 kbyte, more pictures and frames).

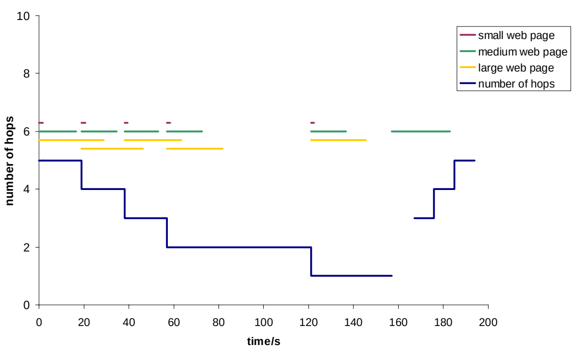

Fig. 8. Load times (crossway)

Fig. 8 depicts the load times in the crossway scenario for the different hops a vehicle is away from the IGW. On average, the download of a small web page takes 1.48 s. Medium-sized web pages require a time period between 15.28 s and 16.5 s, whereas it takes between 24.49 s and 28.85 s to download a large page from ‘receiver’. When the vehicle reconnects to the IGW after 167 s, it was not possible to download the large web page before it left the IGW’s coverage area.

In the freeway scenario, the time to download a web page is very short compared to the crossway scenario. The small web page was loaded after 0.18 s, the medium-sized page took 0.81 s, and the large page needed 1.56 s for the download.

V. CONCLUSIONS

The communication characteristics of vehicular ad hoc networks are completely different compared to wireless and wire-bound local area networks. The characteristics not only depend on the mobility of the vehicles, but also on the scenario. In this paper, we introduce two time-variant emulation models of “typical” scenarios: communication at a crossway, and communication on a freeway at night. We used these models to evaluate the performance of Internet access. The crossway scenario showed that the number of hops between vehicles and gateway and the reconnection process affects the TCP throughput. In the freeway scenario, communication was more consistent; even a handoff only has a minor impact on TCP. Further work will include the emulation of more road scenarios as well as possible options to improve communication performance in these scenarios.

VI. REFERENCES

[1] W. Franz et al., “FleetNet – Internet on the Road,” in *Proc. 8th World Congress on ITS*, Sydney, October 2001.

[2] M. Bechler et al., “Internet Integration in FleetNet,” in *Proc. 13. KiVS*, Leipzig, April 2003

[3] G. Hoffmann et al., “Beschreibung von Verkehrsabläufen an signalisierten Knotenpunkten,” *Forschung Straßenbau und Straßen-verkehrstechnik*, Heft 693, Bundesministerium für Verkehr, 1994

[4] M. Lott, “Performance of a Medium Access Scheme for Inter-Vehicle Communication,” in *Proc. International Symposium on Performance Evaluation of Computer and Telecommunication Systems*, San Diego, July 2002

[5] M. Bechler et al, “Efficient Discovery of Internet Gateways in Future Vehicular Communication Systems,” in *Proc. 57th IEEE Semiannual Vehicular Technology Conference*, Jeju, April 2003

[6] M. Rudack et. al., “On the Dynamics of Ad Hoc Networks for Inter Vehicle Communications (IVC),” in *Proc. International Conference on Wireless Networks*, Las Vegas, 2002.

[7] J. Kienzle, “Analyse von Einzelfahrzeugdaten,” Master Thesis, University of Stuttgart, Germany, August 2001.

[8] D. Forsberg et al., “Distributing Mobility Agents Hierachically under Frequent Location Updates,“ in *Proc 6th IEEE MoMuC*, San Diego, November 1999.

[9] NISTNet network emulator: http://snad.ncsl.nist.gov/itg/nistnet