Evaluation of Routing Protocols for Vehicular Ad Hoc Networks in City Traffic Scenarios

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Abstract: *Vehicular multi-hop ad hoc networks (VANETs) are an important technology for future developments of vehicular communication systems. Vehicles are able to exchange information within these networks without the need of installing any infrastructure along the roadside. VANETs can be used to improve the road safety by e.g. warning drivers about accidents in front of the road or to provide Internet access to the passengers via gateways along the road. However, the routing of data packets through the VANET is very complex since network topology and communication conditions may vary heavily. To evaluate the performance of routing protocols in urban traffic scenarios, we developed a realistic city mobility model, which was used to examined the performance of AODV, DSR, FSR and TORA on the basis of network simulations. We found out that TORA is completely unsuitable for vehicular environments, whereas FSR, DSR and AODV showed promising results in the city scenarios.*

Keywords: Vehicular Ad Hoc Networks, Routing Protocols, Performance Evaluation, Network Simulation

1. INTRODUCTION

The exchange of information between communicating vehicles without any fixed infrastructure like access points or base stations is an intensive field of research. Projects like FleetNet [1] propose the establishment of multi-hop ad hoc networks between vehicles based on Dedicated Short Range Communication for future vehicular communication systems. In order to participate in such a network, a vehicle has to be equipped with the necessary radio communication hardware. Since each network node acts as wireless station and mobile router at the same time, distant vehicles can communicate with each other by using intermediate vehicles for packet forwarding. The application range of such networks may cover safety related applications like the warning of drivers about accidents or congestions in front of the road. For these purposes, not only vehicles but also traffic signs may take part in the VANET. Moreover, vehicles may also be provided with Internet access via the ad hoc network using e.g. gateways installed along the roadside [2].

However, the fast changing network topology and heavily varying communication conditions are challenging for the routing protocols being used. Several factors like the type of the road, daytime, weather, traffic density and even the driver himself affect the movements of vehicles on a road. In addition, there may be a significant difference in the speeds of two communicating vehicles. Hence, the routing protocol used has to adapt itself to theses unreliable conditions continuously. Previous work on mobile ad hoc networks (e.g. [3,4]) is mainly focused on quite small scenarios with a low node mobility and simple movement patterns. In order to have more realistic simulation results, we developed a mobility model that reflects the movement of vehicles in city scenarios.

The remaining paper is organized as follows: in section 2, we present the routing protocols used for the evaluation. Section 3 introduces our city mobility model. The simulation scenario and the evaluation results are discussed in section 4. Finally, the paper closes with a conclusion in section 5.

2. ROUTING PROTOCOLS

Various ad hoc routing protocols have been proposed in recent years, whereas two main classes of unicast protocols can be distinguished: location-based and topology-based protocols. These protocols enable the exchange of data between distinct pairs of nodes, using intermediate network participants for forwarding packets on their way to the destination. Location-based routing protocols use additional information on the node's geographical positions to find suitable routes. These positions may be e.g. the node's GPS coordinates. However, when using location-based protocols, there is always a need for location services and servers. For that reason, we focus on topology-based routing protocols that do without these additional mechanisms. We chose four well-known routing protocols to be evaluated in our city traffic scenario: Ad Hoc On Demand Distance Vector (AODV) [5], Dynamic Source Routing (DSR) [6], Fisheye State Routing (FSR) [7] and the Temporally-Ordered Routing Algorithm (TORA) [8].

FSR is a proactive routing protocol that maintains routes to all possible destination nodes in its routing table. Moreover, the table is updated continuously. For that reason, nodes are exchanging link-state updates in order to determine a local view on the network topology. AODV, DSR and TORA are reactive routing protocols that discover routes only when they are needed. This way, the protocols do without periodical routing updates, but the initial packet delay can be expected to be clearly higher due to the route discovery mechanisms. All of these protocols use a kind of response-reply mechanism to discover routes, whereas they differ in the way how packets are forwarded and routing information is stored.

3. CITY MOBILITY MODEL

Previous work showed that the choice of specific mobility models for network simulations has significant effects on the simulation results [9]. Hence, realistic movement patterns are very important for network simulations. For that reason, we developed a city mobility model that is able to model realistic urban traffic scenarios. In these scenarios, vehicles move on a road network that is characterized by a large number of crossings. At each crossing, vehicles may stop and change their directions. Thus, the characteristics of the traffic flow are much more heterogeneous than e.g. on a freeway and the network reconfiguration rate can be expected to be very high.

In our city mobility model, we assume a Manhattan-like road network. All vehicles are supposed to be points moving along a street section. For simplicity reasons, we do not distinguish between different types of vehicles like e.g. passenger cars or trucks. The speed of the vehicles is determined with the help of the Intelligent-Driver Model (IDM) [10]. IDM is a macroscopic car-following model that adapts a vehicle's speed according to other vehicles driving ahead. Moreover, it is also possible to model the approach of vehicles to crossings. Another advantage of IDM is that it uses a quite small set of parameters which can be evaluated with the help of real traffic measurements.

As shown in Figure 1, the influencing variables on the IDM acceleration of vehicle *n* are the net distance s_n to the vehicle $n - 1$ driving ahead, the vehicle's current speed and its approaching rate Δv to vehicle $n - 1$.

$$\dot{v}_n^{IDM}(v_n, s_n, \Delta v_n) = a_n\left[1 - \left(\frac{v_n}{v_{des}^{(n)}}\right)^{\delta} - \left(\frac{s^*(v_n, \Delta v_n)}{s_n}\right)^2\right] \qquad (1)$$

The first two terms in equation (1) represent the vehicle's acceleration on an empty street. They include the its maximum acceleration a_n, its desired speed v_{des} and the acceleration exponent δ. The third term describes a brake retardation in the case that there are other vehicles or obstacles in front. It depends on a desired distance s^* to the vehicle/obstacle, which is determined with the help of equation (2).

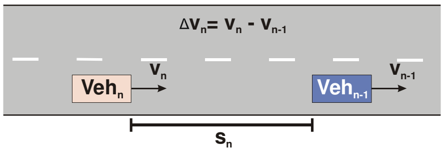

Figure 1: Influencing variables on IDM

$$s^*(v_n, \Delta v_n) = s_{jam}^{(n)} + T v_n + \frac{v_n \Delta v_n}{2\sqrt{a_n b_n}} \qquad (2)$$

s^* is influenced by the jam distance s_{jam} between two successive vehicles, the safe time headway *T* and a term describing the vehicle's brake retardation, when approaching to any obstacle or vehicle in front of the road. The vehicle's comfortable deceleration is given by *b*. Table 1 summarizes the constant parameters used for IDM in our mobility model.

A vehicle approaching a crossing is modeled according to approaching an obstacle. Each time a vehicle moves towards a crossing, it has to reduce its speed and stops in front of the crossing. Afterwards the vehicle may drive ahead or change its direction at a specific probability. We used a FIFO mechanism to control the traffic flow at a crossing if several vehicles want to pass it at the same time.

We implemented our city mobility model into a scenario generator that is able to create urban movement patterns with different traffic characteristics.

Param.	Description	Value
a	Maximum acceleration	1.2 m/s^2
b	Comfortable deceleration	1.5 m/s^2
δ	Acceleration Exponent	3
s_{jam}	Minimum Jam Distance	2 m
T	Safe time headway	1.4 s

Table 1: Constant IDM parameters

4. EVALUATION

In order to evaluate the performance of the routing protocols, we chose the network simulator ns-2 [11]. It is freely available and widely used for research on mobile ad hoc networks. Furthermore, users can easily extend the simulator with additional protocols. The simulation is done on the packet level. Thus, a detailed analysis of the simulation results is possible.

4.1. City Scenario

Our city scenario is based on the road network shown in Figure 2. It consists of eight vertically and horizontally oriented streets as well as 16 crossings. Each modeled street has a total length of 1500 m, whereas parallel streets are separated by a distance of 500 m. According to German traffic rules, the speed

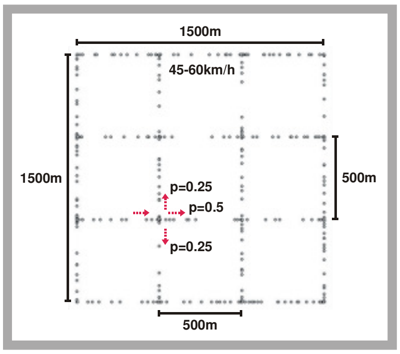

Figure 2: Characteristics of the city scenario

limit in build-up areas is 50 km/h. Since not all drivers always keep to this limit, we assume the desired speed of the vehicles to be between 45 km/h and 60 km/h. At each crossing a vehicle may change its direction at a specific probability. These probabilities are chosen according to UMTS reference scenarios [12]. This way, a vehicle turns right or left at a probability of 0.25 each, and it keeps its current direction at a probability of 0.5.

In this paper, we compare the performance of the routing protocols at varying traffic densities. A traffic density is typically described as high if it reaches a value of 30 vehicles/km (per lane) [13]. We can expect that not all of these vehicles will typically be equipped with the necessary communication hardware for participating in the network. Thus, we simulated traffic densities between 2 and 25 vehicles/km, whereas all of these vehicles take part in the VANET for simplicity reasons. Each simulation run lasts six minutes. In addition, we assumed that on average each node participates in a TCP connection. The important parameters of the scenario are summarized in Table 2.

traf. density per lane [vehicles/km]	#nodes	max. #conn.
2	48	24
5	120	60
10	240	120
15	360	180
20	480	240
25	600	300

Table 2: Parameters of the city scenario

4.2. Evaluation Results

For analyzing the performance of AODV, DSR, FSR and TORA, we considered four typical performance measures for ad hoc networks: data throughput, packet delivery ratio, routing overhead and average packet delay. The average TCP throughput per connection is depicted in Figure 3. At first, we notice that the throughput of all protocols clearly increases between a traffic density of 2 and 5 vehicles/km. This behavior results from the network connectivity in the VANET. At a traffic density of 2 vehicles/km, there are on average only from 0.8 to 1.6 neighbors in a vehicle's radio transmission range (100m). Hence, in many cases it may not be possible to establish a communication path from the source to the destination. At higher traffic densities, the connectivity in the network is significantly better. The clear difference between both measured values can be put down to TCP's reaction to high packet loss rates. Moreover, the results also may be subject to statistical fluctuations since communication partners are selected randomly. At higher traffic densities, the throughput of all routing protocols clearly declines again, because more and more vehicles have to share a common wireless channel and the routing overhead increases. In our measurements, AODV clearly outperforms the other protocols, especially at traffic densities higher than 5 vehicles/km. While FSR's throughput at traffic densities up to 10 vehicles/km is lower than the throughput of DSR, the results of both protocols converge at higher traffic densities. However, their throughput is only about 15% (FSR) and 9.8% (DSR) of AODV's throughput at a density of 25 vehicles/km. Here, AODV delivers 53.35 byte/s. TORA has obvious problems to cope with high traffic densities in the city. Its throughput plunges down to values below one byte per second.

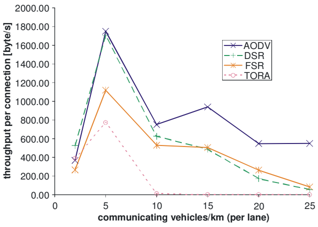

Figure 3: TCP throughput

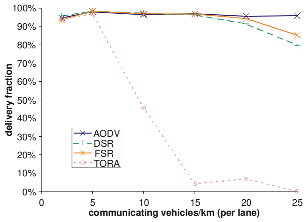

Figure 4: Delivery ratio

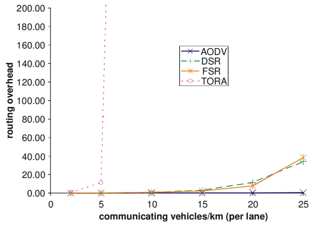

Figure 5: Rt. Overhead

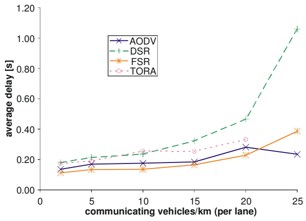

Figure 6: Avg. delay

Figure 4 summarizes the delivery ratio of TCP data packets. The results basically confirm our conclusions of the throughput measurements. Up to a traffic density of 5 vehicles/km, the delivery ratio of all routing protocols ranges between 93.56% and 98.35%. After this point, the curve progression of TORA shows a sharp decline. At traffic densities higher than 15 vehicles/km, the delivery ratios of DSR and FSR decrease compared to AODV, whereas FSR behaves a little better than DSR. Assuming a traffic density of 25 vehicles/km, AODV's delivery ratio is 95.86% while FSR reaches a value of 85.22%. DSR was only able to transfer 79.70% of the packets successfully in this case.

The routing overhead relating to the amount of user data that has been exchanged between sender and receiver is shown in Figure 5. We can observe the huge overhead caused by TORA compared to the other protocols. At a traffic density of 5 vehicles/km the amount of routing data sent is 11.40-times of the amount of user data that was delivered successfully. Assuming a density of 10 vehicles/km this factor increases to 10334.96. Again, AODV causes the lowest routing overhead. Increasing the density of communicating vehicles from 2 to 25 vehicles/km, its overhead changes from 0.013 to 0.38. FSR and DSR cause similar routing efforts in the city scenario. FSR performs a little bit better than DSR between traffic densities higher than 5 vehicles/km and lower than 25 vehicles/km.

Finally, we examine the average delays of data packets (Figure 6). The delays of all routing protocols range between 112.6 ms and 1.06 s. As expected, DSR has the highest delays at nearly all simulated traffic densities (up to 1.06 s). Particularly, its route discovery process takes a quite long time compared to other protocols. FSR has the lowest delays at traffic densities of up to 20 vehicles/km. Assuming a traffic density of 25 vehicles/km, AODV gets ahead of FSR (0.23 s vs. 0.39 s), but FSR was able to deliver about six times fewer packets than AODV. Like in case of FSR, the delays of AODV increase only slightly. The maximum delay of 0.28 s is reached at a traffic density of 20 vehicles/km. The curve progression of TORA is also quite smooth, but runs at a slightly higher level than that of AODV. Its average delay is between 0.17 s and 0.33 s.

All in all, we can summarize that AODV showed the best performance in the simulated scenarios. Its mechanism of storing route information on intermediate nodes causes the lowest overhead. Moreover, it has the highest throughput and is able to deliver packets quite fast. AODV is followed by FSR, which has a lower throughput than AODV and DSR especially at traffic densities lower than 15 vehicles/km, but also reaches good results. DSR suffers from a very high delay in our simulations since the source routes change continuously in these fast changing environments. Finally, the results showed that TORA is completely inapplicable for VANETs in urban environments.

5. CONCLUSIONS

VANETs will play an important role for future automotive developments since they enable a wide range of applications. The routing of data packets in these fast changing networks is still subject of intensive research. In this paper, we compare the routing protocols AODV, DSR, FSR and TORA, and analyze the differences in their performance. These performance evaluations are important to improve the routing efficiency in vehicular ad hoc networks. We developed a city mobility model that enables the generation of realistic urban road traffic scenarios. An important observation was that the examined routing protocols showed highly heterogeneous performance results. We found out that TORA is completely unsuitable for vehicular environments, whereas FSR and AODV showed promising results in the city scenarios. Although FSR's throughput at lower traffic densities is less than that of AODV (and DSR), both protocols cause the lowest routing overheads and deliver packets quite fast. DSR suffers especially from very high end-to-end delays.

Future work will include the integration of traffic signs and traffic lights into the simulation environment, in order to develop novel driver assistance systems and services as well as intelligent cooperative mechanisms for controlling traffic flows in urban environments.

REFERENCES

[1] W. Franz, R. Eberhardt, T. Luckenbach, "FleetNet – Internet on the Road", 8th World Congress on Intelligent Transportation Systems, Sydney, October 2001.

[2] M. Bechler, "Internet Integration of Vehicular Ad Hoc Networks", Logos Verlag Berlin, 2004.

[3] J. Broch, D. A. Maltz, D. B. Johnson, Y.-C. Hu, J. Jetcheva, "A performance comparison of multi-hop wireless ad hoc networks routing protocols", In Proc. of MOBICOM '98, Dallas, Tx, pp. 85-97, 1998

[4] G. Holland, N. Vaidya, "Analysis of TCP performance over mobile ad hoc networks", In Proc. of MOBICOM '99, pp. 219-230, 1999

[5] C. Perkins, E. Belding-Royer, S. Das, "Ad hoc On-Demand Distance Vector (AODV) Routing", RFC 3561, July 2003

[6] D. Johnson, D. A. Maltz, Y.-C. Hu, "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR)", IETF Internet Draft, work in progress, draft-ietf-manet-dsr-09.txt, April 2003

[7] M. Gerla, X. Hong, G. Pei, "Fisheye State Routing Protocol (FSR)", IETF Internet Draft, work in progress, draft-ietf-manet-fsr-03.txt, July 2002

[8] V. Park, S. Corson, "Temporally-Ordered Routing Algorithm (TORA) Version 1 Functional Specification", IETF Internet Draft, work in progress, draft-ietf-manet-tora-spec-04.txt, 2001

[9] T. Camp, J. Boleng, V. Davies, "A Survey of Mobility Models for Ad Hoc Network Research", *Wireless Communication & Mobile Computing (WCMC)*: Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications, vol. 2, no. 5, pp 483-502, 2002

[10] D. Helbing, A. Hennecke, V. Shvetsov, M. Treiber, "Micro- and Macrosimulation of Freeway Traffic", Mathematical and Computer Modelling, vol. 35, no. 5/6, pp. 517-547, 2002

[11] The ns-2 Network Simulator, http://www.isi.edu/nsnam/ns/

[12] B. Rakoczi, E. R. Fledderus, B. Heideck, P. Lourenço, T. Kürner, "Reference Scenarios", MOMENTUM project, Deliverable D5.2, 2003

[13] J. Kienzle, "Analyze von Einzelfahrzeugdaten", Diploma thesis, University of Stuttgart, 2001