

Scalable and Efficient Car Communication Topology

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ABSTRACT

Car communication acts as a base for advanced traffic and car services. There is a strong potential to utilize existing hardware to introduce first car communication applications and services. Potentially first car communication technologies should be seen as initial base to learn about car communication while not all expected functions can be realized with this setup. The more time critical the required communication for a specific car communication application is, the more optimized communication technologies are needed. Considering only already existing communication technologies like UMTS and WLAN, there is a significant potential to implement first car communication solutions in near future. Thus this paper investigates which network topologies provide enough scalability and efficiency to realize first car communication functions based on available hardware.

Keywords

UMTS, WLAN, network topology, car communication, geographic clustering, dynamic gateways

1. INTRODUCTION

Car communication will be one potential solution to improve car traffic situation. Each car will be able to add a significant amount of sensor data from a specific street section to an overall traffic scenario analysis. Based on this information, optimal values for traffic flow parameters can be calculated. Such calculation can be done via a central server or local in-car processing units. With this approach new, efficient traffic regulation can take place, as shown in Figure 1.

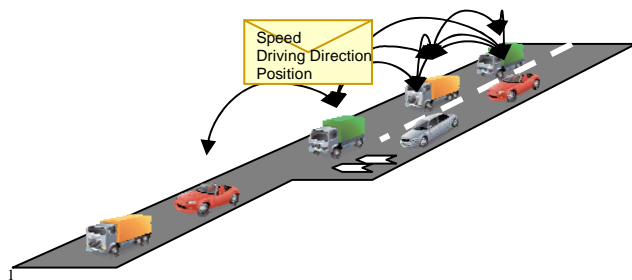


Figure 1 - Computer-based lane switching

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Car communication could be implemented via specific car communication infrastructure. Such an approach allows building technical communication system, which are optimized for traffic properties like high-speed driving, increased bandwidth at peril points, optimal frequency handling during different times of day, etc. However, such a system is extremely expensive to be ramped up, because the infrastructure should cover a complete road network of a nation, might require complete new in-car hardware to communicate with the roadside units and needs to provide financial earnings from car services to guarantee long-term availability.

Considering these terms and conditions, it seems to be a valid question, whether it is a realistic alternative to utilize only already installed, available wireless infrastructure, and whether to use mobile communication devices, like mobile phones, which the consumer already owns and carries around anyway. If this question turns into a valid assumption, which technically can be realized, it is obvious that investment costs of that overall car communication system are evanescent low compared to the initial scenarios of a complete new car communication infrastructure.

Even if the existing technical equipment does not allow realizing all possible and finally required features like automatic or autonomous emergency reactions of the car without any driver's help, it offers a great chance to start car communication in the near future with more relaxed services. With such a basic starter setup, first technical and commercial experiences can be collected with car communication, which finally helps to develop the technology further to a final car communication scenario, which then includes partly of fully own infrastructure and optimized mobile or in-car communication devices.

Thus, this paper assumes that in a few years it will be reality that cars communicate to each other via existing hardware from the infrastructure perspective as well as from the mobile handset perspective. Therefore the paper investigates which communication technologies are most promising from the availability point of view and from the costs and technical properties perspective. The second section analyzes potential communication principles, whereas the third chapter chooses the corresponding communication technologies and the interaction strategies. Finally simulation results are presented, which indicate, that the chosen principle satisfies the requirements.

2. COMMUNICATION PRINCIPLES

Generally, one can differentiate between comfort and safety critical communication. This is one of the most obvious ways to

think about car communication scenarios. However, there are also other differentiating factors, which carefully need to be investigated before one decides for a specific approach.

2.1 Uni- and Geocast

One should think about information addressing. There exist a strong requirement to communicate between two parties directly, thus unicast communication must be supported, see Figure 2.

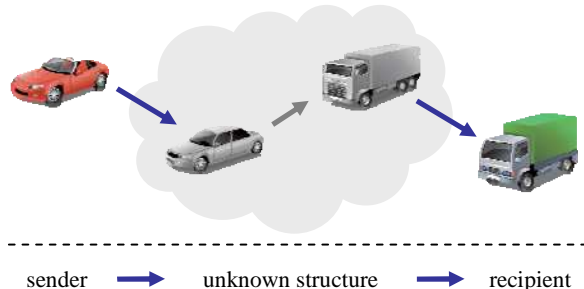


Figure 2 - Forwarding unicast message via different cars

Another important option is multicast communication, where several users will receive the same information. In the case of car communication multicast can be realized via geocast information distribution. The information is not transferred to a specific number of cars but to a geographic region, where a number of cars is actually located, see Figure 3.

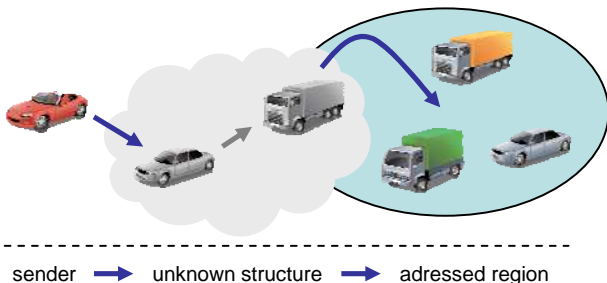


Figure 3 - Geocast information distribution

To transmit unicast messages a recipient needs to be identified. Therefore address tables need to be handled efficiently and updated in time. Especially in car networks, which quickly changes their properties as well as the number of participants unicast messaging introduces significant organizational work amount. Instead of geocast transmission is simpler and requires less overhead.

2.2 Number of participants

The number of participants is a key parameter when thinking of a benefit from car communication principle for consumers. It would be a wrong way to think first about technological details, instead of the question, how many participants are required that the overall system provides benefit to each user.

Thus, it is important to choose the network, that at any time the overall car communication system does fully work! It must not be a technical decision, that there is required a minimum number of participants larger than one, to guarantee first time a working system. It is highly important to make sure that the market acceptance at the beginning of the technology will not be slowed down by generating a chicken-and-egg problem.

On the other hand, it must be guaranteed, that the network properties are scalable, so that in case of a large consumer number the overall system is still working properly.

The benefit or content of a car service is a different topic to discuss and is often depending on the number of participants. However, this topic does not belong to the scope of the paper.

3. SCENARIO

To realize the overall car communication, two technologies are considered to evaluate a fully working system

- UMTS (GSM)
- WLAN 802.11b

These technologies have been chosen to realize the system based on the requirements described in the last sections. First of all, the cellular infrastructure does already exist and is in use already for voice communication and mobile internet access. Further on, Wireless LAN can be used to interconnect devices and users in a smaller region. This approach has two advantages. The first one is, that UMTS and WLAN hardware is available in several smart phones today. The second point is that both technologies are complementary from the coverage and bandwidth perspective. Another important item is that UMTS provides a high degree of communication security, thus, the problem of attacking the WLAN connections can be avoided by considering UMTS as the main information carrier.

3.1 Example Use Case

Figure 4 provides a typical use case scenario. A car wants to inform other cars about exceptional road conditions in a specific road section. Therefore, an information via WLAN is transmitted from the detection car to the so-called uplink node car. The transmitted WLAN signal and information does not provide absolute high level of security and thus one cannot assume that the information is fully reliable in any case.

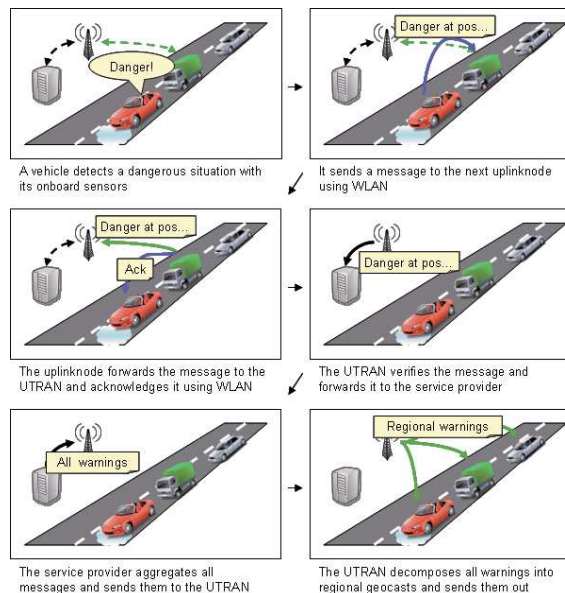


Figure 4 - Car communication scenario

The car, providing the uplink node, takes over the information and transmits it via UMTS securely to the next application server, which is connected to the internet. From that transmission, one can clearly identify the uplink node owner. This does not help to identify the original information author, who has transmitted the information via WLAN, but gives a first base, to keep track from which local network subsection the information are coming from. The application server aggregates all incoming information. The more similar information from different authors are transported via the identified uplink node over a period of time to the application server, the more increases the reliability of the overall information, independent of the reliability of each and every WLAN station.

Depending on the meaning of the information, the application server might ask information authors to switch from indirect to direct UMTS communication, when there is the need to increase the reliability level. Then the information author does not transmit via WLAN to the UMTS uplink node, but connects on his own as uplink node via UMTS to the application server. This leads to clear identification of the information author if needed. The disadvantage is that extremely time critical information cannot be handled or be verified in time. However, this is not the intention of this overall car communication setup at the beginning of market introduction.

Thus the overall approach is able to start communication with WLAN, utilizing free bandwidth with the risk of unreliable information. The application server judges about the information reliability, based on various parameters such as statistical data. If the information is really critical and additional author identification is required, the application server might ask the author to connect directly via reliable cellular access.

Coming back to the communication principles, the propagation of the new information from the application server to all users will be done via UMTS broadcast downlink or, as an alternative, via terrestrial broadcast using DAB, Digital Radio Mondiale (DRM), DVB-H/T and so on.

Additionally the overall setup scales very well with the number of users. When only one user is available, the setup uses only one UMTS connection. The more users enter the scenario, the more local communication is done via WLAN to the selected UMTS uplink node car. This helps to keep the traffic for the UMTS network that low, that typical voice and data communication, which is not related to the car communication, does not need to operate in an overloaded cellular network. Finally, if a car does not have any contact to an uplink node, it decides to act as an uplink node itself. This procedure makes the overall communication principle very self-organizing, easy to handle from technical perspective and keeps the overall communication overhead low.

3.2 Optimization

The approach described above provides several degrees for optimization. Figure 5 provides an exemplary insight into different topics that can be optimized.

On the one hand, the communication overhead must not eat up the locally available WLAN bandwidth. In addition to that, the number of cellular connections needs to be kept as low as possible, because the cellular network capacity is optimized on

voice call operation which a high share of idle users and not on car communication. Finally, when handing over the uplink node responsibility from one car to the next, the ramp up and ramp of each UMTS connection induces additional load on the cellular network. Therefore and for stability reasons of the network itself it is important to keep the network structure as stable as possible.

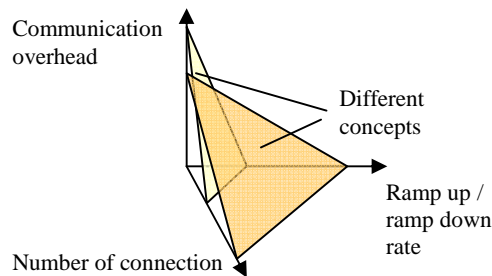


Figure 5 - Potential topics for optimization

Based on these assumptions the next subsections provide an overview, how to organize the network topology.

3.3 Structure

This paper compares two different approaches to realize the overall network topology. On the one hand, it is Geographic Clustering; on the other hand, it is the Dynamic Gateway approach. First, Figure 6 shows the Geographic Clustering.

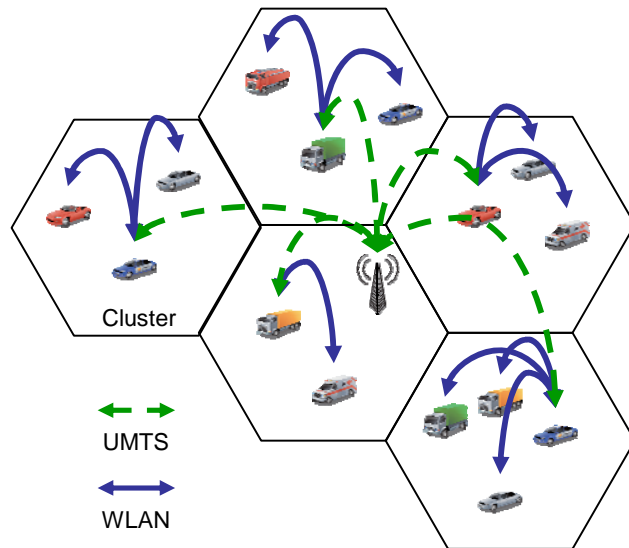


Figure 6 - Geographic Clustering

An undefined number of clusters with a predefined size are mapped on the landscape. Every car can determine by (GPS) positioning, to which cluster it belongs to. Among all cars in the cluster one car is elected for being uplink node. This can be accomplished using WLAN messages, wherein each car includes its own score defined by a given metric. Upon election, the new uplink node will establish a UMTS connection. In case of new messages, all cars within the cluster may ask the elected uplink node via WLAN to forward their message to the infrastructure. When leaving the cluster or on deselection an uplink node must resign and terminate its UMTS connection.

As an alternative to the Geographic Clustering principle the Dynamic Gateway approach is shown in Figure 7.

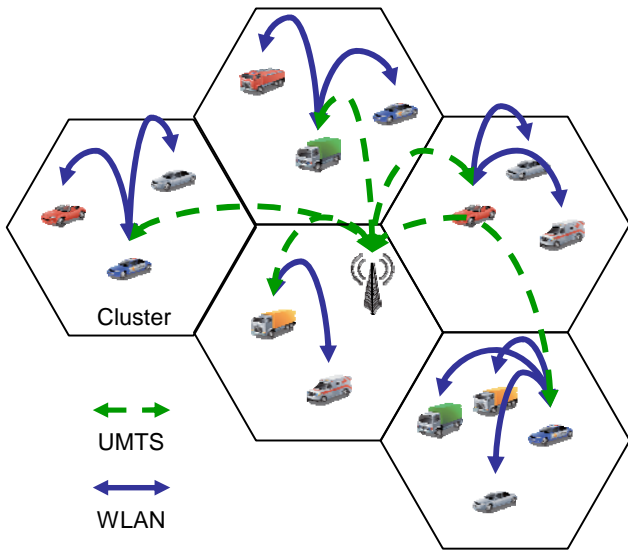


Figure 7 - Dynamic Gateways

Within the gateway approach, no (GPS) positioning is required, as groups are not defined by geographical predefined clusters but dynamically by the reception of existing uplink nodes' service advertisements.

When a new message occurs, a car checks if it knows at least one existing uplink node. In case there is no uplink node available, the car acts as an uplink by itself and thus, offers the uplink service to all cars within communication range by sending out service advertisements. In case there are known uplink nodes around, the car connects to the uplink node which appears most reliable and sends of the message using WLAN. The question, to which group a car belongs to, is automatically answered by the ability of receiving an uplink nodes' service advertisements. If a car can receive an advertisement, it temporarily belongs to that self-organized communication group. By receiving advertisements of more than one uplink node, the car is part of more than one group, which adds some extra connectivity. The higher the locally available communication range is, the bigger groups will constitute.

4. SIMULATION RESULTS

Both concepts were implemented in an OMNeT++ simulation environment, using own models both for mobility and WLAN channel. The map measures 600x600m. The road network is shown in Figure 8.

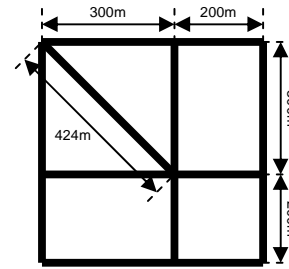


Figure 8 - Simulated road network

As all streets are bidirectional, the total length accumulates to approx. 6.648 km. For the simulation of different car densities, the number of cars is varied from 1 to 800 cars, which leads to a maximum density of in average one car every 8.56 meters. To investigate the impact of speed, two different scenarios are used: city, where all cars drive between 50-60 km/h, and highway, where the cars move at 100-180 km/h. Cars on the same street are assumed to have an LOS channel with a Rice-distributed communication range of 300m, whereas cars on different streets have an NLOS channel with a Rayleigh-distributed communication range of 45m.

4.1 Geographic Clustering

The simulation of the Geographic Clustering approach is based on the following values: the predefined size of a cluster is $130 \times 150 = 19.500m^2$. In further work the size might be dependent on different parameters. The cluster period, for which an election is valid, equals 100ms. The active uplink time of 100ms has been chosen because of expected car speeds and cluster size. Figure 9 shows the simulation results.

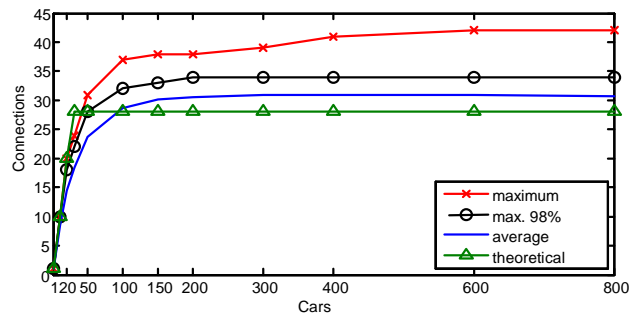


Figure 9 - required UMTS connections (Geographic Clustering, city scenario)

The x-axis shows the number of simulated cars on the whole map, whereas the y-axis indicates the number of required UMTS connections. There are three curves visible. The uppermost, provides the absolute maximum number of used for each run with an given density. The curve in the middle, shows the number of cellular uplinks for 98% of the time to filter out outliers, whereas the lower curve shows the average. Additionally, a theoretical bound is given. It is either determined by the number of clusters which cover part of a road, which is 28, or, if the number of cars is less than that, the number of cars.

The starting point with one car reaches the number of only one cellular connection. This result is trivial and definitely expected. With an increasing density/number of cars, the number of uplink connections increases less than linear, see also **Fehler!**

Verweisquelle konnte nicht gefunden werden. There the theoretically expected curve is given by the triangular curve. Up to about 30 cars, the number of uplink nodes should increase, with further more cars the number of uplink nodes should saturate at 28 uplinks. The first very positive property of the system is, that all simulated curves saturate at an absolute value of at most 43 connections, even if the total number of cars rises up to a number of 800 cars, which means that in average there are 29 cars per cluster. Thus, it can be seen, that the overall network topology provides a stable connectivity. Theoretically, the upper level of number of uplink nodes in this scenario equals 28 uplink nodes. The reason, that there are more than 28 uplink nodes active is twofold. First of all, there appear some problems during coordination and selection of a specific uplink node. Assume that actually there is no uplink node available and more than one car enters the cluster. Each of the car starts to apply the right to act as an uplink node, and, e.g. because of bad channel conditions, the cars do not receive the simultaneously transmitted uplink node applications. In that case, it is possible that more than one car acts as an uplink node, because they do not know from the other cars' cellular connection. The second reason is that there exists already an uplink node but another car does not have wireless connection to that uplink node. Thus, the car decides to act as an own uplink node in the same cluster. Figure 10 shows that similar results can be achieved when driving on a highway.

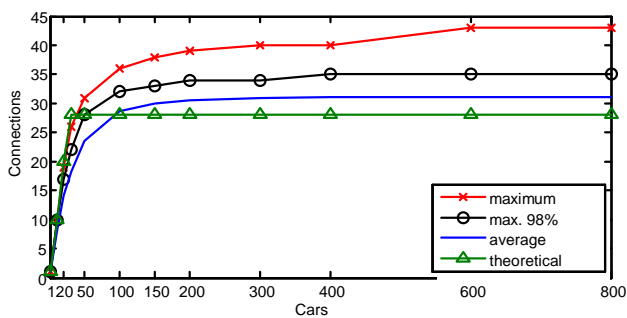


Figure 10 - required UMTS connections (Geographic Clustering, highway scenario)

The results for both the rate of ramp-ups and ramp-downs of UMTS connections as well as the average time an uplink node keeps its function are shown in figure 11.

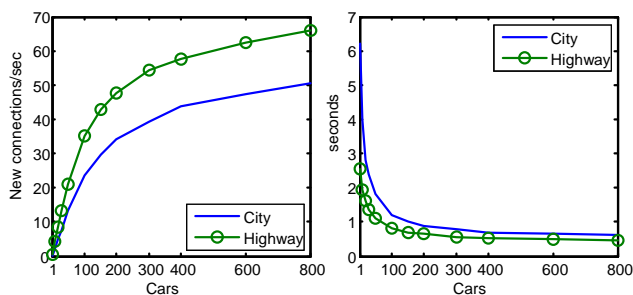


Figure 11 - change rate and active time (Geographic Clustering)

As expected, the rate of new connections increases while the time a node acts as uplink node decreases with increasing density. This

makes sense because competition between the cars increases as well.

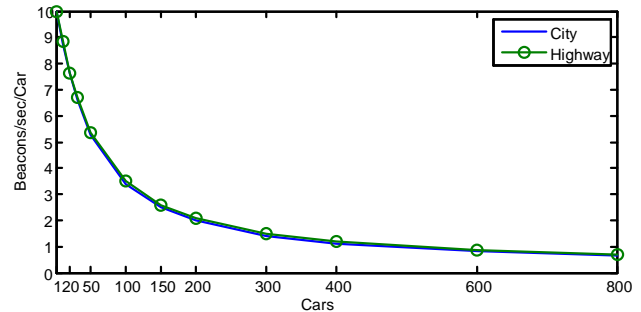


Figure 12 - signaling overhead (Geographic Clustering)

Figure 12 shows the number of WLAN messages required for maintaining the topology per second and car. As it can be seen, the number decreases from 10, which means one message per car and cluster period, to less than 1 at 800 cars, which means that not even every tenth car needs to send out a message each period for maintaining the topology.

4.2 Dynamic gateway

The Dynamic Gateways simulation is based on the following values: an active uplink node is allowed to stay idle for at most 800ms. In case no further information needs to be transmitted in that time span, the uplink node must automatically shut down its connection to the cellular base station. In case a message is received and forwarded, the timeout process is reset. Figure 13 and Figure 14 show the simulation results for the number of required UMTS connections.

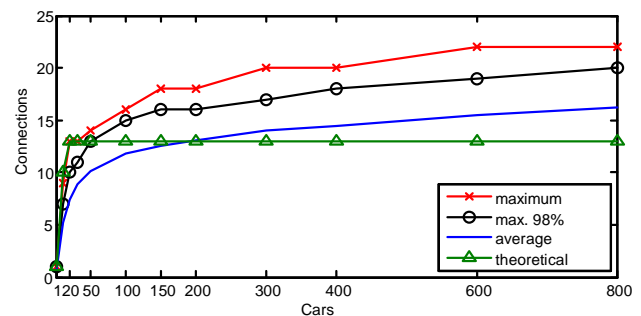


Figure 13 - required UMTS connections (Dynamic Gateways, city scenario)

The number of required cellular connections in the Dynamic Gateways scenario is for all densities below or equal to 22 and thus significantly lower than for the geographic clustering with at most 43 connections. The reason for that is the optimized geographic location of the active uplink nodes with regard to the channel properties. The uplink node positions are indirectly chosen because of the reception quality for the other users. This leads to a significant improvement of the available resources. The theoretical maximum number of uplink nodes is 13, originating from the map-layout and the communication ranges. This bound is definitively not reached by the overall implementation but still, the absolute numbers of the dynamic gateway approach is much better than the geographic approach.

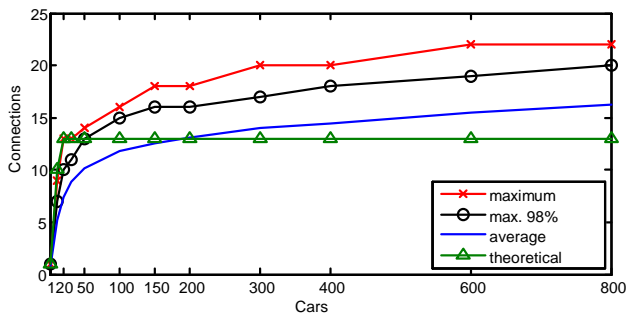


Figure 14 - required UMTS connections (Dynamic Gateways, highway scenario)

Even more interesting the rate of connections ramp-ups and ramp-downs as well as the time the uplink nodes stay active have an inverse directions compared to the Geographic Clustering, as it can be seen in Figure 15.

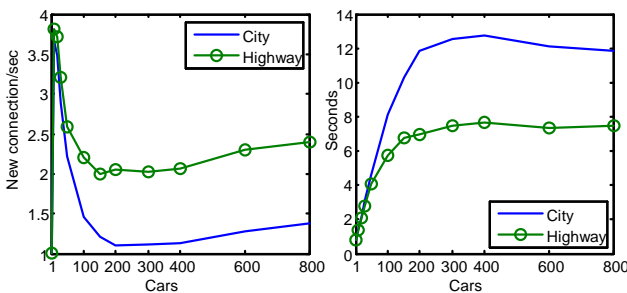


Figure 15 - change rate and active time (Dynamic Gateways)

Up to 200 cars, the higher the density gets, the more stable is the topology. This is because of the fact that more cars mean more potentially customers for the active uplink nodes. If there is more traffic at the uplink node it gets more likely that it will be able to reset its connection-timeout and therefore stay active for a longer time span. While the rate stays almost constant between 200 to 400 cars, it slowly starts rising again after that. Nevertheless, the slight increase is still way less than the increase in density, which shows the concept scales very well.

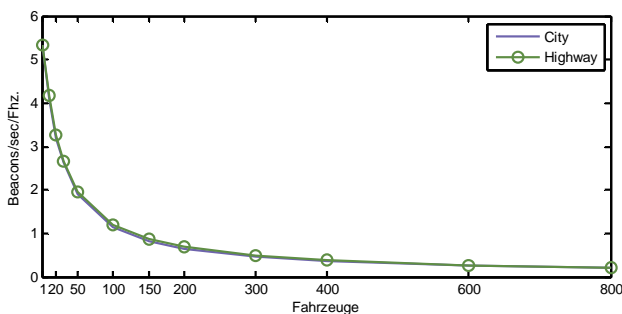


Figure 16 - signaling overhead (Dynamic Gateways)

Figure 16 shows the required signaling overhead for the Dynamic Gateways concept. Like the previous concept, the signaling overhead per car significantly decreases with increasing density. At 800 cars in the city scenario it reaches as low as 0,2025 beacons per car and second.

5. SUMMARY

This paper proposes two car communication concepts, utilizing only existing wireless communication technologies. The UMTS and WLAN combination offers an attractive base to implement car communication in the near future. The investigated system will definitely not fully solve the car communication task for long term, but provides a highly interesting solution, which can handle many car communication applications and services. There have been compared a geographic-based solution with a so-called dynamic gateway approach. Both solutions provide a stable setup while the dynamic gateway implementation offers lower resource allocation than geographic-based system. The approaches offer good starting point to implement car communication services.

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