Decentralized Discovery of Free Parking Places

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ABSTRACT

This paper proposes a topology independent, scalable information dissemination algorithm for spatio-temporal traffic information such as parking place availability using vehicular ad hoc networks (VANET) based on Wireless-LAN IEEE 802.11.

The algorithm uses periodic broadcasts for information dissemination. Broadcast redundancy is minimized by evaluation of application layer information and aggregation. Due to the spatio-temporal characteristics of parking place information, the spatial distribution of information is limited by utilizing techniques, which take the local relevance and age of information into account.

Based on a realistic model of a german city with up to 10000 vehicles, our results show that a decentralized parking place information system works efficiently even with 5% of vehicles equipped with Wireless-LAN and without the help of any message relaying infrastructure. This fact makes such a non-safety driver assistance application very interesting, especially in the rollout phase of vehicular ad hoc networks.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless Communications; C.2.2 [**Network Protocols**]: Applications

General Terms

Algorithms, Design

Keywords

Vehicular Ad Hoc Networks, Parking Place Search, VANET Applications

1. INTRODUCTION

Searching for free parking spaces in urban traffic conditions is a serious mobility problem in everyones daily life.

Consider driving into a city center/downtown for an important appointment. The normal psychology of the driver or passenger is to reach and park at a street that is closest to the intended destination. Moreover, they do not have sufficient time at their disposal to drive around searching for available parking space after reaching the destination. In such a scenario, it would be very helpful for the driver/passenger to have up-to-date knowledge of the traffic situation, in particular information about free parking places around the destination.
A study in [3] provides results regarding the free parking spaces problem in the district Schwabing of Munich, Germany. This study shows the extent of the annual damage resulting from searching parking space traffic (values given per year for Schwabing):

- Total of 20 million Euros economical damage
- 3.5 million Euros for gasoline and diesel, which are wasted in search of free parking spaces
- 150 000 hours of waiting time
- The proportion of traffic searching for free parking places amounts to 44% of the entire traffic, i.e. nearly every second vehicle is in search for a free parking space. (The statistically determined vehicle traffic in Schwabing is about 80 000 km per day.)

Projected on larger cities in Germany comprising multiple districts of similar size, a total economical damage from two to five billion Euros per year is estimated.

Our parking place search algorithm presents a solution to inform drivers about the parking place situation under urban traffic conditions. The algorithm exploits broadcasting techniques for information dissemination and takes the spatio-temporal character of parking places into account. The information exchanged between vehicles and parking automats (parking automat is the german word for road side parking fees payment terminal), which are central elements in our model, is categorized into atomic and aggregated information. Atomic information represents the availability of free parking places coordinated by one parking automat and aggregated information represents summarized information about an area covering more than one parking automat. The covered regions of aggregates are disjunct and hierarchically organized. Using the defined hierarchy allows building parking place situation reports for regions of variable geographic extensions.

Compared with broadcasting atomic information, broadcasting aggregated information drastically reduces the overall needed bandwidth. Hence in our concept, each vehicle aggregates received information before it distributes it to other vehicles.

Aggregation of multiple information atoms yields a processed information that covers a greater geographical range. Moreover, due to their more generalized nature, aggregates are relatively more time-stable, as compared to atomic information. These longer validity periods are indicated as timestamps in the aggregates. Generalization of information in aggregates leads however to lesser accuracy, which decreases with increase in distance to a parking area. The loss of accuracy is contained within acceptable limits by application of our proposed selection strategies for aggregated as well as for atomic information.

This paper is organized into the following sections: the next section introduces our algorithm in detail. Section 3 describes the utilized simulation environment based on multiple interlinked simulators and its parameters, such as the city model and the characteristics of the wireless channel. The simulation strategy used to verify algorithm and our results obtained are presented in section 4. Section 5 discusses related work in the field of decentral traffic information systems based on VANETs. Finally, the last section concludes this paper.

The main contributions of our work are an efficient and scalable algorithm for the distribution of information on parking place availability and a detailed simulation study of this algorithm based on realistic vehicle movement patterns.

2. PARKING PLACE DISCOVERY ALGORITHM

Due to scalability with respect to high number of queries as well as the problems caused by network partitioning for unicast routing, we have decided to implement a proactive dissemination scheme.

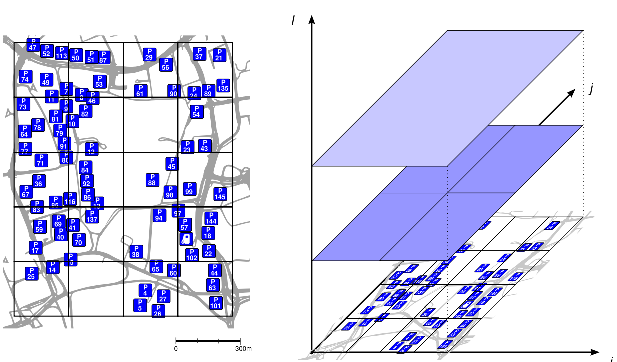

Figure 1: Adopted Aggregation Scheme

The working principle of the algorithm can be briefly described as follows: A pre-defined periodic broadcast interval is used to disseminate received atomic and aggregated information cached in a vehicle. Atomic information represents the availability of free parking places coordinated by one parking automat. Aggregated information provides information about the parking place situation in an area and covers more than one parking automat.

The time interval between subsequent broadcasts is exploited to sort cached information and to generate new information for other vehicles. In this phase a vehicle replaces older entries with newer ones and builds aggregates for different spatial granularities termed in this paper as aggregate levels. Each aggregate level represents a non-overlapping partitioning of the covered region. The aggregation is performed by using an overlay grid of a hierarchical quad-tree structure. As depicted in figure 1, four aggregates of a lower level cover the area of a higher level aggregate.

Our algorithm distributes aggregates as wireless messages over wider areas, but keeps the distribution of atomic information confined to local proximity. This way, two major goals are achieved: First, compared with broadcasting atomic information over the entire topology, bandwidth consumption is reduced. Second, aggregates about suitable parking areas are distributed over large distances which could provide vehicles entering in a large area for an initial orientation to parking situation from a macro-perspective.

The distribution of atomic and aggregated information is controlled by selecting a subset of all received information with specific attributes. The applied strategy to select the information to be sent is introduced in section 2.4. In our algorithm all vehicles act as information servers producing and relaying parking place information for the VANET.

The building blocks of our algorithm can be described as follows:

- Grid: The overlay grid subdivides the map into non-overlapping areas. Based on the grid, information is classified and organized into different levels. Each level represents the spatial dimensions of the covered region and the relevant consolidated information.

- Resource: Every information available is defined as a resource.

- Broadcasting: Information is periodically broadcast to other vehicles.

- Selection strategies based on relevance: The spatial distribution of atomic information and aggregates is controlled through an information selection strategy. Available information cached in a vehicle is updated by more relevant information. The relevance is calculated by taking distance and age of a resource into account.

Next, we introduce the elements used by our algorithm.

2.1 Grid

The overlay grid is depicted in figure 2, splits the city area into non-overlapping, hierarchically organized sections and is the basis for building aggregates. The presented quad-tree structure is similar to the scheme used in scalable position based multicast [10].

The point $(x_0, y_0) = (0, 0)$ of the cartesian coordinate system depicted in figure 3 with i as abscissa and j as ordinate, defines the origin of the grid. Cells of the grid spread along the positive i- and j- axis. Furthermore the cells are quadratic with an adjustable edge length denoted by k and define the granularity of the lowest level aggregate. The value of the system parameter k is determined by the desired distribution area of local information. A cell is uniquely identified by a triplet (i, j, l) where l denotes the level of

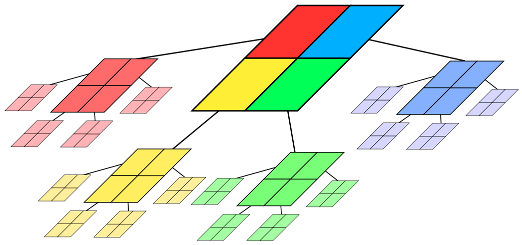

Figure 2: Gridtree Structure

aggregation. Any aggregate from level $l+1$ comprises 4 aggregates from level $l \geq 0$. The figures 3b. and 3c. show the grid 3a. at levels 1 and 2. Considering different levels of aggregation, the edge length size $k(l)$ on different levels l with a constant value for $k(0)$ is calculated as follows:

$$\begin{aligned} k(l) &= 2 \cdot k(l-1), \ l \geq 1 \\ &= \underline{2^l \cdot k(0)} \end{aligned}$$

Assuming the geographical position of a resource is denoted

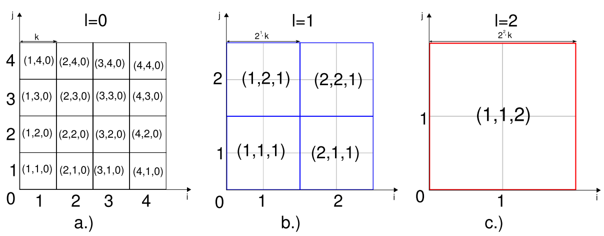

Figure 3: View of the Grid

by (x_r, y_r), the cell (i, j, l) to which it belongs is identified by the following two formulas:

$$\begin{aligned} i &= \left\lfloor \frac{x_r - x_0}{k(l)} \right\rfloor + 1 \quad (0 < x_0 < x_r, \ l \geq 0) \\ j &= \left\lfloor \frac{y_r - y_0}{k(l)} \right\rfloor + 1 \quad (0 < y_0 < y_r, \ l \geq 0) \end{aligned}$$

2.2 Resources

In our context, resources define traffic information available in vehicles. Traffic information has two dimensions: a temporal and a spatial one. In our application, the availability of a parking place is a spatio-temporal resource. The occupancy of a parking automat on a fixed coordinate varies over time. For the rest of this paper the term resource will refer to atomic or aggregated parking place information. Next, we introduce these two resource types in detail.

2.2.1 Atomic Information - Definition

Atomic information represents information about a parking place that is observed by one parking automat. Atomic information has the following attributes:

- ID: Every parking place possesses a unique identifier coupled to its name.
- POO: The point of origin, also referred to as the home of the resource, is a point in the three-dimensional geospace which specifies the location of the resource. In terms of parking places, POO is the position of the broadcasting parking automat.
- TOO: The time of origin is the initial broadcasting time of a report.
- The capacity $C(P_n) > 0$ of a parking place P_n is the maximum number of slots available.
- The occupancy $O(P_n) \geq 0$ of a parking place P_n is the number of occupied slots of a parking place P_n with $O(P_n) \leq C(P_n)$.

2.2.2 Atomic Information - Parking Place Availability Reports

A parking place availability report R is also referred to as resource report or atomic information.

Two packet types are defined, one for the resource report and another as a container packet that allows vehicles or parking automats to send an arbitrary number of resource reports. The packet format containing the reports is illus-

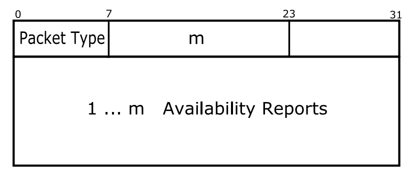

Figure 4: Container Packet for Resource Reports

trated in figure 4. The header is 4 bytes in size and the payload of this packet contains an arbitrary number of resource reports. The fields are as follows:

- *Packet type* defines the resource type for this packet and the broadcasting entity, either a parking automat or a vehicle.
- m specifies the number of encapsulated resource reports.

A single resource report is 16 bytes in size. Figure 5 illustrates the fields of the report. The age t_n of a parking place availability report R_n is determined by the difference between the current time and the TOO.

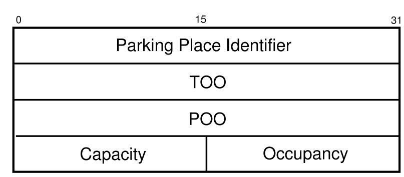

Figure 5: Resource Report Packet Format

2.2.3 Aggregates - Definition

Aggregates are special resource types representing accumulated information. An aggregate of level l combines atomic information of level $l-1$. Information which cannot be received due to network partitioning, propagation losses or multipath fading is ignored.

As described in figure 1, aggregates contain information about non-overlapping discrete areas of a grid.

The number of atomic information accumulated into one aggregate is denoted by n. In contrast to non-aggregated atomic resources the values TOO (time of origin) and POO (point of origin) of aggregates are used to prolong the spatial distribution over time. The TOO of an aggregate is calculated as $\sum_{i=1}^{n} t_i/n$ where t_i equals to the TOO of the $i-th$ atom in the aggregate. This average is used to compare available aggregates of same level and position.

Aggregates are generated by vehicles on the basis of their resource cache. Building aggregates is an incremental two-stage process.

1. Composition of level zero aggregates
   (a) associate every resource in the resource cache to the cell at level zero
   (b) for every cell generated in the previous step generate an aggregate and put all resources belonging to the cell into the newly created aggregate
      i. increase atom counter of the aggregate
      ii. add the parking place availability information of the resources to the values stored in the aggregate
      iii. recalculate the TOO
2. Composition of upper level aggregates in order to build aggregates of level $l > 0$. Iterate through all aggregates at level $l-1$ in the cache and combine them into aggregates of level l. Merging aggregates involves the recalculation of TOO and occupancy information.

All upper level aggregates are built from their child aggregates one level below. The level of accuracy decreases with increasing level of aggregation.

2.2.4 Aggregates - Parking Place Availability Reports

A single aggregate report is 20 bytes in size and illustrated in figure 7. Along with the fields used in parking place availability reports depicted in figure 5 two additional values are included within the aggregate report. Firstly the level of the cell belonging to the aggregate and secondly the number of atoms n. Referring to section 2.1 a cell is identified by two further parameters i and j which can be extracted from the POO of the aggregate.

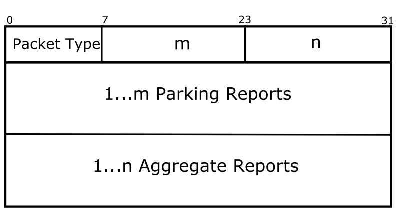

Figure 6: Payload of a Resource Report Packet with Aggregates

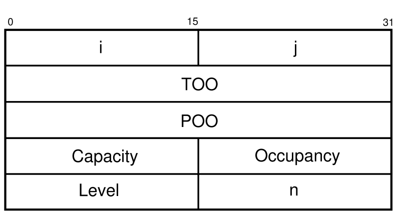

Figure 7: Report Packet Structure Aggregates

2.2.5 Resource Cache

Every vehicle maintains its own resource cache for atomic information and aggregates. The vehicle cache is not limited in size. Each time a vehicle enters the scenario it receives entries and sends its own cache entries periodically to other vehicles. If a vehicle receives different reports about the same resource, the most up-to-date one is integrated into the vehicle cache. To control the cache size growth over time a validity duration of for example 500 seconds can be defined. Resource reports can then be deleted after their validity duration is expired. Because aggregates are more time stable, the validity duration for aggregated information is higher than for atomic information.

2.3 Broadcasting

2.3.1 Broadcasting Parking Place Information

Parking automats are the producers of resource reports. They are able to sense their occupation status at any point in time and broadcast this information encapsulated in a resource report packet.

The minimum broadcast interval needed to exchange information with nearly all passing vehicles for reports can be estimated as follows. Considering a communication range of 300 m, a vehicle driving past the parking automat with approximately 40 km/h on a straight lane is able to communicate with the parking automat for approximately 54 seconds. Because of the validity period of a report, which can be greater than 200 seconds and the fact that vehicles rebroadcast received information, a parking automat must not necessarily exchange its information with every passing vehicle. Furthermore, obstacles and unpredictable vehicle movement patterns also influence the time period a parking automat can exchange its information with a vehicle. In our simulations we have fixed the broadcast interval of parking automats to 10 seconds. The size of a report packet disseminated by a parking automat is 92 bytes.

2.3.2 Inter-Vehicle Broadcast

Each vehicle starts with an empty cache, i.e. it has not obtained any resource report. During its trip, it receives resource reports from parking automats or other vehicles. Received reports are integrated into a vehicle's cache. The size of a report packet in inter-vehicle broadcast is $76+(n \cdot 16)$ bytes, where 76 bytes represent the packet overhead (IP, MAC and Container Packet) for control information and n the number of reports integrated (see section 2.2.2). For a maximum allowed packet payload size of 2312 bytes for IEEE 802.11, a packet is able to contain up to 139 parking place reports.

The optimal vehicle broadcast interval heavily depends on street topology, velocity of vehicles, vehicle density as well as obstacles and therefore cannot be determined through analytical calculations. To overcome the difficulties caused by these parameters, the optimal broadcast interval is determined by simulation.

Considering an average vehicle velocity of 40 km/h ($\approx$ 11 m/s) and a transmission range r of 300 m the communication interval (CI) for two vehicles on a straight road can roughly be calculated by the following equation:

$$CI = \frac{2 \cdot r}{v_{rel}} = \frac{2 \cdot 300m}{2 \cdot 11\frac{m}{s}} = 27s$$

This calculation encourages us to state that the optimal inter-vehicle broadcast interval should not be higher than 27 seconds. The optimal inter-vehicle broadcast interval guarantees a certain level of information distribution quality and optimizes the bandwidth consumption of our algorithm.

2.4 Selection Strategies based on Relevance

In general, relevance describes how applicable some information is. The relevance of a resource report R is calculated through a relevance function $r(R)$. The given definition allows to compare and rank reports based on defined criteria.

The goal, by applying a selection strategy, is to disseminate information in a user-centric way. This means that the driver receives inaccurate information about regions farther away and precise information about its local neighborhood. Received inaccurate information, i.e. aggregates of different levels are used to determine the best suited parking area. For this, it must be ensured that aggregates are distributed over larger distances than atomic information.

To achieve this, we have applied a strategy in which information is prioritized and selected based on its local relevance. We have identified two influencing parameters: the age of a resource and the distance to a resource. Combined with the periodic broadcast interval, these parameters are used to control the distribution of atomic and aggregated information.

The selection of resources is a two step process:

1. Determine the relevance separately for atomic and aggregated resources.

2. Select most relevant reports for broadcasting.

In particular the selection strategies for resources and aggregates are:

2.4.1 *Selection Strategy for Atomic Information*

For the relevance of atomic information $r(R)$ two factors are considered: firstly, the age of a resource and secondly, the distance d to a resource. We convert the distance into time by assuming an average speed v of vehicles in urban traffic conditions. The formula for the calculation is depicted below:

$$r(R) = -\frac{d}{v} - t$$

After ranking reports based on this calculation, top m entries are selected and local distribution is ensured. The value m directly influences the distribution distance of atomic information within level 0 borders and therefore should be set to the maximum number of resources within a level 0 area.

2.4.2 *Selection Strategy for Aggregates*

To control the spatial distribution of aggregates, we have adopted subtle changes to our selection strategy for atomic information. Our selection strategy is based on the calculation of aggregates' relevance and is described as follows:

$$\mathrm{r}(A) = \begin{cases} -t & : \text{ vehicle inside aggregate A} \\ \frac{1}{n}\left(-\frac{d(A)}{v} - t\right) & : \text{ vehicle outside aggregate A} \end{cases}$$

After calculating the relevance of aggregates, they are seperately ordered for each level with respect to their relevance. A fixed number of relevant aggregates are then chosen from each of these levels and broadcast to other vehicles. The number of aggregates to be sent can be different for each aggregate level. In this way, the aggregates from each level would be distributed in a higher level as efficient as possible. The distribution of aggregates from a subordinate level must be ensured in its superior level because the quality of a higher level aggregate depends heavily on the availability of its lower level aggregates.

Our strategy guarantees the following selection: Aggregates of level $0, ..., l$ which correspond to the area covering a particular vehicle, are selected at first. The number of all other aggregates selected next, depends on the total number of aggregates limited by the maximum packet size. We define $d(A)$ as the relative distance between the cell border of an aggregate and the position of a vehicle. We take $d(A)$ and $\frac{1}{n}$ the number of atomic information within an aggregate additionally into account when two aggregates of same level are compared. By applying this selection strategy, most up-to-date aggregates in the closer proximity are ranked first.

An example will clarify the selection of aggregates. Let us return to figure 3, where a vehicle driving within the level 0 cell $(3, 2, 0)$ will first select the covering aggregates $(3, 2, 0)$, $(2, 1, 1)$ and $(1, 1, 2)$. Next, the aggregates are selected that do not cover this vehicle, but are relevant based on the relevance function. This will ensure the distribution of local aggregates. Again following our approach, the preferred aggregates of level 0 as shown in figure 3 are basically all surrounding level 0 aggregates $\{(2, 3, 0), (2, 2, 0), (2, 1, 0), ...\}$, the level 1 aggregates $\{(1, 2, 1), (2, 2, 1), (1, 1, 1), (2, 1, 1)\}$ and the top level aggregate $(1, 1, 2)$. The distribution of level $0, 1, 2, ...$ aggregates in the immediate neighborhood is again ensured through this selection strategy. Here we have omitted the time component and the number of atomic information within an aggregate to simplify our example, but in our simulation the impact of the age of aggregates and the number of atomic information within an aggregate has also been considered within the relevance function.

3. SIMULATION ENVIRONMENT

In this section, we present the simulation environment and its setup used to carry out the simulations that were used to analyze our parking place algorithm. The simulation environment consists of two parts, a traffic simulator including a realistic model of a german city and the ns-2 network simulator [1]. These two parts are coupled in order to simulate VANETs [6]. The algorithm has been implemented using the ns-2 network simulator. The microscopic traffic simulator VISSIM [2] is used to generate a realistic city model including vehicle movements on complex multiple lanes, traffic lights and radio obstacles.

3.1 Scenario Setup

The traffic simulator, VISSIM, is a microscopic, discrete time simulation model developed to model urban traffic and public transport systems. A speciality of VISSIM is the model used to simulate the driving behavior. This is not based on constant speeds or a deterministic car following logic, but the psychophysical driver behavior model developed by Wiedemann [11]. 129 existing parking automats are modelled in our simulation set-up. Each of these automats constantly broadcasts its information to vehicles in its immediate neighborhood.

The scenario used for the simulation is a model of the city of Brunswick situated in north Germany. Average dimensions of the city are north-south: 19.1 km and east-west: 15.7 km with round about 522 km street length and up to 10000 vehicles.

The traffic model is based on actual measurements taken by the city of Brunswick at strategic measurement points. The model represents the traffic situation from 6:00 A.M. till 10:00 A.M. with a maximum tolerance of 15% at the measurement points. For the results to be independent from any specific vehicular movement pattern, simulations were performed with 20 different initial random seeds for vehicular movement generation, resulting in 20 different movement patterns. The number of vehicles over time in the scenario is depicted in figure 8.

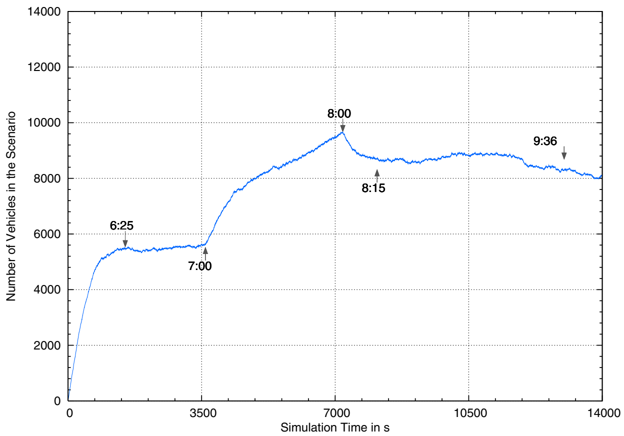

Figure 8: Number of Vehicles over Time in the Brunswick Scenario

3.1.1 *Variation of Occupancies*

Since our research is focused on information distribution, we have chosen a simple approach for the purpose of modelling the temporal nature of parking place occupancies. The occupancy information is derived according to a uniformly distributed random variable X between $[0, 1]$ which can be interpreted as follows:

- $0 \leq X < 1/3$: a vehicle arrives and would park if there is at least one slot left.
- $1/3 \leq X \leq 2/3$: neither a vehicle parks nor a vehicle leaves.
- $2/3 < X < 1$: a vehicle leaves the parking place.

The calculation of the occupancy is done everytime before a parking place broadcasts its information, i.e. every 20 seconds. Each modelled parking automat is used to pay for parking time for free parking places in its responsibility area. All positions and parking capacities are obtained from the department of traffic and civil engineering, city of Brunswick.

3.2 Ns-2 Settings for IEEE 802.11b

For the purposes of this study, we took the specifications from the ORiNOCO 11b [9] client PC card which complies with the IEEE 802.11b specifications and adopted them to the network simulator ns-2. The data transmission

Penetration rates %	1, 3, 5, 8, 10, 20
Broadcast Intervall	10, 20, 30, 50
Replacement Strategy	Timestamp Based

Table 1: Parameter Simulation I

rate used for the simulations is 11Mbps with a transmission range of 300m. The Two-Ray-Ground propagation model has been used in conjunction with the modelling of obstacles in the traffic simulator VISSIM. Obstacle modelling allows dropping packets at the physical layer, if an obstacle is encountered between two communicating vehicles. To analyze worst case performance every other object in the model except streets and junctions is considered as obstacle.

4. SIMULATION STUDY

In this section, the performed simulations are described. Our simulation starts with the traffic situation at 06:25 A.M. with approximately 5600 vehicles on the roads. The time from 06:00 till 06:25 is used to let the vehicle movements stabilize to a realistic traffic state. This is necessary due to restrictions given by the traffic simulator VISSIM.

4.1 Methods of Simulation and Measured Values

We have defined three simulations, where each preceding simulation is the basis for the next simulation run. In simulation I we are interested in understanding system parameters such as the inter-vehicle broadcast interval and the impact of penetration rates. Simulation II proves the applicability of our presented strategy to keep information local. Finally simulation III introduces aggregates to distribute aggregated information over large distances.

In our simulations, we do not delete entries out of the vehicle cache. This is because we assume that vehicles have an unlimited cache size. Furthermore, the information validity, i.e. how long information is valid, depends heavily on the topology. For example the city environment, parking place characteristics and traffic situation are different for each city. Therefore, the deleting process of entries depending on a certain validity threshold is an application layer issue and will not be discussed further.

4.2 Simulation I: Plain Dissemination

In plain dissemination every vehicle broadcasts all its cache entries periodically assuming that surrounding vehicles will benefit from every single report. In simulation I, only atomic information is exchanged among vehicles. The applied information replacement strategy is based on timestamps, i.e. older reports of the same resource in the vehicle cache are replaced by more recent ones.

The objective of this simulation is to reveal the performance of plain periodic broadcasting of atomic information in a realistic scenario. We are especially interested in the optimal broadcast interval which yields to optimal information distribution. The vehicle broadcast interval (VBI) explained in section 2.3.2 and the penetration rates figured out in simulation I will be set as the broadcast interval in our simulation studies II and III.

Several simulation runs with different penetration rates and vehicle broadcast intervals are taken. Researched parameters and their variations are depicted in table 1. The measured values and plots showing the results are presented in the following subsections.

4.2.1 Cache Over Time - COT

Objective and Realisation: Our COT measurement shows the cache size over time. In particular we would figure out the time needed to distribute information about the modelled 129 parking places to all vehicles in the network. For each configuration we have summed up the number of cache entries in each vehicles cache in every simulation second. In the graphical example depicted in figure 9, the y-axis

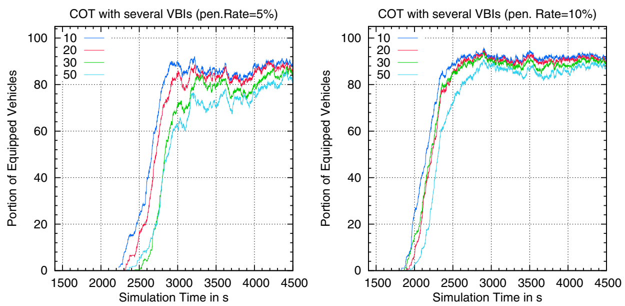

Figure 9: Influence of the VBI on Vehicles Obtaining a Cache Size Greater than 120 Entries

denotes the portion of equipped vehicles with a cache size $\geq$ 120 entries. The vehicle broadcast intervals vary from 10 to 50 seconds. The left graph shows the obtained results for 5% penetration rate and the right one for 10% penetration rate.

Through simulations we observed two effects:

1. The elevation of the curves, which represent the time needed to distribute up-to-date parking place information to nearly all vehicles, increases with penetration rate. In figure 9 the time where the first vehicle reaches a cache size $\geq$ 120, by using a penetration rate of 5% and a vehicle broadcast interval (VBI) of 10 seconds, is at simulation second 2300. With 10% penetration and the same VBI, the cache size of $\geq$ 120 is reached at simulation second 1800.

2. For low penetration rates, a VBI value greater than 20 seconds has negative influence on the information distribution. Independent of the penetration rate VBI values $\leq$ 10 seconds have no significant positive effect on the information distribution quality. This can be justified by the fact that, if vehicles are in transmission range the communication time is between 10 and 30 seconds. However, once the penetration rate rises, vehicles encounter other equipped vehicles more often and the information distribution no longer suffers from VBI values $\geq$ 30 seconds. Keeping characteristics of the wireless medium in mind, setting the VBI to values $\leq$ 10 second would increase the MAC-layer load. For this reason, we have set the VBIs for all simulations as shown in table 2.

Conclusion: We conclude from our COT measurement, the higher the penetration rate and the lower the vehicle broadcast interval (VBI), the faster information is distributed through the VANET. An optimal VBI is scenario specific, but for vehicular movements in city environments the order of 10 seconds is a reasonable value.

Penetration rate	VBI
1%	10s
3%, 5%, 8%	20s
10%, 20%	30s

Table 2: VBIs chosen for the Brunswick scenario

Penetration Rate	Age
10%	8 minutes
8%	10 minutes
5%	13 minutes
3%	15 minutes
1%	30 minutes

Table 3: Average Age of Information at Different Penetration Rates

4.2.2 Age Of Resources - AOR

Objective and Realisation: We observed in our COT measurements that through our periodic broadcast approach, it can be assured that after a certain time, more than 80% of equipped vehicles receive information about nearly all parking places. After the saturation phase, information has almost spread throughout the network, hence vehicles entering the scenario will receive information instantly. Therefore we are interested in the age of resources in the vehicle cache.

In every simulation step, we have calculated the minimum, maximum and average age of resources. In addition we have calculated the deviation between the maximum and the average age of resources in the vehicle cache.

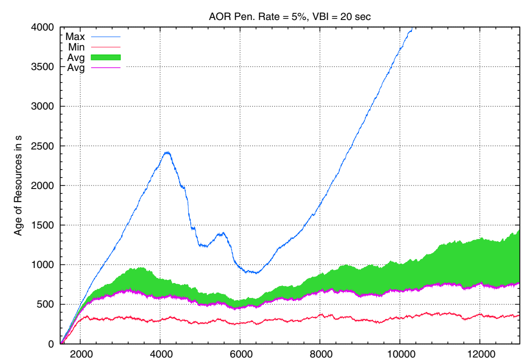

Figure 10: Resource Age over Time Measurement with 5% Pen. Rate

As shown in figure 10, considering the simulation results for a penetration rate of 5% and a vehicle broadcast interval (VBI) of 20 seconds, the average age of information is about 5 minutes and the average deviation in between 100 and 750 seconds. The maximum curve is caused by a small amount of parking automat reports which are located at streets with low traffic flow. Information in the VANET about these parking places becomes very old in the simulation. But excluding these parking automats the average age of information is close to the observed minimum age of entries available in vehicles cache. Table 3 shows the measured average age of information for different penetration rates in our scenario.

Conclusion: We conclude from our AOR measurements,

Penetration Rate	Distance
20%	4500 meters
10%	3000 meters
8%	2500 meters
5%	2000 meters
3%	1500 meters

Table 4: Average Distance Reached by Resource Reports with Age Less than 5 Minutes

the resource age in the vehicle caches correlate with the equipped vehicle density and the vehicle broadcast interval (VBI) in the scenario. Although it is possible to send information to up to 80% of all vehicles the information ages with distance. This is primarily caused by the vehicular movement pattern which divides the vehicular ad hoc network unpredictably into partitions.

4.2.3 Distance Over Time and Distance Over Age - DOT and DOA

Objective and Realisation: DOT measures the distance between the position of an actually received information and the POO (point of origin) of this resource. Through the DOA measurement we obtain the age of particular resources at certain distances in the network.

We have taken an arbitrary parking place for our DOT and DOA measurements. In the DOT measurements we have plotted the maximum distance where a resource report about an observed parking automat is received for each simulation second. Our DOT measurements in figure 11 show that in average, a maximum spatial distribution of about 6300 meters at simulation time 4000 seconds around the parking automat is reached. Additionally the DOA plot in figure 11 shows that information is up-to-date in its surrounding area, which for example can be 2000 meters, assuming 300 seconds as validity duration for a parking automat information.

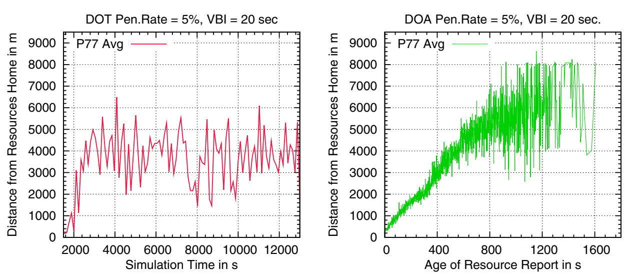

Figure 11: Average Distance over Time and Distance over Age Measurement with 5% Pen. Rate

The measurements in table 4 show the maximum distance for information of age less than 5 minutes.

Conclusion: We observe that the age of information always grows with distance. Received information in larger distances from the home location of a vehicle is more up-to-date with increasing penetration rates.

The information received by vehicles this way should include time delays caused by network partitioning, however the improved validity of aggregated information makes such delays tolerable.

	5% Pen. Rate
VBI	*20s*
n	5926
n_D in Mb	348

Table 5: MAC-Layer Load with 5% Pen. Rate and Plain Dissemination

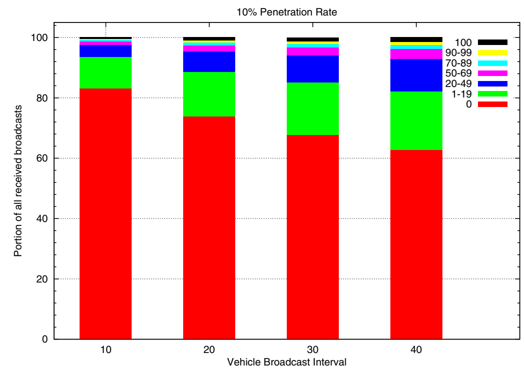

Figure 12: Broadcast Hit Ratio with 10 % Pen. Rate

4.2.4 MAC-Layer Load Measurement

The proposed algorithm is based on single-hop best effort burst transmission using a shared wireless medium. For this reason the channel utilization of each vehicle and the produced channel load of each application should be as low as possible. Along with a high density of parking automats, a high number of equipped vehicles and many simultaneously running applications, the consumption of available bandwidth remains an important criterion. The produced MAC-Layer load on the wireless channel for our specific scenario is depicted in table 5. Here n denotes the number of equipped vehicles, n_D the produced network load over simulation time. In simulation III we show that the network load could be reduced by applying our strategies, namely selective dissemination and aggregation.

4.2.5 Broadcast Hit Ratio - BHR

Objective and Realisation: Continuous data dissemination produces redundancy of broadcast information. The broadcast hit ratio is defined as the number of successfully integrated resource reports m after receiving a broadcast container with n entries, $m \leq n$. Every integrated entry during the complete simulation time is defined as a hit. The focus of this measurement is to quantify the level of redundancy caused by our information dissemination scheme.

$$BHR = \frac{m}{n}$$

As depicted in figure 12 the number of broadcast hits is quite low. This, in turn, means that the number of redundant broadcasts is very high even with VBIs of 40 seconds.

Conclusion: Due to the expected partitioning of the vehicular ad hoc network, especially in the rollout phase of this technology, where the number of equipped vehicles will be low, redundancy shall assist information distribution and is therefore desirable.

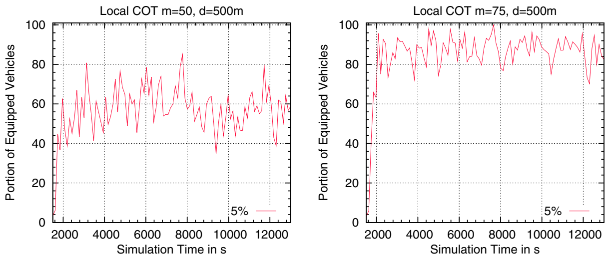

Figure 13: Number of Local Cache Entries over Time with 5% Pen. Rate

4.3 Simulation II: Selective Dissemination

Objectives and Realisation: From simulation I in section 4.2.3 we can derive that up-to-date atomic information cannot be distributed over the complete city area, but within a given locality. Therefore the main focus of simulation II is to restrict the spatial distribution of local information by applying the selection strategy defined in 2.4. We assume, vehicles only need accurate parking place information of their vicinity. By broadcasting only a subset of entries we assure the local spatial distribution of information. To achieve the local distribution of entries, we select a subset m of cached information.

In figure 13 we have plotted in every simulation step the portion of equipped vehicles in a predefined radius of 500 m with at least 75% of information out of all parking automats available (up to 60). We observe, if the number of broadcast entries m is higher than or equal to the number of parking automats in the defined radius, nearly all vehicles receive their information. Otherwise the distribution of information in the defined radius is not assured.

Conclusion: From the taken measurements, we state that it is possible to restrict the spatial distribution of information by applying our selection strategy. The number of broadcast entries must be greater than or equal to the number of parking automats available in the defined radius.

4.4 Simulation III: Distribution of Aggregates

Objectives and Realisation: Simulation II shows that the distribution of up-to-date information can be limited by space as well as time and that local distribution can be assured. To ensure a system behavior that matches the defined use case outlined in chapter 2, the driver receives coarse information while driving into a city. To achieve this we have proposed in our algorithm in section 2.2.3 the usage of aggregates. An aggregate combines several reports into one and represents inaccurate information covering larger regions. Inaccurate in this context means that information located in a certain area is summarized. The distribution of aggregates follows the hierarchical concept defined in chapter 2.2 and the selection strategy described in chapter 2.4. Figure 14 depicts a measurement with 5% penetration rate, m=3 for aggregates, m=75 for atomic information and a VBI of 20 seconds. m=3 denotes that a vehicle sends out the most relevant 3 aggregates. In our simulation for each vehicle, we have summed up all received aggregates in predefined ranges from 500 m to 7000 m. We observed that in a range between 0 m and 500 m the number of received level 6 aggregates is around 23%. The percentage of level 6 aggregates increases to more than 60% when a range of 7000 m is considered.

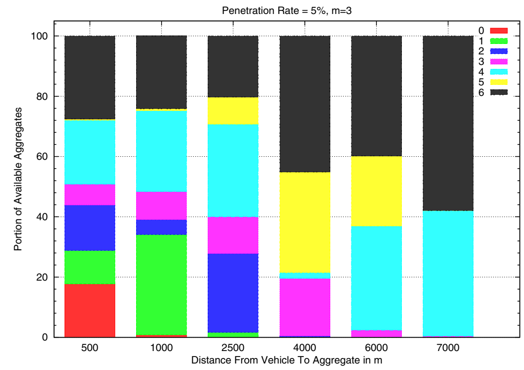

Figure 14: Received Aggregate Levels over Distance

	5% Pen. Rate
VBI	*20s*
n	6028
n_D in Mb	220

Table 6: MAC-Layer Load with 5% Pen. Rate and Aggregation

Table 6 shows that MAC-Layer load can drastically be reduced when selective broadcasting combined with aggregation is used. The produced overall network load n_D is 37% less than the produced network load for the scenario in table 5.

Conclusion: By applying the proposed selection strategy, the spatial distribution of aggregates can be controlled. The portion of higher level aggregates in a vehicle cache increases with distance and reduces the needed bandwith.

5. RELATED WORK

The goal of TrafficView [8] is to exchange information about speed and positions among vehicles in order to enable each vehicle to view and assess traffic conditions. Similar to our approach, vehicles in TrafficView periodically broadcast information. To be scalable, the broadcast information among vehicles is aggregated. In SOTIS [12], received traffic information is aggregated based on road segments on the highway. Compared to SOTIS or TrafficView, both of which are concepts mainly designed for highways, our algorithm is designed to inform drivers about free parking places within a city area in particular downtown areas. The main difference is that our aggregation is based on a hierarchical quad-tree structure instead of road segments. Aggregates generated in this way are used to control bandwidth consumption and to adjust the accuracy of distributed parking place information.

Our algorithm determines the attractiveness of each parking place or parking area by taking the temporal and spatial validity into account. Wolfson [13] proposes a similar resource discovery scheme for spatio-temporal information. Each vehicle broadcasts a subset of available resources to its neighborhood. A vehicle starts its search by moving around an area where a spatio-temporal resource may be available. In case of parking places, the search continues until a free parking place is found. This is because the distributed information is about one single parking place and therefore not necessarily time-stable. In our approach, we guide the driver towards areas with a high number of free parking places. This is very useful, especially while driving into an unfamiliar city. Therefore, we build aggregates starting from single parking place information and distribute them to other vehicles within a VANET. Aggregated parking area information is more time-stable than a single parking place information and can therefore be distributed over larger distances. Moreover, compared to sending information about all parking places to all vehicles, broadcasting aggregated information reduces the consumed bandwith as proven in this paper.

In contrast to our proactive approach introduced here, a reactive query-response scheme using unicast routing [7] is proposed for interlinking parking meters in [4]. This concept assumes that parking meters are within communication range. Moreover they cluster parking meters within communication range via wireless links. Each parking meter has a defined role, such as being a cluster head. The parking meter network built in this way, is able to respond to queries from vehicles passing by. The usage of radio frequency techniques such as RFID or IEEE 802.11 is suggested but not specified and no simulation results are presented. A vehicular information transfer protocol (VITP) is presented in [5]. VITP is also query-response based and defines a service model for querying vehicles over large distances. Simulation results of VITP show that with increasing distance and decreasing number of equipped vehicles, the number of dropped queries increases drastically. Therefore the authors propose either to improve caching strategies for vehicles or to additionally use GSM or GPRS for routing purposes.

The simulations presented in this paper are performed in the integrated simulation environment, introduced in [6].

6. CONCLUSION

Based on our introduced algorithm and the obtained results from our simulation study, we conclude that applications like the free parking place discovey algorithm are potentially attractive rollout applications for VANETs. With the overlay grid and the selection strategies applied, we have achieved our goal to send aggregated information into farther regions and confine atomic information within local areas. Due to our periodic broadcasting scheme, the efficient coding of information and our selection strategy, the introduced algorithm proved to be bandwidth efficient.

We believe that the deployment of IEEE 802.11 infrastructure shall assist our application, because it will positively effect the wireless connectivity of vehicles.

It may be noted that our algorithm is not limited to parking place information and can be applied to efficiently disperse all kinds of traffic information with spatio-temporal nature. However, the way how each vehicle processes this information to reach a decision regarding the most appropriate resource for itself, has not been our focus as yet. Such information processing could be different in each vehicle, and many different parameters could be taken into account. Examples of such parameters in case of parking places could be least tolerated walking distance of a parking place from destination, cheapest parking rates, special parking places for handicapped persons etc. If multiple vehicles were to use the same algorithm to find out the most appropriate parking place by evaluating the same parameters, there is a possibility that many vehicles would attempt to reserve the same parking place at the same time. Fair resource sharing in the context of our parking place search application is left for future work.

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