Het verbeteren van stedelijk parkeren door betere informatie: de mogelijke impact van auto-naar-auto communicatie

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Samenvatting

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Onderzoek heeft uitgewezen dat tot dertig procent van het al het verkeer in drukke stedelijke gebieden kan bestaan uit voertuigen die actief op zoek zijn naar een parkeerplaats. Door enerzijds het aantal voertuigen te verlagen dat zoekt naar een parkeerplaats of anderzijds de zoektijd per voertuig te verlagen moet het mogelijk zijn om de vervuiling en verspilling van tijd en brandstof terug te brengen. Het beschikbaar maken van informatie voor automobilisten kan mogelijk helpen om de zoektijd voor deze automobilisten te verkleinen en daaruit volgend de zoektijd voor het verkeer in het algemeen. Meeste steden voorzien automobilisten tegenwoordig van informatie met betrekking tot de bezetting van de aanwezige parkeerfaciliteiten, echter de informatie met betrekking tot straat-parkeren was tot kort geleden niet beschikbaar. Het doel van dit paper is het onderzoeken van de impact van bottom-up verspreiden van informatie over elke parkeerplaats op straat en de daaropvolgende gevolgen voor de individuele automobilist en het algehele systeem van alle automobilisten bij elkaar. In het onderzoek wordt gebruik gemaakt van een agent-based simulatie model dat de prestatie vergelijkt tussen een strategie waarbij bottom-up auto-naar-auto communicatie wordt gebruikt en een strategie waarbij parkeersensoren worden gecombineerd met auto-naar-auto communicatie. Bij de tweede strategie worden alle parkeerplaatsen op straat uitgerust met een sensor die in staat is om informatie te verspreiden over de huidige status. In tegenstelling tot onze verwachtingen laten de resultaten zien dat voor beide strategieën de zoektijd nauwelijks verminderd wordt. De prestaties met betrekking tot de loopafstand worden alleen beter in situaties waarbij de initiële bezettingsgraad tegen de 100% ligt, bij het gebruik van auto-naar-auto communicatie. Daarentegen wordt loopafstand bij het gebruik van sensoren juist in alle situaties teruggebracht.

1 Introduction

Studies have shown that the amount of cars cruising for parking can exceed one third of all traffic in large crowded city centers (Shoup, 2005). By either decreasing the amount of cars cruising for parking or decreasing the cruising time per car, it is possible to reduce the unwanted effects of this phenomenon, including pollution and waste of resources (time and fuel). The provision of information to drivers on available on-street parking places may be one way to achieve this. Such information can potentially be beneficial for the overall system, as well as for individual drivers.

While most cities provide drivers with information on the occupancy rates of off-street parking facilities, information on single on-street parking places was non existing until recently. This is changing rapidly, as a number of (start-up) companies have entered the market to provide this type of information, making use of the widespread penetration of smart phones and in-car navigation devices ("LA Express Park", "Park.it SF Parking made easy", "Streetline: Parker Mobile"). The aim of this paper is to explore whether information provision on on-street parking places can indeed reduce search time for the individual driver as well as for the entire population of drivers in search for parking.

There are a number of technologies to provide information on on-street parking places. One possibility is the use of vehicle-to-vehicle communication using Vehicular Ad-Hoc Networks (VANETs) (Leontiadis & Mascolo, 2007; Prinz, Eigner & Woerndl, 2009). VANETs are derived from MANETs (Mobile Ad-Hoc Networks), and provide a way to share information among nodes in a network using bottom-up dissemination. Given their properties, VANETS are very suited for disseminating on-street parking place information. The network is formed by mobile units (in our case, vehicles) that have the ability to send and receive data via wireless technologies (i.e. dedicated short-range communication, DSRC). Because of the limited spatial range of this technology, as well as by the short-term nature of the information, the networks are referred to as 'ad-hoc'. VANETs have the advantage that they can gather and disseminate information in a dynamic and fast way, which is crucial as the availability of on-street parking places is subject to frequent changes. Another important aspect of VANETs is the way information is disseminated. VANETs enable for bottom-up information gathering and dissemination, instead of centralized dissemination. Bottom-up information dissemination ensures that the system is robust and not dependent on a central organ for collecting and providing information to vehicles in the network.

Besides vehicle-to-vehicle (V2V) communication, there are some derivatives which can also be used in a VANET information management context. These are vehicle-to-infrastructure (V2I), a hybrid architecture consisting of both V2V and V2I, and more recent vehicle-to-pedestrian (V2P) (Liu et al., 2010). Several methods of how to exchange messages exist: push based dissemination, routing protocols dissemination and broadcasting-based dissemination (Kakkasageri and Manvi, 2013). In this study the neighborhood broadcasting method is used, also called a gossip protocol (Das et al., 2004; Tasseron and Schut, 2009). This method is used first and foremost because it is simple. Second, information on parking should be disseminated in all directions, contrary to applications which distribute traffic jam information where the information is disseminated upstream. Third, our goal is to show whether it is useful to share information at all, not to find the most efficient method to distribute information.

While a number of studies have analyzed the possible contribution of vehicle-to-vehicle (V2V) communication to the management of road traffic (ElBatt et al., 2006; Tasseron and Schut, 2009; Wischhof et al., 2005), and a few studies have explored the technical feasibility in a parking context (Caliskan et al., 2006; Delot et al., 2009; Szczurek et al., 2010a, 2010b; Vaghela and Shah, 2011), no research exist that has explored whether the use of V2V communication could actually lead to an optimization of parking dynamics. This paper aims to start filling that void by studying the impact of bottom-up information dissemination on the performance of individual drivers and the system as a whole. We compare a bottom-up strategy in which only vehicles can send and receive information (V2V communication) with a strategy that combines on-street parking sensors ("Nedap Avi", "Park.it SF Parking made easy") capable of disseminating their status and vehicles able to send and receive information (from now on referenced as S2V (sensor-to-vehicle) communication).

2 Bottom-up information provision

Text In both the V2V and S2V simulations, we distinguish cars according to two dimensions: (1) whether a car is capable of communicating (V2V) or not; and (2) whether a car is looking for a parking place in the study zone or not. V2V-cars are able to send and receive messages within a fixed transmission range of 200 meter, which has been shown to be a practically feasible transmission distance, even under non-optimal conditions (Demmel et al., 2012). In the V2V scenario, a V2V-car will send out a message as soon as it leaves a parking place about the availability of the parking place it just vacated. In the S2V scenario, the sensor will send out this message, during the entire period that the parking place is unoccupied. In both cases, the messages are received by all V2V cars within the transmission range, which will pass on the message to other V2V cars. Important to note is that in the V2V scenario, unoccupied parking places at the start of the simulation and departures of non-V2V-cars will not lead to the creation of a message. In the S2V scenario, a message is always created and disseminated. This situation is similar to an early morning snapshot, where no or few people have left yet. Thus, all earlier created messages have been dropped.

In the second series of experiments on-street parking sensors are introduced. The sensor is capable of sensing its occupation status: available or not available, and is able to communicate with nearby cars. In other words, the sensor can be regarded as a static V2V-car with limited capabilities. Limited in the sense that it is not able to store or pass on messages on other parking places, nor does it have an internal knowledge base to store messages. The sensors will transmit their status to nearby cars only when their status is set to available, i.e. the parking place is unoccupied. Sensors have the same transmission range as V2V-cars. As far as we know sensors in real life are not able to communicate directly to vehicles (yet). They are connected to another infrastructural unit such as a parking meter or a lamppost, which in turn is able to communicate with vehicles (V2I). Although this is an unrealistic assumption to simplify the model, the overall process will not differ from using lamppost or parking meters.

A message consists of a number of attributes (*Figure 1*): (1) the timestamp, which is the moment when parking place became available; (2) the location, which is stored as a coordinate; and (3) the number of 'hops'. A hop is the transfer of a message from one car to another. The number of hops thus represents the number of times the message has been passed on to other cars. This is an indication of the chance that another V2V-car looking for a parking place may also have received the information about this available parking place. However, it is important to note that this is a proxy as the message can spread in multiple directions, leading to separate hop-counts for each direction.

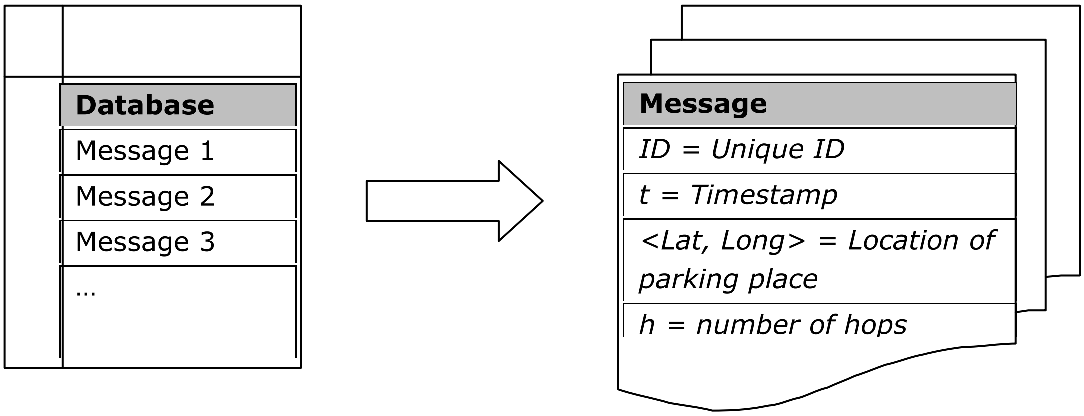

Figure 1. Database and message attributes

Each V2V-car that receives a message on an available parking place will thereafter process the message. If the car is looking for a parking place it will rank the message for its usefulness for own use, depending first of all on the distance between the parking place and the final destination of the car. If it is useful, the message will be stored in a database and ranked according to the relative value (*v*) of the parking place according to the process presented in figure 2. The value is based on the location and the age of the message (*equation 1*).

$$v = \frac{d_c}{V_{car}} + \frac{d_w}{V_{walk}} + \propto \cdot\, h + \beta \cdot t \tag{1}$$

Where:

$d_c = distance\ between\ current\ position\ and\ parking\ place$

$d_w = distance\ between\ parking\ place\ and\ final\ destination$

$V_{car} = cruising\ speed\ of\ all\ cars\ (14\ Km/h)$

$V_{walk} = walking\ speed\ (5\ Km/h)$

$\propto\ and\ \beta\ are\ respective\ weights\ for\ hops\ and\ time$

For now the weights are kept relatively low ($\propto = 1$ and $\beta = 0.1$) and remain the same throughout all experiments. This implies that distance, between parking place and final destination and between current position and parking place, strongly shape the rating of parking place.

Each V2V-car is equipped with two databases that are able to store messages, a private database (*KBpriv*) and a public database (*KBpub*). The private database (*see Figure 2*) has a limited capacity (*Mpriv* = Max. number of stored *private* messages). If the number of messages has reached the maximum capacity and the new message has a higher value than the worst scoring message in the database, the new the message will replace

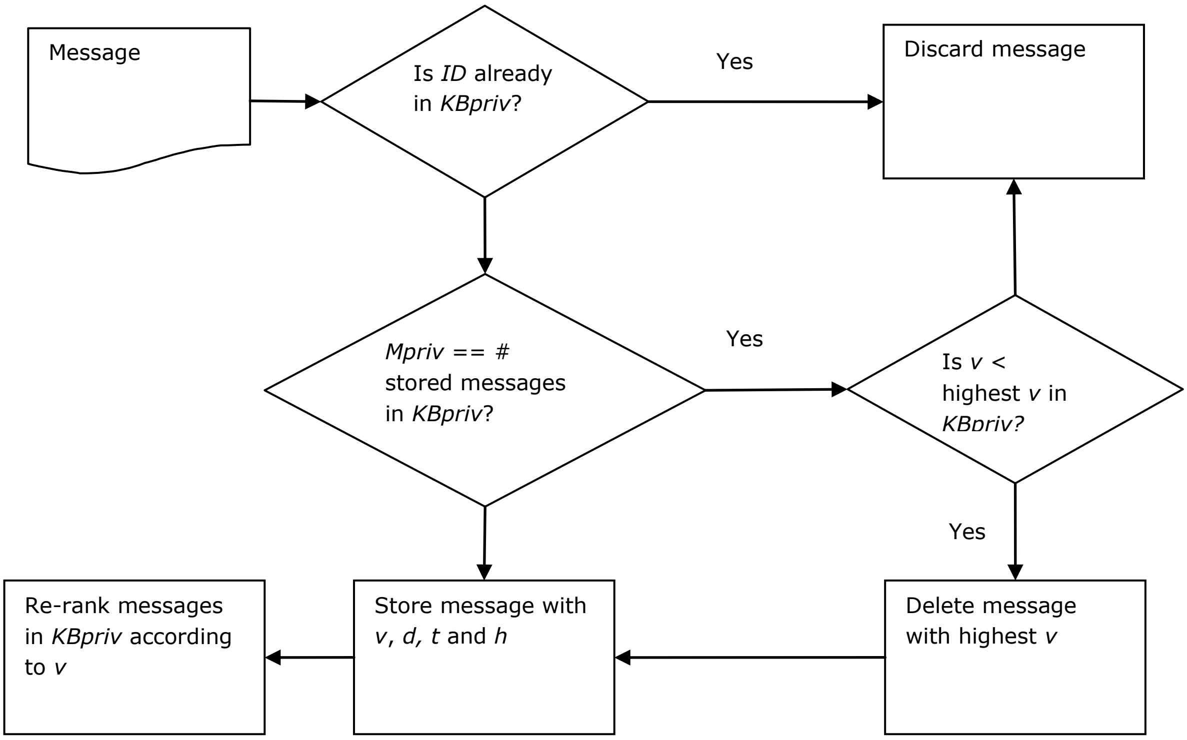

Figure 2. Processing of messages for storage in private database

the worst scoring message.
In addition to the private database, each V2V-car also maintains messages in a public database for general use *see Figure 3*). This public database holds a limited number (*Mpub* = Max. number of stored *public* messages) of messages which are ranked according to age. When the database has reached its maximum capacity, a newly arriving message will replace the oldest message in the database if it has a more recent timestamp. When the message is stored, the value of *h* is increased with one, thus indicating the message has made another hop. V2V-cars that are not looking for a parking place, so called through traffic, will store received messages in their public database as well. Subsequently all V2V-cars will broadcast, on a regular interval, the messages in their public database to cars within the transmission range. Via this method messages on available parking places can traverse the grid in a short time period and thus provide many drivers with information on parking availability. It is important to note that the above described method does not include a reservation system. Thus, it is possible to arrive at a reported parking place and finding it already occupied by another car, which can be a V2V-car as well as a non-V2V-car. Furthermore, note that the private and public database can overlap, i.e. vehicles may broadcast messages to other vehicles that are also stored in the private database and, thus, to potential 'competitors' for the same parking place.

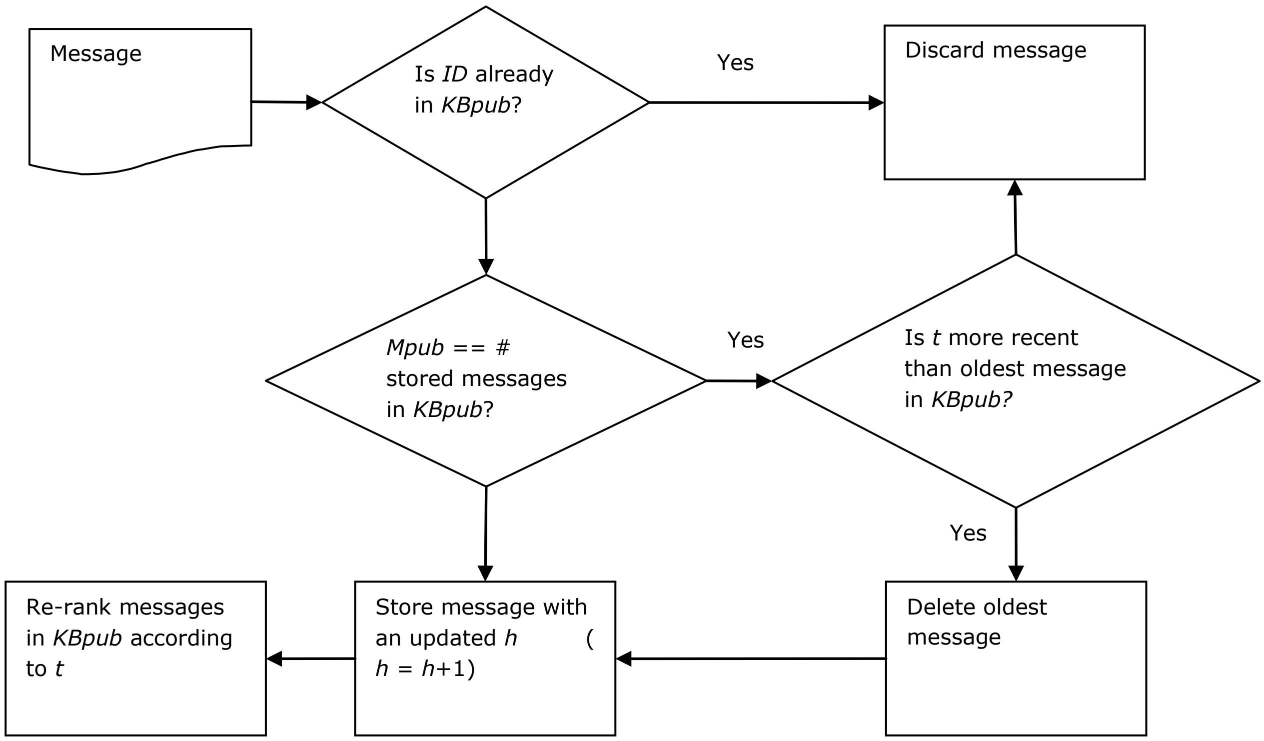

Figure 3. Processing of messages for storage in public database

3 Simulation description

We study the impacts of bottom-up information provision on parking dynamics using PARKAGENT, an advanced agent-based parking simulation model. The basic characteristics of PARKAGENT have been described in a number of papers (Benenson and Martens, 2008; Benenson et al., 2008). For the analysis of parking dynamics under bottom-up information provision we largely follow the simulation environment presented in Levy et al. (2012). The street network used for the simulations is that of a grid (11x11, 12 destinations and 96 on-street parking places on the inner ring of each block), which not only resembles the street plans of many US cities, but also provides the best environment for systematic analysis of parking dynamics. On-street parking places are evenly spaced along all the streets in the network. There are no off-street parking facilities. Destinations (buildings) are also distributed evenly over space. At the same moment an arriving agent is initialized it will receive a random destination as its goal. The starting point of its trip is randomly chosen from a set of starting locations which contains all street locations which are located 400 meters from this particular destination. The route between the landing point and the destination is calculated using Dijkstra's shortest path algorithm.
The choice heuristics with respect to a parking location does not differ very much between a normal driver and a driver of a V2V-car. Drivers of normal cars use the search heuristic already present in PARKAGENT. This heuristic lets the driver monitor the occupancy level along the streets it is driving. The driver then uses this information, together with the distance to the final destination, to estimate the number of expected vacant parking places. The lower the estimation the higher the chance the agent will park

at the next vacant parking place. When the driver overestimated the number of vacant parking places, or there were no vacant parking places at all, the driver will reach the final destination before it has found a parking place. From that moment on the driver will make circular movements around the final destination looking for an empty spot, while slowly expanding its search radius. V2V-cars use the same heuristic; however the estimation of the number of expected parking places is increased by one when it is heading for a disseminated parking place. As the agent knows that there is an extra place available, being the parking place it has received information on. When a V2V-car arrives at the parking place and finds it already occupied it selects the second best parking place from its list and changes direction accordingly. If the list is empty the driver falls back to normal behavior and searches for a vacant parking place by making circular movements around the final destination.

The independent variables are initial occupancy and the penetration rate of cars that are equipped with V2V capabilities. Initial occupancy is the percentage of parking places that are occupied at the start of the simulation. The occupancy level remains more or less the same throughout the simulation period. As the amount of cars that leave a parking place is equal to the amount of cars that enter the simulation area looking for a parking place. During the simulations only situations with an initial occupancy of 90% and above are considered, as these are the conditions at which finding a vacant parking spot can be a daunting task. Besides the occupancy level, the turnover level also has an effect on parking dynamics. Turnover level means the amount of times a parking place is occupied by a different vehicle in a given time interval. High turnover levels will ensure drivers to find a parking spot more easily. During the simulations the turnover level is not varied. Arriving cars will stay parked for the entire duration of the simulation, while the departing vehicles will leave in a uniform fashion. The settings described above create a simulation environment that is similar to that of a residential area with high parking demand, such as cities in western and southern Europe.

Parking performance is measured using parking distance, search time and parking failure. Search time is defined as the amount of time that is passed from the moment the driver has reached a distance of 300 meters from her final destination till the moment she has found a parking place. Parking failure refers to all drivers that have been unsuccessfully searching for a free parking spot for more than 10 minutes. The boundary of 10 minutes has been chosen for two reasons. First, Shoup (2005) has shown that the average search time for a particular residential area is 3.3 minutes overall, while it can be nearly 10 minutes in the busy evening hours. Second, a higher maximum allowed search time can clog up the system very easily in terms of processing performance. We conducted a small sensitivity analysis on the maximum allowed search time in an extreme situation with 100% occupancy. This indicated that a 5 minute maximum search time would yield an increase in the number of cars that failed to park from an average of 26 to 89. An extended maximum search time of 15 minutes decreased the number of parking failures from 26 to an average of 7 failures. For all other initial occupancy rates, 90 and 95%, the number of agents that failed to find a parking place in 10 minutes is below 1‰.

4 Results

The results regarding performance of V2V-cars in comparison with normal cars and the performance of the overall system is described below. The first section covers the results using only V2V-dissemination. Subsequently, the second section covers the results using sensor equipped parking places capable of disseminating their status.

4.1 Vehicle-to-vehicle information provision

4.1.1 Performance of V2V-cars

Contrary to expectations, under most conditions V2V-cars did not perform better in finding a parking place than regular cars, neither in terms of search time nor in terms of distance between parking place and final destination. Only in the experimental settings with an initial occupancy rate very close to 100%, the V2V-cars where performing better than regular cars with regard to walking distance.
Performance for V2V-cars regarding search time does not change much when increasing the penetration rate of V2V-cars (*Figure 4a*). However, the search time for non-V2V-cars is increased slightly with an increasing penetration rate of V2V cars. On the other hand, the performance with respect to walking distance (*Figure 4b*) is increased for V2V-cars when increasing the penetration rate, although only substantial in the case of 100% initial occupancy. When 100% of the cars are equipped with V2V communication, the walking distance is better than in the base situation (0% V2V-cars). The performance in terms of walking distance is higher for V2V-cars than for regular cars in lower initial occupancy settings (90%-95%). This is due to the manner at which VANET-cars evaluate parking places, as choice behavior of normal cars is a bit more influenced by the actual occupancy rate. V2V-cars will always prefer a reported parking place above cruising for parking and have only a small chance of parking at a vacant parking place along their route. This will have a direct result on the parking distance, as low occupancy rates also imply a low number of cars leaving a parking place and thus a low level of information provision. Thus, the chances are higher that a V2V car receives information about a parking place located rather far from the final destination.

4.1.2 Performance of overall system

Performance of the overall system, consisting of all cars looking for a parking place regardless of the type, is not different from that in a situation without any V2V-cars. Considering the slight increase in search time for non-V2V-cars and the stable search time pattern for V2V cars the performance of the overall system is slightly harmed by implementing V2V communication. Search time (Figure 5a) is increased for the overall system at most to 10% (0.8 penetration rate and 100% occupancy).

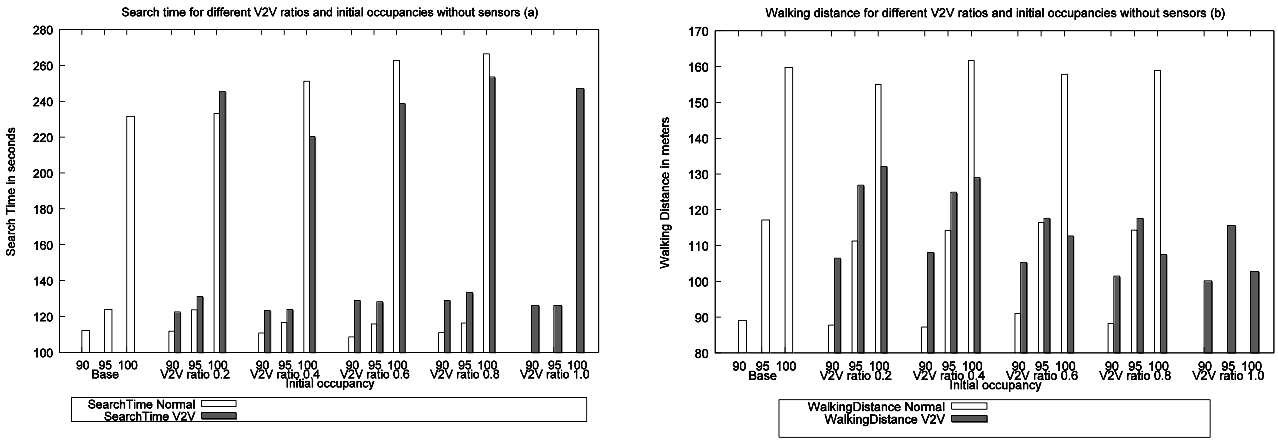

Figure 4. Results using V2V communication for (a) search time; (b) walking distance

However, the overall walking distance (Figure 5b) is decreased with up to 30% for the same penetration rate and occupancy level and even 55% for a penetration rate of 1.0 and 100% occupancy. For lower occupancy levels walking distance stays the same or is raised a little.

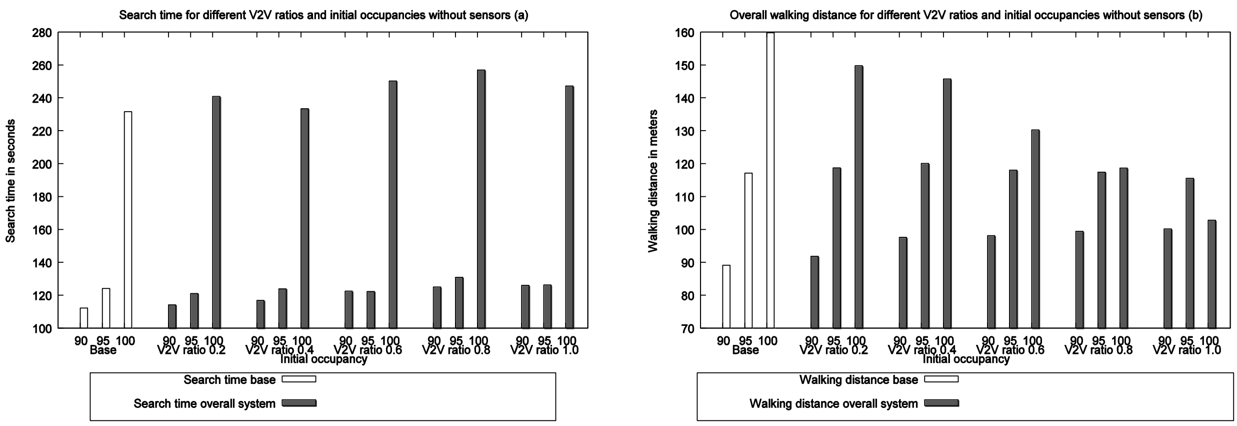

Figure 5. Overall system performance regarding (a) search time; (b) walking distance

4.2 Sensor-based information provision

4.2.1 Performance of V2V-cars

The results show that performance is changed with the implementation of sensors. Search time is similar to the results in section 4.1 for occupancies of 90 en 95%. However, search time is slightly decreased for all experiments with 100% initial occupancy, regardless of penetration rate (*Figure 6a*). Performance with respect to walking distance is better in every situation in comparison to normal cars as well as V2V-cars without using sensors (*Figure 6b*). Walking distance is decreased with an average of 25% for occupancies of 90 and 95%. Furthermore, the results show that walking distance is decreased with an average of more than 40% in situations with 100% initial occupancy.

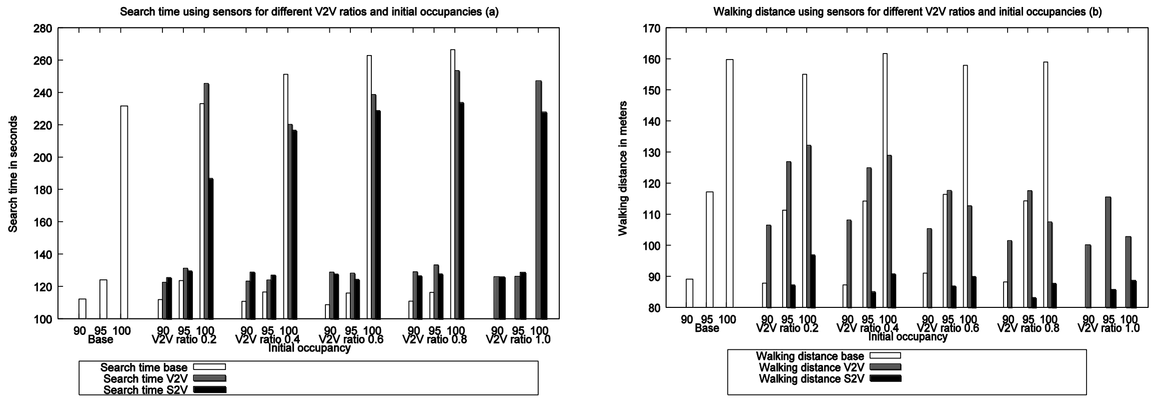

Figure 6. Results using V2V communication and sensor technology for (a) search time; (b) walking distance

4.2.2 Performance of overall system

Considering the slight improve in search time for V2V-cars using sensors, the overall system performance is improved as well. This leads to a search time *(Figure 7a)* on the system level which is more or less equal to the base situation for an initial occupancy of 100%. There is a slight increase in search time for occupancies of 90 and 95%, similar to the results in section 4.1. Overall walking distance is decreased in every situation in comparison to the base situation, with an average performance gain of 33% with a penetrate rate of 1.0 *(Figure 7b)*.

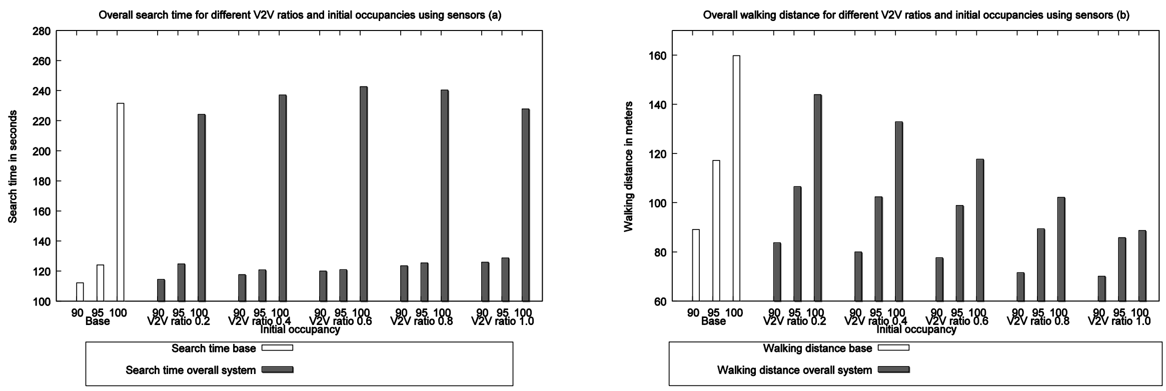

Figure 7. Overall system performance using sensors regarding (a) search time; (b) walking distance

However, the performance gain in search time and walking distance comes with a penalty for the overall system in situations with 100% occupancy. The number of cars that fail to find a parking place within 10 minutes is increased from 5,5 % in the base situation to an average of around 8% without using sensors and around 7 % when sensors are used. This is partly due to the more efficient use of parking places by V2V-cars, which results in longer search times for normal cars (*see Figure 4a and Figure 6a*).

Finally, these longer search times can end up in parking failures for some of the cars. Another reason for the increase in parking failures is the behavior of V2V-cars; they are likely to choose to park at a reported parking place. Instead of parking at an empty spot they may encounter on-route; they all will drive to the reported place, increasing the chance that it is already occupied by another V2V-car. As soon as the car arrives at the occupied place, it will switch to the second best location, and so on. This behavior and the subsequent effect on performance could raise the need for modifications to the system.

4.3 A closer look at search time

Important to note regarding the results is that the search time for V2V-cars can be considered a conservative estimate. Real world drivers using V2V communication will probably drive faster than normal drivers searching for a parking place. In the simulation every car decreases its speed to 14 km/hour when it is within 300 meter of its destination, i.e. cruising speed, the average speed at which cars drive around looking carefully for a vacant parking place. Drivers in a V2V-car will not experience this part of the trip as search time as they will drive directly to the reported parking place. Only when they arrive and find the parking place occupied the actual search, and so search time, starts. When taking this into account the average search time for V2V-cars is decreased from an average of 125 to 14 seconds for initial occupancies of 90 and 95%, which is a decrease of over 80%. For initial occupancies of 100% the search time is decreased from 232 to 114, which is a reduction of approximately 50%.

5 Conclusions & future work

In this paper the effect of bottom-up information provision on performance in the field of parking was studied. The dissemination and use of information on individual parking places could possibly decrease cruising for parking, either by decreasing the amount of cars cruising for parking, or decreasing the average cruising time. Contrary to expectations the results show us that search time is barely decreased and sometimes even increased. This applies to the situation with V2V-cars and for the situation using V2V-cars and parking places with sensors. Only when using a different approach for measuring search time for V2V-vehicles the pursued goal is achieved. The only real benefits for the overall system are noticeable in terms of walking distance. For the situation without sensors this is solely the case in extreme conditions (100% initial occupancy). In the experimental setting where parking places are equipped with sensors the walking distance is decreased in all conditions, so regardless of penetration rate or initial occupancy.

The issue of costs of implementing the system with sensors should however not be neglected. A relevant question to ask is whether this increase in performance regarding walking distance, for situations with high occupancies, justifies the cost for numerous sensors. A decrease in search time is non-existent in most situations, thus leading to no environmental and sustainable performance increase for the neighborhood or city. The only people profiting from a sensor-based approach are the users that have a V2V-car and as such have a high chance of parking closer to their final destination.

Another important aspect in favor of using information provision on on-street parking, which cannot be measured in the simulation, is the psychological aspect of having more guidance in finding an available parking spot. The inherent uncertainty of finding a parking spot is decreased, perhaps leading to more relaxed drivers while looking for a parking place.

As stated in the results section, there is a small increase in the number of cars that fail to find a parking place within 10 minutes. This is partly due to search heuristics of the drivers of a V2V-car. The chance of parking at another vacant parking place along the route should be increased, especially when the driver has already encountered one or more occupied reported parking places. Beside the implementation approach it may also be possible to reduce the number of parking failure by a more systematic approach. Two possible methods to overcome this issue are: (1) a reservation system and (2) providing aggregate information. A reservation system could solve the issue of V2V-cars heading for the same parking place, as it would reduce the competition for parking places among V2V-cars. However, it is impossible to prevent the parking place from being taken by a driver of a non-V2V-car or a driver of a V2V-car that on purpose chooses to park on a different location than the reported parking place. For the second solution, aggregate information, V2V-cars do not receive information on single parking places but receive information on the availability per street segment. This allows for a better estimation of the chance of finding a parking place at the reported location. Furthermore, it would also allow for a reduction in costs as the number of sensors per street segment could be decreased with a certain factor, allowing for the calculation of aggregate information while maintaining the ratio of parking places equipped with a sensor and its availability status.

The first series of experiments shows that the provision of information on available on-street parking places does not lead to an improvement in 'parking success' for informed cars. This may be partly due to the restricted uniform setting in which the experiments took place. The streets, buildings (destinations) and parking places are all evenly distributed over the simulation area. In a more realistic setting buildings are not evenly distributed over space. Furthermore, parking demand per building is even more diversely distributed. This leads to more people wanting to park in the same area or neighborhood, which subsequently ends up in a strong competition for parking places. We expect to find that information is more valuable in such an environment than in a uniform environment. In order to find out the effect of information in such an area we will conduct similar experiments in a more realistic setting, based on a real street network.

In future experiments we want to study scenarios where there are only cars arriving and no cars leaving, leading to more and more competition for places as the simulation progresses. This is similar to the situation of parking in many western and southern European cities in residential areas at the evening hours when people arrive back home from their work. In these conditions the V2V approach will not work properly, as the amount of cars leaving are very low in comparison to the amount of arriving cars. This leads to almost no information on vacant parking places for V2V-cars. The S2V approach however, should perform much better in these conditions as it will result in complete information for V2V-cars.

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