INFORMATION COLLECTION IN VEHICULAR AD HOC NETWORKS

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ABSTRACT

Results from latest developments in wireless mobile communication technologies are quite promising. The utilization of wireless technologies in the emerging field of Car-to-Car communication will make driving more secure and comfortable for the driver as well as for the passengers. Vehicles on the road will form Vehicular Ad Hoc Networks (VANETs) to exchange messages. These messages could be divided into two categories namely "vehicular messages" generated by the vehicle (e.g. sudden break warnings or traffic jam messages) and "personal messages" triggered by the driver, the car or any passenger to fulfil a personal need.

In this paper we discuss the feasibility of exchanging "personal messages" in urban area traffic conditions and present a first concept. Our investigations focus on targeted information collection through parameterized queries in VANETs. As an application example, we analyze the use of personal messages to guide cars towards suitable and free parking spaces nearest to their destination area.

INTRODUCTION

Targeted Information Search in VANETs

In future Vehicular Ad Hoc Networks (VANETs), one vehicle will send inquiries actively to other vehicles, in order to receive individual information about a specific and pre-defined region. Multifarious inquiries possessing special parameters of the sender which give them a personal character are possible. Contents of the inquiries may change in accordance with the driving situation. Hence each vehicle is expected to send different and unpredictable inquiries to the VANET tailored to seek special information.

Examples of inquiries triggered by the car respectively the driver are: the search for a suitable motorway service area on the travel route, finding out the traffic conditions on the travel route, search for information about weather condition in the target area, search for offered leisure activities in a city (e.g. theatre, cinema, social events) or the search for free parking spaces in a target area. Especially "free parking space search" is an application that requires personalized parameters based on the specific situation of the driver with many parameters e.g. target street, tolerated walking distance from exact destination and specific wishes like reserved parking spaces for handicapped persons or those with cheapest parking fare. Summarizing this it can be said that, the target area, the kind of information sought and even the search parameters of the information are individually different for every vehicle.
Existing mechanisms for decentralized information dissemination in VANETs cannot be utilized for personal inquiries triggered by the driver; since they are based on broadcast messaging and the

distributed information (e.g. traffic information) is of general interest. No personal character could thus be embedded into the broadcasted data packets. For these reasons new approaches are needed to solve the problem of targeted information search in VANETs, i.e. from a driver's point of view sending personal inquiries into a pre-defined target area, searching and collecting the requested information in the target area and finally receiving back the results of the inquiries. In this paper, a first concept to overcome the problem of targeted information search in urban traffic conditions using vehicle ad hoc networking is presented. The problem of finding free parking spaces in urban traffic conditions is selected as a reference problem.

Reference Problem: Search for free parking spaces in urban traffic conditions

Searching for free parking spaces in urban traffic conditions is a serious traffic problem becoming from day to day more acute. [1] provides results of a study regarding the free parking spaces problem in the district Schwabing of Munich. 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 for search for free parking spaces
- 150 000 hours of waiting time
- The proportion of park search traffic amounts to 44% of the entire traffic, i.e. nearly every second car is in search for a free parking space. (The statistically determined car traffic in Schwabing is about 80 000 km per day.)

Projected on large cities in Germany with similar districts, a total economical damage from two to five billion Euro per year is estimated.

The question "Whether a free parking space exists in a parking area or not?" can be answered with the help of Car-to-Car communication without the need of additional infrastructure. Such a Car-to-Car application would extend the functionality of today's navigation systems and fill the gap between the navigation system (which navigates a vehicle into a certain road) and the autonomously parking vehicle. Hence investigations in this paper focus on this reference problem.

RELATED WORK

Investigated applications with focus on connecting a vehicle with its surroundings are based on centralized approaches. Communication among vehicles as well as the communication of a vehicle with its surrounding is possible via a backbone network. For example in classical Traffic-Travel-Information-Systems (TTI) [2], the information is collected over sensors installed on road sides, evaluated in a central station and distributed via a dedicated radio channel (e.g. Traffic Message Channel in Europe (TMC)) back to the vehicles. Other applications like Internet-Browsing, SMS, E-mail or Navigation available in cars are also using centralized networks like GSM, GPRS, UMTS or satellite systems like GPS. Since these applications are organized in a centralised manner, they cannot be utilized as such in a decentralized vehicle ad hoc network.

Even though the application of digital radio techniques for ad hoc networking among vehicles is quite new, a few number of applications exploiting the benefits of VANETs are available. One application based on decentralized cross linking of vehicles using the IEEE 802.11 Wireless-LAN standard is the Self Organizing Traffic Information System (SOTIS) [2]. In SOTIS vehicles send periodically SOTIS-Messages by 1-Hop Broadcast into their direct neighbourhood. Each vehicle combines the information contained in the received SOTIS-Message with data from its knowledge-base and generates from this a new SOTIS-Message, and distributes this in the next step by 1-Hop broadcasting. Although applications like SOTIS follow a decentralized approach, they are targeted to disseminate information which is of general interest. Since each node broadcasts periodically pre-defined information to its direct neighbourhood and no point-to-point routing possibilities are implemented, no personalized inquiries can be generated and neither a certain region nor a certain vehicle can be addressed with this kind of applications.

CONCEPT FOR TARGETED INFORMATION SEARCH IN VANETS

Hence there exists no usable solution for the introduced problem; a first concept is presented in next. The concept divides the problem of targeted information search in pre-defined areas into 4 steps. These steps are introduced and the applicability of existing approaches is discussed as follows:

Step 1: Determining the search area and computing the optimal route for the data packet
The road network comprises roads and junctions. Roads represent edges and junctions represent vertices when the given road network is treated as a graph. For this reason, graph algorithms can be used to describe the search area as well as to determine the optimal data packet route. Since in the "worst case" the complete target search area must be scanned, graph algorithms described in [6], [7] can be used to determine the optimal data packet route. Some applicable problems similar to the determination of the optimal data packet route respectively possibly usable algorithms for the defined problem are:

1. TSP (Traveling-Salesman-Problem)
2. Euler-Tour-Construction
3. Chinese-Postman-Problem
4. Local Algorithms, e.g. GSR (Geographic-Source-Routing) and GPSR (Greedy-Perimeter-Stateless-Routing)
5. Construction of partial area search through DFS (Depth-First-Search) or BFS (Breadth-First-Search) Algorithms
6. Heuristic approaches, e.g. Simulated-Annealing, Genetic-Algorithms

The algorithms given in points 1-3 can be used in case that a pre-calculation of the optimal route is planned. These algorithms presume the offline availability of traffic data. If an online calculation of the next roads to be visited by the data packet is desired, the algorithms in points 4-6 can be applied.

Given that two vehicles in communication range perform a part of a possible route for the data packet, the optimization problem can be described as follows: Pre-calculate the road sequence with as much as possible forwarding vehicles for the data packet and maximize the possibility that the data packet can be forwarded through all roads in the given network.

So far no investigations are known for searching the complete target area as well as the determination of the optimal route for a data packet in VANETs. Therefore the target area search problem is dealt-with in more detail in this paper. For a first approach the TSP-Problem which pre-calculates the optimal route based on offline available traffic data is taken into account.

Step 2: Forwarding the data packet up to the borders of the target search area

Step 3: Perform the requested search within the target area

Step 4: Re-find the inquiring vehicle after the search is accomplished

In order to accomplish the steps 2-4 Unicast-Mechanisms in combination with the pre-calculated optimal route in step 1 will be used. Unicast-Mechanisms, particularly position based Unicast describes the transmission of a message from a sender to a known receiver [3], [4], [5].

Additionally to the steps above, a broadcasting mechanism to improve the performance of targeted information search can be implemented. Broadcasting data packets in a network means that data packets are transferred from one point to all participants. Broadcast in Car-2-Car networks is used in two variants. One variant is flooding a region with messages through Multihop-Broadcasting and the other one is beaconing which means 1-Hop broadcasting. In the presented reference problem a 1-Hop-Broadcast-Mechanism can be used to generate pre-information about the target search area. The working principle of such a mechanism is similar to the one described in [2].

In this paper the investigations are limited to problems on data communication level with respect to the free parking space search problem in VANETs. The emphasis of the work is to answer from a data communication point of view, whether or not and in which quality in VANETs targeted information search can be realized.

For this reason all further considerations presume that specific problems not related to data communication concerning targeted information search are solved.

This means that:

- Car-2-Car-Communication radio technology is deployed into vehicles and vehicles communicate among each other via this medium.
- Vehicles can recognize free parking spaces in their direct environment or at roadsides. The recognition can be done by using RF-ID-Tags, pressure sensors or image recognition mechanisms or by any other technology.
- Each vehicle possesses a navigation system or a digital map and vehicles can code the coordinates of the detected free parking spaces into the data packet, so that other vehicles can drive to these coordinates.

SEARCHING THE TARGET AREA USING THE TRAVELING-SALESMAN-PROBLEM

To determine the optimal route for the data packet a well understood optimization problem, the Traveling-Salesman-Problem (TSP) is taken into account. The TSP-Problem appears to be a good candidate for an exemplarily first approach.

This chapter is organized as follows: First the determination of the optimal data packet route using the TSP-Problem is demonstrated. Second break criteria for the algorithm are defined and third the transformation is shown by using a quite simple example. At least the structure of the proposed algorithm is described in pseudo-code for the free parking space search problem.
Regarding the given solution examples for determining the optimal route for the data packet, it is to be noticed that some of them like TSP are NP-Complete. NP-Completeness is described in detail in [6] and basically means that in general it is not possible to find algorithms which can solve a given problem instance within acceptable time and memory boundaries. For this reason it must be examined whether the storage capacity and computing power existing in vehicles are sufficient for executing these algorithms, i.e. whether or not the calculation can be done in time.

Determination of the Optimal Route

Problem Definition

A data packet should successfully go through its search area. Therefore first an optimal route for the data packet is to be determined. In the calculation process actual road conditions and road characteristics have to be taken into account.

The description of an optimal route for a data packet is:

- The optimal route is given by a path in the search area. This is described through a sequence of edges, i.e. roads r_1, $r_{2\ldots}$ $r_{n.}$
- All roads r within the search area are visited by the query packet.
- If possible, no road is visited twice.
- The search begins with the most suitable road and ends with the fewer attractive roads.

The search was successful when the inquiry coded into the packet could be answered. This is when either the maximum number of requested free parking spaces was found, or the complete target area was scanned and less than the maximum number of requested parking spaces was found. Otherwise the inquiry was not successful (e.g. because of exceeding the maximum allowed time to reply) and the packet is rejected.

General Description of the Proceeding

The Traveling-Salesman-Problem (TSP) requires finding the shortest path visiting each of a given set of nodes and returning to the starting node. The shortest path describes the optimal route through the given network. The optimization criteria are costs assigned to each edge in the given graph. The calculation of the optimal route is done by minimizing the total cost value based on pre-assigned edge costs. A more detailed explanation of TSP is given in [7].

In a given road network all roads should be visited at least once. However TSP visits all nodes in a given graph, a transformation of the given road network into its TSP-Representation must be done before TSP can run. For this a new graph is generated, roads are transformed into vertices and junctions are transformed into edges. Formally, the given road network within the search range is considered as a graph G = (V, E), the crossings are the vertices V, and the roads E are the edges of the graph G.

In next the problem of determining the optimal route for the data packet under exemplarily urban traffic conditions using the TSP-Problem is illustrated. First, the problem of finding an optimal route for the data packet in the road network has to be transformed into a TSP compatible representation. The transformation process comprises two steps. First, the transformation of the road network: The graph G is converted into G ' = (V', E') with V' = E and E' = V from the graph G = (V, E), i.e. the edges (roads) of the origin graph (road network) become vertices and the origin vertices (crossings) become edges. Second, the assignment of cost values to streets: In the road network the cost for each edge is calculated through an assigned quality value RQ(r) (Road Quality Value for Road r) for each road. In the TSP-Representation of the road network, this value is weighted by a special metric and assigned to edges in the TSP-Graph.

Transformation: Road-Network ↔ TSP

The following rules define the transformation function and are applied gradually to all vertices and edges of the road network. The transformation rules are:

1. Each road r_i within the search area becomes a vertex v_i.
2. Each possible transition from road i to road j over a crossing becomes the edge i→j in the TSP-Graph.

Figure 1 shows an example road network. The target search area is the drawn oval.

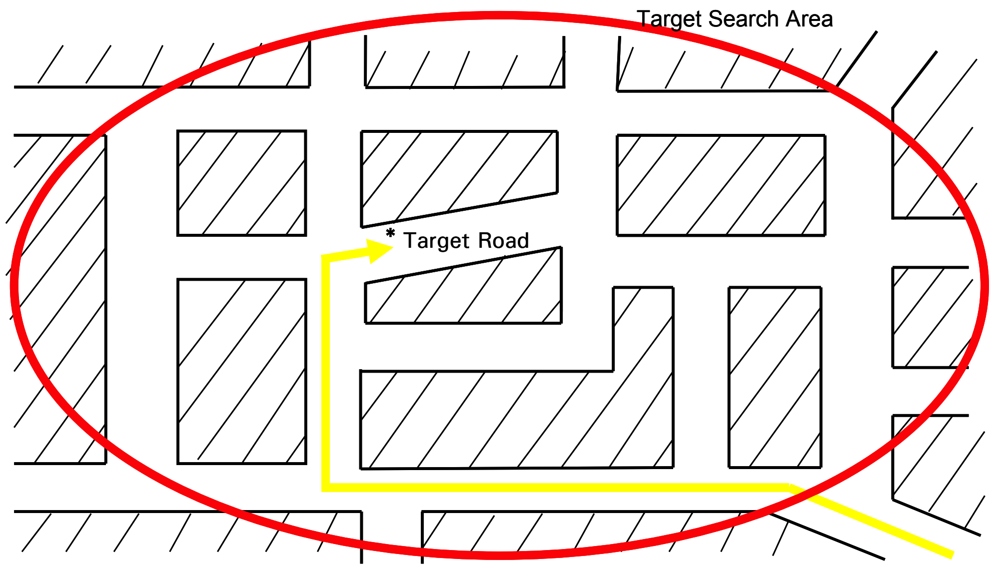


Figure 1 – Road Network

Figure 2 shows the above road network with enumerated roads. The enumerated road network changes after applying the presented rules into the TSP-Graph in Figure 3. A simpler example of the transformation is given in the subchapter “example transformation”.

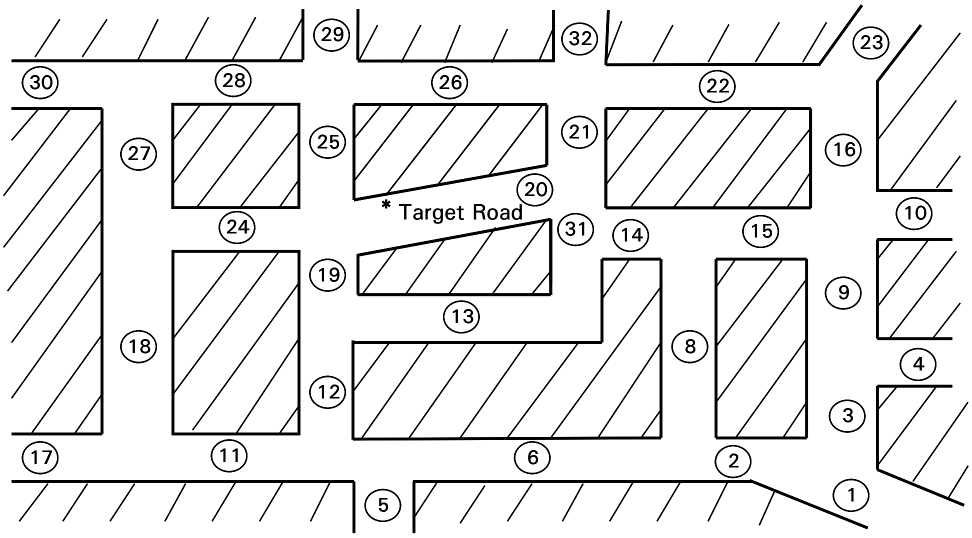


Figure 2 – Enumerated Road Network

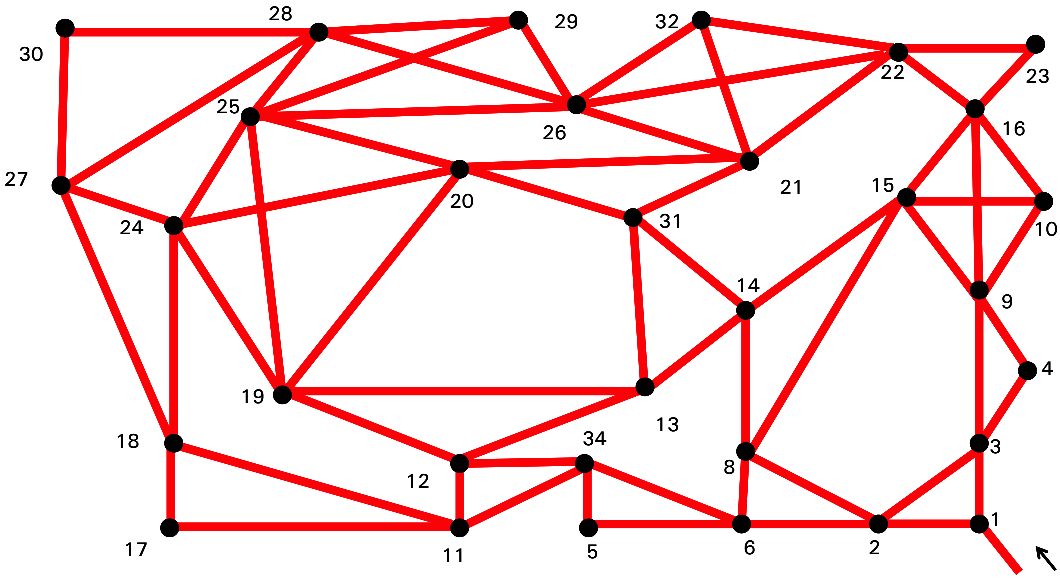


Figure 3 – Transformed Road Network

Determination of the Weighting Function

For the determination of the optimal route a definition of a weighting function is needed. The defined weighting function is based on a pre-assessment of values for roads in the road network. For this, "good roads" can be defined and characterized as follows:

Good roads

- lie on the travel route or in direct neighbourhood to the travel route
- lie in the target road and/or in direct environment of the target road
- are no dead ends or one-way roads
- possess a high vehicle density, the mobility of the vehicles of these roads is high
- offer many forwarding possibilities for the data packet

The quality value of a given road RQ(r), expresses the relevance of the road for the search in the target area. Formally the value RQ(r) is described by the triple RQ(r) = (i, j, RQ_General). The meanings of the defined parameters are:

- i: relative position of the road to the travel route
- j: relative position to the target road
- RQ_General: Estimated value for the road quality. This value comprises parameters like: Number of estimated cars in this road, number of available parking spaces, forwarding quality of the road dependent on traffic density, mobility of nodes, traffic lights, road capacity, channel capacity (on MAC Layer level) of the road and so on. Values for these parameters are based on preceding observations or measurements.

In Figure 4 the quality RQ(r) of some roads in the example road network is drawn based on above explanations. For example reflects the value RQ(26) = (2, 2, RQ_General) road quality parameters for road 26. The road quality parameters for each road RQ(r) are mapped to edge costs during the optimization process. The cost value derived by the quality value of roads RQ(r) in the given road network is used to assign weights to edges in the TSP-Graph.

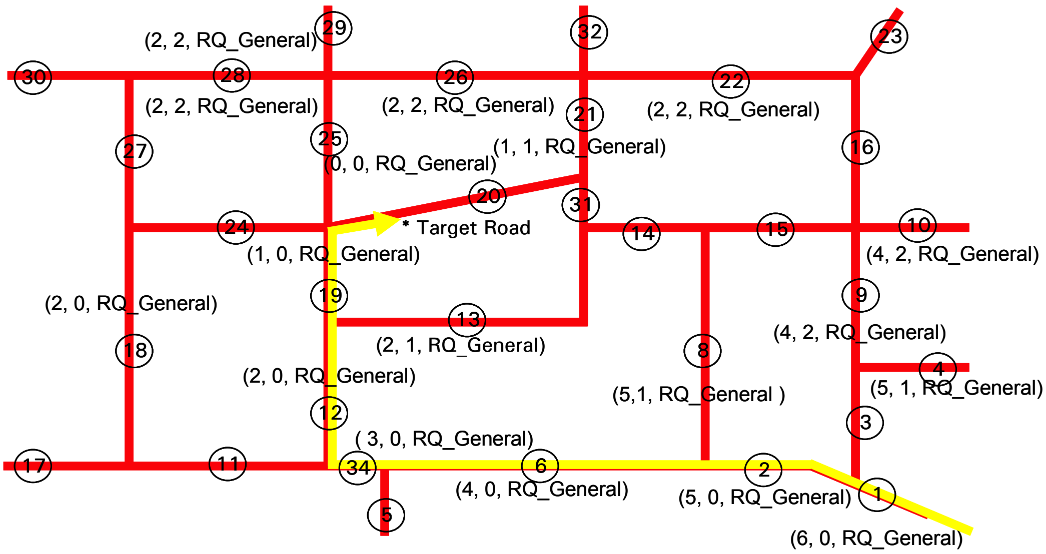


Figure 4 – Road Weightings

After generating the input for the TSP-Problem one proceeds as follows:

1. In the TSP-Graph a path with minimum total costs min(C_{total}) for the vertices 1, 2..., n is determined, i.e. the defined TSP-Problem is solved.
2. The solution for the TSP-Graph with input TSP(vertices, edges, cost function) is transformed back to the origin graph.
3. The resulting path represents the optimal route for the given road network.
4. The resulting starting node corresponds to the entrance road for the vehicle in the target search area respectively in the origin road network.

The values for the parameters are based on estimated values respectively vague data. These values must be available before the calculation of the optimal route in a vehicle starts. These data could be firmly coded on the Navigation-DVD or relevant data about a pre-defined target area must be proactively distributed a priori via broadcast-communication medium to all vehicles. In this case the scoring of the received data is done by the receiving cars and is then used to assign costs to the roads in the road network.

Rules and Break Criteria of the Algorithm

In order to terminate exactly, the algorithm must obey certain rules. First the algorithm has to ensure that the data packet is forwarded between vehicles, i.e. vehicles know that other vehicles are in their communication range. Second the algorithm has to ensure that the data packet traverses the optimal

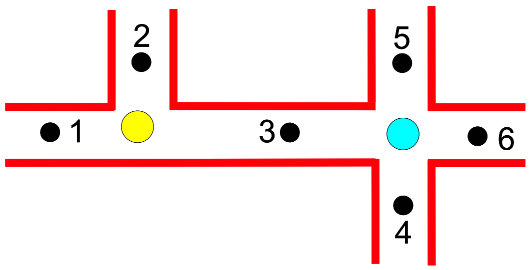
route systematically. For example, if a data packet forwarding vehicle is no longer on the optimal route, an optimal next candidate for further searching the target area should be determined previously and the packet should be passed to this car on time.
In case the inquiring vehicle does not get an answer within a pre-defined time frame, a new inquiry should be generated. In such a case the data packet with the old inquiry is rejected. If additional break criteria are coded into the data packet (e.g. maximum number of parking spaces to be searched) with fulfilment of this condition the data packet is sent back to the inquiring vehicle and the search inquiry is finished successfully.

Sending the message back is realized by using a Unicast-Mechanism, consisting of a simple positioning-service (to locate the actual position of the inquiring vehicle) and a forwarding approach like greedy-forwarding (to guarantee that the inquiring vehicle is reached definitely within a certain time).

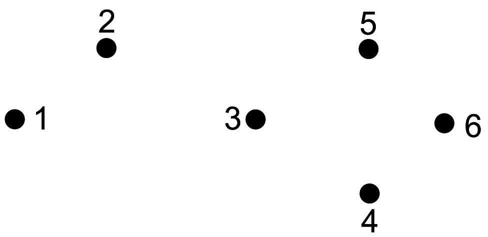
Example Transformation

In order to give a better understanding of the transformation, its working will be demonstrated in a step-by-step manner. For this, a small part of a road network will be transformed into its TSP-Representation. Using this TSP-Representation the optimal route will be calculated and will be mapped back into the real road network. This procedure is explained by the following figures.

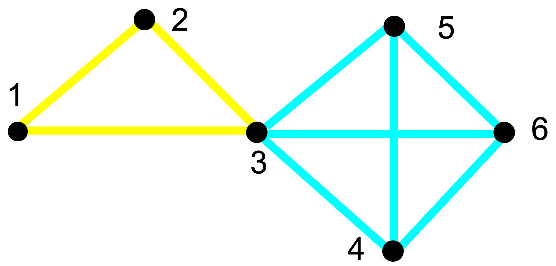
Step 1: We start with an exemplarily portion of a real road network. All roads are numbered. The junctions are highlighted.



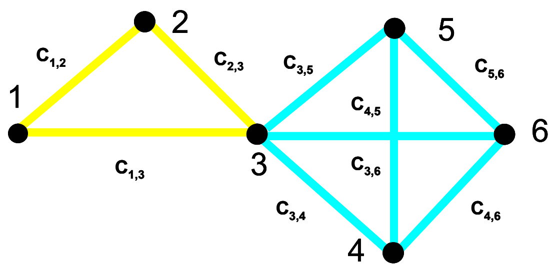
Step 2: These roads are converted into vertices. The vertices form the first part of the TSP-Representation.



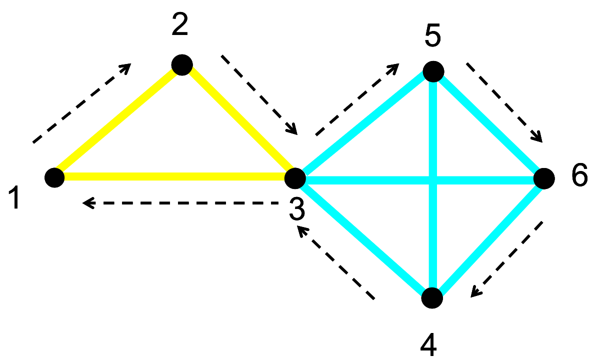
Step 3: When a junction in the real road network between two roads exists, the corresponding nodes are connected with an edge in the TSP-Representation.



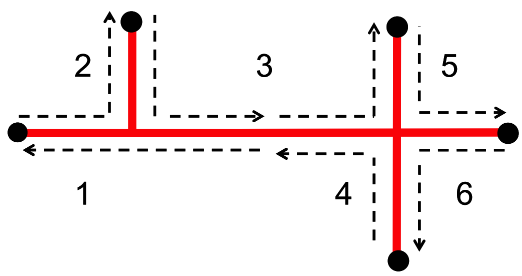
Step 4: A cost value is assigned to every edge in the transformed graph. This value is deduced from the real road network and represents the quality of the corresponding road. Quality here means the possibility for finding enough forwarding vehicles and available free parking spaces in the streets.



Step 5: The TSP-Problem can now be solved in the generated TSP-Representation respectively TSP-Graph. A possible solution to the given example could be a traversal of the nodes 1, 2, 3, 5, 6, 4, 3 and 1.



Step 6: The solution of the TSP-Graph is the optimal route for the data packet. This optimal route is now mapped into the real road network.



The optimal route, i.e. order and frequency of roads to be visited by the data packet, is coded into the data packet. This route is used by vehicles receiving the data packet in order to decide the direction in which the data packet should be forwarded within the next step.

Moreover if the road network contains a route, in which every street is visited exactly once, this route is determined by the algorithm. The reason for this is that each vertex in the TSP-Representation defines one street in the real road network and each vertex is visited once. For real road networks, the probability is very low, that a route visits every street exactly once. For example, main roads and dead-ends have to be visited more than once, to traverse the complete road network. In such a case the calculated solution of the TSP-Representation, i.e. the optimal route of the problem includes some streets more than once.

Free Parking Space Search Algorithm

According to the presentation of determination rules for the optimal route and the definition of break criteria now the structure of the developed algorithm is given in pseudo code.

```
Start_Free_Parking_Space_Search{

        Initialization_of_the_Search () {
                Determine_Search_Range ();
                Start_Graph_Algorithm_and_Determine_Optimal_Route ();
                Code_Abort_Criteria();
        }
        Send_Inquiry_and_Start_Target_Area_Scan() {
                Encode_and_Send_Inquiry();
                Find_Into_Target_Area();
                Start_Searching_Target_Area();
                {
                        WHILE {
                        (Abort Condition not fulfilled) or (Coded Route not completely scanned)}
                        DO
                         Scan_Target_Area();
                        }
                Save_Results();
        }
        Send_Results_Back_to_Inquiring_Vehicle {
        Find_Inquiring_Vehicle();
        Send_Response_Packet_Back_to_Inquiring_Vehicle();
        }
}
```

In next it is to be examined whether or not this algorithm can successfully applied in VANETs. For this, different simulation scenarios comprising real road networks and real traffic movement patterns will be used.

OUTLOOK AND CONCLUSION

Summary

In this paper a first concept for finding free parking spaces in a target area, using personal inquiries among vehicles communicating each other in a decentralized Vehicular Ad Hoc Network is presented. The problem is divided into sub-problems and for the solution of each sub-problem existing methods are discussed. For the insufficiently investigated case of “searching the target area” a first approach is introduced by using the Traveling-Salesman-Problem and described in detail.

Outlook and Further Work

In the presented approach the optimal packet-forwarding route through the vehicle traffic is computed only once. This static approach, which is based on pre-collected data, will be refined in the continuing work. Especially so called “online algorithms” and “local algorithms” will be considered, which compute routes dynamically for varying traffic situations.

To improve the efficiency, known heuristic methods of TSP will be implemented. It is expected that heuristics will lead faster to results. Additional algorithms that are currently under investigation for the free parking space problem are GSR (Geographic Source Routing) and GPSR (Greedy Perimeter Stateless Routing) [4].

The cost function introduced here, will be refined with respect to vague data (e.g. estimated number of cars, estimated traffic density, estimated waiting period at one crossing etc.). Especially the definition, the integration and the weighting of vague data will be considered.

Conclusion

This paper reflects first investigations about the applicability of graph algorithms to the problem of complete area search in VANETs. The focus lies on determining the optimal route for a data packet in a given traffic through pre-collected traffic data. The traffic is mapped to the Traveling-Salesman-Problem (TSP) [6] in order to benefit from known TSP-Solutions. Simulations are planned to find out the suitability of these algorithms for personal inquiries in VANETs and modifications that may be necessary. Further quantitative results (e.g. latency times, necessary total time for complete area search, effects of traffic density and traffic flow on the target area search, number of necessary hops and statements about needed bandwidth to perform a complete area search) shall be revealed by the ongoing investigations.

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