SHARED RIDE TRIP PLANNING WITH GEOSENSOR NETWORKS

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Abstract

Recent technology developments in miniaturization of computing devices, location-sensing technology and ubiquitous wireless networks in a single device enable new types of social behavior such as ad-hoc meetings of people in co-located geographical space. This book chapter investigates a novel usage type of this technology, ad-hoc shared-ride trip planning in transportation networks. Shared-ride trips involve transportation clients such as pedestrians arranging on a short-term basis with transportation hosts such as private automobiles or taxi cabs for flexible travel provision. However, assigning clients and hosts in an ad-hoc, timely manner challenges current trip planning approaches, in particular for non-scheduled hosts. Current approaches based on centralized services do not scale well nor provide optimal trip assignment in such a highly flexible and dynamic environment. Thus, we propose a novel approach considering the transportation network as an ad-hoc mobile geosensor network using a short-range, self-organizing strategy. This approach can be fully scalable if every new transportation request can be solved locally in the geosensor network, a property that we investigate by comparing different communication strategies between nodes in the system. We will demonstrate that local communication strategies save communication costs and still deliver near-to-optimal trips.

1. INTRODUCTION

Recently, advances in technology miniaturization with regard to short-range wireless communication networks such as Bluetooth, tiny computers in the size of a quarter, and the development of microsensors that can be flexibly attached have created a novel type of powerful small computing platform, so-called sensor networks. The computing nodes in sensor networks collaborate and communicate with each other in an ad-hoc way based on availability, short-range communication, power and computing resources and the tasks at hand to accomplish. As a consequence, these inexpensive miniature sensing and computing devices can be embedded in many natural and man-made devices. Each device can connect to an infinite network of other devices to perform tasks without human intervention such as temperature or toxidity detection.

This book chapter investigates how this technology enables new types of social behavior. In particular, we investigate a specific novel application of the type of technology for inner-urban trip planning, envisioning that each actor is equipped and supported by a node in a sensor network. Imagine Hillary who just has missed her bus to a doctor's appointment today (Figure 1). Around Hillary the traffic is floating. Now, she is glad to have subscribed to a service that mediates between her current transportation needs and vehicles going into her direction in an un-preplanned, ad-hoc manner. Hillary opens her mobile phone/hand-held device, and starts the shared ride application. The local program on the mobile phone acts as an agent (or transportation client), announcing the need for a ride from Hillary's current location to a her destination. The local agent negotiates with ad-hoc offers from other vehicles in the neighborhood, and determines and books an optimal offer. Soon after, Hillary sees a friendly car driver stopping for sharing a ride to the train station. The ride takes her a first leg of her trip, and she will be able to catch her train to the city in time. Hillary will not come late to her appointment today.

Figure 1: If the bus is missed riding with cars becomes an alternative—and this requires ad-hoc trip planning.

We envision an ad-hoc shared ride system that integrates the transportation capacities of all types of (volunteering) vehicles in urban traffic in order to identify a trip for persons with an ad-hoc travel demand. The system shall assign persons, or *transportation clients*, to vehicles, or *transportation hosts*, with matching travel plans and free transportation capacities, in an ad-hoc manner. Trip planning is complex in such transportation networks. In contrast to a public transportation system, all transportation hosts act autonomously with individual routes, and they may act based on their own individual policies. They become available, and might disappear from the system. This property makes the transportation network highly dynamic and unpredictable. Therefore, any (centralized or local) trip planner in this network has knowledge that is temporally limited to the current state.

In the traditional trip planning literature, optimal trip planning can be accomplished in a centralized fashion if the routes and the schedule of the transportation hosts in the network are known. However, these strategies are no longer applicable in such highly dynamic and constantly changing environments with individual routes and strategies of automobiles and transportation clients. We pose the hypothesis that using the local communication strategies and adaptive collaboration of mobile nodes in a geosensor network allow for near-optimal trip planning in a highly dynamic transportation network. If one chooses peer-to-peer communication and limits the spreading of messages to a more local neighborhood, the trip planners have also spatially limited knowledge of the transportation supply. Still, trip planners can make reasonable decisions, but they may review and revise their trip plans periodically. With each review, they look at temporally and spatially updated information about transportation supply, since they as well as the hosts may have moved in the meantime. We expect that this approach of trip planning is fully scalable; i.e. if more transportation agents and clients enter the system, incomplete transportation network knowledge a system still can deliver near-to-optimal trips.

Such a shared ride trip planning system causes many questions. In this chapter, we focus on the efficiency and effectiveness of different communication and negotiation strategies between nodes. Hence, we will concentrate on only one wayfinding and route planning strategy. This paper extends our previous work (Winter and Nittel 2005) by specifying a simulation environment for investigating different communication and negotiation strategies. The current research objective is: how far can we spatially limit the knowledge of a route planner without loosing too much in the quality of the traveled trip? This question is particularly important since broadcasting in mobile peer-to-peer communication networks is network bandwidth consuming and needs to be minimized.

We designed and implemented a simulation environment to understand and demonstrate the implication and correlation of the spatial limitation of information dissemination between nodes in the network and quality of the traveled trip according to the chosen cost criterion. The simulation environments enables simulating shared ride trip planning with different parameters, such as density of hosts, or diameter of neighborhoods. We expect to find a negotiation and communication strategy that adapts to a specific situation, and guarantees reasonable route qualities given this situation.

Shared-ride systems have to consider also some other implications and challenges prior to any real-world realization. They comprise, for example, *trust* and *safety*, *liability*, economic incentives and business models, urban mobility and access and *privacy*. When we look into trip planning we are aware of all these other aspects, but leave them for further work.

The chapter is structured as follows. Section 2 defines the technology of geosensor networks; Section 3 describes the behavior of the involved agents, the trip planning task, and the resulting need for information gathering and negotiations. Section 4 translates this into a simulation environment, and summarizes first results. Conclusions are presented in Section 5.

2. GEOSENSOR NETWORKS

The continuing development of ubiquitous wireless communication technology, including miniaturization of computing platforms and the development of micro-scale sensors, is enabling new computer applications that would not have been possible in the past. Recent and projected advances in small, low-cost microelectronic and mechanical systems (MEMS) with limited on-board processing and short-range wireless communication capabilities are also changing the way we collect and process information about the physical world. Today, networked sensor nodes can be constructed by using open source and commercial components at the size of an inch or smaller such as the Berkeley/Intel Mica Motes.

Large collections of untethered, battery powered computing nodes with various sensing functions can be distributed over a geographic area, and measure traffic and road conditions, or environmental activity at a fine-grained temporal and spatial scale that was not possible in the past. Since such sensor nodes are tiny and the limited battery capabilities allow only for short range wireless communication, they must communicate with peer sensor nodes in their spatial proximity. Projecting the continued miniaturization, it is not expected that sensor nodes connect to a centralized computing server to upload or stream data directly; they might, however, communicate with a local `base station', i.e. a more powerful sensor node with larger processing, storage, communication and energy capabilities. In general, information is routed via multiple communication network `hops' to a centralized server or in-network micro-server, or the information is processed in the local geographic environment of sensor node’s location.

Integrating both location-based computing and sensor network technology, we can envision sensor nodes that are aware of their geographic location, equipped with diverse sensors, mobile, and communicate with nodes in spatial proximity about information that they sensed or information or resources they need from other nodes. Sensor nodes can be mobile by either being self-propelled or by being attached to moving objects, like automobiles, USPS packages, or even humans. Sensor networks in which nodes are aware of their geographic location, and environmental phenomena are captured via on-board sensors are so-called *geosensor networks* (Nittel et al. 2004).

Efficient information routing is a significant research challenge in geosensor networks, and sensor networks at large to accomplish tasks, preserve energy and not ‘cloak’ the network bandwidth with too many message. In contrast to information routing in today's communication networks, which is address-based (IP addresses), routing in sensor networks is data-centric. The goal is to distribute information only to sensor nodes that need the information or that can be a source of information. Another aspect of data-centric routing is *scalability*: if the number of nodes in a sensor network increases to thousands of nodes, a decentralized, peer-to-peer information dissemination and data collection strategy can provide efficient information distribution and eliminate the bottlenecks of a centralized database or service architecture.

By adopting the geosensor networks paradigm as the basis for an ad-hoc ride share system, each vehicle can be thought of as a mobile geosensor node, able to sense information about its own location, its own trip needs and resource availability or necessity, process this information, and communicate it to other moving objects in its neighborhood. Potentially, this decentralized collaboration can offer improved reliability and performance, since there exists no centralized service provider acting as a bottleneck to information dissemination and processing.

We distinguish between three different communication strategies between mobile nodes: *Flooding* is a strategy in which each geosensor node that has a request or receives a message about a travel request passes on the information to every other node within its communication range. The second approach is referred to as an *epidemic*, in which each node only inform *n* other agents about events. The third approach is *location-constrained*, in which information is only passed on in proximity to the travel need, and then discarded.

3. SHARED RIDE TRIP PLANNING

In a shared ride trip planning system using geosensor networks, we are interested in assigning clients to hosts such that the clients get quickest to their destinations. Other factors include the number of transfers for a client, his/her wait time in between rides, and required fares or a reward system for car drivers to offer rides.

3.1 Constraints of trip planning

In a local trip planning task we need to specify (a) the transportation demand of a client, (b) the transportation supply of the hosts, (c) the planning task, (d) the communication needs of the involved parties, including the content of messages, and (e) the communication strategies. Without limiting generality we choose the clients to be responsible for their own trip planning, and the transportation hosts to be reactive only. As constraints we consider the following: we expect to find hosts with different ‘behavior’ such as public transportation, taxis, or private automobiles. Some of the transportation hosts show unpredictable behavior in a sense that we do not know their routes, availability or willingness to offer rides ahead of time. Also, hosts have different capacity for accommodating transportation clients.

Overall, we can assume that we have to design a shared ride system in a continuously changing environment, e.g. cars appear or ‘disappear’ (become unavailable because they reached their destination), or they free up capacity or have no capacity. For such an environment, we further assume that no centralized server or planning application exists, but that each client and hosts in the system performs planning tasks solely based on local and short-term knowledge about its environment.

Reformulating our hypothesis, we will prove that mobile ad-hoc geosensor networks are an effective and efficient way of shared ride trip planning, i.e. clients can achieve optimal route planning and trip decision based on this type of information, and with the limited communication and planning horizon. We can further investigate questions of quality of routes (number of stops, or wait time), appropriate negotiation and information dissemination strategies, and optimal route selection in such a highly dynamic environment.

3.2 The transport demand of a client

In ad-hoc trip planning, clients have a transportation demand from their current position to a destination. We assume that clients apply a simple trip planning heuristic: they look for shared rides along the geodesic to their destination. A client is interested to reach a destination for optimal (minimal) costs. The cost function depends in general on the client's context, and may concern, for example, travel time, trip fare, number of transfers, or reputation of hosts. Without limiting generality we choose travel time in our simulation. Thus, clients that follow only the shortest path to their destination can formulate their demand in form of a sequence of street segments. Each segment can be attached with a time stamp for the anticipated earliest departure time.

3.3 The transportation supply of hosts

Transportation hosts travel autonomously, and independent from actual client demand. They do not announce their travel prior to their start, they have their individual travel plan (a route consisting of a sequence of street segments with time stamps), and this travel plan can have any form, including stops, being non-shortest, containing cycles, or traveling back and forth. We assume that although willing to take passengers, they are not willing to make detours for these passengers. Future positions of hosts may be influenced by traffic conditions, and hence may differ from their current plans. Furthermore, some hosts like cars have a limited passenger capacity.

3.4 The planning task

In our systems, clients are the planning agents. They need to know about available transportation supply to choose the optimal available rides. Here, hosts are reactive in the planning process. They only have to maintain their bookings and observe their passenger capacity, and be willing to advertise this information.

At a specific point in time, a client can at most know which hosts are currently traveling, where they are, what their current booking status is, and what their travel intentions are. A client can not know with certainty the future positions of currently traveling hosts, their future booking states, and cannot see which new hosts will enter traffic next. With other words, at any point in time a client can determine an optimal route according to the current state, but in hindsight this might not have been the overall optimal one.

Given that knowledge, clients apply a simple pattern matching technique to filter out supplied street segments that are on their route, and that have a time stamp at their own anticipated earliest departure time or later. From this candidate set, clients select the ones that start earliest (assuming that all hosts travel with about the same speed); otherwise they choose the ones with the earliest arrival times at the ends of the segments. Note, that the chosen segments can cover only a part of the client's trip, and they can have temporal gaps (waiting times at transfer points) and spatial gaps (segments for which currently no supply is known).

After planning their trip, clients need to book these trips with the hosts. Since all travel plans are reviewed and possibly revised from time to time, clients need to be able to cancel previous bookings as well.

3.5 The negotiation needs

Communication and negotiation is needed in ad-hoc trip planning for two purposes: (a) collecting the knowledge about the current transportation supply, and after planning a trip (b) booking or canceling specific hosts. We group these tasks requiring communication in a *negotiation cycle*. The negotiation cycle happens periodically during traveling. Since it is relatively short, we can simplify that the negotiation cycle alternates with a *traveling cycle*.

The need for a negotiation cycle means that in contrast to most other studied problems in mobile ad-hoc geosensor networks our service requires two-way communication for negotiation and assignment. Studies in the dissemination of information (Nittel et al. 2004; Wolfson and Xu 2004) provide basic ideas, but do not handle two-way negotiations. Hence, we need radio-based communication strategies that efficiently spread messages and efficiently return answers.

The task of message broadcasting itself is a resource consuming process (communication bandwidth and drain on the battery). Since the communication bandwidth in urban communication networks is typically limited and used for many different applications at the same time, minimizing the number and range of broadcasting message has priority. For that purpose we propose additional strategies for the communication process.

The negotiation cycle is different from the communication strategy, which is defined by more technical considerations. For one and the same negotiation cycle, different communication strategies can be deployed, and result in varying performance of the negotiation cycle.

In our chosen definition, a negotiation cycle consists of the following steps: (a) a client advertises his/her requests, (b) hosts listen to requests, and make offers, (c) clients receive offers and select one or more of them, and (d) clients respond to a host with an accept of an offer, booking a ride. With (d) the negotiation cycle is finished.

Other aspects of the negotiation are an update of the agreement, and a potential cancellation (by either the client or the host).

3.5.1 Requests

Hosts publish their potential transportation supply only if there is demand. That means, hosts act only on requests from clients. The request from a client is specific, i.e., the request contains the full information of the route to be traveled as identified in 3.2. If hosts receive such a request they can evaluate the relevance of their own travel route and capacity with regard to the request, and respond only if they can contribute to the client’s demand.

3.5.2 Offers

Hosts respond only to a request with an offer if they can contribute to the client’s specified demand.

3.5.3 Booking and Cancellations

The client performs trip planning on basis of the collected offers. The number of collected offers is already reduced to the set of potentially contributing, i.e., spatially overlapping host routes. Clients then book specific segments from selected hosts, and create a booking message for that purpose specifying the host and the segments.

Cancellations concern bookings from previous negotiation cycles. They cannot be dealt with in the manner of the other messages mentioned so far because the communication network has changed, and the host to be addressed may be outside of communication range at the time of the cancellation, which is necessarily another negotiation cycle than the original booking. Even a multi-hop link could be broken. Hence we apply a different cancellation strategy.

3.6 Communication strategies

Communication in mobile ad-hoc geosensor networks can be short-range radio-based (Zhao and Guibas 2004). Messages are broadcasted, and are received only by nodes within radio range. If messages shall be sent further they have to be forwarded by nodes, thus, establishing by multi-hop communication. The receiving nodes also broadcast in a circular radio range, therefore, the original nodes will hear the message again. However, since they recognize the message's id they will ignore it, and only new nodes will process the message, and rebroadcast it to nodes in farther distance from the originating node.

We assume that the nodes communicate in synchronized, relatively short communication windows, and go into a sleep mode in the meantime. Thus, we can assume that all mobile nodes exchange messages every 5 minutes, and put themselves into a sleep mode in-between. These communication windows define the frequency of the negotiation cycles of the shared ride trip planning. In the following we discuss the considerations for communication strategies for the different steps of the negotiation protocol.

3.6.1 Requests

We define that the communication strategy begins with clients advertising their transportation needs, while hosts are passive. The client's request is broadcasted without an addressee but with a message and a client id. It disseminates to neighboring nodes in the network within the hardware-specific local neighborhood. Since we assume short-range communication the request is first received by hosts in close proximity (ca. one city block). However, these might be also be the most relevant hosts to offer rides in this dynamic neighborhood, and negotiation with distant hosts is less promising due to the highly dynamic nature of the system.

Nevertheless, the requests need to be forwarded to more than immediate neighbours, and we consider several communication strategies:

Flooding: a client always informs all other hosts within its communication range of all information about it travel needs; all receiving nodes forward the request to all other nodes in their communication distance, and so forth.

Epidemic: a client informs only the first *n* randomly chosen hosts it encounters within its communication neighborhood about its travel needs; receiving nodes also only forward to the first *n* randomly chosen hosts they encounter.

Spatial Proximity: a client informs hosts within its communication neighborhood and hosts within a certain threshold spatial distance *d* of its destination still rebroadcast the request.

3.6.2 Offers, bookings and cancellations

Since hosts respond only to a request if they can contribute to the client's specified demand, an offer is addressed to a specific client within the message header, and the client's approximate location. Since this message sending is addressed directly, fewer hops are necessary; only a directional message sending is necessary. Similarly, clients' booking messages that specify the host, and the segments to be reserved are routed back to the specified host. Booking have to be confirmed in every communication cycle, or otherwise will be cancelled by hosts and clients automatically for the next negotiation cycle. This way, client and host bookings are always kept consistent, and, in fact, no cancellation message is needed.

4. AGENT-BASED SIMULATION OF TRIP PLANNING

To investigate the proposed shared ride trip planning systems, we implemented a agent-based simulation environment. The simulation emulates the behavior of the transportation clients and hosts introduced in Section 3. Fundamental assumption is that all information exchange within a negotiation cycle takes place in one communication window.

For simplicity, the simulation happens in a rectangular street network. In this network all hosts are moving with the same speed, i.e. one "street" segment per time unit. After each time unit they are located at "street" intersections a new negotiation between clients and hosts takes place. Furthermore, radio range shall be limited to the four-neighborhood of each intersection (± one row, or ± one column).

4.1 The simulation in an example

Consider Figure 2 with client **C** and hosts **1-7**. To model a negotiation process, we first switch from the street network view to a communication network view.

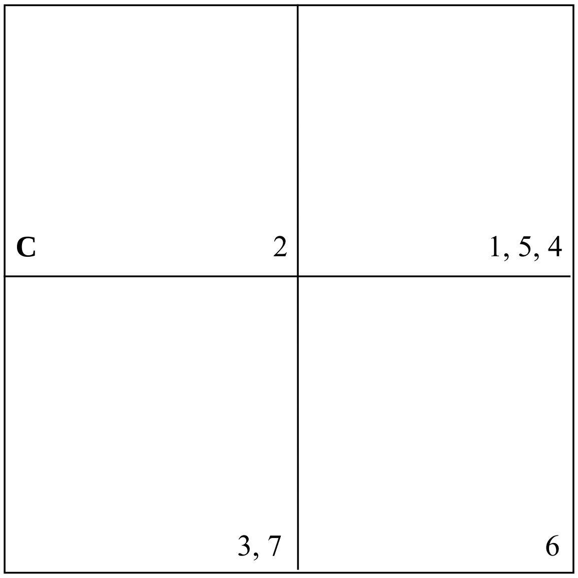

Figure 2: A client **C** and seven hosts in a transportation network (snapshot).

Figure 3 shows how the agents are connected via the communication networks. We assume that the broadcast range of each node is that of one street segment. Due to obstruction via buildings, the connectivity in a diagonal fashion is limited. Thus, **C** can communicate directly with **2**, and **2** can communicate with **1**, **5**, and **4** as well as with **3** and **7**. Both groups of nodes can communicate with node **6**. Thus, one of the shortest paths of **C** to node **6** is between **C**, **2**, **1** and **6** (solid line in Figure 3).

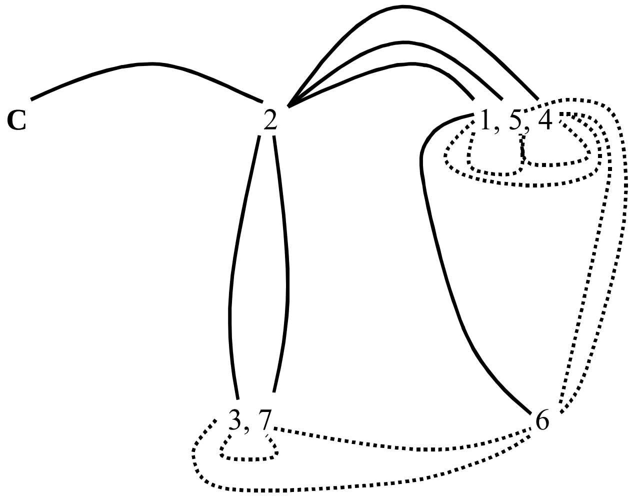

Figure 3: The network of connected agents (neighborhood graph) and a shortest path tree (solid edges).

On the communication network we can demonstrate the three phases of each negotiation: sending *requests* (**r**), sending *offers* (**o**), and sending *booking messages* (**b**, **c**).

4.1.1 Requests

Let us assume that negotiations are not spatially limited. Messages will be forwarded as far as possible. With the single client, the client's request is broadcasted by:

sender	**message**	**receiver**
C	r	2
2	r	**1**, **5**, **4**, **3**, **7**, [C]
1	r	[2], [5], [4], **6**
5	r	[2], [1], [4], [6]
4	r	[2], [5], [1], [6]
3	r	[2], [7], [6]
7	r	[2], [3], [6]
6	r	[1], [5], [4], [3], [7]

In this table, the agents that receive the request for the first time (on the shortest path) are printed bold; the other agents that hear the message but who have heard the message already are printed in brackets. Only when an agent receives a request for the first time it broadcasts it. This means, in this situation each agent in the connected network broadcasts once. In other words, with the flooding strategy the number of broadcasts of a request is equal to the number of agents in the client's connected component.

Now let us consider the protocol of network 'hops' created with broadcasting. This protocol is attached to the request *r* itself. **C** creates the original request, and adds its own id. Node **2** then receives the request, and attaches its own id to the request so it will ignore future receipts of the message.

agent	received request	forwarded request
C		"r, C"
2	r, C	"r, C, 2"
1	r, C, 2	"r, C, 2, 1"
5	r, C, 2	"r, C, 2, 5"
4	r, C, 2	"r, C, 2, 4"
3	r, C, 2	"r, C, 2, 3"
7	r, C, 2	"r, C, 2, 7"
6	r, C, 2, 1	"r, C, 2, 1, 6"

With other words, each recipient knows the shortest path back to the client sending the request. Alternatively, each message can have a unique message id, based on the originating node's identifier, and a time stamp, and the listening nodes manage a local index of messages that they have broadcasted already. In this case, new routes back to the originating nodes need to be found.

4.1.2 Offers

Let us assume that some agents will respond to a request by making an offer. An offer, in contrast to an unaddressed request, is an addressed message to a specific recipient: the requesting client. Each offer shall travel along the shortest path (minimal number of broadcasts). For that purpose the offer contains the reversed protocol of the request as an address. Only agents on the list will forward the message.

In our example hosts **6**, **3**, and **2** are going to make an offer to **C** (**o6**, **o3**, **o2**). In the table below, the hosts in parenthesis are receiving a message, but are not on the address list, and hence, do not forward the offer. For example, node 6 broadcasts a message, which is received by nodes **3**, **7**, **1**, **5**, and **4**. Only node **1** identifies itself in the shortest path, and rebroadcasts. This message is heard by node **5**, **4**, **2**, and **6**, but only node **2** reacts. With other words, each offer causes a number of broadcasts equivalent to the length of the shortest path branch between the offering host and requesting client. The set of broadcasts for these offers consists of:

sender	message	receiver
6	o6	(3), (7), **1**, (5), (4)
1	o6	[(5)], [(4)], **2**, [6]
2	o6	[1], [(5)], [(4)], (3), (7), **C**
3	o3	(7), (6), **2**
2	o3	(1), (5), (4), [3], [(7)], **C**
2	o2	(1), (5), (4), (3), (7), **C**

4.1.3 Bookings

The requesting client collects all offers, and selects the optimal one(s). This choice has to be booked with the offering client(s). In our example client **C** is going to accept an offer of host **3** (**b3**). Then the set of broadcasts consists of:

sender	message	receiver
C	b3	2
2	b3	(1), (5), (4), **3**, (7), [C]

With other words, each booking causes a number of broadcasts equivalent to the length of the shortest path branch between the client and the offering host.

Client **C** would also like to cancel a previous booking with host **7** (**c7**). Note that **C** has currently only offers from **6**, **3**, and **2** in hands, and hence, does not know where **7** is. Host **7** may even be disconnected (it is not in our example). Hence, previous bookings—if not confirmed in this cycle—will time out automatically before the next negotiation cycle.

4.2 Specification of the simulation

The example discussed above gives reason for the following specification of an algorithm. Two measures emerged in the example as critical:

- The number of agents in the client's connected component.
- The lengths of shortest path branches (number of edges) between the client and any connected host.
- For the lengths of shortest path branches between the root (client) and any host Dijkstra's algorithm (Dijkstra 1959) can be accomplished, computing the shortest paths between a single source and all destinations.
- After each negotiation cycle the agents travel according to their current travel plans. The client moves only when he has found a ride. After each travel phase a new negotiation cycle starts, until the client finally reaches the final destination.
- Other parameters of the simulation are the numbers of hosts, i.e., the degree of competition for rides, and the numbers of hosts, i.e., the traffic density.

4.3 Simulation with different communication strategies

So far the simulation applied the flooding strategy. But the same simulation can be applied with spatially limiting communication strategies, i.e. a parameter m specifying the radius of the communication neighborhood. If $m=1$ the simulation realizes the short-range strategy, and if m is larger the simulation realizes a *mid-range strategy*. (The flooding strategy can be considered as the special case of $m=\infty$.)

For describing the behavior of the simulation, the parameter m becomes part of the request message. Each agent receiving such a request determines the number of the previous hops h (length h of the protocol), and forwards the request only as long as $h<m$. The rest of the simulation behavior (offers, bookings and cancellations) remains unchanged.

With other words, for spatially limited communication strategies the neighborhood graph is formed by the shortest path tree, cut at level m. The rest of the algorithm remains unchanged.

4.4 Simulation results

In our simulation, we observed the following results and trends (more detail on the simulation and results can be found in (Winter and Nittel 2006)): we can show that the solution of ad-hoc communication and negotiation with spatially and temporally limited knowledge is *effective* and *efficient* for shared ride trip planning. While an unconstrained communication strategy is most effective (i.e. robust), this strategy is inefficient from a bandwidth standpoint. This strategy is also not feasible: the necessarily short communication windows limit the number of hops of messages. In contrast, the short-range communication strategy (one hop) is the most efficient, but least effective. Compared to the two, mid-range communication strategy proves the hypothesis: it is *effective* (e.g., for 1.56 hosts per street network node 10% longer trips than with unconstrained, but 66% shorter trips than with short-range) and it is *efficient* (e.g., for 1.56 hosts per node 5 times more messages than with short-range, but 9% of the messages with unconstrained communication—and this number is steeply decreasing with an increase of host density).

5. CONCLUSIONS

We have developed and specified a simulation environment for shared ride trip planning in large transportation networks. This agent-based simulation allows investigating the quality of the clients' trips depending on a communication strategy. For that purpose communication strategies are investigated under different traffic densities as well, coming up with recommendations of critical parameters m for specific traffic situations.

The sketched simulation environment can be extended in various directions, to consider additionally factors such as non-gridded street networks, multiple clients and their competition for transportation supply, or alternative trip planning strategies. The simulation environment can also be used for testing the consequences of individual behavior and preferences, such as mutual interest in client and host reputation. Some work in the direction of relaxing the wayfinding strategy and still limiting the communication effort is done in (Winter and Raubal 2006), based on the simulation specification presented in this paper.

An interesting question in the realm of social change is the reputation of such a system, and trust-building mechanisms. Since in a distributed peer-to-peer system no centralized registry knows who traveled with whom, anonymity is of concern. For this reason, we currently are working on a safety measure that builds upon the ability to reconstruct any shared ride from the distributed, local memories of the agents that participated in the negotiation process.

The more important questions are those of social effects of such a system, which are far beyond this rather technical solution. It increases the mobility and access of citizens, in particular in disadvantaged suburbs or from disadvantaged groups (such as teens or the elderly). It is compatible with smart public transport systems, and can be combined with them. Other questions, such as economic impact, or effects on urban dynamics with such a system, come on the agenda as well.

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