

# SHARED RIDE TRIP PLANNING IN LARGE TRANSPORTATION NETWORKS

Stephan Winter<sup>1</sup>, Silvia Nittel<sup>2</sup>, Arda Nural<sup>2</sup>, Trang Cao<sup>1</sup>

<sup>1</sup>Department of Geomatics,  
The University of Melbourne, Australia  
winter@unimelb.edu.au, t.cao2@ugrad.unimelb.edu.au

<sup>2</sup>Department of Spatial Information Science and Engineering,  
University of Maine, USA  
nittel@spatial.maine.edu, arda@spatial.maine.edu

## Abstract

We present and discuss a specification for a simulation of shared ride trip planning in ad-hoc mobile geosensor networks. In this scenario, the nodes—clients with transportation demand, and hosts with transportation supply—have to plan routes and manage bookings collaboratively. The specification enables to compare different communication strategies for that purpose, with the goal to find an efficient communication strategy that still guarantees planning of acceptable trips in a continuously changing environment. In particular it makes the route planning strategies and booking mechanisms transparent, and shows their dependence on communication strategies.

## 1. INTRODUCTION

Imagine Hillary who just has missed her bus to work 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 ad-hoc manner. Hillary switches on her portable hand-held device, and it starts negotiating with devices in the vehicles close-by. The service determines and books an optimal offer, and soon after Hillary sees a friendly car driver stopping for sharing a ride. The ride takes her a first leg of her trip, and during the ride her device collects further offers and books the next leg. Hillary will not come late to her appointment today.



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

The peculiarity of this service is its ad-hoc peer-to-peer communication architecture, realized in a mobile ad-hoc geosensor network. Each node of this network acts as an agent, either as a *client agent*, having transportation demand, or as a *host agent*, offering transportation supply. All these nodes are mobile, and all of them are aware of their current location and their destination. At least the hosts know also their own route ahead.

Trip planning is complex in such transportation networks. In contrast to a public transportation system, the hosts act autonomously, and they may act based on their own individual policies. This property makes the transportation network dynamic and unpredictable. Therefore, any trip planner in this network has knowledge that is temporally limited to the current state. If one chooses peer-to-peer communication and limits the spreading of messages to a more or less 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 and potentially outdated information about transportation supply, since they may have moved in the meantime.

Such a shared ride trip planning system causes many questions. In this paper, we focus on the efficiency and effectiveness of different communication strategies. In a previous paper we have shown already that trip planning is possible with temporally and spatially limited knowledge of this dynamic environment (Winter and Nittel 2005). For that purpose we concentrated on one wayfinding and route planning strategy. Alternatives are possible, but still beyond the topic of this paper. This paper extends the previous work by specifying a simulation environment for investigating different communication strategies. The research objective is: how far can we spatially limit the knowledge of a route planner without losing too much in the quality of the travelled trip? This question is particularly important since broadcasting in mobile peer-to-peer communication networks is energy and network bandwidth consuming and needs to be minimized.

The simulation environment is designed to understand and demonstrate the correlation of the spatial limitation of information dissemination (i.e., numbers of broadcasts) and quality of the travelled trip according to the chosen cost criterion. It will enable simulating shared ride trip planning with different parameters, such as density of hosts, or diameter of neighbourhoods. We expect to find a negotiation and communication strategy that adapts to a specific situation, and guarantees reasonable route qualities given this situation.

The paper is structured as follows. Section 2 describes the behaviour of the involved agents, the trip planning task, and the resulting need for information gathering and negotiations. Section 3 translates this into a simulation environment, and Section 4 summarizes the work and gives an outlook.

## **2. SPECIFYING THE TRIP PLANNING STRATEGY AND WORKFLOW**

Different trip planning strategies, although requiring different sorts of knowledge, all suffer from temporally and spatially limited knowledge of the available transportation supply. Hence, we deliberately choose one simplistic trip planning strategy for our investigation. More sophisticated trip planning strategies have the same dependency on temporal and spatial limitations of knowledge, but we start with investigating the parameters and strategies systematically on behalf of a simple planning strategy first.

In a local trip planning task one needs 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.

## **2.1 The transportation demand of a client**

In ad-hoc trip planning, clients have a transportation demand from their current position—and starting now—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.

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.

## **2.2 The transportation supply of hosts**

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 travelling forth and back. 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, hosts have a limited passenger capacity.

So far we do not differentiate between different types of hosts, for example, private cars, taxis, or public transport vehicles. The above characterization of hosts fits to the behavior of private car drivers; other behaviour could be introduced at later stages.

## **2.3 The planning task**

Clients are the planning agents. They need to know about available transportation supply to choose the optimal available rides. 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 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.

## 2.4 The negotiation needs

Communication 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 travelling. Since it is relatively short, we can simplify that the negotiation cycle alternates with a *travelling cycle*.

The need for a negotiation cycle means that in contrast to most 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 negotiations. Hence, we need radio-based communication strategies that efficiently spread messages and efficiently return answers.

The task of message broadcasting itself is by far the most energy-consuming process in any ad-hoc mobile geosensor network application, compared to the other modes of the communication cycle such as listening, computing, or sleeping (Zhao and Guibas 2004; Stefanidis and Nittel 2005). Since the battery capacity of mobile devices is limited (even if we are not looking for miniature devices in our shared ride trip planning application, but more for smart phones), minimizing the number of messages and range of broadcasting has priority. For that purpose we propose additional strategies for the communication process.

### 2.4.1 The Negotiation Cycle

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 requests, b) hosts listen to request, and make offers, c) clients receive and select one or more offers, d) clients respond to host with an accept of an offer, e) a host confirms the availability of the requested ride, and f) the client acknowledges the offer. With f) 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).

### *2.4.2 Requests*

Hosts shall 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 travelled as identified in 2.1. If hosts receive such a request they can evaluate the relevance of their own travel route with regard to the request, and respond only if they can contribute to the client's demand.

The details of the communication strategy are presented in Section 2.5.

### *2.4.3 Offers*

Hosts respond only to a request if they can contribute to the client's specified demand. To determine their potential contribution they apply a pattern matching between the requested street segments and their own travel plans. The hosts' response is called an offer.

### *2.4.4 Booking / Cancellation*

The clients perform 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.

## **2.5 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 agents within radio range. If messages shall be sent further they have to be forwarded by multi-hop communication, i.e., the agents that received a message repeat the broadcasting.

For energy efficiency, nodes in mobile ad-hoc geosensor networks communicate in synchronized, relatively short communication windows, and go into a sleep or processing mode in the meantime. These communication windows define the frequency of the negotiation cycles of the shared ride trip planning. For shared ride trip planning they have to be large enough to realize the full cycle of requests, offers and booking messages.

Considering a potentially very large number of agents in the shared ride trip problem network bandwidth becomes a problem. Collisions on the channels, limited capacity of the channels, and packet loss may happen and reduce the communication reliability. This is another reason to minimize the number of sent messages.

These are the considerations for communication strategies for the different steps of the negotiation protocol:

### 2.5.1 Request

We define that the communication strategy begin with clients advertising their transportation needs, while hosts are passive, and only publish their potential transportation supply only if there is transportation demand.

The client's request is broadcasted without an addressee, i.e., it disseminates to neighbouring nodes in the network within the pre-defined local neighbourhood. There are different strategies with regard to disseminating the request within the network. Since communication is only short range, the request is first disseminated to hosts in close proximity. On the other hand, these might be the most relevant hosts to offer rides in this dynamic neighborhood, and negotiation with distant hosts is less promising.

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

- **Flooding:** a client always informs all other hosts within its communication range of all information about its travel needs.
- **Epidemic:** a client informs only the first  $n$  hosts it encounters within its communication neighborhood about its travel needs.
- **Spatial Proximity:** a client informs hosts within its communication neighborhood only as long as it is moving and a host is within a certain threshold spatial distance  $d$  of its destination.

The second strategy is about a host forwarding the requests to other hosts. The same strategies apply as for clients.

### 2.5.2 Offers, Booking and Cancellation

As 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.

Bookings have to be confirmed in every communication cycle, or otherwise hosts will cancel their booking automatically for the next negotiation cycle. This way, client and host bookings are always kept consistent, and, in fact, no cancellation message is needed.

### 2.5.3 Other strategies

Furthermore, the clients will review and revise their travel plans regularly. Hence, a host with a relevant contribution for a client that was cut off from communication in one negotiation cycle can get closer in later negotiation cycles. The client can then still

react by revising its travel plan. Also bookings with remote hosts would be subject to frequent cancellations because of the changing environment (and knowledge) of the client. Hence, inclusion of more remote hosts in negotiations is likely uneconomic.

In particular, a simulation of shared ride trip planning shall compare the numbers of messages sent and the quality of the routes travelled for different spatial limitations.

### 3. SPECIFYING A SIMULATION ENVIRONMENT

The following agent-based simulation environment specifies and implements the behavior of the transportation clients and hosts introduced in Section 2. Fundamental assumption is that all information exchange within a negotiation cycle takes place in one communication window.

The simulation happens in a rectangular street network. In this network all hosts are moving with the same speed: 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 ( $\pm$  one row, or  $\pm$  one column).

#### 3.1 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.

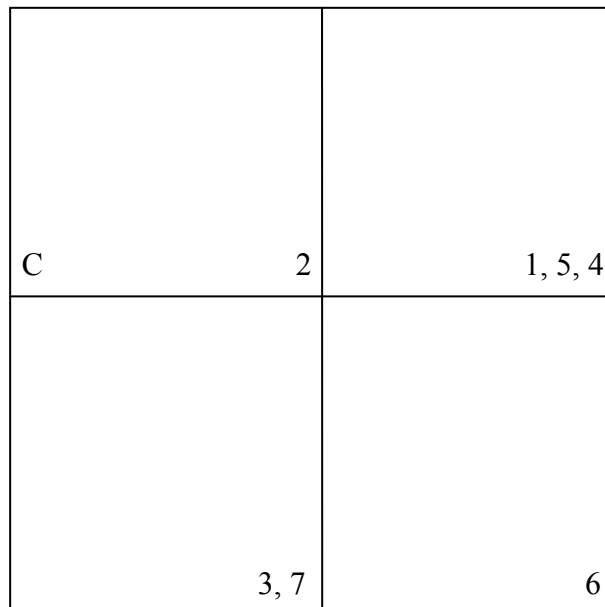


Figure 2: A client and seven hosts in a transportation network (snapshot).

Figure 3 shows only the connected agents. In this case all agents belong to one connected subnet, assuming a broadcast range of one street segment. On this graph a subset of edges forms a shortest path tree rooting in the client’s position.

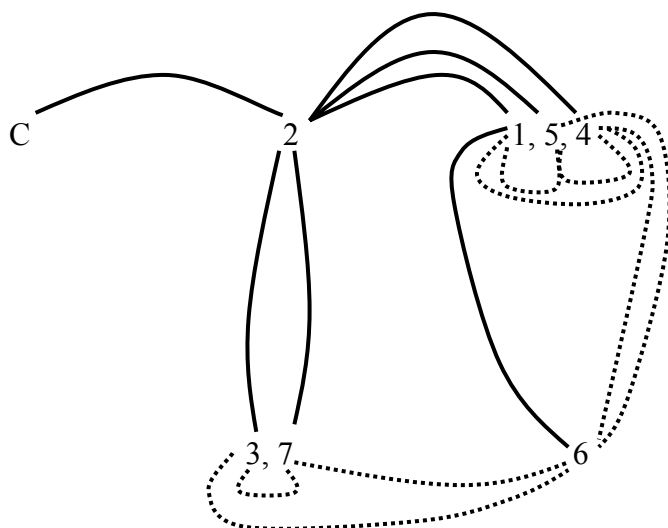


Figure 3: The network of connected agents (neighborhood graph) and a shortest path tree (solid edges).

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**).

### 3.1.1 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
<b>C</b>	r	<b>2</b>
<b>2</b>	r	<b>1, 5, 4, 3, 7</b> , [C]
<b>1</b>	r	[2], [5], [4], <b>6</b>
<b>5</b>	r	[2], [1], [4], [6]
<b>4</b>	r	[2], [5], [1], [6]
<b>3</b>	r	[2], [7], [6]
<b>7</b>	r	[2], [3], [6]
<b>6</b>	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 are printed in brackets. Only when agents receive a request for the first time they broadcast it. That means, in this situation each agent in the connected network broadcasts once. With 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 hops created with broadcasting. This protocol is attached to the request *r* itself:

agent	received request	forwarded request
<b>C</b>		r, C
<b>2</b>	r, C	r, C, 2
<b>1</b>	r, C, 2	r, C, 2, 1
<b>5</b>	r, C, 2	r, C, 2, 5
<b>4</b>	r, C, 2	r, C, 2, 4
<b>3</b>	r, C, 2	r, C, 2, 3

<b>7</b>	r, C, 2	r, C, 2, 7
<b>6</b>	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.

### 3.1.2 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**). The set of broadcasts for these offers consists of:

sender	message	receiver
<b>6</b>	o6	(3), (7), <b>1</b> , (5), (4)
<b>1</b>	o6	[(5)], [(4)], <b>2</b> , [6]
<b>2</b>	o6	[1], [(5)], [(4)], (3), (7), <b>C</b>
<b>3</b>	o3	(7), (6), <b>2</b>
<b>2</b>	o3	(1), (5), (4), [3], [(7)], <b>C</b>
<b>2</b>	o2	(1), (5), (4), (3), (7), <b>C</b>

In the table above, the hosts in parenthesis are receiving a message, but are not on the address list, and hence, do not forward the offer. The client does not forward offers addressed to him. 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.

### 3.1.3 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
<b>C</b>	b3	<b>2</b>
<b>2</b>	b3	(1), (5), (4), <b>3</b> , (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.

### 3.2 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.

In general, the number of agents of a connected component of a specific client is equivalent to the number of nodes in its neighborhood graph. For the example the neighborhood graph is shown in Figure 3, with every agent belonging to one 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.

With these measures the simulation is as follows:

```
msg_count = 0
for each client
  construct agent neighborhood graph
  calculate dijkstra (client)
  no_agents = number of nodes in graph
  generate request
  msg_count += no_agents
  for each host in component
    if (going to make an offer)
      generate offer
      msg_count += dijkstra (client, host)
  choose optimal offer
  generate booking
  book specified host
  msg_count += dijkstra (client, host)
end
```

This solution is particularly elegant because it does not need to simulate each single hop.

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.

### **3.3 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, being called with 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. 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 behaviour and preferences, such as mutual interest in client and host reputation.

Other questions, such as economic impact, or effects on urban dynamics with such a system, are on the agenda as well.

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