Intelligent Self-Organizing Transport

Stephan Winter

Intelligent self-organizing transport is transport arranged in an ad-hoc manner between clients (agents with transport demand) and hosts (agents offering transport supply) in a peer-to-peer manner. The absence of any centralized transport management system allows for a fully scalable solution that works in real-time in a transportation network of unpredictable and transient agents. Self-organizing transport also requires no further infrastructure than agents being equipped with positioning sensors and able to communicate locally via radio. This project report demonstrates the feasibility of such a system, presents preliminary results of simulations, and defines future research questions.

1 Motivation

Globally we experience an increasing demand for mobility that provides equitable access in sprawling cities [e.g., 4]. The complexity of modern cities needs smart transport solutions, which may emanate from the observation that urban traffic consist of many under-utilized transport resources, such as buses occupied far below capacity, private cars with low occupancy, and taxis with idle times, as well as some over-utilized resources, such as crammed trains or buses, or lack of resources in the outskirts of cities with no developed transportation system. This observation identifies an assignment problem of transportation clients—agents with transport demand—and hosts—agents offering transport supply.

In this situation, a major shift of paradigm in transportation management is suggested, called *self-organizing transport*. In self-organizing transport, clients and hosts negotiate directly for transportation, giving up any dependency or reliance on a centralized service. Note that for *intelligent transportation systems* (ITS) engaged in travel planning centralized services are still the standard paradigm. Car sharing, ride sharing or dial-a-ride services all rely on a centralized service. Centralized services may have a better overview of the transportation network—the set of vehicles offering transportation, their locations and their directions—. But in particular where transportation demand and supply is non-predictable, i.e., non-scheduled, they are overstrained by maintaining a real-time picture of the transportation network and serving and maintaining ad-hoc assignments automatically. Existing services are not capable to do that for large numbers of agents. Self-organizing transport addresses and solves this bottleneck.

Self-organizing transport is a novel approach to design decentralized ITS for travel planning. The approach is based on *mobile sensor networks* (MANETs), which are designed here as networks of social agents: nodes that have individual beliefs, desires and intentions, and are able to collaborate. This design is in contrast to classical mobile sensor network designs where nodes are homogeneous, redundant and of limited intelligence [21]. The paradigm shift towards self-organizing transport enables an ad-hoc transport management that is inherently ubiquitous, real-time, and independent from any external infrastructure. The system design is tested and demonstrated in simulations.

2 Current state in ITS and MANET

Current research in decentralized ITS focuses on the *autonomous vehicle* and *telematics* [2]. Vehicle-to-vehicle communication and vehicle-environment communication to centralized services via roadside equipment are the keys, and form so-called vehicular ad-hoc networks [e.g., 5]. This research is largely led by the automotive industry and governments[1], and in a few multi-disciplinary projects such as MIT's CARTEL [8]. The focus of these projects is on sensor observations and information for local actions, such as traffic flow management, congestion avoidance, and driving safety. Global information needs, such as supporting wayfinding or assigning transport resources, are frequently ignored. Other agents than car drivers, such as people, goods, and non-automobile means of transport, are also largely ignored.

In decentralized ITS, communication has to be wireless because of the mobility of most agents. Current developments of peer-to-peer communication standards are wireless LAN, Bluetooth, WAVE (Wireless Access for the Vehicular Environment), and ZigBee (for wireless personal area networks and sensor networks). Even if these standards are not compatible nowadays, and hence, inhibit the development of comprehensive intelligent transportation systems, they demonstrate already a trend towards peer-to-peer communication, and raise the expectation that in future all agents in an intelligent transportation system can communicate with each other in an ad-hoc manner. Alternatively, wireless communication can be realized in a non-ad-hoc manner. An example for one-way communication of this type is the radio data services [10], and an example for two-way communication of this type is the wireless internet access via cell phones. Both ways, ad-hoc or non-ad-hoc communication, can include immobile agents in the environment, although they are less limited and can also communicate by other means such as wired internet with centralized services.

In contrast to current ITS designs for travel planning and assignment, self-organizing transport should function without centralized control instances. Central control instances are known to be the major obstacle to reliable and ubiquitous management schemes for the incessantly growing transportation networks of modern cities; they form bottlenecks and central points of fail-

[1] For example, `http://www.car-to-car.org` or `http://www.internetits.org`.

ure. Imagine traffic as an emerging complex system of non-scheduled and transient individual participants. A central system would have to keep track of the current state of the system, including the positions and travel intentions of all individuals, and additionally it would have to maintain up-to-date assignment and travel plans for every individual participant. Such a requirement makes any centralized system clearly not scalable. Also, in case of disasters the whole emergency policy can be at stake, as has become evident, for example, after the London bombing and its subsequent break-down and closure of the mobile communication network.

Also in contrast to current ITS designs, self-organizing transport should consider other types of agents than car drivers. Including other types of agents in ITS requires different communication concepts that consider the limited on-board battery power of some of these agents. These concepts can be found realized in MANETs [21]. MANETs are ad-hoc networks of mobile nodes that communicate via short range radio in synchronized time windows. Nodes are linked as long as they are in radio range with each other.

As a specialization of MANETs, *geosensor networks* started to be studied quite recently [12]. They are mobile sensor networks that are location-aware, i.e., their nodes are equipped at least with a positioning sensor. While current research on MANETs is mostly looking into hardware, protocols, routing of messages, and data aggregation [6, 17], the current research on geosensor networks specifically is concerned with the efficient distribution or extraction of information of sensor observations [e.g., 11, 19]. Sensor networks with heterogeneous nodes are investigated as well [9]. Novel for geosensor network research is the focus of self-organizing transport on the movements of the nodes instead of the movement of information in the network. The intentional mobility of nodes is not considered in other research so far, although this property could even be used to carry information through the network.

In the context of this project, nodes get characteristics of agents: they have individual beliefs, desires and intentions [18]. Hence, in contrast to classical MANETs, in transportation management every node counts. Beliefs of agents in urban mobility are formed by their individual knowledge of the environment. Their desires are to do specific things, at specific locations. Thus, their intentions are to move to these locations [13]. The accepted approach to study the behavior of complex agent-based systems—as well as MANETs—is simulation. Close to the current context are large scale simulations of traffic [1], which study the relationship between the behavior of individual agents and the emerging traffic patterns.

3 Self-organizing transport

This project studies the design of an ad-hoc intelligent transportation system that allows:

- to include all sorts of mobile agents in urban traffic (the universe of discourse);
- to exploit the following properties of the mobile agents for the purpose of collaborative transportation planning in a purely peer-to-peer manner: their intentional mobility, their ability to ad-hoc communicate, their location awareness, and finally, their capacity to transport (hosts), or alternatively, their desire to be transported (clients).

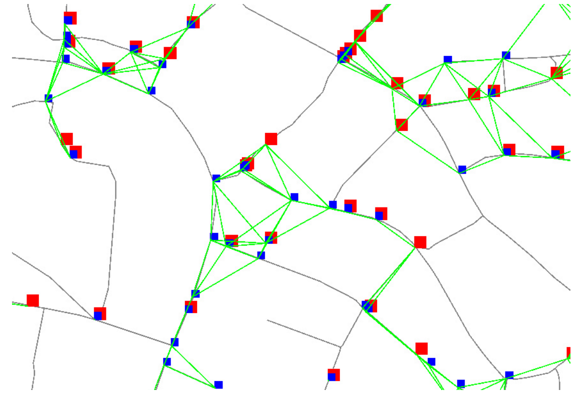

Figure 1: Clients (blue), hosts (red), and their actual communication networks (green) on top of an inner-urban street network (gray). Some clients are currently being transported by hosts (courtesy M. Braun).

The challenge of this endeavor is the transience of the agents: agents enter traffic without pre-announcement and mostly unscheduled, and they may change their travel intentions at any time. Also, their communication connectivity, which is limited in range by battery power anyway, is highly volatile due to their mobility. Furthermore, communication bandwidth also requires a system that limits itself to local communication only.

According to these requirements let us design the following system:

- Nearby clients and hosts communicate with each other in regular, synchronized time windows.
- They negotiate locally for transport assignments.
- Assignments are revised every cycle.

Figure 1 demonstrates the agents moving on a street network, and communicating with other agents nearby. In this communication network negotiations between clients and hosts can take place, both in single-hop or multi-hop communication. For readability, only a small portion of the street network used in this simulation is shown. The total length of streets in this simulation is 60km, and accordingly, there are many more agents around than in this small snippet.

Note that each agent's communication network is volatile. We assume stable networks during a (short) negotiation, but a changed communication network at the next negotiation cycle. By repeated negotiations and plan revisions, agents can react on the continuously changing transportation network in their neighborhood.

The negotiation consists of three steps:

- Clients send their requests to nearby hosts.
- Hosts check whether their travel intentions and transport capacity allows to make an offer, and if so, they make offers on specific requests.
- Clients collect all their offers, select the best one if it is advantageous, and book the corresponding host.

In the selection process, clients can apply an arbitrary cost function, such as minimizing fares or travel time or arrival time, or maximizing comfort or reputation. Between the cyclic negotiations, agents travel. After some cycles, the clients should have reached their destinations.

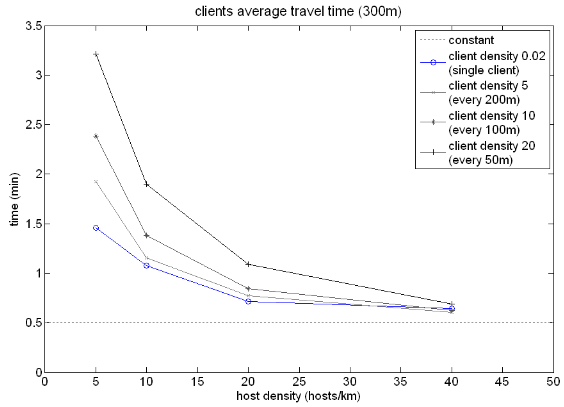

Figure 2: Competition

4 Preliminary results

We have investigated various aspects of a self-organizing transport service so far. Always the approach used a multi-agent simulation of an ad-hoc shared ride system, in which pedestrians are looking for rides in an urban environment.

The first question was: does the designed system work? In a simple simulation (grid street network, homogenous hosts of random travel behavior, an immobile and inflexible client, and an optimization criterion of travel time) it could be shown that the local knowledge of the transportation network collected by the client is absolutely sufficient: compared to complete knowledge of the current transportation network, the rides chosen based on local knowledge were only about 10% worse [16, 14].

Based on these encouraging results, individual constraints on the first simulation were lifted, and the consequences were investigated for each constraint. Clients can walk, and they can consider offers more flexibly, allowing for detours. In this context, effective planning heuristics were developed [7]. Hosts can be of different types, such as private car, bus, or taxi [20]. The street network can be irregular [15]. Looking for quickest trips, extending the first simulation showed in all cases improvements of the average trip times. In principle, other optimization criteria, and also multi-criteria optimization can be included [20].

Also, multiple clients can compete with each other for seats, such that also hosts compete for passengers [3]. This problem is also known as multi-commodity flow over time problem: multiple 'commodities' (clients) with individuals sources and sinks 'flow' through the transportation network that changes continuously its flow capacity with time. The multi-commodity flow over time problem an NP hard problem, which could be solved in this project with an elegant heuristics based on partitioning the transportation network and preferential offers. Figure 2 shows that competition decreases average trip times compared to a single client with no competition, as expected. But it also shows that this factor maximally doubles the trip time, within the chosen parameter variations made in the simulations, and is typically much smaller. Noting that walking would have taken 5.5 minutes, ride sharing with stiffest competition is still at least saving half the trip time (within the chosen parameter variations).

5 Conclusions and outlook

So far, we have suggested an innovative, decentralized, and hence, robust and scalable intelligent transportation system, and we have demonstrated in simulations its feasibility and general behavior as a complex system. This system enables for ad-hoc negotiations between moving agents, and does not require any further infrastructure or centralized system. It is fully scalable for any (large) numbers of concurrent transient agents constituting urban traffic.

Next on the research agenda are questions such as large scale simulations with realistic supply and demand assumptions. Availability of a peer-based self-organizing transport service may change supply and demand over time, such that modeling a change of mobility behavior is a challenging research question. This question involves activity scheduling and learning of the agents. Also, hybrid architectures—peer-based negotiations enriched with centrally provided information—can be investigated.

The vision of such a system rises also questions that are beyond the interest of this project. These questions concern, for example, safety and liability issues, economic incentives, micro payment, and the social dynamics that will emerge as soon as such a system becomes available.

Acknowledgements

The author is indebted to the following people contributing to the presented ideas: Monika Sester, Silvia Nittel, Martin Raubal, Yunhui Wu, Lin-Jie Guan, Christian Gaisbauer, Sören Dupke, Matthias Braun, Sven Tessmann, and Carlos Vieira. While writing this paper the author was also supported by a fellowship of the Hanse Institute for Advanced Studies, Delmenhorst. Intelligent Self-Organizing Transport is a project funded by the Australian Research Council (DP0878119).

References

[1] Balmer, M., Nagel, K., Raney, B., 2004. Large scale multi-agent simulations for transportation applications. Journal of Intelligent Transport Systems 8 (4), 205–221.

[2] Beresford, A. R., Bacon, J., Cottingham, D. N., Davies, J. J., Jones, B. D., Guo, H., Guan, W., Lin, Y., Song, H., Iftode, L., Fuchs, S., Lamprecht, B., Kyamakya, K., Fernandez, J. G., Yelmo Garcia, J. C., Martin Garcia, Y., de Gracia Santos, J., Nimesh, M., Pan, G., Wu, Z., Wu, Q., Shan, Z., Sun, J., Lu, J., Yang, G., Khan, M. K., Zhang, J., 2006. Intelligent transportation systems. Pervasive Computing 5 (4), 63–67.

[3] Braun, M., Winter, S., 2007. Multiple clients in ad-hoc shared ride planning. In: GI Days 2007. IfGI, University of Münster, Münster, Germany.

[4] Duarte, A., Collins, C., Bethune, A., Walker, M., 2002. Providing sustainable transport systems. Techical Report AP-R212/02, Austroads Inc.

[5] Eichler, S., Schroth, C., Eberspächer, J., 2006. Car-to-car communication. In: Proceedings of the VDE-Kongress - Innovations for Europe. Vol. 1. VDE, Aachen, pp. 35–40.

[6] Estrin, D., Govindan, R., Heidemann, J., Kumar, S., 1999. Next century challenges: Scalable coordination in sensor networks. In: Fifth Annual International Conference on Mobile Computing and Networks (MobiCOM '99). ACM Press, Seattle, Washington, pp. 263–270.

[7] Gaisbauer, C., Winter, S., 2006. Shared Ride Trip Planning with Free Route Choice. In: Raubal, M., Miller, H. J., Frank, A. U., Goodchild, M. (Eds.), Geographic Information Science. Vol. 28 of IfGI Prints. Institute for Geoinformatics, University of Münster, Münster, Germany, pp. 73–75.

[8] Hull, B., Bychkovskiy, V., Chen, K., Goraczko, M., Shih, E., Zhang, Y., Balakrishnan, H., Madden, S., 2006. Cartel: A distributed mobile sensor computing system. In: Proceedings of the 4th International Conference on Embedded Networked Sensor Systems. ACM Press, Boulder, CO, pp. 125–138.

[9] Jain, S., Shah, R. C., Brunette, W., Boriello, G., Roy, S., 2006. Exploiting Mobility for Energy Efficient Data Collection in Wireless Sensor Networks. Mobile Networks and Applications 11 (3), 327–339.

[10] Kopitz, D., Marks, B., 1999. RDS: The Radio Data System. Artech House, London, UK.

[11] Nittel, S., Duckham, M., Kulik, L., 2004. Information Dissemination in Mobile Ad-hoc Geosensor Networks. In: Egenhofer, M., Freksa, C., Miller, H. J. (Eds.), Geographic Information Science. Vol. 3234 of Lecture Notes in Computer Science. Springer, Berlin, pp. 206–222.

[12] Nittel, S., Stefanidis, A., Cruz, I., Egenhofer, M., Goldin, D., Howard, A., Labrinidis, A., Madden, S., Voisard, A., Worboys, M. F., 2004. Report from the first workshop on geo sensor networks. SIGMOD Record 33 (1), 141–144.

[13] Raubal, M., Miller, H. J., Bridwell, S., 2004. User-Centered Time Geography for Location-Based Services. Geografiska Annaler B 86 (4), 245–265.

[14] Raubal, M., Winter, S., Tessmann, S., Gaisbauer, C., 2007. Time geography for ad-hoc shared-ride trip planning in mobile geosensor networks. ISPRS Journal of Photogrammetry and Remote Sensing 62 (5), 366–381.

[15] Tessmann, S., 2006. Time Geography for Efficient Shared-Ride Trip Planning in Transportation Networks. Diploma thesis, University of Münster.

[16] Winter, S., Nittel, S., 2006. Ad-Hoc Shared-Ride Trip Planning by Mobile Geosensor Networks. International Journal of Geographical Information Science 20 (8), 899–916.

[17] Wolfson, O., Xu, B., 2004. Opportunistic Dissemination of Spatio-Temporal Resource Information in Mobile Peer-to-Peer Networks. In: First International Workshop on P2P Data Management, Security and Trust. DEXA, Zaragoza, Spain, pp. 954–958.

[18] Wooldridge, M., 2002. Introduction to Multiagent Systems. The MIT Press, Cambridge, MA.

[19] Worboys, M. F., Duckham, M., 2006. Monitoring qualitative spatiotemporal change for geosensor networks. International Journal of Geographical Information Science 20 (10), 1087–1108.

[20] Wu, Y.-H., Guan, L.-J., Winter, S., 2007. Peer-to-peer shared ride systems. In: Nittel, S., Labrinidis, A., Stefanidis, A. (Eds.), GeoSensor Networks 2006. Lecture Notes in Computer Science. Springer, Berlin, p. Paper accepted in December 2006.

[21] Zhao, F., Guibas, L. J., 2004. Wireless Sensor Networks. Elsevier, Amsterdam.

Contact

Dr.-Ing. habil. Stephan Winter
Associate Professor
Department of Geomatics
The University of Melbourne
Victoria 3010, Australia
Email: winter@unimelb.edu.au

Bild

Stephan Winter is lecturing geographic information science. His research focuses on system engineering for human wayfinding and intelligent transportation. In this area he is also interested in representation and communication of spatiotemporal information.