GUIDEWEB: AN INTRODUCTORY SOLUTION FOR V2V-COMMUNICATION

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ABSTRACT

In this paper a new paradigm named GuideWeb for networks based on vehicle-to-vehicle (v2v) communication is presented. GuideWeb is a support network for vehicle navigation and guidance. It is constituted by the cooperation of a multitude of autonomous MapSynthesiser nodes located in vehicles. A MapSynthesiser, being the autonomous core of GuideWeb, receives over radio communication traffic flow information using information-enhanced maps (called map syntheses) from other GuideWeb participants' MapSynthesiser. From received map syntheses and the information of its own travel route it creates a new map synthesis, which is then broadcasted. MapSynthesiser provides timely and accurate information on traffic flow and density as well as traversability everywhere within a radius of approx. 100 km to a navigation system for driver assistance. MapSynthesiser cooperation is based on short range radio communication e.g. Wireless Local Area Network (WLAN) according to IEEE 802.11 standards.

GuideWeb deploys the simple method of broadcast for network formation and thus, avoids the issues arising from setting up and maintaining an ad-hoc network. By the map based data design, data security and privacy are ensured. Therefore, GuideWeb can serve as a commercially viable introductory phase for full-fledged v2v communication network. The lessons learned from GuideWeb deployment provide insights for v2v network design.

INTRODUCTION AND BACKGROUND

There is an increasing demand for individual traffic and route information and navigation. The existing systems are typically based either on elaborate infrastructures for traffic measurement or on traffic patterns derived e.g. from individual mobile phone movements. Both concepts have their drawbacks.

The first one requires substantial investment into setting up the infrastructure, its maintenance incurs cost and in the case of a privately run enterprise should result in some profits. Therefore, this service for the end user can't be free of charge. Furthermore, the measurement infrastructure is typically only available on motorways.

The second one collects data by tracking individual user-movements e.g. mobile phones. By processing this data and matching it to maps allows the derivation of traffic flow estimations. This process can't ensure privacy as patterns of movement of individuals are recorded. The potential misuse of this data mandates a rigid supervision of the process by independent auditors. Again, the effort to put these concepts into place incurs capital expenditures in computing infrastructure and operational cost.

v2v communication offers a remedy for these drawbacks. Firstly, v2v communication allows in addition to navigation a variety of different other applications e.g. communicating to other vehicles dangerous situations (1, 2, 3) and/or mobile Internet (4, 5) with their corresponding issues of security (6) etc. v2v communication will be based on IEEE 802.11p standard. A German study (7) indicates that v2v communication networking will not be in place before 2020 (see figure 1), though the European Union supports a variety of projects with this target (8, 9, 10, 11, 12).

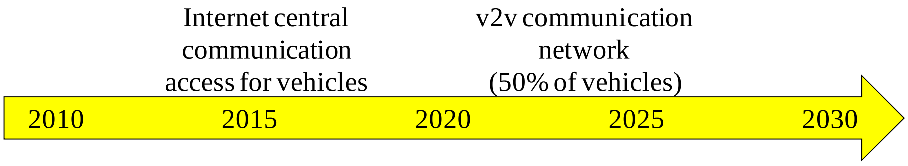

Figure 1. Time line of v2v communication introduction

Very often, especially in Europe, the propensity of customers to spend money for services on a recurrent basis is rather low; they prefer a one-time payment if necessary. Finally, the quality of data sets the price customers are willing to pay for this service.

This sets the scene for the concept presented here. The requirements derived from above are:

- to create most up-to-date traffic flow information and navigation support everywhere – **city, over-land or motorway,**
- to offer most up-to-date information on temporarily traversable/non-traversable routes not provided by the maps of a navigation system,

- to ensure privacy and data security,
- to avoid recurrent service charges.

The implications of these requirements are manifold. The most important one is: **No investments into infrastructure and cost for system maintenance:** Making the reasonable assumption of there being no public subsidy, the direct structural implication is that no centralized processing, evaluation or distribution unit must be required for the functioning of the process.

The concept GuideWeb presented in the following fulfils these requirements. **GuideWeb** is a systemic process, in which a multitude of participants are involved, for transmitting and receiving information of vehicles, using a radio transmitter and receiver and, more particularly, based on a device, which also processes the information received and enables the presentation of synthesized information to the user. A similar concept has been presented in (13). Furthermore, GuideWeb communication technology is simple and easy to implement, and can therefore serve as an intermediate introductory step in the full-fledged v2v communication networking (see figure **2**) that is technologically and commercially viable.

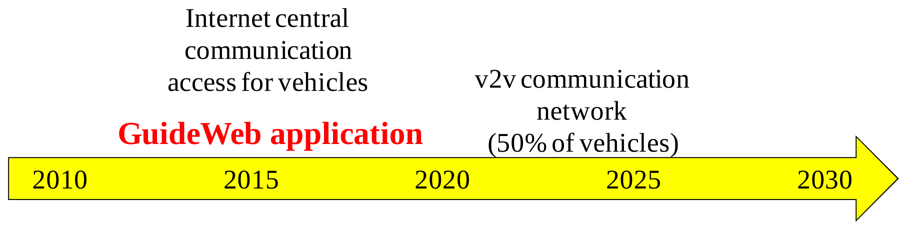

Figure 2. Time line of v2v communication introduction: GuideWeb positioning

This paper describes the functioning and implementation of GuideWeb. First the concept of GuideWeb and the autonomous MapSynthesiser as its constituting element is introduced followed by a description of how GuideWeb/MapSynthesiser fits into a driver assistance environment. The next two sections present the MapSynthesiser and its map processing capabilities. Simulation results that quantify penetration requirements and a conclusion complete the paper.

GUIDEWEB

The principle of GuideWeb is intriguingly simple – one gets information, processes it, uses it and distributes the processed information. Information is freely offered and everyone can take it (give and take). GuideWeb is constituted by a multitude of participants where the participants continuously broadcast their information and knowledge about current traffic and environment in the form of map syntheses. A map synthesis is a data compressed form of the synthesized map (**NowMap**) derived from the aggregation of all routes GuideWeb participants have traversed including averaged speed and traffic density information of route segments. Thus, the individual map synthesis is built up from every participant's best knowledge of traffic flow and environment. In order to facilitate this process each participant is equipped with a device called MapSynthesiser of which the functional diagram is shown in Figure 3.

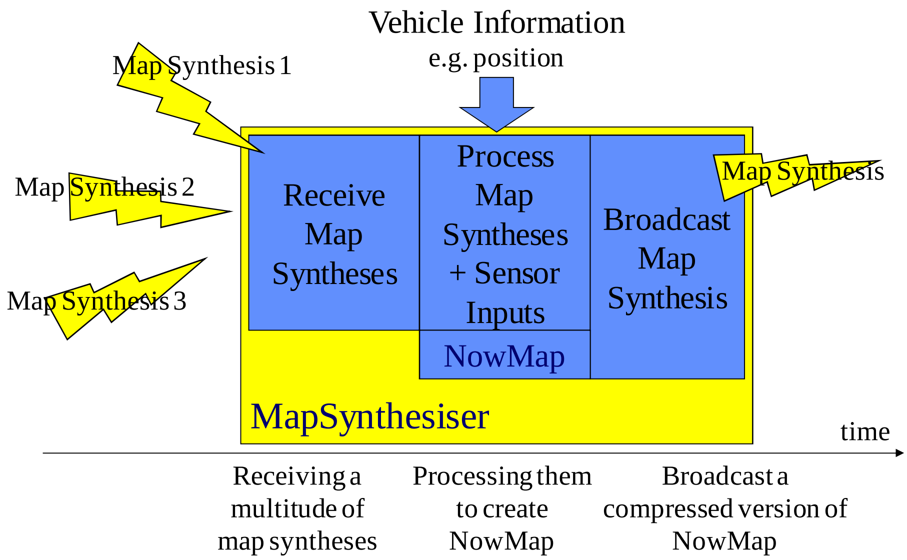

Figure 3. Functional diagram of the MapSynthesiser

The **MapSynthesiser** is typically a software application (executing together with a navigation application), which autonomously enables the functionalities of the GuideWeb only requiring connectivity from the communication platform and some basic vehicle information. MapSynthesiser provides timely and accurate information on traffic flow and density as well as traversability of roads everywhere within a radius of approx. 100 km. This information can be further processed and displayed to the driver e.g. by a navigation system. The MapSynthesiser generates the NowMap, the representation of the current information and knowledge about the environment, from which the broadcasted map synthesis is derived.

Conceptually GuideWeb is self-organizing and self-contained and independent of any infrastructure. Functionally GuideWeb rests entirely on the cooperation of the multitude of autonomous MapSynthesiser nodes.

ENVIRONMENT FOR MAPSYNTHESISER OPERATION

MapSynthesiser typically operates in a driver assistance environment and figure 4 shows how MapSynthesiser fits into this. MapSynthesiser exploits the v2v communication platform to send and receive messages. Two message types have been defined:

Synthesis messages contain a data condensed version of NowMap, and additional information, e.g. road conditions, radar traps, etc. when available and appropriate. Synthesis messages comprise on the incoming side the data compressed NowMaps of other GuideWeb participants' MapSynthesiser and on the outgoing side of its own NowMap. From the incoming synthesis messages the corresponding map data are extracted and made available for further processing.

Presence messages contain a minimum of information indicating the presence of a MapSynthesiser. Presence messages are very short and from their reception together with the reception of synthesis messages an estimate of traffic density can be derived. Furthermore, in phases of very low MapSynthesiser density, i.e. traffic density, presence messages serve as a trigger to broadcast synthesis messages; if no MapSynthesiser is in radio reach to receive synthesis messages they will not be transmitted.

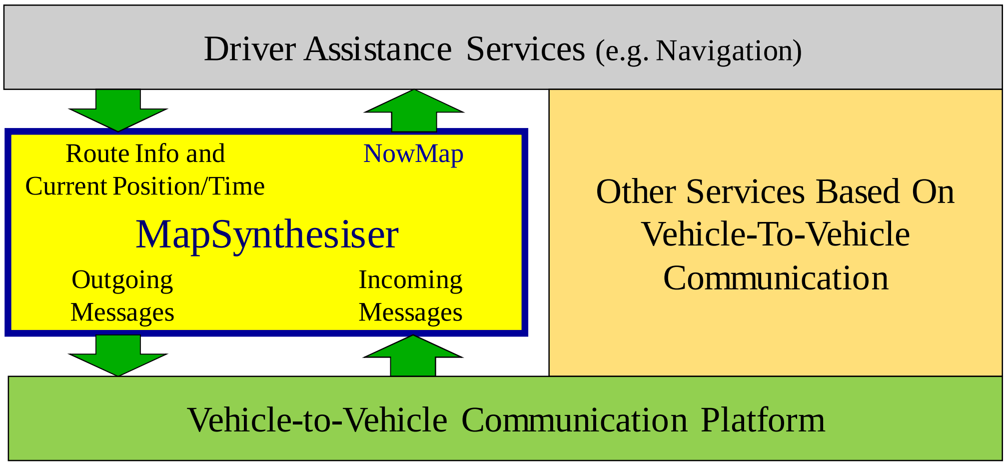

Figure 4. MapSynthesiser in the driver assistance environment

Further, MapSynthesiser uses driver assistance services for positioning as well as time information and optionally for a map of the environment of the navigation system. This map may then serve as the basis for the map processing in the MapSynthesiser. The map representation in MapSynthesiser is based on Earth coordinates to ensure independence from the map representation of the navigation system (14). As a result MapSynthesiser provides the navigation system with a map representation that comprises attributes for route segments – most prominently traffic flow and traffic flow trend estimation as well as traffic density. These attributes are time stamped.

OUTLINE OF MAPSYNTHESISER

The MapSynthesiser comprises the functionalities as described in the following based on the block diagram shown in figure 5. The MapSynthesiser broadcasts its messages in two modes:

- In Broadcast Mode 1 it broadcasts a synthesis message,
- In Broadcast Mode 2 it broadcasts a presence message.

In addition to the flow control mechanisms of the v2v communication platform stochastic processes control the broadcast modes to ensure a maximum throughput of messages.

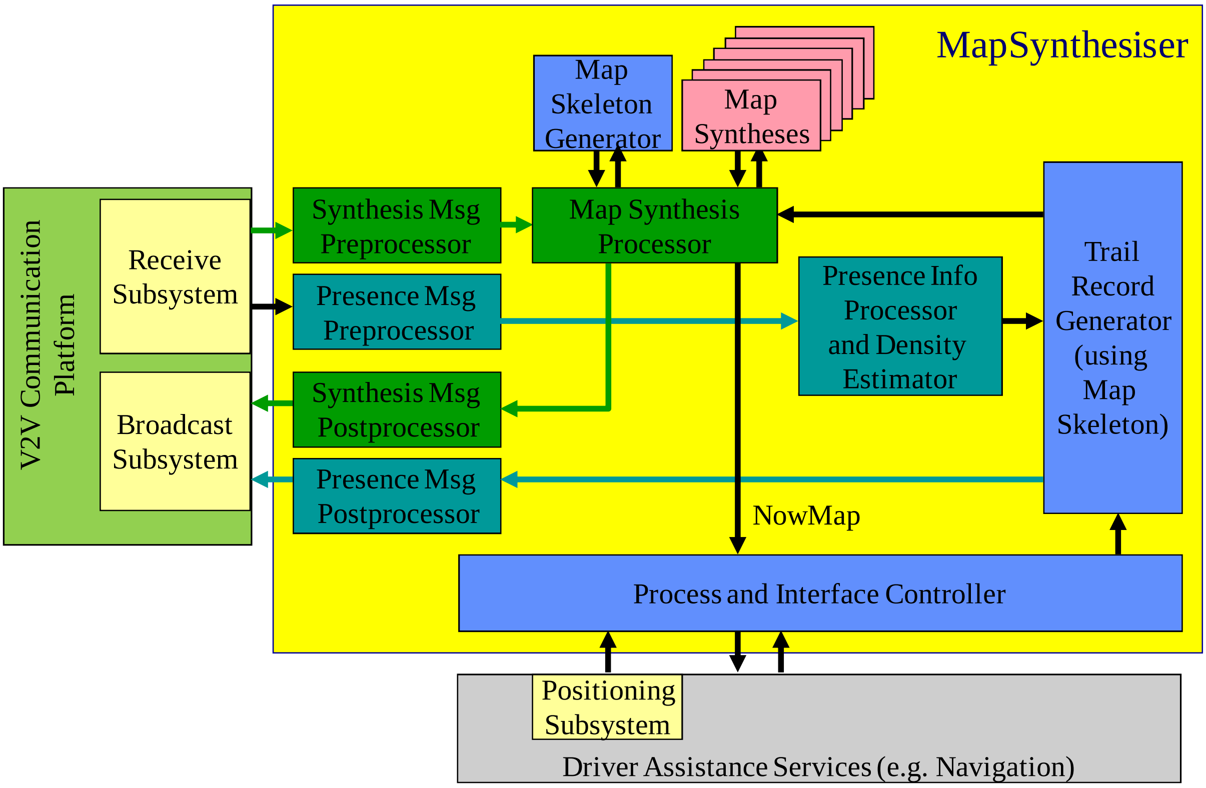

Figure 5. MapSynthesiser block diagram

The v2v communication platform sends the messages on some carrier frequency typically in the 2,4 GHz or 5 GHz band reserved for short-range applications (WLAN – Wireless Local Area Network). In order to minimize the expenses of the radio devices it is most cost effective when all radio subsystems transmit and receive information on the same carrier frequency. Furthermore, this choice makes a more elaborate communication protocol unnecessary. When each of the MapSynthesisers employs the same frequency selection algorithm for broadcasting, reception is ensured.

PROCESSING MAP SYNTHESES

MAP SYNTHESIS ATTRIBUTES

The map synthesis processor generates the map synthesis. From the received synthesis messages the relevant map synthesis information and additional information is extracted in a preprocessing stage. An example of an extracted map synthesis is shown in figure 6. On the right the **map skeleton** is presented, which summarizes the retrieved knowledge about routes in the chosen environment. On the left the map synthesis is shown with the attributes for the route segments. For each segment of the map skeleton – typically of length 100 m – the six values indicate average speed (AS), average density (AD) and traffic flow trend (T) for each direction of the road as determined. Together with a weight indicating the relevance of the information, i.e. the older the information the less relevant it becomes, they form the route segment attribute.

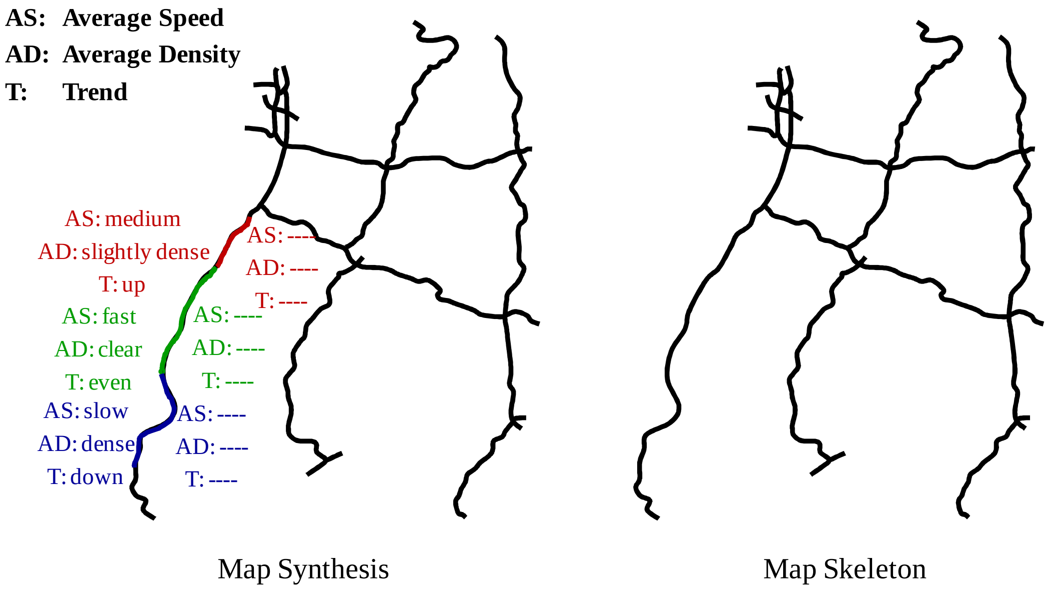

Figure 6. Example of a map synthesis

MAP SYNTHESIS HISTORY

To generate the NowMap the map synthesis processor collects and processes all received map syntheses for a defined time period, and keeps the history of the information of each route segment in memory as shown in figure 7.

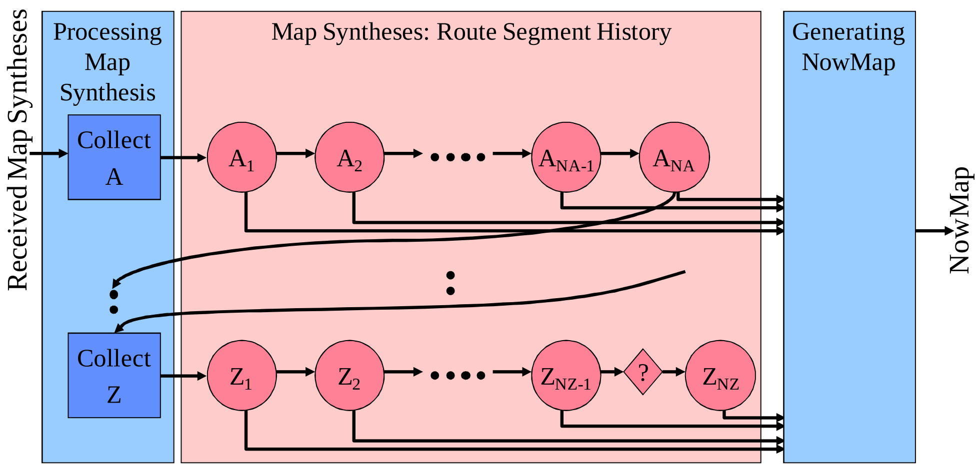

Figure 7. Route Segment History

The weights of the route segment attributes provide the time references to create this **route segment history**. The route segment history is used for computing the actual route segment attributes as well as for trend calculation. The history is stored in different levels e.g. in level A the time difference of the attributes A_i and A_{i+1} is 1 min, in level B B_i and B_{i+1} is 5 min, and so on. The number of levels and the corresponding timing is a matter of map synthesis processor configuration.

Keeping the route segment history enables the map synthesis processor to perform plausibility checks to detect and eliminate unrealistic attribute values (e.g. introduced to the system by a malicious user) as well as to compute the attributes for NowMap taking into account historical attributes. Furthermore, the historical attribute data allows a trend computation that indicates how traffic has evolved over time and what is to be expected.

GENERATING TRAIL RECORD

The most important ingredient to create a map synthesis is the trail record. A trail record is generated according to the following mechanism. When the process is started in a vehicle, the position is recorded with respect to the information received from the positioning subsystem e.g. a GPS receiver, and the time. For a certain distance e.g., 100 m, called a trail segment, the instantaneous speeds of the vehicle are determined and their average is computed resulting in an average speed for this trail segment and forms the trail segment record together with traffic density information that is computed by counting the received presence and synthesis messages and inferred from this number and the speed indications. Then the process is started again.

The trail comprises the multitude of trail segments traversed and the trail record comprises the multitude of the corresponding trail segment records. The position indications of points of the trail segments, in particular the start point, provide the information of the form of the trail and the average speeds and densities on the trail segments provide suitable information to be advantageously processed for the map synthesis.

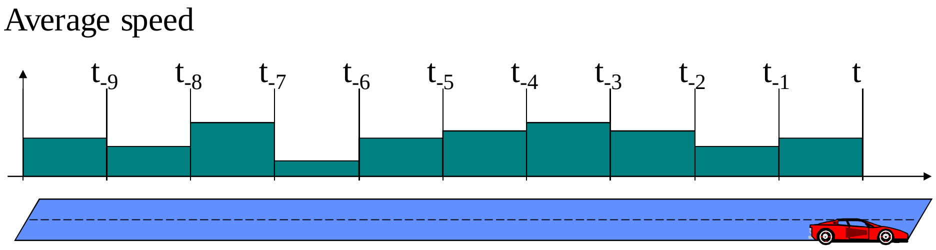

Figure 8. Trail record contribution to map synthesis

The vehicle under consideration generates a trail record (see figure 8), which it contributes to its present map synthesis. Initially i.e. without having received a synthesis message from another participating vehicle, a map synthesis consists of just the trail record. If speed is low, a time-out terminates and restarts this process after e.g., 1 min. In the case where the vehicle is not actively participating e.g., a vehicle with switched-off engine, it may cease to contribute.

SIMULATION

GuideWeb has been simulated and some of the results are presented in this section. Most importantly, introducing route segment attribute historical data adds a level of complexity to the system that requires careful examination. On the one hand, GuideWeb needs to learn about a traffic situation and on the other hand, it must forget when this traffic situation changes.

This learning and forgetting is implemented in a Learn-Forget algorithm which has been simulated extensively. For ease of implementation the simulation has been based on a "Manhattan" street model, i.e. the streets have a grid arrangement of 20 streets vertical and 20 streets horizontal. The distance between two neighboring streets is 100 m. This 100 m piece is called a segment. In total the grid has $20 \cdot 19 = 380$ segments and thus, a street length of $380 \cdot 100$ m = 38 km. The vehicles drive randomly around in the grid.

To introduce a traffic situation a road block appears on one of the streets in one direction causing a traffic jam when cars move on this road in this direction. The simulation is performed in cycles, each cycle consisting of two phases:

- The first phase starts when the first "car" learns about the jam. It is completed when all vehicles know about the jam, i.e. the NowMap of all cars indicate a jam on the corresponding route segments.
- The second phase starts with the removal of the roadblock and the traffic starts flowing again. It is completed when all vehicles have forgotten about the jam, i.e. the NowMap of all cars indicate a flowing traffic on all route segments.

GuideWeb has been simulated according to the procedure outlined above with the following environmental parameter: Number of vehicles = 1000; Radio Reach = 100 m and the percentages of vehicles equipped with MapSynthesiser: 1%, 2,5%, 5%, 7,5%, 10%.

The number of cycles has been at least 100. The results are summarized in table 1 and figure 9.

Percentage of vehicles with MapSynthesiser	**1,0%**	**2,5%**	**5,0%**	**7,5%**	**10,0%**
Average time to learn (in min)	30,40	23,72	18,62	15,94	14,11
Average time to forget (in min)	39,57	28,66	16,90	14,05	12,41

Table 1. Learn/forget cycle times against MapSynthesiser density

Obviously, as expected the average times to learn and to forget, respectively, decrease when the MapSynthesiser density increases.

A very interesting insight from this simulation is that the system, i.e. the entirety of the vehicles and MapSynthesiser in the area, has a "systemic memory". The "quality" of the systemic memory, i.e. the times for the system to learn and to forget about an incident, depends on the frequency of MapSynthesiser interaction. This is substantiated by the simulation results presented in figures 10 and 11. Relative frequency means in how many simulation cycles a time to learn and a time to forget, respectively, of $t + \Delta t$ appeared.

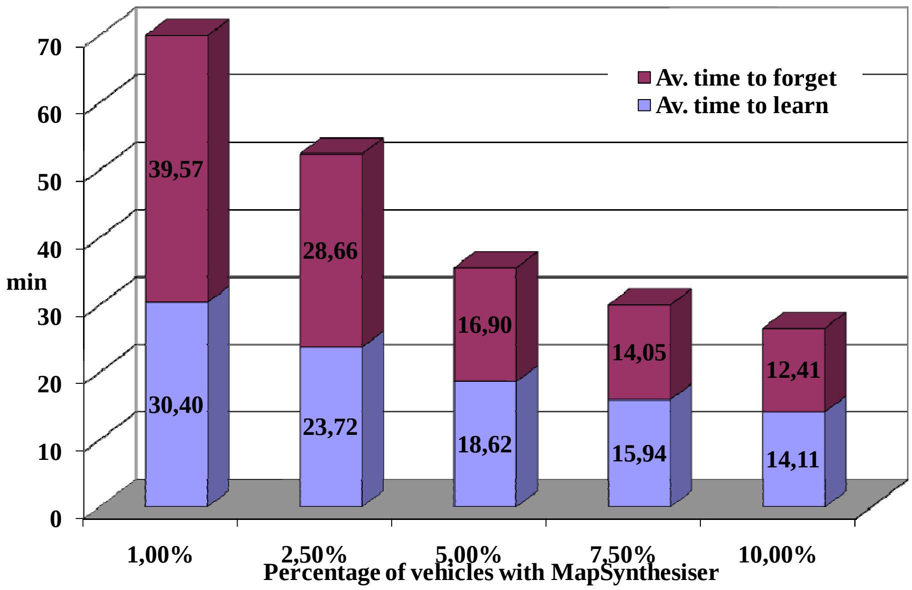

Figure 9. Average learn/forget cycle times against MapSynthesiser density

From figures 10 and 11 it is seen that

- average learn and forget times, respectively, (indicated by vertical lines) become shorter as the density of MapSynthesiser increases (as already stated above),
- the relative frequency function or histogram becomes sharper as density increases implying that learn and forget times become more predictable when more MapSynthesiser interactions are possible.

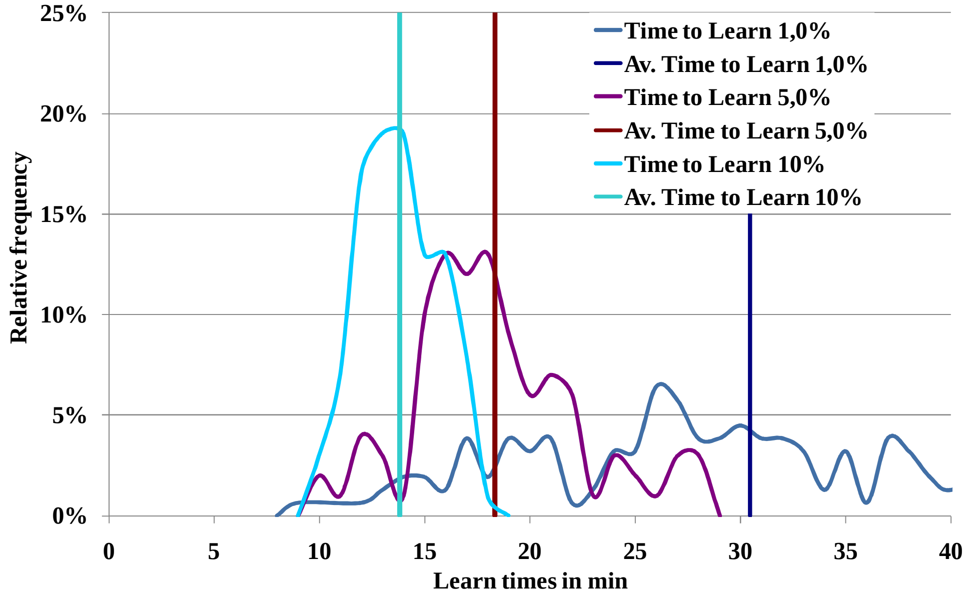

Figure 10: Relative frequency of learn cycle times (MapSynthesiser density is parameter)

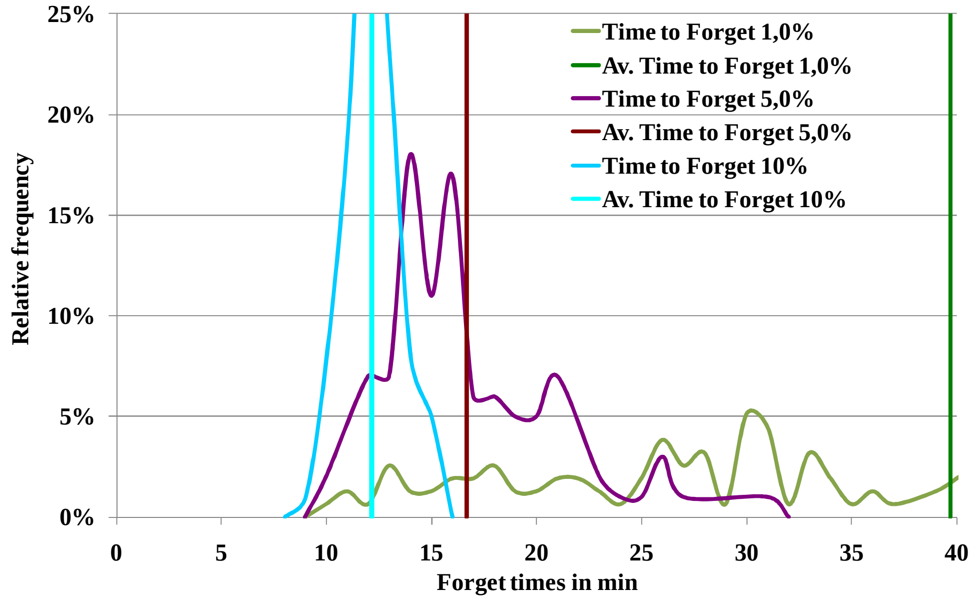

Figure 11: Relative frequency of forget cycle times (MapSynthesiser density is parameter)

CONCLUSION

In this paper the concept GuideWeb for vehicle navigation support based on v2v communication has been presented. It has been shown that GuideWeb is a very suitable candidate for a commercially viable introduction of v2v communication imposing a minimum requirement on networking. By using a broadcast communication concept, important difficulties in v2v communication are overcome or circumvented, and due to its coordinate-based exchange format it is independent of map suppliers and easily integrated in any driver assistance system. GuideWeb finds its application window beginning now until all the challenges of the v2v networking capabilities are resolved.

Further, the insights derived from GuideWeb deployment and its behavior allows learning about v2v communication system performance. Keeping historical data of the route segment attributes adds a new level of complexity – the systemic memory. However, the advantages of historical data (detection of implausible attributes or malicious users, computing trends ...) trade off favorably with the implications of the systemic memory as shown by simulation. Furthermore, by concept the penetration level required for GuideWeb to function is much lower than in other v2v communication systems. The processing methodology allows that information about specific vehicles can neither be extracted nor traced, i.e. that privacy is ensured.

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