GuideWeb: Information Acquisition Analysis in a Conceptually Infrastructure-Free Vehicle Navigation System

Dr. Bernd X. Weis

BlackForestLightning, Bernd.Weis@BlackForestLightning.de

Abstract

GuideWeb is a support network for vehicle navigation and guidance. It is constituted by the cooperation of a multitude of autonomous MapSynthesiser located in the vehicles. A MapSynthesiser, being the autonomous constitutional core of GuideWeb, receives over radio communication traffic flow information via information-enhanced maps (called map syntheses) from other GuideWeb participants' MapSynthesiser. It creates from received map syntheses and the information of its own travel route a new map synthesis, which is then broadcasted. MapSynthesiser provides timely and accurate information on traffic flow, density and trend on how traffic will develop 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. Further, the information acquisition analysis shows that a MapSynthesiser density of only 2% in a medium traffic load class enables the acquisition of 500 km of route information in approx. 15 min.

1 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 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.

v2v communication allows a variety of 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. A German study [7] indicates that v2v communication networking will not be in place before 2020.

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 (ubiquity),
- 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 no cost for system maintenance. The direct 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 [8, 9, 10]. GuideWeb is a systemic process, in which a multitude of autonomous participants are involved. A similar concept has been presented in [11].

This paper describes briefly the functioning and implementation of GuideWeb. First the concept of GuideWeb and the autonomous MapSynthesiser as its constituting element is introduced. The next two sections present the MapSynthesiser and its map processing capabilities. Simulation results that quantify penetration requirements and a conclusion complete the paper.

2 GuideWeb and MapSynthesiser

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 1.

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.

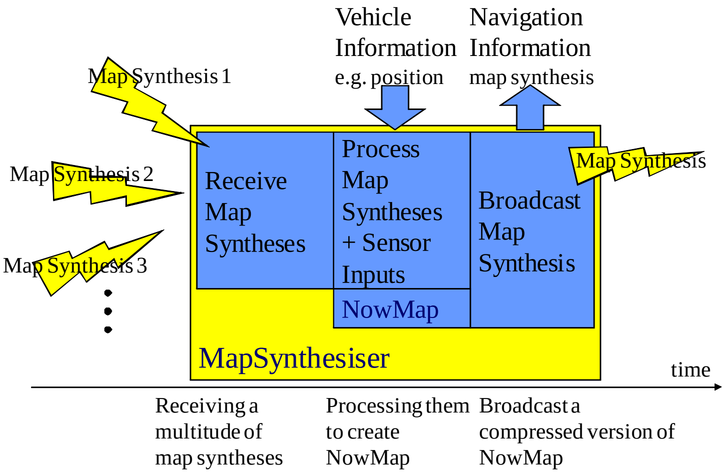

Fig. 1. Functional diagram of the MapSynthesiser

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.

3 Analysis of Information Acquisition in MapSynthesiser

The following analysis discusses how quantitatively MapSynthesiser acquires route information. Two cases will be considered.

The first case is based on the scenario that all MapSynthesiser in a specific area start collecting information at the same time, i.e. all MapSynthesiser have no information about the environment.

The second case is based on the scenario that only the MapSynthesiser under consideration has no information at all. The other MapSynthesiser have already acquired information of the environment. Reality is somewhere in between – however it is safe to assume that it is closer to the second case than to the first.

The system to be analyzed is rather complex and the full stochastic analysis is rather tedious. Therefore, the analysis given in the following restricts itself to a mean value analysis. The main results are not affected by this limitation.

3.1 Definitions and Notations

When describing traffic situations typically the following two parameters are stated:

Traffic flow (or flux) Q: Number of vehicles per time unit
Traffic density D: Number of vehicles per length unit

Traffic flow and traffic density relate through the average vehicle velocity, i.e.

$$v_{av} = \frac{dQ}{dD} \quad \text{or in the steady state} \quad v_{avSteadyState} = \frac{Q_{av}}{D_{av}}$$

The following table classifies traffic density in traffic load classes with Traffic density = Number of Vehicles per km.

Traffic Density	**Traffic Load Class**
0 – 16	Low
16 – 23	Medium
23 – 32	High
32 – 45	Very high
45 –	Overload

It is called “encounter” when in traffic two vehicles both equipped with a device executing MapSynthesiser exchange route information. For further explanation of the notations see figure 2.

t_{En}: Point in time of encounter n
τ_n: Time period between encounters n and n+1
$K_{in}(t)$: Route information in km stored in the map of MapSynthesiser i after encounter n at time t
$S_i(\tau_n)$: Distance in km driven of MapSynthesiser i between encounters n and n+1
K_{max}: Maximum route information in km that can be stored
$P_i(\tau_n)$: Maximum route information in km that can be processed in time τ_n between encounters n and n+1 (determined by processing power of MapSynthesiser computing platform)
α: Parameter to account for maps not completely matching in their respective map areas

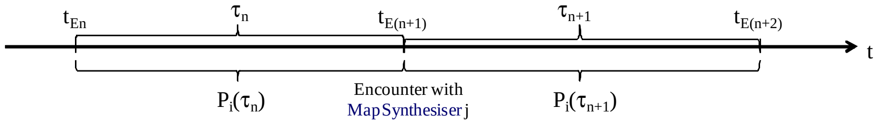

Fig. 2: Definition of notations

3.2 Route Information in MapSynthesiser

The route information available in MapSynthesiser i at time t is the information at the last encounter $K_{in}(t_{En})$ and the information from its own travel experience $S_i(t - t_{En})$ adjusted by the information load already in place, which accounts for multiple traversed route segments, i.e.

Information load adjustment: $\left(1 - \frac{K_{in}(t_{En})}{K_{max}}\right)$

During the encounter n+1 the route information $K_{jm}(t_{En})$ received in encounter n from MapSynthesiser j is processed into the route information $K_{in}(t_{En})$ creating $K_{i(n+1)}(t_{E(n+1)})$. However, since the processing power of the platform on which MapSynthesiser is executing is limited only that information that is actually processed contributes to $K_{i(n+1)}(t_{E(n+1)})$. This accounts for the minimization term. Further, since the some of the route information may not be of relevance the minimization term is adjusted by the parameter α as defined above. Hence,

$$K_{i(n+1)}(t_{E(n+1)}) = K_{in}(t_{En}) + \left(S_i(\tau_n) + \alpha \operatorname{Min}\{K_{jm}(t_{En}), P_i(\tau_n)\}\right)\left(1 - \frac{K_{in}(t_{En})}{K_{max}}\right)$$

Case 1: GuideWeb in formation state

For a more detailed analysis of this formula assume that all MapSynthesiser start at the same time t = 0, i.e. GuideWeb is in the process of being formed. Then, stochastically there is no difference between K_{in} and K_{jm} with respect to the size of the route information available, thus

$$K_{i(n+1)}(t_{E(n+1)}) = K_{in}(t_{En}) + \left(S_i(\tau_n) + \alpha \operatorname{Min}\{K_{in}(t_{En}), P_i(\tau_n)\}\right)\left(1 - \frac{K_{in}(t_{En})}{K_{max}}\right).$$

Case 2: GuideWeb in steady state

In this case the MapSynthesiser enters the system when it is already in steady state. The information acquisition is only limited by the processing power of the computing platform, thus

$$K_{i(n+1)}(t_{E(n+1)}) = K_{in}(t_{En}) + \left(S_i(\tau_n) + \alpha P_i(\tau_n)\right)\left(1 - \frac{K_{in}(t_{En})}{K_{max}}\right).$$

3.3 Average Case Analysis

In order to evaluate this formula the average case is analyzed. For that assume that the encounters in which map information is exchanged between vehicles in traffic is with respect to time equidistant, i.e. $\tau_n = \tau$ for all n. Thus, $t_{E(n+1)} = t_{En} + \tau$.

The size of the map information available in MapSynthesiser i at the (n+1)-st encounter is given by

Case 1: $K_{i(n+1)}(t_{E(n+1)}) = K_{in}(t_{En}) + \left(S_i(\tau) + \alpha \operatorname{Min}\{K_{in}(t_{En}), P_i(\tau)\}\right)\left(1 - \frac{K_{in}(t_{En})}{K_{max}}\right)$

Case 2: $K_{i(n+1)}(t_{E(n+1)}) = K_{in}(t_{En}) + \left(S_i(\tau) + \alpha P_i(\tau)\right)\left(1 - \frac{K_{in}(t_{En})}{K_{max}}\right)$

3.4 Average Case Results

For the following it is assumed that the route information corresponding to 3000 km road can be handled in MapSynthesiser which corresponds to a payload size for transmission of approx. 100 kB. When the transmission is based on WLAN using the UDP protocol the payload is limited to 1522 Byte. Thus, the information to be transmitted is broken down in suitable chunks of payload whose sizes don’t exceed 1522 Byte resulting in approx. 75 messages each representing approx. 40 km of road information. A received message (~ 1350 Byte payload) needs less than 1 s processing time. This processing time has been determined on an ASUS 636N with Windows Mobile 5. But MapSynthesiser is not the only application executing on the platform, at least a navigation application runs in parallel; therefore only a certain percentage is available for MapSynthesiser execution.

In summary

Maximum length of 1 map (K_{max})		3000 km (< 100 kByte)
75 messages (per 1 map):	⇒	40 km per message
Processing time for 1 message = 1 s	⇒	μ_{max} = 60 / min
Processing time for MapSynthesiser 25%	⇒	μ = 15 / min
Traffic density: 30 veh./km @ 50 km/h (both directions)	⇒	Traffic flow: 3000 veh./h

Case 1: Evaluation With Respect to Traffic Density

Figure 3 presents the results for the following parameter settings:

Parameter	Value	Traffic load class
α =	0,8	
Traffic density =	10 – 40 veh. / km	from low to very high
Traffic flow =	1000 – 4000 veh. / h	
MapSynthesiser Density =	1% and 2%, resp.	
Share of processing power =	25%	

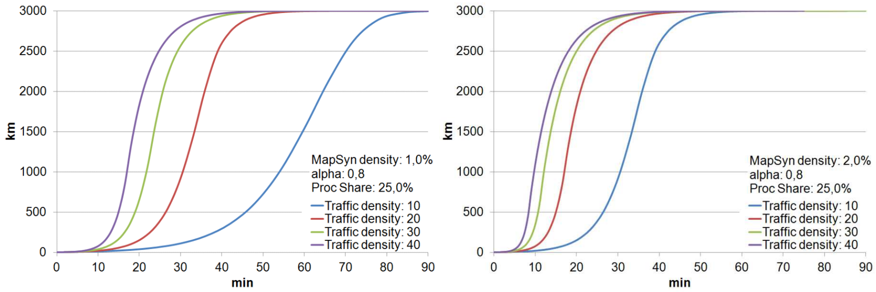

Fig. 3: Road information in MapSynthesiser in km vs. acquisition time with traffic density as varying parameter

Acquisition time in min of 500 km road information

	Traffic density			
MapSynthesiser density	**10**	**20**	**30**	**40**
1,0%	46	26	21	15
2,0%	26	15	11	9

Case 1: Evaluation With Respect to MapSynthesiser Density

Figure 4 presents the results for the following parameter settings:

Parameter	**Value**	**Traffic load class**
α =	0,8	
Traffic density =	20, 30 veh. / km	medium and high
Traffic flow =	2000, 3000 veh. / h	
MapSynthesiser Density =	0,5% – 3,0%	
Share of processing power =	25%	

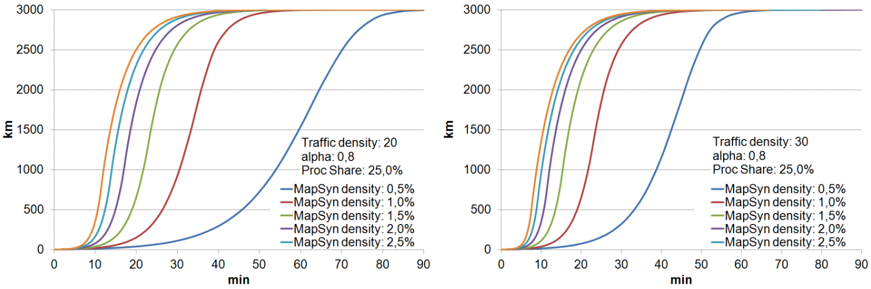

Fig. 4: Road information in MapSynthesiser in km vs. acquisition time with as MapSynthesiser density varying parameter

Acquisition time in min of 500 km road information

	MapSynthesiser density					
Traffic density	**0,5%**	**1,0%**	**1,5%**	**2,0%**	**2,5%**	**3,0%**
20	47	26	19	15	13	11
30	33	19	14	11	9	8

Case 1: Evaluation With Respect to Processing Power Share

The acquisition times in min of 500 km road information for the following parameter settings

Parameter	**Value**	**Traffic load class**
α =	0,8	
Traffic density =	20, 30 veh. / km	medium and high
Traffic flow =	2000, 3000 veh. / h	
MapSynthesiser Density =	2,0%	
Share of processing power =	25% – 10%	

show only minor variances with respect to the share of processing power.

	Processing Power Share			
Traffic density	**25%**	**20%**	**15%**	**10%**
20	15	15	15	15
30	11	11	11	11

Case 2: Evaluation With Respect to MapSynthesiser Density

In this case the MapSynthesiser enters the system when it is already in steady state. The processing of the data exchanged is then only limited by the processing power of the computing platform.

Figure 5 presents the results for the following parameter settings:

Parameter	Value	Traffic load class
α =	0,8	
Traffic density =	20, 30 veh. / km	medium and high
Traffic flow =	2000, 3000 veh. / h	
MapSynthesiser Density =	0,5% – 3,0%	
Share of processing power =	25%	

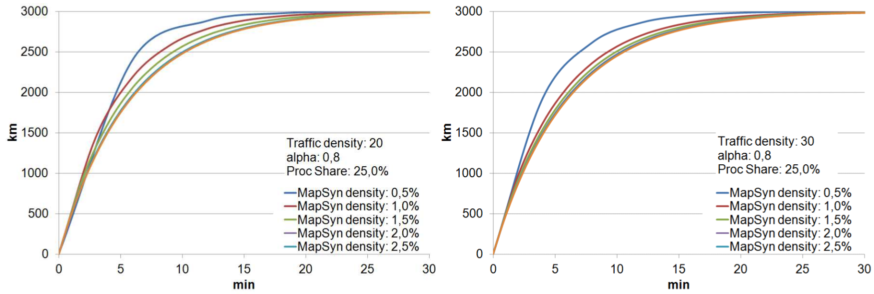

Fig. 5: Road information in MapSynthesiser in km vs. acquisition time with MapSynthesiser density as varying parameter entering GuideWeb in steady state

The time to acquire 500 km road information is approx. 1 min in both cases.

3.5 Summary

Case 1: A MapSynthesiser enters GuideWeb in formation state

A MapSynthesiser enters a GuideWeb that is just forming, i.e. the road information exchanged in encounters is likely to be of the same size. From the results presented above for a medium traffic load class and a MapSynthesiser density of 2% the acquisition time for 500 km road information is **approx. 15 min**.

Case 2: A MapSynthesiser enters GuideWeb in already steady state
A MapSynthesiser enters a GuideWeb that is already in a steady state, i.e. the road information received is of maximum size. In this case the acquisition time of 500 km road information is **approx. 1 min**.

4 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.

5 References

[1] Schnaufer S. et al., Vehicular Ad-Hoc Networks: Single-Hop Broadcast is not enough, Proceedings of 3rd International Workshop on Intelligent Transportation (WIT), Hamburg, Germany, pp. 49-54, 2006

[2] Torrent-Moreno M., Inter-Vehicle Communications: Assessing Information Dissemination under Safety Constraints, 4th Annual IEEE/IFIP Conference on Wireless On Demand Network Systems and Services (WONS), Obergurgl, Austria, 2007

[3] Baldessari R. et al., NEMO meets VANET: A Deployability Analysis of Network Mobility in Vehicular Communication, Proceedings of 7th International Conference on ITS Telecommunications (ITST 2007), Sophia Antipolis, France, pp. 375–380, 2007

[4] Bechler M. et al., Mobile Internet Access in FleetNet, in Proceedings of KiVS 2003, Leipzig, Germany, 2003

[5] Baldessari R. et al., Flexible Connectivity Management in Vehicular Communication Networks, Proceedings of 3rd International Workshop on Intelligent Transportation (WIT), Hamburg, Germany, pp. 211-216, 2006

[6] Harsch C. et al., Secure Position-Based Routing for VANETs, Proceedings of IEEE 66th Vehicular Technology Conference (VTC Fall), Baltimore, MD, USA, 2008

[7] Zukunft und Zukunftsfähigkeit der Informations- und Kommunikationstechnologien und Medien, Internationale Delphi-Studie 2030, Münchner Kreis e.V., EICT GmbH, Deutsche Telekom AG, TNS Infratest GmbH, 2009

[8] Weis B., Sandweg A., GuideWeb: A New Paradigm for Navigation Support based on v2v Communication, Proceedings of AMAA, Berlin, Germany, pp. 423-432, 2010

[9] Weis B., Sandweg A., GuideWeb: An Introductory Solution For V2V-Communication, Proceedings of ITS World Congress, Busan, Korea, SP23-1, 2010

[10] Weis B., Sandweg A., GuideWeb: a conceptually infrastructure-free vehicle navigation system, IET Intell. Transp. Syst., pp. 1–6, September 2012

[11] Wischhof L. et al., SOTIS – A Self-Organizing Traffic Information System, Proceedings of 57th IEEE Semiannual Vehicular Technology Conference VTC 2003-Spring, Jeju, South Korea, 2003

[12] ISO, Intelligent Transport Systems (ITS) – Location Referencing for Geographic Databases – Part 3: Dynamic Location References (Dynamic Profile), Draft Standard 17572-3, 2009

Authors' Information

Dr. Bernd X. Weis
BlackForestLightning
Haeberlinstr. 29b
70563 Stuttgart
Germany
E-mail: Bernd.Weis@BlackForestLightning.de

Keywords

Vehicle Navigation, Privacy, Ad-Hoc-Networks, Autonomous Systems, Data Acquisition, Dynamic Systems