Improving Information Dissemination in Sparse Vehicular Networks by Adding Satellite Communication

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***Abstract*— Information dissemination in pure Vehicular Ad Hoc NETworks (VANETs) such as ITS-G5 becomes problematic when the network is sparse. In situations where the number of vehicles, that can act as a communication node, is insufficiently low, e.g. in rural areas, during night-time or because of a low market penetration of the technology in the early years of market introduction, certain range limits (unavailability of forwarding nodes) or timing limits (store-and-forward techniques) are stressed. Due to the limited communication range, VANETs start to build separated clusters, if the density of equipped vehicles is too low. Consequently, information dissemination without delay-massive store-and-forwarding is only possible within one cluster, but not beyond. This paper investigates the integration of Car-to-Car (C2C) with an additional satellite communication technology, referred to as Car-to-Satellite (C2S). A realistic sparse vehicular network scenario has been simulated and evaluated with respect to the in-time reception of safety-related information. The results show that information dissemination can be significantly improved through a limited number of vehicles which are additionally equipped with satellite terminals. In fact, even the market introduction of VANET-based ITS can be significantly accelerated with just a few vehicles equipped with non-VANET communication technology.**

I. INTRODUCTION

In Europe, many traffic fatalities occur each year, of which more than half on rural roads. In 2009, $35,000$ people died in traffic accidents and over 1.7 million were injured. Therefore, the road safety guidelines of the European Union (EU) aim to cut European road deaths by $50\,\%$ until 2020 [1]. One of the objectives for achieving this goal is, to promote the deployment of Intelligent Transport Systems (ITS) [1].

In particular the introduction of ETSI[1] ITS-G5, i.e. the European Car-to-Car (C2C) communication standard for ITS, enables vehicle cooperation, in order to increase road safety. By using this communication technology, vehicles are able to exchange safety-related information among each other. This information is processed by different safety applications, with the objective to warn the driver about an imminent danger, or even to react autonomously without any human interaction.

The ITS-G5 communication technology is based on IEEE 802.11p, which is an amendment of IEEE 802.11 (ordinary wireless LAN) to adapt this well known technology for vehicles and their dynamic environment [2], [3], [4]. For

[1]European Telecommunications Standards Institute

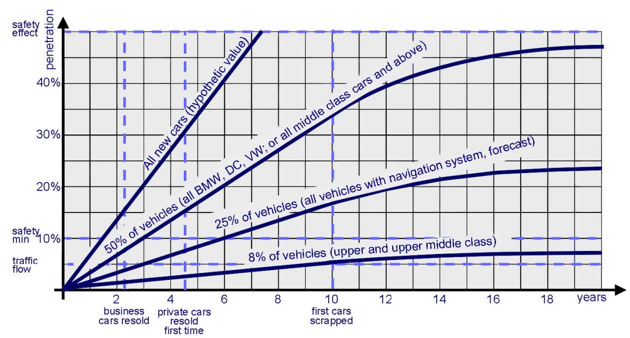

Fig. 1. Penetration rate of ITS-G5 equipped vehicles in Germany over years for different introduction strategies as estimated by Volkswagen and others [6]

radio transmissions, a dedicated spectrum in the 5.9 GHz frequency band is used, split into 3 channels (ITS-G5A) for safety related applications and 2 channels (ITS-G5B) for non-safety related applications with 10 MHz bandwidth for each. An additional frequency band (ITS-G5C) is reserved for additional applications. The access technology makes use of the probabilistic Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism. It allows a fully decentralized medium access control without any dependency on infrastructure components. As a result, VANETs span a very flexible network structure.

Despite many advantages, ITS-G5 is not without any drawbacks: an important one is the still short communication range. IEEE 802.11p was designed to support a communication range of $1000\,m$ and more[2], but due to the more or less optimal environmental conditions for radio propagation in real world scenarios, the communication range can even drop to $250\,m$ or less. This becomes a severe problem if the vehicle density in VANETs is sparse, which is certainly the case during the initial phase of market introduction, because of the low penetration rate of vehicles equipped with ITS-G5 technology. This problem is highlighted by Fig. 1, which shows the progress of the penetration rate over years for different introduction strategies of the ITS-G5 technology.

Safety and safety related information for a plethora of

[2]In our real world experiment leading to the results published in [5] a communication range of more than $2.200\,m$ has been achieved.

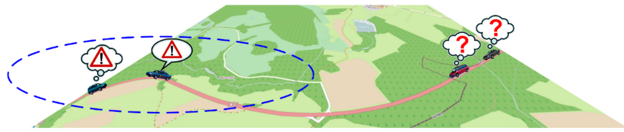

Fig. 2. Clustering of VANETs in case of low density of equipped vehicles. Information dissemination is possible only between vehicles within the same cluster (left), but not between different clusters (from left to right) without any additional mechanisms.

new cooperative applications are encoded and transmitted predominantly in two different types of messages:

- **Cooperative Awareness Message (CAM) [7]:** This message is used to inform other vehicles about the current status of the transmitting vehicle, such as the current geographical position, speed and heading. CAMs are typically broadcasted as periodical beacons with a frequency of 1-10 Hz. As they are most relevant for other vehicles in the close vicinity, but outdated after a short time, CAMs are usually not re-broadcasted by a receiver.
- **Decentralized Environmental Notification Message (DENM) [8]:** This message is used to inform vehicles about a special event, such as a roadwork construction or an accident, within a certain area. The destination area for DENMs is often much larger than the communication range itself, and the information about the event is valid for a much longer time (up to hours). Hence, DENMs are re-transmitted by the receivers, at a rate dependent on the application and the used dissemination scheme.

Any safety application which builds on the availability of DENMs, relies on a communication with reliable delivery of DENMs within a certain time, place or distance. If the density of equipped vehicles is too low, the VANET falls apart into clusters. Consequently, only vehicles within one cluster are able to communicate and exchange safety related information with each other, as depicted in Fig. 2. Moreover, transmitting safety related information from one cluster into another is not possible without any additional measures or mechanism, such as store-and-forward [10]. This becomes a problem during the dissemination of DENMs if the dissemination area spans multiple clusters.

This work investigates the use of an additional complementary communication technology, i.e. satellite communication, which provides a large coverage and hence a far communication range. It will be analyzed to which extent and under which conditions the serious disadvantage of ITS-G5 in sparse vehicular networks as described earlier, can be eliminated by adding satellite communication components to some of the vehicles. Using satellite communication, the reception range of a single message can be significantly extend, which includes the bridging of different vehicle clusters as shown in Fig. 3. Obviously, this is particularly suitable for DENM-based applications, since CAMs are outdated too fast and less relevant in far areas. The main contribution of this work is that we quantify the potential gain of supplementing ITS-G5 with satellite communication by simulating a real-world scenario.

The following steps give an overview of our investigation procedure:

- **Scenario selection:** To meet the requirements of a sparse vehicular network, we decided to simulate a rural area in the southern part of Germany.
- **Scenario implementation:** To have a realistic scenario, we used OpenStreetMap data for modeling the road topology, real traffic data for vehicle generation and SUMO, a well known traffic simulator, for modeling the vehicle movement and behavior. For communication and tracing the network simulator ns-3 has been used.
- **Evaluation:** The generated trace files have been evaluated with respect to our key metric for accident avoidance, namely the *In Time Reception Ratio*.

The rest of this paper is structured as follows: Sec. II discusses relevant work for this research area. The simulation scenario is explained explicitly in Sec. III. Finally, the results of the evaluation are shown in Sec. IV.

II. RELATED WORK

The research area of ITS is very much alive. Numerous papers are written about vehicular networks. In [12], the problems of broadcasting in VANETs with changing traffic densities are addressed. If traffic is sparse, a broadcast can totally fail if there is no other car within the transmission range of the source.

Mechanisms that deal with this problem have been proposed. Epidemic Routing [13] addresses the sparsely connected nature of mobile wireless networks and in [14] a similar approach is proposed in the context of VANETs. Both advocate the concept of store-and-forward. This technique allows vehicles to store received packets and re-broadcast them if new vehicles in the vicinity are recognized. Because this solution heavily depends on the movement and behavior of vehicles, it cannot be guaranteed, that information from one cluster reaches the vehicles in another cluster and there is also a timing aspect. For some applications it might be very useful to receive the information much earlier than close to the event itself. For instance, the area of a serious accident can be bypassed at large-scale if informed early and sufficiently far away.

Another option to mitigate the problem of disconnected VANETs is the use of infrastructure points known as Road Side Units (RSU). The effects of including RSUs as relay

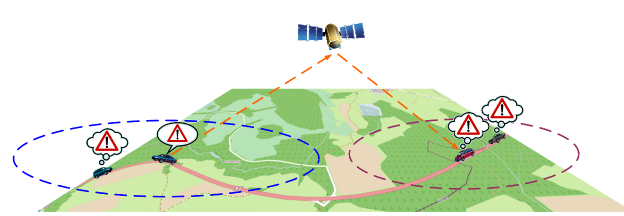

Fig. 3. Despite of VANET clustering, transmission of safety related information between clusters is possible by using an additional satellite link.

nodes is studied in [15] and a similar approach is proposed in [16]. Overall results show that RSUs are indeed able to solve the problem of disconnected VANETs. However, for scenarios with low vehicle density, such as rural areas, the costs of deploying the required RSUs may be prohibitive.

A very interesting approach for overcoming the problem of disconnected VANETs is to integrate C2C with other complementary communication technologies, such as cellular systems, as proposed in [9]. In contrast to that, our paper investigates the approach of using a communication satellite as an additional complementary communication technology (C2S communication link) and quantifies the potential gain in performance by means of simulating a real-world scenario.

The development of a concrete open platform for vehicles using the S-band satellite technology (DVB-SH) as the basis for its communication infrastructure is aimed in the SafeTRIP project [11]. One important task in SafeTRIP was to analyze the benefit of integrating ITS-G5 with its satellite communication technology, which is re-described in the following sections.

III. Scenario and Simulation Setup

In this work we focus on the behavior of ITS-G5 in sparse VANETs and investigate the benefit of adding an additional communication link, in this case a satellite link. The scenario consists of a rural road topology, an area with low traffic density.

We assume that road hazards can be identified by drivers or on-board vehicle sensors. The information about the road hazard is compiled into a Road Hazard Warning (RHW). This application uses DENMs to inform other vehicles about this imminent danger ahead (DENMs are mainly used by the RHW application) [8]. It is of utmost importance that the dissemination of the RHW is reliable and in time. If a vehicle receives the warning too late, or does not receive the message at all, the safety application will fail, and the vehicle could possibly run into an accident. Therefore, our most important evaluation metric is the *In Time Reception* of the RHW. The evaluation of this metric is done by comparing the braking distance of a vehicle to the current distance to the hazardous location at the point it receives a RHW. If the braking distance is smaller than or equal to the distance to the hazardous location, it is assumed that the vehicle received the RHW in time. The approach is exemplified in Fig. 4.

The braking distance of the vehicle is given by,

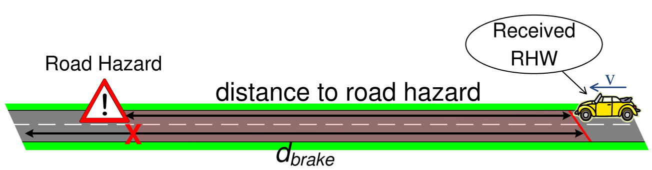

Fig. 4. Evaluation of the *In Time Reception* of the RHW. In this example, the RHW is not received in time, since the braking distance d_{brake} is larger than the distance to the hazardous location, indicated by the warning triangle. The velocity v of the vehicle is used in the calculation of the braking distance.

$$d_{brake} = \frac{v^2}{2 \cdot b} + \Delta t_{reaction} \cdot v$$

which is calculated by its velocity v at that point and deceleration b. We assume a deceleration of $5\,m/s^2$, comparable to deceleration on wet asphalt [18]. The delay $\Delta t_{reaction}$ represents the popular human reaction time of one second.

To have a realistic scenario we use OpenStreetMap as a source to generate the road topology for our simulation, as shown in Fig. 5. For this, the area "Obere Donau" is chosen, a $20 \times 20\,km$ rural area south of Stuttgart, Germany. The generation of traffic is based on the assumption that the inter-arrival time of vehicles can be modeled by an exponential distribution if traffic density is low, i.e. less than $1000\,veh/h$ [19]. Vehicles are generated on the edges of the road topology, in addition some vehicles are also generated in the villages depicted by the clustered roads in Fig. 5.

Using the exponential distribution, we generate traffic according to the average traffic volume for the L218 (the center road of the area) given by road traffic census of the province Baden-Württemberg 2005 [17], of what the "Obere Donau" is part of. For the L218, the traffic volume during day time is approximately 155 vehicles per hour. The traffic simulation is done by using SUMO, an open source microscopic road traffic simulation software [20].

The communication between the vehicles is simulated with the open source discrete-event network simulator ns-3 [21]. The ns-3 mobility model is fed by the SUMO generated trace to simulate the movement of our realistic traffic scenario. For the communication model we assume no access control and no collisions in our implementation, to reduce complexity of the communication simulation. This simplification is indeed justified because of a sparse VANET scenario, which is the

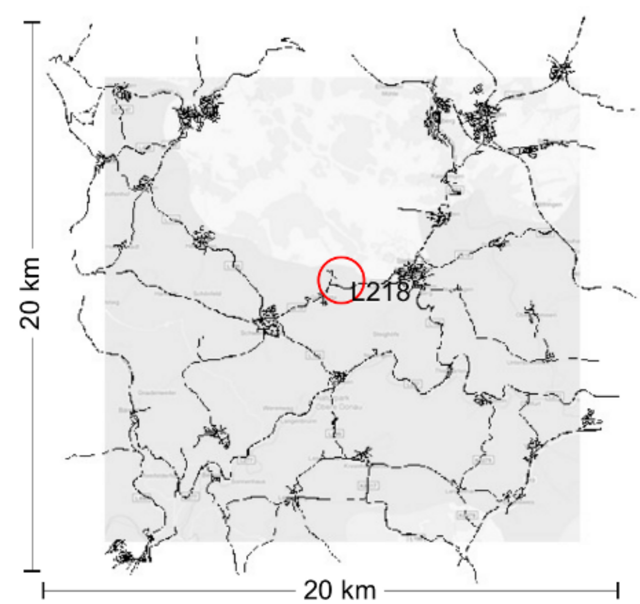

Fig. 5. Distilled road topology from Open Street Map, as used by SUMO with the original map in the background. The red circle indicates the place of the road hazard, located at the L218.

Parameter	Values
Number of runs	30
Penetration rate C2C	$0, 2.5, 5, \ldots, 50\%$
Penetration rate C2S	$0, 20, 40, \ldots 100\%$
Range C2C (m)	250
Range C2S (m)	∞
Delay C2C (s)	0
Delay C2S (s)	1
Rebroadcast interval (s)	$4, 10, 25$
RHW time to live (hrs)	2

TABLE I

Main parameters used for the simulation setup

focus of this paper. Due to the low number of communicating vehicles, the load on the communication channel is low, too. Hence, contention for medium access at the same time is very unlikely and we omit the chance of a busy medium and collision.

The main parameters used in the simulation are shown in Table I. Each set of parameters is simulated 30 times. Each run, random vehicles are equipped with C2C, and of these vehicles some are randomly selected to be also equipped with an additional C2S communication link. E.g. consider a C2C penetration rate of $50\,\%$ and a C2S penetration rate of $50\,\%$, and assume 100 vehicles. That means 50 vehicles are equipped with C2C technology and 25 of them also have an additional C2S communication link. The communication range and delays are fixed to simplify the model to clearly identify the impact of the addition of satellite communication. The rebroadcast rate indicates the frequency at which a vehicle will resend the RHW.

Flooding is used as a broadcasting mechanism for information dissemination. Every vehicle receiving a RHW it did not receive before, will start broadcasting the same RHW periodically, according to the rebroadcast rate. By broadcasting the RHW, the vehicle will forward it over all available communication channels. Despite the bandwidth inefficiency, flooding is reliable and robust, because it does not need any information about the underlying network topology.

For our scenario, we assume that a hazardous location occurs on a specific place on the L218 (see Fig. 5), after an initialization phase of the simulation. The first vehicle, equipped with communication technology, passing the hazardous location, will detect this danger and initiate the broadcast of a RHW. Using the periodic rebroadcast, vehicles make an endeavor to keep the RHW alive. The RHW is discarded if its time to live is exceeded and vehicles discontinue the periodic rebroadcast, in this case this is after two hours.

IV. Performance Evaluation

The *In Time Reception Ratio* is used as a metric to evaluate the performance of information dissemination. The previous section described how this is calculated for individual vehicles (see Fig. 4). The ratio is the number of vehicles that received the RHW in time divided by the number of vehicles equipped with one or more communication technologies. This ratio is a mean of the outcome of the 30 runs. Error bars indicate the uncertainty of the mean, based on the $95\,\%$ confidence interval.

A. Centralized Satellite Hub

The first approach was using the satellite as a relay. This means that, if a vehicle is equipped with a satellite link, it will broadcast the RHW via the satellite. If flooding is used the number of duplicates received by each vehicle will grow exponentially, this results in an excessive use of the satellite link. To overcome this problem, a centralized satellite hub was introduced in a second step. The first vehicle equipped with a satellite link will inform the satellite hub by sending the RHW over the uplink. Subsequently, the hub will start the periodic broadcast to all vehicles equipped with a satellite link. All vehicles that receive the RHW over the satellite link know the hub is notified and will not inform the hub again. Hence, the uplink usage is reduced dramatically. Another advantage is that the downlink is now only dependent on the rebroadcast rate of the satellite hub. In both approaches the performance results were similar with respect to the *In Time Reception Ratio*. Therefore, the centralized satellite hub approach has been used for all the following simulations.

Fig. 6 shows the information dissemination performance for various penetration rates. The *In Time Reception Ratio* is the percentage of vehicles equipped with C2C communication technology that have received the RHW in time and this is plotted for different C2C penetration rates. Each different curve shows the performance where part of the C2C equipped vehicles are also equipped with an additional C2S communication link. For instance, the case where only ITS-G5 is used, i.e. none of the vehicles use an additional satellite link, is shown by the red curve. The other curves show the performance if the penetration of vehicles equipped with an additional satellite link is increased, up to the blue curve

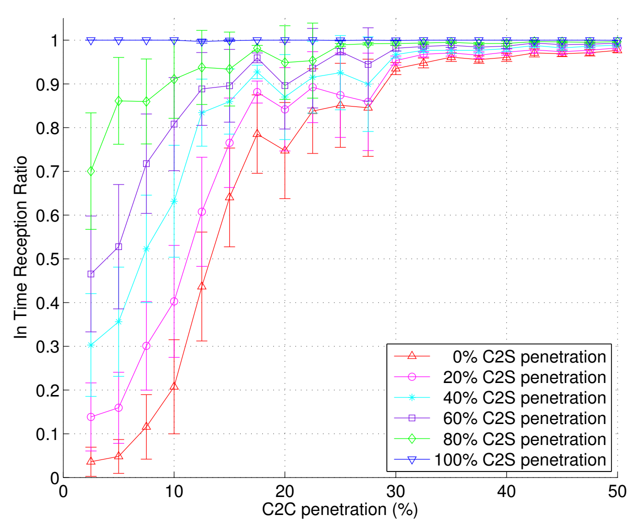

Fig. 6. In time reception of RHW for different penetration rates using a centralized satellite hub and rebroadcast rate of 0.1 Hz (10 sec interval).

where all vehicles are equipped with C2C as well as C2S technology.

The results show that, if the C2C penetration rate is higher than 30 %, there is no significant performance gain when additional satellite technology is added. However, if the C2C penetration rate is lower than 30%, an additional satellite link has a significant impact on the performance. If, for example, the C2C penetration rate is lower than 10 % and no C2S is added, only a small percentage of vehicles receive the RHW in time. By adding a satellite link to 80 % of these vehicles the *In Time Reception Ratio* is increased up to more than 0.9!

Almost all curves show drops at 20 % and 27 %. This is because of the relative small amount of 30 runs for each data point. If the initiating vehicle is not able to broadcast the RHW to other vehicles, the resulting *In Time Reception Ratio* for this run is zero. This has a strong influence on the mean, reflected as a drop in the graph. These drops occur at each curve, since the same mobility pattern is used for each simulation run.

B. Trade-off: Rebroadcast Rate vs. Performance

The performance of the information dissemination is dependent on the rebroadcast rate. If the rebroadcast rate is too low, a vehicle might not be able to forward the RHW to a passing vehicle via ITS-G5, because the passing vehicle is already out of communication range by the time it rebroadcasts the RHW. In our scenario the maximum speed is $100\,km/h$. This leads to a relative speed of approximately $56\ m/s$ considering two opposing vehicles. If one of these two vehicles wants to forward a RHW over ITS-G5 it is safe to have a 4 second rebroadcast interval (i.e. a rebroadcast rate of 0.25 Hz), assuming a $250\,m$ communication range. The results of this simulation are shown in Fig. 7. If these results are compared to those in Fig. 6, there is only a slight increase in performance, while the number of duplicates sent via ITS-G5 is more than doubled. This increase of performance only

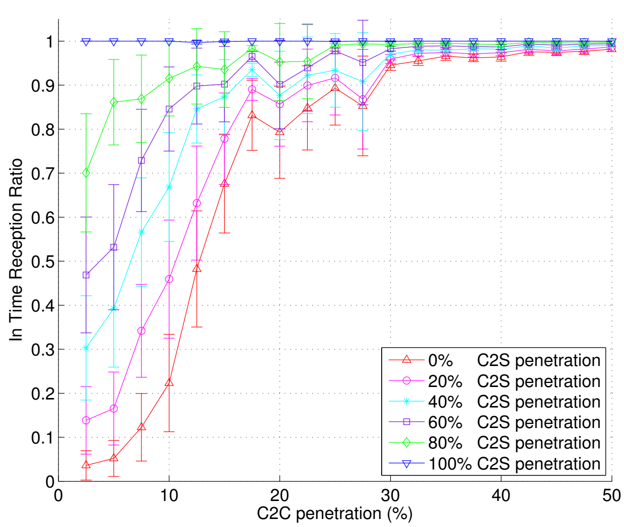

Fig. 7. Increasing the rebroadcast rate from 0.1 Hz (10 sec interval) to 0.25 Hz (4 sec interval) only results in a slight increase of performance.

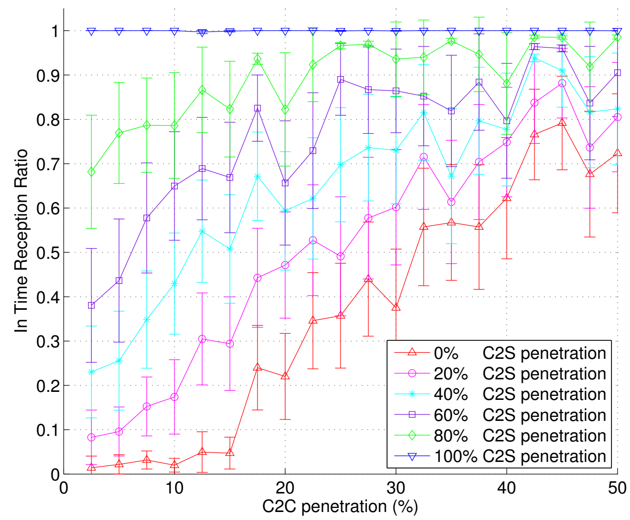

Fig. 8. Increasing the rebroadcast interval to 25 seconds dramatically decreases performance.

holds for low penetration rates. The influence of increasing the rebroadcast interval from 10 to 25 seconds is more dramatic. The results, depicted in Fig. 8, show an enormous drop in performance. The influence is strongest when most vehicles are not equipped with an additional satellite link, this shows the inability to disseminate information to other vehicles via ITS-G5 if the rebroadcast rate is too low.

C. Behavior of Information Dissemination over Time

Apart from looking at the overall performance of information dissemination, it is also interesting to see what happens over time. Fig. 9 shows the *In Time Reception Ratio* over time for the duration of the RHW, i.e. two hours. It represents the scenario where 2.5 % of the vehicles are equipped with ITS-G5 technology only, so without an additional C2S communication link. It illustrates the inability to keep the RHW alive within the area, according to it's duration. After about 50 minutes, none of the following vehicles passing the hazardous location are informed in time. The red line indicates the average over time, it shows that in total not even 5% of the equipped vehicles are informed in time. The reason for the information dissemination to stall, is the inability to rebroadcast the message to other vehicles within the area. This is mainly due to the limited number of equipped vehicles together with the limited communication range of ITS-G5. Moreover, because of the limited rebroadcast area, in this case restricted by the finite simulation area.

A possible solution for this problem is re-initiating the RHW. The scenario is the same: 2.5 % of the vehicles are equipped with ITS-G5 technology only, so no additional C2S communication link. Here, the difference is that an equipped vehicle, that passes the road hazard and has not been notified by means of a RHW before, will re-initiate the RHW broadcast, i.e. restart the broadcast of the same information. The results are shown in Fig. 10. Of course, this way the RHW does not get lost after some time, since it is re-initiated every time it gets lost. The red line indicates

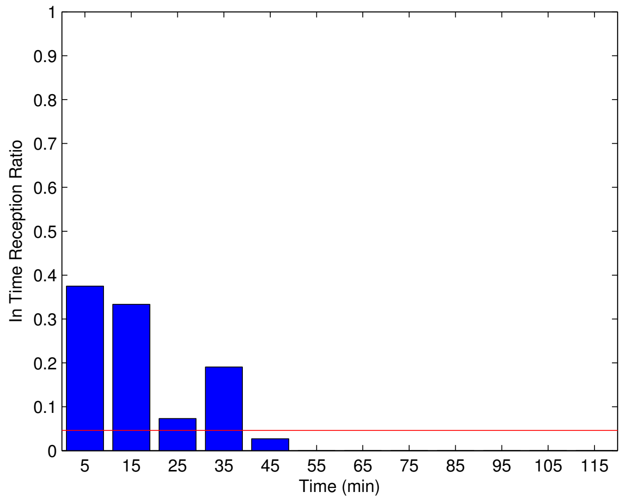

Fig. 9. Information Dissemination stalls with the lapse of time. In this simulation 2.5 % of the vehicles are solely equipped with ITS-G5 technology.

the average again, which is more than 40% better than in Fig. 9. However, still half of the vehicles do not receive the RHW in time on average, since each re-initiating vehicle obviously did not receive the RHW in time. This reactive solution, however, is not always suitable, in particular if missing a notification might result in a severe accident.

Therefore, the solution proposed in this paper is the addition of an additional satellite link. Because of the centralized satellite hub, the RHW can be kept alive actively as long as the warning is valid without having to rely on the number of C2C equipped vehicles within the area, i.e. C2C penetration rate. The performance increase is then related to C2S penetration rate.

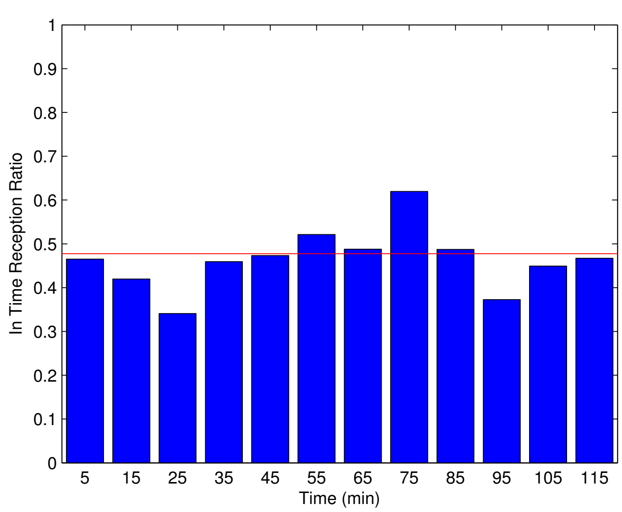

Fig. 10. With re-initiation, the RHW is kept alive over time. Re-initiation significantly improves performance, as compared to Fig. 9, however still almost half of the equipped vehicles are not informed in time.

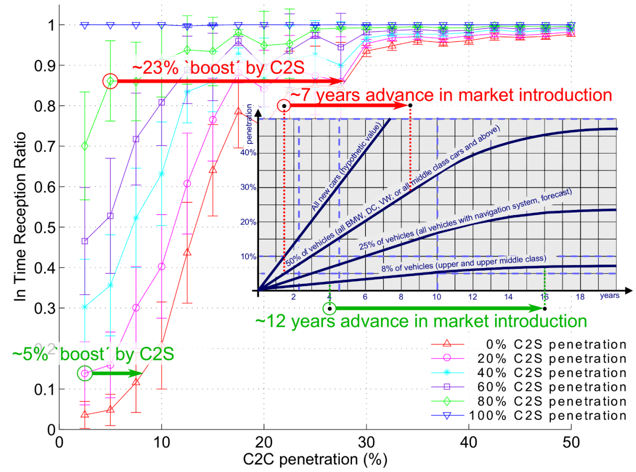

Fig. 11. How C2S can boost C2C market introduction.

D. Boosting initial phase of C2C market introduction

Introducing a satellite component to overcome some of the limits in VANETs is not only a gain in performance. Also the market introduction of the VANET technology itself can benefit significantly. This shall be illustrated with two concrete examples using the scenario and simulation results described above as a baseline. The effect can be shown by mapping the results of the performance analysis for the RHW application, as shown in Fig. 6, to the market forecast, as shown in Fig. 1. The resulting Fig. 11 highlights two arbitrary chosen examples. The lower left example (green) shows the boosting effect if 20% of the vehicles equipped with C2C are in addition equipped with C2S at an early stage after market introduction, i.e. the performance which can be reached by 7.5 % pure C2C penetration can be reached already with 2.5 % C2C penetration, if 20 % are additionally equipped with C2S, in other words every 200th vehicle. If mapped to a rather pessimistic market introduction forecast of 8 % of new vehicles equipped, this is equivalent to a gain of about 12 years of market introduction time!

In contrast, the upper left example (red) shows the boosting effect if a relative high number, viz 80%, of the vehicles equipped with C2C are in addition equipped with C2S at an early stage after market introduction. The performance which can be reached by 28% pure C2C penetration can be reached already with 5 % C2C penetration, if 80 % are additionally equipped with C2S. If mapped to a relative optimistic market introduction forecast of 50% of new vehicles equipped, this is equivalent to a gain of about 7 years of market introduction time. Obviously, the 'boosting effect' is maximized in the early years of the introduction of C2C in the market and depends on the application.

V. CONCLUSIONS AND FUTURE WORK

A. Conclusions

In this paper we introduced the problem of sparse vehicular networks, which can lead to clustered and disconnected VANETs by using the European ITS-G5 communication technology. To overcome this problem, the approach in this paper was to add a complementary communication technology, in particular a Car-to-Satellite communication link, based on the DVB-SH technology. To get a realistic sparse VANET scenario, a rural area in the southern part of Germany has been simulated, by using OpenStreetMap and real traffic data in combination with SUMO and ns-3. The results have shown, that the information dissemination in sparse vehicular networks can be improved significantly by using an additional C2S communication link to connect the clustered and disconnected VANETs to each other. Moreover, the combination of C2C with C2S can have great impact to speed up the market introduction of cooperative ITS systems.

B. Future Work

Future investigations will include the improvement of information dissemination strategies, especially with regard to the specific requirements of integrating two complementary communication technologies like C2C and C2S. More advanced information dissemination strategies can increase the bandwidth efficiency, which is especially important for satellite communication, without loss of performance.

One communication spot of the SafeTRIP satellite covers parts of Europe. Hence, the satellite has to serve all requesting vehicles within this spot at the same time, which might come to be a bottleneck for information dissemination. Due to the simplified implementation of the C2S communication link here (see Sec. III), the shown results don't reveal potential performance losses with respect to this bottleneck. Future work has to consider this potential problem, too.

Finally, other communication technologies can also be taken into consideration. Besides a C2S communication link, there might be other communication technologies (e.g. WiMAX, UMTS, LTE, etc.) that could fulfill the same task. A comparison of other communication technologies could not only consider the performance improvements, but also the costs of integrating such technologies into the VANET domain.

VI. ACKNOWLEDGMENTS

This work has been mainly funded by the European Commission in the FP7 project SafeTRIP [11].

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