A Prototype Study on Hybrid Sensor-Vehicular Networks

Extended Abstract

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1. INTRODUCTION

In this paper we present a concept where we combine two forms of networks that both attracted a lot of research efforts recently. Both Vehicular Ad-hoc Networks (VANETs) and Wireless Sensor Networks (WSNs) are subject of ongoing research activities. However, the characteristics of VANETs and WSNs are very different.

Nodes in sensor networks are highly miniaturized, mostly static, very resource and energy constrained, and usually have good sensing capabilities. In contrast, VANETs have very dynamic topologies and the vehicles do not suffer from significant energy constraints. The vehicles could be equipped with sensors themselves. However, the sensor coverage cannot be guaranteed, as vehicles are not present everywhere and at all times and some kinds of events cannot be reliabily detected by moving entities.

We introduce the new concept of Hybrid Sensor-Vehicular Networks so that both network types can benefit from the strengths of each other while compensating the weaknesses. We use a Wireless Sensor Network deployed in or near roads as a sensor grid with constant availability and dense coverage in contrast to the vehicle-to-vehicle network which might have only sparse coverage. The sensor network constantly communicates its sensor data to the vehicles driving on the road, delivering them with accurate and up-to-date sensor information. Vehicles communicate to disseminate this information to over comparatively long distances. There, the vehicles deliver this data back the sensor network where it is stored for future retrieval by other vehicles. This relieves the sensor network from the energy-consuming task to transfer the data hop-by-hop inside the WSN itself.

Such Hybrid Sensor-Vehicular Networks are suited for all applications where a stationary WSN collects sensor data that is disseminated only on a small scale within the WSN, then delivered to vehicles which transfer it to other regions by multi-hop routing or vehicle movement and either hand it off to interested vehicles or to remote WSN nodes that store the data and deliver it to approaching cars on certain conditions.

We use an example for further explaining this concept. Assume we have a road segment as shown in Figure 1. The application implements a dangerous road condition warning, where drivers are warned about potentially dangerous road conditions like e.g. icy road. First, a WSN node detects ice on the road and shares this information with neighboring motes (①) inside a small region.

When a vehicle A enters this region, the WSN triggers a vehicle-present event and the information is transmitted to the car (②). This way, the driver of vehicle A would receive a short-term warning and can react accordingly. Vehicle A forwards the information via the long-range VANET to vehicle B (③). A relevance function determines that vehicle B is in a good position to feed the information back to the WSN for further availability. As the road splits at position B, the icy road information would otherwise become unavailable to vehicles approaching from the lower road. So B transfers the information back to the WSN (④) and the nodes distribute it in a small neighbourship for redundancy purposes (⑤). A and B leave this road segment (⑥) and are out of communication range, when vehicle C approaches the intersection and still receives the warning information from the WSN (⑦). The vehicle displays a warning to the driver who has plenty of time to adapt his driving style to the approaching danger.

There are two important observations here:

1. Vehicle C is never in direct reach of the other cars. So a vehicular sensor network composed only of the vehicles would never deliver the warning to vehicle C.

2. There is a significantly lower number of mote transmissions compared to the case where the motes try to deliver the information hop-by-hop from the source to the position of vehicle C. A lot of mote energy is saved and the lifetime of the WSN nodes is prolonged.

2. INFORMATION DISTRIBUTION

Within Hybrid Sensor-Vehicular scenarios, five different ways of information flow can be distinguished:

1. Information flow within the Wireless Sensor Network

2. Data transition from WSN to VANET

3. Dissemination within the VANET

4. Information injection from VANET to WSN

5. "Physical" data transport by moving vehicles

Each information distribution method faces specific challenges, which we are going to point out in the following sections.

2.1 Distribution inside the WSN

When events are captured by the wireless sensor network these events are about to be reported to mobile nodes. A central idea in our perspective on such scenarios is that the

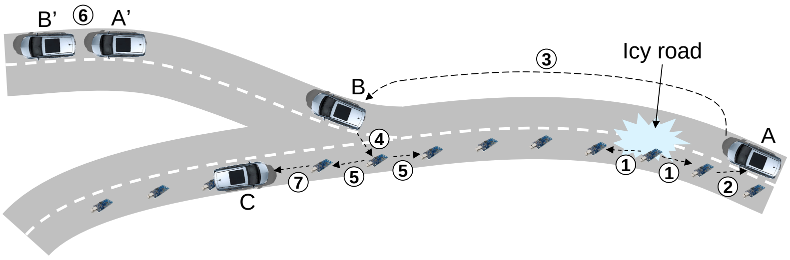

Figure 1: Example scenario for a Hybrid Sensor-Vehicular application

WSN and the VANET are coupled directly, and hence, certain wireless sensor nodes that transmit WSN data to vehicles have to be chosen. Those **gateways** are distinct from the **reporting nodes** which are mainly responsible for event detection and multi-hop routing.

As we rely on information transport using a VANET, the sensors do not form one huge wireless sensor network. Instead, we propose a dynamic decomposition of the sensor nodes in many small to mid-size sensor networks in which data is reported to gateway sensors. Further spatial coverage of events is reached using VANET message dissemination.

After an event has been detected or sensor data has been collected, this information needs to be reported to a gateway sensor which can be realized by standard WSN source-to-sink techniques like spanning trees. To equalize energy consumption, the gateway role will change periodically.

2.2 Data transition from WSN to VANET

As illustrated, gateway sensors interact directly with mobile nodes, and basically two questions are of particular interest according to this way of information flow. First of all, one might ask *when information is to be sent to the vehicle.* Instead of a periodic transmission, we propose a triggered scheme: Once a new vehicle is present, data should be transmitted - and therefore, vehicle presence can be regarded as a special type of an event detected by special sensors.

Once triggered, the actual transmission from sensors to mobile nodes is a time-crucial task: As sensor nodes have a limited transmission range, the data needs to be sent within a very short time. Vehicles may move with relative speeds up to 70 m/s, and as a delay between vehicle detection and data transmission exists, the time frame left may be lower than a second. Hence, all data being transmitted must be fitted compactly into one or very few frames in order to improve the probability of the transmission to succeed.

2.3 VANET Message Dissemination

The main task of the Vehicular Network in our approach is to disseminate messages picked up from a local gateway sensor. The primary goal is of course to inform approaching vehicles about a potential hazard that was measured by a local WSN. However, for the Hybrid Sensor-Vehicular Network, the purpose of the vehicular part is also transporting messages to remote locations for re-injection into a WSN. This way, information becomes time stable and does not rely on the presence of vehicles.

Geocast [1] is a well-known primitive in the VANET domain that is suitable for this kind of information dissemination.

2.4 Information Injection

Once information has been distributed over the VANET, it can be stored back from the vehicle to the wireless sensor network. While at first glance this might look like a unnecessary gimmick, we argue that this mechanism is a key feature of Hybrid Sensor-Vehicular information distribution:

It might happen that the VANET looses connectivity if vehicles move out of range. In this case, messages cannot be distributed to other vehicles using the VANET itself, although cars approaching the current node's position later in time might be interested in this information, for example if it is a warning notification. In this case, the warning message can be stored to the WSN where it is kept until other vehicles pass by and retrieve this information again. Similarly, this mechanism could be further utilized for other tasks like gateway notifications.

2.5 Physical data transport

Besides the vehicles' interconnection, their spatial movement can be utilized for data dissemination as well. If vehicle density is sparse, data sampled from the wireless sensor network will be cached by vehicles. Based on the relevance function's results, the information is injected back to wireless sensor network.

3. PROTOTYPE ARCHITECTURE

One approach to investigate the characteristics and issues that arise in Hybrid Sensor-Vehicular Networks would be a complex simulation that incorporates realistic models of WSN data propagation, traffic flow, and an appropriate simulation of VANET message dissemination. Combining those modules into one simulation is challenging. In addition, it is questionable, how meaningful such results would be, as integration of multiple radio systems like ZigBee and IEEE 802.11 within one single simulation is not well understood.

Therefore, we decided to create a prototype architecture as starting point for future work. The goal behind the prototype is to prove that all five ways of information flow can be realized. Furthermore, the prototype allows us to spot out more interesting issues and questions related to the new field of Hybrid Sensor-Vehicular Networks. Within this section, a brief overview over the prototype and its architecture is given.

Figure 2 depicts the basic architecture of the prototype, which consists of two subsystems, a *Sensor Network Subsystem* running on motes and a *Mobile Node System.*

3.1 Sensor Network Subsystem

As laid out before, the main task of the *Sensor Network*

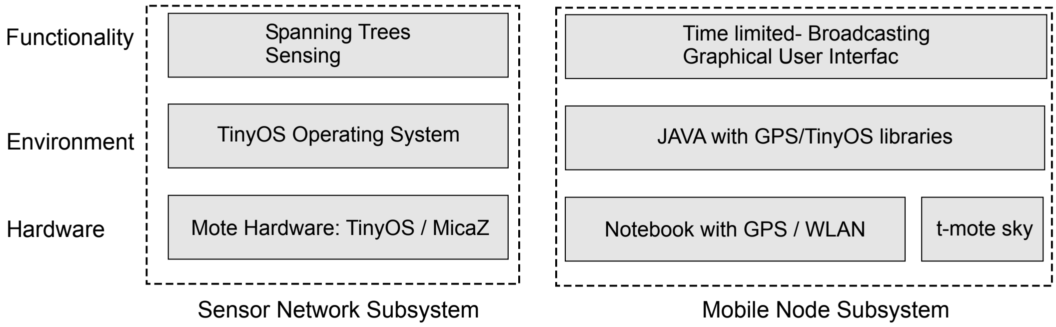

Figure 2: Prototype architecture

Subsystem is the detection of events and the delivery of adequate notifications to a near gateway sensor: Among the sensor nodes, we distinguish between ordinary sensor nodes and gateway sensors. While ordinary sensors report their readings to a near-by gateway sensor, those gateway sensors are responsible for reporting that information to a vehicle once it is in range. Within the wireless sensor network, we use simple spanning trees which are rooted at the gateway sensors for data collection. As we assume that all sensor nodes are provided with the same, limited energy supply, we argue that having fixed gateway sensors assignment is not feasible. Instead, all sensors act as gateway sensors at some point in time: If a node does not know any gateway sensor, it simply waits for a randomized time after which it decides to become a gateway sensor itself. In this case, a spanning tree is constructed within a limited range (measured by the hopcount). Similarly, gateway sensors cease functioning as such after a certain period which forces other sensors to take over.

Gateway sensors have to report the collected information to mobile nodes once they are in range, and hence, the presence of vehicles must be detected. Two basic approaches exist: Passive vehicle detection and active detection. Active detection of vehicles relies on periodic beacon messages that are sent by the mobile nodes, announcing their presence. While passive detection of cars is possible using adequate sensors, like magnetometers, we argue that a main drawback of this approach is the disability to distinguish between cars that can interact with gateway sensors directly and ones that can not: If passive detection is used, cars might be detected correctly although they are not equipped with the hardware required to receive data from gateway sensors. Passive detection will however lead to a transmission of data in such cases. As unnecessary transmissions are to be avoided in order to save energy, we decided to use active detection within the prototype, where the cars announce their presence using periodic beacon messages. Once such a beacon is received, the collected data is sent to the mobile node immediately. It is noteworthy that this way of information flow might be time crucial as mobile nodes are in range of a gateway sensor for a short time period only. Hence, the data is fitted into one single data packet.

All mentioned functionality has been implemented using TinyOS 2.0, which allows us to run the software on a variety of platforms.

3.2 Mobile Node Subsystem

The *Mobile Node System* is responsible for data-collection from the gateway sensors and the propagation of that data to other vehicles. In order to retrieve sensor data, periodic beacons are sent which also contain data to be stored into the wireless sensor network: This way, readings from a distant location can be stored at gateway sensors. Doing so enables us to notify vehicles that pass by later when no other cars are in reach. By using this piggy-back scheme, the information flows from the sensors to the cars and vice versa are interweaved and therefore the communication overhead is reduced.

In order to send data to other vehicles, so far a WLAN-based UDP flooding scheme is used in the implementation. The sensor information that is retrieved from gateway sensors is serialized and broadcasted to other vehicles in range. A additional timestamp allows to control the data's period of validity. This also leads to a limitation of the informations' geographical spread. While the current UDP dissemination scheme is a very basic approach, we argue that much research is currently carried out in the field of VANET message distribution. The implementation allows an easy integration of more advanced schemes, like Geocasting.

Considering the interaction of the mobile nodes with the gateway sensors, information is not simply retrieved from the sensor network, but also stored back into the WSN. By doing so, some kind of information persistence can be achieved: It is imaginable that the VANET breaks down, for example because of low traffic density. In this case, it is still possible to deliver information about distant events to a car if they have been sent to a gateway sensor beforehand. Within our architecture, the messages to be stored at the gateways are embedded in the beacon messages used for vehicle detection. Consequently, the gateway sensors in fact report both their own data and, if available, injected information upon the retrieval of a beacon message in an alternating manner.

4. FIELD STUDIES

In order to investigate the principal feasibility of Hybrid Sensor-Vehicular Networks, we conducted two field experiments during Spring 2007 in order to address two questions. First of all, we were interested if the direct communication between mobile nodes and gateway sensors is possible. Furthermore, a second field study with the prototype introduced in Section 3 was carried out to show that all five ways of in-

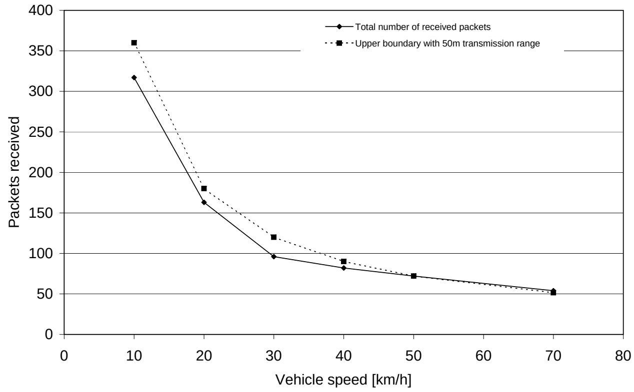

Figure 3: Beacon messages received at various speeds

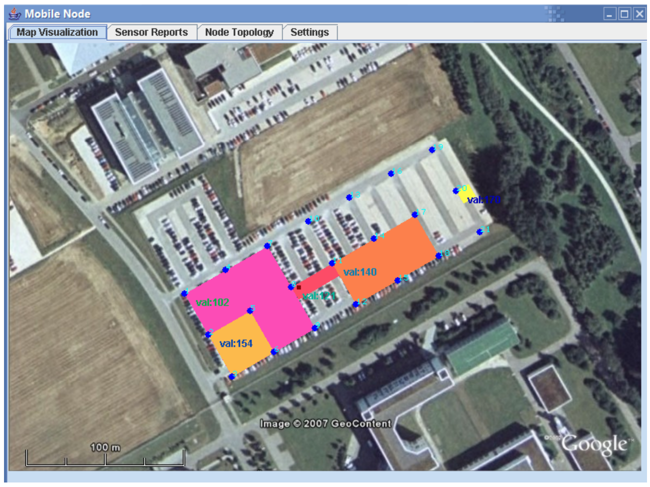

Figure 4: Sensor Data Visualization during field test

formation flow can be integrated into one, cooperative system. Within this section, we present our results and experiences originating from those experiments.

4.1 Direct Communication

Within the first experiment, we deployed a Tmote SKY module alongside a country road about 30 cm over ground. The mote was flashed with a small application that broadcasted 40 packets per second. Passing by the mote with a car at various speeds, we investigated how the used 802.15.4 technology deals with mobility. Therefore, we simply counted the number of packets that could be received at various speeds. The results are summarized in Figure 3 where we compare the number of packets that were totally received with a theoretical, upper boundary. The upper boundary is derived from the vehicle speed, the packet rate and the maximum transmission range according to the specification of a Tmote SKY. As one can see, we were able to receive a significant number of packets at all speeds between 10 km/h and 70 km/h, suggesting that 802.15.4 might be a considerable option for environments where care move with low to medium speeds. Tests with higher speeds are planned for the future, but need special preparation for safety reasons.

4.2 Prototype Field Test

In a second experiment, we verified the functionality of the prototype introduced in Section 3. For this test, we deployed 16 motes on a parking lot, where the distance between two motes was about 30 m each. In order to allow an analysis of the topology, we configured five motes as static gateway nodes and used the TinyOS 2.0 Collection framework to gather the global topology within the network. A mobile node, which consisted of a notebook computer equipped with GPS and an attached Tmote SKY, was carried through the field. Figure 4 shows a screenshot of the prototype's GUI component that provides real time visualization of the sensor data gathered from gateway sensors.

Furthermore, the prototype allows to control the injection behaviour of the mobile node and logs any packet that is received from a gateway sensor. An analysis of these log files revealed that both ways of information flows, from the gateway sensors to the mobile node and vice versa, could be realized. In addition, we checked if the communication between two mobile nodes was possible. Therefore, a second mobile node was turned on in range, and as this mobile node was equipped with WLAN but no mote for sensor network communication. As expected, all data was available at the second mobile node within a one or two seconds.

5. SUMMARY

Within this paper, we presented some key ideas and results from our work on on Hybrid Vehicular-Sensor Networks. Our work can be considered as initial analysis of such systems where yet many challenging questions exist. Of particular interest are questions regarding energy efficiency within the WSN and questions on reliability. We believe that Hybrid Sensor-Vehicular Networks could be a tool to effectively warn drivers in case of dangerous road situations such as ice and aquaplaning and that the direct combination of wireless sensor networks and VANETs is also more cost effective than solutions which address the same application domain but which rely on a more complex infrastructure. At the same time, availability and accuracy should be much higher compared to solutions that rely on vehicles alone.

6. REFERENCES

[1] J.C. Navas, T. Imielinski. GeoCast – Geographic Addressing and Routing. Proceedings of the 3rd annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom), 1997, 66-76