

IROAD – COOPERATIVE ROAD INFRASTRUCTURE SYSTEMS FOR DRIVER SUPPORT

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ABSTRACT

This paper discusses the design and implementation of a cooperative road infrastructure systems, which uses an intelligent road surface. Using an overtaking assist feature as an example it is shown how such a feature can be designed and implemented on a road infrastructure and integrated with drivers and passengers using IMS. The feasibility of this feature is assessed from a functional and communication perspective. Moreover, first results from real-life tests on the Swedish highway E4 are presented which motivate the next research and development steps.

KEYWORDS

Cooperative systems, road surface, wireless sensor networks, safety, overtaking assist, road markings, intelligence, energy efficiency, IMS.

INTRODUCTION & MOTIVATION

Fatality in road traffic is the dominating cause for non-natural human death in our societies, [1]. There, an annual cost to society by all traffic accidents is estimated to exceed 160 billion Euro a year, which corresponds to 2% of EU GNP, [1]. Adding cost for general traffic problems in the EU, *i.e.* traffic jams, yields a cost to society of 3% of the EU GNP.

Currently active safety systems are an approach to assist drivers in difficult and hazardous situations to avoid or mitigate accidents. Despite the high development pace and upcoming new safety features, there are certain accident types that will be hard to address with stand-alone solutions, *i.e.* head-on collision with vehicles drifting out of their lane. An alternative to stand-alone system is a cooperative approach to preventive safety where road surface based units, vehicles and other road infrastructure cooperate in order to create support system for road users. Despite the apparent increase in complexity and arise of other issues like security, the common sense is that the limits of stand-alone systems can be circumvented. This is in line with current research activities in the EU, [2, 3, 4].

One of the major challenges of the cooperative approach to road safety is its availability to road users, since the equipment level of both roads and vehicle varies largely, that is, not all vehicles are equipped with transponder and not all roads are equipped intelligent unit. In order to overcome this the design of cooperative systems need to fulfill certain aspects, like Low cost; adaptability to local needs (versatility); ad-hoc usability as soon as the road user enters the perimeter;

re-use of existing communication channels to road users; and most importantly dependable performance. If any of these aspects is not addressed by the solution, it is questionable to proceed with the design. Especially, since acceptance by road users largely depend on the last aspect, which relates to the safety benefit.



Figure 1 – A snapshot of the real installation of CRIS near Piteå (Norrbotten region, Sweden). Road sensor placement (left), Road in adverse light conditions (right)

In this paper we describe the concepts associated with the design of a cooperative road infrastructure system (CRIS). CRIS aims at making the road surface intelligent and is being developed in the scope of the iRoad project comprising a constellation of Swedish governmental, industrial and academic partners [5]. Currently the first units that for a CRIS are deployed on a test site along a highway in the northern Sweden (The photograph in Fig. 1 shows a snapshot of a real deployment in different light conditions). After the first year of operation in harsh geo-climatic conditions knowledge on survival rate in different placement and composition of the components is gathered. Besides the revealed serious research-technological challenges, placement and protection of the nodes could be determined.

Furthermore, the paper presents the first results for preferred layout and implementation of a CRIS along a road, and the technology pieces of the underlying wireless sensor actuator network (WSAN) and their design. A long term goal is to design a driver support features that benefits from the CRIS approach, the overtaking assist feature. The feature will be discussed more in detail and how the concept is intended to be implemented in the future.

A COOPERATIVE ROAD INFRASTRUCTURE SYSTEM

The iRoad CRIS combines in itself the state-of-the-art advances in low power highly integrated electronics and efficient autonomous energy sources, wireless sensor and actuator networks and modern road marking technology. The uniqueness of CRIS stems from the fact that the road surface itself becomes an intelligent entity and the essential link between a driver, a car and the road side infrastructure.

The intelligent road surface is composed of nodes, called road marking units (RMU) that have the ability to measure and estimate properties of the road surface, vehicles and estimate traffic situations. For the estimation of properties or traffic situations it is also possible that information from other nodes can be used and distributed estimation schemes can be employed. In a further development it could also be possible to use information from a third party, like vehicles or other infrastructure elements. It is important to note that the proposed concept does not need any wiring which introduces both redundancy and cost-efficiency for roll-out and maintenance.

The estimation accuracy for vehicle properties and traffic situations largely depends on the layout of the RMUs on the road. Currently the distance between the RMUs along a lane marking is chosen to 50 m, which yields a radio coverage of two units upstream and downstream. Left and right lane marking positioning is chosen to be in line with each other. Clearly, the positioning itself is a trade-off between the estimation performance, energy consumption and radio coverage.

Thus, the CRIS architecture enable the implementation of distributed driver support features. Principally, the information that is gather and distributed by the RMUs can be the basis for safety features that otherwise are restricted by the telematic capabilities of vehicles. Moreover, the safety features for a certain road can be selected on a needs-basis, which means that accident types and rates should guide the selected.

It has also to be noted that the RMUs are no high complexity computing units and they are on a limited energy budget which means that the safety feature and their implementation are a trade-off with the safety benefit that has to be achieved. Examples for support features, that are expected to benefit from a the iRoad CRIS approach are the following: (1) Queue end warning; (2) Warning of driving in the wrong direction on the highway (ghost driving); (3) Warning of the overtaking driver about the critical distance to the car driving in the opposite direction (overtaking assistance).

Features (2) and (3) relate to head-on collisions which have a high fatality rate for the occupants. An overtake assist feature has already been evaluated in [6] and it is also assumed that such a feature is not available in the near term, according to [7]. The information that is needed for the decision making of an overtaking assist feature can be provided by the CRIS concept. It can be expected that the information for features like (1) and (2) will be a subset of (3). Thus, the overtaking assist feature will be discussed more in detail.

Regarding feature (1), research has been on-going for quite some time, see [8] as well as the more recent articles [9], [10]. Still, permanent installations are rare, which can be related to the costs for current solutions. It is therefore expected that such a feature could be a spin-off from the research towards the overtake assist feature, where the technical requirements on the traffic situation estimation, decision making and countermeasure are not that high. The intelligent electronic devices, further on referred to as *road marking units* (RMU) shown in Fig. 2, are integrated in road markings of next generation [11]. The hardware part of RMUs consists of the following blocks: sensors, actuators, processing module, radio communication module and energy supply block. The RMU and its preferred placement are depicted in Fig. 2.

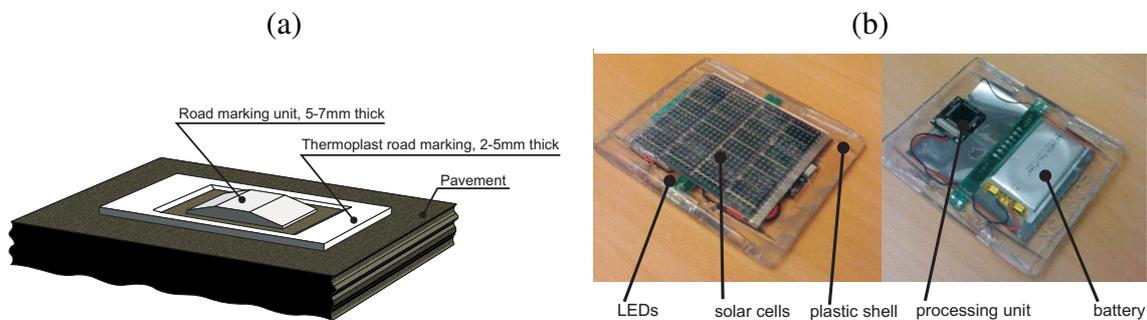


Figure 2 – (a) Structure of a road marking unit and its placement on the road surface; (b) Integrated RMU, 100mm wide, 140mm long, 7mm high.

RMU implementation

The practical feasibility of the iRoad CRIS stems from the fact that we have built our road marking units using only the off-the-shelf hardware components. Note that the current technological content of the iRoad RMUs described below is experimental and is the subject to change depending on the overall system performance.

The heart of our proposed RMU is the Mulle, a networked sensor platform, manufactured by Eistec AB [12], The new Mulle architecture, with an Atmel RF230 IEEE 802.15.4 transceiver, features functionality for detection and classification of vehicles, low-power optimizations, power

management, and support for mesh sensor networks. Vehicle detection and classification is performed by a Honeywell three-axis magnet sensor. An accelerometer can optionally be used to improve the classification's accuracy, but results in higher power consumption. The combination of a low power magnetic sensor with the performance of a high frequency accelerometer will enable the RMU to achieve a good power/performance ratio. The power consumption of the microcontroller depends heavily on the type of sensor in use. The magnetic sensor for example, allows the microcontroller to spend most of its time in sleep mode where it only consumes a few micro amps, while the accelerometer requires a sample rate of several kHz which leaves little time to sleep in between samples.

The RMU's power supply supports energy scavenging and consists of a thin and flexible solar panel and up to two Lithium-polymer rechargeable batteries from VARTA. Each battery can hold up to 750 mAh, which, when combined with the Mulle's low power consumption of less than 1 mA when detecting vehicles using the magnetic sensor and the radio in low-power mode can enable out RMU to operate for several months, even without requiring energy from the solar panel.

Sensing subsystem

Our proposed RMU consists of two different sensors: a magnetic sensor and a high-performance accelerometer. The magnet sensor, however, can only provide limited information about passing vehicles and can therefore only be used for a certain class of applications, such as queue detection, ghost drivers, etc. Extensive information about the use of magnetic sensor in ITS applications can be found in [13]. The accelerometer can provide the system with more detailed information than the magnetic sensor, but with a higher power consumption as a result. The output from the magnetic sensor has a frequency in the range of DC to a few hertz, while the accelerometer must be sampled at several kHz. The magnetic sensor can also be duty-cycled to further reduce the power consumption. Approaches of reducing the power consumption when using the accelerometer has not been fully investigated and is considered future work. One promising solution could be to use the magnetic sensor to detect the presence of a vehicle, and only then power up the accelerometer. Another factor that influences system performance and lifetime is the fact that most vehicles will not pass during the night, and thus the solar panels will produce the most power at the time when the system's power consumption is at its peak.

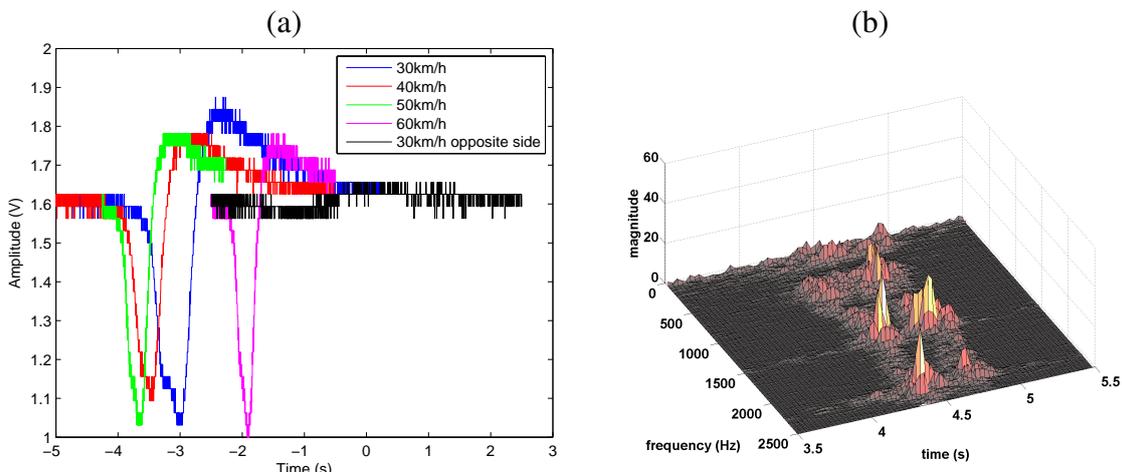


Figure 3 – Autonomous detection of passing cars by iRoad CRIS

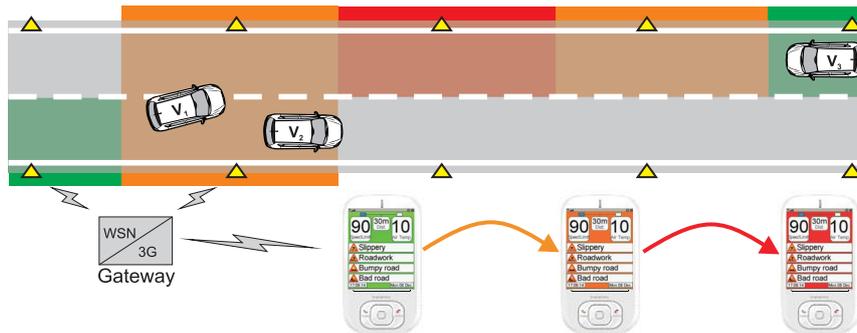


Figure 4 – Schematic of an overtake scenario with different zones for information (green) or warning (orange) to the driver and an intervention (red) to mitigate a collision.

WSAN implementation

Implementation of the iRoad support features described in the previous section require cooperative processing of the information from several road marking units. The topology of the wireless sensor and actuator network in our CRIS is a *string* (see Figure 4) due to specifics of the RMUs layout. Note that these specifics allows also RMUs to overhear transmission in two hop neighborhood. RMUs that are place along other lane markings can also be used as a backup route in the case of node failures.

The addresses to communicating RMUs are assigned deterministically during network roll-out. The address spaces for road lanes with opposed directions are not intersecting. The addresses are assigned to RMUs in increasing order along the direction of the particular lane. In this topology we differentiate two traffic directions: *Downstream*, in the direction of increasing addresses (along the car traffic direction) and *Upstream* in the opposed direction. With this addressing scheme and using the information about geographic position of each RMU and the distance between neighboring nodes it is rather straightforward to deploy geocast type of communications.

The essential part of the iRoad network architecture are gateways to wide area networks, depicted also in Figure 4. The gateways are placed on long distances between each other in the order of several kilometers.

Inside the iRoad WSAN, the data is transmitted using low power radio technology. Currently, the iRoad RMUs are equipped with IEEE 802.15.4-based radio transceivers. The 3G modem is installed on a road side unit (smart sign, fence, camera pole, etc.) and connected to a permanent source of energy. Due to space limitation in this paper we do not further discuss issues and challenges related to real-time propagation of data over multi-hop wireless links.

FEATURE EXAMPLE: OVERTAKING ASSIST

Overtaking of slower vehicles on single-lane highways, rural roads or occasions where a multi-lane highways merges to fewer lanes creates a potential hazard for the passengers when there is oncoming traffic or a hinder. The consequence could be a head-on collision or a collision with a fixed object. Preventive safety function for passenger vehicles that address these types of accidents are already proposed and are under development, see [6], [14] and [15]. Despite their low occurrence rate compared to other accidents, these accidents have a high risk for a fatal outcome, [16].

Moreover, the overtaking scenario puts high performance requirements on the support function. This is simply due to the high relative velocities that occur in the scenario which are associated with the necessity for long range sensing capabilities.

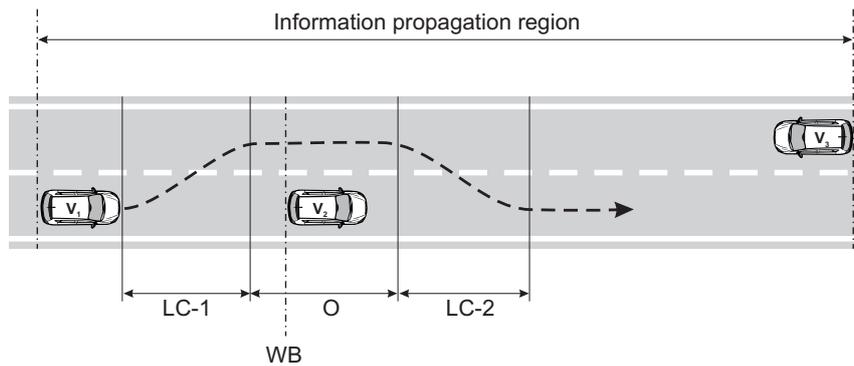


Figure 5 – Geometry of an overtaking scenario on rural roads and one lane highways. Vehicle V_1 overtakes vehicle V_2 while there is an oncoming vehicle V_3 .

Feature description

In Fig. 4 and Fig. 5 an overtaking scenario is depicted. There are several zones associated with the feature, that relate to the criticality and urgency for a required action by the road-user. When an overtake occurs and the road-user is in the green shaded areas, there is no action required from a safety perspective, but the information might be convenient for the user to plan his/her driving. In the orange shaded area, there is a high probability that the driver is affected by ongoing overtake and an action is required to avoid a hazardous situation, and a warning should be issued. Such a warning should also be issued before the overtaking vehicle has reached the warning boundary (WB). In the red-shaded zone, an accident has become imminent and requires immediate action/intervention by either road-user or the vehicle itself.

In detail, the overtaking itself consists of four phases. First, the driver is taking the decision that he or she wants to overtake the lead vehicle V_2 and that it should be possible without putting other road users at risk. Second, the first lane change occurs, denoted LC-1. Third, the vehicle V_1 passes the lead vehicle V_2 on the opposite lane, denoted O. Fourth, the overtaking is completed by the second lane change back into the original lane of the vehicle, denoted LC-2.

Before a driver starts to overtake he or she assesses the forward environment on risks, like oncoming traffic. This assessment has to consider the future behaviour of three vehicles in relation to each other, *i.e.* range, relative velocity and acceleration of the pairs (V_1, V_2) and (V_1, V_3) . In many cases this assessment is very difficult due to weather conditions and the associated forward visibility, as well as the estimation of distance and speed of the oncoming traffic. Not to mention, road curvatures and obtrusive objects that reduce the field of view and introduce shadowed areas. A support function for this scenario has the aim to reduce the risk for collisions. Thus, it can be described as follows: A driver shall be warned prior to or during the first lane change, if it is likely that the vehicle V_1 can not complete the overtaking well before the range between V_3 and V_2 reduces to zero.

Warning schemes and functional flow

There are several ways to implement the support feature and some of them are discussed shortly. It has to be kept in mind that the feature needs to be implemented in a way that yields low energy consumption and that even road-users with neither smart phone or intelligent vehicle can get a benefit from the feature.

As already mentioned above, the driver that wants to overtake should be warned prior to the overtaking phase. This can be achieved in two ways. First, a driver that initiates an overtake would get the warning as soon as the feature determines a high risk for this action. Second, any

driver the would meet an oncoming vehicle would get the information that overtaking is unsafe prior to any attempt. The latter might cause less computational efforts that would result and the distribution of many warning signals. Thus, the first scheme will be further discussed here.

Two warning scheme are considered here: direct visual warning using red LEDs integrated in the RMUs, warning through an IMS application in a smart-phone, which is called iRide. Of course, intelligent vehicles and variable message signs (VMS) could be used as interface, but will not be considered here.

The functional flow of an overtaking assist feature consists of several steps, which are the detection of a lane change, the detection of the hazard and the issuing of a warning. The lane change detection is assumed to be solved within one RMU using an estimation of the lateral speed and/or position of the vehicle. After the lane change is detected, the feature has to detect an oncoming vehicle that could create a hazard, see next section. This also established the needed detection ranges for this feature.

Hazard detection

A more exact description of the scenario dynamics is needed to assess performance and reliability requirements for the function. For the modeling of the dynamics, some assumptions are made: (1) Only the longitudinal motion along the road shape is considered; (2) The average acceleration of each vehicle during the overtaking scenario is zero, thus a constant velocity motion model can be used; (3) The increase in traveled distance due to lateral motion can be neglected.

Consequently, a one-dimensional constant velocity motion model can be used to determine the dynamics. We judge that more complex models are needed for the design of a support function, but for the derivation of the requirements on hardware and software this is not needed.

Now, a condition for a safe overtaking maneuver is given by

$$t_{\text{overtake}} \leq t_{\text{approach}} - t_{SM} \quad (1)$$

where t_{overtake} denotes the total time which is needed for the overtaking and the right hand side is the time t_{approach} for vehicle V_3 to reach vehicle V_2 minus a certain time t_{SM} as a safety margin.

Given that the position of the front end x and the current speed \dot{x} of each vehicle can be observed, it is straightforward to derive t_{overtake} and t_{approach} . This is done in terms of ranges R and relative speeds \dot{R} . For example the range or distance between two vehicles is denoted R_{V_2,V_1} and computed as $x_{V_2} - x_{V_1}$. A similar notation and computation is applied for relative speeds.

$$t_{\text{overtake}} = \frac{R_{V_2,V_1} + l_{V_1} + l_{SM}}{-\dot{R}_{V_2,V_1}} \quad (2)$$

with l_{V_1} and l_{SM} being the vehicle length of vehicle V_1 and a predefined safety margin, respectively.

$$t_{\text{approach}} = \frac{R_{V_3,V_2}}{-\dot{R}_{V_3,V_2}} \quad (3)$$

Thus, a decision can be taken if the overtaking is safe or not. From a system design perspective it is necessary to know how far ahead the vehicle V_3 has to be detected. Solving (3) for R_{V_3,V_2} and adding R_{V_2,V_1} yields the detection range

$$R_{\text{detect}} = R_{V_2,V_1} - t_{SM} \dot{R}_{V_3,V_2} + \frac{-(R_{V_2,V_1} + l_{V_1} + l_{SM}) \dot{R}_{V_3,V_2}}{-\dot{R}_{V_2,V_1}} \quad (4)$$

Obviously, the detection distance for vehicle V_3 is a function of the range and relative velocities, besides the additional tuning parameter t_{SM} , l_{V_1} and l_{SM} . Assuming that the speed of vehicle V_3

is bound by the speed limit on the current road type, the detection distance can be approximated from properties of vehicles V_1 and V_2 alone.

Additionally, there are timing constraints. Since the information on vehicle V_3 has to be gathered via the WSN and a warning has to be issued before the warning boundary is reached, it is necessary to consider the transmission delays in the system design.

To get a feeling for the distance that has to be looked ahead a worst case scenario is assessed: On a Swedish highway a passenger car will overtake a long heavy truck with a length of $l_{V_2} = 30\text{ m}$ while complying to legal regulations. The speed limits for passenger vehicles is 110 km/h and for heavy trucks 90 km/h . For the safety margins t_{SM} and l_{SM} some typical values are 3 sec and l_{V_1} , respectively. The average vehicle length l_{V_1} is set to 5 m . Additionally, it is assumed that the driver of the passenger vehicle is taking the decision at a time gap $t_{gap} = 3\text{ sec}$ to the vehicle V_2 . For this case, the detection distance becomes approximately 750 m .

Cooperative warning decision

In order to assess the feasibility of the overtaking assistance application, let us now design a somewhat simplified communication architecture and estimate its performance.

We assume a rather idealized radio communication medium with very low bit error rate so that reliable communications are possible without packet retransmission on any layer. Since the road marking units are autonomous and battery powered the obvious design objective for the communication part is to prolong system's life time as much as possible. It is well known that most of the energy is drawn by a node's radio in the listening mode. Therefore, a typical design choice for such communication systems is a duty-cycled wireless networking. Following this concept all nodes are put in a suspended mode most of the time waking up periodically to perform certain actions.

A simplified overtaking assistance protocol is as follows:

1. The protocol starts when a lane change is detected by the vibration-based accelerometer sensors.
2. All wireless road marking units along both sides of the road in detection range calculated in the previous subsection are activated as described below. The protocol uses position-based coordinates, introduced previously, as addresses;
3. The units remain active for a maximum on-coming car detection time;
4. As soon as the unit is activated the accelerometer based movement detection sensors on the opposite direction lane are started and sample the environment in order to detect a meeting car.
5. If a car is detected the signal to activate red LEDs is sent unicast along the lane in the direction of the overtaking car.

We take the SMAC protocol [17] which functionality is illustrated in Fig. 6. The protocol works in cycles of duration T_c . In the beginning of each cycle each node turns the radio transceiver on and remains in the the active state for duration t_a . Whenever a node wants to communicate with its neighbor it transmits a short message called preamble. The destination node remains active for the entire period of communication. When a node does not detect any activity in the air during t_a , it puts the radio in the suspend mode. Ratio t_a/T_c is called a duty-cycle parameter of the protocol.

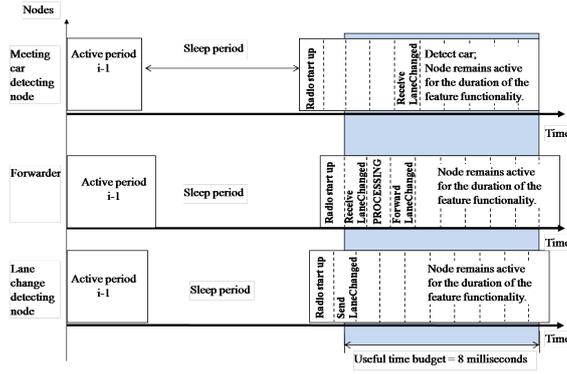


Figure 6 – Signaling protocol based on S-MAC medium access control protocol. The difference in the starting times of active periods is due to allowed synchronization error.

The tunable parameters of SMAC are dimensioned in order to ensure 1% duty-cycle: The length of the cycle is set to 1 second; correspondingly, the length of the active period is set to 10 milliseconds. With these settings and technical characteristics of the ZigBee transceiver (16mA in TX mode at full power) and battery used in iRoad RMUs the node can remain active for several months without recharging.

Out of 10 milliseconds of the active period one millisecond is spent for fast radio start-up which leaves us with nine milliseconds useful time per node. For the overtaking-assistance protocol we require that starting times of active periods in all nodes are synchronized with one millisecond precision¹. With this precision the active periods of the nodes overlap at least within eight milliseconds. This is the time frame where the overtake-assist protocol operates.

The protocol itself is rather a straightforward extension of SMAC for reliable multihop communications. As soon as the lane change is detected the detecting node sends a “LaneChange” signal in the closest active period. The signal is forwarded by the nodes on the opposite direction’s lane within the detection range using position based coordinates. The signal message is a six bytes tuple $\langle \text{SourceID}, \text{timestamp}, \text{signal}=\text{“LaneChange”}, \text{DetectionRange}, \text{GW_ID} \rangle$ where *DetectionRange* is the maximum number of hops in the detection range, *GW_ID* is the ID of the closest gateway to 3G network. Each node in the detection range forwards the message to node $n + 1$ and decrement the *DetectionRange* counter. If one of the intermediate nodes is a gateway to wide area network, it resets the *GW_ID* field and forwards the message further. The node at the end of the detection range is the one which observes *DetectionRange* = 1. Thus the signal message is propagated either until it reaches the end of the detection zone or until it reaches the gateway node (whichever is located farther).

In the previous subsection the on-coming car detection range is approximated to 780 m. In iRoad RMUs we use a communication unit based on RF230 radio chip the communication range for this transceiver communicating at full power is around 130 meters. Placing the nodes 50 meters from each other makes it 16 radio hops within the detection range.

The wake up time of the whole chain in the detection range is $T_{activate} = N \cdot (D_h + \tau)$, where N is the number of hops and D_h is the per hop latency including transmission and processing times and τ is a random backoff time before forwarding message in order to reduce probability of collisions with concurrent transmissions. Recall that with the settings of duty cycle described above we have 8 milliseconds budget to wake up the whole chain. At 250 kb/s the transmission time of 6 Bytes takes 200 microseconds per hop including the propagation time. Using 300 microseconds backoff time it is therefore feasible to wake up 16 hops within the available budget.

¹This precision is feasible with currently available synchronization protocols, which we do not describe further in this article.

As for the backwards propagation of the warning signal, assuming already active nodes, collision free communications and the maximum size packets (128 B for 250 kb/s RF230 chip), $T_{TX}^{Signal} = N \cdot 4ms = 128ms$.

All in all the node activation and propagation of the warning signal is limited by the duration of the cycle period which is one second. This value is definitely within the critical time margin for the overtaking assistance feature.

Warning and Information

The iRoad system offers two independent means to warn the drivers and passengers. Firstly, if a car is detected by sensors in the detection range the signal to activate red LEDs is sent unicast along the lane in the direction of the overtaking car. This warning channel is however not reliable enough in bad weather conditions when RMUs are covered with snow, water or mud.

Faced with the dilemma of choosing a communication link from the road surface directly to the driver or passenger for an early warning, we found that IP Multimedia Subsystem (IMS) is best suited for this role. Being an architectural framework for delivering IP multimedia services outside the control of traditional wireless operators, IMS on the one hand provides interfaces to heterogeneous radio access technologies and on the other has a number of ready to use communication primitives allowing data transmission to the user terminal equipment. We designed iRide, an IMS application and the supporting communication architecture for preventive hazard warning in the iRoad CRIS. Due to space limitation in this article we present a high level overview of iRide and refer the reader to [18] for the detailed technical description.

The hazard signal (in this case “Lane Change”) reaches a server in the infrastructure side of IMS through a WSN-to-3G gateway as described above. At the same time iRide users entering the intelligent road area login to the system from their mobile terminals. For logged in users, iRide determines their position on the road. For the prototype implementation, we assume that position information is supplied by GPS-enabled smart terminals or by a specialized device in the car that communicates this information to user terminals.

The system then jointly processes the information supplied by the intelligent road and the position and trajectory of the iRide users. Using the position of the end of the queue the system determines that a particular iRide user is located in the warning zone. In this case iRide sends a warning signal to the mobile terminal of this user. Users obtain warnings visually (changed screen color, displayed textual messages) and audibly (warning tone) from the terminal. An example of a visual warning in different zones are shown in Fig. 4.

RESULTS & DISCUSSION

A nearly 5 km long road strip in Northern Sweden has been equipped with RMUs. There, more than 200 units have been glued to the road surface. The aim of the experiment was to collect knowledge about the level of harshness, feasible placement and needed protection during a one year period with a complete winter period. Additionally, different types of components in the RMU were tested for their compatibility with the climatic and their resistance to mechanical wear and affect. The RMUs were exposed to extensive snow plowing, large temperature variations, ice, snow, and water coverage. During fall, the first positive feedback came from road users reporting that the RMUs improved visibility in adverse light conditions which facilitated driving (see right part of Fig. 1).

After the winter period the majority of RMUs were destroyed or had disappeared. The ones that survived had a better protection to resist snow plow affect and were functional. In order to follow the RMUs activities during the winter, some of the units were collecting temperature information

and reported the information via a GPRS/3G gateway to a server. These units were also equipped with a better protection for snow plows and all of them survived. It can be concluded that the RMUs with snow plow protection are feasible for placement in such a harsh environment.

Regarding the energy consumption and the charging capabilities, the test could show that the units had to work without charging for longer periods of time. As a result, the task that the unit have to perform need to be implemented with a low-power perspective and that task need to be distributed between units depending on the charge status of the batteries. Thus, distributed implementation of features is a necessity from the low-power perspective.

As exemplified by the overtaking assist feature, there is need to have vehicle properties like speeds and lateral positions available more or less at any. But the accuracy and availability of these estimates largely depend on the layout of the RMUs on the road, *e.g.* distance between the units. These problem can be overcome by more complex estimation schemes. Still, more complex estimation schemes results in a higher energy consumption as more sensing information need to be processed. Naturally, this is connected with radio coverage.

The radio coverage depends on curvature and vertical geometry of the road and the distance between the units has to be smaller for any small curve radius. Nevertheless there is no analytic way to determine the distance between the nodes, as environmental factors also contribute to the decision. In order to solve the layout problem, the functional content, estimation requirements, communication requirements, energy consumption have to be weighed in. The current assumption is that simulation studies where the environment and traffic scenarios are represented can be used to find solutions to this problem.

CONCLUSIONS AND FUTURE WORK

In this paper the design of a cooperative road infrastructure system is discussed and the concept is exemplified on an overtaking assist feature. Based on the discussion and the knowledge that was gathered through real-life experiments, it is our belief that driver support feature can be design and implemented on a CRIS.

While a CRIS can be a stand-alone approach to road safety, the integration with vehicles, infrastructure and telephone service providers which use the information that the CRIS can provide, is an important future step. In this case availability is a necessity which depends largely on robustness and energy efficiency of the units. It is still an open question what levels of reliability can be achieved with a CRIS, which will be addressed in future.

In the near term, features like traffic counting and running lights will be evaluated during another fall, winter, spring period. These feature already require schemes for energy efficiency and dependable communication under different climatic conditions and close to the road surface.

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