

# On the Design of Cooperative Road Infrastructure Systems

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**Abstract**—This paper discusses the design of cooperative road infrastructure systems for infrastructure-based driving support functions. The background of such systems is mapped out and it is shown that there is a need for a cross disciplinary approach. Using an example of a support function, namely the overtaking support, it is shown that such a system is feasible. The different challenges and technological problems that are identified are given and the future work is indicated.

## I. INTRODUCTION

Fatality in road traffic is the dominating cause for non-natural human death in our societies, [1]. These accidents are the main cause of death in the under 45 age group and cause more deaths than heart disease or cancer in that group. 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. Similar figures for the USA can be derived from, [2].

Hence sustainable and safe transport solutions, which do not interfere with our need of being mobile, are needed. Intelligent Transport Systems (ITS) are a technological response to the problem and traditionally, there are two approaches: Infrastructure-centric and vehicle-centric. The infrastructure-centric approach focuses on traffic management and safer roads, while the vehicles centric view focuses on more convenient vehicles with increased passenger safety, security and protection. Clearly, those two approaches go hand in hand.

Thus, a recent trend is to develop an integrated ITS approach where the road users, *i.e.* vehicles and the road infrastructure cooperate. There are many initiatives of the European Commission that focus around e-Safety, *e.g.* ongoing European research projects are [3], [4], [5]. Beside these efforts there is still an open question: Where to put the intelligence and why?

Current research efforts indicate that there is a need for road side units and vehicles that have long range communication, advanced sensing and high processing capabilities. Usually this comes with high energy consumption and large investment costs for both infrastructure and vehicles owners.

In this paper we suggest and discuss a different approach which we call cooperative road infrastructure system (CRIS). Recent advances in wireless sensor networks, [6], [7] and low

power highly integrated electronics [8], [9] enable the design of small autonomous units that create a collective alongside the infrastructure. These units have sensing, processing and wireless communication capabilities and do not rely on an external power supply. We conjecture that this approach yields high precision sensing, redundancy, robustness and autonomous functionalities.

Moreover, we advocate the need for cross disciplinary research on the intersection of automatic control, communication architecture and network protocols, and hardware and software for embedded systems.

The paper is organised as follows. First a CRIS is described with its components, followed by an illustrative example of a support function implemented as a CRIS. After the assessment of the example, the identified research challenges and technological problems are discussed. We conclude with a summary.

## II. COOPERATIVE ROAD INFRASTRUCTURE SYSTEM

As the term already indicates there are intelligent elements deployed in the road infrastructure. Schematically, the CRIS architecture is shown in Fig. 1 and Fig. 2. The intelligent elements, further on referred to as *road marking units* (RMU), are integrated in road marking of next generation<sup>1</sup>. The schematic and the major scale characteristics of new markings [11] are also shown in the figure. The CRIS RMU, therefore is a combination of the next generation road marking and electronics with associated software implementing the CRIS functionality. The architecture of the CRIS is illustrated by the hatched square in Figure 1. It consists of the following blocks: sensors, actuators, processing module, radio communication module and energy supply block. Thus, CRIS architecture may sense environmental information communicate to other RMU and distributively implement different applications.

In this article, we focus on a CRIS that communicate information on both low and high level. Low level information can be real-time sensor measurements like acceleration or temperature, and high level information can be collected sensor measurement, estimated information and decisions. The latter is very application oriented and depends on the purpose of the CRIS. The Intelligent Road MARKing project (IRMA) at Luleå University of Technology develops an architecture for infrastructure based driving support functions.

It is important to note that the technological filling to the functional blocks of CRIS architecture is already available

<sup>1</sup>Here we refer to recent developments in road marking technology. In particular, according to studies of the economical efficiency of the marking process performed by GEVEKO [10] it is cheaper to use pre-fabricated thermally applicable polymeric plates instead of painting with colors.

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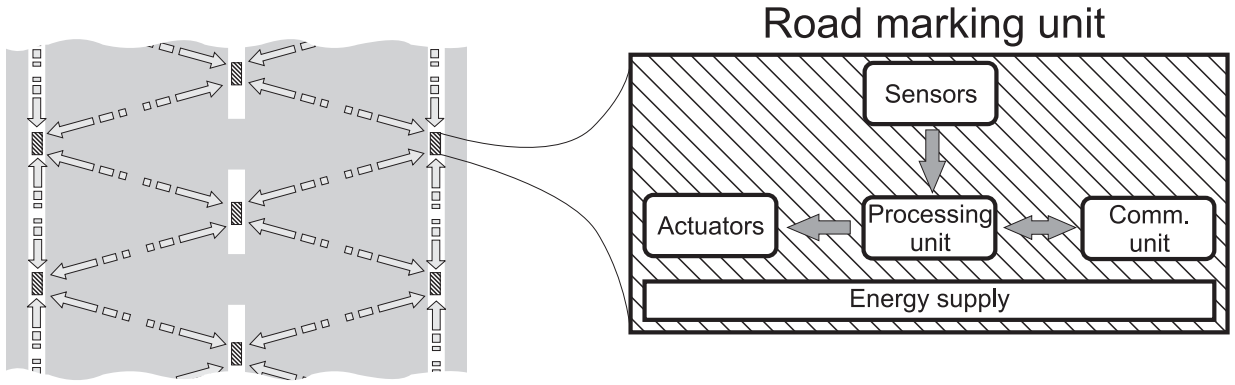


Fig. 1. Principal architecture for a CRIS. Broken arrows indicate radio communication and block arrows indicate internal data communication

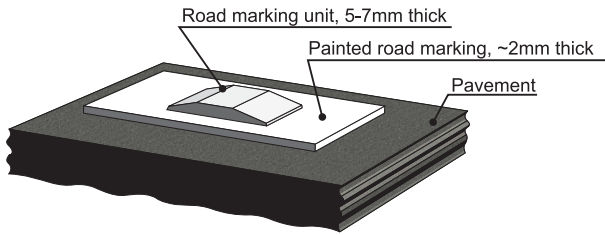


Fig. 2. Principal architecture for a CRIS. Broken arrows indicate radio communication and block arrows indicate internal data communication

as separate pieces on the market. In order to understand the design challenges and the boundary performance of the CRIS application in the following subsections we outline a possible technical content of the CRIS blocks selected from the available off-the-shelf products.

#### A. Microcontrollers

Along the recent development lines 8-bit and 16-bit microcontrollers show the best performance with respect to energy efficiency to processing power ratio. The available on the market low power sensor platforms are based on two types of microprocessors: the 8-bit ATmega128L [9] micro controller from ATMEL and the 16-bit MSP430 family [21] from Texas Instruments. The first microprocessor is equipped with 128 kB flash code memory, 4 kB EEPROM data memory and 4 kB RAM. The MSP430 processor has 48 kB flash code memory, 256 bytes flash data memory and 10 kB RAM. An important note to make here is the scarcity of computational resources that implies hard requirements on the complexity of software developed for those low power devices. Amongst the most popular low-power microcontrollers MSP430 offers the best power consumption to computation capabilities ratio.

#### B. Sensors and actuators

In CRIS applications we are mainly interested in detecting a vehicle presence on the road, lane changing events and road friction condition. These phenomena can be captured by light, temperature, relative humidity, acceleration, and vibration sensors supplying their measurements for further processing in either digital or analog (via an analog-to-digital

converter) form. The actuators used in the RMU are low power LEDs of different colors [11]. Sensors and actuators themselves do not consume much energy while in the active mode, however starting them up and computing the results contribute to various system delays.

#### C. Communication unit

Most of the existing wireless sensor nodes use single chip transceivers. The two most popular radio chip families are CC1000 [6] and CC2420 [7] both from Texas Instruments. The first class of radio transceivers operate in 433 MHz or 868 MHz band while CC2420 radios implement 2.4 GHz ZigBee standard. The ZigBee compliant CC2420 devices transmit data with 250 kbit/s data rate while CC1000 chips allow data rates in the range 38.4 to 76.8 kbit/s depending on the encoding scheme on the physical level. We have to point out that operating in this bandwidth the transceivers have to be placed on the line-of-sight. Communications are extremely sensitive to radio interferences.

#### D. Energy supplies

CRIS RMUs use a combined energy source consisting of thin plate with solar cells and a Polymer Lithium rechargeable battery from VARTA with capacity up to 1000 mAh. It is important to note that being deployed on the road surface CRIS RMUs are subjects to natural soiling by mud, snow, water etc. This implies that RMUs should operate only on batteries for long periods of time. The energy efficient CRIS operation when sensing, processing and communicating information is therefore a serious design issue.

### III. EXAMPLE: OVERTAKING SUPPORT

In order to get a better understanding of the requirements and boundary conditions for a CRIS, we will use an example for a potential driving support function.

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

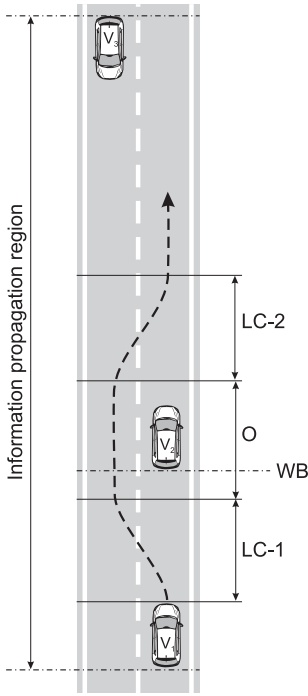


Fig. 3. Typical overtaking scenario on rural roads and one lane highways. Vehicle  $V_1$  overtakes vehicle  $V_2$  while there is an oncoming vehicle  $V_3$ . LC-1 and LC-2 indicate the two lane change phases, O represents the overtaking phase and WB indicates the warning boundary.

object. Preventive safety function for passenger vehicles that address these types of accidents are already proposed and are under development, see [12], [13] and [14]. Despite their low occurrence rate compared to other accidents, these accidents have a high risk for a fatal outcome, [2].

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.

#### A. Function description

In Fig. 3 an overtaking scenario is depicted. 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 behavior 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 truck size 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.

This gives rise to several design parameters:

- Time gap between  $V_1$  and  $V_2$  before the first lane change occurs.
- Point in time when the warning has to occur at the latest, denoted warning boundary WB.
- Range between  $V_1$  and  $V_2$  at which the lane change occurs at the latest.
- Range between  $V_2$  and  $V_1$  at which the second lane change occurs at the earliest.
- Range between  $V_1$  and  $V_3$  at which the second lane change is completed at the latest.
- False warning rate.
- Missed warning rate.

Clearly, settings for the first five parameters effect how far ahead the vehicle  $V_3$  has to be detected with its properties and how much time there is between the detection of the first lane change and the signaling of a warning. The last two parameters effect the requirements on the sensing quality and prediction capabilities of the function itself.

All these parameters have a direct effect on system cost (design and implementation), system reliability and acceptance by users, which has to be assessed.

#### B. Assessment of functional feasibility

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:

- Only the longitudinal motion along the road shape is considered.
- The average acceleration of each vehicle during the overtaking scenario is zero, thus a constant velocity motion model can be used.
- 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  $t_{\text{overtake}}$  denotes the total time which is needed for the overtaking and the right hand side is the time  $t_{\text{approach}}$  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  $t_{\text{overtake}}$  and  $t_{\text{approach}}$ . 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.

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

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

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

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

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

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  $110 \text{ km/h}$  and for heavy trucks  $90 \text{ km/h}$ . For the safety margins  $t_{SM}$  and  $l_{SM}$  some typical values are  $3 \text{ sec}$  and  $l_{V_1}$ , respectively. The average vehicle length  $l_{V_1}$  is set to  $5 \text{ m}$ . 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  $780 \text{ m}$ .

### C. Assessment of feasibility of communication architecture

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.

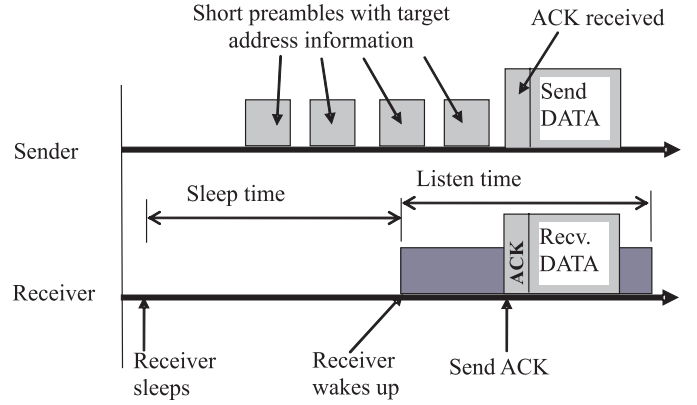


Fig. 4. X-MAC medium access control protocol.

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 using a special MAC protocol as described below. The protocol uses geographic coordinates 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 the signal to activate red LEDs is sent unicast along the lane in the direction of the overtaking car.

We take the X-MAC protocol [15] as the most efficient representative of medium access control schemes for duty cycled WSNs. Figure 4 summarizes functionality of the protocol. When a node wants to communicate to another node it issues a train of short sized frames indicating the address of the target node (strobed preamble). Upon waking up the target node intercepts one of the *preamble* frames signals the ready-to-receive acknowledgement back to the sender by this establishing the communication channel. The duration of sleep, listen times and their relation to the number and duration of wake up preambles is carefully chosen in order to minimize the per hop latency.

In the previous subsection the on-coming car detection range is approximated to  $780 \text{ m}$ . Assuming that we use a communication unit based on CC2430 radio chip (see Section II) the communication range for a 2.4 GHz transceiver placed at the ground level is around  $25 \text{ m}$ . Hence in the detection range we can fit 32 devices forming a 31 hops long chain-type topology. Assume a wake up signal message is one byte long, since the address information is transmitted in the preamble train there is no need for an extra header in the signal message. The wakeup time of the whole chain in the detection range is  $T_{activate} = N \cdot D_h$ , where  $N$  is the number of hops and  $D_h$  is the per hop latency. Due to the very fast start-up time, CC2420 can remain in power down mode until a transmission session is requested. We can also neglect the transmission and

propagation time for one byte of data at 250kb/s which is in the order of 30 microseconds. Therefore, using the calculation for the average per hop delay for the XMAC protocol in [15]:

$$T_{activate} = N \frac{T_{TX}^{Pream}(T_{Listen} + T_{Sleep})}{T_{Listen} - T_{TX}^{Pream}} \quad (5)$$

In (5)  $T_{TX}^{Pream}$  is the time to transmit the preamble train,  $T_{Listen}$  is the duration of the listen interval and  $T_{Sleep}$  is the duration of the sleep interval. Taking  $T_{TX}^{Pream} = 10$  ms,  $T_{Listen} = 50$  ms and  $T_{Sleep} = 100$  ms the activation time for a chain is  $T_{activate} \leq 1.5s$ .

As for the backwards propagation of the warning symbol, assuming already active nodes, collision free communications and the maximum size packets (128 B for 250 kb/s CC2420 chip),  $T_{TX}^{Signal} = N \cdot 4ms = 128ms$ . As it is visible for the simplistic analysis above the most time consuming part is the node activation sequence. All in all we showed that communications in our CRIS applications may happen within the critical time margin of three seconds.

#### IV. RESEARCH CHALLENGES AND TECHNOLOGICAL PROBLEMS

As it has been seen, the design of a support function is feasible, but numerous challenges have to be addressed on the way. These challenges are directly connected to the conceptual layout of a CRIS.

##### A. Function development

The car industry has a long history in the integration of many parts into a vehicle with verifiable performance and quality. Since the entry of vehicle networks, like CAN, the information flow between units has increased tremendously and opened up for new opportunities and also challenges. The main opportunity is the possibility to re-use information within a car and also to access information in an inexpensive way.

The flip-side of this coin is the distributed nature of functions and their specification. Even though there are rigid implementation processes available, these processes produce long development cycles when these function need to be fully verified. An Approach by the car industry that try to solve this problem is the AutoSAR [16] initiative.

Similar problems occur during the CRIS design. Since the functions are depending on information that is distributed within the road marking network, the function itself is composed by the cooperation of several unit. Additionally, these units along the roads are autonomous in the sense that the same decisions can be made in any node and that they operate independently. Still, a function is not created by one node alone.

This is quite obvious from the example, as information ahead of the vehicle is needed and that the decision making that is made will move alongside the road with the traveling vehicle. One of the challenges is therefore, to create a framework from design and specification to implemented and verified function in the units.

Another challenge is the estimation of properties, like distance between vehicles which can not be estimated by one unit alone. Beside the estimation at a requested quality, it has

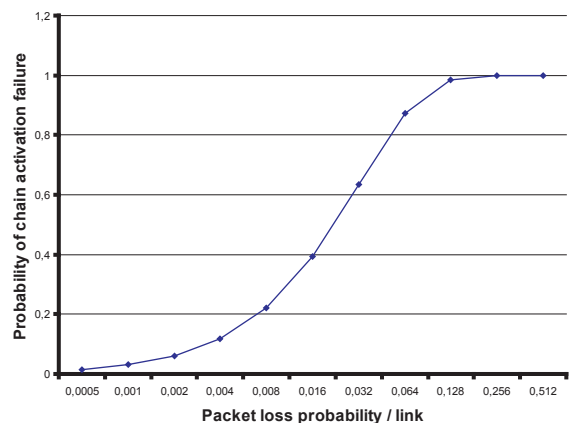


Fig. 5. Probability of 31 hops chain activation failure as a function of packet loss probability

to be understood which information has to be computed at all times and which only on request from another unit. The same counts for communication of the information, which is provided at all times and which is provided on request.

##### B. Communication aspects

In Section III-C we assessed general feasibility of CRIS overtaking application from the communication point of view. It is important to note, however, that this assessment is based on several critical assumptions solving which places serious technological and scientific challenges. In the first place we point out the instability of radio communication medium. In comparison to reliable wireline communication links, radio links suffer from very high bit error rates. This in addition to multihop communication nature makes the task of designing reliable on the one hand and high performance and energy efficient protocols on the other very difficult. Figure 5 shows that as soon as packet loss approaches 50% the chain activation failure probability is close to 100%. There is obviously a non-zero chain failure probability for even close to zero packet loss rates.

The probability of bit errors and associated packet loss rate per link depends mainly on the characteristics of radio environment (type of multipath propagation), type of antennae (directionality) and cross link interferences (induced by cross traffic). The radio propagation issues are particularly critical since the nodes will be placed on the zero level above the ground, this certainly makes it difficult to ensure stable communications and reduces the degree of freedom when designing antenna shapes.

In our message propagation time computations we also did not account for the time to detect the car presence and the event of lane change. A communication protocol for efficient and fast distributed car localization is needed to be developed. One of the main questions here is the number of sensors that are needed for reliable car localization and the complexity of the localization protocol.

A general design objective for CRIS communication part is energy efficient and provably reliable performance. As we discuss in the next section creating a methodology to

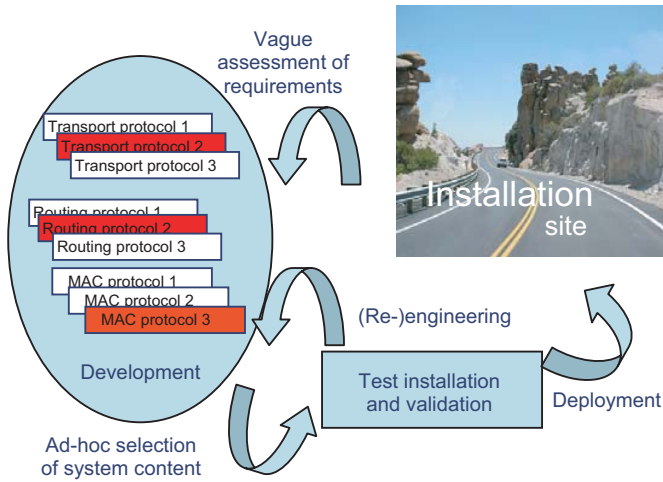


Fig. 6. Current Development cycle of a WSN application.

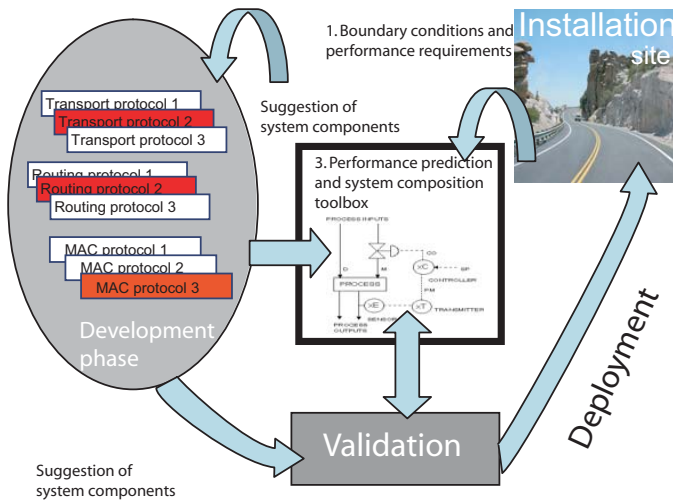


Fig. 7. Target performance driven development cycle of a WSN application.

systematically design an architecture with target performance parameters is one of the key scientific challenges.

There are also numbers of problems in the adjacent to communication networks scientific areas that should contribute to the acceptance of CRIS applications given that technical challenges are addressed. Security of involved communication protocols is one of the most critical problem areas.

### C. Performance prediction and system composition toolbox

In the previous section we discussed the research and development challenges associated with the design of CRIS overtaking assistance application. It is obvious that in order for such a life critical application to be accepted by road authorities and be trusted by drivers the performance of the system should provably be within the identified boundaries.

The major difficulty here is unavailability of methods and tools for network deployment planning, which would yield cost- and time- efficient system development cycle suitable for a variety of installation sites. The current WSN development cycle illustrated in Figure 6 consists of: a) A vague assessment of performance requirements; b) A rather ad-hoc selection of the functional content of the communication stack; c) A test

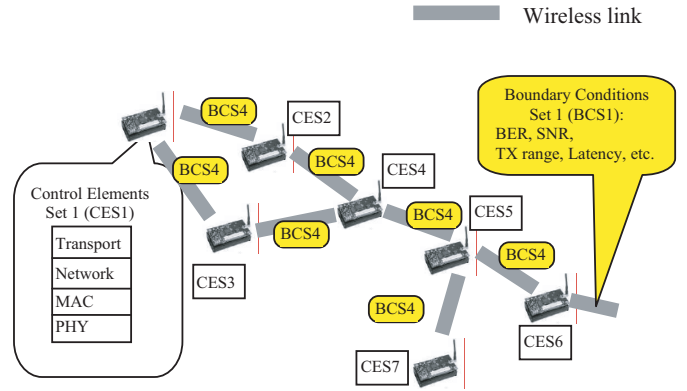


Fig. 8. WSN as a complex interconnected dynamic system.

installation of the application and d) Tuning the system configuration depending on the performance of the test installation. It is important to note that the initial system configuration is done mainly based on the experience and familiarity of a particular developer with a specific set of protocols. This may lead to a situation when at the last development step a complete re-engineering of the system is needed.

We advocate that in order to design provably robust and reliable WSN based life critical applications the design approach illustrated by Figure 7 should be adopted by the developers. The two central elements in the figure are the performance prediction and system composition framework and an accurate functionality and performance validation framework. The input to system composition toolbox is formed by on-site measurements of environmental boundaries obtained for a particular installation site, modularized communication primitives along with identified performance variables and the results of validating trials. In the following subsection we identify the functionality of the system composition toolbox and highlight the necessity of developing an accurate validation tool in a form of *combined simulation environment*.

1) *Performance driven design test loop*: From a control theoretical perspective a WSN as it is displayed in Figure 8, is a complex interconnected dynamic system. Each node is equipped with a control mechanism that should enable high performance of the WSN. All components including specific protocols of the communication stack, physical parameters of the links constitute a decentralized and sparse control mechanism. Thus, each control mechanism pursues one control objective, e.g. achieve a desired data flow rate between the sensor nodes and in-time delivery of signal to the vehicle. It is a well known fact that decentralized control mechanisms in complex dynamic systems only yield suboptimal performance. In the worst case, oscillations and instabilities can arise. Moreover, the performance is affected by a) structure of the WSN level control mechanism, i.e. the selection of the pairs (control objective, node); b) structure of the node level control mechanism, i.e. selection of the components that make up the protocol stack; c) tuning of the control mechanism, i.e. tuning of the parameters within the selected protocol stack components. A good summary in the analysis and controller design of multivariable systems (complex systems) is given in [17].

2) *Combined simulation environment*: The performance of CRIS-based applications is hard if not impossible at all to capture analytically. The major difficulty here comes from the heterogeneity and complexity of interconnected processes. Consider for example modeling of the communication protocols over multihop wireless links isolated from other CRIS components. While there exist a well established analytic framework for the analysis of individual protocols in the wireline Internet, the cross-layer dependencies introduced by the dynamically changing radio communication environment dramatically reduce their usability for the performance analysis in wireless networks. Network simulators, therefore, remain virtually the only means to assess the performance of communication protocols over wireless communication links.

Simulators, in general, are popular in nearly every field of engineering, like vehicle dynamics, electronics, only to mention some. It is common practice to re-use simulation models developed for a specific scientific area with their assumptions and simplifications in an other scientific area. Thus, the majority of network simulators use extremely simplified motion and mobility models. On the other hand the traffic or vehicle dynamics simulators in many cases make use of unrealistic radio channel models and neglect the effect introduced by communication protocols.

Clearly, when it comes to simulate the behavior of a CRIS application, several "conventionally unrelated" fields of science suddenly overlap which calls for an simulation environment modeling jointly the road environment, vehicle dynamics, driver behavior and wireless data communications. We call this tool a *combined simulation environment* (CSE).

We conjecture that the CSE has at least the following features:

- Simulation of network traffic within a dynamic physical environment, with disturbances like packet loss or reduced bandwidth.
- Dynamic vehicle motion simulation
- Vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication.
- Simulation of vulnerable road users and their motion.
- Visualization of the ITS in at least 2D.
- Sensor and actuator models both on vehicles and on infrastructure nodes
- Driver models and route planning

## V. SUMMARY

In this article we considered technological and scientific challenges associated with design and development of an architecture for Cooperative Road Infrastructure System. The key functional elements of the CRIS architecture are miniature solar powered sensor devices embedded in the next generation road marking units. The sensors nodes are able to communicate between each other and with passing by vehicles via an extremely low power radio. The internetworking wireless sensor nodes installed with a high density in critical parts of a road create means to communicate the essential for vehicle's safety ground truth information (i.e. true coordinates, true road conditions etc.). While the application of wireless sensors in traffic safety scenarios has been addressed in many research projects the actuality of the findings presented in this paper

comes from the fact that infrastructure based ITS still do not exist in reality despite the availability of all technological pieces.

On an example of designing an infrastructure cooperated overtaking assistant we showed that the strict boundary performance requirements of this life critical applications can only be fulfilled by following a systematic performance driven design-test loop. We advocate that only joint efforts on the intersection of automated control and communication systems research areas should enable creation of the performance prediction and system composition toolbox described in this article and the overall acceptance of CRIS based systems on public roads.

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