SHORT TERM SCIENTIFIC MISSION (STSM) – SCIENTIFIC REPORT

The STSM applicant submits this report for approval to the STSM coordinator

Action number: CA15127
STSM title: Applying inter-packet coding to increase reliability of vehicle-to-roadside communications (41386)
STSM start and end date: 0110912018 - 1510912018
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PURPOSE OF THE STSM/

- Studying channel conditions in real-life scenarios using experimental data obtained at the AstaZero testing facility.

- Develop inter-packet error-control coding which would allow for recovering those packets which were not successfully delivered because of abrupt degradations of channel conditions Expected gain from inter-packet error correction coding is increasing the probability of successful receiving data packets. In turn, better performance of communications entails higher sustainability of the Intelligent Transportation System and robustness with respect to weather conditions. Below we discuss the specific communications environment to be investigated and formulate restrictions and performance measures appropriate to the studied problem of increasing ITS reliability.

1. Safety testing of C-ITS

The emerging concept of Cooperative Intelligent Transportation Systems (C-ITS) suggests a widespread adoption of information and communication technologies in diverse vehicular applications that aim at increasing transport safety, efficiency and comfort. C-ITS vehicles exchange information with each other as well as with roadside infrastructure over vehicular ad-hoc networks (VANETs). An important milestone for VANETs has been the worldwide allocation of reserved bandwidth for C-ITS in the 5.9 GHz spectrum. The developing communication technology is called as DSRC in USA, and ITS-G5 in Europe. Intensive testing is being performed so that C-ITS systems could be introduced on public roads.

AstaZero in Sweden is an advanced testbed for research and development in the area of active road safety and autonomous transport. The unique capacities of the testbed offer the opportunity to support and accelerate research and development of active safety and C-ITS features through partnerships and close collaboration with vehicle manufacturers, suppliers, legislators, universities and colleges from throughout the world. Different traffic and communication environments are available at the facility, and this makes it possible to test and analyze systems from function level to vehicle integration -- and this in all kinds of traffic and traffic situations.

2. Roadside units and quasi real-time transfers

By leveraging remote connectivity supplied by Road-Side Units (RSUs) deployed along the road in VANETs, vehicles can retrieve/update maps or road and weather conditions via V2I (vehicle-to-infrastructure) and vehicle-to-roadside (V2R) communications. In the latter case, vehicles may exploit storage and processing capabilities locally offered by RSUs, according to the recently proposed mobile edge computing (MEC) paradigm.

V2R communications are expected to be short-lived and intermittent, due to the high mobility of the vehicles and to the high costs to deploy an ubiquitous roadside infrastructure. Because of the huge data traffic demands of vehicles coupled with the limitations of V2R communications, a practical design must make the best of connectivity opportunities in drive-thru scenario, where moving vehicles spend at most a couple of minutes in the coverage area of a RSU. When a non-reliable transport protocol is used, an application layer inter-packet coding turns out to be an attractive solution if we aim at transferring as much data as possible.

Thus, the goal is developing tools for evaluating channel conditions and design appropriate inter-packet coding.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

Reliable V2I (vehicle-to-infrastructure) and V2R (vehicle-to-roadside) communication is an important factor of overall reliability of transportation systems. Among the factors influencing the communication conditions are weather-based disruptions like heavy rains, fog etc. There two important connections between weather-based disruptions and transportation safety. First, local weather forecasts represent important data to be broadcasted via road-side units RSU. On the other hand, there is a strong dependence of channel performance on the weather conditions.

V2I and V2R communications suffer from information packet losses caused by channel degradation. A widely-used approach to the analysis of packet losses is modeling this discrete process based on measurements performed on the observed data stream. Typically, discrete models are constructed once based on a rather long data stream, and then used to further predict the behavior of the process. This restricts their applicability to ”quasi-stationary” processes which correspond to varying channel conditions.

We suggested an approach to constructing discrete models suitable for communication scenarios with adaptation of communication system parameters. The main feature of the new technique is that a model providing high accuracy prediction of the studied process is based on relatively short measurements. On the other hand, models constructed by using the suggested approach can also be applied in combination with known techniques such as the Baum-Welch algorithm. The new approach leads to higher accuracy model.
Our approach is based on models belonging to a wider class of probabilistic automata determined via so-called pseudo-Markov matrices (PMM). It has the following important practical advantages:

- Since the obtained models belong to a wider class of probabilistic automata then, in general, higher accuracy of approximation is achievable.

- Parameters of the discrete model can be computed directly from the analog model of the discrete time random process without generating a data stream.

- Computational complexity is rather low, it grows only polynomially with the model order.

- This approach is applicable if frequent model updating is required.

We used the constructed models for the analysis of error-correcting coding at the packet level of the network. Low delay and low complexity requirements narrow down the number of coding techniques suitable for this application. Another feature of V2I and V2R communications is a short lifetime of the transmitted information. This restriction makes convolutional coding practically the only suitable solution to the problem.

Thus, we studied two classes of high-rate convolutional codes with sliding-window (SW)-decoding. We compared the SW-decoding performance of the binary Wyner-Ash (WA) convolutional codes and the Read-Solomon (RS)-convolutional codes.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

In order to construct a model of packet losses in V2R and V2I communications without taking into account packet structure at the physical layer of the network, as well as specific of implementation of the physical layer protocol, we suggested a simplified model of packet processing. This model allows us to analyze how the parameters of the channel transmission coefficients, such as signal-to-noise ratio (SNR) and correlation, affect the state transition probabilities in the discrete Gilbert-Elliott model or PMMs.

In order to compute parameters of the PMM of order w one needs to know probabilities of length l subsequences in the studied discrete random process, where $l = 1,2,\ldots, 2w-1$. In practice these probabilities can be measured from the observed realization of the random process. Another possibility is approximation by an HMM or PMM a discrete time random stationary process with known model.

In our research we considered both the Rice fading model with exponential correlation which is simple and analytically tractable, but it cannot capture the rich interactions in a high mobility environment in V2I and V2R communications and more general correlation model which is simulated by means of the digital Bessel filter of order 5.

We compared different models by computing probabilities $P(m,n)$ of m errors on the length n. The performed simulations showed that the PMC of rank 3 provides better match with the simulations on the random process than the commonly used BWA. Moreover, computations of order 5 probabilities on the observed data stream have much lower complexity than that required by the 50 iterations of the BWA. Simulations on the packet traces provided by AstaZero company demonstrated consistence of the experimental results with theoretical findings.

As was mentioned before, V2R communications are expected to be short-lived and intermittent, due to the high mobility of the vehicles and to the high costs to deploy a ubiquitous roadside infrastructure. Because of the huge data traffic demands of vehicles coupled with the limitations of V2R communications, a practical design must make the best of connectivity opportunities in drive-thru scenario, where moving vehicles spend at most a couple of minutes in the coverage area of a RSU.

For a given vehicle and a given RSU in this scenario one should distinguish poor communications zones (entry zone and exit zone) when the distance between the receiver and the transmitter is large, and so-called production zone with relatively good transmission conditions. In order to compare different coding schemes for this communication scenario we introduced a new performance measure called *the successful delivery function (SDF)*. It characterizes the average (over session) probability of successful delivery of length K messages, as a function of K.

We simulated two convolutional coding schemes both on the obtained theoretical channel models and on the packet traces provided by AstaZero. The obtained coding gain over the uncoded transmission is about 4.75 dB for the WA code and about 5.75 dB for the RS code.

FUTURE COLLABORATIONS (if applicable)

Our future work is planned in three main directions.

First is the implementation and experimental proof-of-concept validation of the developed coding scheme, to be performed at AstaZero.

Secondly, we are planning to contribute to the ongoing ISO 22133-1 standardization of messages formats and communication protocols for automotive testing facilities.

Finally, we intend to address tighter requirements on decoding delays. The studied coding scheme introduces some delays which are acceptable for noncritical (quasi real-time) VANET scenarios like maps updates, but these delays are not acceptable for hard real-time data traffic (e.g. the tracking of objects under test). Therefore, designing of appropriate coding schemes which meet the reliability requirements for hard real-time C-ITS applications will be a subject of our future work.