DRISI
CALTRANS DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION

Research Notes

Deep-learning-based radio channel prediction for vehicle-to-vehicle communications

Continued/Expanded Research on Enhanced Traffic Signal Performance Measures

Advanced Research

MAY 2024

Project Title:
Deep-learning-based radio channel prediction for vehicle-to-vehicle communications

Task Number: 3465

Start Date: June 1, 2023

Completion Date: May 31, 2024

Task Manager:
Edwin Yeung
Transportation Engineer (Electrical)
edwin.yeung@dot.ca.gov

WHAT IS THE NEED?

Vehicle-to-vehicle (V2V) communications are an essential component of future driving. It is essential for any type of assisted or autonomous driving, e.g., for a vehicle warning those driving behind it that an emergency braking is imminent, to cars talking to each other to arrange smooth lane changes. Yet the general adoption of V2V has been slow – a fact that is partly due to economic reasons but is also impacted by limited and unpredictable performance of such systems. This, in turn, is related to the difficult operating environment – both in terms of signal propagation between transmitter (TX) and receiver (RX), but also the high density of devices, leading to strong interference, and thus possible packet loss. Further research to improve reliability and latency is thus urgently needed.

Optimization of the network requires proper planning of the transmission parameters, e.g., the direction in which transmission should be done obviously, providing power in a direction in which there are no communications partners is pointless. Similarly, power control needs to be implemented since excessive transmit power does not benefit the desired receivers, while it increases interference to other devices.

Furthermore, the system needs to schedule when to transmit which packets. Packets that do not require immediate transmission, e.g., those that provide velocity and other status information can be sent in a manner that optimizes throughput efficiency and minimizes collisions; this is especially important when the vehicle density is high and per-area throughput is close to its theoretical limit.

Caltrans
DRISI provides solutions and knowledge that improves California's transportation system

WHAT ARE WE DOING?

This project will investigate machine learning (ML) based vehicular channel extrapolation on actual measurements, instead of simplified channel models as done in the past. The measurements are for multiple-input and multiple-output (MIMO) antenna which are 8x8 MIMO channels, enabling the exploitation of the directional information of the channels and beamforming for improving signal-to-noise ratio (SNR) and reducing interference. At the same time, development of such V2V MIMO channel predictions with ML has – to the best of our knowledge – rarely been investigated in the past. To close these gaps, we will develop new ML algorithms not only for channel extrapolation, but also transmission parameter adaptation and scheduling. We will consider the topics of neural network design, training strategy, data augmentation, and whether a separate channel prediction and scheduling is superior or inferior to a joint approach. With these novel ML designs and carefully designed time schedules, the effectiveness and robustness of the proposed solutions will be accessed by the actual V2V measurements collected in multiple scenarios, e.g., car-to-car, car-to-truck, truck-truck in campus, city street, and highway.

WHAT IS OUR GOAL?

A key outcome of this project will be a methodology for optimizing resource assignment in V2V communications. The first part of the methodology, namely the channel prediction, is independent of the specific type of system; this is important because currently there is a debate about whether the Institute of Electrical and Electronics Engineers (IEEE) standard of IEEE 802.11p/WAVE system will be used, or the 5G New Radio (NR); our work will be useful in either case. The actual resource allocation algorithms developed in the second part will show differences in absolute performance depending on which system they are used with, but in either case will provide a significant improvement over the state of the art, where suboptimum resource allocation is a major source for inefficiencies and outages in V2V communications.

WHAT IS THE BENEFIT?

These outcomes will eventually lead to the following broader impact: 1) Improved traffic safety, i.e., packet drops and insufficient coverage, may lead to vehicles not learning safety-critical information, or warning of a pile-up, in time to react. It is worth remembering that on-board sensors of a car are not sufficient to avoid all accidents (this is a key motivation for V2V communications in the first place). 2) Energy savings, since more reliable communications allows cars to drive more closely to each other in a convoy formation, which in turn reduces energy consumption due to reduced wind drag. At the same time, this also leads to reduction of traffic jams, because the capacity (throughput) of the road is improved.

WHAT IS THE PROGRESS TO DATE?

January 1st to 31st, 2024: We addressed the complex task of channel state information (CSI) prediction using data from three distinct environments: the USC campus, downtown Los Angeles, and the I10 highway. Specifically, we introduced a new predictive model named Squeeze-and-Excitation long short-term memory network (SE-LSTM), crafted for the nuanced task of CSI sequence modeling. This model skillfully manages dependencies both within and between sequences by combining a Squeeze-and-Excitation (SE) module and an attention mechanism within an LSTM architecture. Its efficacy was demonstrated through various performance indicators (root mean squared error (MSE), mean absolute error (MAE), etc.), where it achieved results surpassing those of existing state-of-the-art methods.

February 1st to 29th, 2024: We conducted cross-environment testing for our proposed method to assess its effectiveness across various settings. It was observed that all recurrent neural network-based methods are prone to cumulative errors in such tests. To address this issue, we introduced an innovative training approach called adaptive meta-learning. Our case studies confirmed that this method effectively reduces performance degradation in cross-geometry tests, keeping the performance loss within an acceptable margin, such as 3dB.

March 1st to 30st, 2024:
We applied the proposed training strategy to existing methods, such as ConvLSTM and Recurrent PredRNN, and found through case studies that this strategy is effective for them as well, maintaining performance loss within an acceptable range. Furthermore, we assessed the computational complexity of all methods used, with the aim of evaluating their efficiency in practical scenarios. Measures of computational complexity included parameters, floating-point operations per seconds (FLOPs), memory usage, as well as training and testing time. The findings indicated that the complexity of the proposed methods and certain existing methods like ConvLSTM is manageable for most devices, demonstrating their viability for practical applications.

We completed the evaluation of all comparison methods, including both existing state-of-the-art approaches and the method we proposed, for CSI prediction using datasets gathered from three distinct scenarios.