System Level Simulation of Scheduling Schemes for C-V2X Mode-3

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Abstract

The 3rd Generation Partnership Project (3GPP) introduced Cellular Vehicle–to–Everything (C-V2X) as a novel technology to support sidelink vehicular communications. While a distributed scheduling approach has been proposed by 3GPP for the out-of-coverage scenario, i.e. C-V2X mode-4, there is no standardized scheme for centralized systems in C-V2X mode-3. In this paper, we propose two scheduling approaches for C-V2X mode-3. One of them is based on the minimization of the overall power perceived by the vehicles. The second approach is based on the maximization of the subchannels re-usage distance. The two centralized schemes are compared against the distributed approach. Through simulations we show that the proposed schemes outperform C-V2X mode-4 as the subchannels are assigned in a more efficient manner with mitigated interference.

Index Terms

subchannel scheduling, vehicular networks, mode-3, sidelink, C-V2X

I. INTRODUCTION

Cellular Vehicle–to–Everything (C-V2X) communications is one of the novel paradigms introduced by the 3rd Generation Partnership Project (3GPP) in Release 14. C-V2X communications is envisaged as a dependable technology with the capability of satisfying stringent latency and reliability requirements in dynamic scenarios. Two operation modalities have been described within C-V2X, namely mode-3 and mode-4. The former one is aimed for centralized systems
and therefore relies on the availability of cellular infrastructure such as eNodeBs. Thus, eNodeBs may pursue any criteria to allocate subchannels to vehicles. For instance, [2] describes a setting where maximization of the system sum-capacity is aspired based on the subchannels signal–to–interference–plus–noise ratio (SINR) that vehicles report to eNodeBs. Furthermore, [3] extends the previous work including additional constraints where differentiated QoS requirements per vehicle are considered. Once an eNodeB has computed a suitable distribution of subchannels, vehicles will be notified of the allocation via downlink—upon which direct vehicle–to–vehicle (V2V) communications will take place over the sidelink. Contrastingly, mode-4 operates autonomously and distributedly without the necessity of a central orchestrator. As a consequence, vehicles have to monitor the power levels on each subchannel and select a suitable one for their own utilization. A vehicle will self-reserve a subchannel which may be unoccupied or experiences low interference in order to improve the likelihood of its own transmitted messages being received reliably. In mode-3 the sidelink subchannels can be more efficiently utilized due to the huge amount of knowledge arriving at the eNodeBs from all the vehicles in coverage. Conversely, a noticeable drawback of mode-4 is the restricted local knowledge of each vehicle, which may cause the most appropriate subchannels not to be always selected. Moreover—due to incoordination—several vehicles may compete over the same subset of subchannels, and therefore leading to severe packet reception ratio (PRR) degradation. In order to diminish the occurrences of conflicts, 3GPP standardized a semi-persistent scheduling (SPS) scheme whereby vehicles can reserve subchannels on a quasi-steady basis until re-scheduling is required. Thus, under the presumption of short-term invariability, any receiving vehicle is capable of acquiring a degree of understanding about the subchannels utilization.

In the absence of centralized scheduling schemes for C-V2X broadcast communications, we have devised two approaches and compare them against mode-4 proposed by 3GPP [1]. The paper is structured as follows. In Section II, the two centralized schedulings approaches for mode-3 are described. In Section III, the 3GPP SPS scheduling scheme for mode-4 communications is briefly revisited. Section IV is devoted to simulation results. Finally, Section V summarizes the conclusions of our work.

II. SCHEDULING APPROACHES FOR MODE-3

In this section, we briefly describe two schedulings approaches that we propose.
**Preliminaries:** A 10 MHz intelligent transportation systems (ITS) channel for exclusive support of sidelink communications has been considered. Thus, the whole channel is divided into several time-frequency resource partitions—hereinafter called subchannels. Each has dimensions of one subframe (1 ms) in time and a number of resource blocks (RBs) in frequency. A subchannel is assumed to be capable of carrying a cooperative awareness message (CAM). In this work we have assumed a nominal message rate of $\Delta_{CAM} = 10$ Hz; therefore the maximum amount of time divisions is 100. In a similar manner as subchannels in mode-4 are reserved on a semi-persistent basis—in the centralized schemes presented herein—the same assumption prevails in order to make a fair comparison between the approaches. Thus, subchannels are utilized by vehicles for $T_{SPS}$ seconds. During this period, a vehicle will periodically broadcast on the assigned subchannel, and upon termination a new reservation will be required. In addition, at any time instance there is a number of vehicles in the system that require re-scheduling. The eNodeB will be notified of such a requirement and based on either (i) the received power sensed by the vehicles at every subchannel or (ii) the position and usage of subchannels, a new allocation of resources will be attempted. Both approaches presented herein are based on maximum weighted bipartite graph matching.

**A. Minimization of Overall Received Power**

In this approach the objective is to minimize the overall received power of the assigned subchannels. Thus, vehicles requiring re-scheduling transmit via uplink the conditions they experience on the monitored subchannels. Based on this information, a distribution of resources that minimizes the total received power will be computed. The intuition behind this approach is that subchannels with low received power may be more suitable as they might be unoccupied or experiencing negligible interference. In this case, the vertices of the graph are either vehicles or subchannels and the edge weights are represented by the RSSI values of the subchannels.

**B. Maximization of Subchannel Re-usage Range**

The objective of this approach is to attain maximal re-usage distance for every subchannel in the system. Intuitively, this will help in mitigating co-channel interference. In this case, the edge weights are determined by the minimum distance at which other vehicles are reusing a particular subchannel.
III. 3GPP-based Scheduling for Mode-4

In the following, we briefly describe the 3GPP mode-4 scheduling scheme. For a more detailed explanation, the reader is referred to [1] [4]. It consists of the following stages.

A. Power Sensing

The vehicles continuously monitor the received power on each subchannel except on those where monitoring was not possible, e.g. due to half-duplex limitation.

B. Subchannels Categorization

Some subchannels will be excluded from selection based on the average PSSCH-RSRP. This is an iterative stage where a threshold is gradually increased in order to admit more subchannels with incremented interference until there are at least 20% of candidate subchannels for selection.

C. Subchannel Selection

Among the pre-selected candidates in the previous stage, a subchannel is randomly chosen.

IV. Simulations

In this section, we compare the standardized 3GPP scheduling method against the two proposed approaches. We assess a freeway scenario with 600 vehicles over 40 seconds of simulation.

| Description                                      | Symbol | Value | Units |
|--------------------------------------------------|--------|-------|-------|
| Number of RBs per subchannel (per subframe)      | -      | 30    | -     |
| Number of sub-bands                              | $F$    | 3     | -     |
| Number of subchannels                            | -      | 300   | -     |
| CAM message rate                                 | $\Delta_{CAM}$ | 10 | Hz     |
| CAM size                                         | $M_{CAM}$ | 190 | bytes |
| MCS                                             | -      | 7     | -     |
| Transmit power per CAM                           | -      | 23    | dBm   |
| SINR threshold                                   | $\gamma_T$ | 3.98 | dB    |
| Scheduling period [4]                            | $T_{SPS}$ | 0.5-1.5 | s     |
| Antenna gain                                     | $G_t, G_r$ | 3  | dB    |
| Shadowing standard deviation                      | $\Delta_{\sigma}$ | 7  | dB    |
| Shadowing correlation distance                    | -      | 10    | m     |
The simulations have been performed at least 5 times with different seeds in order to evaluate deviations. The relevant parameters for the experiments are shown in Table I.

We can observe in Fig. 1 the PRR curves for the mentioned approaches. Furthermore in shaded colors, we depict the deviations which are originated due to performance variations when using different seeds. These representations can be regarded as intervals with 99.999% of confidence. We can observe that the scheduling scheme based on distance maximization outperforms mode-4 across all the distances. However, the approach based on minimization of the sum of received powers can only outperform mode-4 in the near field—which is a critical region. In the far-field (150 m an beyond) its performance is comparable to mode-4.

V. CONCLUSION

We have proposed two centralized scheduling schemes for C-V2X mode-3. We can conclude that only the distance-based approach performs better than the distributed mode across all the distances. For further study, we aim at combining both RSSI values and distance information to improve the performance of the centralized approach.

REFERENCES

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