SHORT TERM SCIENTIFIC MISSION (STSM) – SCIENTIFIC REPORT

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

Action number: CA 15127
STSM title: Adoption of the LTE-D2D Communications for V2V Applications
STSM start and end date: 18/06/2018 to 23/06/2018
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PURPOSE OF THE STSM

Safety applications for vehicles are attracting a significant interest: vehicles need to communicate with each other and with the infrastructure. The current standard for these applications is IEEE 802.11p/1609 Wireless Access in Vehicular Environments (WAVE). The interest of this activity is to explore the potentialities of existing LTE-A communications and, in particular, Device-to-Device (D2D) communications as a communication basis for vehicular cooperative safety systems.

Cooperative safety applications are based on the frequent exchange of short status messages also known as beacons (CAM messages) among the vehicles in a neighboring area. Beacons carry the information about the vehicle, such as its position, velocity, and acceleration. If the beacon to be transmitted is outdated, it is dropped and not transmitted to the intended recipients.

The idea to be explored with this mission is the possibility to use the D2D communications of LTE-A to support vehicular communications. In particular, D2D communications underlying a cellular network have been recognized as an important approach for the performance improvement of 5G systems. We consider the underlay mode where D2D pairs can communicate directly each other by sharing sub-channels with Cellular Users (CUEs). The aim of this study is to model the interference conditions for D2D communications in this scenario (SINR model) and to study the successful delivery of messages among vehicles. .

The focus of this STSM will be on the platoon scenario, where a leading vehicle is controlling the other vehicles of a group like a train.

This STMS is carried within the framework of WG3 ("Technology-Related Disasters") of the RECODIS Action.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSM

Recent efforts in the V2V field are towards the development of Cellular Vehicle-to-Everything (C-V2X) technology, conceived by 3GPP in Release 14 to optimize D2D communications among vehicles under high mobility conditions. A few studies have been published focusing on assessing the performance of C-V2X for the delivery of Cooperative Awareness Messages (CAMs) in the neighbourhood of the sender. In this STSM we have referred to platoon applications where there is the need to exchange CAM messages among vehicles.

After a survey on this topic of the literature, an analytical approach has been developed during the STSM to determine the successful delivery of V2V messages within a suitable deadline. Some details are provided below considering the adoption of the D2D technology of LTE with the underlay approach.

Let us refer to the general pairing conditions depicted in Fig. 1. The D2D Rx does not experience outage because of the pairing with the CUE if the D2D Rx distance y from the CUE fulfils the condition $y > l_{max}(D)$, where $l_{max}(D)$ is determined later, being D the distance between D2D Tx and D2D Rx (in our scenario the first and the last vehicles in a platoon group).

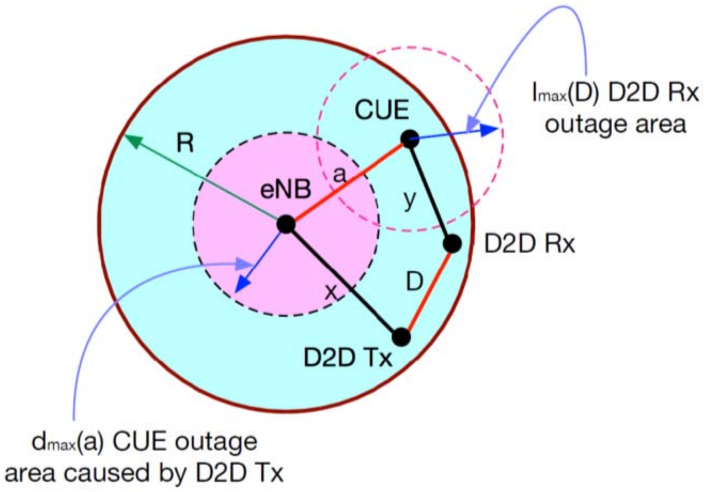

Fig. 1: CUE and D2D outage areas (and conditions) because of D2D pairing in the underlay mode.

Let us now determine the generic RB loss probability for D2D transmissions using a certain CQI LTE mode and corresponding $SNIR_{min}$ value. In particular, we have been able to characterize $l_{max}(D)$ considering the following condition that the SINR at the D2D Rx is equal to the threshold $\boldsymbol{SINR_{min}}$ here expressed in dBs:

$$\frac{\dfrac{P_{Tx}D2D}{pathloss(D)\times 10^{\frac{s}{10}}}}{N_0 B + \dfrac{P_{Tx}CUE}{pathloss(l_{max})\times 10^{\frac{z}{10}}}} = 10^{\frac{SINR_{min}}{10}} \qquad (1)$$

where

- *Pathloss*(D) is the path loss in linear scale of the D2D link at a distance D;
- *Pathloss*(r) is the path loss in linear scale of the CUE link at a distance y.

and where we have included the shadowing terms in every path loss. In particular, s and z are Gaussian independent random variables with zero mean and variances σ_s^2 and σ_z^2, respectively.

We adopt simple path loss models for both CUE and D2D communications according to 3GPP TR 36.942 and the METIS PS9 model, respectively. We have determined the pdf of the distance between D2D Rx and CUE. Then, we have integrated this pdf to express the loss probability at the D2D RX, thus using the probability distribution function $F_d(y|\omega)$ to be computed in $l_{\max}(D\ ,\ \omega)$. Through some manipulations, we have:

$$F_d(l_{max}(D,\omega)|\omega) = \begin{cases} \dfrac{-\theta(2\theta^2+1)\sqrt{1-\theta^2}+4\theta^2 arccos(\theta)+arcsin(\theta)}{\pi/2}, & if\ \ \theta < 1 \\ 1,\ otherwise \end{cases} \quad (2)$$

where $\theta = \frac{l_{max}(D,\omega)}{2R}$.

We have removed the conditioning on ω by averaging $F_d(l_{max}(D,\omega)|\omega)$ by means of the Gaussian pdf of ω, denoted as $Norm(\omega, 0, \sigma_s^2 + \sigma_z^2)$. We achieve the D2D outage probability $p_{loss}(D)$ for a given D as:

$$p_{loss}(D) = \int_{-\infty}^{\infty} F_d(l_{max}(D,\omega)|\omega) \times Norm(\omega, 0, \sigma_s^2 + \sigma_z^2) d\omega\ . \quad (3)$$

$p_{loss}(D)$ can also be considered as the average loss rate of an RB transmitted in the platoon scenario for a given CQI with the corresponding $SNIR_{min}$ value. Let $m = m$(CQI) denote the length in RBs of a CAM message for a given CQI value. We have determined the m(CQI) value according to the LTE standard. Let us assume that every RB experiences the same and independent interference conditions (no correlation assumption for the worst case study): then, every RB can be lost with a probability $p_{loss}(D)$. Hence, the CAM loss rate $p_{loss\_CAM}(D)$ can be expressed as:

$$p_{loss\_CAM}(D) = 1 - \left(1 - p_{loss}(D)\right)^{m(CQI)} \quad (4)$$

Let t_{lim} (= 300 ms) denote the maximum time age for the CAM message.

The delivery of a CAM message at each attempt requires time Δ as:

$$\Delta = t_{tx} + t_{ver} = \left\lceil \frac{m(CQI)}{N_{RB}} \right\rceil + 30 \quad \text{[ms]} \quad (5)$$

where t_{tx} denotes the CAM transmission time in TTI units (i.e., in ms) and t_{ver} denotes the verification time at the D2D receiver in ms.

Since the CAM message can be lost at each attempt with probability $p_{loss\_CAM}(D)$, we have adopted a geometric distribution to model the time to deliver correctly the message and we have used the corresponding cumulative distribution to characterize the probability that the CAM message is delivered within the deadline t_{lim}, P_{suc_CAM}, where we consider for D the most distant vehicle of the platoon; we have analysed this result for different CQI values.

Finally, a Matlab study has been carried out to estimate P_{suc_CAM}, for different CQI values and numbers of vehicles in the platoon group.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

Under our modelling assumptions for LTE and V2V scenario, Fig. 2 shows the probability to fulfil the time age constraint for the CAM message (PL-to-PM CAM for the last vehicle) P_{suc_CAM} as a function of CQI for varying numbers N of vehicles in the platoon group. In all the different cases of N values, P_{suc_CAM} has an optimal condition as a function of CQI. In fact, for low CQI values, too many RBs are needed to deliver the CAM message and then P_{suc_CAM} is high. On the other hand, if CQI is too high, few RBs are needed to transmit the CAM message, but the loss CAM rate is very high. Then, the right CQI value is around 11. Moreover, the P_{suc_CAM} values reduce with N since we are referring to the last vehicle of the platoon group that is therefore at an increasing distance with N. The P_{suc_CAM} performance could be improved by increasing the V2V transmission power or using dedicated resources for V2V communications.

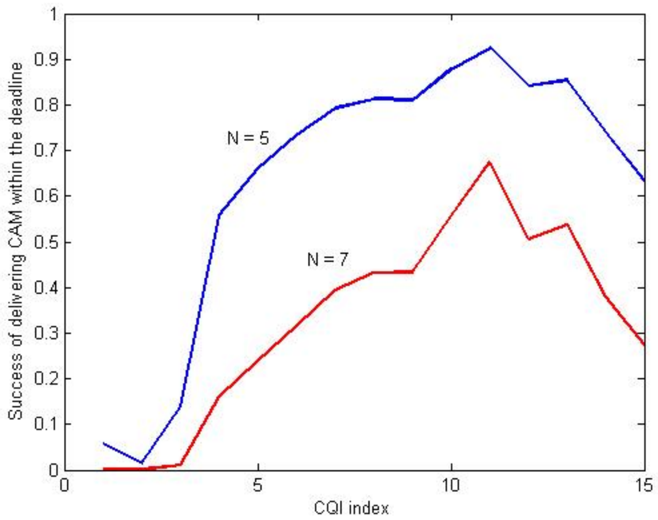

Fig. 2: Probability to deliver the CAM message correctly using different CQIs within the deadline P_{suc_CAM} for the farthest vehicle in a platoon with different numbers N of vehicles.

The suitability of D2D communications to support the message exchange among vehicles has been investigated for platoon applications. The scenario has been described a list of assumptions has been provided. Analytical efforts have been pursued to characterize the time and the loss rate experienced by a CAM message to be delivered at the farthest distance within a platoon group.

FUTURE COLLABORATIONS

This STSM has aimed to join the expertise of the two teams for the application of D2D communications to the V2V scenario. The modelling efforts and the results achieved are quite promising. Future work will be needed to further investigate the impact of different settings on the CAM delivery performance and to investigate how to further elaborate on the conservative assumptions regarding interference effects made in this study. Therefore, there is interest to progress further on this topic. We plan to work with Prof. Alexey Vinel for a conference or a journal paper. Finally, as requested, an extended version of this report will be used as a contribution to the final COST book, as requested by the Chair of CA 15127.