Performance and fairness in VANETs

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***Abstract*—This paper presents performance and fairness analysis of the 802.11p Medium Access Control (MAC) in one-hop periodic broadcast V2V communication used in cooperative driving applications aimed for improving vehicle safety and traffic efficiency. We show that both performance and fairness strongly dependent on the random relative phasing (Φ_0) of the vehicles and on the impact of Hidden Nodes (HNs).**

I. Introduction

Many cooperative driving applications aimed for improving vehicle safety and traffic efficiency enabled by a new standard 802.11p [1] will rely on one-hop periodic broadcast communication (BC). For instance, periodic one-hop BC that is needed in the forward collision warning application [2] requires a frequency of 10 packets per second with a maximum latency of 100 ms and a minimum communication range (CR) of 150 meters. In general, one-hop periodic BC comes in two flavors: event-driven and periodic. In event-driven, a vehicle starts periodic BC when a hazardous situation is detected, hence, packets are not sent in a normal situation. In periodic, a vehicle pro-actively informs neighboring vehicles about its status (e.g. position, speed), which is used to predict potential hazardous situations. In the latter case, each vehicle starts periodic BC when the vehicle is switched on. Therefore, we can assume that each vehicle has a relative phase Φ_0, which is randomly initialized and constant thereafter.

II. Collisions in BC mode

There are two main causes for collisions during BC. First, if there are many vehicles in a CR, the probability that multiple vehicles have the same Φ_0 will increase. As a result, the probability that multiple vehicles choose the same random number from a given contention window (CW) interval will also increase, causing collisions for receivers of both senders. Second, the HN problem causes collisions. HNs are nodes that cannot see each other but are seen by the nodes in the intersection of the CR of both. When the difference between the Φ_0 of two HNs is less than a packet transmission time, they will disrupt each others communications over the nodes in the intersection. Note that the phasing plays a crucial role in both causes for collisions.

III. Metrics and experimental setup

We use three metrics to evaluate performance and fairness as well as impact of phasing:
Successful Packet Reception (SPR) - the fraction of vehicles in CR that receive a broadcast package (BP).
Packet Loss (PL) - gives the fraction of lost BPs from transmitter's viewpoint. We assume that a BP is lost if the SPR of that BP is less than 70%. A vehicle is called invisible if its BP is lost.
Consecutive Packet Loss (CPL) - the duration (in terms of BPs) a vehicle becomes invisible.

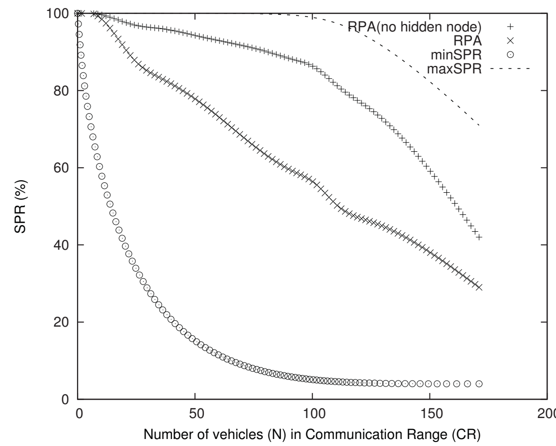

Fig. 1. Average SPR of overall network with respect to N in CR.

The experimental results are obtained using our own simulator and the results are also verified by NCTUns network simulator [3]. We choose a two ray ground channel model and 6Mbps data rate. The CW size is selected as 7 slots and the Arbitrary Inter Frame Space (AIFS) is 6 slots, where one slot is 16μs. For the vehicle traffic, a highway is modeled as a large loop with length of 1500m. The inner, middle, and the outer lanes have vehicles with a speed of 110, 90 and 72 km/h respectively. We changed (*i*) the distance between vehicles to get different densities in CR and (*ii*) Φ_0 to see the effect of phasing. For instance, for 48 vehicles (48v) in CR, the inner-most lane's vehicles are placed 45m and the other two lanes' vehicles are placed 40m and 35m apart from each other respectively. Each vehicle broadcasts a packet with length of 500bytes periodically in every 100ms after an initial Φ_0 chosen uniformly from an interval [0:100ms]. We assume the same signal strength (i.e. CR = 300m) for all vehicles. Each simulation is performed for one minute.

IV. Experimental results and analysis

Performance: Fig. 1 shows the average SPR of the overall network. The dashed and circled lines show the Max and Min SPR. The $maxSPR$ is given by:

$$maxSPR(N) = \begin{cases} 1 & \text{if } N < N_{max} \\ N_{max}/N & \text{if } N > N_{max} \end{cases}$$

where N is the number of vehicles in CR and N_{max} is a

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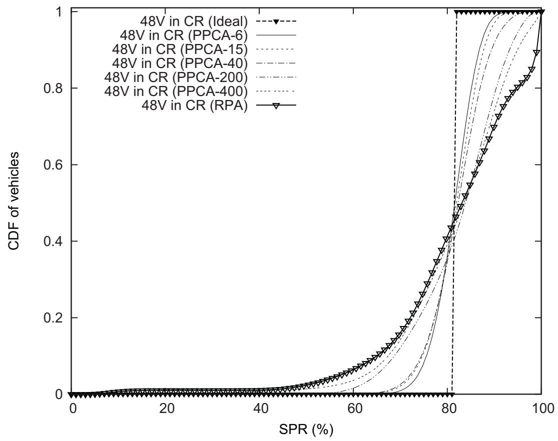

Fig. 2. CDF of vehicles with respect to their SPR.

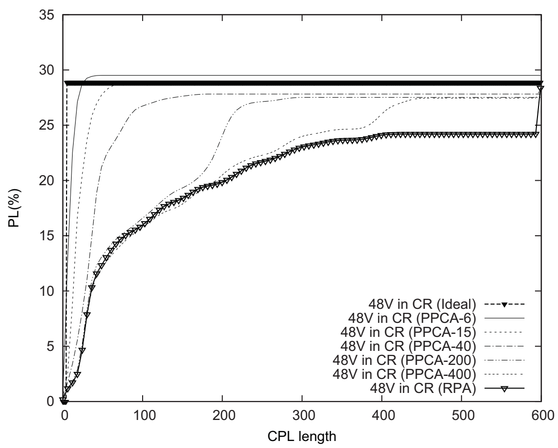

Fig. 3. Cumulative distribution of CPL in total PL percentage.

saturation point [2]. The upper boundary can be approached by synchronizing the phases at the application level. The lower boundary shows a scenario that can occur when all vehicles start periodic BC from the same Φ_0. The line with plus signs shows an artificial scenario we call Random Phased Applications (RPA) where we do not consider the HN problem. The line with cross signs shows the RPA case with consideration of the HN problem. From this graph it is clearly seen that the HN problem is the major cause of the lower packet reception rate. This last case can be regarded as the situation that occurs in practice and is discussed further.

Fairness: Fig. 1 presents the performance of the overall network rather than of individual vehicles, which is a key metric to measure fairness. As an example, although the SPR is around 80% for 48v in CR and the average PL is 29%, the SPR and average PL for individual cars may differ significantly. Fig. 2 shows the cumulative distribution function (CDF) of vehicles with respect to their SPR for 48v in CR. The simulation results for RPA clearly show the unfairness where some vehicles have 100% SPR while some suffer from a lower SPR down to 10%. The ideal "fair" case where each vehicle has an SPR of 80%, is a step function and is shown by a dashed line with black triangle. We further investigate the SPR using PL and CPL to determine vehicle invisibility. Fig. 3 presents the average PL as a function of the cumulative distribution of CPL. Notably, most PLs occur consecutively in various length. From this result, we can assume that the static phasing of RPA introduces a bad visibility condition to a vehicle. It can be better explained by a simple scenario where two vehicles as HN are traveling in the same direction. Assume further that the difference between the Φ_0 of the vehicles is less than a packet transmission time, and they do not have any contenders (i.e. no vehicle in CR with the same Φ_0). In that scenario, both vehicles would remain broadcasting nearly at the same time and the packets would always collide at receiving vehicles in the intersection of the CRs. One simple solution to fix this is to change the Φ_0 periodically. We call our approach Periodic Phase Changing Application (PPCA). In Fig. 2, the results of PPCA cases with different frequencies to change the Φ_0 are shown. Here, the PPCA-20 means that the Φ_0 is changed by picking a random number from an interval of [0:200ms] after every 20 periodic BCs. The results clearly show that the PPCA line is getting closer to the ideal cases when the frequency increases and any of these changes have no effect on the performance except small fluctuations due to the randomness, i.e. the average PL is 29% +/- 1%. As a result, long lasting CPL are now reduced significantly as shown in Fig. 3. However, obviously the frequency to change the Φ_0 should not be selected closer to the frequency of broadcasting otherwise it breaks the periodicity. From the graph, the changing the Φ_0 after between 6 till 15 periods appears to be the most suitable for reducing CPL.

V. Conclusion

The simulation results suggest the HN problem is the main cause of performance degradation and unfairness. Particularly, the HN problem combined with a constant Φ_0 can cause vehicles to have a low packet reception for a long time, making those vehicles invisible to their neighbors. We propose a simple and effective method called PPCA where the phase is changed periodically. The PPCA is tested at different frequencies and it is shown to provide better fairness and to reduce the invisible period at higher frequency while showing no impact on overall network performance.

References

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