Adapting the Wireless Carrier Sensing for VANETs

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Abstract—**Vehicular Ad-Hoc Networks (VANETs) aim at preventing accidents by providing more information to the drivers than they can visually perceive on their own. Communication according to IEEE 802.11p foreseen for VANETs allows for a ranges of up to 1 km. However, this range can strongly be degraded by other distant vehicles transmitting at the same time, causing interference. The concept of spatial reuse works well in common wireless LANs allowing independent access points and stations to operate on the same channel. Carrier sensing (CS) is the process to evaluate prior to a transmission if the medium is clear or busy. It has been shown that CS for wireless LANs works well [1]. In this paper, we show the limitations of CS in VANETs and motivate an adaptation according to the goals of reliability and high transmission range instead of throughput. We conclude that a different static setting for CS improves the communication significantly, however at the expense of increased but still tolerable delay.**

Index Terms—**Vehicular Ad-Hoc Networks, VANET, Carrier Sensing, Spatial Reuse**

I. INTRODUCTION

In typical 802.11-based networks, the communication between Access Point (AP) and Station (STA) has been mainly optimized for throughput. The standard foresees the so-called Carrier Sensing as a mechanism for sharing a particular communication channel among multiple AP-STA sets. Two stations (associated with different APs) are allowed to transmit at same time as long as they are sufficiently separated from each other. Sufficiently here means that the two concurrent transmissions do not interfere with each other. This concept is known as spatial reuse of the communication channel.

In IEEE 802.11 [2] networks using OFDM signal modulation, this is done by carrier sensing which works as follows. Once the own receiver decoded the Phy header of a packet, the it reports a busy channel to the MAC layer for the whole time of the packet reception. According to the standard, a receiver must be able to sense a preamble with an energy level of -85 dBm. If it is not possible for the receiver to receive the preamble, the CS reports a busy channel once the total energy on the communication channel is above a certain threshold. In the following, we will refer to the threshold as CCA sensitivity. As specified in IEEE 802.11, this sensitivity is typically 20 dB above the receiver sensitivity.

In this paper, we study the different requirements for which carrier sensing had been optimized for in common wifi appliance. We compare them with the communication requirements for VANETs and derive ideas for adapting the CCA sensitivity for appropriate carrier sensing in VANETs. Basically, the idea is to mitigate hidden stations: Transceivers should listen more sensibly to the channel when determining channel clearance. By a simulation study, we display which concept performs better compared to the original carrier sensing.

II. RELATED WORK

In [1], the authors have shown that Carrier Sensing is close to optimal for wireless communication according to IEEE 802.11 using infrastructure (access points). However for VANETs, it has been found that this standard setup leads to a significant degradation in communication performance especially in high load scenarios, e.g. [3].

Existing approaches for adapting carrier sensing mainly address the optimization of throughput. Zhu et al. [4] do not only perform an adaptation of the CCA sensitivity but also an adaptation of the receiver sensitivity. The dynamic adaptation is based on the currently measured packet error rate as well as the received signal strength indicator. The goal is to balance hidden stations and exposed stations in high node densities. The approach also aims at optimizing the (unicast) throughput, which is also obvious from the adaptation of the receiver sensitivity. This adaptation reduces the number of exposed stations. By ignoring the receiver state for a certain (low) level of signal strength, a station is allowed to ignore a reception in case it has a packet pending for transmission. This reduces also the reliability as the station then becomes a hidden station w.r.t. the ignored transmission.

Zhang et al. [5] optimize the carrier sensing for multihop communication in MANETs. Using the RTS/CTS messages, neighboring nodes are informed about each other's current receiver sensitivity. So, this threshold is adjusted based on the received information as well as the success/failure history attempts. Further, stations are allowed to disable RTS/CTS. In addition to the benefits by adapting the sensitivity, the throughput is further increased by this step.

A similar idea is targeted by Zhu et al. in [6] where the aggregated throughput is optimized for IEEE 802.11 mesh networks. Interestingly, in [7] Ryu et al. revise the Phy layer model in the QualNet network simulator. They show how the throughput increases when increasing the CCA sensitivity in 10 dB steps starting from the Receiver sensitivity. However, they do neither investigate the reliability nor the delay.

All of these approaches assume nearly static topologies and unicast communication. This allows for applying algorithms with feedback on the adaptation effectiveness using RTS/CTS/DATA/ACK, e.g. how the local variation of the threshold affects the packet error rate at the receiving node. However for VANETs, these approaches can not be applied. The communication resources are much more limited: The data rate is suggested to be set to 6 MBit/s, acknowledgments are inefficient in broadcast as well as RTS/CTS. Moreover, due to the quickly changing topology, the communication channel state changes quickly. The interference from other transmissions is unpredictable. Therefore, only simple adaptations are possible as even the impact of increasing or decreasing the CCA sensitivity on far-distant transmissions can not be foreseen.

III. WIRELESS CARRIER SENSING

In IEEE 802.11, carrier sensing is implemented by two mechanisms, virtual carrier sensing (VCS) and physical carrier sensing (PCS). VCS is implemented in the MAC layer whereas PCS is implemented in the Phy layer, where it is called Clear Channel Assessment (CCA).

These two mechanisms basically[1] implement the following principles which define when a station is not allowed to access the medium:

1) Do not transmit while the own receiver is busy.
2) Do not transmit while sensing high energy on the channel.
3) Optionally, when the receiver lost the signal, wait until calculated end of transmission.

These principles support a high amount of spatial reuse of the medium which is an optimization towards throughput. Causing interference at far distances is not a typical issue in MANETs. Most of the communication is done by unicast with communication partners close-by.

IV. REQUIREMENTS FOR ADAPTING CARRIER SENSING IN VANETS

In contrast to MANETs, the communication requirements in VANETs [8] mostly aim at reliability. Most important for carrier sensing are the following ones:

- *High reliability for every single message:* For active safety applications, every message is important, even those received from far distances.
- *Sufficiently high communication range:* The communication range should be as high as possible to increase the driver's horizon as much as possible. However, due to the limited communication resources, cooperative awareness applications are designed to operate within a range of 300 to 1000 meters [9] as a trade off between the limited communication resources and reaction time.
- *Low message delay:* The received information should not be older than some hundred milliseconds. For specific applications, this delay should be even less than 100ms [8].

V. ADAPTATION CONCEPTS

From the communication requirements derived in the previous section, we are able to review the standardized medium access principles and discuss how they can optimally be applied to VANETs. The additional guideline in VANETs would be to strongly avoid to become a hidden station even with respect to transmission at far distances.

Principle 1 is suitable for VANETs. Even for more sensible receivers, it makes sense to wait for the reception to finish and not to interfere with this transmission by an own transmission. *Principle 2* is also suitable however the sensitivity for Clear Channel Assessment may be adapted. *Principle 3* should be always applied in VANETs. In case the receiver lost the signal, the Phy layer should at least hold the medium busy for the

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[1] For this discussion, we neglect the interframe spaces and the contention window.

remaining transmission time[2]. Otherwise, if the vehicle has a pending packet to be transmit, it may become a hidden station, interfering the reception at vehicles closer to the other transmitting vehicle. The special procedure for broadcast mode is described in the Appendix. Especially principle 2 is a promising and simple means to mitigate the emergence of hidden stations, leading to several vehicles suffering from interference. Even worse, a high number of even low interfering signals stemming from different directions is supposed to cause packet loss [3]. Increasing the reliability of communication demands a higher sensibility in the decision when to transmit. This implies a significantly lower CCA sensitivity, e.g. to set it equal to the standardized minimum receiver sensitivity of -85 dBm.

As a result of the adaptation, the spatial reuse will be degraded as a tribute to reliability causing a higher packet delay. However, the idea is to better align the transmissions considering transmissions even at far distances. It is assumed that by waiting a little longer, the interference situation will be better soon.

Fixed Parameter	**Value**
Simulation time	60 seconds
Number of runs	10
Signal propagation	Friis' Transmission Equation
Transmit Power	16 dBm
Carrier/Receiver SINR	5/8 dB
Signal propagation delay	Distance-based
Beacon delay jitter	-1 . . . 1 ms
Noise/Interference model	Thermal/Accumulative avg power
Maximum communication range	≈ 1 km
MAC-Layer Protocol	IEEE P802.11p 8.0
AIFS (AC_VI)	3
Contention Window	3 slots
Data rate	6 MBit/s
Beacon length	200 Bytes
Beacon rate	2 Hz
Field size	4 km × 4 km
Mobility and road model	Street-Random Waypoint (Straw)
Varied Parameters	**Values**
Number of vehicles	100, 200, 400, 800, 1600
CCA sensitivity	-65, -75, -85 dBm
NAV option	On/Off

TABLE I
SIMULATION PARAMETERS OVERVIEW

VI. EVALUATION

By a simulation study using JiST/SWANS and extensions, we evaluate the performance of the adaptation of the CCA sensitivity in comparison to the standardized value. Further we compare the results with the optional NAV for broadcast.

In the study, we measure and analyze the overall communication reliability and the packet delay. The reliability is measured by summing up the number of received packets over all vehicles per simulation run. Note that the number of packets sent per vehicle is constant and no loss in the message queues occurs. Consequently, also the number of the overall sent packets is constant. Therefore, a higher reliability is achieved when there are more packets received overall. In the simulation, a packet can be received when the absolute received power is sufficiently (receiver sensitivity) high and the minimum signal-to-interference ratio is fulfilled for the whole reception duration. Note that the preamble can be decoded at a lower SINR than the payload due to different modulation schemes.

With a lowered CCA sensitivity, a higher average delay is expected due to less spatial reuse. Therefore, we measure the average delay for all transmissions per simulation run. We are aware that the metric for reliability does not fully show if reliability is increased for each vehicle. It may hide that packets in the near field may be lost in favor of packets received from far distances. For this reason, we will investigate the impact on the reliable communication range and fairness per vehicle in a separate study.

As the differences among the approaches is assumed to become obvious with increasing node density, we vary the number of vehicles. By initial simulations of different beacon rates, we found the same trends as with 2 Hz. For all other important parameters please refer to Tab. I.

In order to get statistically valid results, we perform 10 simulation runs per parameter setting and compute the 95% confidence interval according to the Student-T distribution.

In the following simulation study, we evaluate the adaptation and compare the results to the currently standardized CS. The evaluation is guided by two questions, how high is the increase in the number of successfully received packets and what is the increase of delay when lowering the CCA sensitivity?

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[2] This is a similar procedure as the Network Allocation Vector (NAV) in the MAC layer but without RTS/CTS message overhead. Hence, we will refer to this principle as NAV for broadcast instead of *PLCP-level virtual carrier sense*.

A. Reliability

From the results shown in Fig. 1, we see which adaptation performs best in terms of the absolute number of received packets. We find that in low node density scenarios there are only slight differences between the standard CS and the proposed adaptations. Reason behind that is that there are only few packet losses in general. Carrier sensing is dominated by the preamble detecting which works well with low interference. In medium node density scenarios we find a noteworthy improvement especially by the lowered CCA sensitivity of -85 dBm.

We have detailed analysis of the improvements by looking at the ratio of improvement compared to the standardized carrier sensing, as seen in Fig. 2. We also combined the two sensitivity variations with the NAV option turned on. With increasing number of potential transceivers, the improvement of a sensitivity variation -85 dBm strongly increased. In this figure, we also see the improvement of the NAV combined with the lowest CCA sensitivity, mainly in low vehicle density scenarios. The explanation for this is twofold: Only when the inference is low, a preamble can be detected and the information on transmission duration can be extracted. Also, it only prevents a vehicle from transmitting in case the reception has been interrupted by increased interference. The latter explains also, why the NAV does not provide much benefits in high densities for the lowest sensitivity of -85 dBm. The different results for the two varied sensitivities are also of interest. They show that with a sensitivity of -75 dBm, a significant increase occurs only in high densities starting from 800 vehicles whereas the improvement of -85 dBm sensitivity is already observed at a density of 200 vehicles.

B. Delay

Fig. 3 displays the results for the measurement of the average transmit delay. By means of logarithmic scale, the differences in the increase of the delay become visible. For the standardized CS as well as the NAV extension, the delay even slightly *decreases* with increasing vehicle density which appears to be paradox. However, knowing that there is more interference on the channel at higher densities, a busy channel is mainly indicated by CCA instead of a busy receiver, i.e. the CCA sensitivity optimized for throughput dominates the carrier sensing. That is, once the density significantly increases, also the interference increases and therefore even the preamble can not be decoded.

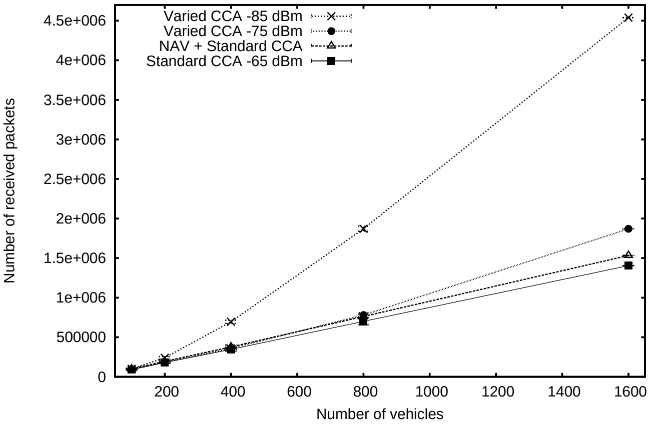

Fig. 1. Number of received packets over all vehicles.

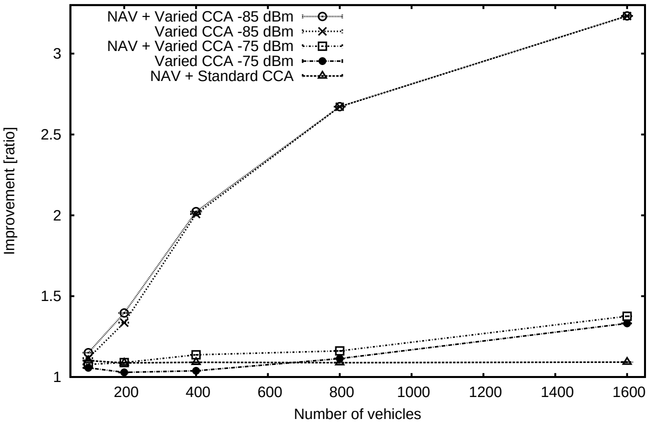

Fig. 2. Ratio of improvement w.r.t. to received packets compared to standardized CS.

The same reason holds for a different effect in case the CCA sensitivity is lowered to -75 or even -85 dBm: A significant *increase* of the delay at higher vehicle densities. This increase is even in the order of two magnitudes, reaching some milliseconds for -75 dBm and even some ten milliseconds for -85 dBm. The differences between both are the same as the increase in reliability: The lower the setting the earlier the differences become effective. For -85 dBm, the delay is already significantly to 2 milliseconds for 200 vehicles. Whereas for -75 dBm, the delay stays below 2 milliseconds even at a density of 800 vehicles.

However, as said in Sec. IV, delays up to 100 milliseconds are tolerable for active safety applications. Therefore, even in the extreme case for a density of 1600 vehicles, the average delay is still sufficiently low for the

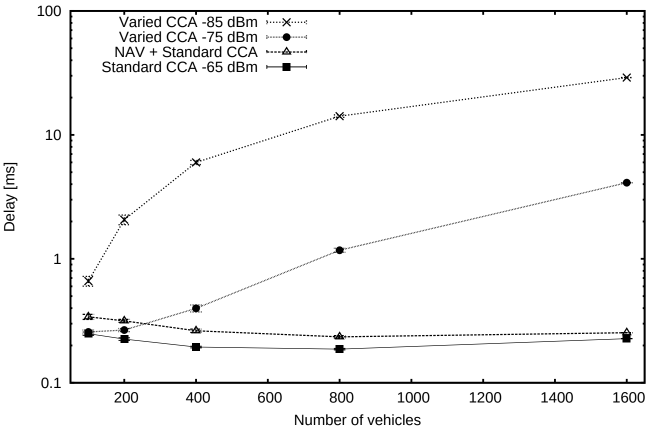

Fig. 3. Average delay per packet.

applications to work within its operation limits but with the benefit of much more information on the surrounding available.

C. Summary

At the first glance, the adaptation of the CCA sensitivity in order to improve reliability while maintaining low delay appears to be a common optimization problem. A reasonable trade-off in delay and reliability is achieved for a CCA sensitivity between -85 and -75 dBm. The number of received packets is much higher when applying the lower sensitivity, however at the expense of a much higher delay compared to -75 dBm. We expect a significant increase in delay when lowering the sensitivity even further. Even worse, if the delay becomes too high, packets will have to be dropped locally. On the other hand, for a sensitivity higher than -75 dBm or even higher than the original sensitivity, the CCA will only rarely indicate a busy channel. Hence, much more hidden stations will arise leading to a much more packet losses.

However, we also find that this reasonable trade-off does only reflect the average case. One challenging property of VANETs is the dynamic topology change and hence the continuously changing local vehicle density which is also observed in our simulated road scenario. As the experienced local densities vary from vehicle to vehicle, so does the average delay per receiving vehicle. This clearly motivates for an appropriate dynamic adaptation, e.g. considering the vehicle density. Nevertheless, to summarize the results, the general conclusion to lower the CCA sensitivity remains. Also, the NAV option should be always enabled in VANETs.

VII. CONCLUSIONS

In this paper, we discussed the common wireless carrier sensing as defined in IEEE 802.11 for VANETs. We identified the communication requirements that guided slight modifications, i.e. the modification of CCA sensitivity however with significant impact.

By a simulation study, we show that the communication reliability can be improved drastically by statically setting the CCA sensitivity to a much lower value, e.g. -75 dBm or even -85 dBm. Especially in medium and high load situations, the reliability is significantly increased by even up to 300% at the expense of an increase of the average packet delay (which nevertheless stays below 100 milliseconds).

Because of the continuously changing topology and channel conditions, it is to be expected that there is no optimal static setting for the CCA sensitivity. This motivates for an appropriate dynamic adaptation of the CCA sensitivity as part of our future work.

We can further confirm improvements resulting from enabling the virtual carrier sensing for broadcasts which is defined as an option in IEEE 802.11. As we show, it provides slight improvements in lower densities. In higher densities, it will not provide much benefits as the lower CCA sensitivity already reduced the interference but it does also not harm in terms of delay.

Our future work comprises an in-depth study of the delay increase and how the delay can be treated by a dynamic adaptation approach. We also aim at quantifying the increase of communication range and fairness in channel access among the vehicles. When combining this approach with dynamic control of the beacon rate (e.g. [10]) an additional significant increase of communication performance is expected.

APPENDIX
BACKGROUND ON IEEE 802.11 NAV

Assuming absence of RTS/CTS messages, the information on the transmission duration has to be retrieved from the Phy layer. The solution is that the Phy layer provides the packet duration extracted from the PLCP header to the MAC layer. There, the PSDU Length Word (PLW) field indicates the payload length by a 12 bit field, allowing payloads up to 4095 bytes. This length in bytes has to be translated into microseconds by using the PLCP Signaling (PSF) field in order to set the 15 bit duration field at the MAC layer. In the MAC layer, the carrier will then be hold busy for the calculated duration unless there is another strong signal received which resets the NAV.

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