Optimal Contention Window size for beaconing in VANETs

René Reinders
Faculty of Electrical Engineering, Mathematics and Computer Science
University of Twente, the Netherlands
r.reinders-1@student.utwente.nl

ABSTRACT
Vehicular applications, such as traffic safety applications used to increase the road safety and traffic efficiency applications used to decrease the traffic jams are mainly supported using VANETs (Vehicular Ad-hoc Networks). An important VANET feature is beaconing. This paper uses simulation experiments to analyze how the reception probability of beacons can be increased by optimizing the Contention Window (CW) size. From these experiments it can be concluded that the combination of the contention window size and the number of vehicles using the same VANET radio channel has an impact on beaconing reception probability. In particular, by increasing the CW size and the number of vehicles, the beaconing reception probability is decreased. Moreover, the currently used initial CW maximum value (i.e. 15) applied for beaconing is the best selected value.

Keywords
VANET, Cooperative Adaptive Cruise Control (CACC), Beaconing, Contention Window.

1. INTRODUCTION
A Vehicular Ad-Hoc Network, or VANET is an wireless ad-hoc network that supports the communication (1) amongst vehicles and (2) between vehicles and Road Side Units (RSUs) while the same wireless technology, such as IEEE 802.11p [8], is used. RSUs are fixed wireless access points that are located at the side of highways. For communication, a special electronic device, denoted as On Board Unit (OBU), can be placed inside each vehicle which will provide Ad-Hoc Network connectivity [20]. The main goal of VANETs is to support vehicular applications that provide road safety and traffic efficiency, such as providing comfort for passengers and reducing traffic jams.

Two traffic safety application use cases are shown in Figure 1 [10]. In use case (a) denoted as Rear-end collision avoidance, vehicle B detects that vehicle A in front of it is moving at a slow pace and broadcasts this information, thereby warning vehicle C. In use case (b) denoted as Extended Emergency Brake Light, vehicle B cannot see vehicle A because a truck is blocking its view. Vehicle A brakes and sends a broadcast about this event, thereby warning vehicle B.

A traffic efficiency application that can be used to increase passenger comfort and to reduce traffic jams is the

Cooperative Adaptive Cruise Control (C-ACC) [1]. Using the VANET, the vehicles (and if possible RSUs) are cooperating with each other to obtain the necessary lead vehicle dynamics information (such as acceleration) and a general view of traffic ahead (time headway). This information is used to enhance the performance of the current Adaptive Cruise Control (ACC) system. In particular the system controls the accelerator, engine powertrain and vehicle brakes to maintain a desired time-gap (time headway) to the vehicle ahead [13]. By maintaining this time-gap the so-called vehicle traffic shock waves, i.e. travelling disturbances in the distribution of cars on a highway [6], can be filtered out of the main traffic flow.

C-ACC uses a Cooperative Awareness that can be described as a radar screen on which all nearby vehicles are placed. To get a Cooperative Awareness view each vehicle periodically sends a short message with information such as position, speed and acceleration [12], called beaconing. C-ACC relies on accurate and timely situational awareness to perform its task. That is, aid in the longitudinal control of the vehicle like the traditional Cruise Control (and Adaptive Cruise Control), but improved with enhanced situational awareness based on information communicated by the vehicles in front [4].

For communications in the VANET, the IEEE 802.11p protocol is used [8]. This is a Draft Amendment to the IEEE 802.11 protocol [7]. IEEE 802.11p uses a Media Access Control (MAC) protocol that is based on a Carrier Sense Multiple Access Protocol with Collision Avoidance (CSMA/CA). Due to the fact that beacons may be sent several times per second and vehicular density can vary greatly (and become large during traffic jams), it is expected that the channel may become congested [4]. When a node wants to access the medium and finds the channel busy, it chooses a random backoff time uniformly at random from the interval [0, CW(maximum)] and delays the medium access for this random amount of time [4, 11]. CW(maximum) represents the
CW maximum value, which for IEEE 802.11p is initially set to 15. In this case the CW size is equal to 16. If another collision occurs the CW size is increased and the process starts over. However, because of the lack of acknowledgments when performing a beaconing broadcast, the CW size is actually never increased [17].

The probability that two nodes will choose the same random backoff time is small, but when there are e.g. 100 nodes the probability that two nodes will choose the same time is quite high. Increasing the initial CW size might be a way to deal with this but making the CW size too large will result in nodes having to wait a long time before they can send any information. A way that might solve this problem is to make the CW size adaptive to the number of nodes. If there are a lot of nodes the CW size should increase and if there are fewer nodes the CW size should decrease.

This paper will investigate the impact of the initial CW size on beaconing performance. The following main research question will be answered:

What is the optimal Contention Window size for beaconing in VANETs?

To answer the main research question the research is divided into 4 sub questions:

1. How is beaconing performed in VANETs?
2. Which parameters can increase the performance of beaconing in VANETs?
3. Which experiments can be performed in order to analyze the performance of beaconing in VANETs?
4. How could the optimal Contention Window size be defined?

For the first two sub questions a small literature study was done. This provided the information needed to answer the third research question. The fourth sub question was answered by running multiple simulation experiments. These simulation experiments had different parameters and were run several times to get statistically significant results. The results of each simulation experiment were logged into a file. These files were then parsed by a program and analyzed.

The remainder of the paper is divided as follows: Section 2 briefly introduces beaconing and it discusses how its performance can be improved. In section 3 the simulation experiments that were run are discussed and in section 4 the results of these simulation experiments are analyzed. Section 5 concludes and provides recommendations for future activities.

2. BEACONING

In VANETs beacons are sent by a node, which can be a vehicle or an RSU, on a regular interval, i.e. the beaconing interval. Many vehicular applications use a beaconing interval equal to 100ms, which is the same as a generation rate (λg) of 10Hz.

In wireless MAC protocols such as CSMA/CA, a window based backoff mechanism is used. A node willing to transmit a beacon will sense the medium first, and if the medium is not free it will choose a backoff time uniformly at random from the interval \([0, \text{CW(maximum)})\], where the initial CW maximum value equals 15, and delays medium access for this random amount of time [4, 11].

The beacon includes information such as position, speed, and acceleration. Since beacons are sent in a broadcast communication manner, upon receiving a beacon no acknowledgement is sent back to the sender [4, 12].

2.1 Improving Beaconing Performance

In order to increase beaconing performance several things can be done.

2.1.1 Contention Window size

The initial CW maximum value in the IEEE 802.11p is 15 [7, 8]. In this case the CW size is equal to 16. Because of the lack of acknowledgments when performing a beaconing broadcast, the CW size is never increased [17]. So increasing the initial CW size when there are a lot of nodes that use the same VANET radio channel could improve beaconing performance.

2.1.2 Generation rate

The generation rate is the rate at which beacons are sent by the node per second. Since the beacons are used to create a Cooperative Awareness the beaconing rate should be in the order of several beacons per second to provide the system with accurate information about the close surrounding [19, 23]. Increasing the rate results in more beacons being sent, but also increases the probability for collisions. Decreasing the rate, results in less beacons and less collisions, but if the rate is too low, it also affects the Cooperative Awareness as it does not get updated that often [21]. In many vehicular applications the default beaconing interval is 100ms which is the same as a generation rate (λg) of 10Hz.

2.1.3 Transmission power

The transmission power affects how many nodes will receive the beacon. If the transmission power is low only the closest neighbor might receive the beacon, but the next node might not. If the transmission power is high, a significant number of nodes might receive the beacon, but the probability for a collision also gets higher [23]. The optimization criterion for improving safety has to be built upon the concept of fairness. That is, a higher transmission power of a sender should not be selected at the expense of preventing other vehicles to send/receive their required amount of safety information [19].

3. SIMULATIONS

This section provides a description of the used simulation environment, simulation setup and the accomplished simulation experiments.

3.1 Simulation Environment

For the simulations experiments OMNeT++ is used. OMNeT++ is a discrete event simulation environment. Its primary application area is the simulation of communication networks. OMNeT++ provides a component architecture for simulation models. Components (modules) are programmed in C++, then assembled into larger components and models using a high-level programming language (NED) [15]. OMNeT++ is not a vehicular traffic simulator itself and therefore the MiXiM framework was used [14]. This is a mobility simulation framework for wireless and mobile networks.

In order to accomplish the simulation experiments a beaconing model of IEEE 802.11p was designed and implemented. The MiXiM framework was also altered slightly in order to allow for the fixed y-axis and random x-axis placement of nodes. Furthermore, the propagation loss was disabled in order to isolate collision loss.

3.2 Simulation setup

In order to emulate realistic situations, the following simulation parameters are used. A realistic 4-lane highway is considered, see Figure 2. The playground area used as input for the MiXiM framework is set to 250m x 250m. Moreover, the length of each lane is considered to be 250 meters. In
order to realize this topology, the vehicles are placed on one of the 4 fixed y-coordinates and the x-coordinate is randomly chosen. The data rate is set to 6Mbit/s and the radio range was set to 250m [5]. The beacon package length was set to 3200 bits. All the other values used in the IEEE 802.11p simulation model are conforming to [8]. The nodes remain stationary on the playground during each simulation. In the OMNeT++ configuration file the sim.world.useTorus is set to true. This wraps the world and makes sure that each node has the exact same number of neighbors. If this setting is false, neighbors on the edge of the playground might have fewer neighbors than the ones in the middle of the playground.

During each simulation, each node will send 100 beacons. These beacons are sent with a generation rate (λg), which is varied in the different simulation experiments. The number of nodes per lane and the CW size also vary per simulation experiment.

An overview of the different values used can be seen in Table 1. The values for these parameters (except the nodes per lane) are typical IEEE 802.11p values [2, 3, 7, 8, 16]. The different nodes per lane simulate different highway densities.

Each simulation was run 10 times to get statistical significant results. This means that a total of $7 \times 11 \times 4 \times 10 = 3080$ simulations were run. During each simulation each node recorded the following:

- time of the first and the last beacon sent by the node
- total number of beacons received per node
- time of the first and the last beacon received per node

These results were used to determine the generation rate (λg) per node, i.e., number of beacons sent divided by the time it took to send these beacons, reception rate (λr) per node, i.e., the average number of beacons received per node divided by the time it took to collect all these beacons, and the reception probability (Ps), i.e., λr per node divided by λg per node, see Equation 1.

$$Ps = \frac{\lambda r}{\lambda g}$$ (1)

The results were written to a log file after each simulation. When all the simulations were done all these log files were parsed and results were stored in a database. The results in the database were then analyzed by a script that determined the λg, λr and Ps per simulation run and by using these results an average could be determined for each set of simulation parameters.

3.3 Simulation results

Several performance measures can be used in order to be able to recommend an optimal CW size for beaconing in VANETs. Such performance measures could be latency and/or reception probability. Beaconing latency defines the time that is needed to send a data frame from a sender to a receiver. Beaconing reception probability defines the probability that a beacon sent by a sender is received by a receiver. The beaconing reception probability (Ps) represents the beacon reception rate (λr) (in average) per node divided by the generation rate (λg), see Equation 1. Due to time constraints we only focus on the reception probability as performance measure.

Figure 3 to Figure 6 show the Ps for each of the CW maximum value, in relationship with the number of nodes per lane, when 4-highway lanes are used, with the given generation rate λg. For each of these figures the 95% confidence intervals of the average values are calculated [9].

Figure 3 shows the Ps results versus nodes per lane, when λg is 5Hz. All the confidence intervals associated with the average values shown in Figure 3 are lower than ±0.000036% of their average values. Figure 3 shows that the Ps for CW(maximum) = 15, is the highest for every value of the nodes per lane. Interestingly to see, is that at 2 nodes per lane the Ps for CW(maximum) = 15, 63 and 255 are equal to 100% while the Ps for CW(maximum) = 1023 is equal to 99.29%. As the nodes per lane are increased the Ps slowly decreases, and as shown in Figure 3 it decreases more for the higher CW maximum values. At 50 nodes per lane Ps = 99.99% for CW(maximum) = 15 and Ps = 99.89% for CW(maximum) = 1023.

If the generation rate is doubled, the Ps results become a bit different, as shown in Figure 4, where the generation rate λg is 10Hz. The confidence intervals for the average values shown in Figure 4 are lower than ±0.000068% of their average values. At 50 nodes per lane the reception probability for each CW maximum value decreases. At 40 nodes per lane the Ps for each CW maximum value is: Ps = 97.78% for CW(maximum) = 15, Ps = 97.41% for CW(maximum) = 63, Ps = 96.20% for CW(maximum) = 255 and Ps = 91.00% for CW(maximum) = 1023. At 50 nodes the Ps value is around 78% for CW(maximum) = 15, 63 and 255, while the Ps is only 73% for CW(maximum) = 1023.

Figure 5 shows the Ps results versus nodes per lane, when the generation rate λg is 25Hz. The confidence intervals for the average values shown in Figure 5 are lower than ±0.001329% of their average values. Now the Ps starts to decrease at 20 nodes per lane. In particular, Ps = 78% for CW(maximum) = 15 and Ps = 67% for CW(maximum) = 1023. However at 30 nodes or more the Ps for all CW sizes gets closer together. At 30 nodes: Ps = 52% for CW(maximum) = 15 and Ps = 47%, for CW(maximum) = 1023, a 5% difference. At 50 nodes this Ps difference is only 1.9%, 32.1% for CW(maximum) = 15 vs. 30.2% for CW(maximum) = 1023.

Figure 6 shows the Ps results versus nodes per lane when the generation rate λg is 50Hz. The confidence intervals for the average values shown in Figure 6 are lower than ±0.002158% of their average values. As seen before, when the generation rate gets doubled the Ps starts to decrease earlier, in this case at 10 nodes per lane. What is also interesting to see is that, just as with generation rate of λg = 5Hz, at 5 nodes per lane

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**Table 1. Simulation values.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes per lane</td>
<td>2,5,10,20,30,40,50</td>
</tr>
<tr>
<td>Generation rate (λg) in Hz</td>
<td>1,5,10,15,20,25,30,35,40,45,50</td>
</tr>
<tr>
<td>Maximum value of Contention Window (CW)</td>
<td>15,63,255,1023</td>
</tr>
</tbody>
</table>
the Ps values for CW(maximum) = 15, 63, 255 are 100% while the Ps value for CW(maximum) = 1023 is only 94%. Just as in Figure 5, the Ps for CW(maximum) = 1023 starts to decrease more rapidly than the other CW(maximum) values and as the number of nodes per lane increases the Ps for the different CW maximum values gets close again. At 50 nodes per lane, Ps is around 16%.

Figure 7 to Figure 10 show the Ps for each of the CW maximum values in relationship with the generation rate \( \lambda_g \) and the given number of nodes per lane, when 4-highway lanes are used. For each of these figures the 95% confidence intervals of the average values are calculated [9].

Figure 7 shows the Ps at 5 nodes per lane. The confidence intervals for the average values shown in Figure 7 are lower than ± 0.001867% of their average values. At 5 nodes per lane the Ps for CW(maximum) = 15 and 63 are around 99.9%. For CW(maximum) = 255 the Ps is 99.9% until the number of nodes per lane reaches 45, and ends at Ps = 99.8% at 50 nodes per lane. For CW(maximum) = 1023 the Ps is 99.9% until 20 nodes per lane are reached, and ends at Ps = 94% at 50 nodes per lane.

Figure 8 shows the Ps at 20 nodes per lane. The confidence intervals for the average values shown in Figure 8 are lower than ± 0.001861% of their average values. Until the generation rate reaches 20Hz the Ps for all the CW maximum values are above 99%. At \( \lambda_g = 20 \) Hz, the Ps values for CW(maximum) = 15 and 63 are 97% and for CW(maximum) = 255, Ps = 95%. For CW(maximum) = 1023 however, the Ps = 84%, only. In particular, the Ps at \( \lambda_g = 20 \) Hz, for CW(maximum) = 1023 is much lower than the Ps values for the other 3 CW maximum values. At \( \lambda_g = 50 \) Hz this Ps difference is still 3%.
Figure 9 shows the $P_s$ at 40 nodes per lane. The confidence intervals for the average values shown in Figure 9 are lower than $±0.002388\%$ of their average values. At 40 nodes per lane the $P_s$ starts to decrease at $\lambda_g = 15$Hz. In particular, $P_s = 65\%$ for CW(maximum) = 15, 63 and 255, and $P_s = 90\%$ for CW(maximum) = 1023. As the generation rate increases the $P_s$ decreases, but the $P_s$ values for all the CW maximum values are approximately equal, see Figure 9. At $\lambda_g = 10$Hz the $P_s$ difference is 6.7% ($P_s = 97.7\%$ for CW(maximum) = 15 and $P_s = 91.0\%$ for CW(maximum) = 1023). At $\lambda_g = 20$ Hz the $P_s$ difference is only 3.6% and at $\lambda_g = 50$Hz the $P_s$ difference is reduced to 1.5%.

Figure 10 shows the $P_s$ at 50 nodes per lane. The confidence intervals for the average values shown in Figure 10 are lower than $±0.001753\%$ of their average values. As seen in Figure 10 the $P_s$ starts to decrease at $\lambda_g = 10$Hz. Until $\lambda_g = 10$Hz the $P_s$ is around 99% for all CW maximum values. At $\lambda_g = 10$Hz the $P_s$ is around 78% for CW(maximum) = 15, 63 and 255 and for CW(maximum) = 1023 the value of $P_s$ = 73%, which is a difference of 5%. This $P_s$ difference is 2% at $\lambda_g = 15$Hz and only 1% at $\lambda_g = 50$Hz.

4. ANALYSIS OF THE RESULTS

The value of the acceptable reception probability depends on the type of the vehicular application supported by the VANET.

For emergency situations the beacon interval should be less than 500ms such that drivers and automatic control
mechanisms in the vehicle have enough time to react [18, 23]; the probability of message failure should be less than 1%. In other words, the packet reception probability should be higher than 99% [21].

For other types of vehicular applications, such as C-ACC, the value of the reception probability can be much lower than 99%, depending on the loss tolerance of the C-ACC controller [3].

The simulation results show that $P_s = 99\%$ is only achieved if the number of nodes per lane are low or if the generation rate is low. If there are 5 nodes per lane, the $P_s$ is around 99%, for all $\lambda_g$ values when CW(maximum) = 15, 63 and 255. For CW(maximum) = 1023 PS severely decreases when $\lambda_g = 45$ Hz. If the number of nodes equals the maximum number of nodes used in the simulation (i.e., 50 per lane), a $P_s$ value of 99% is observed only when CW(maximum) = 15 or 63 and when the generation rate is 3Hz, which is below the default beaconing interval. Looking at the default beaconing interval it is clear that until we reach 40 nodes per lane the $P_s$ is >99%. At 40 nodes per lane, the $P_s$ value is the best for CW(maximum) = 15, where $P_s = 97.8\%$ and the $P_s$ is worst for CW(maximum) = 1023, where $P_s = 73.8\%$.

By observing all the simulation experiments we can derive a similar conclusion. The $P_s$ for CW(maximum) = 15 is always better than the $P_s$ obtained for CW(maximum) = 63, 255 and 1023. Even if the number of nodes per lane is very high (e.g. 40-50), we observe that these $P_s$ differences are very small. Hence, we can conclude that, increasing the CW maximum value (or the CW size) when the number of nodes is increased, the beaconing reception probability is not increasing. Therefore, we can deduce that the currently used default initial CW maximum value (i.e. 15) for beaconing is the best selected value.

Another conclusion that can be derived from these simulation experiments is that the beaconing reception probability can be increased by decreasing the beaconing generation rate when the number of vehicles on a lane, which are using the same VANET radio channel, is high.

5. CONCLUSION AND FUTURE WORK

In this paper the optimal Contention Window (CW) for beaconing in VANETs was determined. The way beaconing operates was explored and analyzed to see what could improve beaconing performance. By changing either the CW maximum value (or CW size), or the beacon generation rate or the transmission power, the performance could be improved. Several simulation experiments have been performed in order to study the beaconing reception probability when the CW maximum value (or CW size), the beaconing generation rate and the number of vehicles on the road were varied. From these simulation experiments it can be concluded that the effect on the beaconing performance when increasing the CW maximum value, is not the one that it was expected to be. In particular, when the CW maximum value is increased, the beaconing reception probability decreases. However, as expected, the beaconing performance could be increased when the beaconing generation rate is decreased.

In terms of future work, it is planned to study the beaconing performance when the transmission power is varied. Another future activity will be to accomplish simulations experiments in which the vehicles move at different speeds.

6. ACKNOWLEDGEMENTS

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7. REFERENCES


