Development of Reliable V2V system based on WAVE

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ABSTRACT

This paper proposes a dynamic congestion control algorithm for a reliable message transmission in V2V communication environment based on IEEE 802.11p WAVE technology. Each vehicle periodically exchanges its status information like a position, speed and break control with other vehicles within a communication range. Without any control, each vehicle always uses the maximum transmitting power and data rate. From our experiments, at heavy traffic flow, the higher transmitting power and the higher data rate makes the wireless channel contentions and packet collisions more serious. In this paper, we propose the mean-based dynamic data rate control algorithm and the phase control using epoch to mitigate the congestion. The performance evaluations in Qualnet confirm that the proposed algorithm achieves better communication performance than the existing solutions and is more robust to the hidden terminal problems.

INTRODUCTION

The WAVE (Wireless Access in Vehicle Environment), also known as the IEEE 802.11p is the technology to support Intelligent Transportation Systems (ITS) regarding Vehicle to Infrastructure, and Vehicle to Vehicle communication.
The U.S. Department of Transportation (US DOT) funded government projects to develop the V2X system using the WAVE are underway in North America and the 2013 NHTSA regulatory decision will be make based on the result of those projects. To support the reulatory, each OEM is required to develop the core technologies like a congestion control, relative positioning, V2V security for the system production. Among these core technologies, the congestion control is very important to gurantee the reliable V2X communication performance and that is not defined as technical standard yet.
For cooperative vehicular safety applications, each Vehicle must periodically broadcast its current status to its neighboring vehicles. The current status includes speed, longitude, latitude, heading, car type and so on. Each vehicle can monitor its neighboring vehicles' status to help the driver to avoid the traffic accidents possibility like a forward collision, rear-end collison, intersection collision, etc.
Because the existing WAVE technical specification does not consider the congestion control, each vehicle always use the maximum transmitting power and the fixed data rate and message sending period. From our experiments, at heavy traffic flow, the higher transmitting power and the smaller data rate and the frequent data transmission can cause the safety packet collisions. It causes a serious problem for the V2V system to operate successfully.
In this paper, we identify these problems and we propose the dynamic data rate control algorithm and phase control algorithm using the epoch to solve the congestion condition. We confirm the performance of our algorithm using the Qualnet simulator.

RELATED WORKS

The congestion algorithm in V2X communication environment to exchange the vehicle to vehicle safety message has been studed in the several papers.
[2] proposes a distributed and localized algorithm, distributed fair power adjustment, for adaptive transmit power level which is formally proven to achieve max-min fair allocation, based on the location of the other vehicles within the sender's range. [5] proposes a method to increase channel coverage and reduce latency for safety messages in multi-channel vehicular environments. It includes the congestion control protocol for vehicular communication networks that use CSMA/CA channel access mechanism. [6] uses the GPS error measured by host vehicle and relative vehicle and controls the transmission rate control and power control independently. The power control depends on the channel state estimated periodically. Because each vehicle determines the control value independently, anomaly can occur.
In [7], each vehicle determines the congestion state by measuring CBP and the vehicle controls the message rate according to the CBP value.

THE PROPOSED ALGORITM

In order to design and analyze the congestion control algorithm, we define the two performance metrics : Channel Busy Percentage (CBP), PDR (Packet Delivery Rate). CBP is the percentage of the time during which the wireless channel is busy to the period of time over which CBP is being measured. The busy is determined by that energy level is higher than the carrier sensing threshold. The PDR is percentage of the number of received packets at a receiver from particular transmitter and total number of packets sent by that transmitter.

Figure 1 shows the CBP comparison result estimated during the simulation. The simution is performed under vehicle number 150, 600 (one lane), 600 (2 lanes), 900 (3 lanes), 1200 (4 lanes). The more vehicles cause the higher CBP and this results an decrease of the PDR value. So, we need to maintain the certain level of CBP to gurantee the V2V communication performance regardless of the number of vehicle within the communication coverage.

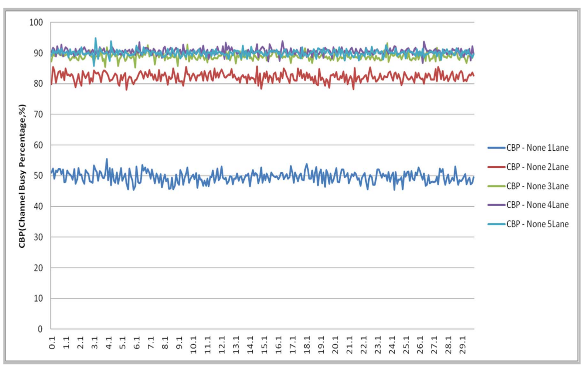


Figure1. CBP comparison under vehicle number

The figure 2 shows the total procedure of the proposed algorithm. The proposed algorithm is composed of two main procedure. The first one is Mean-based data rate adaptation. The second one is Phase control algorithm using Epoch.

(1) Mean-based Data Rate Adaptation procedure

The 802.11p defineds 8 data rates: 3 ~ 27Mbps. But according to the result of field test using the WAVE module, we don't consider the 24, 27Mbps in our algorithm because the PER value is estimated as very high remarkably like figure 2. In high SNR condition, the higher data rate causes the high throughput. But in low SNR condition, the lower data rate can gurantee the reliable transmission.

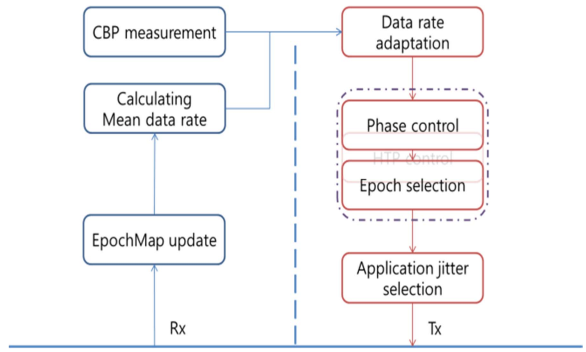


Figure2. The proposed algorithm

We calculated the coherence time and the expected time to finish a successful transmission, which are calculated as we vary the mobility of the vehicle and the number of contending vehicles. We consider the transmission rate 3 and 18Mbps. The required time duration is approximatey 760μs (3Mbps), 520μs (4.5Mbps), 400μs (6Mbps), 280 μs (9Mbps), 224μs (12Mbps), 160μs (18Mbps). For this calculation, we assume that the packet size is 266 byte considering the standard message size, BSM(basic safety message) defined in IEEE SAE J2735.

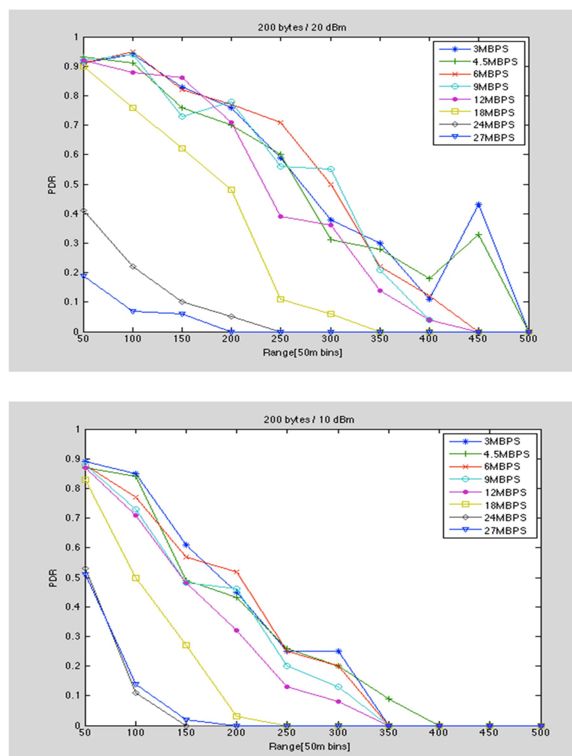


Figure3. Packet Delivery Rate vs Data rate

When the transmission duration is reduced, the packet collision possibility from the MAC collision and hidden terminal can be reduced. By selecting the higher data rate in the heavy traffic condition, the transmission duratation can be reduced. Also, Because the increase of the data rate bring the scale-down of the communication coverage, that can reduce the number of vehicle which attend the transmission competition and reduce the packet collision case. But, in the case of the light traffic condition, the lower data rate is good for the communication coverage and throuput aspect. So, our proposed algorithm determines the realtime channel status and controls the data rate based on that to reduce the packet collision possiblity. To determine the channel status, our algorithm uses the CBP value measured every 100msec. If the CBP is over the pre-defined value, 40%, our algorithm regards the current channel condition as the congestion.

The our algorithm for the mean-based data rate adaptation is like table 1. R_init is 6Mbps as the initial data rate. $\bar{R}(N)$ is the mean data rate and $\bar{R}(N)$ is calculated using the data rate value in the WSMP header in the received BSM message from the neighboring vehicles. If the CBP is over θ , 40% and its data rate value is smaller than minimum data rate value, the vehicle changes the data rate value to the minimum value between the next level data rate and maximum data rate value. If the CBP is recovered to under θ and the current data rate is higher than mean data rate, the vehicle changes the data rate to the maximum value between the previous lower value and minimum data rate.

Table1. Mean-based data rate adaptation

```
R = R_init
for each period T do
   if CBP ≥ θ then
      if R ≤ R̄(N) then
           R = min(R + 1, R_max)
      end if
   else if CBP < θ then
      if R > R̄(N) then
           R = max(R - 1, R_min)
      end if
   end if
Transmit with data rate R
end for
```

(2) Phase control algorithm using Epoch

Even though we can reduce the packet collision possibility by controling a data rate, if two more vehicles try to transmit the safety message at the same time, the packet collision is inevitable. So, as the second step, we proposed the phase control algorithm using the pre-defined time interval, Epoch to solve that packet collision condition. Under the heavy traffic condition, that situation can occur very frequently.

In the proposed algorithm, we define the epoch. The epoch size is defined as 2ms and the number of BSM which one epoch can accept depends on the data rate of each BSM. In case that all vehicles which try to transmit using the specific epoch use 3 Mbps, the epoch can accept 4 vehicles. If there are vehicles using the higher data rate, the epoch accepts more vehicles.

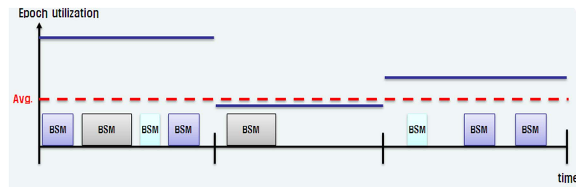


Figure4. Epoch utilization example

To distribute the vehicles to the epoch evenly, we use the proposed phase control algorithm. Whenenver each vehicle receives the BSM message, it creates and updates its neighboring epoch table. The epoch table has the data rate and vehicle's MAC ID as an element. Each vehicle calculates the utilization for the epoch it usese and average unitilization value in the neighboring epoch table every 100msec. The calculation considers the number of BSM as well as the data rate of each BSM. The BSM with higher data rate has the high weight factor.

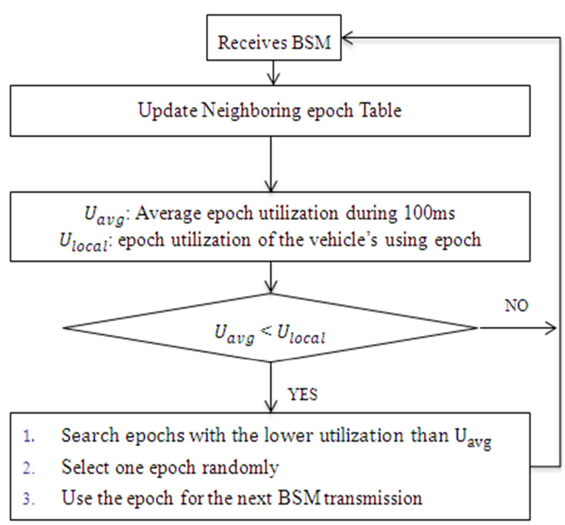


Figure5. Phase control algorithm

If the calculated utilization value is lower than the average value, the vehicle uses the current epoch for the next BSM transmission. But, if the calculated utilization value is higher than the average value, the vehicle determines it's jump rank. The jump rank can be calculated by considering a data rate, vehicle's MAC ID and the number of using time of the current epoch. The vehicle can calculate the required number of vehicle to satisfy the average utilization value with the neighboring epoch table. If the number is higher than the calculated jump rank, the vehicle re-selects other epoch with the lower utilization and uses the epoch for the next BSM transmission.

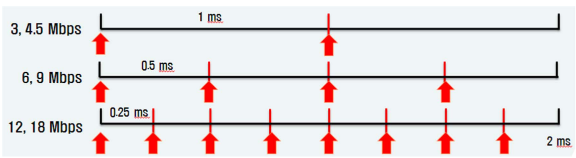


Figure6. Intra epoch definition within epoch

The proposed phase algorithm defineds on the intra epoch to avoid the packet collision within the one epoch (2msec). To distribute the vehicles without overlapping interval, we define the different transmittable time depending on the BSM's data rate within the epoch like figure 6. Also, we apply the application random jitter to prevent the same transmission in the intra epoch.

PERFORMANCE EVALUATIONS

We implement WAVE and our proposed algorithm with the Qualnet simulator. For our simulations, we define the following parameters.

Table2. Simulation parameters

Parameter	Value
Path-loss	Two-ray ground model
Shadowing	Constant/Mean 4.0
Fading	Rician, K-factor 3
MAC-model	802.11p with 1609.4 (continuous mode), CW-min: 3
Road	3000m, 2 lane
Mobility	Average 30Km/h, variance 0.3
Vehicle spacing	5m, 10m equal-distance
BSM size	200 bytes
Number of Vehicle	1200, 600

For the performance evaluation, we compared the our algorithm's performance with the existing algorithm defined in [6]. We call that algorithm as the AlgX and our algorithm as the AlgH. The AlgX uses the GPS error measured by host vehicle and relative vehicle and controls the transmission rate control and power control independently. We estimate the PDR and CBP under the same simulation environment and compare with AlgX and AlgH.

Figure 7 shows the PDR comparison between AlgX and AlgH, PDR versus range. We choose one reference node and measure the distance from the reference node. We make a congestion condition with 1200 vehicles. The distance between two vehicles is fixed to 5m. We get the lower PDR values at longer ranges due to packet collision in addition to the othe factors like a fading. The higher PDR values are experienced at shorter ranges because of the packet collision. Our algorithm's PDR is about 51% and the AlgX's one is about 39%. In the total range, our algorithm showed the better PDR results.

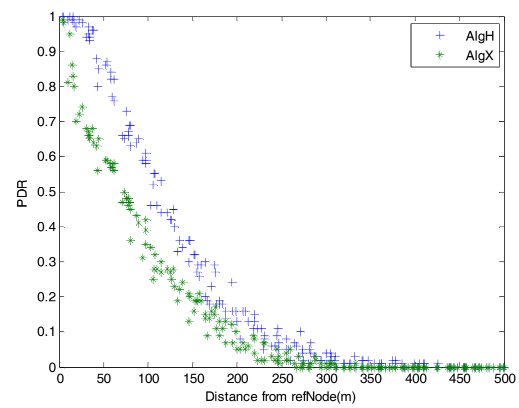


Figure7. PDR comparison (PDR vs Distance)

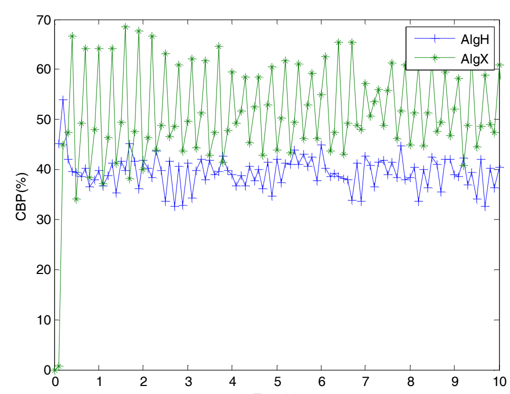
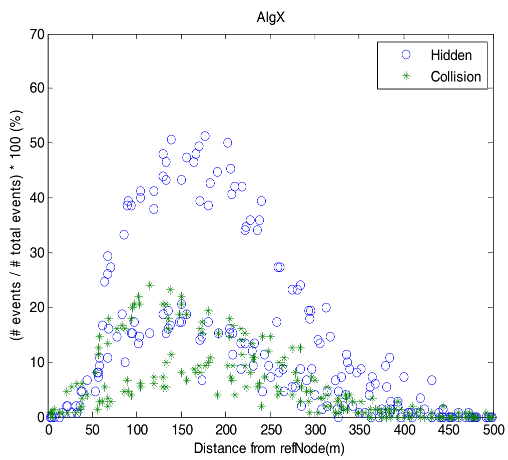


Figure8. CBP comparison (5m equal-distance)

Figure 8 shows the CBP comparison between AlgX and AlgH measured every 100msec. While the AlgX controls the message interval and transmission power in the traffic congestion condition, our algorithm reduces the CBP by controlling a data rate and prevent the packet collision with the phase control. For the traffic congestion modeling, we put 1200 vehicles for the simulation. Our algorithm's average CBP is about 39% and the AlgX's one is about 51%. We can validate that our algorithm can control the traffic congestion condition and maintain the stable channel condition thn AlgX.

We evalulates the impact of hidden terminal to the AlgX and AlgH. Because the our algorithm is based on the data rate contol according to the real-time channel condition, we expect our algorithm is robust to the hidden terminal problem. For the validation, we simulated with 600 vehicles. The distance between two vehicles is fixed to 10m.



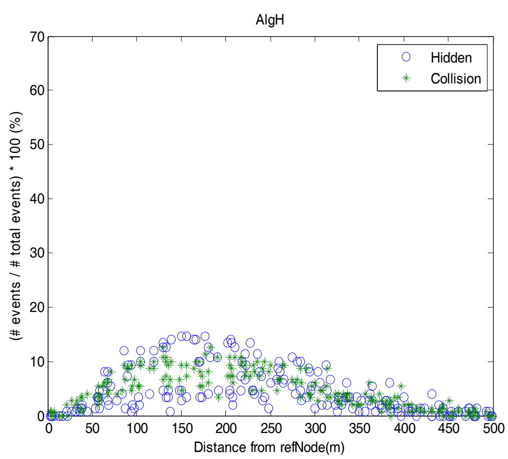


Figure9. Hidden terminal impact (AlgX vs AlgH)

From the simulation result, AlgX has a packet collision caused by the hidden terminal. Because the design of AlgX does not consider the hidden terminal problem, it does not manage the problem efficently. But, our algorithm is validated that it can drop the possibility of the hidden terminal efficently.

CONCLUSIONS

In this paper, we have analyzed WAVE performance under traffic congestion condition. Based on the analysis, we proposed the dynamic congestion control algorithm using the mean-based data rate control and the phase control using epoch.

The performance evaluations in Qualnet confirm that the proposed algorithm achieves better communication performance like a channel busy percentage and packet delivery rate than the existing solutions and is more robust to hidden terminal problems.

The proposed algorithm does not consider the coverage reduction from the data rate control. As our future work, if a variable transmission power is used by each vehicle with the data rate control, there could be further performance improvement.

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