# *STDMA for Vehicle-to-Vehicle Communication in A Highway Scenario*

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***Abstract*—Vehicle-to-vehicle communication within the intelligent transportation systems has been a hot topic recent years. In this paper the medium access control (MAC) method self-organizing time division multiple access (STDMA) has been simulated in a highway scenario with periodic broadcast packets. Rapidly changing road conditions requires a real-time deadline, so timely and predictable access is especially important to the channel. However, the traditional medium access method used in 802.11p makes a node drop over 80% of its heartbeat messages and as a result, 802.11p using carrier sense multiple access with collision avoidance (CSMA/CA) does not support real-time communications. With STDMA, nodes always get predictable channel access regardless of the number of competing nodes and the maximum delay can be expected. In this paper, we build a simulation platform where the topology dynamically changes and all the nodes need to communicate during the whole simulation in a highway scenario. Then we elaborate with different parameter settings and the results illustrate the relationship between the ratio of reuse and other parameters. Finally we come to a conclusion that with system load increasing, it is helpful to change sensing range and other configuration to reduce the probability of reusing slots by about 10% in order to improve the system performance.**

***Keywords- ITS; MAC; STDMA; highway***

## I. INTRODUCTION

Vehicular ad hoc networks (VANET) known as a special case of mobile ad hoc networks (MANET) using unique characteristics has been a hot topic recent years [1]. A VANET can't be predicted when nodes in the system have highly dynamic characteristics and a special demand for low delay. Due to this, the safety system within the intelligent transportation systems (ITS) has attracted a lot of interests in how to decrease the number of accidents in highway scenario using wireless data communication. We face the difficulties in not only coping with the unpredictable wireless channel but also taking both the reliability requirements and strict timing into account.

For vehicle-to-vehicle (V2V) ad hoc communication in highway condition, 802.11p is the only standard currently which supports direct communication. The medium access control (MAC) method carrier sense multiple access (CSMA) [2] has distinct drawback: unbounded delays, that is, a node can experience very long channel access delays. The reason is as follows: in a carrier sense system, the node must first listen to the channel and after the channel has been free for a certain time period, the node occupies the channel directly with the implication that other nodes can have conducted the same procedure. So if there are nodes in the listening queue, a node will experience very long channel access delays. Further, when the CSMA algorithm is implemented in wireless communication, an interferer could easily jam a geographical area, and all nodes in the special area would suspend their access even though there is no data transmitting in the channel.

Considering all the reasons, it is crucial for an application to provide the real-time communication with high reliability properties, which means packets must be transmitted successfully before a certain deadline. We use a concept called heartbeat messages where vehicles periodically broadcast position messages [3] containing information about their own position for reference. This method will build up an advanced map of a node's neighbors and according to the map, all the member's speed, direction and position information are transparent to each other. Real-time communication implies that there needs to be an upper bound on the communication delay which is smaller than the deadline. Information that is delivered after the deadline in critical real-time communication system [4] is not only useless, but implies severe consequences of the traffic safety system.

Another point is how the shared communication channel should be divided in a fair and predictable way among the participating users. TDMA will perfectly solve the problem. Considering the above two aspects, an algorithm called self-organizing time division multiple access (STDMA) is capable to our requirement. The Automatic Identification System (AIS) supports direct ad hoc communication between ships but it has a completely different MAC method, where the available time is divided into slots and the nodes choose their slots. When the network load increases due to increased data

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traffic or many participating members, the nodes will start to pinch slots from each other based on the available position information, and slots are always pinched from nodes currently situated furthest away from the pinching node. The algorithm is predictable implying that all nodes always get a timely access regardless of the number of competing nodes. In this paper, we focus on how the nodes are pinching slots from each other, when the wireless channel becomes crowded, how the pinched slot is selected and what the parameter set implies the selecting.

We organize the reminder of this paper as follows. Section II describes the proposed STDMA protocol. Then section III is dedicated to the explanation of simulation scenario. And section IV explains the results. At last we will give the conclusion about this paper.

## II. STDMA MAC METHOD DESIGH

*Mechanism Description*

Decentralized scheme as far as we know, is different from the centralized system that only one base station is responsibility for scheduling and nodes controlled by the station just need to be obedient. Without the central brain, network members in this system are responsible for sharing the communication channel. Thanks to the development of GPS, nodes equipped with GPS keep pace with each other and this invention enables decentralized control.

All nodes in the system regularly send packets that contain information (position information) about their own position and this algorithm assures the independence of each node. The position messages are obviously different from each other and according to the diversity of position messages, we use them as the mark of each node when choosing slots in the frame. To decide the number of position messages that will be sent during one frame, all network members start by determining a report rate and a certain rate means a certain number of slots containing data in each frame. When a node is going to join in the system, first it will listen to the channel and get information from other nodes' position messages for preparing, and then four different phases will follow: initialization, network entry, first frame, and continuous operation.

In the phase of initialization, the node will listen for every slot in one frame to get position messages of nodes which already occupied the slot. Then according to the following algorithm, the system will determine the slot allocation.

In the phase of network entry, we describe the access algorithm as follows:

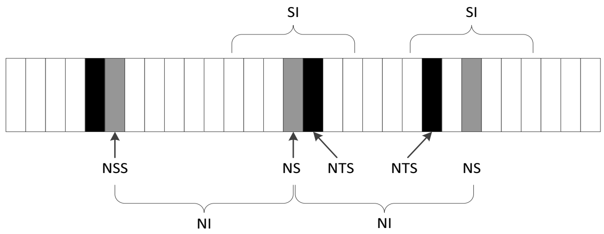


Figure 1. STDMA Frame Format

*1) According to the report rate, that is, the number of time slots the node use for one frame's time, calculate a nominal increment, NI.*

*2) From the start of the frame, select a random number (0 to 100) of slots to determine the location of a nominal start slot (NSS) and select the slot as nominal slot (NS) every other NI.*

*3) Decide a selection interval (SI) of slots by using a factor k, which is chosen to determine the ratio SI taken over within a NI, and put this SI around the NSS according to Fig. 1, the center of SI is just the location of NS.*

*4) The nominal transmission slot (NTS) is the actual transmission slot, which is determined by randomly picking a slot within SI, but this slot can't currently be occupied by someone else. The slot already used by slot, which is determined by randomly picking a slot within SI, but this slot can't currently be occupied by someone else. The slot already used by a station will be occupied by another station located furthest away from itself only if all slots within the SI are occupied.*

In the phase of first frame, except for the first NTS, the rest of transmission slots decided by report rate will be assigned right after reaching the first chosen NTS. If the report rate is 8 messages per frame, then around each NS there will be a NTS in a random slot according to the algorithm above. To keep track of the frame start for this particular node, every node has only one NSS, that is, all nodes keep track of its own frame and they look at it as a ring buffer with no end. The parameters like NS, NSS, SI and NI are not changed during the time when the node is up running, just as Fig. 1 describes. However, the report rate may change and that time the parameters except for NSS should be count out on the basis of the algorithm again.

In the phase of continuous operation, the system will deal with the changeability of the fast moving cars. As the highway condition is changing fast, network may be totally different from the one a second ago. So NTSs must not be valid all the time. We describe the solutions like this, during the first frame phase, each NTS is allocated with a random integer n, which is designed in a range of special integers. Like $n \in \{3,\ldots,8\}$, 3 means the lower limit and 8 means the upper limit. After the

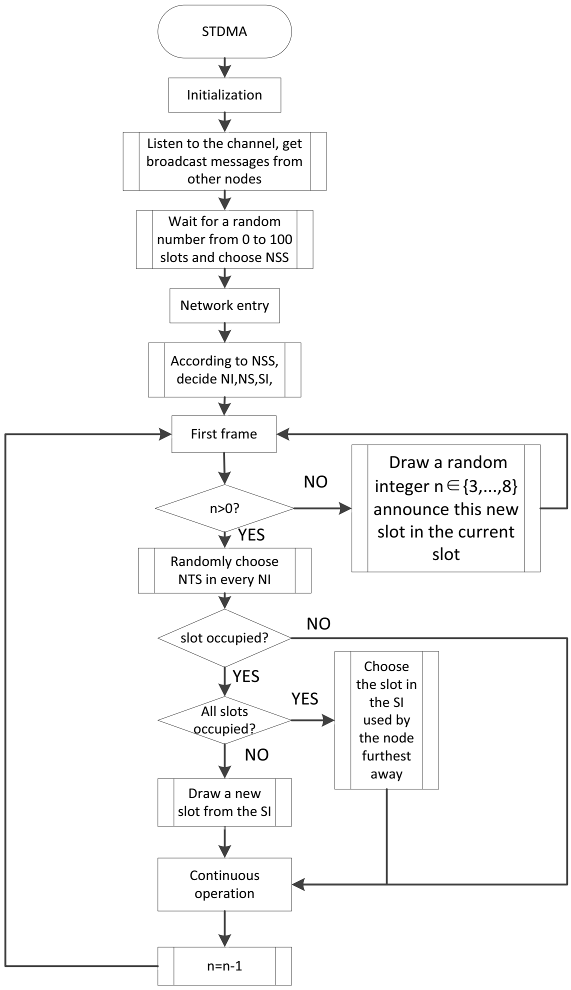


Figure 2. STDMA Algorithm Structure

NTS has been used for the n frames, a new NTS will be allocated in the same SI as the original NTS. The narrower the range is, the better the system copes with changeability. Two nodes that use the same NTS which was not in radio range of each other could have come closer and will then interfere if the NTS allocation was not changed. STDMA algorithm flow chart is shown as Fig. 2 [5]. Four phases just constitute a closed loop and in real simulation it lasts from the first frame to the end.

*Continuous collision probability*

Assume that there are X nodes' slot selecting window partially overlap in the system, the overlapping area is Y slots. If the selecting window of user A ( $A_W$ ) is confirmed, other (X-1) nodes randomly locate their own selecting windows $B_W$, $C_W$ ,..., and assume that the evens of each node selecting the window are independent. Then the probability of this event's happening is:

$$P_{SI} = \frac{1}{(\mathrm{S}_L - \mathrm{SI})^{X-1}} \tag{1}$$

Each node selects its own slots window (as is depicted in Fig. 2) independently, if slots windows of X nodes overlap and Y slots are reused [6], let's discuss the possibility of collision in this assumption.

When Y < SI, the probability that X nodes choose their slots in the overlapping region of Y slots is: $P_y = (\frac{Y}{SI})^X$ , so the probability that one slot in the overlapping region is chosen by X slots the same time is: $\frac{Y^{X-1}}{SI^X}$ .

When 1≤Y≤SI/2, in the overlap area there exists two disjoined block , and under this circumstance the probability of slot collision is: $2\frac{Y^{X-1}}{SI}$ . Through Probability analysis and calculation, formula(2) is achieved. It shows the probability that X nodes conflict in the overlapping region Y :

$$P_1 = \begin{cases} \dfrac{2Y^{X-1}}{SI^X} & Y < \dfrac{SI}{2} \\ \dfrac{Y^{N-1}}{SI^X} + \dfrac{(\mathrm{SI}-\mathrm{Y})^{X-1}}{SI^X} & \dfrac{SI}{2} \le Y \le SI \end{cases} \tag{2}$$

$$P_2 = \begin{cases} (\dfrac{2Y^{X-1}}{SI^X})^n & Y < \dfrac{SI}{2} \\ (\dfrac{Y^{N-1}}{SI^X} + \dfrac{(\mathrm{SI}-\mathrm{Y})^{X-1}}{SI^X})^n & \dfrac{SI}{2} \le Y \le SI \end{cases} \tag{3}$$

In conclusion, the probability that X nodes conflict with each other in n successional packets is:

$$P = P_{SI}P_2 = \frac{1}{[(\mathrm{S}_L - \mathrm{SI})\mathrm{SI}^n]} = \frac{SI^{(\mathrm{n}+1)}}{k^n X_{frame}^{(\mathrm{n}+1)}(SI-k)} \tag{4}$$

$X_{\mathrm{frame}}$ is the number of slots in a frame. From the formulas above, we can see that it's unlikely that slots collision happens continuously.

## III. SYSTEM SIMULATION AND EVALUATION

The purpose of this simulation is testing the capability of the MAC method described above with a special parameters set. The parameters are designed according to the highway scenario. What we are interested in is how the parameters' change influence the performance of the system and which set meets the upper limit of the capability. The highway condition determines that the network topology changes rapidly and it's hard to simulate with different parameters sets in a unified reference. But we try to describe a topology like this, that is, each lane of the highway road has a fixed speed and in order to be practical, the car's speed in the left lane is faster than the one in the right. Here we don't take cars' traffic collision into account, and either we don't need to consider the reception of all the nodes.

In this paper, let's assume the highway condition like this: the road is 10000 meters long [7], which is

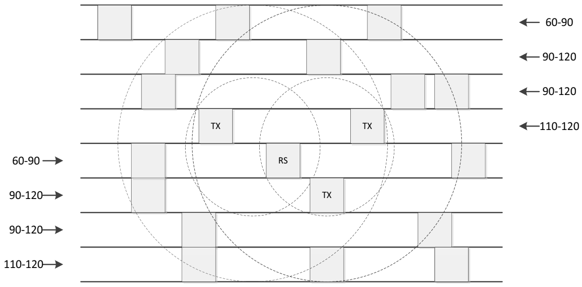


Figure 3. Simulation Topology

long enough to simulate substantial cars. And the road is 4 lanes for two opposite directions. For the purpose of protecting security, each car enters the road after a mean interarrival time of fixed seconds. Naturally not all the cars keep the same speed, but as we know, in each lane the car's velocity is generally consistent. So for each lane the node's speed is modeled as a Gaussian random variable, and the average value for these variables has to accord with the highway provision. The requirement of speed is as follows: 60 to 90 km/h for the slowest lane, 90 to 120 km/h for the middle two lanes and 110 to 120 km/h for the fastest lane. We pick up the mean speed in these ranges and by the way, the standard deviation is 1 m/s. An important assumption needs to be explained here, that is, even when the two nodes locate at the same point in our simulation, we suspect that no collision happens. The topology is described as Fig. 3.

The vehicles will have the same speed as long as they are staying on the highway and the vehicles do not overtake. The purpose of this simplistic mobility model is to achieve a realistic density of vehicles on the highway to test the performance of our communication system. The channel model is a simple circular sensing range model in which every node within the sensing area receives the message perfectly (we suspect), because on the basis of AIS system, within a special sensing range the throughput will be close to 100 percent. There will be a problem called hidden and exposed sites because a node may at the same time receive packets from two other different nodes. So inevitably there will be a collision in the air. But for simplifying the model we ignore this problem and suppose two cars will never crash on the highway.

Three different sizes of packets for transmission are designed. As can be seen in TABLE I. N=800, 2400, 4000 bits for 3 different needs of information. It is very important that heartbeat messages can be trusted since many traffic safety applications will be depending on these. Every packet has to contain the heartbeat message, that is, for security and integrity we have to use a digital signature being about 1000 bits [8] together with header and other constitutions. 4000 bits' packet is sufficient large, therefore redundancy will lead to unnecessary overhead.

TABLE I. THREE KINDS OF PACKETS WITH DIFFERENT SIZES

| Packet | length(bits) |
|---|---|
| 800 | 3076 |
| 2400 | 1165 |
| 4000 | 718 |

TABLE II. SIMULATION PARAMETERS SETTINGS

| Parameter | Value |
|---|---|
| Transfer rate, R | 3 Mbps |
| Packet sizes, N | 100, 300, 500 bytes |
| Sensing ranges | 500 to 1000 meters |
| No. of lanes | 2×4 |
| k (SI/NI) | 0.2 |
| Frame size | 1s |
| Heartbeat message Frequency | 10 |

In the simulation, a STDMA frame lasts one second. As there are three different sizes of packet, the number of slots within one frame has to change. As can be seen in TABLE I, we will simulate with packets of 100byts, 300byts, and 500bytes.

And the parameter k is within a range of 0.1_ 0.5. In practical, the greater the k is, the more probability two nodes reuse the same slot. In this simulation, for convenience, SI has to be odd number, so it's fair that NTS chose a slot from both sides of NS.

STDMA always guarantee the real time channel access. Even when the link load is very high, a node can immediately join in the transmission queue using a slot which is already occupied by a node furthest away within the sensing range.

STDMA scheme has been set to 1 second and the number of slots is changed inside the frame to cater for different packet lengths. A transfer rate, R, of 3 Mbps has been used and this rate is available with the PHY layer of 802.11p, which has support eight transfer rates in total where 3 Mbps is the lowest. This choice is made since the system pays more attention on the reliability rather than the throughput, and the lowest transfer rate has the most robust modulation and coding scheme. All the parameter settings are shown in TABLE II.

In the STDMA simulations, the vehicles will go through three phases: initialization, network entry, and first frame before it ends up in the continuous operation. The vehicle stays in the continuous phase after it has passed the other three. STDMA always guarantees channel access even when all slots are occupied within an SI, in which case a slot taken by the node located furthest away will be selected.

## IV. SIMULATION RESULTS

We want to find out the exact description of performance of STDMA MAC method, but each time we generate many random parameters for our simulation, the results we obtained change more or less. So we can't ignore the diversity of the results. To describe the performance of this system we pick up average data and surely we can see how different parameters sets influence the performance of the system.

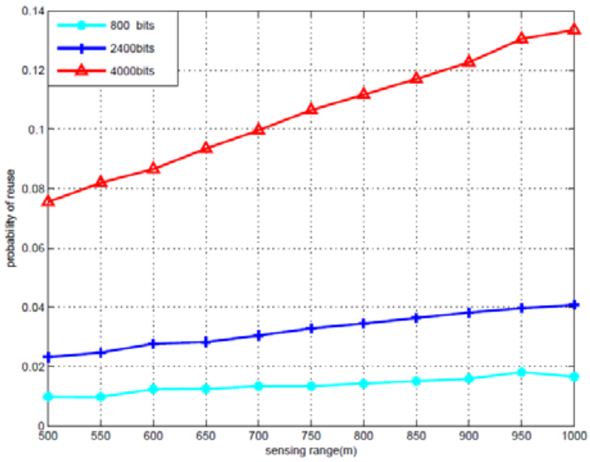


Figure 4. Probability of Reusing for Different Sensing Range

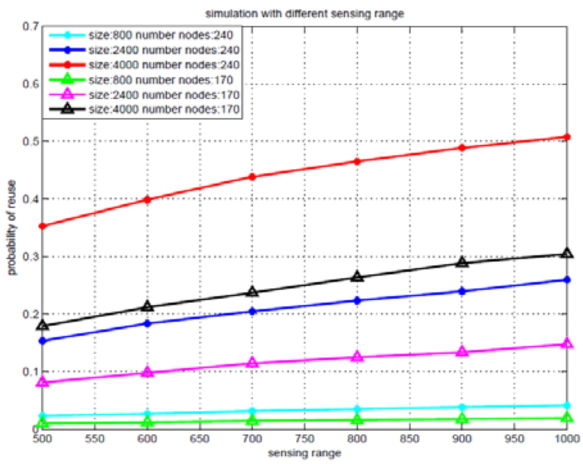


Figure 5. Probability of Reusing for Different Sensing Range with different packet sizes and numbers of nodes

The vehicle density is decided by parameters set, and in this simulation the ideal MAC method can contain about 70 nodes in the sensing range of 1000 meters without packet collisions but actually there are over 200 neighbor nodes competing for the slots. So the system is overloaded and the reuse of slot is obviously existence.

In our simulation, there are less than 100 nodes in the sensing range of 1000 meters and it is unlikely that many packet collisions happen. The ratio of reuse for each slot is low. The main factor affecting the results is packet size. As shown in Fig. 4, the gap between 4000 bits' packet and 2400 bits' packet is more than that between 2400 bits' packet and 800 bits' packet. And with the sensing range growing, the reusing rate grows more quickly. When the packet size is larger, the performance is more sensitive to the sensing range. About 10% slots are reused when the sensing range is 1000 meters but this small probability of reuse puts little impact on the performance of STDMA.

When the road is crowed and too many nodes compete for limited slot resources, the whole system must be overloaded. In Fig. 5, we clearly recognize an interesting phenomenon. There are six simulation lines and first we divide the lines into 3 groups using a rule that the two lines in each group have the different number of nodes but the same packet size. The gap between the red line and the black line is about 20% , the gap between the blue line and the pink line is 10%, and the gap in the last group is less than 3%. The bigger the packet size is, the increasing of nodes' amount leads to much more probability of reusing. Second, we divide the lines into 2 groups with the rule that three lines in each group have the same number of slots but different sizes. The first group includes the red line, the dark blue line and the light blue line. The other group is constituted with the rest of the lines. Comparing the two groups, it is clearly shown that when there is a fixed number of nodes, the ratio of reusing increases with equal proportion. And with more nodes in the system, the lines have lager differences.

## V. CONCLUSIONS

The STDMA algorithm always grants packets channel access since slots can be reused if all slots are currently occupied within the selection interval of a node. In our paper, we analyze the advantage of STDMA. Even though packet collision will occur in the air with a lot of randomness, the correlation between nodes gets smaller. So there will be less possibility that successional packets drops occur. As a result we guarantee the reliability and a best schedule for all nodes.

Selecting the correct parameters according to the road condition has an important impact on the system. The reuse of slots can be ignored until 2400 bits packet size is applied when there are not too many nodes in the system. With sensing range becoming wider, more slots have to be reused, which means STDMA is sensitive to sensing range. When the road is sparse, a larger sensing range helps a node choose the slot occupied by a neighbor furthest away from it. Nevertheless, when the road is crowed we had better choose a small sensing range to reduce the possibility of reusing slots by about 10%. As is depicted in Fig. 5, the two endpoints of the red line differ by about 15% and the two endpoints of the blue line differ by about 10%.

The more nodes hosted in a particular sensing range, the faster the system load increases since the distance between two nodes sharing the same slot gets smaller, and thus it's more likely to cause unnecessary interference and transmission collisions, which means STDMA is sensitive to the user amount. The number of nodes puts a greater impact on the performance than on the packet size, and it's explained in the results that how the two factors influence the system. STDMA suits for communication in the highway scenario because within a fixed range the system contains not too much users. To improve the system performance, it is better to select a packet size as small as possible. While in the worst case that the road condition is bad and we have to transfer data with large packet size for a special service, it's essential that we choose a appropriate sensing range.

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