Performance Analysis for Uniform and Binomial Distribution on Contention Window using Different Hop Distance

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***Abstract*—In this paper, we present a mathematical analysis on the performance of uniformly distributed and non-uniformly distributed backoff timer based on binomial algorithm for contention window. We evaluates these protocols under mathematical modelling in order to analyze the average throughput, end-to-end delay and collision probability performance by using different value of hop distance during data transmission process by varying number of nodes from 50 to 300 vehicles. The simulation results show that binomial distribution outperforms the conventional uniform distribution in terms of throughput, delay and collision probability in all scenarios. We also can observed that by using longer hop distance, the better performances have been achieved in both distributions, particularly by using binomial distribution. Thus we can say that the binomial probability distribution that is specifically designed to replace the conventional uniform probability distribution in order to differentiate the selection probability during the backoff process of selecting the transmission slot can be implemented in MAC protocol for vehicular network.**

Keywords—Uniform and non-uniformly distibuted backoff timer, binomial algorithm, MAC protocol

I. INTRODUCTION

The MAC protocol for vehicular network is known as Distributed Coordination Function or DCF, which the standard is based on CSMA/CA. The DCF should be implemented in all stations, where it is used in ad-hoc and infrastructure network configurations [1]. As in Figure 1, for a node to do the transmitting process, it shall sense the medium to be idle. If the medium is idle, then transmission process can be continued [2]. The CSMA/CA distributed algorithm will command an interval of minimum specified time that exist between transmissible frame sequences. A transmitting station must make sure that the medium is idle for this required duration before attempt to do the transmitting process. If the medium is busy, then that station shall defer until the end of the current transmission, in which the medium is sensed idle for a DIFS (Distributed Inter Frame Space) period. After defer, or before attempting to resend after a successful transmission, the station will choose a random backoff interval and would decrease the backoff interval counter while the medium is idle.

At the beginning process of backoff procedure in which a collision happen, a station will chooses its backoff stage to 0 and arms the backoff timer by executing a uniformly distributed random time backoff from the initial contention window which representing the number of minimum contention window size. If the medium is idle, the backoff timer will be decremented. Otherwise, the process will be frozen when there is a medium activity. The decrementing process of backoff timer is resume if the medium is sensed idle again for a DIFS time. Here, the station will transmits its frame only if the backoff timer reaches zero. Let say the transmitted frame has not received any ACK frame, a collision is detected and the station will retries to transmit the frame by switching to the next backoff stage where the contention window size will be doubled [3].

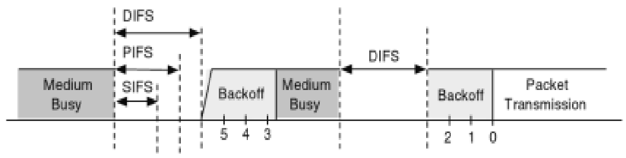

Fig. 1. Basic access method of DCF

After the maximum backoff stage, the transmission attempts will no longer affect the contention window, in which this latter remains constant value with the maximum number of contention window. If a maximum number of retransmissions is reached, the frame will be dropped. During the backoff procedure, when an ACK frame is received, the station will resets the contention window at its initial backoff range, so that the backoff procedure shall be invoked for a node to transmit the next frame. This process is done after it reached the maximum backoff stage too, no matter the transmission is successful or not. Noted that, a Short InterFrame Space (SIFS) time is used for ACK frames. If a DATA frame is correctly received, the receiver station will wait for a SIFS time before transmitting the ACK frame. If the ACK frame is not received within an ACK timeout interval, it is assumed that a collision has been occurred.

Nevertheless, the main characteristics in vehicular network where nodes are typically move on a road with higher mobility and frequent network topology change dynamically than those in other ad-hoc network scenarios lead to several challenges in network design, especially on MAC layer [4]. Aiming to improve the MAC performance, we propose a mathematical analysis by implementing a non-uniformly distributed backoff timer based on binomial distribution for contention window, so that we can increase the performance of throughput while reduce the delay and collision probability.

II. Related Works

The usual method of avoiding collision is to adjust a contention window size to the current number of competing nodes. From previous studies, there a several methods of tuning a number of contention slots in terms of varying workload of the network that have been proposed and successfully used, where most of them focused on contention window extension after a collision and a contention window size reduce in case of a successful packet transmission. As in [5], they proposed the MAC layer of Tiny Operating System which called as B-MAC. It is a type of fixed-window CSMA protocol where it selects contention slots uniformly at random. B-MAC is designed based on a fixed size of contention window because of the reasonably well performance that has been sustained in an actual environment. On the contrary, there is a limitation in the network scalability where it has low intermittently in a high-load state. While in Multiple Access with Collision Avoidance for Wireless (MACAW), the researchers exploits the Binary Exponential Backoff method by not sharing the channel state information since it does not make use of carrier sense [6]. By using this protocol, it will restarts contention for the upcoming transmission because of the contention window size has been initialized to the minimum number only if the previous node succeeds in transmitting a packet. Nevertheless, an overhead is suffered when the medium is accessed, since the nodes competing to access the medium are centered in a certain interval and the contention window size changes substantially. Thus MACAW resolves this limitation by using a learning method that does not newly reset the contention window size, instead decreases the contention window size that has been used in the previous contention as a size for the next contention, only after a packet is successfully transmitted.

In 802.11 specification, it resolves the fairness problem of service by using a memory technique [7,8]. As in conventional procedure, a node that participates in a contention mode, in which one of the slots in the contention window is randomly picked by implementing a uniform probability distribution, will cause the value of selected slot is set in a countdown backoff timer. The countdown backoff timer is stopped when node sensed that the medium is busy, and it will resumes countdown when the medium is idle. Let say the number of countdown timer becomes 0, the corresponding node starts to transmit. When the transmission process is completed, the contention window size is initialized to the predetermined minimum value. Consequently, the bandwidth will dissipates since the node always requires to determine a sufficient contention window size. In order to solve such a limitation, a Differential Probability of Selection MAC (DPSMAC) protocol has been proposed [9]. It exploits the fixed contention window size and random slot selection method with non-uniform probability by implementing a geometric distribution function. In their analysis, this protocol has minimizes the collisions between nodes, reduces the delay time, and maintains the fairness of service relatively and constantly, although the simplicity of the protocols structure as compared to conventional 802.11 MAC protocols. As for the limitation, this protocol has some difficulty of reconfiguring the protocols after execution, thus lacking in flexibility.

The alternative technique proposed recently consists in introducing a non-uniform distribution using geometric probability of choosing slots, such as in Dynamical Adjustment on Contention Window (DACW) that specially designed for vehicular ad hoc networks by considering vehicle's travel information such as location, speed and direction [10]. From their analysis, we can see that this protocol has decreases the possibility of continuous collisions among the competing nodes, together with increases the average throughput for either symmetrically or asymmetrically bidirectional traffic condition. However, compared to the conventional Enhanced Distributed Channel Access (EDCA) mechanism, it can be concluded that the effectiveness of this protocol only works in bidirectional highway scenario.

In a nutshell, we can conclude that size of contention window is the major factor affecting the MAC performance in vehicular network. Thus in this research, we propose a modified backoff algorithm that can decrease the possibility of continuous collisions among the competing vehicles by generating a non-uniformly distributed backoff timer based on binomial distribution.

III. The Modification of MAC Protocol

Our proposed protocol is based on a non-uniform probability distribution, where the selection of transmission slot differs most notable from that in conventional CSMA based wireless MAC protocols, so that it can reduces the overlapped selection rate of a slot by essentially choosing a slot according to the differentiated probability. As in Figure 2, if a random slot succeeds in transmitting in the contention window used for backoff, slots in the remaining locations can be selected for the next process, except for the slot that has been used before. In other words, the probability distribution function must be designed such that those remaining slots that are located except the slot that has successfully transmitted can be deliberately chose. The probability distribution function of such a property can be derived by multiplying the probability with which remaining slots can be selected by that with which succeeding slots can be selected based on a random slot for all slots.

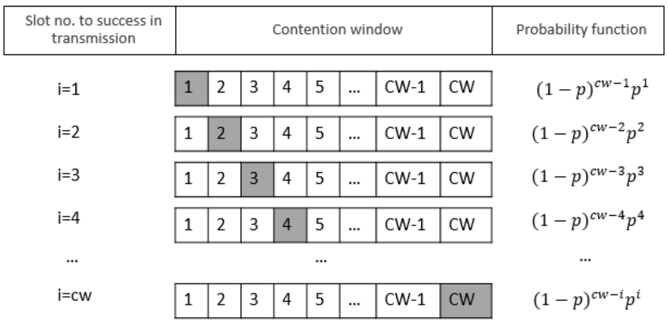

Fig. 2. Probability of selecting a slot in order to reduce the contention between nodes

Looking towards at the designation of probability distribution function, it shows that the best performance can be determined if the first slot is selected when no other contention happens in the current contention window, which is at i= 1. If there is a collision again, it might be better to choose the earlier slot again even though the first slot has already been selected before. So, the slot is selected in order to transmit data without a collision for the minimum delay time. In order to sustain such an optimum selection method, if the probability distribution function is derived using the probability with which the remaining slots can be selected, it could be said that the probability (i) with which each node chooses the i^{th} slot within the range of the contention window follows a binomial distribution with a parameter p, thus the probability mass function can be given as follows:

$$f(x\!:p,n) = \binom{n}{x} p^x (1-p)^{n-x} \quad (1)$$

where n is number of trial, x is number of success in n trial and p is probability of success in single trial [11].

IV. MATHEMATICAL ANALYSIS

By implementing binomial distribution function, we have $P_i = (1-p)^n$ as probability that the slot is in idle state, $P_s = (np)(1-p)^{n-1}$ as the probability that a transmission occurring on the channel is successful, and $P_c = 1 - [(1-p+np)(1-p)^{n-1}]$ as the probability of collision transmission. The transmission probability, p can be calculated with minimum value of contention window as $p = \frac{2}{CW_{min}+1}$. From P_i, P_s and P_c, the expected value of collision number before a successful transmission can be determined as:

$$E(N_c) = \frac{P_c}{P_s} \quad (2)$$

Thus it becomes:

$$E(N_c) = \frac{1-((1-p+(\alpha.d)p)(1-p)^{(\alpha.d)-1})}{(\alpha.d)p(1-p)^{(\alpha.d)-1}} \quad (3)$$

If there is a collision of transmission, the time taken will consists the message transmission time and DIFS time. So, the total collision time before a successful transmission can be obtained as:

$$T_{col} = \sigma.\frac{1-(1-p+(\alpha.d.p))(1-p)^{(\alpha.d)-1})}{(\alpha.d.p)(1-p)^{(\alpha.d)-1}} \quad (4)$$

If the collision is happen between 2 idle periods, the expected number of idle period will be:

$$E(N_i) = \frac{(1-p+(\alpha.d)p)(1-p)^{(\alpha.d)-1})}{(\alpha.d)p(1-p)^{(\alpha.d)-1}} \quad (5)$$

The number of time slots in each idle period is obtained by p and contending vehicle number, which is αd. The expected value of this situation will be:

$$E(T_i) = \sigma\left[1-(1-p^{(\alpha.d)}\right]\sum_{i=0}^{\infty} i.(1-p)^{(\alpha.d)i} \quad (6)$$

Then it becomes:

$$E(T_i) = \frac{\sigma.(1-p)^{(\alpha.d)}}{1-(1-p)^{(\alpha.d)}} \quad (7)$$

Next, the total collision time before a successful transmission occur can be obtained as:

$$T_{idle} = \frac{(1-p+(\alpha.d.p))(1-p)^{(\alpha.d)-1})}{(\alpha.d.p)(1-p)^{(\alpha.d)-1}}.\frac{\sigma.(1-p)^{(\alpha.d)}}{1-(1-p)^{(\alpha.d)}} \quad (8)$$

While the equation for a successful transmission time will be:

$$T_{trans} = \sigma m + \sigma D \quad (9)$$

Since single hop transmission supposed to consist the summation of collision time, idle time and successful transmission time, then the equation will be:

$$T_{hop} = T_{col} + T_{idle} + T_{trans} \quad (10)$$

From source to destination, the end-to-end multi hop flow is resulting due to L/d relay hops [12]. So, end-to-end delay can be determined as:

$$\text{Delay} = \left(\frac{L}{d}\right) \times T_{hop} \quad (11)$$

While the average throughput [13] can be expressed as

$$\text{Throughput} = \frac{P_s \times payload}{[P_i \times t_{slot}] + [P_s \times t_{success}] + [P_c \times t_{col}]} \quad (12)$$

V. RESULT AND ANALYSIS

We validate our analysis using MathCad Prime 3.0 Software. We choose 1 km road segment that composed of 4 lanes. We set the message size, m of 1000 Bytes with 1 Mbps of wireless transmission rate which corresponds to the transmission time of 32 time slots. As shown in Table 1, we presented the road traffic parameters and MAC protocol settings. Noted that the vehicle densities are set as 50, 100, 150, 200, 250 and 300 vel/km/lane, thus the corresponding values of vehicle density α are 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 vel/m, respectively. We also vary the hop distance d at 50, 75 and 100 m in order to see the differences of using different value of hop distance during data transmission process.

TABLE 1. Simulation parameter

Parameter and setting	**Value**
Vehicle density, α	50, 100, 150, 200, 250, 300 vel/km/lane
Road length, L	1000 m
Number of lanes	4
Time slot, σ	20μs
DIFS time, σD	50μs
Message transmission time, σm	8ms
Hop distance, d	50, 75, 100 m
Message size	1000 bytes
Wireless transmission rate, r	1 Mbps
CWmin	31 slots
CWmax	1023 slots
Payload	8184 bits

We determine the throughput for uniform and binomial distribution for hop distance of 50 m while the number of nodes is set at 50, 100, 150, 200, 250 and 300 vehicles. As in Figure 3, we can see that when the number of vehicles increases in all scenario, in which the hop distance is vary from 50, 75 and 100 m, the throughput reduces. We can conclude that, a protocol that using binomial distribution achieve better result than uniform distribution. Noted that from the calculation using our mathematical analysis, the uniform distribution has higher collision probability than binomial distribution due to inability of the nodes to select its own backoff integer. Thus the throughput using uniform distribution for each node will be lower. We also can conclude that the time required for backoff procedure is comparatively increase because of the slot selected in the contention window is relatively located toward the rear side. In a multi-hop ad hoc network, if all flows select to use short hop distances to transmit the packets, it will cause more channel contention. This is because the node does not adjust its transmission power down when transmitting to its close neighbors. The reasons why short hop routing is not beneficial as it seems to be is because of short hop transmission does not help spectrum reuse and achieves less bit-distance compare to long hop transmission. On the contrary, if all flows select to use long hop transmission, then it will cause more hidden node interference. This argument indicates that there exists an optimal transmission range for maximizing throughput [15]. In a nutshell, it can be concluded that better throughput should be achieved with longer hop distance [16, 17].

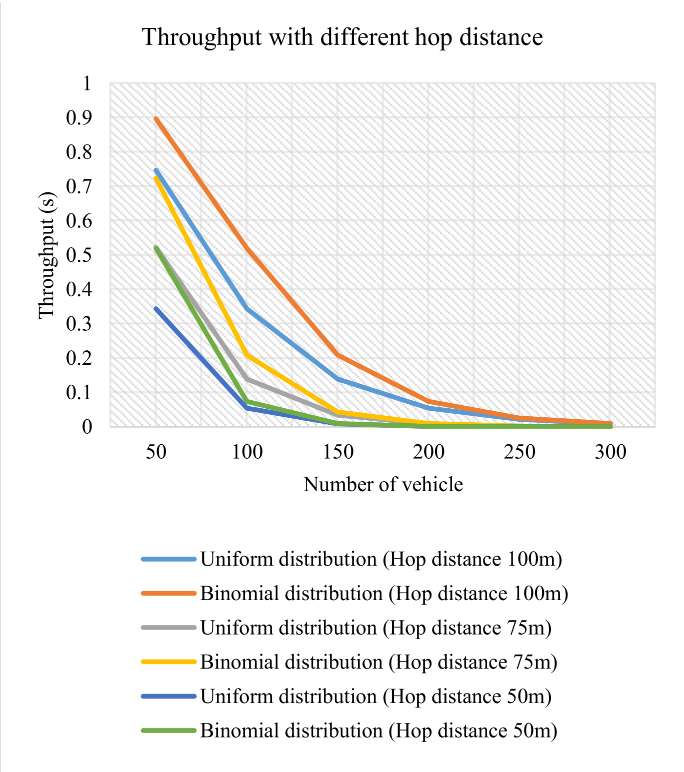

Fig. 3: Throughput with different number of vehicles using hop distance of 50, 75 and 100m

As in Figure 4, we change the hop distance d from 50, 75 and 100 m and investigate the delay for uniform and binomial distribution for the number of vehicles at 50, 100, 150, 200, 250 and 300 vehicles. We can conclude in all scenarios, a protocol that using binomial distribution achieve slightly better result than uniform distribution, in which for a hop distance for 50m, 75m and 100m, the difference between both distributions is only 0.67%, 2.06% and 6.41%, respectively. From our developed mathematical model for end-to-end delay analysis, we can say that the delay is sensitive to the vehicle density. We can see that in a situation where the vehicle density is large, for an instance at 300 vehicles, the delay always increases with decreasing range of hop distance. This is because, when the contention is high, the data dissemination will be decelerated, thus resulting in high message collision ratio and long contention delay [13].

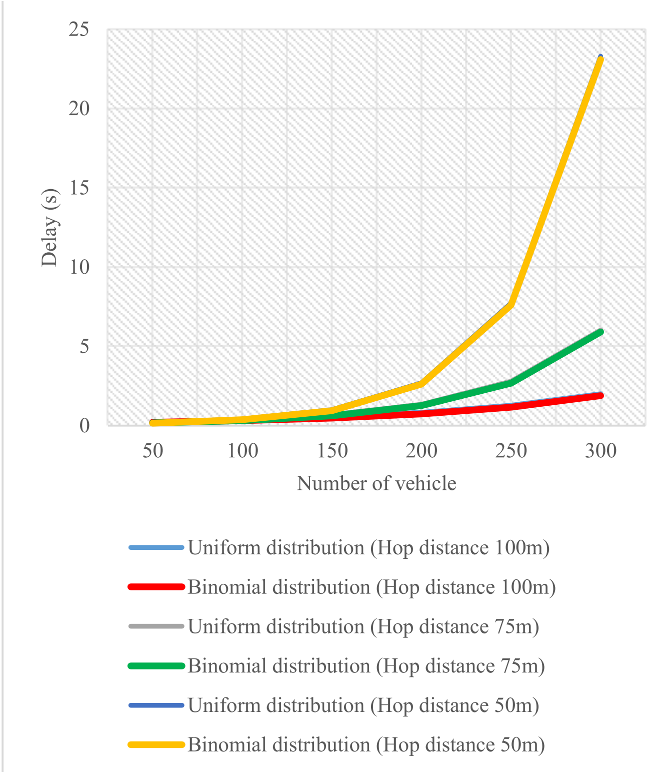

Fig. 4: Delay with different number of vehicles using hop distance of 50, 75 and 100m

From Figure 5, we can infer that when the number of vehicles are increase from 50, 100, 150, 200, 250 and 300, the collision probability will also increase. Noticeably the collision probability will always grow up with the increasing in number of data flows. In all scenario where the hop distance being changed from 50, 75 and 100 m, we can see that the collision probability of binomial distribution is less than uniform distribution. This is because, nodes can select their backoff integer in order to avoid on choosing the same backoff integer as the other nodes do. It means, each node has enter different channels in order to reduce the possibility of collision. In a nutshell, we can say that in a situation where the vehicle density is large, the collision probability will always increases, as well as the shorter range of hop distance.

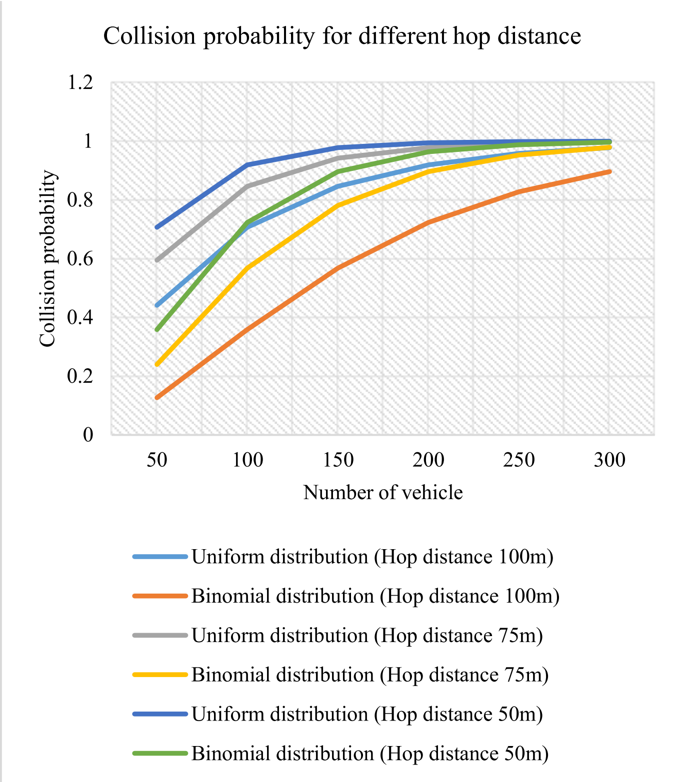

Fig. 5: Collision probability with different number of vehicles using hop distance of 50, 75 and 100m

VI. RESULT AND ANALYSIS

This paper presented the analysis of two different distribution which is uniform distribution and non-uniformly distributed backoff timer based on binomial algorithm for contention window. We determine the throughput, delay and collision probability for uniform and binomial distribution for different hop distance of 50 m, 75 m and 100 m in order to see the differences of using different value of hop distance during data transmission process, while the number of nodes are set at 50, 100, 150, 200, 250 and 300 vehicles. In a nutshell, the simulation results show that binomial distribution outperforms the conventional uniform distribution in terms of throughput, delay and collision probability in all scenarios. We can observed that by using longer hop distance, the better performance of throughput, delay and collision probability have been achieved in both distributions, especially by using binomial distribution. Thus we can say that the binomial probability distribution that is specifically designed to replace the conventional uniform probability distribution in order to differentiate the selection probability during the backoff process of selecting the transmission slot can be implemented in the future. For future work, we will evaluate and study more on the behaviour of binomial backoff algorithm, in addition we can test the protocol performance with real large scale of test bed experiment using NS-2.

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