Modeling and Analysis of Collision Avoidance MAC Protocol in Multi-Hop Wireless Ad-Hoc Network

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***Abstract*:**. The absence of centralized administration, multi-hop transmission, and the nature of wireless channels pose many challenging research area in Mobile Ad hoc NETworks (MANETs). In this paper, a collision avoidance Medium Access Control (MAC) protocol was used for the modeling and analysis of multi-hop wireless ad hoc network, in which RTS/CTS/DATA/ACK handshake and Exponential Increase Exponential Decrease (EIED) back-off mechanism were adopted. A simple n-vertex undirected graph G(V, A) is used to model the topology of MANET while three-state Markov chain was used to model channel state and node state of MANET. Simulation results show that throughput increases with increase in persistent probability, sensing range and length of a DATA frame. Also throughput has a peak value at some point of the persistent probability, sensing range and length of a DATA frame, which is influenced by the number of nodes. In the other hand throughput increases along with the increase of transmission range for some values, then it start decreasing with increase in transmission range. Furthermore throughput decreases with increase in the number of nodes and back-off time. In order to validate the proposed models, a performance comparison of the throughput of existing model with the throughput of the proposed model by considering persistent probability, sensing range, transmission range, length of DATA transmission and back-off time was carried out. The overall results show that the proposed model achieve better throughput than the existing model.

***Keywords*:** Mobile ad hoc networks, medium access control, back-off mechanism, RTS/CTS, multi-hop, Markov Chain.

1. Introduction

A wireless ad hoc network or a mobile ad hoc network (MANET) is a network where a set of mobile devices communicate among themselves using wireless transmission without the support of fixed or stationary infrastructure. It provides a flexible access method and is applied in many areas where traditional networks cannot work. Due to its infrastructure-less nature, an ad hoc network can be deployed very fast at a relatively low cost enabling communication when it is not possible or too expensive to deploy a support infrastructure (e.g., disaster relief efforts, battlefields, etc.).

The standard for Wireless LAN's IEEE 802.11 specifies two medium access control mechanisms, Distributed Coordination Function (DCF), and Point Coordination Function(PCF). The DCF scheme has been developed for use within both IBSS (Independent Basic Service Set) and infrastructure network configurations. The DCF is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The Carrier Sense(CS) is performed through physical (by air interface, PHY - Physical Layer) and Virtual Carrier Sense (VCS) mechanisms . Both sensing mechanisms are used to determine the state of the medium. The VCS is referred to Network Allocation Vector which contains the remaining time of the on-going transmission exchange of data. The VCS employs Request-To-Send/Clear-To-Send (RTS/CTS) packets exchange for channel reservation. The sender transmits a Request-To-Send frame to its receiver. The receiver sends a Clear-To-Send frame if the Network Allocation Vector (NAV) at the receiver indicates idle channel. Then the sender transmits the DATA frame and waits for acknowledgement ACK [1].

The IEEE 802.11 MAC protocol uses a protocol scheme knows as CSMA/CA. This protocol avoids collisions instead of detecting a collision like the algorithm used in 802.3. It is difficult to detect collisions in a Radio Frequency (RF) transmission network and it is for this reason that collision avoidance is used.

Several mechanisms have been proposed to avoid collisions in Medium Access Control (MAC), namely carrier sense, handshake, and back-off mechanism [2], [3]. Carrier sense requires that a node transmit only if the channel is sensed idle. Multiple handshakes between the transmitter and receiver include some short messages to avoid long collision time of data packets, and acknowledgements of successful transmissions.

The back-off mechanism forces each node to wait for a random period before attempting the next transmission Every station has a back-off counter and a back-off stage. The back-off counter value is initially chosen as described below. The back-off procedure selects a random number of time slots between 0 and the Contention Window (CW), according to the following equation:

$$\text{Back} - \text{off Counter} = \text{Int}(\text{CW} * \text{Random}(\quad) * \text{Slot Time} \tag{1}$$

Where CW is an integer between CW_{min} and CW_{max}, typical values being 31 and 1023, respectively. Random () is a random number between 0 and 1. Slot time is fixed for a given physical transmission scheme [4].

Although Binary Exponential Back-off (BEB) is widely used in many contention-based MAC protocols for its simplicity and good performance, it is not a perfect back-off mechanism in fairness and efficiency [5]. In BEB, each node doubles its CW size after every failed transmission, and resets its CW to the minimum value after every successful transmission. Therefore, it might be quite likely that a node that has won the collision and transmitted successfully will capture the channel again in the following channel contention. The worst case is that one node monopolizes the channel while all other nodes are completely excluded for channel access. Because of the drawbacks of BEB, some new back-off mechanisms were proposed [6] - [9] .

A Multiplicative Increase and Linear Decrease (MILD) mechanism is adopted in the MACAW protocol [6] to address the large variation of the contention window size and the unfairness problem of BEB. In MILD, the contention window size is multiplied by 1.5 upon a collision but decreased by 1 step upon a successful transmission, where the step is defined as the transmission time of an RTS frame. MILD performs well when the traffic load is steadily heavy [10].

However, the “linear decrease” sometimes is too conservative, and it degrades the performance when the traffic load is light or the number of active nodes changes sharply [8]. To overcome these problems, the Exponential Increase Exponential Decrease (EIED) back-off algorithm has been studied in [11], [8]. In the EIED algorithm, the contention window size is increased and decreased exponentially on every collision and successful transmission, respectively. As a result, EIED is not as conservative as the “linear decrease” of MILD and not as radical as the “reset” of BEB.

The MAC layer defined by IEEE 802.11 standard is the lower part of the data link layer and is placed between the dependent sub layer of the physical layer and Logical Link Control (LLC) sub layer of the data link layer. The MAC architecture is composed by two basic coordination functions that is PCF and DCF. Each of these functions defines an operation mode for the stations that want to access the wireless medium. The primary goal of MAC is to coordinate the channel access among multiple nodes to achieve high channel utilization and high network capacity. In other words, the coordination of channel access should minimize or eliminate the incidence of collisions and maximize spatial reuse at the same time.

2. Related Work

The absence of centralized administration, multi-hop transmission, and the nature of wireless channels pose many challenging research topics in the area of MANET. Modeling of the Distributed Coordination Function (DCF) at the MAC layer of the IEEE 802.11 standards has recently gained interest in the scientific community. Bianchi [12] proposed a bi-dimensional Markov model of the back-off stage procedure adopted by the DCF in saturated conditions.

However, his model is limited for single-hop wireless network. As shown in [13], a multi-hop topology is more suitable to ensure scalability in MANETs. Wang and Garcia-Luna-Aceves [14] firstly adopt a simple multi-hop network model to derive the saturation throughput of a sender-initiated collision avoidance scheme, in which nodes are randomly placed on a plane according to two-dimensional Poisson distribution with density λ. Varying λ has the effect of changing the congestion level within a region as well as the number of hidden terminals. In the model, it is also assumed that each node is ready to transmit independently in each time slot with probability p, where p is a protocol-dependent parameter. This model was first used by Takagi and Kleinrock [15] to derive the optimum transmission range of a node in a multi-hop wireless network, and was used subsequently by Wu and Varshney [16] to derive the throughput of non-persistent CSMA and some variants of busy tone multiple access (BTMA) protocols . They assume that both carrier sensing and collision avoidance work perfectly, that is, the nodes can accurately sense the channel busy or idle, and that the RTS/CTS mechanism can avoid the transmission of data packets that collide with other packets at the receivers. The latter assumption can be called perfect collision avoidance and has been shown to be doable in the floor acquisition multiple access (FAMA) protocol [17].

The IEEE 802.11 is the most widely used MAC protocol in both Ad-hoc and client/server wireless networks.

However, in multi-hop setting where relay nodes are used to achieve end-to-end communication, there is no widely accepted model. Therefore, it is paramount to model and analyze the IEEE 802.11 four-way sender-initiated collision avoidance MAC protocol with a truly multi-hop network as potential interference from hidden nodes always exists, which is a salient characteristic of multi-hop ad hoc networks.

There have been many studies on modeling and performance analysis of single-hop 802.11 wireless networks but only a few on the modeling and analysis of multi-hop wireless networks. Some analysis of multi-hop wireless networks [14] assumed that each node has the same transmission and receiving range and hidden node problem exist only in the transmission range of nodes. Also the channel has a circular region in which there are some nodes in which the decision of inner nodes to transmit, defer and back-off is almost unaffected by that of outer nodes and vice versa.

This paper will address these problems by modeling and analysis of a collision avoidance MAC protocol in multi-hop wireless Ad hoc networks. The models consist of topology, channel and node state models. The topology is modeled by using an undirected graph G (V, A) and by considering number of neighbours of each node, instead of node density, making the analysis more practical while the channel and node state were modeled by using three-state Markov chain. These models were used to derive the duration time, transmission probabilities, transition probabilities and steady-state probabilities of the states of node as well as the throughput of MANETs by adopting EIED back-off mechanism.

3. Modeling and Analysis of Collision Avoidance MAC Protocol

Considering a generic multi-hop network which used 802.11 as MAC protocol in which nodes in the network are distributed as a two-dimensional Poisson process with mean $\overline{N}$, i.e., the probability of finding x nodes in the sensing range of each node is given by $\frac{\overline{N}^x e^{-\overline{N}}}{x!}$,where $\overline{N}$ is the average number of nodes within the sensing range of each node. Assuming all the nodes in the network transmit in a single channel and when the channel is idle, a node begins its transmission with persistent probability p. With a probability $1 - p$ it defers until the next slot. If the transmission is unsuccessful, the node will back-off for a period of time T_b before it retransmits. Also assume that all the nodes use the same transmission range of radius R_t, within which a packet is successfully received if there is no interference from other nodes and use the same sensing range of radius R_s, within which a transmitter triggers carrier sense detection. Since the signal power required for carrier sense is lower than that for transmission, R_s can be larger than R_t. For convenience, the time in the network is slotted. The length of each time slot is denoted by τ , which includes propagation delay as well as the overhead such as the transmit-to-receive turn-around time, carrier sensing delay and processing time. For the sake of simplicity, it is assume that all frame transmission times are multiples of the length of a time slot and when a node is transmitting, it cannot receive at the same time.

The rationale of these assumptions is on the basis of IEEE 802.11 MAC layer specification and also for the sake of simplicity in modeling the protocol in multi-hop network.

3.1 Topology Model

To model the topology of a MANET a node density is used in some existing analysis [8], [18], [19] .To obtain the node density, the information about the total number of nodes in the network and the whole area size is needed. However, it is not easy to obtain the information about the area size in an actual MANET, since it varies with the locations of the nodes. To address this issue, another parameter $\bar{k}$ is used the average number of neighbors of each node within its sensing range.

To obtain $\bar{k}$, the topology of MANET is modeled by an undirected graph G(V, A). V denotes the node set in the network and A is an adjacency matrix that describes the topology of the network. An adjacency matrix is a {0,1} matrix. If G' is a relation on some n-element set X = {x1,x2, ..., xn} then G' is completely described by an n × n matrix A =(a_{ij}), where a_{ij} =1 if x_i, x_j belong to the relation G', and otherwise a_{ij} = 0 [20]. In this case, X is the set of nodes, "1" denotes two corresponding nodes that are in the sensing range of each other, "0" denotes they are not, and a_{ii} =0. Then $\bar{k}$ is calculated by

$$\bar{k} = \frac{\sum_{i,j\in(1,n)} a_{ij}}{n} \qquad (2)$$

With $\bar{k}$ derived from Equation (2), $\bar{N}$ can be easily obtain from the relationship below.

$$\bar{N} = \bar{k} + 1 \qquad (3)$$

For example, in Fig 1, there are eight nodes in an MANET, connected by dashed lines which denote two nodes are within the sensing range of each other. The adjacency matrix A is shown in Fig 2. According to Equation (2) $\bar{k}$ = 1.75. Then from Equation (3) $\bar{N}$ = 2.75. According to Equation (2), $\bar{k}$ is determined by the distribution and number of nodes, which are not related with MAC..

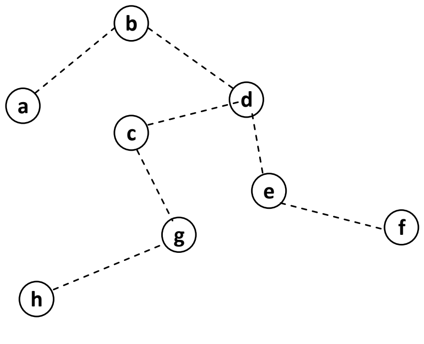

Fig 1. Network Topology

A =

	a	b	c	d	e	f	g	h
a	0	1	0	0	0	0	0	0
b	1	0	0	1	0	0	0	0
c	0	0	0	1	0	0	1	0
d	0	1	1	0	1	0	0	0
e	0	0	0	1	0	1	0	0
f	0	0	0	0	1	0	0	0
g	0	0	1	0	0	0	0	1
h	0	0	0	0	0	0	1	0

Fig 2: Adjacency Matrix.

3.2 Channel State Model

The channel around node i is modeled by a three-state Markov chain. The significance of the states of this Markov chain is: Idle is the state when the channel around node i is sensed idle. Its duration is $T_i = \tau$. Busy-success is the state when the channel around node i is sensed busy because at least one successful four-way handshake is in process during the same period of time. This contains two circumstances. One is that the transmitter and receiver are both within the sensing range of node i. The other one is that the transmitter (or receiver) is within the sensing range of node i, and the receiver (or transmitter) is outside the range. The duration of busy-success state is $T_{bs} = T_{RTS} + T_{CTS} + T_{DATA} + T_{ACK} + 4\tau$. Busy-failure is the state when the channel around node i is sensed busy because a node within the sensing range of node i initiates a failed handshake. For example, two source nodes transmit RTS frames to the same destination node at the same time, and their frames collide. The duration of busy-failure state is $T_{bf} = T_{RTS} + T_{CTS} + 2\tau$.

The transition probabilities between states are shown in Fig 3. The transition probabilities from idle to idle, from idle to busy-success, and from idle to busy-failure are denoted as P_{ii}, P_{is} and P_{if} respectively. Thus,

$$P_{ii} + P_{is} + P_{if} = 1 \qquad (4)$$

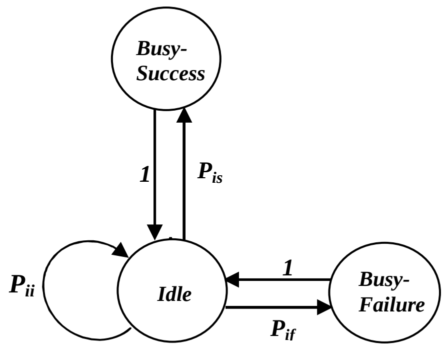

Fig. 3: Markov Chain Model for the Channel Around Node i

Let π_{ii}, π_{is} and π_{if} denote the steady-state probabilities of states idle, busy-success and busy-failure, respectively. Thus, the following relationship exits: $\pi_i P_{is} = \pi_{bs}$; $P_{if} = \pi_{bf}$.

When the channel is sensed idle, in each time slot, a node intends to transmit a frame with the persistent probability p. Therefore, the probability that a node transmits in any time slot is called transmission probability P_t, which is given as:

$$P_t = p \cdot P_i \qquad (5)$$

Where P_i is the limiting probability that the channel is sensed in idle state. Note that even a node transmits; it still may fail due to collisions with other transmissions at the same time. In the analysis, p is specified by the MAC protocol. The limiting probability P_i, i.e., the long run probability that the channel around node i is sensed idle is given as:

$$P_i = \frac{\pi_i T_i}{\pi_i T_i + \pi_{bs} T_{bs} + \pi_{bf} T_{bf}} \quad (6)$$

$$P_i = \frac{T_i}{T_i + P_{is} T_{bs} + P_{if} T_{bf}} \quad (7)$$

Thus

$$P_t = \frac{pT_i}{T_i + P_{is} T_{bs} + P_{if} T_{bf}} \quad (8)$$

The idle channel around node i changes to the busy1-success state in three circumstances. First circumstance is that node i is exposed to at least one source node which performs a successful transmission. Here “expose" means that two nodes can sense each other. Second circumstance is that node i is not exposed to a source node but it is exposed to at least one destination node which performs a successful reception. The third circumstance is that node i itself transmits to a destination node successfully.

Let $P_{is\,1}$ and $P_{is\,2}$ be the probability that there is at least one successful transmission in node i's sensing area and probability that there is at least one successful reception in node i's sensing area respectively. The probability that a node successfully transmits in a slot is P_s , and since on average $\bar{N}$ nodes including node i itself participate in generating a busy slot

$$P_{is1} = 1 - \sum_{n=1}^{\infty} (1 - P_s)^n \frac{\bar{N}^n}{n!} e^{-\bar{N}} \quad (9)$$

In order to eliminate the cases that node i is exposed to both receiver and transmitter, only those cases in which node i is in the exclusive area of a communication have to be considered. This kind of circumstance is illustrated in Fig 4. A parameter A is defined to be the annulus region between two concentric circles of radii R_s and $(R_s + R_t)$. Thus, the area size of A is

$$A = \pi (R_s + R_t)^2 - \pi R_s^2 \quad (10)$$

Let $\bar{N}_A$ be the average number of nodes within the region A, then

$$\bar{N}_A = \frac{A}{\pi R_s^2} \bar{N} \quad (11)$$

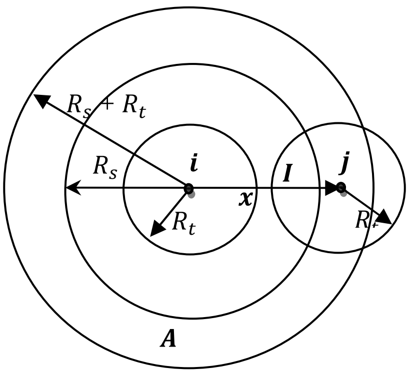

Fig 4 Illustration of Area A and I(x).

Assume that node j in A, as shown in Fig 4, transmits a frame. It may choose any of its neighboring nodes as its receiver with equal probability. I(x) is defined to be the intersection of the sensing area of node i and transmission area of node j. Because P_s denotes the probability that a node begins a successful four-way handshake at each slot, the probability that j initiates a successful four-way handshake to a node in I(x) is given by

$$P_1(x) = P_s \frac{I(x)}{\pi R_t^2} \quad (12)$$

The above results from the assumptions that node j chooses its destination nodes in its transmission range with equal probability and nodes in its transmission range are uniformly distributed. Since the nodes in A are uniformly distributed and j is any randomly selected node in A, the probability density function of the distance between node i and j is

$$f(x) = \frac{1}{(R_s + R_t) - R_s} \quad (13)$$

The probability that any node in A initiates a successful four-way handshake to a node in $I(x)$ is given by

$$P_I = \int_{R_s}^{(R_s+R_t)} P_I(x) f(x) dx \quad (14)$$

The probability that at least one of the transmissions from nodes in A has a destination node in the sensing range of node i, is given by

$$P_{is2} = 1 - \sum_{n=0}^{\infty} (1 - P_I)^n \frac{\bar{N}_A{}^n}{n!} e^{-\bar{N}_A} \quad (15)$$

Therefore, the transition probability P_{is} is given by

$$P_{is} = P_{is1} + P_{is2} \quad (16)$$

The idle channel stays in idle state if none of the nodes in the sensing area of node i transmit in this slot. Thus P_{ii} is given by:

$$P_{ii} = \sum_{n=1}^{\infty} (1 - P_t)^n \frac{\bar{N}^n}{n!} \quad (17)$$

Having P_{is} and P_{ii} in Equation (15)-(16), from Fig 3, P_{if} can be obtained as

$$P_{if} = 1 - P_{ii} - P_{is} \quad (18)$$

3.3 Node State Model

The action of every node in different states is modeled by using a three-state Markov chain as shown in Fig 5. The three states of this Markov chain are : *Wait* is the state when node i defers for other nodes or backs off. Its duration is T_w. *Success* is the state when node i can complete a successful four-way handshake with other nodes. Its duration is T_s. *Failure* is the state when node i initiates an unsuccessful handshake with other nodes. Its duration is T_f.

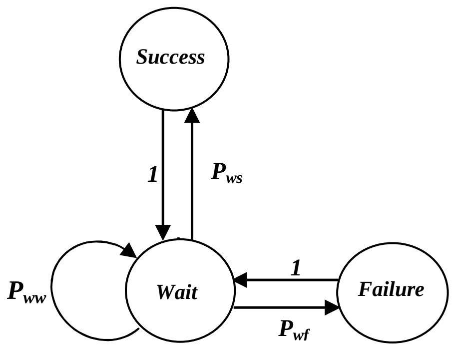

Figure 5 : Markov Chain for Node State Model

By the assumption that collision avoidance is enforced at each node, no node is allowed to transmit data frames continuously, i.e., each node must transit to the wait state after a successful or failed transmission. Therefore, the transition probabilities from success to wait and from failure to wait are both equal to 1. The transition probabilities from wait to wait, from wait to success and from wait to failure are denoted as P_{ww}, P_{ws} and P_{wf}, respectively. Thus,

$$P_{ww} + P_{ws} + P_{wf} = 1 \quad (19)$$

To analyze the transition probability P_{ws} from wait to success state in Fig 5, the probability $P_{ws}(x)$ that node i successfully initiates four-way handshake with node at given time slot and distance (x) between them need to be derived. Exclusive area $E(x)$ is defined to be the region which is the part of sensing area of node j but is not covered by the sensing range of node i as shown in Fig 6.

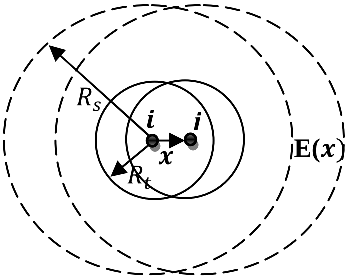

Fig 6 Illustration of Exclusive Area for transmitter i and Receiver j

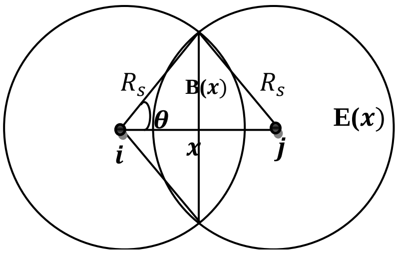

Fig 7 Illustration of Calculation of E(x)

The derivation of $P_{ws}(x)$ is given by:

$$P_{ws}(x) = P_1 \,.\, P_2 \,.\, P_3(x) \quad (20)$$

Where P_1 is the probability that node i transmits in a slot, P_2 is the probability that node j and all the other nodes except node i within R_s of node i does not transmit in the same slot, $P_3(x)$ is the probability that none of the nodes in area $E(x)$ transmits for ($T_{RTS} + \tau$) time. $P_1 = P_t$ and P_2 can be derive using the Poisson distribution of the nodes. Assuming that each node transmits independently, the probability that $(n-1)$ nodes within the sensing range of node i keep silent in a time slot is $(1-pt)^{n-1}$,

Where $(1-pt)$ is the probability that a node does not transmit in a time slot. Thus P_2 is given by

$$P_2 = \sum_{n=2}^{\infty}(1-P_t)^{n-1}\frac{\bar{N}^n}{n!}e^{-\bar{N}} \quad (21)$$

Similarly, the probability that none of the terminals in E(x) transmits in a time slot is given by

$$Pn3(x) = \sum_{n=0}^{\infty}(1-P_t)^n \frac{\left(\frac{E(x)}{\pi R_s^2}\, X\, \bar{N}\right)^n}{n!} e^{-\frac{E(x)}{\pi R_s^2} X \bar{N}} \quad (22)$$

Thus

$$P_3(x) = (Pn3(x))^{T_{RTS}+\tau} \quad (23)$$

Given that each sending node chooses any one of its neighbors as the receiver with equal probability, x can be considered as a uniform random variable in the range 0 < x< R_t

Then, the probability density function of the distance x between node i and j is

$$f(x) = \frac{1}{R_t} \quad (24)$$

From the total probability theorem [11], P_{ws} can be written as follows:

$$P_{ws} = \int_0^{R_t} f(x)\, P_{ws}(x)dx \quad (25)$$

In order to analyze P_{ww}, $\bar{M}$ is defined to be the average number of nodes within the transmission range of node i. Since when the node density does not change, the number of nodes is proportional to the area size,

$$\bar{M} = \frac{\bar{N}\pi R_t^2}{\pi R_s^2} \quad (26)$$

From the Markov chain shown in Fig. 5, the transition probability P_{ww} that node i continues to stay in *wait* state in a given slot, is the probability that node i does not initiate any transmission and there is no node within the transmission range of node i initiating a transmission.

Fig 7 Illustration of Calculation of E(x)

P_w … $\bar{M}$ (27)

$$P_{wf} = 1 - P_{ww} - P_{ws} \quad (28)$$

π_w, π_s and π_f denote the steady-state probability of wait, success, and failure, respectively. Thus, the relationship $\pi_s = \pi_w P_{ws}$ exits.

$$\pi_w + \pi_s + \pi_f = 1 \quad (29)$$

$$\pi_w = \frac{1}{2-Pww}. \quad (30)$$

Therefore,

$$\pi_s = \frac{Pws}{2-Pww} \quad (31)$$

$$\pi_f = 1 - \pi_w - \pi_s \quad (32)$$

3.4 Throughput of a MANET

Throughput of a MANET is defined as the fraction of time the channel is used to successfully transmit payload bits. Let Qs_i be the steady-state probability for state s_i of the node, T_{DATA} be the data transmission time, Ts_i be the time which the node spends on state s_i, the throughput of MANETs is equal to the limiting probability that the node is transmitting data and thus can be denoted by

$$Th = \frac{Qs_i\, T_{DATA}}{\sum_{s_i} Qs_i\, Ts_i} \quad (34)$$

The throughput can also be written as.

$$Th = \frac{\pi_s\, T_{DATA}}{\pi_w T_w + \pi_s T_s + \pi_f T_f} \quad (35)$$

For EIED back-off mechanism the contention window size is decreased by a factor r_D upon a successful transmission, and increased by a factor r_L upon a collision. Simulation results in [6] show that EIED with relatively smaller value of r_D compared to the value of r_L has higher performance gain. For example, let $r_L = 2$, and $r_D = 2^{1/8}$, Then the back-off time can be written as

$$\bar{T}_b = \frac{\frac{1}{2} \cdot \frac{r_L}{r_D}\bar{m}\tau}{pi} \quad (36)$$

It is known that a node transmits with the transmission probability p_t in each slot, therefore the maximum number of deferring time slots for each transmission is $1/p_t$. Reasonably, it is assumed that the average number of deferring time slots for each transmission is a half of the maximum number, i.e., $1/2p_t$. Then $\bar{T}_d$ is given by

$$\bar{T}_d = \frac{\tau}{2p_t} \quad (37)$$

Thus T_w can be calculated from

$$T_w = \bar{T}_b + \frac{\tau}{2p_t} \quad (38)$$

4. Results and Discussions

The model has been verified through extensive simulation using MATLAB 7.1 release 14.

Fig 8 illustrates the influence of persistent probability on throughput of MANET in multi-hop networks by varying number of nodes. Sensing range and transmission range are set to be R_s = 550 m and R_t = 250 m as used in [22] and [23], while duration of data transmission is set to be T_{DATA} = 100 τ. The result indicate that throughput of a MANET increases with increase in persistent probability. Also the throughput decreases as the number of nodes increases because the more collisions take place the more time is needed for a successful transmission, for example when the number of nodes increases from 3 to 8 the throughput drops by 85.7%. This result is consistent with the result presented in [24] which used BEB mechanism.

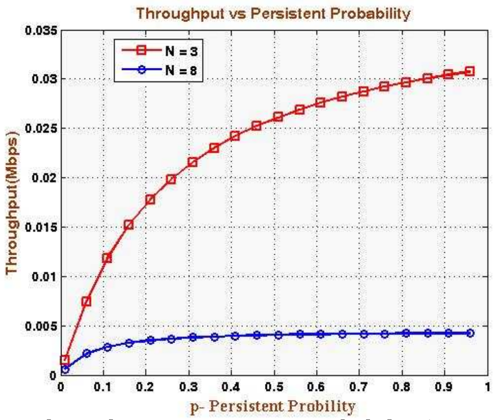

Fig 8: Throughput vs Persistent Probability(Varying $\bar{N}$)

Fig 9 illustrates the influence of transmission range R_t on throughput of MANET in multi-hop networks by varying number of nodes. Sensing range and duration of data frame transmission are set to be R_s = 550 m and T_{DATA} = 100 τ respectively. The result indicate that throughput of MANETs increases along with the increase of transmission range R_t for some values, then it start decreasing with increase in transmission range R_t. This shows that maximum throughput increases when the value of the transmission range is less than half the value of sensing range. Also for the same value of transmission range, the throughput decreases with increase in the number of nodes. This indicates that the number of nodes has significant effect on the maximum throughput for example at a transmission range of R_t = 250m the throughput drops by 66% when the number of nodes increases from 3 to 8.

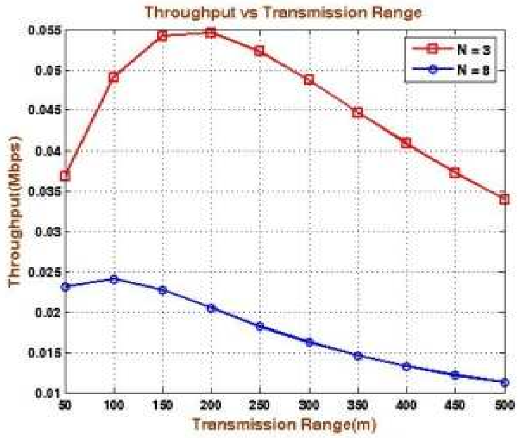

Fig 9 Throughput vs Transmission Range (Varying $\bar{N}$)

Fig 10 illustrates the relationship of sensing range R_s with throughput of MANETs. It is observed that throughput increases along with the increase of R_s. The maximum throughput decreases with increase in the number of nodes, for example when $\bar{N}$ increases from 3 to 8 at a sensing range of R_s = 400m, the maximum throughput dropped by 63.4%. Moreover, the value of R_s for achieving the maximum throughput is varied along with $\bar{N}$. This illustrates that the number of nodes has to increase along with the gain of the sensing range to obtain the maximum throughput.

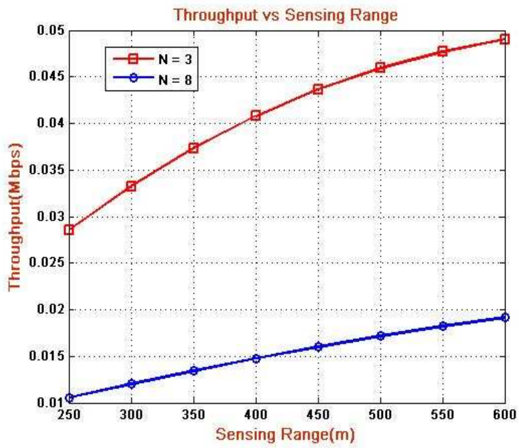

Fig 10: Throughput vs Sensing Range

Fig 11 shows that throughput of MANETs increases with increase in length of DATA frames and achieve it maximum value at some point of length of DATA frame. It indicates that increase in the duration time of DATA frames has more effect on the throughput for the case when the number of nodes is 3, the throughput rises faster. This means that for a large number of nodes, it is not worthy to employ a collision avoidance scheme due to the proportionally larger overhead.

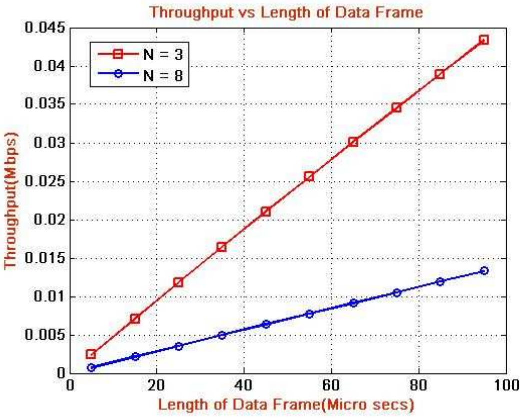

Fig 11 Throughput vs Length of DATA Frame (Varying $\overline{N}$)

Fig 12 illustrates that throughput decreases as the number of nodes increases. This reveals that when the number of nodes increases, the collisions may grow up and significantly affect the throughput. It is observed that the throughput decreases drastically when the number of nodes is greater than 20, for example when the number of nodes increases from 20 to 30 the throughput dropped by to 50%. Also when the number of nodes is more than 50 the throughput dropped to zero.

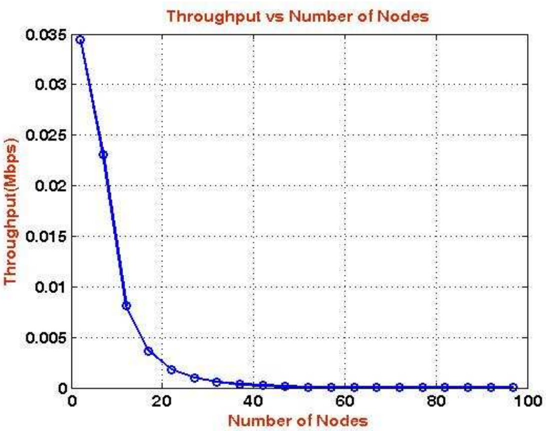

Fig 12 Throughput vs Number of Nodes

Fig 13 revealed the influence of back-off time on the throughput for various numbers of nodes . It is observed that the throughput decreases with the increase of the back-off time, almost linearly. For example, when $\overline{N}$ = 3, the throughput is around 0.053 Mbps, while for $\overline{N}$ = 8 the throughput is about 0.018 Mbps, which is 63% lower than the former. This is because the more number of nodes, the more time is needed for successful transmissions. At the same time, the back-off time increases along with the increase of $\overline{N}$. This can be seen as the reason for the decrease of the throughput.

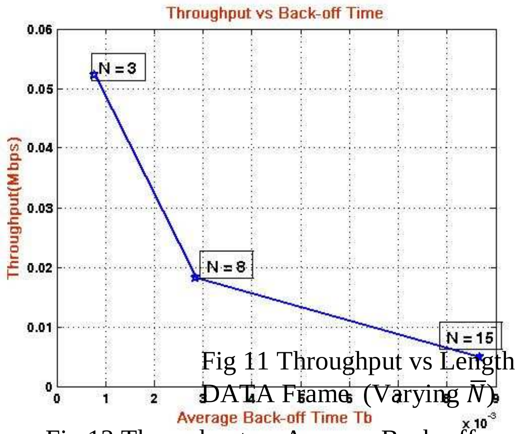

Fig 11 Throughput vs Length of DATA Frame (Varying $\overline{N}$)
Fig 13 Throughput vs Average Back-off

In order to validate the proposed models, a performance comparison of the throughput of an existing model(BEB model) that used BEB as back-off mechanism with the throughput of the proposed model (EIED model) that used EIED as back-off mechanism was carried out by considering persistent probability, sensing range, transmission range, length of DATA transmission and back-off time.

Figs 14 and 15 illustrate the relationship between the persistent probability p and the throughput of MANETs for $\overline{N}$ = 3 and $\overline{N}$ =15 respectively. The results show that the BEB model becomes inefficient when there are many active nodes and hence aggravates the contention of the channel and the aggregate throughput decreases along with increase in number of nodes. For example, when $\overline{N} = 3$ as in fig 14, the throughput of the proposed model at $p = 0.8$ is almost equal to the throughput of BEB model, but for $\overline{N}$ =15 as in fig 15 the throughput of the proposed model at $p = 0.8$ is 93% more than the throughput of BEB model. Similarly, in fig 16 the throughput of the proposed model at sensing range $R_s = 250m$ is 37.1% more than the throughput of the BEB model at the same sensing range.

Furthermore In fig 17 the throughput of the proposed model at transmission range $R_t = 200m$ is 10% more than the throughput of the BEB model at the same transmission range. Likewise In fig 18 the throughput of the proposed model at length of DATA $T_{DATA} = 60\mu s$ is almost the same as that of the BEB.

Fig 19 shows that the throughput of BEB model is always less than the throughput of the proposed model because the back-off time for BEB is the longer than that of the proposed model.

The overall results indicate that the proposed model outperform the BEB model.

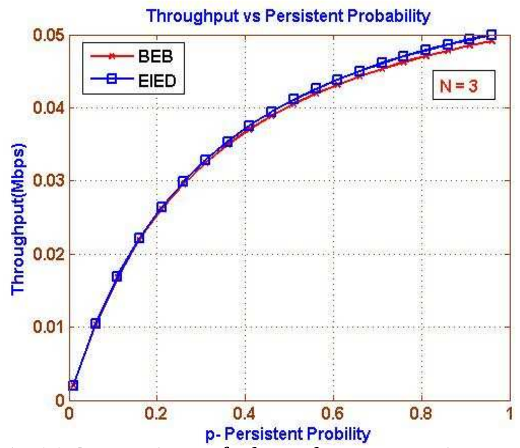

Fig 14 Comparison of Throughput vs Persistent

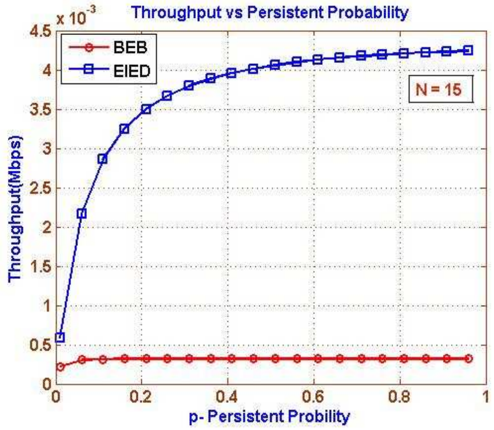

Fig 15 Comparison of Throughput vs Persistent

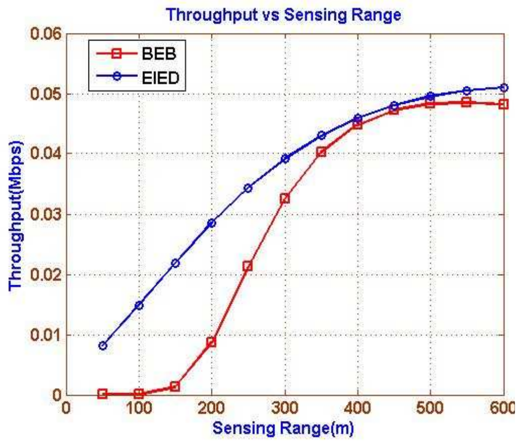

Fig 16 Comparison of Throughput vs

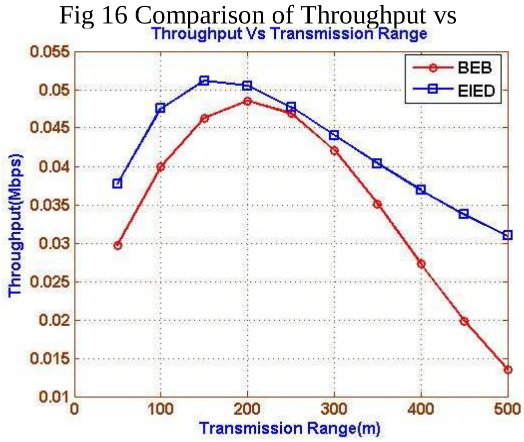

Fig 17 Comparison of Throughput vs

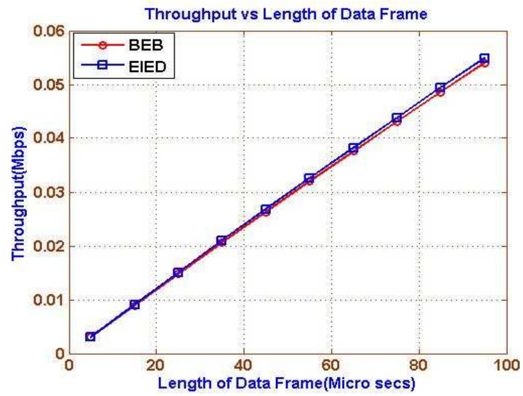

Fig 18 Comparison of Throughput vs

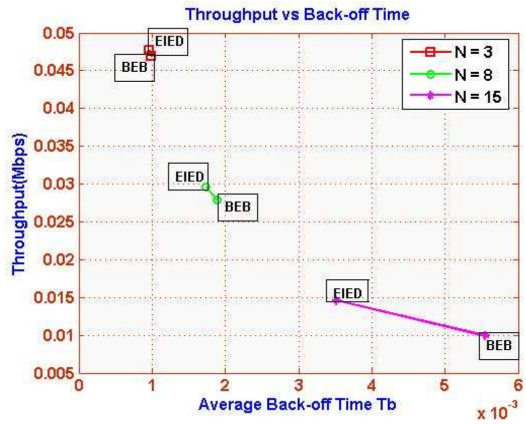

Fig 19 Comparison of Throughput vs

5. Conclusions

A simple n-vertex undirected graph G(V, A) is used to model the topology of MANET while three-state Markov chain is used to model channel state and node state of MANET. These models are used to derive the duration time, transmission probabilities, transition probabilities and steady-state probabilities of the states of node as well as the throughput of the network by adopting Exponential Increase Exponential Decrease (EIED) back-off mechanism. The model has been verified through extensive simulation.

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