EFFECT OF MEDIUM ACCESS CONTROL (MAC) ON THE THROUGHPUT OF MULTI-HOP WIRELESS AD-HOC NETWORK

I. Mustapha[1], J. D. Jiya[2], B. U. Musa[1]
[1]Department of Electrical and Electronic Engineering,University of Maiduguri, Nigeria
[2]Electrical Engineering Programme,Abubakar Tafawa Balewa University, Bauchi Nigeria.
E-mail: ibrahimmassa@yahoo.com, jibjiya@yahoo.co.uk , musa_bu@yahoo.com

ABSTRACT

Medium Access Control (MAC) protocol is the main element that determines the efficiency in sharing the limited communication bandwidth of the wireless channel in IEEE 802.11 wireless networks. This paper, investigate the effect of MAC on throughput of multi-hop wireless ad-hoc network. A Markov chain is used to model a collision avoidance MAC protocol for multi-hop wireless ad-hoc networks. In the models, two fundamental issues in MAC, i.e., collisions and spatial reuse in terms of persistent probability, sensing range and back-off time mechanism were considered. Simulation results show that collision avoidance MAC mechanism such as persistent probability; sensing range and back-off time have significant effects on the performance of multi-hop wireless ad hoc networks. The effects of these MAC mechanisms were influenced by the number of neighbors, transmission range and length of data frame. It is observed that throughput increases with increase in persistent probability and also effect of sensing range on the throughput is weakening when the transmission range is short. Similarly throughput increases with increase in sensing range and back-off time when number of neighbors increases. On the other hand throughput decreases with increase sensing range and back-off time when transmission range increases

Keywords: Mobile ad hoc networks, medium access control, back-off algorithm, RTS/CTS Mechanism, Markov Chain.

INTRODUCTION

A Mobile Ad Hoc Network (MANET) is a network consisting of a collection of nodes capable of communicating with each other without any central authority, e.g., a central server. In this network each mobile node is able to communicate by radio waves with other nodes within its transmission range and relays on other nodes to communicate with mobile nodes outside its transmission range. Applications of MANETs include the battlefield applications, rescue work, as well as civilian applications like an outdoor meeting, or an ad-hoc classroom.

The IEEE 802.11 MAC protocol uses a protocol scheme knows as carrier-sense, multiple access, collision avoidance (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 RF transmission network and it is for this reason that collision avoidance is used. The standard [1] for Wireless LAN's IEEE 802.11 specifies two MAC mechanisms, the Distributed Coordination Function (DCF), and the Point Coordination Function (PCF). DCF designed to support asynchronous data transport where all users have an equal chance of accessing the network. PCF is designed for transmission of delay sensitive data. The PCF is built on top of the DCF, and is used only on infrastructure networks. There are two access methods that are used under DCF, namely the basic access method and the RTS/CTS access method. 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 (NAV) which contains the remaining time of the on-going transmission exchange of data.

Several mechanisms have been proposed to avoid collisions in 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.

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 primary goal of MAC is to coordinate the channel access among multiple nodes to achieve high channel utilization and high network throughput. In other words, the coordination of channel access should minimize or eliminate the incidence of collisions and maximize spatial reuse at the same time [4]. In the carrier sense mechanism, a node determines the channel is busy when the received signal power exceeds a certain threshold, referred to as Carrier Sense Threshold (CST). Otherwise, the channel is determined idle. It can be seen clearly that the value of CST decides the sensing range and affects both the collision possibility and spatial reuse in MANETs. Every station has a back-off counter and a back-off stage. The back-off procedure selects a random number of time slots between 0 and the Contention Window (CW) [1].

The dynamic topology, multi-hop transmission, and the nature of wireless channels pose many challenging research topics in the area of mobile ad-hoc network (MANET). This paper investigates the effect of MAC on the throughput of a MANET. The analysis involves modeling a channel state by using a three-state Markov chain and a node state model using a three-state Markov chain. In the models, two fundamental issues in MAC, i.e., collisions and spatial reuse, in terms of the persistent probability, sensing range and back-off time mechanism are considered.

RELATED WORK

The primary goal of MAC is to coordinate the channel access among multiple nodes to achieve high channel utilization and high network throughput. Bianchi [5] provided an extensive throughput performance evaluation for both standardized access mechanisms of the 802.11 protocol. However, his model is limited to single-hop MANETs. Gobriel et al [6] presented a collision model together with an interference model of a uniformly distributed network. They derived the effect of collisions on both the throughput and the total energy consumption. A collision resolution scheme (exponential back-off) was applied whenever a collision is detected. The higher the number of collisions, the lower the network throughput and the higher the energy consumed resolving these collisions. Wang and Garcia-Luna-Aceves [7] adopted 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 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 [8] to derive the optimum transmission range of a node in a multi-hop wireless network, and was used subsequently by Wu and Varshney [9] to derive the throughput of non-persistent CSMA and some variants of busy tone multiple access (BTMA) protocols[10].

MATERIALS AND METHOD

A Markov chain will be use to model a channel states and a node states of a contention-based IEEE 802.11 DCF protocol. In the models, two fundamental issues in MAC, i.e., collisions and spatial reuse in terms of persistent probability, sensing range and back-off time mechanism will be consider. The models will used to derive the duration time and steady-state probabilities of the states of node as well as the throughput of MANETs.

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(Qs_j equals the long run proportion of transitions which are into state s_j), 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

$$\mathrm{Th} = \frac{\mathrm{Qs_i\ T_{DATA}}}{\sum_{\mathrm{s_i}} \mathrm{Qs_i\ Ts_i}}$$

(1)

In MANETs, it is assumed that all the nodes use the same sensing range of radius R_s and the same persistent probability *p*. The average back-off time of each node during a transmission is denoted by $\bar{T}_b$. During the transmission, it is assumed that each node has three states: a successful transmission state *success*, a wait state *wait*, and a failed transmission state *failure*. We use $s_i = (i = s, w, f, respectively)$ to denote these states.

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:

$$P_t = p \cdot P_i$$

(2)

Where P_i is the limiting probability that the channel is 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.

In order to investigate the action of every node in different states, taking node i as an example, a three-state Markov chain was adopted to model the states of node i as shown in Fig 1. The three states of this Markov chain are *Wait, Success and Failure* and their durations are T_w ,T_s and T_f respectively.

$$T_w = \bar{T}_b + \bar{T}_d$$

(3) Where $\bar{T}_b$ is the average back-off time and $\bar{T}_d$ is the average deferring time.

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,

$$P_{ww} + P_{ws} + P_{wf} = 1 \quad (4)$$

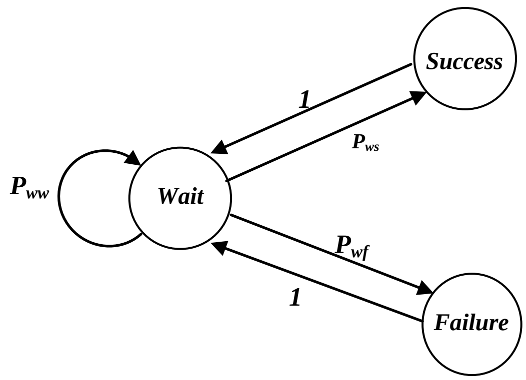

Fig 1: Markov Chain for Node State Model

To obtain the transition probability P_{ws} from wait to success state in Fig 1, 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

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

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

(5)

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. According to the Poisson distribution, the probability of having n nodes within the sensing range R_s of node i is $\frac{\bar{N}^n e^{-\bar{N}}}{n!}$,where $\bar{N}$ is the average number of nodes within the sensing range of each node i. 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

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

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

$$Pn3(x) = \sum_{n=0}^{\infty}(1 - \mathrm{P_t}\ )^n \frac{(\frac{E(x)}{\pi R_S^2}\ X\ \bar{N})^n}{n!}\ e^{-\frac{E(x)}{\pi R_S^2}X\,\bar{N}}$$

(7) Thus

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

(8)

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

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

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

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

(10)

In order to analyze $\mathrm{P_{ww}}$, $\bar{M}$ 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,

$$\bar{M} = \frac{\bar{N}\pi R_t^2}{\pi R_S^2}$$

(11)

From the Markov chain shown in Fig. 1, the transition probability $\mathrm{P_{ww}}$ 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.

$$P_{ww} = (1 - \mathrm{P_t}\ )\sum_{n=1}^{\infty}(1 - \mathrm{P_t}\ )^{n-1}\frac{\bar{M}^n}{n!}e^{-\bar{M}} \qquad (12)$$

$$P_{wf} = 1 - P_{ww} - P_{ws}$$

(13)

Let π_w , π_s and π_f denote the steady-state probability of state *wait, success*, and *failure*, respectively. Then

$$\pi_w + \pi_s + \pi_f = 1 \qquad (14)$$

The steady-state probability of wait and failure states are given by $\pi_s = \pi_w \mathrm{P_{ws}}$, $\pi_f = \pi_w P_{wf}$.

$$\pi_w = \frac{1}{2 - \mathrm{Pww}}.$$

(15)

Therefore,

$$\pi_s = \frac{\mathrm{Pws}}{2 - \mathrm{Pww}}$$

(16)

$$\pi_f = 1 - \pi_w - \pi_s$$

(17)

The channel around a node i is modeled by a three-state Markov chain that is *Idle, Busy-success and Busy-failure* as shown in Fig 2 and their durations are denoted as T_i , T_{bs} and T_{bf} respectively .

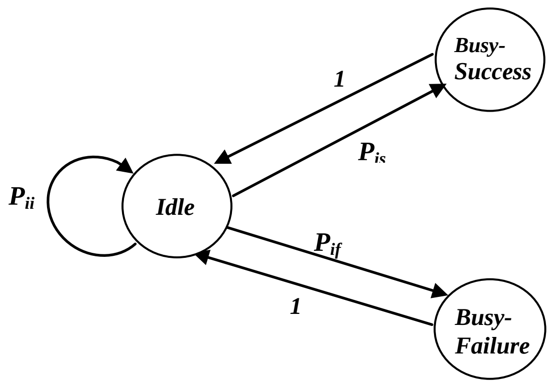

Fig. 2: Markov Chain Model for the Channel around Node i

P_{is} and P_{if} are the transition probabilities from idle to busy1-success and from idle to busy2-failure, as shown in Fig.2. 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. 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,

$$P_{is1} = 1 - \sum_{n=1}^{\infty}(1 - P_s)^n \frac{\bar{N}^n}{n!} e^{-\bar{N}} \qquad (18)$$

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. 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

$$A = \pi(R_s + R_t)^2 - \pi R_s^2 \qquad (19)$$

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

$$\bar{N}_A = \frac{A}{\pi R_s^2}\bar{N} \qquad (20)$$

Assume that node j in A, 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

$$P_1(x) = P_s \frac{I(x)}{\pi R_t^2} \qquad (21)$$

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

$$f(x) = \frac{1}{(R_s+R_t)-R_s} \quad (22)$$

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

$$P_I = \int_{R_s}^{(R_s+R_t)} P_I(x) f(x) dx \quad (23)$$

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

$$P_{is2} = 1 - \sum_{n=0}^{\infty} (1 - P_I)^n \frac{\bar{N}_A{}^n}{n!} e^{-\bar{N}_A} \quad (24)$$

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

$$P_{is} = P_{is1} + P_{is2} \quad (25)$$

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:

$$P_{ii} = \sum_{n=1}^{\infty} (1 - \mathrm{P_t})^n \frac{\bar{N}^n}{n!} \quad (26)$$

$$P_{if} = 1 - P_{ii} - P_{is} \quad (27)$$

When Binary Exponential Back-off (BEB) is applied in the MAC protocol, $\bar{\mathrm{m}}$ is assumed to be the average number of collisions for each transmission. Therefore for each successful transmission, there are average $\mathrm{P_{wf}}/\ \mathrm{P_{ws}}$ collisions, i.e.

$$\bar{\mathrm{m}} = \frac{\mathrm{P_{wf}}}{\mathrm{P_{ws}}} \quad (28)$$

The contention window size is $2^{\bar{\mathrm{m}}}$. Thus, the node selects a random back-off timer uniformly distributed in [0; $2^{\bar{\mathrm{m}}}$ - 1]. The middle is chosen as the average back-off timer. Since the back-off timer decreases as long as the channel is sensed idle, "frozen" when a transmission is detected, and reactivated when the channel is sensed idle again, then the average back-off time for each node in one transmission is given by

$$\bar{\mathrm{T}}\mathrm{b} = \frac{2^{\bar{\mathrm{m}}-1}\,\mathrm{T}}{\mathrm{pi}} \quad (29)$$

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

$$\bar{\mathrm{T}}\mathrm{d} = \frac{\mathrm{T}}{2\mathrm{p_t}} \quad (30)$$

Thus $\mathrm{T_w}$ can be obtained as

$$\mathrm{T_w} = \bar{\mathrm{T}}\mathrm{b} + \frac{\mathrm{T}}{2\mathrm{p_t}} \quad (31)$$

Therefore, the throughput of MANET can be wirtten as.

$$\mathrm{Th} = \frac{\Pi_s T_{DATA}}{\Pi_w T_w + \Pi_s T_s + \Pi_f T_f}$$

(32)

SIMULATION RESULTS AND DISCUSSIONS

The persistent probability p, sensing range R_s, and back-off time T_b, representing the MAC mechanisms in IEEE 802.11 DCF scheme, are contained in the analysis of the throughput. Thus, p, R_s, and T_b can be adjusted to observe the effects of MAC mechanism on the throughput of MANETs. When evaluating one variable's effect on the throughput, the other two variables are fixed. The simulation was carried out using MATLAB 7.1 release 14.

Fig 3 illustrates the effect of persistent probability p on the throughput of MANETs, with different values of average number of neighbors $\bar{k}$. Sensing range and transmission range are set to R_s = 550m and R_t = 250m as used in [12] and [13], while duration of data transmission is set to be T_{DATA} = 100 τ .The result show that for $\bar{k}$ = 3, 5, and 8 the throughput decreases when $\bar{k}$ increases because the more number of neighbors, the more collisions may happen, and the more time is needed for a successful transmission. For example, in Fig 3 if we increase $\bar{k}$ from 3 to 5, the throughput reduces by 40%. This is because when the number of neighbors increases, the collisions may grow up, but a smaller persistent probability can alleviate such a trend.

Fig 4 illustrates the effect of persistent probability on the throughput of MANETs, with different values of transmission range R_t. The maximum throughput increases when R_t increases because when p is high, with a larger transmission range, a node can transmit to more other nodes so as to increase the spatial reuse of the channel, which leads to a higher throughput. For example, in Fig 4 when R_t = 120m, the throughput reaches 0.045 Mbps; when R_t = 150 m, the throughput rises to 0.05 Mbps, 11.11% higher than the former.

Fig 5 illustrates the effect of persistent probability p on the throughput of MANETs for different values of length of DATA T_{DATA} = 5 τ , T_{DATA} = 15 τ and T_{DATA} = 100 τ. The former is the case that the data frame size is less than the aggregate size of RTS, CTS, and ACK frames. The latter is the case that the data frame size is much larger than the aggregate size of RTS, CTS, and ACK frames while the other case is when the data frame size is equal to the aggregate size of RTS, CTS, and ACK frame. Obviously, when p is increases the throughput is also increases. In the other hand, when length of the DATA frame increases the throughput also increases. For example, in Fig 5 when T_{DATA} is increase from 15 τ to 100 τ , the throughput increases to 50%.

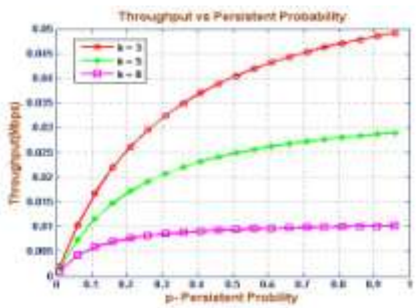

Fig 3 Throughput vs Persistent Probability(Varying $\bar{K}$)

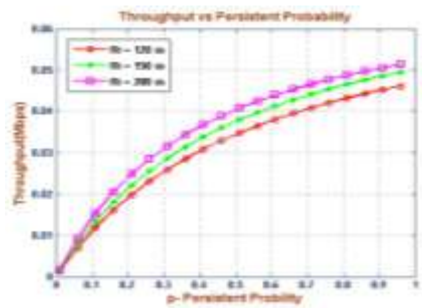

Fig 4 Throughput vs Persistent Probability (Varying R_t)

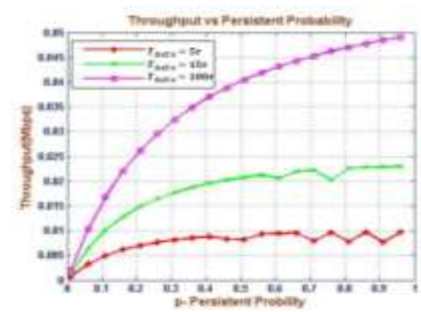

Fig 5 Throughput vs Persistent Probability (Varying T_{DATA})

Fig 6 illustrates the effect of sensing range R_s on the throughput of MANETs, with different average number of neighbors $\bar{k}$. It is observed that for every value of $\bar{k}$, the throughput increases along with the increase of R_s. The maximum throughput decreases with the increase in the number of neighbors. For instance, in Fig 6 when $\bar{k}$ is increase from 3 to 5 at a sensing range of R_s = 300 m, the maximum throughput dropped to 72.2%. Similarly, when $\bar{k}$ is increase from 3 to 5 at a sensing range of R_s = 550 m, the maximum throughput dropped to 40.5%. This illustrates that the number of neighbors has to increase along with the gain of the sensing range to obtain the maximum throughput.

Fig 7 illustrates the effect of sensing range on the throughput of MANETs with various transmission ranges. The throughput increases along with the increase of R_s for transmission range $R_t = 200\ \text{m}$, while for transmission range of $R_t = 120\ \text{m and } R_t = 150\ \text{m}$, the throughput increases with increase in sensing range R_s, but when it reaches the maximum throughput it will start decreasing with increase in R_s. For example, the maximum throughput for $R_t = 120\text{m}$ and $R_t = 150\text{m}$ occured at R_s = 300m and R_s = 400m respectively, while the maximum throughput for $R_t = 200\text{m}$ increases with R_s . It is also observed that for the same R_s, the larger transmission range has a higher throughput. For example, in Fig 7 when $R_s = 550\ \text{m}$, the throughput curve for $R_t = 120\text{m}$ is 12.2% lower than the throughput curve for $R_t = 200\text{m}$. Moreover, the throughput curve for $R_t = 200\text{m}$ rises faster along with the increase of R_s. This indicates that the effect of sensing range on the throughput is weakening when the transmission range is short. Also a smaller transmission range means more transmission hops which leads to more collisions.

Fig 8 illustrates the effect of sensing range on the throughput of MANETs for different length of DATA frames. Three kinds of length of DATA frames are assumed: T_{DATA} = 5τ , T_{DATA} = 15τ and T_{DATA} = 100τ, while $\bar{k}$ = 3 and $R_t = 250$m . It is observed in Fig 8 that increase in the sensing range has more effect on the throughput for the case when the data frame size is larger than the aggregate size of RTS, CTS, and ACK frames. When T_{DATA} = 100τ, the throughput curve rises faster and the maximum throughput increases with increase in the sensing range R_s. When the data frame size is less than the aggregate size of RTS, CTS, and ACK frames i.e T_{DATA} = 5 τ , the throughput curve rises slowly and the maximum value of the throughput is lower than that for T_{DATA} = 100 τ . Therefore, when the DATA frames are short, it is not worthy to employ a collision avoidance scheme due to the proportionally larger overhead. .

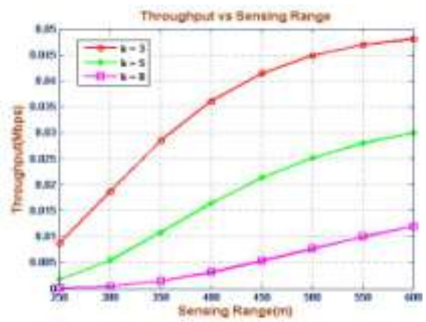

Fig 6 Throughput vs Sensing Range (Varying $\overline{K}$)

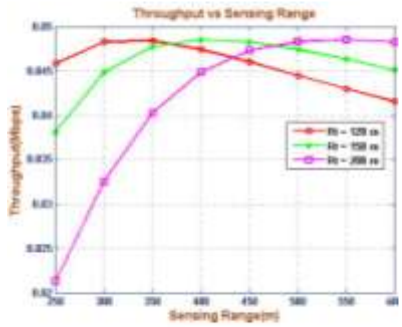

Fig 7 Throughput vs Sensing Range (Varying R_t)

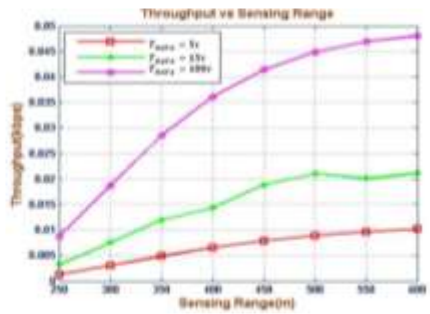

Fig 8 Throughput vs Sensing Range (Varying T_{DATA})

Fig 9 revealed the effect of back-off time on the throughput for various numbers of neighbors in the sensing range of each node. It is observed that the throughput decreases with the increase of the back-off time, almost linearly. For example, when $\bar{k}$ = 3, the throughput achieves at 0.13Mbps, while for $\bar{k}$ = 8 the throughput is about 0.048 Mbps, which is 63% lower than the former. At the same time, the back-off time increases along with the increase of $\bar{k}$. For instance, the back-off time of $\bar{k}$ = 3 is 1000 µs while for $\bar{k}$ = 8, it grows up to 1900 µs. This can be seen as the reason for the decrease of the throughput. The effect of back-off time on the throughput for various transmission ranges R_t is shown in Fig 10, when $\bar{k}$ = 3 and $T_{DATA} = 100\tau$. It is observed that the throughput increases along with the increase of the transmission range for R_t from 150m to 200m, and then decreases with increase in transmission range. For instance, when $R_t = 150$m , the throughput is about 0.09Mbps; when $R_t = 250$m, the throughput is about 0.1 Mbps, which is about 10% lower than the former. Therefore, with the same number of neighbors and sensing range, increasing the transmission range can improve the throughput for some values.

Fig 11 illustrates the effect of back-off time on the throughput for the three kinds of DATA frames i.e T_{DATA} = 5τ and T_{DATA} = 15τ and T_{DATA} = 100τ, while $\bar{k}$ = 3 and $R_t = 250$m. It is observed 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. For example when T_{DATA} = 100τ the throughput is 0.13 Mbps; when T_{DATA} = 5τ, the throughput is 0.025 Mbps, which is about 80.7% lower than the former. Clearly, the throughput for the larger DATA frames is much higher than that for the shorter DATA frames. As for the back-off time, the throughput increases with increase in back-off time.

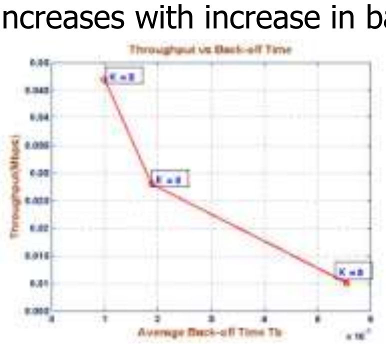

Fig 12 Throughput vs Average Back-off Time (Varying $\overline{K}$)

Fig 13 Throughput vs Average Back-off Time (Varying R_t)

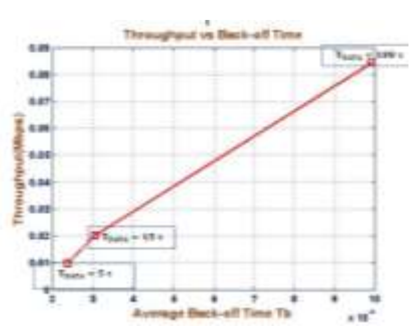

Fig 14 Throughput vs Average Back-off Time (Varying T_{DATA})

CONCLUSIONS

Throughput of a collision avoidance MAC protocol for multi-hop wireless Ad hoc networks and the effect of MAC on the throughput of a MANET have been presented. The analysis involves modeling a channel state by using a four-state Markov chain and a node state model using a three-state Markov chain. In the models, two fundamental issues in MAC, i.e., collisions and spatial reuse, in terms of the persistent probability, sensing range and back-off time mechanism are considered.

Simulation results show that collision avoidance MAC mechanism such as persistent probability; sensing range and back-off time have significant effects on the performance of multi-hop wireless ad hoc networks and also the effects of these MAC mechanisms were influenced by the number of neighbors, transmission range and length of data frame.

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