INFLUENCE OF PHYSICAL CARRIER SENSING THRESHOLD ON SPATIAL REUSE IN AD HOC NETWORKS

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Abstract

IEEE 802.11 MAC having two methods for medium reservation. 1) virtual carrier sensing and 2) physical carrier sensing. VCS having many drawbacks in wireless ad hoc networks. Physical carrier sensing is more advantage than the virtual carrier sensing in terms of throughput, spatial reuse and probability of collisions and its playing important role to remove hidden terminal problem and exposed terminal problem. Choice of physical carrier sensing threshold is trade-off between the amount of spatial reuse and probability of packet collisions in a wireless ad hoc network. In this mechanism no need of extra amount of packets to reserve the medium and its somehow removing hidden terminal problem and exposed terminal problem compared to virtual carrier sensing. we present a new analytical approach for optimizing the PCS threshold as measured by probability of packet collisions and the aggregate one-hop throughput. The goal of this work lies in developing an analytical model for PCS tuning to evaluate its impact on network metrics such as the saturation throughput and the probability of collisions. We developed a markov chain model for each node to estimate the optimal physical carrier sensing threshold for a network.

Keywords: Throughput, Physical Carrier Sensing, MAC, Ad hoc Network, IEEE 802.11, Threshold

I. INTRODUCTION

Ad hoc network does not depend on the existence of base stations or network infrastructure. Instead, it consists only of a collection of hosts. Hosts of these networks function as routers that discover and maintain routes to other hosts in the network. Now a day ad hoc networks are providing broadband connectivity to the backbone networks for Internet for mobile clients such as campus, office and home must exploit the limited system bandwidth available via spatial reuse to enhance aggregate 1-hop throughput. However, enhancing spatial reuse in such dense ad hoc networks depends on various factors [1]: the type of radio, signal propagation environment and network topology. In particular, the random topology of an ad hoc network has a significant impact on interference management and can cause large local variability in achievable spatial reuse.

In IEEE 802.11, Distributed Coordinating Function (DCF) [2-4] or CSMA/CA uses carrier sensing to determine if the shared medium is available before transmitting.

Two types of carrier sensing are supported by DCF: mandatory physical carrier sensing [2] monitors RF energy level in the medium and optional virtual carrier sensing [3] using RTS (request to send) and CTS (clear to send) to preserve the medium. Before going into the concepts of Physical Carrier Sensing let us see the braw backs of Virtual Carrier Sensing in section II. Interference mitigation via PCS is explained in section III. And last section deals with simulation results how Physical Carrier Sensing threshold (range) affects the network throughput.

II. NECESSITATE OF PHYSICAL CARRIER SENSING

A. Hidden Station Problem

The hidden terminal problem [3]. Node A and C are out of transmission range of each other and A sends packets to B. Before C is going to start its transmission to node B as well it senses if the medium is available. Since it will not hear node A, it will falsely conclude that the channel is free and start its transmission to node B, resulting in garbled packets sent by A. Thus, the cause of the hidden terminal problem is that a sender does not know about other competitors that are out of transmission range and transmitting to the same destination

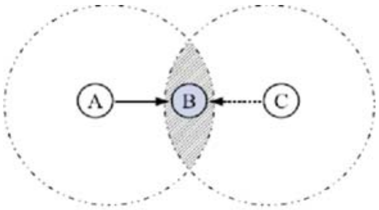

Fig. 1. Hidden Terminal Problem

B. Exposed Terminal Problem

In the exposed terminal scenario depicted in Fig. 2 node B is transmitting to node A and node C is going to send to node D, whereas B and C are within transmission range of each other. Node C senses the medium and falsely concludes that the transmission to node D will interfere with the data sent by node B and thus will not start its transmission. However, the two transmissions will not interfere at the receiver nodes A and D.

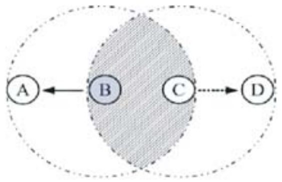

Fig. 2. Exposed Terminal Problem

C. Theoretical Analysis for RTS/CTS Handshake

The RTS/CTS handshake of IEEE 802.11 MAC does not work as well as we expected in theory. It cannot prevent hidden terminal problems completely. In this section, we explain this through a simple theoretical analysis. For better understanding, we first define three radio ranges related to a wireless radio, namely Transmission Range (Rtx), Carrier Sensing Range (Rcs) and interference Range (Ri). Transmission Range (Rtx) represents the range within which a packet is successfully received if there is no interference from other radios. The transmission range is mainly determined by transmission power and radio propagation properties (i.e., attenuation).

Carrier Sensing Range (Rcs) is the range within which a transmitter triggers carrier sense detection. This is usually determined by the antenna sensitivity. In IEEE 802.11 MAC, a transmitter only starts a transmission when it senses the media free interference Range (Ri) is the range within which stations in receive mode will be" interfered with" by an unrelated transmitter and thus suffer a loss.

The transmission range and carrier sensing range are generally well known. They are fixed ranges only affected by the properties of the wireless radios installed at the sender and receiver. The interference range, however, draws little attention. Generally interference range not a fixed range it is varies with the distance between the transmitter and the receiver. In some situations, the interference range can goes far beyond the transmission range, resulting various problems that have been involved wireless ad hoc networks.

Nodes within the interference range of a receiver are usually called hidden nodes. When the receiver is receiving a packet, if a hidden node also tries to start a transmission concurrently, collisions will happen at the receiver. When a signal is propagated from a transmitter to a receiver, whether the signal is valid at the receiver largely depends on the receiving power at the receiver. Given transmission power (Pt), the receiving power (Pr) is mostly decided by path loss over the transmitter-receiver distance, which models the signal attenuation over the distance. Other factors include multipath fading, shadowing, environment noise etc. Here we ignore these factors since they are minor factors in the open space environment. According to [4], in the open space environment, the receiving power (Pr) of a signal from a sender d meters away can be modeled as (1).

$$P_r = P_tG_tG_r \frac{h^2th^2r}{d^k} \qquad (1)$$

From (1), Gt and Gr are antenna gains of transmitter and receiver respectively. ht and hr are the height of both antennas.

Here, we assume that the ad hoc network is homogeneous, that is all the radio parameters are same at each node. k should be larger than 2 and reflects how fast the signal decays. The larger it is, the faster the signal attenuates. In the open space environment, the TWO-RAY GROUND path loss model is generally adopted. Within this model, when the transmitter is close to the receiver (e.g. within the Freznel zone [4]), receiving signal power is inverse proportional to d2. When their distance is larger (e.g. outside of Freznel zone), the receiving signal power is then inverse proportional to d4 [4].

A signal arriving at a receiver is assumed to be valid if the Signal to Noise Ratio (SNR) is above a certain threshold (TSNR). Now, we assume a transmission is going from a transmitter to a receiver with transmitter-receiver distance as d meters and at the same time, an interfering node r meters away from the receiver starts another transmission. Let Pr denote the receiving power of signal from transmitter and Pi denote the power of interference signal at the receiver. Then, SNR is given as SNR = Pr/Pi. Here, we ignore the thermal noise since it is ignorable comparing to interference signal. Under the assumption of homogeneous radios, we get

$$SNR = P_r / P_i = \frac{P_tG_tG_r\frac{h^2{}_t h^2{}_r}{d^k}}{P_tG_tG_r\frac{h^2{}_t h^2{}_r}{r^k}} = (r/d)^k \ge T_{SNR} \qquad (2)$$

$$\therefore r \ge \sqrt[k]{T_{SNR}} * d \qquad (3)$$

This implies that to successfully receive a signal, the interfering nodes must be at least $r \geq \sqrt[k]{T_{SNR}} * d$ meters away from the receiver. We define this as the interference range R_i of the receiver regarding to a specific transmission with transmitter-receiver distance as d meters. Thus we have the formal definition of as R_i

$$\therefore R_i \geq \sqrt[k]{T_{SNR}} * d \qquad (4)$$

From (4), it is easy to see that when the transmitter-receiver distance d is larger than $R_{tx} * T_{SNR}^{-\frac{1}{k}}$ interference range then exceeds the transmission range R_{tx}. In practice T_{SNR} is usually set to 10. Under the TWO-RAY GROUND pathloss model, k is equal to 4. Then we have interference range as $R_i = \sqrt[4]{10} * d = 1.78 * d.$

When d is larger than 0.56 * R_{tx}, R is large than R_{tx} .This is easy to understand that power level needed for interrupting a transmission is much smaller than that of successfully delivering a packet. With the formal definition we can now define the interference area Ai around a receiver

$$A_i = \Pi R^2{}_i \qquad (5)$$

D. Effectiveness of RTS/CTS Handshake

Since the major purpose of RTS/CTS handshake is to avoid interference caused by hidden nodes, it is interesting to evaluate how effective it is. To do so, we first define the effectiveness of RTS/CTS $(E_{RTS/CTS})$ as below.

$$E_{RTS/CTS} = \frac{A_{i \cap RTS/CTS}}{A_i} \qquad (6)$$

Here, Ai is the total interference area defined in (5).

$A_{i \cap RTS/CTS}$ Represents part of the interference area where nodes can receive RTS/CTS successfully. When $d \leq R_{tx} * T_{SNR}^{-\frac{1}{k}}$, apparently is $A_{i \cap RTS/CTS}$ equal to Ai since transmission range is now larger than the interference range. Thus $E_{RTS/CTS}$ is smaller than 1. When d increases beyond $R_{tx} * T_{SNR}^{-\frac{1}{k}}$, $A_{i \cap RTS/CTS}$ becomes smaller than Ai, resulting the $E_{RTS/CTS}$ smaller than 1. $E_{RTS/CTS}$ further decreases along with the increase of d. The upper bound of d is R_{tx} since if d is larger than R_{tx}, the two nodes are out of range of each other. The situation that d is larger than $R_{tx} * T_{SNR}^{-\frac{1}{k}}$ and smaller than R_{tx} is illustrated in fig. 3.

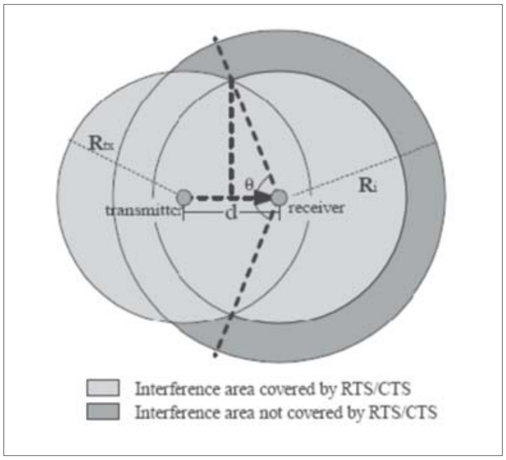

Fig. 3. RTS/CTS Handshake

From Fig.3 we can approximately calculate the RTS CTS E / when d is within $[T_{SNR}^{-\frac{1}{k}} * R_{tx}, R_{tx}]$ The dark shaded area in Fig. 3 represents part of the interference area which is not covered by RTS/CTS handshake (e.g. $A_i - A_{i \cap RTS/CTS}$). To calculate this area, we should first calculate the angle £ as shown in Fig.3.

$$\cos\left(\frac{\Theta}{2}\right) = \frac{d/2}{R_{tx}} \Rightarrow \Theta = 2\arccos\left(\frac{d}{2R_{tx}}\right) \qquad (7)$$

We approximately calculate the shaded area in Fig.

$$3 \text{ As } \frac{2\Pi - \Theta}{2\Pi}\left(\Pi R^2{}_i - \Pi R^2{}_{tx}\right).$$

Thus, the interference area covered by RTS/CTS is given

$$\text{as } A_{i \cap RTS/CTS} = \Pi R^2{}_i - \frac{2\Pi - \Theta}{2\Pi}\left(\Pi R^2{}_i - \Pi R^2{}_{tx}\right) \qquad (8)$$

The total interference area is given as $A_i = \Pi R^2{}_i$,

$$E_{RTS/CTS} = \begin{cases} 1, & \text{if } 0 \leq d \leq R_{tx} * T^{-\frac{1}{k}}{}_{SNR} \\ 1 - \dfrac{\left[\Pi - \arccos\left(\dfrac{d}{2R_{tx}}\right)\right]\left[d^2 * T^{\frac{2}{k}}{}_{SNR} - R^2{}_{tx}\right]}{\Pi d^2 * T^{\frac{2}{k}}{}_{SNR}}, & \text{if } T^{\frac{1}{k}}{}_{SNR} * R_{tx} < d \leq R_{tx} \end{cases} \qquad (9)$$

E. Influence of Physical Carrier Sensing

The effectiveness of RTS/CTS can be improved by the physical carrier sensing (CSMA part of IEEE 802.11 MAC which is known as CSMA/CA) performed at each node before it starts a transmission. However, since interference happens at receivers while carrier sensing is detecting transmitters (The same situation as hidden terminal problem which inspires the RTS/CTS handshake.), we can see how physical carrier sensing eliminate the hidden problem is this section. Three dotted circles in Fig. 4. Represent three different carrier sensing ranges.

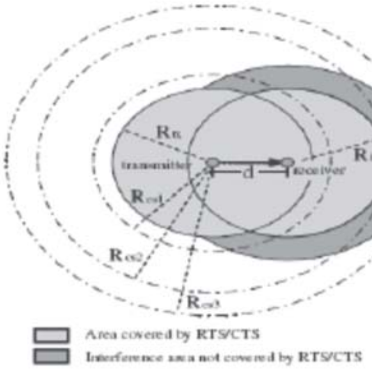

Fig. 4. Illustration of how physical carrier sensing help reducing interference.

R_{cs1} Represents the ordinary case where carrier sensing range is slightly larger than the transmission range. Such physical carrier sensing cannot reduce the uncovered interference area much. If we can further increase the carrier sensing range to R_{cs3} (equal to (d + R_i)) as shown in Fig. 4, we can now totally cover the interference area. Interestingly, when the carrier sensing range exceeds R_{cs2} (equal to (d + R_{tx})), all the area covered by RTS/CTS handshake is now totally covered by carrier sensing. That means when the carrier sensing range is larger than(d+ R_{tx}), RTS/CTS is no longer needed! Three issues are concerned for such a large carrier sensing range. First, carrier sensing range is usually a fixed range. Adaptively adjusting this range according to different transmitter-receiver distance d would be complex. Thus, the maximum values of R_{cs2} and R_{cs3} when d equals to R_{tx} should be taken, which are 2 * R_{tx} and R_{tx} +1.78R_{tx} = 2.78* R_{tx} respectively (under assumption of two-ray ground pathloss model). Second, the carrier sensing range is decided by the sensitivity of antennas. Thus there is a hardware limitation. Third, too large carrier sensing range will reduce the network throughput significantly. we mentioned that physical carrier sensing not a fixed value or a static threshold value it has to vary according to the distance between transmitter and receiver. So it is very complex to vary distance so we will fix one value which will give the high throughput, less probability of collisions and high spatial reuse.

In wireless networks mobility leads to interference with other nodes. Interference mainly happens with hidden terminal problems. So to resolve the hidden terminal problem [4] becomes one of the major design considerations of 802.11 MAC protocols. IEEE 802.11 DCF is the most popular MAC protocol used in both wireless LAN and ad-hoc networks. Its RTS/CTS handshake is mainly designed for such a purpose. However, it has an underlying assumption that all hidden nodes are within the transmission range of receivers. In this paper we can see such an assumption man not hold when the transmitter-receiver distance exceeds a certain value. In Fig 5 shows this distance effect on performance.

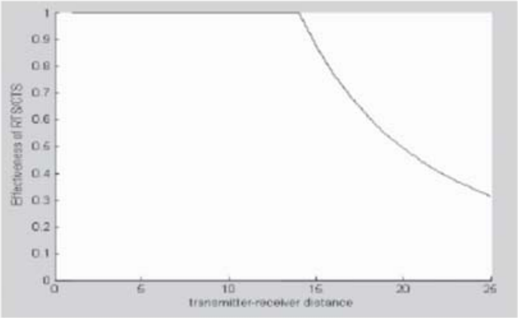

Fig. 5. Effectiveness of Virtual Carrier Sensing

Fig. 5 shows the virtual carrier sensing implemented by RTS/CTS handshake cannot prevent all interference. Effectiveness RTS/CTS handshake is depended on distance between the transmitter and the receiver. When the distance exceeds 0.56*Rtx, the effectiveness of RTS/CTS handshake drops rapidly.

We consider a 1-D chain network for simulation results. In this chain networks all nodes are placed in one by one and distance between the nodes is 200m. When distance between the transmitter-receiver is 200m which is large value then the interference range is 356m. Basically in first case throughput is nearly 600Mbps very less because of large distance between the nodes. Throughput is decreased because of hidden terminal problem.

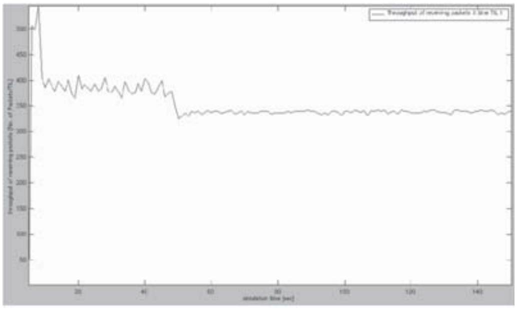

Fig. 6. Effectiveness of long distance on RTS/CTS

In second case distance between the transmitter and receiver is 150m. Then the interference range is occupied up to 267m. In this situation distance between the transmitter-receiver is very less so throughput very high nearly 1200Mbps from Fig. 7.

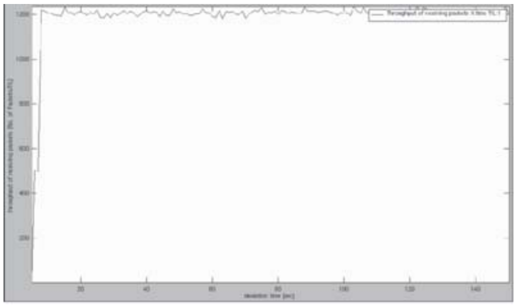

Fig. 7. Effectiveness of small distance on RTS/CTS

We can conclude when the transmitter-receiver distance is less can get maximum throughput because of hidden terminals are very less. Otherwise in second case throughput is minimum because hidden terminals are very high. Practical applications such assumption can hold properly not only this reason RTS/CTS handshake won't give maximum spatial reuse. Physical Carrier Sensing can eliminate all this drawbacks.

III. INTERFERENCE MITIGATION VIA PCS

In this section, we discuss the properties of radio communication that determine the effectiveness of carrier sensing and point out several shortcomings of the carrier sensing techniques commonly employed in 802.11 MAC [5].

A. Communication model

Path loss models are commonly used to describe the radio propagation property in wireless networks [6]. A typical path loss model expresses the average signal strength at the receiver as a function of the T-R (transmitter-receiver) separation distance, d, i.e

$$P_{rx}(d) = \bar{P}_{rx}\left(\frac{\bar{d}}{d}\right)^{\gamma} \tag{10}$$

Where γ is the path loss exponent that characterizes how quickly a signal fades in the particular network environment. $P_{\gamma x}$ denotes the signal strength at a receiver at distance d away. Finally, $\bar{P}_{\gamma x}$ is the reference receiving signal strength as measured at the reference distance (usually 1 meter). The aggregate energy detected by a receiver consists of signal (from intended transmitter), interference (from unwanted transmitter(s)) and noise. In ad hoc networks, a receiver can receive a packet with high probability of success only if the receiving strength of the intended signal is greater than a threshold (denoted by P_R), and the signal-noise-interference ratio (SNIR) is above a threshold (denoted by S_o).

$$P_{rx}(d) \geq P_R \tag{11}$$

$$\frac{P_{rx}(d)}{P_N + \sum P_{rx}(d_i)} \geq S_0 \tag{12}$$

Where P_N is the strength of the ambient noise, and $P_{rx}(di)$ denotes the signal strength from interference sources i at distance *di* . In most cases, the noise level is negligible compared to either the signal and interference.

B. Link Layer Model for Communication

The common path loss model relates the average power at a receiver as a function of the transmitter-receiver separation distance, d via

$$P_{rx}(d) = \bar{P}_{rx}\left(\frac{\bar{d}}{d}\right)^{\gamma} \tag{13}$$

Where γ is path loss exponent and $\bar{P}_{rx}$ is the power received at a reference point in the far field region at distance d from the transmitting antenna.

Following [6], the aggregate energy at any receiving node consists of the desired signal, the interference (from unwanted transmitter(s)) and the background noise. A node can receive a packet with high probability of success only if a) the received signal strength is greater than a threshold (denoted by P_R, i.e. reception sensitivity) and b) the received Signal-to-Noise Ratio (SNR) exceeds a threshold denoted by S_0 .Accordingly, the transmission range *R* defined as the maximum transmitter-receiver separation distance within which a packet is successfully received in the presence of no interference, is given by

$$R = \bar{d}\left(\frac{\bar{P}_{rx}}{\max(P_N S_0, P_R)}\right)^{\frac{1}{\gamma}} \tag{14}$$

Where P_N is Background Noise Power. Note that in order to increase the number of simultaneous transmissions for better spatial reuse, one can set P_R to be higher than

$P_N S_o$ to keep R small. In this case, the transmissions become less vulnerable to interference and the transmission range

$$R = \bar{d}\left(\frac{\bar{P}_{rx}}{P_R}\right)^{\frac{1}{\gamma}} \qquad (15)$$

The carrier sensing range X, defined as the distance within which a node will detect an existing transmission with high probability via PCS is given by

$$X = \bar{d}\left(\frac{\bar{P}_{rx}}{P_C}\right)^{\frac{1}{\gamma}} \qquad (16)$$

Furthermore, the interference range I, defined as the maximum distance at which the receiver will be interfered with by another source (i.e. the received SNR at reference receiver drops below the threshold S_o) is given by

$$I = \left(\frac{1}{\frac{1}{S_0} - \left(\frac{d}{\bar{d}}\right)^{\gamma}\frac{P_N}{\bar{P}_{rx}}}\right)^{\frac{1}{\gamma}} d \approx S^{\frac{1}{\gamma}}{}_0 d \qquad (17)$$

From Fig. 8 since the carrier sensing area of the transmitter (circle centered at TX with radius of X) does not coincide with the interference area of the receiver (circle centered at RX with radius I), any node within the interference range of the receiver but outside the carrier sense range of the transmitter is potentially a hidden terminal [7]. Likewise, any node within the carrier sense range of the transmitter but outside the interference range of the receiver becomes an exposed terminal.

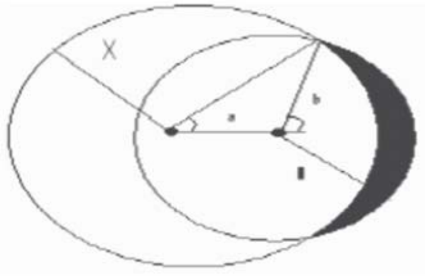

Fig. 8. Geometry of carrier sensing(X) and interference area (I)

The "hidden" area to the sender, denoted by A(d) can be expressed in terms of d, X and I as

$$A(d) = \begin{cases} 0 & (X \geq I + d) \\ \beta I^2 + dX|\sin(\alpha)| - \alpha X^2 & (\mathrm{I\text{-}d} \leq \mathrm{X} \leq \mathrm{I+d}) \\ \pi(\mathrm{I}^2 - X^2) & (\mathrm{X} \leq \mathrm{I\text{-}d}) \end{cases} \qquad (18)$$

Where

$$\alpha = \cos^{-1}\left(\frac{X^2 + d^2 - I^2}{2dX}\right), \beta = \pi - \cos^{-1}\left(\frac{d^2 + I^2 - X^2}{2dI}\right)$$

From (18) can be rewritten as

$$A(d) = \begin{cases} 0 & (0 \leq \mathrm{d} \leq \mathrm{d}_0) \\ \beta I^2 + dX|\sin(\alpha)| - \alpha X^2 & (\mathrm{d}_0 \leq d \leq \min\{R_L, d_1\}) \\ \pi(I^2 - X^2) & (\mathrm{d}_1 \leq d \leq R) \end{cases} \qquad (19)$$

with

$$d_0 = \frac{1}{1 + S_0^{\frac{1}{\gamma}}}\left(\frac{P_R}{P_C}\right)^{\frac{1}{\gamma}} R$$

and

$$d_1 = \frac{1}{S_0^{\frac{1}{\gamma}} - 1}\left(\frac{P_R}{P_C}\right)^{\frac{1}{\gamma}} R$$

From the above, we can see that when d ≤ d0 ,A(d)=0, i.e., the interference area of the receiver is contained in carrier sensing area.

However, when d increases, both the "hidden" area A(d) and interference range I increase as well, thereby, the hidden terminals in A(d) may lead to increased packet collisions. We may be tempted to reduce A(d) and the hidden terminal problem by increasing carrier sense range X; however the exposed terminal problem becomes more pronounced in this case, which prevents simultaneous transmissions and reduces spatial reuse. Therefore, tuning PCS threshold Pc (i.e. equivalent to tuning X) directly affects both the hidden and the exposed node problem, which have opposing effects on the system throughput. Clearly, this inherent tradeoff lies at the core of optimizing the performance of multihop ad hoc networks by balancing the number of simultaneous transmissions in the system and the probability of packet collision at any node.

C. System Model for PCS

By using markov model we developed a system which will be estimate the physical carrier sensing threshold and optimal transmission range in multi-hop wireless networks and used subsequently in to derive the saturation throughput of non-persistent CSMA and some variants of busy tone multiple access (BTMA)[8][9].this model is motivated from the references [8][9]. However, CSMA and BTMA models do not consider the effect of PCS threshold – therefore, a new Markov model which captures the effect of PCS threshold choice on the one-hop aggregate network throughput is needed. Implicitly, this requires modeling channel status in both space and time.

We assume that collisions occur mainly due to hidden terminals of the senders; secondarily they may occur due to `intrinsic' properties of the 802.11 MAC – i.e., several nearby nodes select the same slot to transmit. Since ACK packets are much smaller than data packets and typically transmitted using the lowest (most reliable) data rate, the probability of successfully receiving a data packet but losing an ACK is assumed to be negligible. Furthermore, we assume that nodes are distributed over the 2-D plane obeying the two dimensional homogenous Poisson distribution with density ofl , i.e. for any given area S, the probability of the number of nodes N is given by

$$P(N=n)=\frac{(\lambda S)^n}{n!}e^{-\lambda S} \tag{20}$$

From the above assumptions, the channel status around any node A in the network can be modeled as a four-state Markov chain. We consider the channel status within the carrier sensing range of node A, instead of the transmission range; we combined the two Markov chain models in [8] (one for channel status, the other for node activity) into one Markov chain model by introducing a new state — the Deferring state.

D. Markov Chain Model for Channel Status

Markov chain model will describes the channel statues around A node in network by using idle, fail, success and deferring states. for every state find-out the time taken to entered into that state and spending time in that state and also find out the transmission probabilities for each state $P_{id,}$, P_{is}, P_{if} and P_{id} throughput and probability of collisions are can be calculated using transmission probabilities and transmission times for each state. Let us see the definitions all states in markov model from fig .9

The Idle state:

The channel around reference node A is sensed idle and its duration i T is the length of an empty time slot defined in the IEEE 802.11 standard [10]. 2.

The Success state:

The channel is occupied with a successful transmission from node A for duration S T .3.

The Fail state:

The channel is occupied with an unsuccessful transmission from node A (either due to hidden terminals or intrinsic reasons) for duration f T .

The Deferring state:

The channel around node A is occupied with transmission from other nodes; thus node A freezes its backoff counter and defers its access until the channel around node A is sensed idle again. In this state, node A can also be a receiver.

We denote the duration of deferring as T_d .

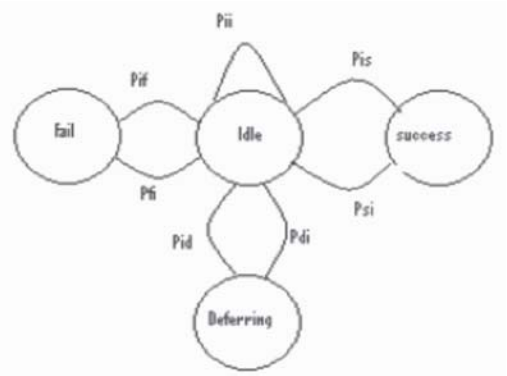

Fig. 9. Markov chain model for channel status around any node A

Where T_i, T_s, T_s and T_d to denote a generic time slot duration of the channel around node A in the various states. Note that a busy channel will revert to the idle state after duration of T_s, T_f or T_d with probability 1 assuming there is no other transmission immediately following the current one. Thus, we have

$$\begin{aligned} P_{ii} &= 1-\left(P_{is}+P_{if}+P_{id}\right) \\ P_{fi} &= P_{si} = P_{di} = 1 \end{aligned} \tag{21}$$

Furthermore, we denote $P_w = P_{is} + P_{if}$, which is the transmission probability of any node in the next time slot given that channel is sensed idle. The value of P_W can be obtained from the analysis of the collision avoidance algorithm in [11].

$$P_W = \frac{2}{CW+1} \tag{22}$$

In the computation of transition probabilities for the above Markov model, the status of surrounding nodes needs to be considered since the channel is, in principle, shared with all neighbors of the reference node implicitly coupling their respective status. When the channel around A is sensed idle, the transmission probability in the next time slot of all neighbors of node A equals to that of node A is assumed.

Which is reasonable if all the nodes within the carrier sensing range of node A are synchronized. However, with increasing distances between neighboring nodes, the difference between their channels statuses will become pronounced due to their large non-overlapping carrier sensing area; thus the transmission probability in the next time slot of these nodes may be lower than W P ,since they may be in the deferring state. Therefore, the transition probabilities of our Markov chain are computed based on the assumption when the channel around node A is sensed idle, the nodes within the transmission range of node A share the same channel status as node A; however the status of all neighboring nodes outside the transmission range of node A in the next time slot are statistically independent of the current channel status of node A. With this assumption, when the channel around node A is sensed idle, the transmission probability of the neighboring nodes within and outside the transmission range of node A in the next time slot can be calculated using W P and P (the average transmission probability per generic slot) derived in the following, respectively.

E. Average Transmission Probability per Generic Slot

Let the limiting probabilities of the Idle, Success, Fail and Deferring states be denoted by: $\pi_i, \pi_s, \pi_d, \pi_d$ respectively. Then we denote the average transmission probability per generic slot for each node as p, which is sum of the limiting probabilities of the Success and Fail state.

$$P = \pi_s + \pi_f = P_W . \pi_i \tag{23}$$

$$\pi_i = P_{ii}\pi_i + (\pi_s + \pi_f + \pi_d) \tag{24}$$

Hence, using the normalization

$$\pi_i + \pi_s + \pi_f + \pi_d = 1$$

$$\pi_i = \frac{1}{2 - P_{ii}} \tag{25}$$

P_{ii} is the transition probability from state Idle to itself which is identical to the event that none of nodes (including the reference) within carrier sensing range X transmits in the next time slot (denoted as P_x); this is given by

$$P_{ii} = P_X\,(1 - P_W) \tag{26}$$

For a 2-D Poisson distribution of the number of nodes within a given area

$$\begin{aligned} P_X &= \sum_{i=0}^{\infty}(1-p)^i \cdot \frac{(\pi(X^2-R^2)\cdot\lambda)^i}{i!} e^{-\pi(X^2-R^2)\cdot\lambda} \\ &\cdot \sum_{i=0}^{\infty}(1-p_W)^i \frac{(\pi R^2\lambda)^i}{i!} e^{-\pi R^2 \lambda} \\ &= e^{-\pi(X^2-R^2)\cdot\lambda\cdot p} e^{-\pi R^2\cdot\lambda\cdot p_W} \end{aligned} \tag{27}$$

Substituting i p in (23) with (25-27), we get the average transmission probability per generic slot *p* as

$$p = p_W \cdot \frac{1}{2 - e^{-\pi(X^2-R^2)\cdot\lambda p} \cdot e^{-\pi R^2 \lambda p_W}(1-p_W)} \tag{28}$$

F. Performance Analysis

We next derive expressions for the number of transmissions per node per second, the successful rate of packet transmission per node and the saturation throughput per node or per unit area it requires all the transition probabilities. The transition probability from idle state to Deferring state id p is the probability that some of nodes within carrier sensing range X transmit in the next time slot but node A itself does not transmit.

$$p_{id} = (1 - p_X)(1 - p_W) \tag{29}$$

Next, the transition probability from state Idle to Success is p can be calculated via:

$$p_{is}(d) = p_1 p_2 p_3(d) p_4(d) \tag{30}$$

Where d is transmitter-receiver separation distance between node A and B,

p_1 = Prob {node A transmits in the next time slot}.

p_2 = Prob {the destination node B does not transmit in the next time slot}.

p_3 (d) = Prob {No intrinsic collision}.

p_4(d) = Prob {No collision due to hidden terminal during the transmission of node A}.

Obviously, $p_1 = p_W$,when the channel around node A is sensed idle, the transmission probability of the neighboring nodes within and outside the transmission range of node A in the next time slot can be calculated with p_W and p respectively; therefore we have p_2=1- p_W. In addition, p_3(d) -the probability that no other nodes within both the interference range of node B and the carrier sense range of node A transmits in the next slot is given by

$$
\begin{aligned}
p_3(d) &= \sum_{i=0}^{\infty}(1-p)^i \frac{((\pi I^2 - A(d) - B(d))\lambda)^i}{i!} e^{-(\pi I^2 - A(d) - B(d))\lambda} \\
&\cdot \sum_{i=0}^{\infty}(1-p_W)^i \frac{(B(d)\lambda)^i}{i!} e^{-B(d)\lambda} \\
&= e^{-(\pi I^2 - A(d) - B(d))\lambda \cdot p} \cdot e^{-B(d)\cdot\lambda\cdot p_W} \\
&= e^{-(\pi(S_0^{\frac{1}{\gamma}})^2 - A(d) - B(d))\lambda\cdot p - B(d)\cdot\lambda\cdot p_W} \qquad (31)
\end{aligned}
$$

Where $\pi I^2 - A(d)$ is the area of the intersection of the interference range of node B and the carrier sense range of node A. B(d) is the area representing the intersection of the interference range of node B and the transmission range of node A. Similar to the calculation of A(d) , B(d) is given by

$$
B(d) = \begin{cases} \pi I^2 & (0 \le d \le d_2) \\ \pi I^2 - \beta I^2 - dR\left|\sin(\alpha)\right| + \alpha R^2 & (d_2 \le d \le \min\{R, d_3\}) \\ \pi R^2 & (d_3 \le d \le R) \end{cases} \qquad (32)
$$

with

$$
d_2 = \frac{1}{1+S_0^{\frac{1}{\gamma}}}R, \quad d_3 = \frac{1}{S_0^{\frac{1}{\gamma}}-1}R
$$

$$
\alpha = \cos^{-1}\left(\frac{R^2+d^2-I^2}{2dR}\right), \quad \beta = \pi - \cos^{-1}\left(\frac{d^2+I^2-R^2}{2dI}\right)
$$

The probability of no collision due to hidden terminals during a transmission of node A, p_4 (d) can be calculated assuming that the duration of a data transmission (not counting ACK packet duration) is N times the average length of a generic slot time, gives

$$
\begin{aligned}
p_4(d) &= \left(\sum_{i=0}^{\infty}(1-p)^i \frac{(A(d)\cdot\lambda)^i}{i!} e^{-A(d)\cdot\lambda}\right)^{2N} \\
&= e^{-2A(d)\cdot\lambda\cdot p\cdot N}
\end{aligned}
$$

Both p_3(d) and p_4(d) depend on transmitter-receiver separation distance d that is a random variable; therefore, we will average them based on the probability density function (PDF) of d for p_{is} . We assume that a node chooses any of its neighbors as its destination within it transmission range equiprobably and we do not consider the retransmission of collision packets. Thus, according to the characteristic of two-dimensional Poisson distribution, we obtain the PDF of the distance between a node and its neighboring nodes within the Transmission Range R (one-hop distance), which is given by

$$
f(d) = \frac{2d}{R^2} \qquad (0 < d < R)
$$

Hence

$$
\begin{aligned}
p_{is} &= \int_0^R f(d)\cdot p_{is}(d)\,dd \\
&= \int f(d)\cdot p_1 \cdot p_2 \cdot p_3(d) \cdot p_4(d)\,dd \\
&= p_W(1-p_W) \\
&\cdot \int_0^R \frac{2d}{R^2} e^{-\left\{\pi(S_0^{\frac{1}{\gamma}}d)^2 - A(d) - B(d)\right\}\lambda\cdot p - B(d)\cdot\lambda\cdot p_W} e^{-2\cdot A(d) N\cdot\lambda\cdot p}\,dd
\end{aligned}
$$

Ultimate of aim this work to finding thethroughput and probability of collisions by using transmission probabilities and the duration of states.

First off all we will find the probability of successful packet transmission per node can be

$$
\begin{aligned}
P_{success} &= (1-p_W) \\
&\cdot \int_0^R \frac{2d}{R^2} e^{-(\pi(S_0^{\frac{1}{\gamma}}d)^2 - A(d) + B(d))\lambda\cdot p - B(d)\cdot\lambda\cdot p_W} e^{-2A(d) N\lambda\cdot p}\,dd
\end{aligned}
\qquad (33)
$$

The transition probability p_{if} is equal to

$$p_{if} = p_w - p_{is} \quad (34)$$

Now, with the above transition probabilities of the Markov chain described earlier, we can get the limiting probability of the Idle, Success, Fail and Deferring state: $\pi_i, \pi_s, \pi_f, \pi_d$ as follows:

$$\pi_i = \frac{1}{1+P_{if}+P_{is}+P_{id}}$$

$$\pi_f = \frac{1}{1+P_{if}+P_{is}+P_{id}}$$

$$\pi_s = \frac{1}{1+P_{if}+P_{is}+P_{id}}$$

$$\pi_d = \frac{1}{1+P_{if}+P_{is}+P_{id}}$$

p_{if} is transmission probability of idle to fail.

p_{is} is transmission probability of idle to success.

p_{id} is transmission probability of idle to deferring.

p_{ii} is transmission probability of idle to idle.

Duration of each Idle, Success, Fail and Deferring states can be calculated according to IEEE 802.11 specifications [10] as below:

$$\begin{aligned}
T_i &= \delta \\
T_s &= \frac{PHY_{hdr}}{v_h} + \frac{MAC_{hdr}+L}{v} + SIFS + \sigma + \frac{PHY_{hdr}}{v_h} + \frac{ACK}{v} + DIFS + \sigma \\
T_f &= \frac{PHY_{hdr}}{v_h} + \frac{MAC_{hdr}+L}{v} + DIFS + \sigma \\
T_d &= T_s
\end{aligned} \quad (35)$$

where δ is the length of an empty slot time defined in the IEEE 802.11 standard, σ is propagation delay, L is the packets length in bytes, PHY_{hdr} is the header of physical layer and MAC_{hdr} is the header of MAC layer.

$\frac{PHY_{hdr}}{v_h}$ is the transmission time of PLCP preamble and PLCP header, for simplicity, we assume $T_d = T_s$, which means that the duration of each deferring interval is the same length as a successful transmission. Then, it can be shown that the number of transmissions per node per second can be expressed as

$$N_t = \frac{\pi_s T_s}{\pi_i T_i + \pi_s T_s + \pi_f T_f + \pi_d T_d} \times \frac{1}{T_s} + \frac{\pi_f T_f}{\pi_i T_i + \pi_s T_s + \pi_f T_f + \pi_d T_d} \times \frac{1}{T_f} \quad (36)$$

Which is the sum of the number of successful and unsuccessful transmission attempts for a node within unit time. Clearly with increasing t N more simultaneous transmissions are expected in the network.

The average saturation throughput per node (total successful transmissions from each node within unit time) can be evaluated by

$$TH_n = \frac{\pi_s \cdot L}{\pi_i T_i + \pi_s T_s + \pi_f T_f + \pi_d T_d} \quad (37)$$

The aggregate saturation throughput per unit area is,

$$TH_a = TH_n \cdot \lambda = \frac{\pi_s \cdot L \cdot \lambda}{\pi_i T_i + \pi_s T_s + \pi_f T_f + \pi_d T_d} \quad (38)$$

Then, the aggregate saturation throughput of a region with area S is

$$TH = TH_u \cdot S = TH_n \cdot \lambda \cdot S \quad (39)$$

Further, N (the ratio between the duration of a data packet transmission and the average slot time) can be estimated by

$$N = \frac{T_{\text{data}}}{\pi_i T_i + \pi_s T_s + \pi_f T_f + \pi_d T_d} \quad (40)$$

Where T_{data} is the duration of a data packet transmission, which equals $\frac{PHY_{hdr}}{v_h} + \frac{MAC_{hdr}+L}{v}$.

The above requires the limiting probability of each state; this can be obviated by the approximation below in (41) without incurring much accuracy loss since T_s, T_f and T_d are approximately the same. Hence, we have

$$N \approx \frac{\mathrm{T}_{\text{data}}}{\frac{1-p_{ii}}{2-p_{ii}} T_d + \frac{1}{2-p_{ii}} T_i} \quad (41)$$

IV. SIMULATION RESULTS

In this section, investigate the performance of PCS threshold on throughput and spatial reuse. We use ns-2 [10] as the network simulator. The choice of PCS threshold is trade-off between the probability of collision and spatial reuse. Higher values of physical carrier sensing threshold leads to low throughput or high probability of collision and one high spatial reuse. Lower values of physical carrier sensing threshold leads to high throughput or low probability of collisions and low spatial reuse. In both cases having advantages and disadvantages so we have take one optimal threshold value which will optimize this disadvantage. To demonstrate the effects the PCS threshold on probability of collisions and throughput, we did a simple experiment using NS-2.27. The topology is demonstrated in Fig. 10

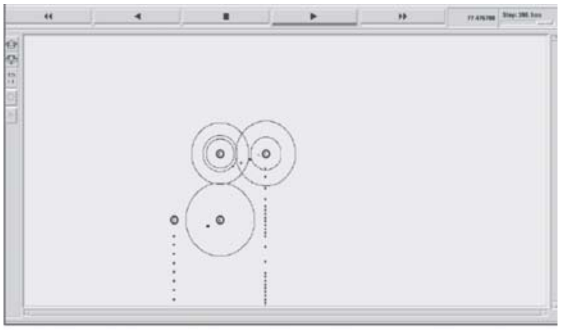

Fig. 10. Scenario for investigation of PCS threshold on throughput

The distance from node 1 to node 2 and node 3 to node 4 is fixed as 300m. Transmission range of the wireless radio is 250m with channel bandwidth as 2Mbps. We vary the vertical distance between node 3, 4 and node 1, 2 to check the influence of PCS threshold. Two CBR sessions based on UDP are involved with directions from node 1 to node 2 and node 4 to node 3 correspondingly. Since the CBR is constant rate traffic without retransmissions, it is possible that the two flows may synchronize to each other rendering the results not general enough. The packet rates of two CBR flows are set to 800Kbps with packet size 1024 bytes (thus 100 packets per second). The packet rate of CBR is selected as to utilize the full bandwidth when the two flows share the channel (e.g. the available channel bandwidth to each flow is 1.7Mbps/2=850Kbps). It is interesting to notice that when the PCS threshold is equal to transmission range which is very low value and in second case PCS threshold is large value greater than the transmission range which is very big value.

Consider first case physical carrier sensing is equal to transmission range (250m=250m).we can see the throughput in Fig. 11 is very high value nearly 1400Mbps.

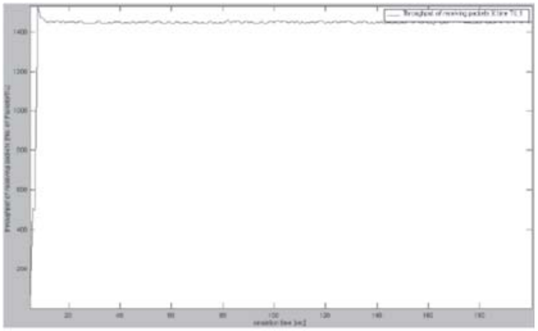

Fig.11 Effects of lower PCS threshold value on network throughput

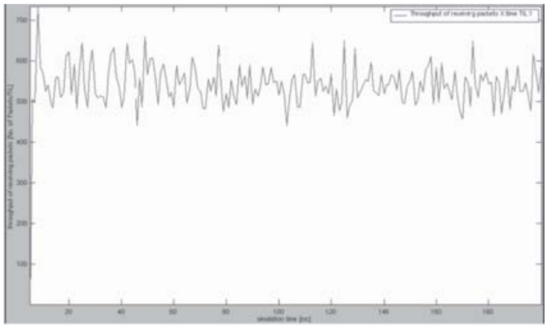

Fig. 12 Effects of higher PCS threshold value on network throughput

This because of there is no hidden terminal in transmission range of transmitter (node 0). In this case very less chance of probability of collision because of node 2 and 3 are out range. These two nodes are not disturbing the transmission between nodes 0 and 1. But one drawback is spatial reuse is very low. In second case we consider physical carrier sensing (500m) is equal to double of the transmission range (250m). In this case we can observe more hidden terminals in the transmission range of transmitter (node 0) from Fig. 10.

So node 2 and node 3 are disturbing present on going transmission from node 0 to node 1.from the Fig. 12 we can observe total network throughput is 700 Mbps. From the above two cases throughput (or probability of collisions) is less in very less in second case compared to first case this because of hidden terminal presented in environmental network.

A. Influence of PCS Threshold on Throughput

The choice of physical carrier sensing is trade-off between the probability of collision and spatial reuse.

Higher values of physical carrier sensing threshold leads to low throughput or high probability of collision and one high spatial reuse. Lower values of physical carrier sensing threshold leads to high throughput or low probability of collisions and low spatial reuse. In both cases having advantages and disadvantages so we have take one optimal threshold value which will optimize this disadvantage. To demonstrate the effects the PCS threshold on probability of collisions and throughput, using NS-2.27. The topology of experiment is demonstrated in Fig. 10

B. Influence of PCS Threshold on SpatialReuse

Spatial reuse is characterized by the separation distance between simultaneous transmitters, i.e. the value of k, in number of hops. We have identified that spatial reuse is determined by the receiver SIR(Signal-Interference Ratio) requirements, the propagation path loss. Fig. 13 plots the spatial reuse in a chain network with respect to pathloss exponent for three SIR threshold: 8dB, 13dB and 18dB, respectively. Here we considered three PCS threshold one is very high value (18dB), one is low value (8dB) and one is medium value (13dB). We can observe from Fig. 13 for large value we can get high spatial reuse and for low value leads to low spatial reuse. So 13dB is reasonable value.

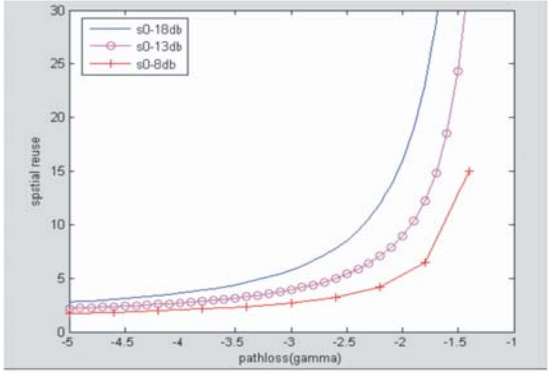

Fig.13. Influence of PCS threshold on 1-D chain network.

Likewise, Fig. 14 plots the spatial reuse for 2-D symmetric network. For comparison, the result for a 1-D chain network at 8db is also included in this Fig.14.

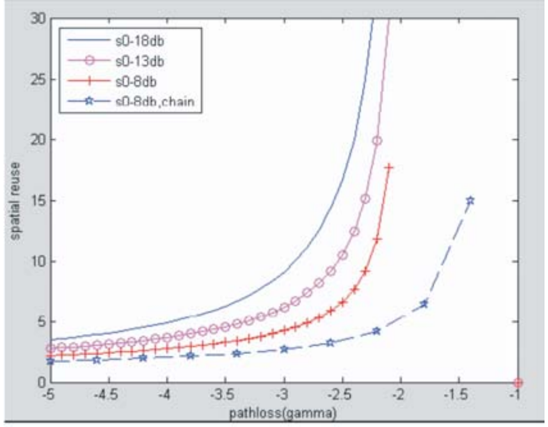

Fig.14. Influence of PCS threshold on 2-D chain network.

C. Analytical Results for Optimizing PCS Threshold

We implemented numerical computations of Markov chain model with MATLAB [20] to examine how PCS threshold affects network performance under different settings for packet length, node density, data rate, contention window size, transmission range and path loss exponent. Fig.15 shows the successful rate of packet transmission per node is derived using hidden area and exposed area. Here we considered two cases node ensityl =1/400and l =1/200.By seeing the figure we can say as the PCS threshold increases, successful rate of packet transmission per node drops significantly. The reason is that with shorter carrier sensing range, the hidden area increases and hidden terminals problem occurs more frequently.

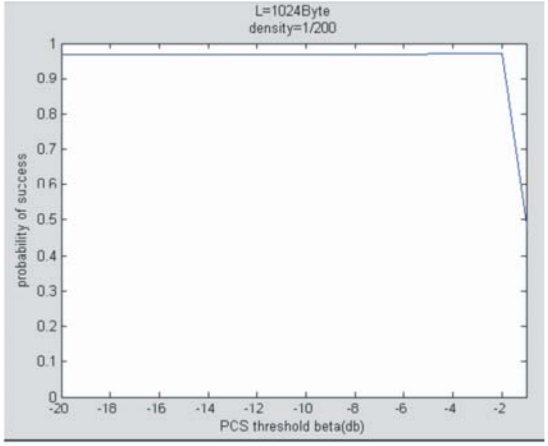

Fig.15. Successful rate of packet transmission per node as a function of PCS threshold (1/400).

When node density l =1/400 means no nodes in environment is very less. Probability of success of packet is very high which is 0.9770 so it leads to probability of collisions is very less. Successful rate of packet transmission per node is also very high. Therefore net throughput of network is very high. Consider Fig.16 node density l =1/200 which is high compared to 1/400.the no of nodes in an environment is high due high density of node probability of success is very less. Successful rate of packet transmission per node is also very less nearly 0.9685.So ultimately net throughput is very less.

When the PCS threshold is lower, the deferring probability d P is little, but the case that the available medium is considered as busy has more probability, which can not meet to the communication requirements differing probability d P the channel around node A is occupied with transmission from other nodes is more prominent. So it gives low throughput for overall network.

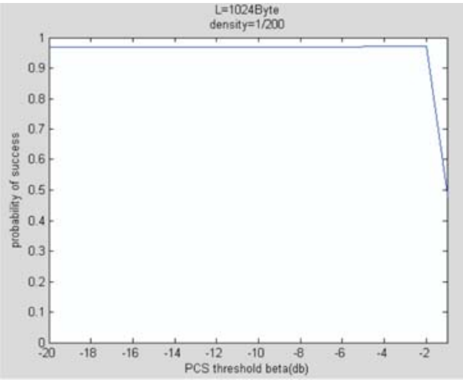

Fig. 16. Successful rate of packet transmission per node as a function of PCS tehreshold (1/200).

Now see the probability of success S P is very low for higher values and lower values. At particular value PCS threshold probability of success is very high. When we consider medium value (PCS threshold) leads to high throughput for network. We can observe all this three probabilities in Fig .17

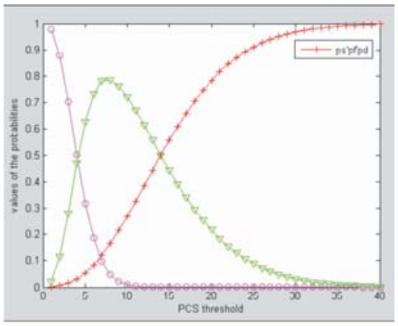

Fig. 17. The probabilities and PCS threshold

V. CONCLUSION

In this novel approach we can say choosing Physical Carrier Sensing (PCS) range plays an important role in wireless networks. It is not a very large value which leads to less throughput (High probability of collisions) Otherwise it is not a very less value which leads to large throughput (less probability of collisions). Finally Physical carrier sensing with the optimal sensing threshold is effective at leveraging throughput in multi-hop ad-hoc networks. Such improvement does not require the use of virtual carrier sensing.

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