Impact of Nakagami-m Fading Model on Multi-hop Mobile Ad Hoc Network

Dr. Mohammed Tarique
Faculty of Engineering,
American International University
Bangladesh (AIUB)

Md. Tanvir Hasan
Faculty of Engineering,
American International University
Bangladesh (AIUB)

ABSTRACT
Several theoretical and experimental based models have been proposed to predict the fading envelope of the received signal in multipath condition. In this paper, we considered a model named Nakagami-m model. Nakagami-m can model a variety of fading environments, where it closely approximates the Nakagami-q (Hoyt) and the Nakagami-n (Rice) models, and has the Rayleigh and one sided Gaussian models as special cases. This model provides the best fit to land-mobile system like wireless mobile ad hoc Network (MANET). Under Nakagami-m fading model, received packet may not be clearly understood by the receiving node, which affects the routing protocol as well as the medium access control protocol of a network. The severity of Nakagami-m fading model on the network performance has been presented in this paper which is demonstrated via simulation results. Simulation results illustrate that the performance of a network may become unable to meet the expectation if Nakagami-m fading model is used in contrast to the simple two-ray model. A physical layer solution and a Medium Access Control (MAC) layer solution been proposed in this paper to overcome the effects of Nakagami-m fading model. Simulation results prove that these two solutions condense the Nakagami-m fading effect and improve network performance.

Keywords
Multi-Hop Mobile Ad Hoc Networks (MANET), Nakagami-m Fading Model, Delivery Ratio, DSR, MAC layer, Long and Short Retry Limit and Probability Density Function (PDF).

1. INTRODUCTION
An elementary property of each communication network is its connectivity. In cellular communication systems, a well established network infrastructure supports communication between users. It deploys a sufficient number of base stations and maintains the access and core networks. This network infrastructure guarantees, to a certain extent, the connectivity among mobile users. In contrast to this, the connectivity in wireless multi-hop mobile ad hoc cannot be guaranteed. Each node acts as a relay for other nodes, if two hosts are not within radio range of each other, all message communication between them must pass through one or more intermediate hosts that double as routers. The hosts are free to move around randomly, thus changing the network topology dynamically. Thus the level of connectivity depends on the spatial density and transmission characteristics of the mobile nodes themselves. As the location and mobility of the nodes are nondeterministic, we can only give probabilistic measures for the connectivity.

Radio signals generally propagate according to the mechanisms of reflection, diffraction, and scattering, which roughly characterize the radio propagation by three nearly independent phenomena: Path loss variance with distance, shadowing (or long-term fading), and multipath (or short-term) fading. Except path loss, which is only distance dependent, the other two phenomena can be statistically described by fading models where their parameters can be determined by using outputs of experimental radio propagation measurements. As expectations for the performance and reliability of wireless systems become more demanding, the significance of accurate channel modeling in system design, evaluation, and deployment will continue. Due to the existence of a great variety of fading environments, several statistical distributions have been proposed for channel modeling of fading envelopes under short- and long-term fading conditions. Short-term fading models include the well-known Rayleigh, Weibull, Rice, and Nakagami-m. Among them, Nakagami-m distribution has gained a lot of attention, due to its ability to model a wider class of fading channel conditions and to fit well the empirical data in a more convenient way [21]–[24]. Through the parameter m, this distribution can model signal fading conditions that range from severe to moderate, to light or no fading. The primary justification for the use of the Nakagami- fading model is its good fit to empirical multipath fading data [25, 26]. Much theoretical and numerical analysis of the performances of diverse communication systems operating in Nakagami-m fading has been reported in the literature [21]–[24], [25, 26].

To analyze the impact of Nakagami-m on the network performance, the delivery ratio has been considered as a performance metric. The delivery ratio is defined as the ratio between the number of packets received at a destination and the number of packets that was sent by a source to that destination. Therefore, the packet delivery ratio point outs the efficiency of a network. A concise explanation of Nakagami-m fading model has been presented in section 3. In order to examine the Nakagami-m effects on a routing protocol, we selected Dynamic Source Routing (DSR) [27] protocol as the candidate. A brief description of the DSR protocol has been provided in section 4.1 for the comprehensiveness of this work. The effects of Nakagami-m on the DSR protocol have been explained in the section 4.2. The Nakagami-m has severe effects on a medium access control scheme. Since IEEE 802.11 MAC layer protocol has been used in this paper, section 4.3 contains a brief description of IEEE 802.11 MAC layer protocol and section 4.4 shows the effects of Nakagami-m on IEEE 802.11 MAC layer protocol. Simulation models and results have been presented in section 5. Two solutions of Nakagami-m problem have been presented in section 6. Finally, we conclude this paper in section 7.

2. RELATED WORKS

One of the first papers to address different fading channel where the authors surveyed the error modeling methods of fading channels in wireless communications, and provided a novel user-requirement based approach to classify the existing wireless error models was in [1] the connectivity issues in multi-hop networks was illustrated in [2] in which authors investigated how far a node's broadcast message percolates, if the nodes are randomly distributed according to a homogeneous Poisson point process on an infinitely large area. The connectivity issues for nodes that are randomly distributed according to a uniform probability distribution on a one-dimensional line segment were addressed in [3]. Gupta and Kumar [4] performed a fundamental study on the connectivity of uniformly distributed nodes on a circular area. Penrose [5] also proved similar results independently. Santi and Blough [6, 7] conducted analytical investigations of the connectivity in bounded areas. The critical transmitting range for connectivity in an adhoc network in the presence of node mobility was first addressed in [7]. Bettsetter and Hartmann [8] addressed the impact of lognormal shadowing on the connectivity of ad hoc networks. Work in [9] also addressed the same issue independently. Orriss and Barton [10, 11] obtained the connectivity results for the case of superposition of shadowing and fading phenomena. Haenggi [12] studied the impact of Rayleigh fading on network connectivity. The impact of interference on connectivity was analyzed in [13]. Miorandi et al. [14] presented analytical solution for network connectivity in the presence of channel randomness. Authors of [15] addressed the problem of finding the critical density of sensors required to achieve complete coverage of a desired region. Xiaole Bai et. al. In [16], a useful closed formula for the exponentially correlated n-variate Nakagami-m probability density function is proposed. Moreover, an infinite series approach for the corresponding cumulative distribution function is presented. Bounds on the error resulting from the truncation of the infinite series are also derived. Finally, in order to check the accuracy of the proposed formulation, numerical results are presented. [17] Addressed the problem of determining an optimal deployment pattern that achieves both coverage and k-connectivity in a wireless sensor network. In [18], authors investigate the connectivity problem when directional antennas are used. While authors of [19] consider how physical layer cooperation can be used to improve the connectivity in wireless ad hoc networks.

3. NAKAGAMI-M FADING MODEL

In urban areas, fading occurs frequently as the radio channel contains several obstacles and reflectors and consequently there is no line of sight path exists between the transmitting and receiving node. If a line of sight exists, multi-path still occurs due to reflection from different the ground and the surrounding objects. The incoming radio waves arrive from different directions with different propagation delays. The signal received by the mobile at any point in space may consist of a large no of plane waves having randomly distributed amplitudes, phases and angles of arrival. These multipath components combine vectorially [31] at the receiver antenna, and can cause the signal received by the mobile to distort or fade. Even when a mobile receiver is stationary, the received signal may fade due to movement of surrounding objects in the radio channel.

If objects in the radio channel are static, and mobile nodes are moving, then fading is purely a spatial phenomenon. The spatial variations of the resulting signal are seen as temporal variation by the receiver as it moves through the multipath field. Due to the constructive and destructive effects of multipath waves summing at various points in space, a receiver moving at high speed can pass through several fades in a small periods of time. In a more serious case, a receiver may stop at a particular location at which the received signal is in a deep fade.

In mobile radio channels, Rayleigh and Rician distributions are commonly used to describe the statistical time varying nature of the received envelop of a fading channel or the envelop of an individual component. But Nakagami-m distrubution is found to provide a better match to experimental data than Rayleigh and Rician distributions. The Nakagami distribution matches some empirical data better than other models. The sum of multiple independent and identically distributed (i.i.d.) Rayleigh-fading signals have a Nakagami distributed signal amplitude. This is particularly relevant to model interference from multiple sources. The Rician and the Nakagami model behave approximately equivalently near their mean value. This observation has been used in many recent papers to advocate the Nakagami model as an approximation for situations where a Rician model would be more appropriate. In the early 1940's Nakagami introduced the Nakagami distribution to fit empirical data gathered from HF channels. It was initially proposed because it matched empirical results for short wave ionospheric propagation. If the envelope is Nakagami distributed, the corresponding instantaneous power is gamma distributed. The Nakagami power distribution that we use in this paper is shown below.

The PDF of the received signal envelope R under Nakagami-m fading is

$$f_R(r) = \frac{2\, m^m r^{2m-1}}{\Gamma(m)\Omega^m} e^{-\left(\frac{m}{\Omega}\right) r^2} \quad \text{……..…………………..(1a)}$$

Where, $\Omega = E[R^2] = \overline{R^2}$ ……………………………………(1b)

E[.] is the expectation operator and

$$m = \frac{\left(\overline{R^2}\right)^2}{\left(R^2 - \overline{R^2}\right)^2} \geq 1/2 \quad \text{………………………………………..(1c)}$$

In (1a), m is a parameter that controls the severity, or depth, of the amplitude fading. This parameter m is called the 'shape factor' of the Nakagami-m or the gamma distribution. The value results in the widespread Rayleigh-fading model [28], while values of m less than one correspond to fading more severe than Rayleigh fading and values of m greater than one correspond to fading less severe than Rayleigh fading. Figure 1 shows the pdf for some different values of m. Note that for integer and half-integer values of m, the pdf is that of the amplitude of a sum of squared Gaussian RVs appropriately normalized. That is,

$$R = \sqrt{X_1^2 + X_2^2 + X_3^2 + \dots\dots\dots + X_n^2} \quad \text{................................(1d)}$$

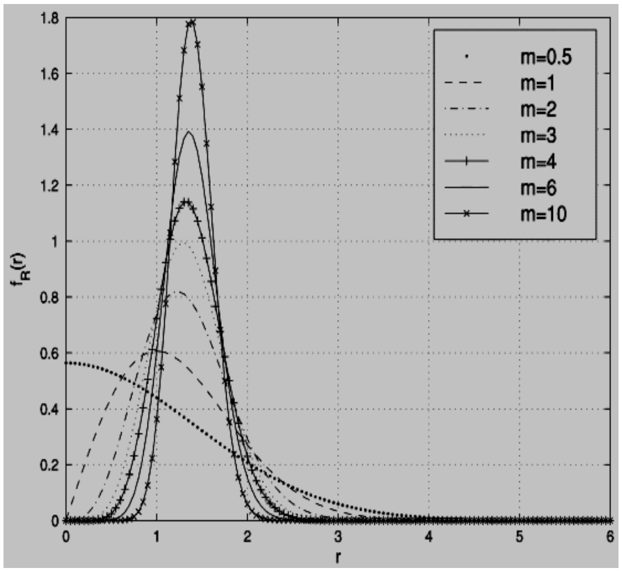

Figure 1: Nakami-m PDF for various values of fading parameter m [28].

Where, X_i, i = 1,2,………n are independent and identically distributed (i.i.d.) Gaussian RVs each with zero-mean and variance σ^2_x. The RV R in (2) has a Nakagami- pdf with parameter m = n/2 and second moment $\Omega = 2m.\sigma^2_x$. If the second moment is held constant, then in the limit as m tends to infinity, the Nakagami-m pdf tends to an impulse as seen in Figure 1; this is a consequence of the normalization chosen by Nakagami and permits obtaining a static signal amplitude as a limiting case (obtained as $m \rightarrow \infty$).

From [29] we can also analyze the effect of m of Nakagami-m model with respect to the node distance. We can see, as the value of m0 decreases, strength and quality of the received power is degraded. Worst case happens when m0 have the lowest value (m0 = 0.25). In that case, received signal fluctuates tremendously and its strength may go beyond the lowest acceptable limit. This degradation not solely depends on the node distance, as we can see for lower node distance, the fluctuation can be higher than that for the higher node distance. As the value of m0 increases, the strength of the received signal is increased and fluctuations get more tolerable.

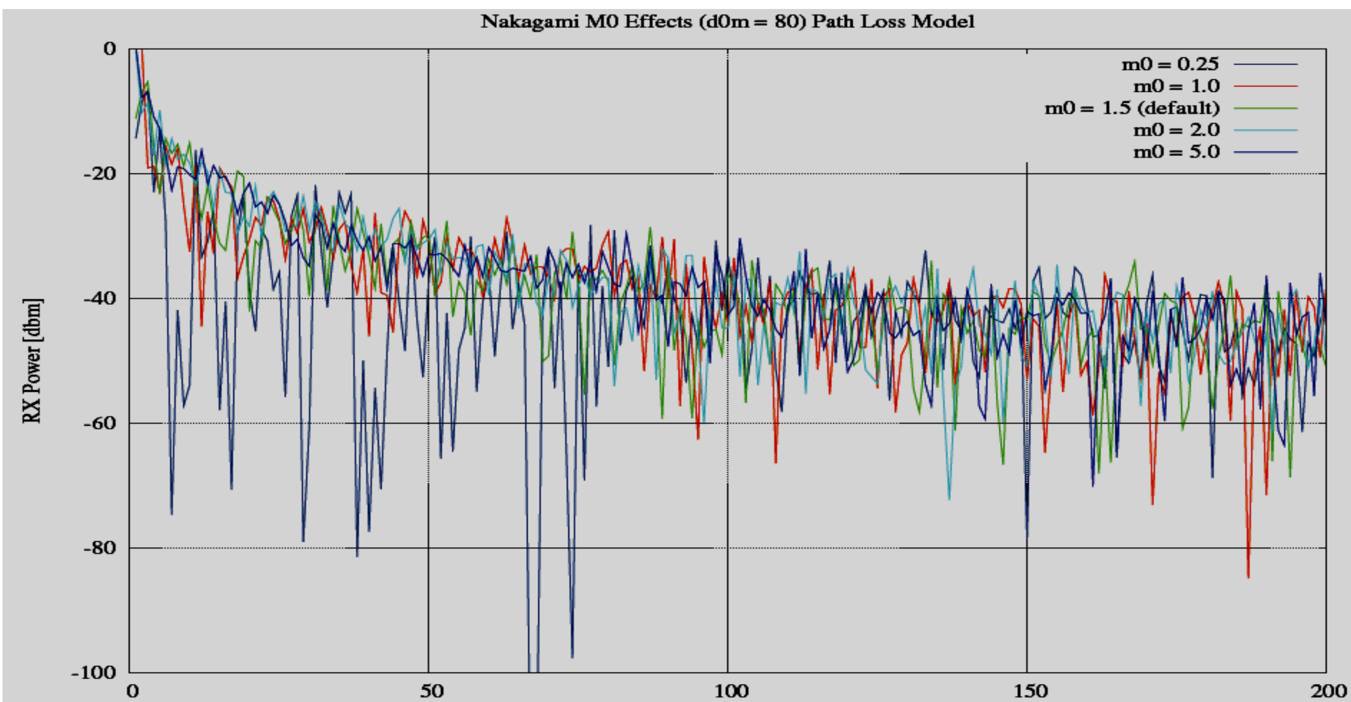

Figure 2: Nakagami M0 Effects Path Loss Mode [29]

4. EFFECT OF NAKAGAMI-M FADING MODEL ON MULTI-HOP WIRELESS MOBILE AD HOC NETWORK

The transceiver at the Physical layer of the mobile ad hoc network must have the potential to meet the growing demands for signal robustness in wireless channels that is subject to co-channel interference and multipath fading. Though solutions to enhance link quality by antenna arrays and optimum combining methods have been employed in other wireless communication systems, this approach has not thoroughly been exploited in ad hoc networks and is still in its infancy stages. Until recently, physical size combined with functionality created a barrier to implementations of antenna arrays at the transceiver. That's why unfortunately until today its quiet unfeasible to evade the multipath fading effect (modeled by Nakagami-m model) in a multi-hop wireless system.

4.1 The DSR Protocol

The Dynamic Source Routing protocol (DSR) [27] is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. The DSR protocol is composed of two mechanisms that work together to allow the discovery and maintenance of source routes in the ad hoc network - **Route Discovery** and **Route Maintenance:**

Route Discovery is the mechanism by which a node **S** wishing to send a packet to a destination node **D** obtains a source route to **D** and is used only when **S** attempts to send a packet to **D** and does not already know a route to **D**. When some node **S** originates a new packet destined to some other node **D**, it places in the header of the packet a source route giving the sequence of hops that the packet should follow on its way to **D**. Normally, **S** will obtain a suitable source route by searching its Route Cache of routes previously learned, but if no route is found in its cache, it will initiate the Route Discovery protocol to dynamically find a new route to **D**. In this case, we call **S** the initiator and **D** the target of the Route Discovery. For example, Figure 3 illustrates an example Route Discovery, in which a node **A** is attempting to discover a route to node **E**. To initiate the Route Discovery, **A** transmits a ROUTE REQUEST message as a single local broadcast packet, which is received by (approximately) all nodes currently within wireless transmission range of **A**. Each ROUTE REQUEST message identifies the initiator and target of the Route Discovery, and also contains a unique request id, determined by the initiator of the REQUEST. Each ROUTE REQUEST also contains a record listing the address of each intermediate node through which this particular copy of the ROUTE REQUEST message has been forwarded. This route record is initialized to an empty list by the initiator of the Route Discovery.

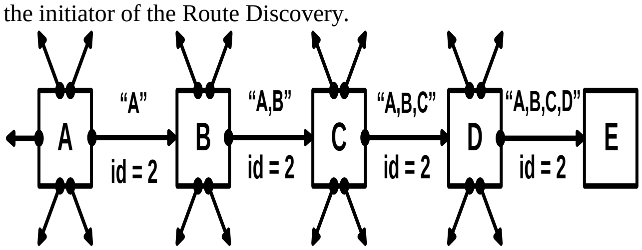

Figure 3: Route Discovery example: Node A is the initiator, and node E is the target.

When another node receives a ROUTE REQUEST, if it is the target of the Route Discovery, it returns a ROUTE REPLY message to the initiator of the Route Discovery, giving a copy of the accumulated route record from the ROUTE REQUEST; when the initiator receives this ROUTE REPLY, it caches this route in its Route Cache for use in sending subsequent packets to this destination. Otherwise, this node appends its own address to the route record in the ROUTE REQUEST message and propagates it by transmitting it as a local broadcast packet (with the same request id).

Route Maintenance is the mechanism by which node **S** is able to detect, while using a source route to **D**, if the network topology has changed such that it can no longer use its route to **D** because a link along the route no longer works. When Route Maintenance indicates a source route is broken, **S** can attempt to use any other route it happens to know to **D**, or can invoke Route Discovery again to find a new route. Route Maintenance is used only when **S** is actually sending packets to **D**.

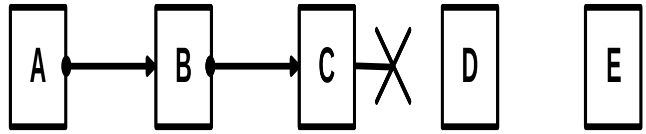

Figure 4: Route Maintenance example: Node C is unable to forward a packet from A to E over its link to next hop D.

When originating or forwarding a packet using a source route, each node transmitting the packet is responsible for confirming that the packet has been received by the next hop along the source route; the packet is retransmitted (up to a maximum number of attempts) until this confirmation of receipt is received. For example, in the situation illustrated in Figure 4, node **A** has originated a packet for **E** using a source route through intermediate nodes **B**, **C**, and **D**. In this case, node **A** is responsible for receipt of the packet at **B**, node **B** is responsible for receipt at **C**, node **C** is responsible for receipt at **D**, and node **D** is responsible for receipt finally at the destination **E**. If the packet is retransmitted by some hop the maximum number of times and no receipt confirmation is received, this node returns a ROUTE ERROR message to the original sender of the packet, identifying the link over which the packet could not be forwarded. For example, in Figure 4, if **C** is unable to deliver the packet to the next hop **D**, then **C** returns a ROUTE ERROR to **A**, stating that the link from **C** to **D** is currently "broken." Node **A** then removes this broken link from its cache; any retransmission of the original packet is a function for upper layer protocols such as TCP.

4.2 Effects of Nakagami-m Fading Model on Routing Protocol

According to DSR protocol mechanism (route discovery and route maintenance operation), the link between two nodes is assumed to be stable and fluctuation of signal level is considered to be dependent on the distance between them. A neighboring node is always assumed to be 'accessible' unless that neighbor node falls in power shortage or that neighbor node is out of the transmission range of the corresponding transmitting node. But in a multipath fading environment modeled by Nakagami-m fading model, the mobile or indoor radio channel is characterized by 'multipath reception' - the signal offered to the receiver contains not only a direct line-of-sight radio wave, but also a large number of reflected radio waves. Even worse in urban centers, the line-of-sight is often blocked by obstacles, and a collected of differently delayed waves is all what is received by a mobile antenna. These reflected waves interfere with the direct wave, which causes significant degradation of the performance of the link. If the antenna moves the channel varies with location and time, because the relative phases of the reflected waves change. This leads to fading: time variations of the received amplitude and phase. This results quick amplitude variation of the received signal and also causes misinterpretation of the transmitted bit at the receiver, which increases the probability the signal level may go below a certain required level called a 'threshold' level and also the receiver is unable to detect the desired message, consequently the following predicaments may occur:

(a) During the Route Discovery process, the ROUTE REQUEST packet may become faded and hence may not be received by the surrounding neighbors and hence there is a probability of an unsuccessful route Discovery.

(b) Nakagami-m fading environment also may hamper the efficiency of Route Discovery mechanism. The intension of the Route Discovery mechanism of the DSR protocol is to find out as many paths as possible. The motivation is that in case of one path's failure, a source can select a substitute path immediately. But this kind of flexibility may be lost in Nakagami-m fading model. Since only a few numbers of paths are discovered, there is a probability that a source may not find any other alternative route once a current route fails.

(c) After the determination of some routes, the source node starts sending data packets using one of the discovered routes, a neighboring node may not receive the desired data due to constructive and destructive interference of different versions of same message and hence due to fading of the received signal. As a result, a data packet may not be received by the desired node in a true sense.

(d) There also exists uncertainty in the Route Maintenance operation of the DSR protocol as there is a probability that a ROUTE ERROR message may not be received well by the intermediate nodes in a multipath fading environment during its way to a source mobile node. If a source cannot detect the ROUTE ERROR message, it cannot detect a link fracture. The source continues sending data packet using the route that contains the broken link. All these data packets will be lost at the broken link.

(e) If an immediate protocol presumes that a link is no longer utilizable for further use when it actually is, then it will commence a pointless route search. This suspends the existing transmission process and exploits inadequate bandwidth to carry out the search.

The Nakagami-m fading model not only affects a routing protocol but also makes troubles for a medium access control scheme. In all the simulation results presented in this paper, IEEE 802.11 has been chosen as the medium access protocol. A brief description of IEEE 802.11 MAC layer has been described in the following section.

4.3 Overview of IEEE 802.11 MAC [30]

IEEE 802.11 MAC provides the basic access method based on the CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) scheme to access the channel. According to this scheme, when a node receives a packet to be transmitted, it first listens to the channel to ensure no other node is transmitting. In order to detect the status of the medium, IEEE 802.11 performs carrier sensing at both the physical layer, referred to as the physical carrier sensing and at the MAC layer, referred to as the virtual carrier sensing. A virtual carrier sensing mechanism (Figure 5) is done via the use of two control packets (RTS/CTS) as follows: A source node ready to transmit senses a medium, if the medium is busy then it defers. If the medium is free for a specified time called Distributed Inter Frame Space (DIFS) then it sends a Request to Send (RTS) packet towards the destination. All other nodes that hear the RTS then update their Network Allocation Vector (NAV), which indicates the amount of time that must elapse until the current transmission session is complete and the channel can be sampled again for idle status. The destination node, upon reception of the RTS responds with another short control packet Clear to Send (CTS). All other nodes that hear the

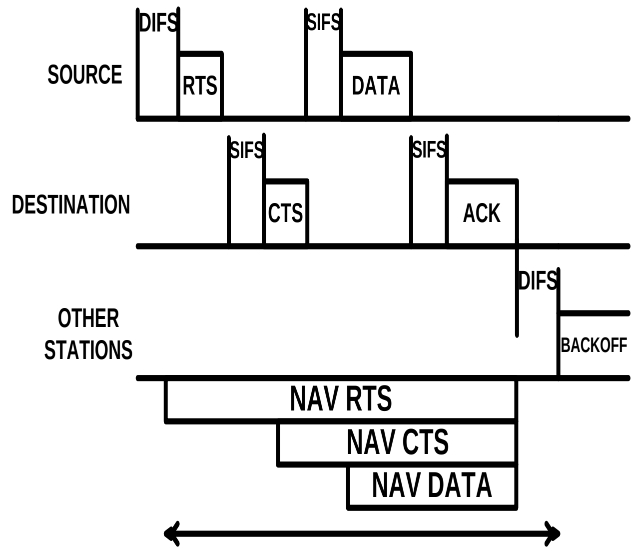

Figure 5: Virtual Carrier Sense and Data Transmission in IEEE 802.11 MAC

CTS packet also defer from accessing the channel for the duration of the current transmission. This means that, the channel is marked busy if either the physical or virtual carrier sensing mechanisms indicate the channel is busy. The reception of the CTS packet at the transmitting node acknowledges that the RTS/CTS dialogue has been successful and the node starts the transmission of the actual data packet after a specified time, called the Short Inter Frame Space (SIFS) and then transmits the packet. Otherwise, it chooses a random back-off value and retries later. If the receiver gets the packet without error, it initiates the transmission of Acknowledgement packet after a SIFS towards the sender. The SIFS is shorter than DIFS in order to give priority to the receiving station to over other possible stations waiting for transmission. However if the Acknowledgement packet is not received at the sender within a certain time, the Data packet is presumed to have been lost and a retransmission is scheduled. This retransmission is done up to a certain number of attempts known as the Long Retry Limit (LRL) which has a default value statically set at 4. Similarly, if CTS control packet is not received when the MAC sent the RTS then MAC resends the RTS up to predefined limit which is known as the Short Retry Limit (SRL) which has a default value statically set at 7.

4.4 Effects of Nakagami-m Fading Model on MAC Layer

The assumption that is considered by CSMA/CA based multi-access technique is that the medium is a discontinuous synchronous multi-access bit pipe on which idle periods can be distinguished from packet transmission periods. If the idle periods are quickly sensible by the nodes, it is realistic to expire idle periods quickly and to permit nodes to commence packet transmission after such idle detections. This is the viewpoint of a CSMA/CA based multiple access technique. Multipath fading effects in Nakagami-m fading model may put barrier on the normal operation of IEEE 802.11 MAC layer operation in the following ways:

(a) IEEE 802.11 carrier sensing is carried out at both the air interface, which is referred to as physical carrier sensing and at the MAC sub-layer referred to as virtual carrier sensing. Physical carrier sensing may not work properly in Nakagami-m fading model because at receiver it is possible that different versions of same transmitted signal that are generated due to multipath fading, combine in destructive approach. That causes the strength of received signal level to go below a definite threshold level so that it cannot be detected. Therefore both physical carrier sensing and virtual carrier sensing may not work accurately.

(b) Virtual carrier sensing is performed by a source station by attaching the MPDU duration information in the header of RTS, CTS and data packets. This information in the duration field is used by the stations in a given area to adjust their Network Allocation Vector (NAV). The NAV indicates how much time must pass before these stations are allowed to check the channel for idleness. The stations in a given area may not be able to pick up the bit duration information from the packet because of the poor quality of signal arises at Nakagami-m fading environment. Hence the adjustment of NAV cannot work properly

(c) The exchange of RTS and CTS frame between a source node and a destination node may not be successful due to misreading of received signal at corresponding receiver. If the destination node does not receive RTS packet appropriately, it does not respond that RTS by sending a CTS packet. Since a source node is unable to forward a data packet without receiving a CTS packet from the destination, a source station has to keep the data packet in the buffer for longer period of time, which causes unnecessary delaying of a packet transmission. Similarly, if the CTS packet is not successfully received by a source station due to misreading of received signal, a source station also delays its transmission. Hence unsuccessful reception of RTS and CTS packets can cause pointless waiting of a packet transmission.

(d) According to IEEE 802.11, after receiving a data packet, a destination node forwards an acknowledgement packet to the source node. In a Nakagami-m fading environment, it is possible that, this data packet may become faded at the corresponding receiver. Hence, a source station has to resend a data packet several times. These surplus packets will reside in the channel unnecessarily and waste scarce channel bandwidth. On the other hand, a destination node may successfully receive a packet, but the acknowledgement packet sent by that destination may become faded due to Nakagami-m fading effect. Since a source node does not receive an ACK packet, it keeps sending the data packet repeatedly. According to IEEE 802.11 MAC layer, a source has the opportunity to resend a packet for highest seven times after that it will assume that the destination is unreachable and it drops the packet. Hence there will be a large number of packet losses in a network due to unsuccessful reception of an ACK packet.

5. SIMULATION MODEL AND RESULTS

To analyze the impact of Nakagami-m fading model, 7 networks with areas 100m X 100m, 100m × 200m, 200m × 200m, 200m × 300m, 300m × 300m, 300m × 400m and 400m × 400m was deployed and simulated via Network Simulator (NS-2) [14]. The corresponding node numbers of these 7 networks was 4, 8, 15, 23, 35, 46 and 61. The node density for all networks was kept same and the node numbers for each network were selected carefully so that at worst type of distribution, each node is connected to at least 2 neighbors. Dynamic Source Routing (DSR) was used as routing algorithm. After setting up of a connection, Constant Bit Rate (CBR) agent was used to generate packets. Activity of CBR agent was started at random period of time. The packet generation rate was 20 packets per second. The simulation was performed for 200 ns. The performance metric through which the simulation models were analyzed was delivery ratio which can be defined as $D_r = P_{received} / P_{sent}$, where, P_{sent} is the total number of packets forwarded to the destination node by the source node and $P_{received}$ is the total number of packets received by the destination node. Initially, Two-ray model was used as the propagation model. As mentioned in the previous section that two-ray model is too simple to represent a real world scenario. The two-ray reflection model assumes that there are two paths between a source and a destination. One path is the line-of-sight path and the other one is the reflected path from the ground. The variation of the signal strength follows the following rule [31]:

Table 1: Simulation parameters

Parameter	Values	Parameter	Values
Transmitting power P_t	24.50 dBm	Basic Modulation Scheme	BPSK
Threshold Power P_{th}	-64.38 dBm	Frequency	5.18 GHz
Transmitting Antenna Gain	1	Expected Value, Ω	1
Transmitting Antenna Height	1m	Shape Factor, m	0.5,0.75,1,2,3,5
Receiving Antenna Gain	1	Random Number Generator	False
Receiving Antenna Height	1m	Propagation Model	Nakagami-m and Two-ray model

$$P_r = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where, G_t and G_r are the transmitting antenna gain and receiving antenna gain, h_t and h_r are. The transmitting and receiving antenna heights, P_t is the transmitting power and P_r is the receiving power, and d is the distance between the transmitter and the receiver. Since each mobile node uses the same power level to transmit all kinds of packets (i.e., route discovery, route maintenance and data packets), the link is considered stable up to some distance which is usually less that the transmission range of the transmitting node. That means once a route is discovered, the qualities of all links lying along that route do not change over the time. Hence there is almost no packet loss. The upper graph of Figure 6 also depicts the simulation results. It shows that the delivery ratio for two-ray model is almost 100%. That means a negligible number of packets has been lost. This Figure shows that the delivery ratio is 100% under different network size. The simulation was then repeated using Nakagami-m fading model as the propagation model by using these parameters mentioned in Table I. The corresponding responses of simulation are shown in the Figure 6. Here the gamma value (Ω) of Nakagami-m fading model was kept fixed at 1. Six values (0.5, 0.75, 1, 2, 3, 5) of shape parameter m were used to demonstrate the response of networks in Nakagami-m fading model. It is depicted that, the delivery ratio and hence the performance of the network of a particular area decreases with the shape parameter m. when m has the highest value among the used values, i.e. 5, the network response is relatively fair compared to others. When m has the value of 1, it represents the similar approach like Rayleigh model. Network performance becomes very poor and uncertain when m has the values like 0.75 and 0.5. The delivery ratio decreases as the network is spanned over larger areas. This occurs as larger area increases the probability of existence of larger number of hops between the source and destination node which further increases the probability of dropping packets at any intermediate node between source and destination due to multipath fading effect modeled by Nakagami-m fading model.

6. PROPOSED SOLUTIONS

Two schemes to improve the delivery ratio and hence the system performance in a Nakagami-m fading environment, suggested in this paper are: (1) by increasing the transmission power, and (2) by increasing the long and short retry-limit of MAC layer protocol. The first solution is a physical layer solution, while the second one is a MAC layer solution.

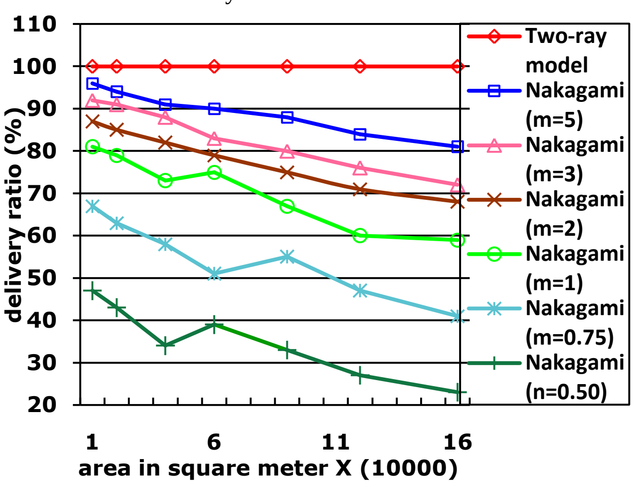

Figure 6: Comparison of simulated delivery ratios of Two-ray model and Nakagami-m fading models for different values of m.

Increasing the transmission power increases the probability of receiving higher average received power. From (1c), we can find that, it increases the value of shape parameter m, which increases the delivery ratio and hence the system performance of the network. For analyzing the effect of high transmission power in improving the performance, the same simulation scenario was deployed for Nakagami-m response with m=0.75 but the only change was made in the transmission power level. The transmission power was increased from 0.2818 W (or 24.5 dBm) to 0.6342 W (or 28 dBm). The responses have been shown in Figure 7. The Figure depicts that for increased transmission power, delivery ratio increases in a fairly manner. The improvement in delivery ratio is less when the network size is small. For a sample scenario where the area is 200m × 200m, the delivery ratio for low or usual transmission power is 63% and for increased transmission power it increases to 66%. This occurs as in small sized network, nodes are relatively close to each other, and so higher transmission power cannot improve too much. As the network becomes larger, effect of high transmission power becomes more noticeable. For instance, when the area in 400m × 400m, the delivery ratio for low or usual transmission power is 41% and for increased transmission power it increases to 51%. Although the higher transmission power improves delivery ratio, it may not be a good choice as high transmission power increases interference level in a network. One unconventional solution to improve the network performance is increasing the Short Retry Limit (SRL) and Long Retry Limit (LRL) of IEEE 802.11 MAC layer protocol. The default values of SRL and LRL are 7 and 4. To improve the network performance, SRL was increased to 14 and LRL was increased to 8, i.e. doubled. It indicates that a sender has the option to send the RTS packets for 7 more times and the DATA packets for 4 more times to the receiver. The simulation result for this increased SRL and LRL in MAC layer solution is shown in Figure 7 labeled as 'Increased SRL and LRL'. This Figure shows that delivery ratio is improved in comparison with low transmission power and also with high transmission power. The Figure shows that in average, almost 15% packet loss can be reduced in a network if SRL and LRL are increased as mentioned above.

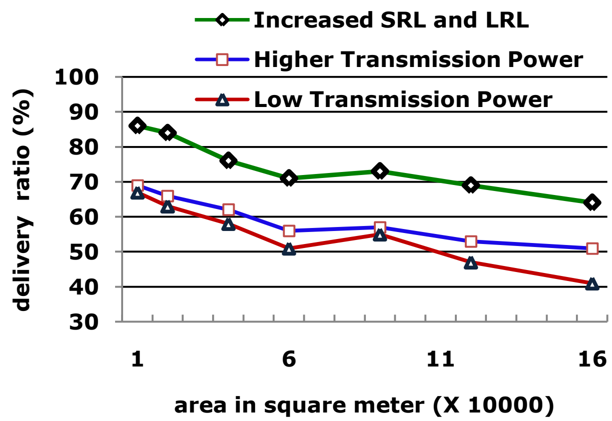

Figure 7: Proposed solutions to improve network performance

7. CONCLUSIONS

In this paper the performance of multi-hop mobile ad hoc network under Nakagami-m fading model has been inspected. Even though the two-ray model is widely used both in simulation and test bed, the paper shows that Nakagami-m fading model embodies more realistic environment that matches closely with practical phenomenon. It is revealed via simulation that the Nakagami-m fading model have severe effects on the performance of a multi-hop mobile ad hoc network. The paper comprehensively investigated the impact of Nakagami-m fading model on the routing protocol and the MAC layer scheme. Two solutions have also been presented in this paper. The simulation results have shown that the effects of Nakagami-m fading model can be minimized by using these proposed solutions.

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