Minimizing Shadowing Effects on Mobile Ad hoc Networks

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Abstract*— Simple two-ray model and FRIIS free-space model have been widely used in the literatures as the propagation models for the performance analysis of Mobile Ad hoc Network (MANET). These models do not represent real world scenarios where the environmental clutter varies widely for a given distance between two mobile nodes. In this paper, a more practical model called shadowing model has been adopted. The performances of ad hoc network have been investigated under this shadowing model. Analytical analysis of shadowing effects has also been presented in this paper. Three solutions have also been proposed in this paper to minimize the shadowing effects. Simulation results show that these three solutions minimize the shadowing effects.

***Index Terms*— Mobile Ad hoc Networks, routing protocol, shadowing, link distance, delivery ratio.**

I. Introduction

MOBILE Ad hoc Networks (MANET) is a highly appealing means of providing network support to a group of people without the aid of any infrastructure support. MANETs are self-organizing and self-configuring. No centralized administration is required to operate and maintain such networks. Necessary controls and networking functions are performed by using a distributed control algorithm. In MANETs, mobile nodes forward packet for other mobile nodes in addition to transmitting their own packets and communicate with each other in a multi-hop fashion. Dynamic topology is an inherent characteristic of MANET. Mobile nodes are free to move at any time in any direction in an unpredictable manner. This kind of topological change results in high route 'breakages' in the network and it imposes significant challenges for the researchers in MANET. Initially MANET was developed to provide networking support in the military applications, where infrastructure based network was almost impossible to setup and maintain. Now-a-days, the applications of MANET have been extended to crisis management, telemedicine, tele-geoprocessing, process control, personal communication, virtual navigation, education and security. Although these applications are very appealing there are some unsolved performance issues too. These issues include, but not limited to (a) overhead control packets, (b) energy conservation, (c) packet loss, (d) end-to-end delay, (e) node mobility, (f) designing as efficient Medium Access Control (MAC) schemes, and (g) shadowing effects. These issues have been widely investigated since the inception of ad hoc networks except the last one. The shadowing is the effect that causes the received signal power fluctuates due to objects obstructing the propagation path between a transmitter and a receiver. The shadowing effects represent a real world propagation model because the wireless propagation channel contains different types of objects that randomly scatter the transmitted signal energy. These scattered signals introduce a variety of channel impairments including fading and multi-path delay spread, Doppler spread, attenuation, and the inherent background noise as well. The constructive and destructive summing of multipath signal components of differing phases result in large fluctuations of signal strength. The short-term variations in the signal strength of 10-20 dB due to multipath fading are typical and it can cause a link to experience unstable behavior. Most of the ad hoc network routing protocols proposed in the literature rely on the consistent and stable performance of individual links. Therefore irregular links can result in high packet loss rates [1-2] [9]. Hence shadowing models are considered more attentions now-a-days compared to other simple models like two-ray ground reflection model and FRIIS free-space model. The effects of shadowing on the performances of MANETs have been investigated in this paper.

II. Factors Affecting Shadowing Effects

In order to investigate the main factor that affects shadowing we consider a uniform network scenario where the location of a mobile node is determined according to uniform random variables [11]. It means that the location of a mobile node is determined by x co-ordinate and y co-ordinate that are uniform random variables between 0 to A and 0 to B respectively, where A and B are the length and the width of a network. To determine the average link distance between a given source-destination pair, we rely on the link distribution model presented in [3]. It is shown therein that the probability density function $p_d(\gamma = \xi D_1)$ for the link distance in a rectangular area can be expressed as

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$$p_d(\gamma = \xi D_1) = \begin{cases} \zeta\xi\,[2\zeta\xi^2 - 4\xi(1+\zeta) + 2\pi], & 0 \le \xi < 1 \\ 4\zeta\xi\sqrt{\xi^2 - 1} - 2\zeta\xi(2\xi + \zeta) + 4\zeta\xi \sin^{-1}(1/\xi), & 1 \le \xi < \zeta^{-1} \\ 4\zeta\xi\sqrt{\xi^2 - 1} + 4\zeta^2\xi\sqrt{\xi^2 - \zeta^{-2}} - 2\xi(\zeta^2\xi^2 + 1 + \zeta^2) + 4\zeta\xi\{\sin^{-1}(1/\xi) - \cos^{-1}(1/\zeta\xi)\}, & \zeta^{-1} \le \xi < \sqrt{1+\zeta^{-2}} \\ 0, & otherwise \end{cases} \quad (1)$$

where $\zeta = \frac{D_1}{D_2} \le 1$ shape parameter rectangular area, $D_1 =$ distance in x-direction of the rectangular area, $D_2 =$ distance in y-direction of the rectangular area, $\xi = \gamma D_1$ where $0 < \gamma \le \sqrt{D_1^2 + D_2^2}$. The expected (i.e., average) link distance $E[\xi] = \int \xi p_d(\xi D_1) d\xi$ is shown in Fig.1. Fig.1 depicts that link distance is almost linearly increasing with increasing rectangular area.

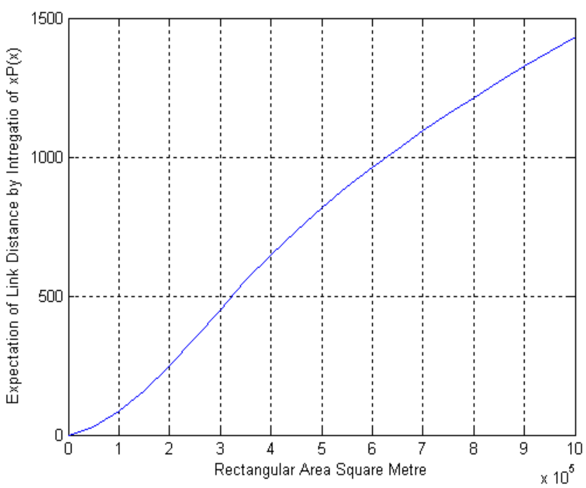

Fig.1 Link distance for a rectangular deployment area

The shadowing effects at any given distance *d* cause the random variation of the path loss PL(*d*) at a particular location. It is distributed log-normally (in dB) about the mean distance dependent value. So, path loss and received power at *d* meter far from transmitter is calculated as follows respectively

$$PL(d)dB = \bar{PL}(d_0) + 10n\log(\frac{d}{d_0}) + X_\sigma$$

$$P_r(d)dB = P_t - [\bar{PL}(d_0) + 10n\log(\frac{d}{d_0}) + X_\sigma] \quad (2)$$

Here $\bar{PL}(d_0) = -10\log_{10}(\lambda^2/(4\pi d_0)^2)$ referred to as a free-space path loss in dB. The probability density function of path loss caused by shadowing is as follows:

$$p_{PL(d)}(x) = \frac{1}{\sqrt{2\pi}\sigma}\exp(-\frac{(x - PL(d))^2}{2\sigma^2}) \quad (3)$$

The probability that the received signal level will be below threshold power P_{th} is given by

$$P_r(P_r(d) > P_{th}) = Q(\frac{P_{th} - \bar{P_r}(d)}{\sigma})$$

$$= \frac{1}{2} - \frac{1}{2}erf(\frac{P_{th} - (P_t - (PL(d_0) + 10n\log(\frac{d}{d_0}))}{\sigma\sqrt{2}}) \quad (4)$$

where $X_\sigma =$ zero-mean Gaussian distributed random variable that represents the error between the actual and estimated path loss, $\sigma =$ shadow standard deviation (in dB), $n =$ path loss exponent which indicates the rate at which the path loss increases with distance *d*, $d_0 =$ the close reference distance close to the transmitter, $d =$ transmitter and receiver separation distance, $P_t =$ transmitting power, $P_r =$ receiving power, $P_{th} =$ threshold power. We can conclude from Equation (4) that the path loss exponent *n* and the standard deviation σ are the main factors of the signal variation. Depending on the location these two parameters may vary widely. To investigate the effects of these two parameters we set the transmission power P_t at 74 dBm and the threshold power P_{th} at 30 dBm. Fig.2 shows the variation of the probability of successful packet reception with the different values of the path loss exponent. It is suggested in the literatures that the variation of path loss exponent should be 2-4. To investigate the impacts of path loss exponent we varied this parameter very slightly from 2.0 to 2.5. It is depicted from the figure that a very small variation of the path loss exponent has grave impact on the probability of successful packet reception. For example, when the path loss is 2.0, this probability decreases to almost zero at the average link distance of 110 meter. So it means that the probability of successfully receiving a packet is zero if the average link distance becomes 110 meter. It is also depicted in this figure that the probability of unsuccessful reception of packet occurs for smaller average link distances when the path loss exponent is varied from 2.2 to 2.5. This figure shows that there will be more unsuccessful packet receptions when the path loss increases.

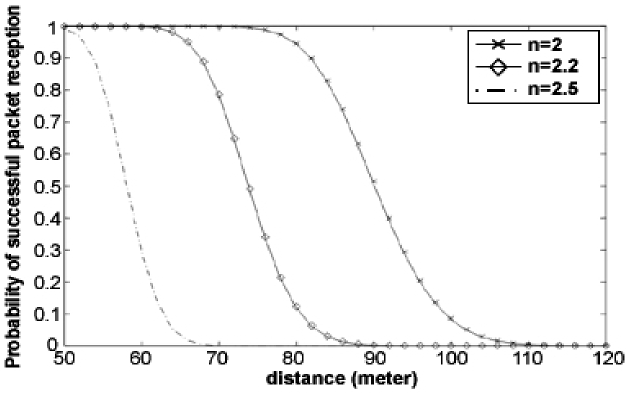

Fig.2 The effects of shadowing with respect to path loss exponent

The other important factor of the shadowing effects is the standard deviation. The variation of the successful packet reception probability with respect to standard deviation is illustrated in the Fig. 3. This figure depicts that higher standard deviation of the signal decreases the probability of successful packet reception. For example, the probability remains 100% till the average distance 70 meter for a standard deviation of 3.0. Hence we should not worry about the shadowing effects for smaller standard deviation. But the probability of successful packet reception decreases rapidly for higher standard deviations (i.e,7 and 9). For example, for the same average distance of 70 meter, the probability of success is only 94% and 88% for standard deviation of 7.0 and 9.0 respectively. Since the path loss exponent and the standard deviation are the main factors in shadowing effects, we have simulated ad hoc networks by varying these two parameters.

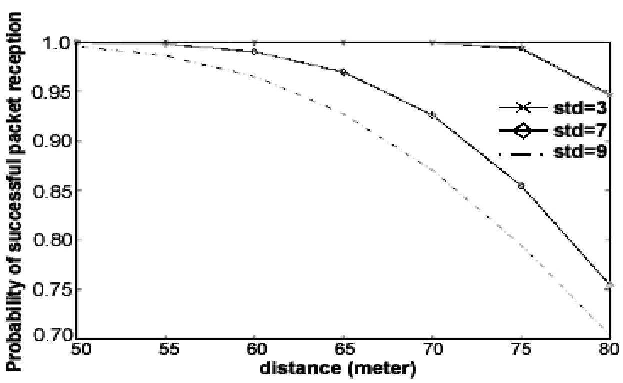

Fig 3 The effects of shadowing with respect to the standard deviation.

The above two figures shows the variation of the probability of successful packet reception for a given hop. But in ad hoc network packet travels for more than one hop from the source to the destination. If the P_i is the probability of successful reception of a packet for the *i*th hop, the probability that the packet will be received successfully over a link consisting of *n* hops is determined by

$$P_{link} = P_1 P_2 \dots P_n \quad (5)$$

Hence, the probability of successful packet reception decreases exponentially for a given link distance as the packet travels more hops. To illustrate the probability of successful packet reception over a link consisting of multiple hops let us assume that the average link distance for a given network is 80 meter. From Fig. 3, we can find the probabilities of successful reception of a packet are 0.94, 0.75 and 0.70 for the average link distance of 80 meter. The probability of successfully receiving the packet for different hop sizes is shown in the Fig. 4. It is depicted in the figure that the end-to-end probability of successfully receiving packet decreases exponentially with size of the network. For small networks, the effect of the number of hop is not significant because packet travels for a few hops. But for a larger network, where a packet travels for a larger number of hops, the probability of successful packet reception decreases significantly. For example, if a packet travels only single hop, the probabilities of successfully receiving a packet are 0.95, 0.88 and 0.75 for the standard deviations of 3.0, 7.0 and 9.0 respectively. On the other hand, if a packet travels for 10 hops, the link probability decreases to only 0.54, 0.22 and 0.7 respectively for the standard deviations of 3.0, 7.0 and 9.0.

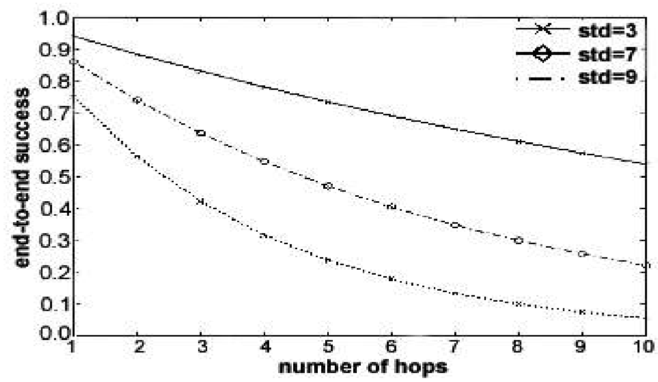

Fig. 4. The variation of end-to-end successfully packet reception over a link of multiple hops

III. SIMULATIONS

To investigate the effects of the shadowing on the performance [4-5] of an ad hoc network, a network consisting of 200 mobile nodes was created and tested via Network Simulator (NS-2) [6]. These nodes were placed randomly over an area of 1000 x 600 sq. meter area. Ten connections were randomly set up in the network. While setting up each connection of the DSR [1] protocol was used as the routing algorithm. Once a connection is set-up, Constant Bit Rate (CBR) agent was used to generate packets. Each CBR connection started at random period of time. Once a CBR connection started, it continued generating packet till the end of the simulation. The packet generation rate was 1 packet per second. Each simulation was tested for an arbitrary 250 seconds simulation time. IEEE 802.11 MAC layer [7] was used as the MAC layer. The network size was then increased to 1000 x 700 sq. meter and 1000 x 800 sq. meters. To measure the performances of ad hoc networks we focused on two parameters namely (a) delivery ratio, and (b) delay per packet. The delivery ratio is the ratio defined by $\gamma = \frac{N_{recvd}}{N_{sent}}$, where N_{sent} is the total number of data packets generated in the network at the source mobile nodes and N_{recvd} is the total number of data packets delivered to the destination mobile nodes was monitored during each simulation. The delay per packet is the ratio of the total delay of the received packets and the total number of packets delivered to the destinations. For a given area, five different topologies were created and tested by using different seeds. Five simulation results were then averaged. The other simulation parameters are shown in Table I Primarily the two-ray model was used as the propagation model in the simulations. We mentioned in the previous section that two-ray model is too simple to represent a real world scenario. Because the two-ray 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.

Table I
Simulation parameters

Parameters	Values
Transmitting Power P_t	24.50 dBm
Threshold Power P_{th}	-64.38 dBm
Transmitting Antenna Height h_t	1 m
Receiving Antenna Height h_r	1 m
Shadow Standard Deviation σ	3 dB
Close Reference Distance d_0	1 m
Path Loss Exponent n	3.0, 4.0

The variation of the signal strength is described by the following rule [8]

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4} \qquad (6)$$

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 received power.

Then the propagation model was changed to the shadowing model. The standard deviation was set to 1.0 and the path loss was set to 3.0. Then the path loss was changed to 4.0 to investigate the impacts of path loss exponent on the received signals. The results are shown in Figure 5 and Figure 6.

Figure 5 illustrates the effects of path loss exponent on the delivery ratio. The simulation results of two-ray model have also been included in the same figure to compare the shadowing effects compared to simple two-ray model. The two ray model curve shows that the delivery ratio is 100% for the simulated networks. But the delivery ratio decreases drastically when we included the shadowing propagation model in our simulations. For example, the delivery ratio is 82% when the path loss exponent is 3.0 for the network size of 1000 x 800 sq. meters. The delivery ratio drops to 56% for the same network size but with the path loss exponent set to 4.0. The same figure also shows that the delivery ratio will further decrease for higher values of path loss exponent. The simulation results verify our previous claim that higher path loss exponents cause higher signal attenuation and lower the probability of receiving a packet.

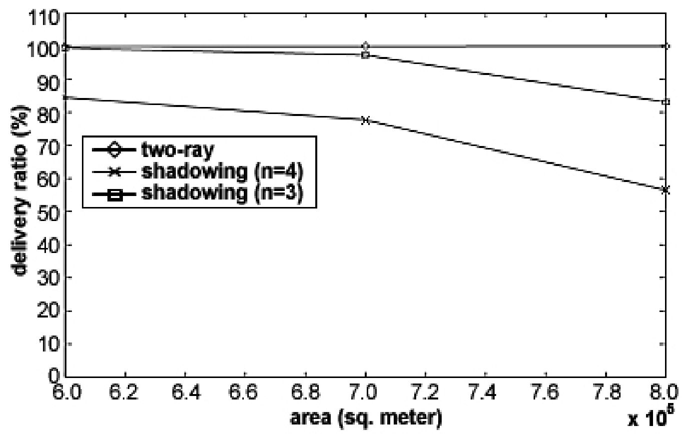

Fig. 5. The delivery ratio comparison

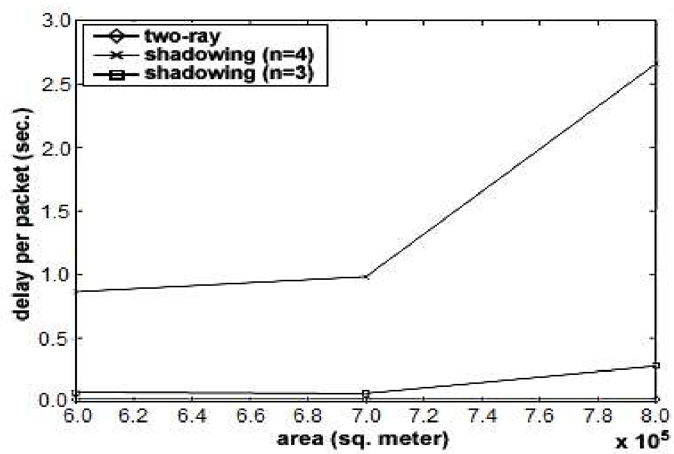

Fig. 6. Delay per packet comparison

The delay per packet is illustrated in Figure 6. The delay per packet is very insignificant for the two-model compared to shadowing models. Because two-model assumes that the signal level remains constant for a given distance, hence less number of packets needs to be re-transmitted. On the other hand, the shadowing effects consider a wide variation of the signal. Hence there will be more re-transmissions of the packet. In another word, a packet has to wait in each hop for longer period of time due to unsuccessful packet receptions. For example, the delay per packet is only 0.1 second for two-ray model when the network size was 1000 x 800 sq. meters. But the delay per packet increases to 0.3 second for the same network size and for the path loss exponent of 3.0. The delay per packet increases to almost 2.5 second for the same network size, but with the path loss exponent set to 4.0.

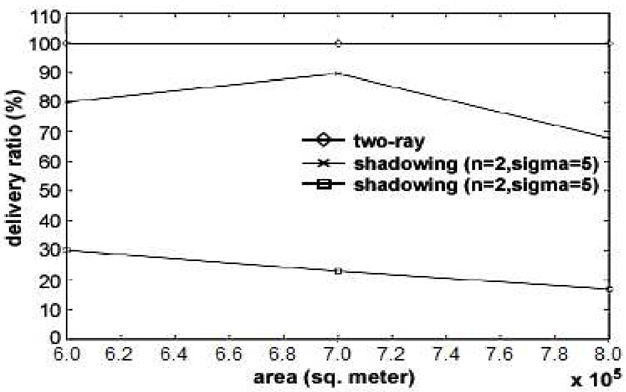

Fig. 7. Delivery ratios under different standard deviations

The variation of the delivery ratio with the standard deviation is shown in Figure 7. This figure shows that the delivery ratio decreases with the higher standard deviation. For example, the delivery ratios are 80% and 30% for the smallest simulated network where the standard deviation was set to 3.0 and 5.0. The delivery ratios decrease to 70% and 20% for the largest simulated network.

IV. Shadowing Solutions

In this paper, three approaches have been investigated to solve the shadowing problems namely (1) increasing the node density, (2) adjusting the transmission power, and (3) modifying the MAC layer protocol.

The first solution has been proposed in the literature. It has been included in this paper to show the comparisons of the three solutions. In the first approach the node density was increased to improve the probability of receiving a packet successfully by at least few neighbors. The basic route discovery mechanism of DSR protocol assumes that all neighbors of a mobile node will re-broadcast a request message received from that node. But the number of neighbors that re-broadcast a request may be considerable low due to shadowing effects. Hence a mobile node will ultimately discover no route or a few routes for sending the packets. Hence the network connectivity will be affected. One of the means to improve the network connectivity is to increase the number of neighbors.

The second approach used in this investigation is to minimize the shadowing effects is by increasing the transmission power. It is shown in Equation (4) that the probability of successfully receiving a packet is defined by

$$P_r(P_r(d) > P_{th}) = \frac{1}{2} - \frac{1}{2} erf\left(\frac{P_{th} - P_t + PL(d_0) - 10n\log(\frac{d}{d_0})}{\sigma\sqrt{2}} \right) \quad (7)$$

This expression shows that this probability can be increased if the transmission power P_t is increased to a higher value. The last approach used to minimize the shadowing effects is to increase the value of a MAC layer parameter called "long-retry-limit". The 'long-retry-limit' determines how many times a mobile node should send packet to its neighbor [10]. The default value of this parameter is 7.0 in IEEE 802.11 MAC layer scheme. It means that a mobile node should try to send packet to its neighbor maximum 7 times and it waits for acknowledgement from that neighbor. If all the seven attempts fail, the mobile node realized that the neighbor is no more available to receive a packet. It means the link between the mobile node and the neighbor is no more available. In this investigation the 'long-retry-limit' has been doubled and it has been set to 14.0 to increase the chance of receiving the packet successfully.

In order to investigate these three approaches we created a network consisting of 80 mobile nodes. These mobile nodes were deployed over an area of 1000m x800m meter. Ten UDP connections were set up in the network. The Constant Bit Rate (CBR) agent was used to generate packets. The path loss exponent was set to 2.0 and the standard deviation was set to 3.0. The number of nodes was increased to 100, 120 and 140 in the same network area. The simulation results are shown in Figure 8. There are three plots namely 'shadow', 'higher power' and 'MAC solution'.

The curve labeled 'shadow' shows that the shadowing effects cannot be improved by increasing the number of neighbors. The results are contrary to the common claim that the shadowing effects can be minimized by increasing the number of neighbors. The main reason of not improving the shadowing effects is that an increase in the number of neighbors can ensure successful discovery of routing paths. But it does not ensure the successful packet transmission along a given route. Hence we can conclude that a higher number of neighbors can only assist a mobile node to discover suitable route (or routes). But it does not ensure successful packet delivery along a route.

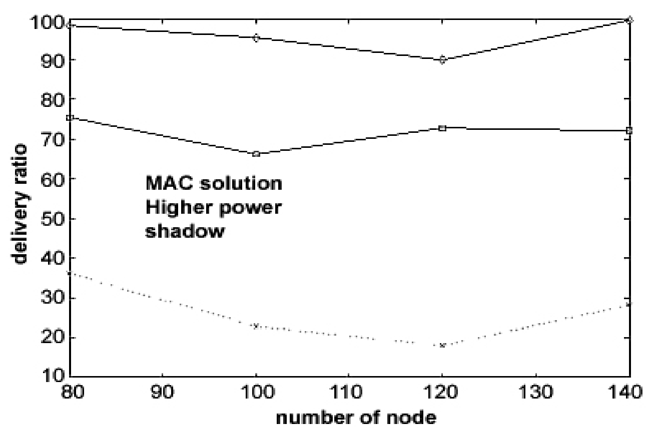

Fig. 8. Comparison of the solutions of shadowing effects

To investigate the effects of high transmission power on the shadowing effects we repeated the previous simulations, but this time, the transmission power was increased to a higher value at +25dBm. The simulation results are depicted in Figure 8 labeled as 'higher power'. This figure shows that the delivery ratio improves considerably in this case compared to that of previous case. The increase in transmission power has two effects (a) the number of neighbor is increased, and (b) the received signal strength is improved. Hence it assists a mobile node in the route discovery operation so that the required route/routes are discovered. It also ensures successful packet delivery between two hops. The figure shows that the delivery ratio is increased by 50% on average compared to that of the previous solutions. For example, the delivery ratio for a network of size 140 nodes has a delivery ratio of 70%. It is almost 50% higher than the delivery ratio for the same sized network under shadowing condition.

Although the delivery ratio can be increased significantly by increasing the transmission power, it may not be a feasible solution for a network that carried high traffic intensity. Because higher transmission power increases the interference level in a network and it also increases the packet collision probability. In the third solution proposed in this paper overcomes this limitation. In this solution the MAC layer protocol parameter has been changed. In this solution the default value of 'long-retry-limit' of MAC protocol has been doubled by allowing a mobile node to resend a packet 14 times instead 7 times. The simulation results are shown the Figure 8 labeled as 'MAC solution'. The figure shows that the delivery ratio can be further improved by this third solution. For example, the delivery ratio is almost 95% for a network consisting of 140 nodes. But the delivery ratio was 30% for the first solution and the same was 70% for higher transmission power.

V. CONCLUSIONS

In this paper the shadowing effects on ad hoc network has been investigated. Although the free-space model and the two-ray model are widely used in simulation. The paper shows that the shadowing effects need to be considered to emulate a real world situation. The importance of shadowing effects has been presented in this paper. It is shown via simulation that the shadowing effects have grave impacts on the performance of an ad hoc network. The paper also presents an in depth investigation of the shadowing effects on the routing protocol and the MAC layer scheme. Three solutions have also been proposed in this paper. The simulation results show that the effects of shadowing can be minimized by using these proposed solutions. The advantages and the disadvantages of these solutions have been presented in this paper too.

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