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The Optimal Receiving Signal Strength to Use the Relay Node in Wireless Network

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Abstract

The connectivity in wireless communication is established based on the receiving signal strength, which is affected by distance, interference, noise, mobility, etc. As a result, a node has a limited coverage area and generally 250m of communication range is assumed for free space environment in MANETs. Therefore, the connectivity becomes one of the significant limitations in deploying wireless networks such as MANETs, cellular, or Wi-Fi. The relaying concept was introduced, which places the additional node between out of range nodes, to overcome the coverage limitation. Therefore, the relay node became one of the solution to improve the connectivity in wireless network and many researchers tried to find the optimal location of the relay node to improve the overall performance. However, only low or no connectivity areas are considered to add the relay node in their study. The effectiveness of relay node for the nodes with the connectivity has not been investigated at the best of our knowledge. In this paper, we investigate the effectiveness of relay node through the experiment. Two protocols, TCP and UDP, are selected for the evaluation of the network performance using throughput, packet loss, and retransmission rate in various receiving signal strength with and without relay node. The results are presented, compared, and analyzed to identify the optimal condition in terms of receiving signal strength for addition of relay node to improve the performance between pair of nodes.

1. Introduction

Recently, wireless network is very popular due to its many advantages including mobility, cost, easy deployment, etc. In addition, it has been developed and applied to lots of application such as sensor network, ad hoc network, LAN, vehicular network, body network, IoT, etc. One of the driving forces of such a rapid growth in wireless network is a convenience in installation. Since wireless network creates the connectivity without wire, network connectivity can be easily established in the most of environment conditions to create or extend the network. For example, instead of installing the cable over the mountain or river, install the antennas to create one or multi-hop wireless connection. In multi-hop wireless network, the nodes must cooperate to establish routes using wireless links and act as a router to forward the packets. The route is established based on given network topology, which cannot be predetermined in most case of Mobile Ad-hoc Networks (MANETs) due to node mobility. In multi-hop wireless network, topology is also dynamic because of the arbitrary node deployment, interference, noise, etc. Multi-hop wireless network also inherits the traditional problems of wireless communications, which when combined with mobility and lack of infrastructure makes their design and development challenging [1-3]. Therefore, the connectivity became one of the important components in wireless network where the connectivity is established based upon a receiving signal strength at receiver. The transmitter transmits the signal in certain power level, which propagates in all direction and suffers from interference, noise, and attenuation. In other words, the detectable receiving signal is only available in near area that limits the communication range in wireless communication, generally represented by a circle centered by transmitting node. Thus, the connectivity is defined by the receiving signal strength that is affected by distance, noise, obstacle, etc.

The relay concept is proposed to overcome the connectivity limitation by placing additional node between pair of nodes. The relay node became one of the common solutions to improve the overall connectivity and performance in wireless network and many literatures focused on finding an optimal location of relay node. Many researchers implement and deploy the relay node in different wireless networks such as cellular network, mobile wireless ad-hoc network, wireless sensor network, etc. Some of them use Unmanned Aerial Vehicles (UAVs) as a relay node to deploy quickly, extend coverage, and improve the network connectivity [4-6]. Some researchers investigate the relay node placement to improve network connectivity, survivability, and lifetime maximization [7-9]. However, they use the relay node to very weak or no connectivity areas to improve a connectivity or survivability in their study. The effectiveness of relay node for the nodes with the connectivity has not been investigated at the best of our knowledge. In this paper, we investigate the effectiveness of the relay node using experimental study. Two protocols, TCP and UDP, are selected for the evaluation in terms of the performance metrics such as throughput, packet loss, and retransmission rate in various receiving signal strengths with and without relay node. The results are presented, compared, and analyzed to identify the optimal receiving signal strength for relay node addition to improve the performance.

The rest of the paper is organized as follows. In section 2, we define the connectivity of wireless communication and relay node in the wireless network. Section 3 presents the experiment setup with selected comparing performance metrics. We illustrate and discuss the results in section 4. Then, we present the conclusions in section 5.

2. Wireless network

2.1 Connectivity

One of the essential components of the network is connectivity for the communication where the connectivity is defined as the connecting link between two network devices. In wired network, transmission medium is physical cable (i.e., twisted pair, coaxial, fiber optic, etc.) which defines the connectivity. Unlike wired network, the transmission medium in wireless communications is an air where the transmitted signal form the source propagates all directions and the signal strength decreases with the distance. Therefore, the link in wireless is unreliable due to the nature of its medium, air, which makes link quality susceptible to many factors such as noise, interference, obstacles, etc. in communication environment.

The connectivity is established for two wireless nodes that are within the communication range, which is determined by receiving signal strength computed from transmission power and pathloss. The common propagation models are free space, 2-ray ground, and shadow fading. Free space model is considered when the network environment is assumed to be open space with no object such as tree, building, excessive noise, etc. 2-ray ground model includes the signal reflecting by the ground, but environment is still assumed to be open without any object. In these models, the pathloss gradually decreases in the distance, which induces that the connectivity is deterministic and determined by the distance between two nodes. If two nodes are within certain range that receiving signal is still good to receive the data, they can communicate. Shadow fading model is considered when the network environment includes any object that makes the random attenuation affecting on the signal propagation, called shadow fading X, in path loss model as shown in equation (1).

$$L_p = L_0 + 10\alpha\log_{10}(d) + X \quad (1)$$

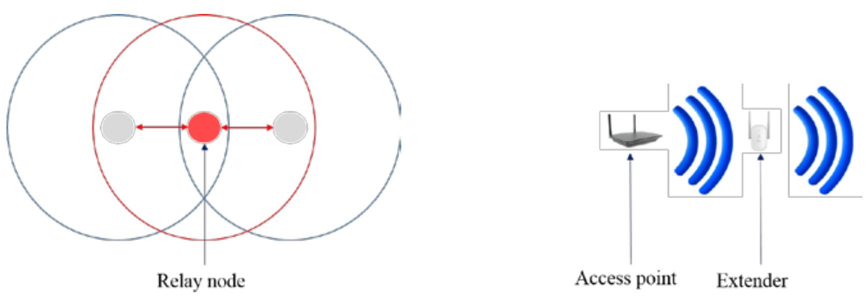
where $L_0 = 10\log_{10}(P_t) - 10\log_{10}(P_0)$, P_t is transmitting power, P_0 is the receiving power at 1 meter, d is a distance, and X is a random variable with log-normal distribution where its probability density function is shown in equation (2).

$$f_{LN}(x) = \frac{1}{\sqrt{2\pi}\sigma x}\exp\left(\frac{-(\ln x-\mu)^2}{2\sigma^2}\right) \quad (2)$$

where μ is the mean received signal strength and σ is its standard deviation. Standard deviation σ is the factor that determines the randomness of the shadow fading effect. The shadow fading heavily affects on the network connectivity. The connectivity of wireless multi-hop network in shadow fading environment is studied in [10] and it shows that the connectivity is probabilistic and the probability of connectivity between two nodes dramatically decreases in distance. This connectivity behavior probabilistically produces the packet loss.

2.2 Relay node

In wireless network, the connectivity is limited by many environmental factors such as distance, noise, objectives, etc. In order to extend the connectivity in wireless network, the relay node is commonly used in many wireless applications such as cellular network, wireless ad hoc network, wireless sensor network, etc. For example, when two wireless nodes are out of communication range each other, relay node can be located between them to connect each other as shown in Figure 1(a). Another common application is Wi-Fi extender, which can extend the coverage area by relaying the traffic between wireless access point and clients (i.e., PCs, mobile devices, etc.) as in Figure 1(b).



(a) Relay node in mobile ad hoc network (b) Wi-Fi extender

Figure 1. Relay node in (a) mobile ad hoc network and (b) as a Wi-Fi extender

Relay node helps wireless network to improve the connectivity and extend the coverage area by creating additional connectivity from exiting network to improve the network performance. Many researchers investigate the usage and deployment of the relay node in many wireless networks to improve the connectivity, extend the connectivity area, survivability, etc. [4-9].

In addition, relay node is used to improve the link quality by adding it for a pair of nodes that has poor link quality. However, an effectiveness of relay node for the existing wireless link has not been investigated at the best of our knowledge. In the rest of this paper, we investigate the effectiveness of the relay node through the sets of experiment.

3. Experimental Study

We use the experiment to study the performance of relay node. In this section, we will explain the experimental setup and measuring performance metrics. Then, we illustrate the results.

3.1 Experimental Setup

We use three Raspberry Pis (Model B) to build the testbed. Each Raspberry Pi is running Linux and equipped with Wi-Fi (2.4GHz) adapter for the wireless communication. One is used as source node, another as destination node, and the other as relay nodes. For the wireless connection, we use 802.11 for the data link layer protocol. One Raspberry Pi is configured as an Access Point using Hostapd in Linux and running Dynamic Host Configuration Protocol (DHCP) while the other is running as a client using Udhcp (i.e., DHCP client program) to create the wireless connection between two Raspberry Pis.

Two network configurations (i.e., one-hop and two-hop) are used to evaluate the performance of the relay node. The first configuration is one-hop communication and two Raspberry Pis are used, one as a source and the other as a destination where one of them is running AP (Access Point). The network configuration with relay node requires point-to-point (P2P) connection between each pair of nodes (i.e., source to relay node and relay node to destination). In other words, source needs to send a packet to relay node even if the destination is within the communication range. We configure the relay node as AP so that it can handle the data transmissions for both connections (i.e., source to relay and relay to destination) so that relay node can manage the data transmissions for both clients to minimize the possible collision. We select 7 receiving signal strengths such as -26, -44, -53, -60, -73, -85, and -90 dBm to measure the performance in various receiving signal levels. In two-hop communication, we maintain above receiving signal strengths between two clients. For example, the receiving signal strength of -26 dBm in two-hop means that both receiving signal strengths at AP from client1 (source) and at client2 (destination) from AP are approximately half of -26 dBm (i.e., -13 dBm). In the testing setup, we locate the client 1 and 2 to have -26 dBm of receiving signal strength and place the AP approximately in the middle of two clients.

The testing environment is open hall way in one of the University building. For each one-hop test, we used one AP and one client and positioned the two Pis in as much of a “straight line” as possible to setup the various receiving signal strengths. Similarly, for the two-hop tests, we locate them in the same receiving signal strength as in one-hop except with a relay node in between.

3.2 Protocols and performance metrics

We use most common two transport layer protocols, Transmission Control Protocol (TCP) and User Datagram Protocol (UDP), to collect the performance metrics. We collect three performance metrics, throughput, retransmission, and packet loss in 7 different receiving signal strengths shown above. Throughput is used to compare the TCP and UDP for both one-hop and two-hop connections. Since TCP requires retransmission for packet loss, we use the number of retransmission to compare two network configurations. Since unreliable transport layer protocol UDP does not require retransmission, packet loss is used instead for the comparison.

For the performance measurement collection, we use open-source software tool iperf3, developed by ESnet and the Lawrence Berkeley National Laboratory. Since we use 7 different receiving signal strength, we determine the signal strength between the client and the access point by using the Linux command *iwconfig* for each test as close as possible. We utilized several features in iperf3 using various arguments in command lines as such: *iperf3 -s* enables server mode, *iperf3 -c* enables client mode, *-u* changes default TCP testing to UDP testing, *-k* (followed by a number) sets the number of packets to send during the test. Following is the example of TCP and UDP testing commands respectively. "*iperf3 -c 192.168.42.1 -p 5021 -k 5000*" and "*iperf3 -c 192.168.42.1 -p 5021 –u*". Iperf3 uses set of packet transmissions, 5000 for TCP and 159 for UDP, to measure the throughput, retransmission, and packet loss. The throughput is computed by use of predetermined fixed size of the Internet Control Message Protocol (ICMP) packet and its round-trip time (RTT). Retransmission, only available in TCP, is measured by counting the resending packets due to any unsuccessful transmission such as packet loss, error, etc. The packet loss is counted by use of successful number of transmissions for fixed 159 total transmitted UDP packets. The test results were obtained from 10 repeated testing.

4. Results and Discussions

In this section, we present and discuss the testing results of throughput, retransmission, and packet loss for given two wireless connectivity configurations, one-hop and two-hop. Then, we discuss the findings from the experiment.

4.1 Results

Here, we illustrate the throughput results of one-hop and two-hop wireless connection for different receiving signal strength (RSS), where the throughput is measured from the fixed size ICMP packet and RTT. Both results in each RSS are plotted in Figure 2. For one-hop wireless connection, it shows that the throughput decreases as RSS decreases in general. However, in two-hop wireless connection, throughput results do not show specific trend with varying RSS. Comparing one-hop and two-hop wireless connection in throughput, one-hop wireless connection shows higher throughput than two-hop overall. In one-hop connection, it reaches highest throughput at strongest RSS (i.e., 17 Mbps at -26 dBm and 1.92 Mbps at -95 dBm). In two-hop, the throughput seems not stable in the range of -26 and -73 dBm; highest (i.e., 15 Mbps) at -53 dBm and lowest (i.e., 1.04 Mbps) at -73 dBm. But it gradually increases in -85 and -90 dBm and shows higher throughput than one-hop at -90 dBm (i.e., 1.92 Mbps for one-hop and 2.76 Mbps for two-hop). Since two-hop communication requires one more transmission and AP cannot transmit and receive at the same time, AP cannot receive a packet from client 1 while it relays the packet to client 2. Therefore, the less number of packet will be delivered to client 2 for a fixed duration in two-hop than one-hop.

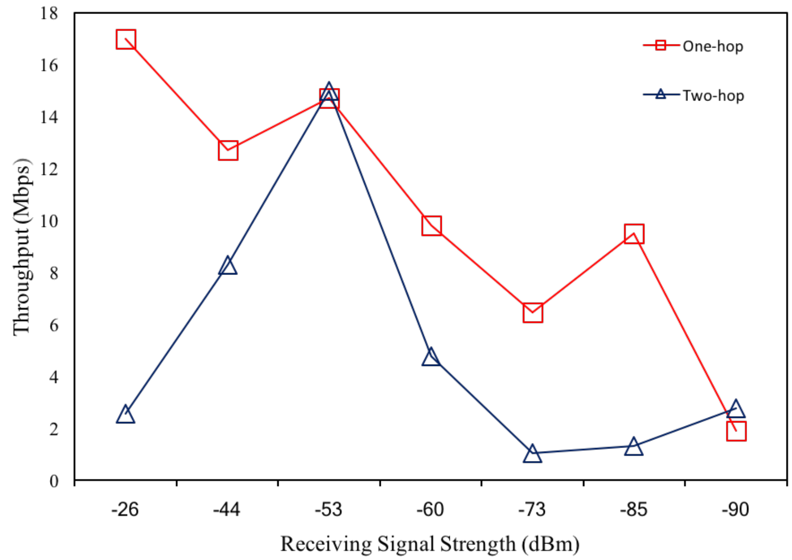


Figure 2. Throughput results in one-hop and two-hop wireless connections

The next comparing performance metric is retransmission used in TCP. The number of retransmissions out of 5000 transmissions in various RSS are measured and plotted in Figure 3. In one-hop connection, the number of retransmission is very low and stable in relatively higher RSS (i.e., -26 to 73 dBm). The retransmission occurs more often with weaker RSS as expected. As the RSS is weaker, the error rate increases in data transmission due to noise, interference, etc., which causes more retransmissions. In Figure 3, it is obviously shown that the number of retransmission considerably increases at -85 dBm (i.e., 321 retransmissions). In two-hop wireless connection, the number of retransmission is not stable; the lowest (i.e., 0) at -53 dBm and highest (i.e., 369) at -73 dBm. One notable finding is continuous decreasing at weaker RSS. It shows 191 at -85 dBm and 9 at -90 dBm. Overall, one-hop requires less number of retransmission that two-hop at relatively stronger RSS (i.e., -26 to -73 dBm) while two-hop shows less at weaker RSS (i.e., -85 and -90 dBm). Statistically, the possibility of the packet error, drop, etc. increases as another wireless link is added. In general, network availability decreases as additional link is added. Consequently, it requires more number of retransmissions in two-hop than one-hop wireless connection.

The next metric is packet loss, which is measured with various RSS in both one-hop and two-hop wireless connections and plotted in Figure 4. In packet loss, we use fixed size of UDP packets and measure it by subtracting the total number of receiving UDP packets from the total number of 159 transmitting packets. The results show similar behavior as retransmission rate in TCP. As stated above, the additional link creates higher risk of packet error, drop, etc. Therefore, it also generates more number of packet loss in UDP while retransmission in TCP. In one-hop connection, there is no packet loss until -73 dBm and it increases dramatically at -85 and -90 dBm (i.e., 37 and 80, respectively). As the RSS is weaker, the more number of UDP packet is losing. In two-hop connection, it seems increases with the weaker RSS until -73 dBm (i.e., 4.4 to 46 packet loss). However, it considerably decreases in -85 and -90 dBm (46 to 3.1 and 0.63 packet loss respectively). Comparing both connections, two-hop generates more number of packet loss as we expected. In weaker RSS such as -85 dBm and -90 dBm, one-hop shows higher packet loss rate than two-hop.

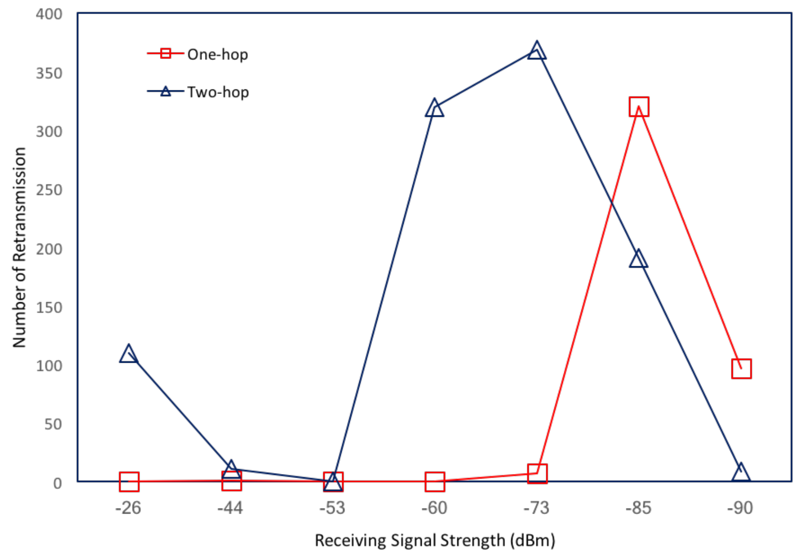


Figure 3. Number of Retransmission in one-hop and two-hop wireless connections

The last comparing performance metric is the jitter, which is measured for both one-hop and two-hop wireless connection and plotted in Figure 5. The time stamp of UDP packet is used to measure the jitter, which indicates the variance of the packet inter-arrival time. In one-hop connection, jitter is stable until -85 dBm, but it significantly increases at -90 dBm (i.e., approximately 2 ms to 29s). It represents that the packet inter-arrival time shows larger variation at weaker RSS. In two-hop connection, it is more stable over all RSS. Comparing both connection, it shows that two-hop shows lower and more stable than one-hop in jitter.

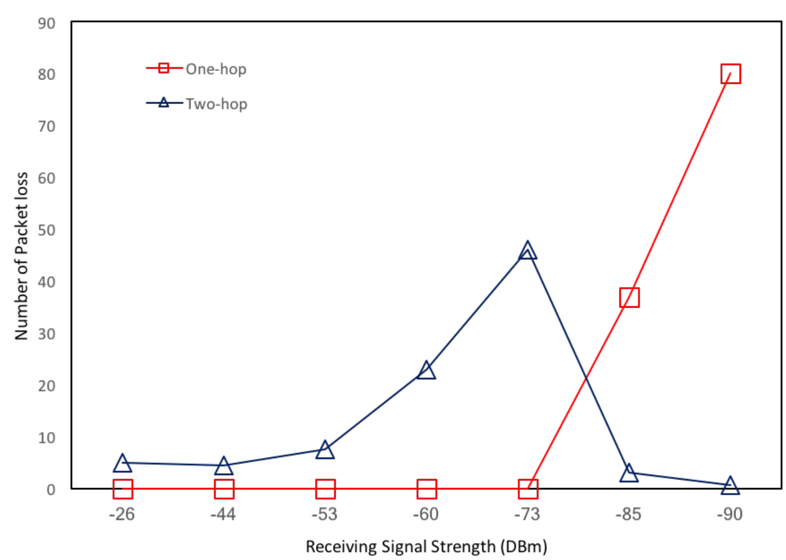


Figure 4. Number of packet loss in one-hop and two-hop wireless connections

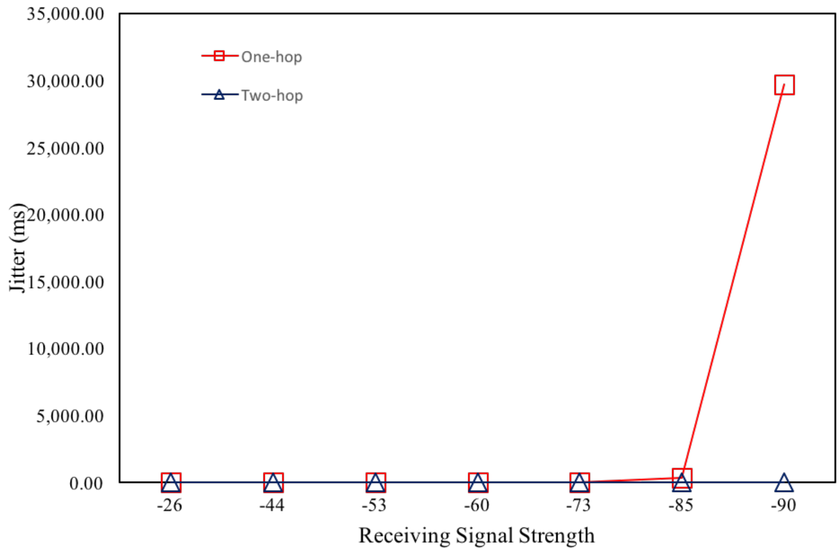


Figure 5. Jitter in one-hop and two-hop wireless connections

4.2 Discussions

In this paper, we compare two wireless connections, with and without relay node, in four network metrics, throughput, retransmission, packet loss, and jitter in two most common transport layer protocols, TCP and UDP. The throughput results show that one-hop connection outperforms comparing to the connection with relay node. This may because of the computation method of Iperf, dividing the size of ICMP packet by RTT. The RTT is generally greater with relay node since it requires additional processes. The total RTT includes transmission time, propagation time, and processing time from client 1 to 2 in one-hop while it includes additional transmission time, propagation time, processing time, and queueing time from AP to client 2 in two-hop connection. In addition, 802.11 allows only one transmission and AP should wait its transmission to client 2 until client 1 finishes its transmission to AP. As a result, it shows lower throughput with relay node overall. However, relay node becomes useful as the RSS is weaker. At -90 dBm, the throughput with relay node tends to be better than one without relay node. Since such a weaker RSS creates disconnection problem, relay node plays more important role in data communication.

The retransmission and packet loss show similar behavior for both one-hop and two-hop in various RSS. Since additional unreliable wireless link is adding with relay node, it adds additional risk of packet error, loss, drop, etc. Therefore, retransmission and packet loss generally increases with relay node. However, relay node shows better performance for both metrics as the RSS is getting weaker. The weaker RSS increases the possibility of disconnection in wireless link, which causes more damaged or lost packets. Thus, retransmission and packet loss increases and the relay node becomes more useful as show in results. In terms of jitter, connection with relay node shows more stable than one without the relay node. In other words, the relay node plays better role for the application running UDP with predictable packet arrival time such as video streaming or voice.

In overall, the results of throughput, retransmission, and the packet loss indicates that the relay node becomes significantly useful with the weaker RSS and application which does not require higher data rate for TCP applications. For real-time application which uses UDP, relay node plays better role with weaker RSS as well.

There are couple of limitations. The first is the location of the relay node. We place the relay node approximately in the middle of two clients to create equal RSS to both. Therefore, our results do not represent the results from any location of relay node between two clients. In addition, the sets of experiment are conducted in the University where campus WLAN exists. The results may be influenced by noises or interferences due to school facilities, APs, or other radio devices in the existing WLAN.

5. Conclusions

The relay node is an additional node placing between two nodes that are out of communication range to overcome the coverage limitation. Thus, the relay node became one of the solutions to improve the connectivity in wireless network. In this paper, we investigate the effectiveness of relay node for varying RSS using experiment study. We use three Raspberry Pi devices to setup the wireless network connection with and without relay node. Four metrics, throughput, retransmission, packet loss, and jitter, are selected to compare both with and without relay node wireless connections. Throughput, retransmission, and packet loss show that the relay node becomes useful as the RSS is about -73 dBm and more significant as the RSS is weaker. In terms of jitter, relay node is useful for all RSS. Our results show that relay node, which creates additional unreliable wireless connection to the network, degrades the network performance when RSS is strong enough. As the RSS is weaker, it starts improve the performance. Therefore, the relay node is useful to increase the network connectivity and coverage area. However, it should be carefully chosen because it may degrade the network performance. In addition, our results also help to identify the possible removal of unnecessary node in the network to improve the performance.

References

[1] I. F. Akyildiz and X. Wang, “A survey on wireless mesh networks”, *IEEE Communications Magazine*, Vol. 43, No. 9, pp. S23–S30, Sept., 2005.
[2] H. Moustafa and Y. Zhang, “Vehicular networks, techniques, standards, and applications”, CRC Press, 2009.
[3] I. Chlamtac, M. Conti, and J. J. Liu, “Mobile ad hoc networking: imperatives and challenges,” *Ad Hoc Networks*, vol. 1, no. 1, pp. 13-64, July 2003.
[4] C. Cheng, P. Hsiao, H. Kung, and D. Vlah, “Maximizing throughput of UAV-relaying networks with the load-carry-and-deliver paradigm,” IEEE WCNC, pp. 4417–4424, 2007.
[5] De Freitas, Edison Pignaton, et al. "UAV relay network to support WSN connectivity." *Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), 2010 International Congress on*. IEEE, 2010.

[6] Zhan, Pengcheng, Kai Yu, and A. Lee Swindlehurst. "Wireless relay communications with unmanned aerial vehicles: Performance and optimization." *IEEE Transactions on Aerospace and Electronic Systems* 47.3 (2011): 2068-2085.
[7] E. Lloyd and G. Xue. Relay node placement in wireless sensor networks. IEEE Transactions on Computers, 56:134–138, 2007.
[8] J. Bredin, E. Demaine, M. Hajiaghayi, and D. Rus. Deploying sensor networks with guaranteed capacity and fault tolerance. In ACM MOBICOM, pages 309–319, 2005.
[9] Y.T. Hou, Y. Shi, H.D. Sherali, and S.F. Midkiff. Prolonging sensor network lifetime with energy provisioning and relay node placement. In IEEE SECON, pages 295–304, 2005.
[10] C. Bettstetter and C. Hartmann, "Connectivity of Wireless Multihop Networks in a Shadow Fading Environment", Wireless Networks, Springer 2005. **11**(5): p.571-579.