Augmenting Packet Delivery Rate in Outdoor Wireless Sensor Networks Through Frequency Optimization

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Abstract

The deployment of a wireless sensor network for real-time monitoring applications encounters numerous challenges. In a typical outdoor scenario the propagation of the radio signal can be affected by several factors like the rainfall, foliage, path loss effect and fading effect. These factors can confront dynamic changes in link quality which will affect the packet delivery rates and can result in the failure of the system. This paper presents an optimized frequency selection for any wireless sensor networks which can enhance the packet delivery ratio at any worst environmental scenarios through a simulated framework in QualNet 5.0.2.

Keywords: Propagation, Path loss effect, Fading, Link Quality, Shadowing, Packet Delivery Rates, Optimized frequency

1. Introduction

Wireless sensor networks are more frequently used for the environment monitoring tasks. These networks need to be mostly deployed in an outdoor scenario to collect the real-time environmental parameters. These data need to be transmitted to the control station using available wireless communication networks. The propagation of a signal through any physical environment is affected by various environmental factors that will affect the strength of the received signal. Accurate prediction of these effects is inevitable in the design and deployment of any robust communication system.

In wireless communication, the major effects can include shadowing and diffraction caused by obstacles along the propagation path, such as mountains in a rural area and buildings in a more urban environment. Attenuation caused by the rainfall, and movement of the vegetation or foliage etc. In the absence of a line-of-sight path for communication these environmental factors have a dominant effect on the fidelity of the received signal through refraction effects, fading, and signal attenuation. We cannot assure a line of sight path in every scenario, so the non line of sight path causes the signal to degrade and cause the low quality in the transmission. To avoid the degradation of the signal strength it is necessary to determine the optimum parameters for the design and deployment of wireless sensor network.

For achieving a robust wireless sensor network, the different quality of service (QoS) parameters to be considered are packet delivery rates, delay etc. In this work we have analyze different possible parameters that lead to degradation of signal strength leading to link failures. We have analyzed the packet reception rate, received signal strength, the link quality value with respect to the dynamic environment changes. This simulation is performed to understand the predominant factors affecting the QoS and the range of each factor that will affect the signal strength. For getting the best performance from the wireless sensor network an optimum frequency for communication is selected with respect to the constraints such as received signal strength and link quality. The optimization of frequency is obtained through several experiments done with the QualNet simulator.

2. Related Works

In [2] Boccur et al. a statistical analyzing on the link quality estimation is done by building a software bench marking tool called RadialE where the authors failed to discuss on the dynamic change of environment effect on the link quality with the change in frequency. In [3] Abiola Fanimokun et.al presented a new near-ground propagation models at 915 MHz based on field measurement data for three naturally occurring environments (open fields, woods and wooded hills). In [4] Margham et al. the effect of rainfall rate on the link quality was analyzed with only one frequency 2.4 GHz and failed to discuss the effect of other frequencies. In [5] Yang et al. the authors discussed the accuracy of the existing path loss model effect on the packet reception with only 2.4GHz. In [6] Ren et al. by using a packet oriented simulation tool, OPNET, the authors realized the effect of Rayleigh fading and shadowing fading. The effect of path loss was also

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optimized through adapting the path loss exponent values at 2.4 GHz. In [7] Irfan et al. have presented the received signal strength measurement results for path loss, shadowing and fading models at 2.4 GHz. In [9] Putra et al. explains that packet delivery rates can even be affected with the effect of vegetation and wind. To prove it, the authors had done a statistical analyzing. The linearity relationship between the received signal strength and link quality is calculated in Ekka [4] et al. In [10] Nose et al. a signal strength based route construction is done to tolerate fault in the network at 2.4 GHz. In [1] Jongwon et.al identified that the link quality and the received signal strength can be used as parameters for developing an adaptive routing protocol. In most of the existing works the network performance was discussed through a single propagation effect, a combined analyzing was not done so far. This paper analyzed the combined effect of the propagation factors in the network quality.

3. Challenges and Design Requirements

When a wireless sensor network is deployed outside the network can endure different environmental challenges like the rainfall, foliage, shadowing, fading etc. In this work we focus mainly the effect of rainfall and foliage on the packet delivery rate, received signal strength and link quality values are analyzed. The data rate can be affected with optimizing the frequency. The modulation scheme used is the binary phase shift keying. The simulation is tested with different transmission powers. The network is tested with the scenario where the effect of rainfall and the vegetation is more.

The rainfall attenuation model used in simulation is [1]:

$$A = \alpha R^{\beta} \qquad (1)$$

Where, R is the rainfall rate in millimeter per hour.

$$\alpha = e^{\left(1.58\ln(f) - 6.23\right)} \qquad (2)$$

$$\beta = e^{\left(0.029\ln(f) + 0.031\right)} \qquad (3)$$

The different models used for the foliage simulation are:

Weissberger model [12]:

$$Lw(dB) = 1.33 * f^{0.284} * d^{0.588} \qquad (4)$$

Where f is the frequency (GHz) , and d is the distance of propagation through foliage it should be between 14 meter and 400 meter.

ITU-R model [12]:

$$L_{ITUR}(dB) = 0.2 * f^{0.3} * d^{0.6} \qquad (5)$$

Where f is the frequency in MHz, and d is the tree depth in meter.

4. Implementation Details

A large scale multi-hop wireless sensor network has been simulated using QualNet, which is capable to imitate the etiquette of a real communications network. This simulator provides an extensive environment for designing protocols, developing and vitalizing network scenarios, and examining their performance. Using this simulator, single hop and multi-hop network performance evaluation scenarios was developed. Different scenarios of dynamically varying environments has been simulated and tested for network performance in the both the network topologies. Dynamic variations in the environment has been simulated and its propagation effects path loss, fading, shadowing were studied and analyzed. Users can evaluate the basic behavior of a network, and test combinations of network features that are likely to work. QualNet provides a extensive environment for designing protocols, developing and vitalizing network scenarios, and examining their performance.

Dynamic variation in the environment due to the rainfall conditions and foliage was programmed and implemented in this simulator. To introduce the effect of rainfall rate and distance of propagation through foliage existing empirical models are implemented and experimented in the simulator. This simulation module was integrated with some of the existing modules in QualNet to study and analyze the effect of path loss, fading, shadowing etc. The combined effects of these dynamic variations with respect to the expected environment has been simulated and experimented for both type of networks such as single hop network and multi-hop network. The results from the simulation are described in the next section

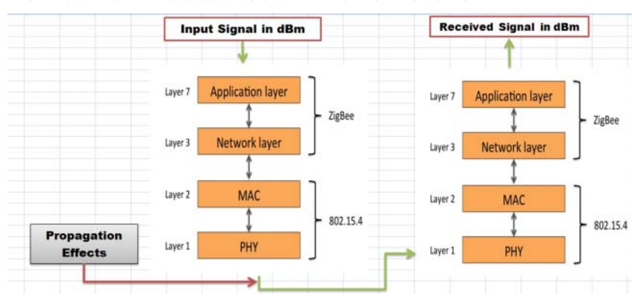

Figure 1: Implemented block diagram in Simulator

The propagation effects are experiencing in the physical layer of the zigbee protocol stack. So the propagation models are implemented in the physical layer

5. Simulation Results

The simulation experiment were performed with zigbee based wireless sensor network with data rate specified as 250 kbps which is the highest data rate available for zigbee, the number of packets that are used to sent for the transmission is about 200 packets per second to make sure the sampling rate to be 200. The experiment was carried out with a single hop network since multihop was tested and explained in [11]. The simulation was done with three different frequency ranges of zigbee as 868 MHz, 902-928 MHz and 2.4 GHz and the result showed that the frequency range between the 902-928 MHz is the optimum frequency range which resulted in the maximum packet reception rate with different scenarios. The simulation were done with a scenario where there is lowest and worst rainfall rate, effect of foliage is in varying range. The simulation results also showed that the maximum packet reception rate is the concomitant of the maximum link quality and RSSI value.

5.1 Packet reception rate with rainfall effect

The figure 2, 3, 4 and 5 shows that frequency range between the 902-928 MHz is showing maximum packet reception rate than 868 MHz and 2.4 GHz with varying rainfall rate from 50 to 600 millimeter per hour.

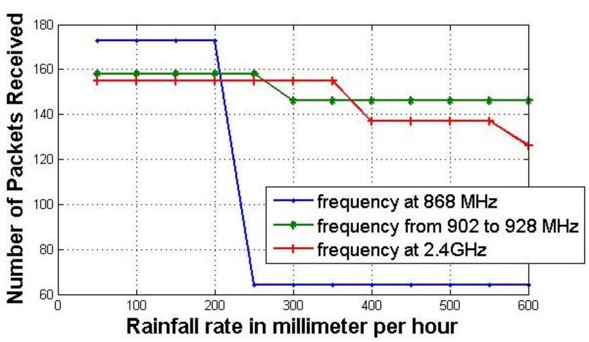

Figure 2 : Packet Reception Rate with the transmitted signal power as 0 dBm

The simulation is done with the transmitted signal power as 0 dBm. The result is plotted in figure(2) from which it is clear that the number of packets received with the channel frequency as 902-928 MHz had showed a high packet reception even in high rainfall rate than channel frequency at 868MHz and 2.4 GHz.

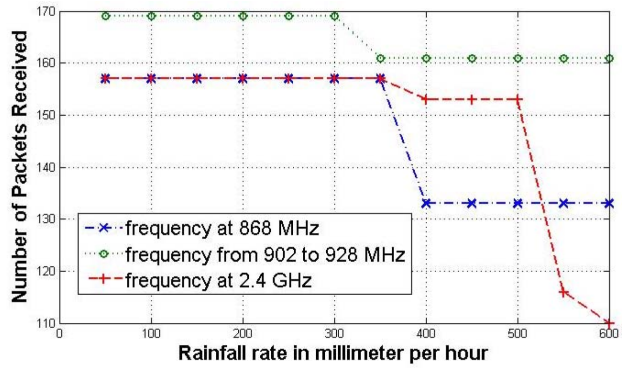

Figure 3 : Packet Reception Rate with the transmitted signal power as 5 dBm

The simulation is done with the transmitted signal power as 5 dBm. The result are plotted in figure (3) which shows when the rainfall rate increases the frequency at 902-928 MHz is showing the best packet reception.

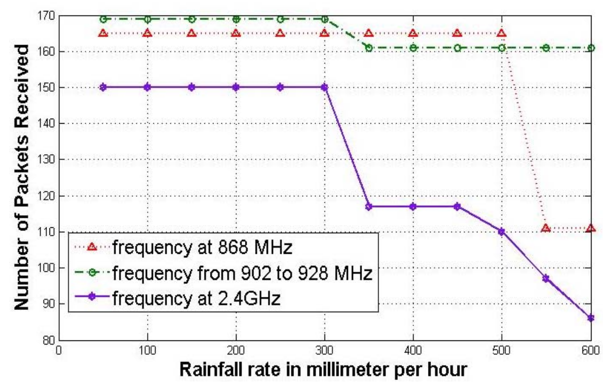

Figure 4: Packet Reception Rate with the transmitted signal power at 10 dBm

The simulation is done with the transmitted signal power as 10 dBm. The result is plotted in figure (4) which evince that the number of packet received maximum is at frequency of 902-928 MHz.

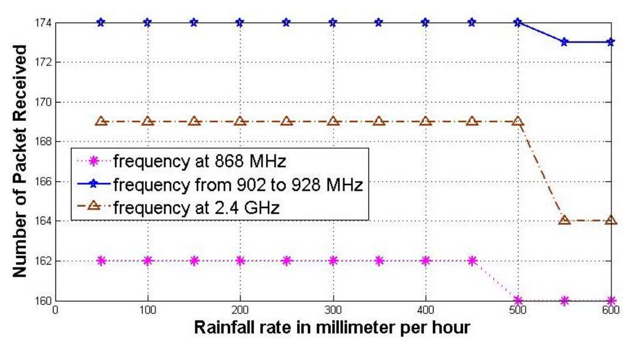

Figure 5: Packet Reception Rate with the transmitted signal power at 15 dBm

The simulation is done with the transmitted signal power as 15 dBm by varying the rainfall rate. The result is plotted in figure (5) which shows that the frequency range 902-928 MHz shows the best frequency to be selected.

5.2 Packet reception rate with foliage effect

The figure(s) 6, 7, 8, 9 shows the packet reception rate with the varying distance of propagation through foliage.

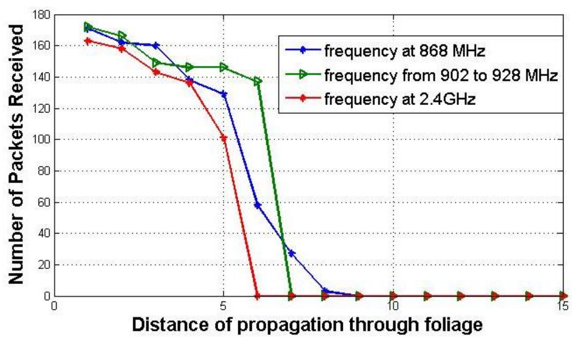

Figure 6: Packet Reception Rate at the transmitted signal power as 0dBm

The simulation is done with the transmitted signal power as 0 dBm. The result are plotted in figure(6) by varying the distance of propagation through foliage. The result showed that the three different frequency range showed almost the same packet reception rate. Out of the three frequency range the frequency range of 902-928 MHz is showing the best range as with large distance of propagation through foliage the packet loss is less.

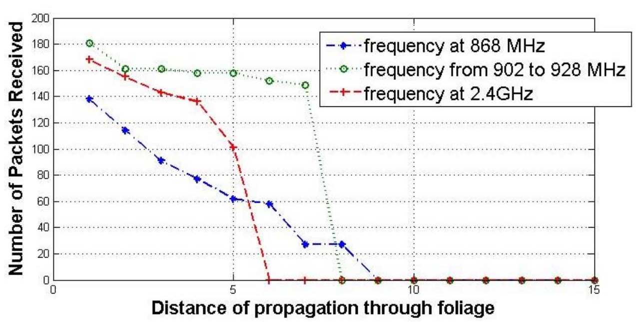

Figure 7: Packet Reception Rate at the transmitted Signal power as 5 dBm

The simulation is done with the transmitted signal power as 5 dBm. The result is plotted in figure (7) the signal is transmitted at 5 dBm also shows the best frequency range as 902-928 MHz.

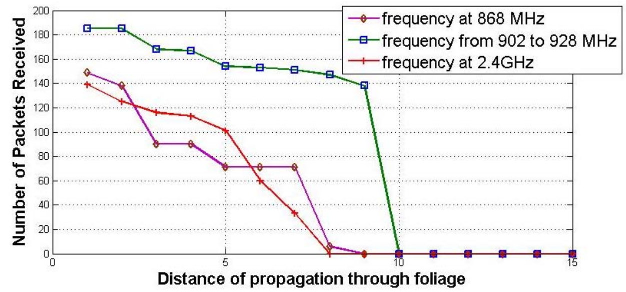

Figure 8: Packet Reception Rate at the transmitted signal power as 10 dBm

The simulation is done with the transmitted signal power as 10 dBm. The result is plotted in figure (8) when the transmitted signal is at 10 dBm the frequency range between the 902-928 MHz showed the highest packet reception.

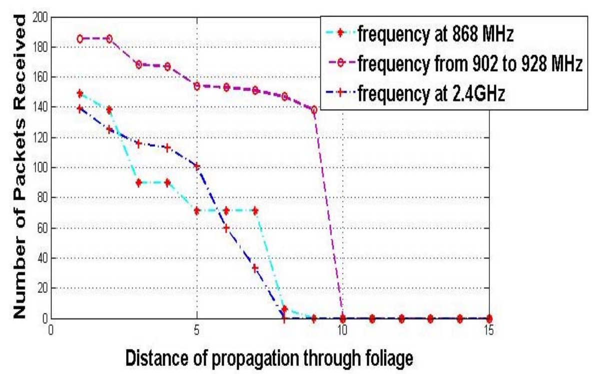

Figure 9: Packet Reception Rate at the transmitted signal power as 15 dBm

The simulation is done with the transmitted signal power as 15 dBm. The result is plotted in figure (9) by varying the distance of propagation through foliage. The result showed that the three different frequency ranges are not experiencing the same packet reception rate. Out of the three frequency range the frequency range of 902-928 MHz is showing the best range as with large distance of propagation through foliage the packet loss is less.

5.3 Received signal strength

The figure(s) 10, 11, 12, 13 shows the received signal strength with varying rainfall rate. The simulation results showed that the frequency range between the 902 to 928 MHz evinced the maximum received signal strength which asserts the result obtained above.

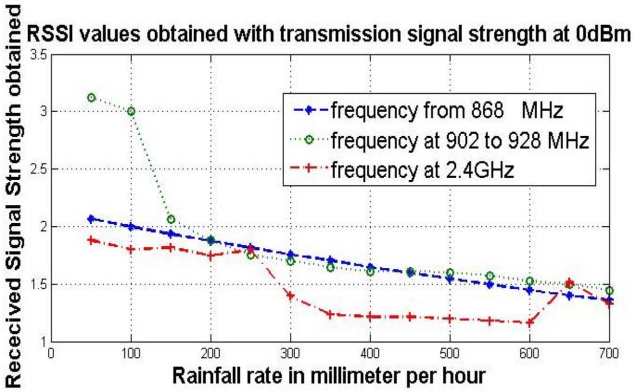

Figure 10: RSSI value variations with Rainfall rate at 0 dBm

The simulation is done with the transmitted signal power as 0 dBm. The result is plotted in figure (10) from which we can conclude that the packet reception rate which showed up a maximum rate at 902-928 MHz also showed the maximum RSSI value at 902-928 MHz which corroborate the above result.

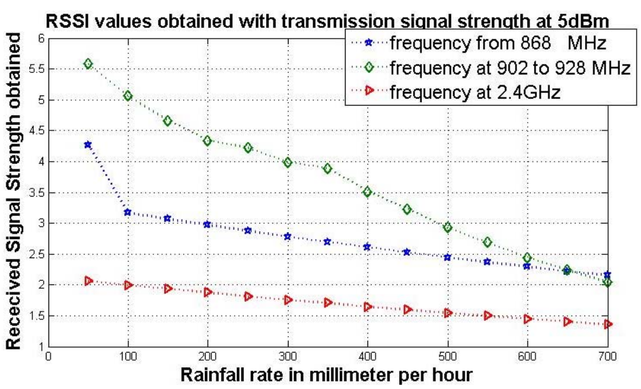

Figure 11: RSSI value variations with Rainfall rate at 5 dBm

The simulation is done with the transmitted signal power as 5 dBm. The result are plotted in figure (11) we can conclude that the packet reception rate which showed up a maximum rate at 902-928 MHz also showed the maximum RSSI value at 902-928 MHz which affirm the above result.

The network topology and the node separation are also key parameters which is kept constant in this simulation.

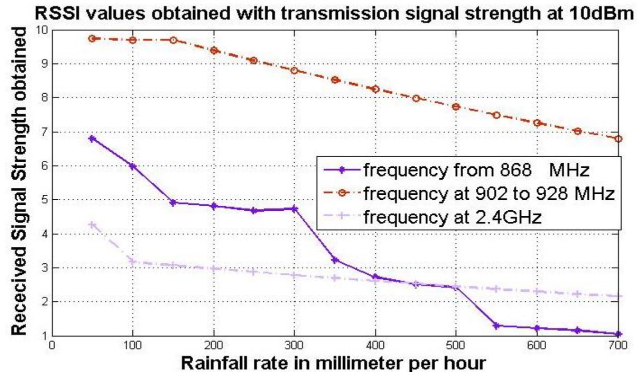

Figure 12: RSSI value variations with Rainfall rate at 10 dBm

The simulation is done with the transmitted signal power as 10 dBm. The result is plotted in figure (12) when the transmitted signal is at 10 dBm the maximum value of RSSI is showing at 902-928 MHz. The variation of RSSI value with frequency at 2.4GHz and 868MHz is close but high value of RSSI at 868 MHz.

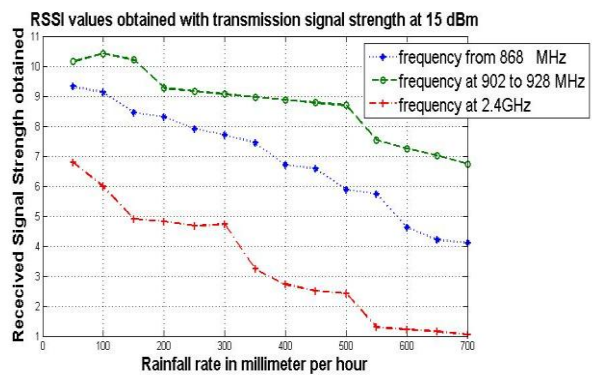

Figure 13: RSSI value variations with Rainfall rate at 15 dBm

The simulation is done with the transmitted signal power as 15 dBm. The result are plotted in figure (13) which reaffirm the above results by which the RSSI value obtained is high at 902-928 MHz.

5.4 Link quality value

The figure(s) 14, 15, 16, 17 shows that the link quality values are at maximum when the frequency range is at 902 to 928 MHz . The link quality is at maximum when the RSSI value is at maximum which is explicit with the result above. The result showed that LQI (link quality indicator) value has a relationship between transmission power level, distance and link quality and reveals how some random disturbances due to external (physical changes) or internal phenomena (node movement, power variation) may affect the dynamics of the network.

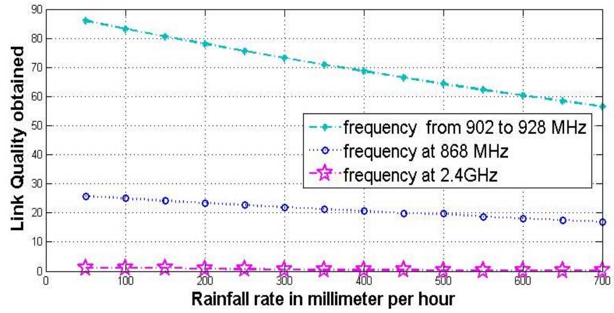

Figure 14: Link Quality Value Obtained with the transmitted signal power as 0 dBm

The simulation is done with the transmitted signal power as 0 dBm. The result is plotted in figure (14) the link quality is maximum at the frequency range of 902-928 MHz. This surmise that a high RSSI can result in a high link quality value.

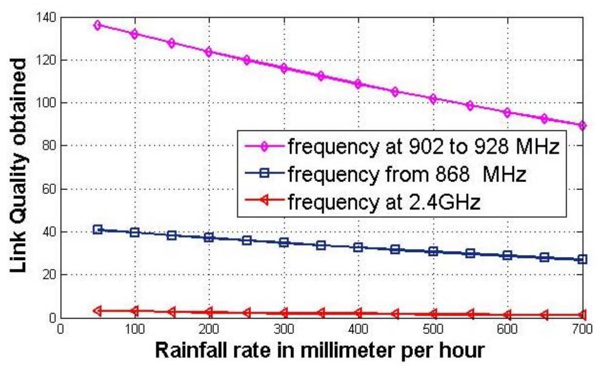

Figure 15: Link Quality Value Obtained with the transmitted signal power as 5 dBm

The simulation is done with the transmitted signal power as 5 dBm. The result are plotted in figure (15) shows that the maximum link quality is at 902-928 MHz .

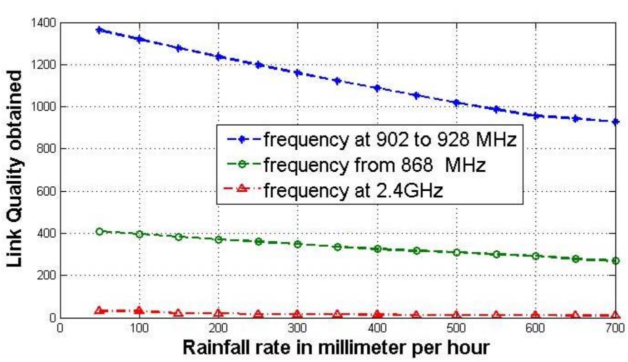

Figure 16: Link Quality Value Obtained with the transmitted signal power as 10 dBm

By analyzing the figure 16 also the best frequency we can choose is 902-928 MHz since it results in high RSSI values.

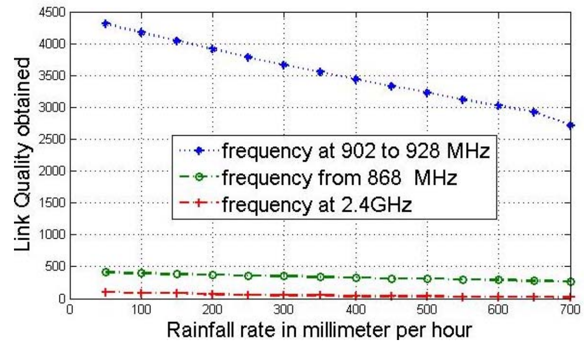

Figure 17: Link Quality Value Obtained with the transmitted signal power as 15 dBm

The simulation is done with the transmitted signal power as 15 dBm. The result are plotted in figure (17) which conjecture the result from the above as when the transmitted signal is at 15 dBm also the frequency at 902-928 MHz is the best frequency.

6. Conclusions and Future Works

Designing a wireless sensor network for environmental monitoring in an outdoor environment involves several steps, including the selection of transmission powers and channel frequency. Network performance indicators such as packet reception rate, link quality, and received signal strength of nodes in the target area of a wireless sensor network depend on the received signal strength at the node. The analyzed results in this paper could help the network designer by providing some useful information while deploying a wireless sensor network in an outdoor environment. By analyzing three different frequencies with the different environmental effects the result concluded that the frequency range of 902-928 MHz is the optimum frequency range.

The simulation results obtained through the experiments can be used to design and implement an adaptive routing protocol for any wireless sensor networks deployed in an outdoor scenario.

7. Acknowledgment

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