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Transmission Power Adaptation Using Link Quality Estimation In IEEE802.11

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DATE	: May 26th, 2009

Acknowledgement

This thesis was done as a Master thesis project in Wireless and Mobile Communication (WMC) group of Faculty Electrical Engineering, Mathematics and Computer Science of the Delft University of Technology (TU Delft, The Netherlands). It was carried out from September 2008 to May 2009. During this period, many people contributed to this thesis. I would like to express my appreciation to all the people who helped and supported me.

Firstly, I would like to appreciate my mentor Jinglong Zhou, who not only guided my thesis but also encouraged me through the whole process. And I also thank Dr. Martin Jacobsson for his supervising. Further, I want to express my deep respect to my supervisor Prof. Ignas Niemegeers for his precise attitude on science.

Secondly, I would like to thank my friends such as Chengcheng Jiang, Jiangjie He who offer me lots of suggestions.

Furthermore, I would like to thank the WMC group for giving me this opportunity to work on this interesting project and allowing me to work with all the wonderful people here.

Finally, I want to thank my parents. With their always support, I can put all my force to the thesis. For me, it is not only just a thesis but also an experience. My life will be affected by this immaterial wealth. And it will be one of the most memorable times.

Abstract

Nowadays, energy saving for wireless communication is more important than before. Lots of wireless devices are battery operated, like devices used in WLAN, ad hoc mode, sensor network, cellular network and so on. For example, Ad hoc networks which are composed of these wireless mobile devices can automatically establish peer to peer communication networks without using fixed infrastructure. Meanwhile, a lot of functions are added to the mobile devices. GPS and camera functions are integrated into the mobile phones. Energy consumed for the communication functions also grows more and more due to rapid improvement of communication technology and the demand for more communication between people, which means that we need larger battery capacity to increase the service time. Unfortunately, the battery technology does not improve much recently. Therefore in this thesis, we propose an energy saving method to extend the service time of wireless device.

There are many different ways to save communication-related energy. For the physical layer, transmit power level can be changed; for the data link layer, strategies of retransmission and wake and sleep mode operations can help save energy. For the network layer, we can choose the best paths for saving energy using power-aware routing protocols. In this thesis, we focus on the smart selection of the one hop transmission power level. Our idea is to not interfere with the present power saving model and to create a new method to save the energy. We designed the method and implemented our method in a real test-bed.

To be able to save the energy, we first investigate the correlation of packet delivery ratio (PDR) and transmission power levels. We have showed the phenomenon in the section of measurement results. Through the phenomenon, we can observe that there is a potential trade off between Txpower and PDR. We divide the method into two phases, the initialization phase and updating phase, the initialization phase use the knowledge to select or just randomly pick up a transmission power to start the communication process, when the updating phase use the relation between different transmit power levels (Txpower) and packet delivery ratio (PDR) to always smartly decide the transmission power level which result in the least energy consumption.

In the last part of our work, we integrated the data rate and transmit power. We designed an algorithm, which considers both data rate and transmission power, then selects the smartest transmission power level. Through the experiment results, we found that in most scenarios, 802.11b have larger PDR than 802.11g. 802.11g have a higher data rate than 802.11b, which consume less transmission time.

Our conclusion is based on our proposed method, energy can be saved up to 50% compared to the default transmission power level for delivering the same amount of information in the two phases separately and the selection the data rate of IEEE 802.11b or IEEE 802.11g main depended on the link quality.

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Introduction

With rapid progress of communication technology, communication speed and information delivery have been increased a lot. Meanwhile, lots of wireless devices use battery based power. Such like WLAN, ad hoc mode, sensor network, cellular or other radio. The fact is the technology on this battery does not increase too much. Therefore, to increase device service duration, energy saving is required for those wireless devices. Energy saving can be achieved by different methods from different communication layers. Power aware routing mechanism can select some route that consume minimum group power or use device which have more power. In the MAC layer, the receiver can turn off the power in some time to save energy also. Another way of saving energy is to use the transmission power control to select appropriate power levels to send the packets. Our basic idea is through the learning of link quality for each link. We can smartly select a transmission power level which consume the least energy.

The power transmission control mechanism has two benefits: reducing the interference level and saving the energy. Previous works are more focused on applying transmission power control to reduce the interference and maintain connectivity [1]. But very few works focus on selecting appropriate transmission power level to save the energy. For single data rate system, a default power level is used in all the nodes. The advantage of this method is that all the nodes are supposed to have the same interference range and neighbor discovery range. However, when the nodes are very close to each other, default power level is much larger than the level that also can successfully deliver all the packets. In another situation, for delivering the same amount of data, lower power level may require larger number of retransmissions but less energy consumed for each transmission. Therefore, a trade off is possible between number of transmissions and energy consumption for each transmission. Further, for multi data rate system, higher data rate may require larger power for each transmission and more number of transmissions for delivering the same amount of information. However, the transmission time is less for each transmission which may also require less total energy consumption.

In this thesis, we carried out measurement study on using the link quality information to smartly select the transmission power levels for the IEEE 802.11 system. We think this energy saving system require two phases to work. Initialization and updating, we proposed three different algorithms for the initialization phase and compare the performance of proposed algorithms with the theory and default algorithms. Better performance is achieved based on our algorithm. In the updating phase, we use the exponentially weighted moving average (EWMA) method to update the link quality information and select the best smoothing factor for the EWMA method. The proposed general energy saving method is based on link quality

information, can save as much as 50% energy compared to the default transmission power level. We mainly considered the trade off between packet delivery radio, data rate and transmission power level in real measurement.
In this chapter, we will also introduce the background and motivation of our work. At last the outline for the whole report will be given.

1.1 Background

For ad hoc networks, which are composed of the wireless devices can automatically establish peer to peer communication networks without using fixed infrastructure. For wireless mobile sensor network, a small battery operated node we expected can work a few months outdoors without people maintained. For our daily life, like cell phone our idea is after each electricity charge, we can use for whole month.

The main obstacle is the limited battery capacity of these devices. It limits the devices' living time. Therefore, the important challenge to us is to reduce energy consumption and find a good energy saving mechanisms. There are many different ways to save communication-related energy at present. For the physical layer, transmission power level can be changed; for the data link layer, strategies of retransmission wake and sleep mode operations also can achieve energy saving; and for the network layer, we can choose the best paths for saving energy using power-aware routing protocols. In this work, we use the transmission power control method to save the energy.

1.2 Benefits

In this thesis, we focus on the best selection of the one hop transmission power level. Our idea is to not interfere with the present power saving model and create a new algorithm to save the energy, and can be compatible with other saving protocols. Two benefits: saving energy; reduce interferences. Because for single data rate system, a default power level is used in all the nodes. The advantage of this method is that all the nodes are supposed to have the same interference range and neighbor discovery range. However, when the nodes are very close to each other, default power level is much larger than the level that also can successfully deliver all the packets. In other situation, for delivery the same amount of data, lower power level may require larger number of retransmissions but less energy consumed for each transmission. Therefore, a trade off is possible between number of transmissions and energy consumption for each transmission.

Energy consuming level is an important parameter that decides the device service time. Because our main consideration is energy consumption, so in this thesis we will ignore the delay caused by retransmission.

- **To extend the useful time**

Via the Fig 1-1, it illustrates the process of wireless sensor networking's operation. We found almost equipments in this graph are battery operated (machine monitoring, animal monitoring, PDA, notebook, etc).

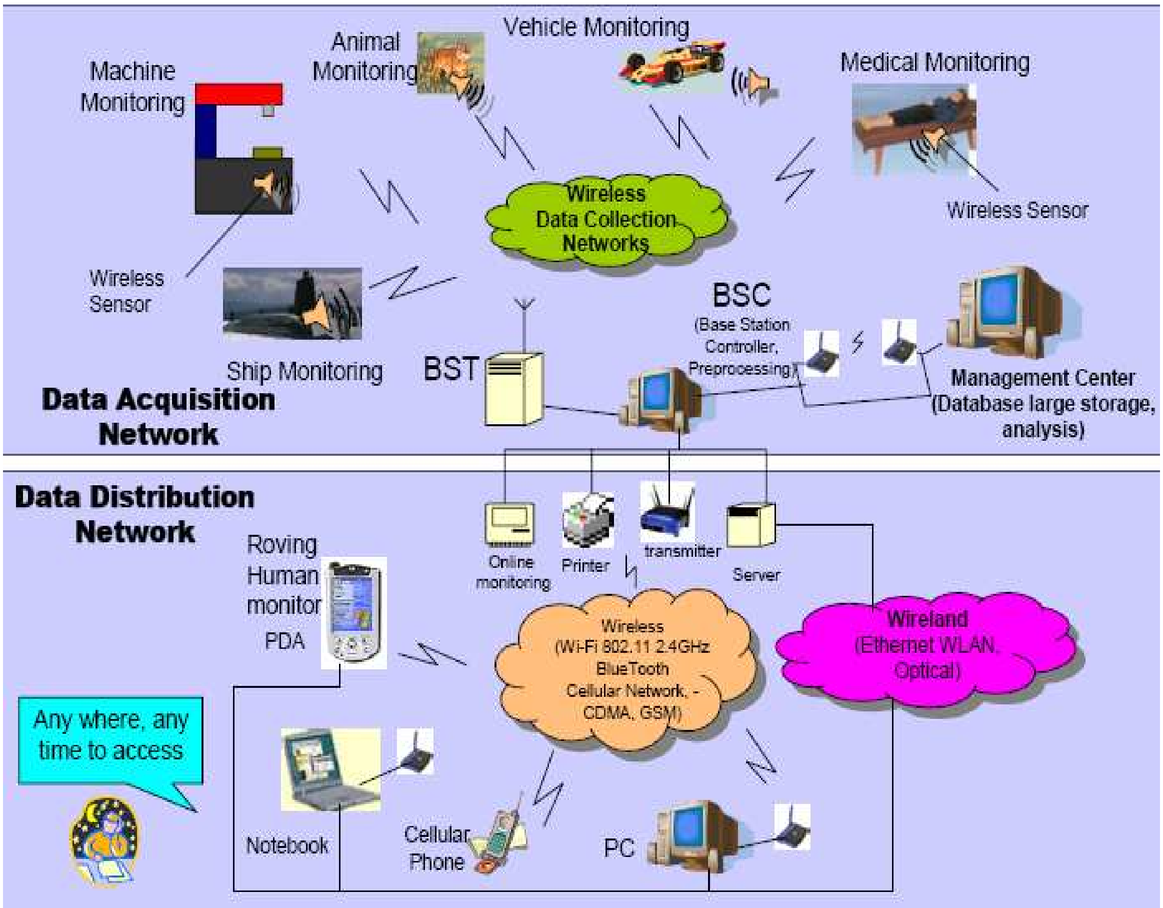

Figure 1-1. Wireless sensor networking.
(http://arri.uta.edu/acs/networks/WirelessSensorNetChap04.pdf)

So in this thesis our mission is to solve the problem of limited battery consumption. Improve transmission adaptation using link quality estimation in IEEE802.11.

l To reduce The Interferences

Obviously saving the transmission power not only can extend useful time, but also can reduce the interferences. Figure 1-2 assume two situations: First, node A and node D used some transmission power level, so they suppose to use same transmission range (Region F). If we let node A communicated with node B, and at same time node D communicated with node C. In the station node C will cause some interference from node A. The second situation used our energy saving mode. In my thesis we will decrease the transmission power of node A, because the range E is enough. So if node A and node D works at same time, node A will not produce so much interference to node C. In that way, it can reduce the interference.

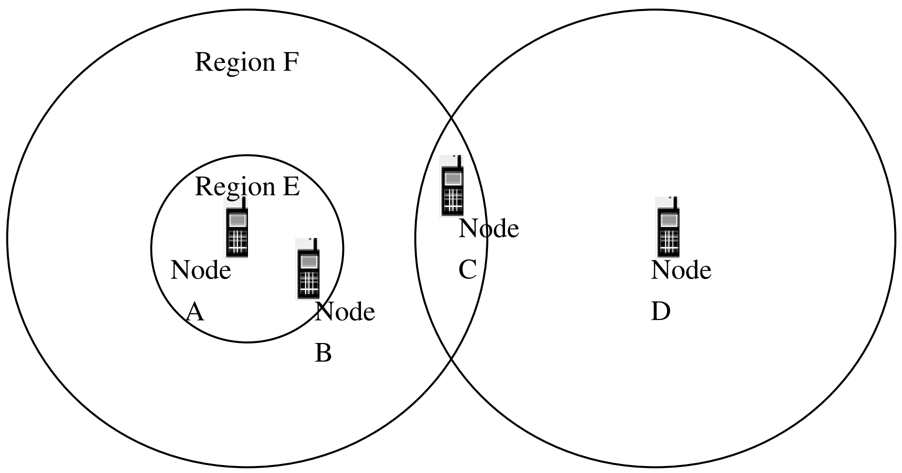

Fig 1-2. Different transmission power region.

l **Objective**

Our idea is the mobile node can adjust the transmission power by itself. There are two benefits for us doing this thesis. The first benefit is that we can choose a suitable transmission power level instead of default value (because in default mode, it always use the maximum value). Secondly, we can reduce interferences through decrease the transmission power level.

To simplify our problem, we assume the method can be used in some application, e.g. machine or ship monitoring, which don't consider the delay.. So in my thesis, ours energy saving method may increase the delivery for packet delivery. We will calculate the energy consumption for retransmission, but we don't mind the delay for retransmission.

Our basic idea is divided the transmission into two periods, initiation and updating. In the initiation period, our mission is to learn the channel, find a best transmission power level. How can we learn the channel? We send lots of packets with different mechanism to be sent with different transmission power levels. We record the packet delivery ratio of each transmission power level. Based on the result, we use our algorithm to choose an best power level to transmist the packet. We also put data rate into consideration, we compare the different date rate in IEEE802.11b/g. So the final best transmission power value depended on data rate and packet delivery ratio. In the updating period, we keep on learning, but the main task is use the best transmission power level to transmit mostly packets.

1.3 Outline

The rest of the chapters are organized as follows. Chapter 2 present the basic knowledge of IEEE 802.11 a little bit and give an introduction about related works. Based on different research aspects, the related work will be classified into three categories and comparison of those works with this report will be given. In Chapter 3 we proposed several methods. Make compare and analysis between theory and practice. Chapter 4 will describe the test-bed we used. Also some hardware, software and operation system will be introduced. And analysis the measurement results and compared different algorithms. We put the data rate in consideration; integrate the date rate and transmission power level to design a more precise algorithm. Chapter 5 will give our conclusions and future work.

2

Literature Survey

2.1 IEEE 802.11

2.1.1 IEEE 802.11b/g

In this thesis, we design our algorithm based on IEEE 802.11b/g system [3], so we introduce these them briefly.

l IEEE 802.11b [4]

IEEE 802.11b used DSSS (Direct-sequence spread spectrum) modulation method. It works in the 2.4GHz ISM band and shared this band with other productions, like microwave ovens, television, Bluetooth devices, cell phones.

In the IEEE 802.11b, there are four data rates can be selected:

1. 1 Mbps: modulation method is differential binary phase shift keying (DBPSK).
2. 2 Mbps: modulation method is differential quadrature phase shift keying (DQPSK).
3. 5.5Mbps: modulation method is Complementary code keying (CCK).
4. 11Mbps: modulation method is Complementary code keying (CCK).

l IEEE 802.11g [5]

IEEE 802.11g is the third modulation method for Wireless Local Area Network (WLAN). It works in the same band like IEEE 802.11b in 2.4 GHz.

In the IEEE 802.11g, there are eight data rates can be selected:

6, 9, 12, 18, 24, 36, 48, and 54 Mbps: modulation method is orthogonal frequency-division multiplexing (OFDM).

2.1.2 IEEE 802.11 Power Saving Model

IEEE 802.11WLAN MAC protocol consists of two coordination functions: one is Distributed Coordination Function (DCF), it works on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). Another is Point Coordination Function (PCF). It works on a polling-based protocol [6].

IEEE 802.11 has different power management modes. A mobile station could have a lot of power management modes. Normally it has two common modes which are active and energy-saving. In the active mode, the mobile station use full power to work. It can send and receive frames at any time. For the mode of energy-saving, the mobile stations have two states: sleep and awake.

2.1.3 IEEE 802.11 Energy Consumption In WLAN

Almost all the laptops have wireless card which help us to browse the webpage and transfer documents without cable in the form of radio waves (IEEE 802.11 a/b/g/n). The laptop have wireless card means we have got a little chip inside our laptop which can send and receive those wireless packets. If we browsed webpage or got through the wireless internet, the wireless chip in our laptop will require operate or consumed a certain amount of energy to download this page. Suppose we have plugged in, that energy is drawn from our wall socket, if we're on battery, then a very small piece of your battery life was donated to downloading webpage.

Our project is energy saving for wireless network, so it is interesting to know how much energy consumed by the wireless card in our computer system. From the paper [7], we found some describing about the energy consumption in wireless radio as following:

1. Energy consumption of idle laptop (energy consumption of screen are not included) with wireless radio turn off = 0W wireless radio energy consumption.
2. Energy consumption of idle laptop (energy consumption of screen are not included) with wireless radio turn on, but not connected to an Access Point (no data being sent or received) = 0.30W wireless radio energy consumption.
3. Energy consumption of idle laptop (energy consumption of screen are not included) with wireless radio turn on, connected to an Access Point (data can be sent and received) = 0.45W wireless radio energy consumption.
4. Energy consumption of idle laptop (energy consumption of display are not included) with wireless radio turn on and Searching for an Access Point = 1.6W wireless radio energy consumption.

So through this paper and we also check some other papers which talk about the energy consumption for CPU. We think when wireless card is in operating, it will consume 2% to 10% energy of all battery capacity.

Because our ideal is change the transmission power level to obtain the goal of saving energy, so we also want to know how much energy consumption of transmission power in all wireless card consumption. This problem has been analyzed in the paper [8]. They did several measurements, and given the following WLAN physical required power levels: Transmit = 2W, receive = 0.9W, listen = 0.8W, sleep = 40mW.

Obviously the transmission mode consisted of more than half of energy consumption in wireless radios. So if we can reduce the transmission power, it's also a good way for saving wireless network's energy.

2.2 Transmission Power Control

2.2.1 Link Quality Based Energy Saving

Lots of previous work focus on the power aware routing and sleep scheduling mechanisms [9] to save the energy. The method of using transmission power control to save the energy is not discussed very much. Some simulation work did some research in adapting the transmission power. In [10], it proposed some energy saving algorithms which adjust the transmission power and extended the network lifetime. In [11], it proposed using RTS-CTS handshake in the highest power level to discover the channel quality, the data packet use the minimum power level that can communicate to save energy. Simulation results show that the proposed power mechanisms can achieve energy saving without degrading the throughput. However, the periodically power level changes to the level that is higher than the default value in the channel also made interference variance in the medium which may harm other communication nodes. Some measurement result shows some real correlation of packet delivery ratio and transmission power level, and also analyzed the correlation of transmit power level and packet delivery probability in different indoor scenarios [12]. Based on their observation, small gratuity power level change can not be differentiated by the packet delivery ratio. In [13] it discussed the using transmission power control to select the reliable links and disable the unreliable links via blacklisting method in order to improve the system performance, but energy consumption is not the focus of this paper. For the data rate adaptation, lots of previous work [14] [15] [16] also proposed many algorithms. However, they all focus on the throughput increase instead of energy saving. The paper [17] is most similar work with our work. Data rate and transmission power is adapted for better transmission. However, the evaluation metric is the throughput which is different from our work.

2.2.2 Link Quality Based Interference and Connectivity Control

In practice, normally method to conserve power is to use energy saving mechanism. A simple energy saving protocol has been used on a hello message handshake in the context of IEEE 802.11 [18]. Different transmit power level among different nodes which proposed in [19]. In this method, both RTS, CTS are transmitted using default highest transmit power level, meanwhile DATA, acknowledge are transmitted using the lowest power which is enough for the node to communicate. The drawback is it will increase collision and decrease the network throughput.

An energy saving method presented in [20]. In this method, it first gets a table of transmit power between each node using theory calculation for all the nodes in the networks. The minimum transmit power based on the delivery ratio we can bear. This scheme allows each device to increase or reduce it's transmit power level dynamically.

For the Power Controlled Multiple Access (PCMA) protocol. It accepts individuals to have different transmission power levels [21]. PCMA have two channels, one channel for "busy tones", and the other channel for all other packets. Normally we use RTS and CTS, but in this protocol we use busy tones to solve the hidden terminal problem. It periodically sends a hello message (busy tone). It uses the maximum transmission power level which equal to the maximum additional noise the node can tolerate. Any node listen the channel for busy tones from other nodes firstly. It will put the information of signal strength into the busy tones, and then decide use which level of transmission power.

To save energy used some routing protocols [22], which presented the Most Forward within Radius (MFR) scheme. In this method, if a node is in transmitting mode, it will always transfers the packet to the neighbor whose progress toward the terminal is maximal for the purpose of minimize the number of hops for the packet to arrival the terminal.

For some other scheme, like [23] which presented a power-aware routing algorithm based on a greedy strategy. In his scheme, it always intends to choose a routing path for packet delivery that consumes the minimal transmission power among all nodes in the wireless network. For this reason, a class of next level of nodes may become responsible for most routing works in the network. Their energy will be exhausted quickly, which leads to the network decreased the performance.

A new algorithm also proposed [24] which is to send RTS, CTS, DATA, and ACK frames with appropriate transmit power levels, instead of a fixed transmission power level. Which quiet similar with us idea, it will choose an appropriate transmit power level at every start of transmission, but the selection algorithm is quiet different from ours since it doesn't consider the channel variations, which means during the transmission, the channel is unstable, so the appropriate transmission power level also varied with the channel altered. In the paper [26], they did a similar job like we did. Their method first checks if the delivery rate and transmission power curve is flat around its maximum power level. For example, the characteristic could look like the Fig 2-1. On such a link any reduction in the transmission power does not adversely impact on its delivery rate. Therefore, reducing the transmit power will typically not degrade the performance of the link. In such scenario, it will execute the algorithm to save energy. If the situation is like Fig 2-2, that mean we meet a bad link quality channel, if we reduce a transmission power will cause a huge affect of delivery ratio. So it will not execute the algorithm.

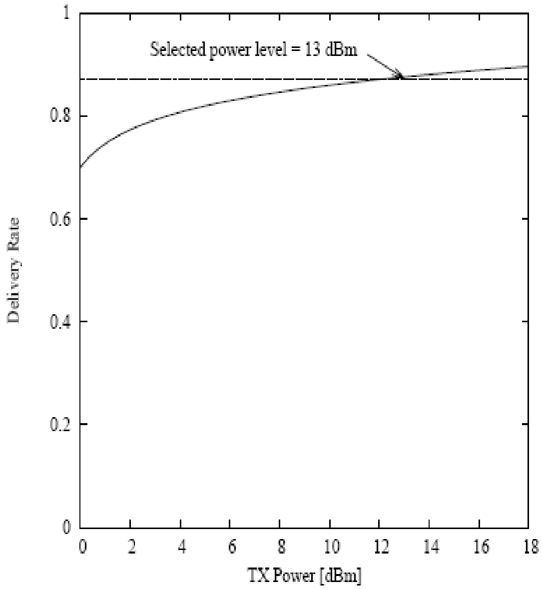

Figure 2-1. Smooth curve [26].

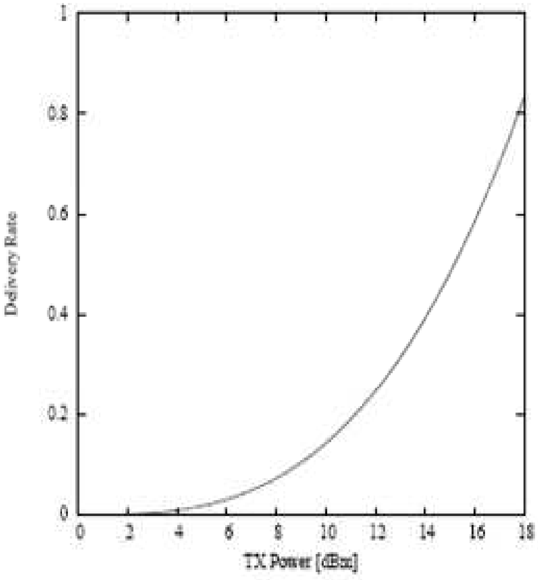

Figure 2-2. Sharp curve [26].

Our idea is even in bad link we still can use energy saving method, because the delivery ratio will go down if we reduce the transmission power, but we don't consider the delay. Of course, we need to calculate the energy consumption caused by retransmission, but it can keep the delivery ratio.

2.2.3 Packet Size Based Energy Saving

The relation between transmit power and packet size is described in the work [27], [28]. The proposed method is based on the observation that decreased transmit power can cause energy savings, but may also cause lots of errors. A very higher BER will lead to increase retransmissions. Their method will introduce larger energy consumption

Some paper analysis the effects of fragmentation in carrier sensing multiple access/collision avoidance (CSMA/CA) MAC protocol [25]. Based on the analysis, the algorithm chooses the optimum fragmentation threshold to slice arbitrary sized packets into best sized packets so that the goodput increases in the time varying channel. To verify the analysis and the benefit of the algorithm, extensive experiments have been performed using an implemented test-bed, which consists of CISCO Aironet 1231 access point with mobile stations in WLAN, and four mobile stations in a multi-hop ad hoc network.

My experiment is follows this paper's [29] way. Use same test-bed, the same experiment equipment. In this paper, based on the model, it proposes several ways of predicting the delivery probability of large data packets using smaller hello packets. Their study shows that methods based on two different hello packet sizes achieve better accuracy than those based on only one hello packet size. However, when using more than two hello packet sizes, the accuracy improvement is very little.

A new energy saving feature for IEEE 802.11 based ad hoc networks is proposed [31]. In the proposed solution, nodes operating in ad hoc power-save mode are allowed to send short broadcast frames during the Announcement Traffic Indication Message (ATIM) window that occurs during a beacon interval.

2.2.4 Data Rate Based Energy Saving

For the purpose of saving energy, there are two ways: adaptive transmission power and adaptive data rate. In the paper [33], they display although adaptive data rate to increase throughput, but also can save the energy.

A new energy saving feature for IEEE 802.11 based ad hoc networks is proposed [31]. In the proposed solution, nodes operating in ad hoc power-save mode are allowed to send short broadcast frames during the Announcement Traffic Indication Message (ATIM) window that occurs during a beacon interval. This is different than the legacy method of forwarding broadcast frames, wherein nodes first announce their intent to transmit a broadcast frame in the ATIM window and then send one or more frames shortly after ATIM window ends. The proposed scheme is helpful since the overhead of transmitting a broadcast ATIM is close to the duration of a short broadcast frame. Simulations show that the proposed scheme provides a substantial reduction in battery consumption compared to the legacy ad hoc power save operations.

3

Link quality based power saving method

3.1 A case study of Transmission Power and Packet delivery ratio

In order to save the power based transmission power control, we need to understand the relation between transmission power levels and packet delivery ratio (PDR). To analyze the influence of transmission power to the packet delivery probability, we created an experiment that we can measure the packet delivery ratio with different transmission power levels.

3.1.1 Experiment set up

In the driver, we are able to change the transmission power level from 1dBm to 18dBm. Because the default one is 15dBm, and we want our algorithm does not interference other power saving method, we adapt the power level between 1dBm to 15dBm. In this experiment., we used 2 Mbps broadcast packets on the wireless link for the purpose of no retransmission. The packet size is 1500 Bytes.

We did this experiment in eight scenarios. In each scenario, we generated 2000 packets for all 15 transmission power levels using Poisson arrival process. We send 10 packets per second from the sender to receiver; We counted the delivery ratio for each transmission power level from 1dBm to 15dBm for each link.
We select six links and we call it different scenarios in the canteen of EWI building of Delft University of Technology. For stationary scenario, we only state the distance between sender and receiver and the type of link.
Scenario1: 8m, Line of sight.
Scenario2: 16m, Line of sight.
Scenario3: 24m, None line of sight.
Scenario4: Line of sight , mobile between 8m-16m.
Scenario5: 28m, None line of sight.
Scenario6: 32m, None line of sight.

3.1.2 Experiment results

We illustrated the results in Fig 3-1. From the figure we found in scenario 1 of lunchroom of EWI building of TUD with 4m distance. No matter what transmission power level we used, the packet delivery ratio is always 100%. This means if the link in indoor environment with short distance, we can even use 1dBm transmit power instead of 15dBm and still keep the same packet delivery ratio. Not only energy consumption can be saved, but also the inferences to other nodes which shared the same medium can be reduced. Now, we start to discuss the scenario 3 of lunch room with distance of 24m. Even we used transmission power level of 15dBm, only 40% packets has successful arrived. In this scenario, we may forced to use transmission power as higher as possible to protect the link performance. Because the default transmission power is not larger enough, so we want to inquire a high transmission power level. In this paper, our main goal is to analyze in scenarios that the link quality is not so good. What relation between PDR and transmission power level. The next step is to design an algorithm to find a best opinion and make a trace off between transmission power level and PDR.

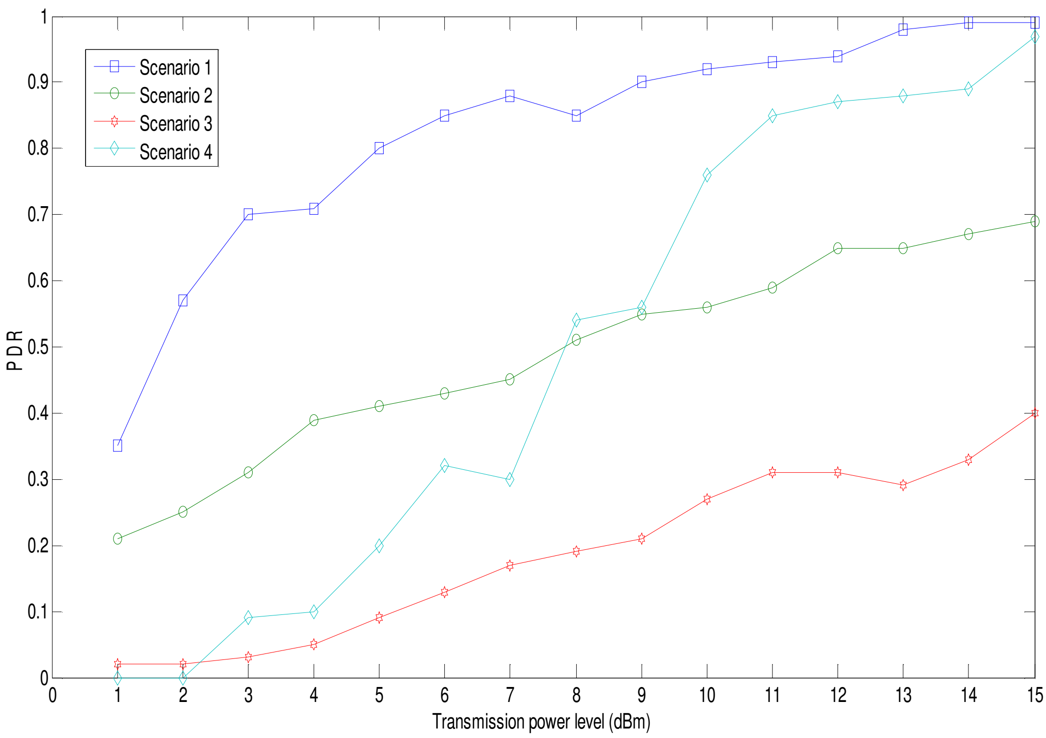

Figure 3-1. Various scenarios with 15 transmit power level.

In Fig 3-1, we found the relation between transmission power level and PDR are quiet different. The green curve is the result which we did in the scenario of Stairs of EWI building. Through the green curve, we can see it has a very bad link quality. And the curves in the middle of our graph, we can identify the relation between PDR and Txpowerlevel are quiet varied.

We also found out in [30], they did similar experiment like us. They did this experiment in more scenarios and longer time than us. However, similar result is achieved and based those two experiment, we know that correlation between Transmission power level and PDR can be quite variable in different links. So we know that the relation between PDR and transmission power level depend on the scenarios.

3.2 Theory Compared with Practice

3.2.1 Convert BER to Delivery Ratio

As discussed previous, there is lots of correlation between PDR and transmission power levels, is it possible to use the theoretical model to model this links? That is our question. Our goal is to discuss the relation between transmission power level and PDR, but in telecommunication we always talk about BER if we discuss the channel loss. So first step we need convert BER to PDR. The PDR can be obtained by the BER and the collision time. In this experiment because we used the data rate of 2 Mbps, that means DQPSK modulation technique. The probability of error for DQPSK is difficult to calculate in general, but we still can use an expression to estimation. The BER for DQPSK can be expressed as

$$P_b = \frac{1}{2}\left\{1 - \frac{E_b/N_0}{\sqrt{(E_b/N_0)^2 + \frac{1}{2} + 2(E_b/N_0)}}\right\} \tag{1}$$

Where function (1) as used in [17]. So the probability of the packet loss by random bit error in L bits packets can be expressed as follows [31].

$$P_{pkt\_err} = 1 - (1 - P_b)^L \tag{2}$$

Consider the collision probability P_c, and we assume that P_c and P_{pkt_err} are independent, then we can use the formulate [15] to expressed the unsuccessful transmission P as

$$P = 1 - (1 - P_{pkt\_err})(1 - P_c) \tag{3}$$

In our experiments, due to we only uses two laptops, P_c is quiet small, so we ignore it. We using function (1),(2) and (3) to derive the Delivery ratio as follows:

$$D = (1 - P_b)^L \tag{4}$$

3.2.2 Theoretical Prediction

We calculated L= 12000 bits as the normal value, because we used packets size of 1500bytes which equals to 12000 bits. Through the expression below (Fig.3-2), the relation between packet delivery ratio and E/N for different packet sizes.

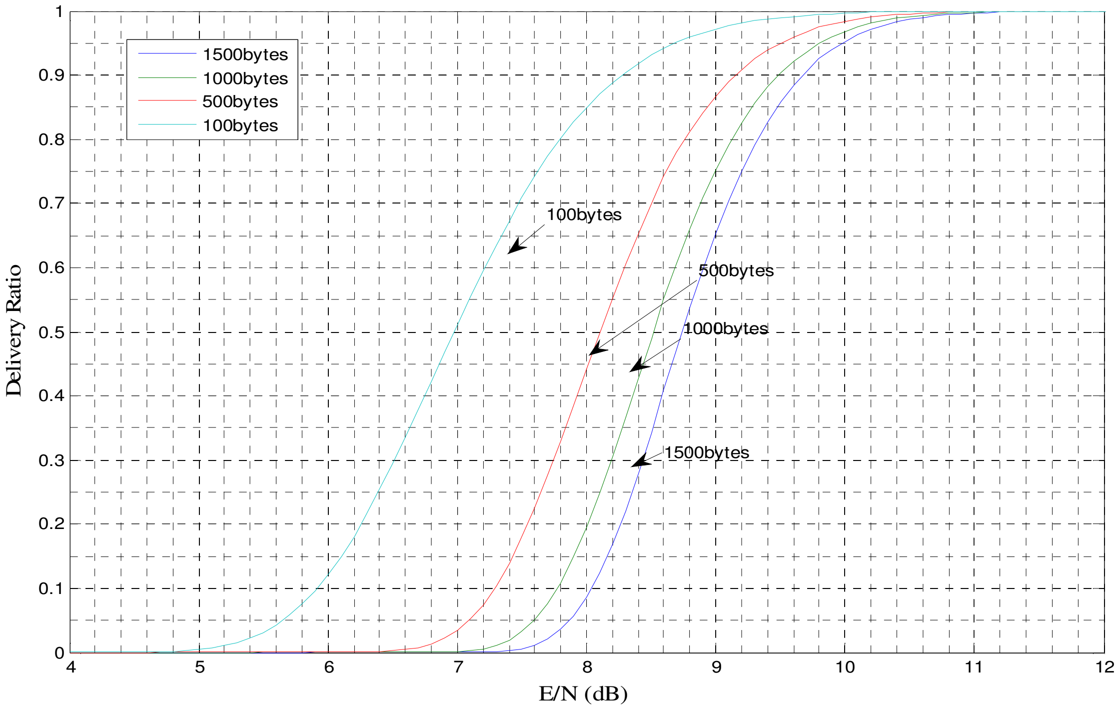

Figure 3-2. Delivery Ratio with different packets size.

The curve of 1500 bytes in Fig 3-2 is which we needed, because the packet size is 1500bytes which used in this experiment. In the later calculation, some information we can read directly from this graph.

3.2.3 Theoretical model does not work!

We did two experiments in two different scenarios use three different methods to achieve the correlation between PDR and transmission power level as show in Figure 3-3 and Figure 3-4. The curve of “theory” is the theoretical prediction, and curve of “theory and measurement” is used part theory and part measurement results, the “experiment results” curve one are draw based our experiments results. We will discuss the three methods in the following section.

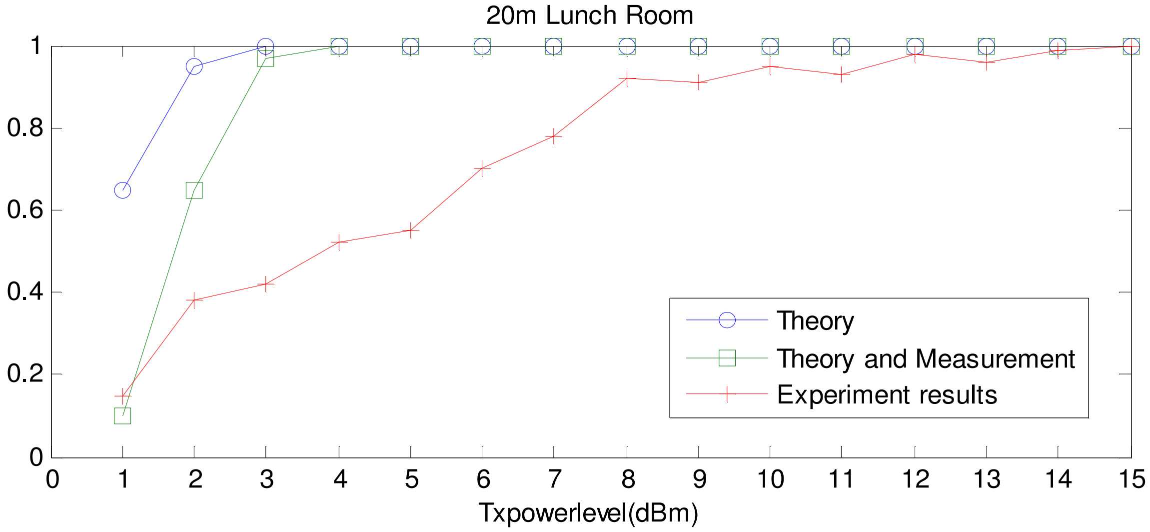

Figure 3-3. Scenario of 20m lunch room.

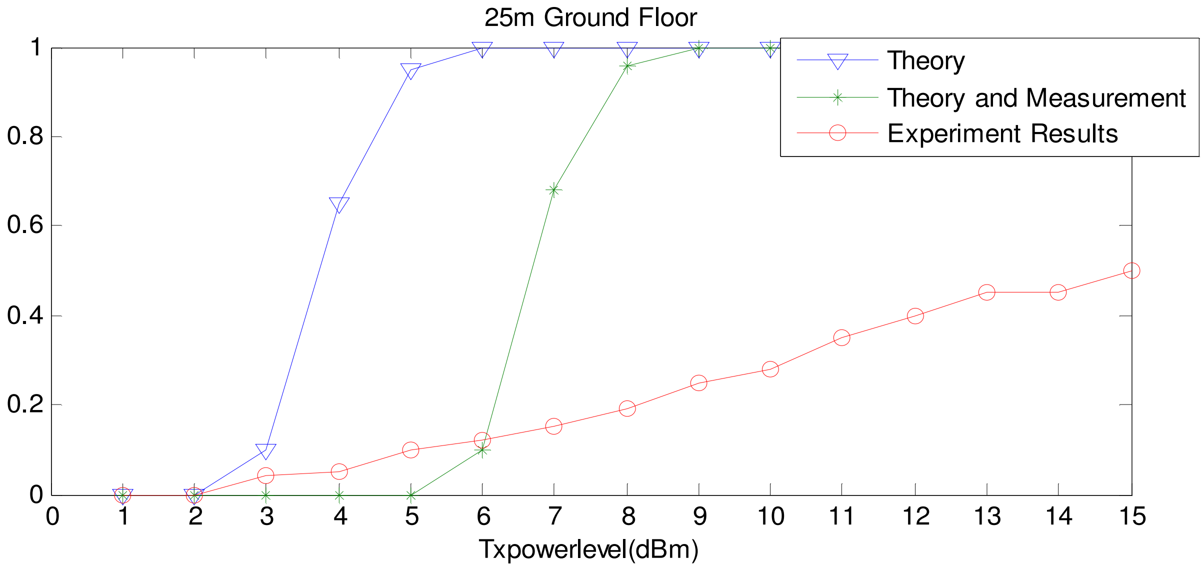

Figure 3-4. Scenario of 25m ground floor.

In curve one (theory), we use the formula (5) to calculate the path loss. We suppose indoor environment and no multipath transmission, so n equal to 2. Because we already knew the value of transmission power level (we can set it up in advance). Meanwhile, we suppose noise level is constant equal to -96dBm. We use function (6) to calculate SNR of different transmission power level, and through the Fig.3-2 we can get different SNR of delivery ratio. Then we can draw the blue curve of relation between delivery ratio and transmission power level like Fig.3-3 and Fig.3-4

$$L_p(d) = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) + 10n\log_{10}\frac{d}{d_0} \qquad d > d_0 \tag{5}$$

$$SNR = -L_p(d) - Noiselevel - transmitpower \tag{6}$$

The result of integration of theory model and measurement result is showed in curve 2 (theory and measurement). From our test-bed we can get the receive signal strength indicator (RSSI) with default transmission power level of 15dBm. We use this value instead of theory calculation. Noise level is still equal to -96dBm which read direct from our driver. Through the function (7), we can get the curve 2.

$$SNR = RSSI - Noiselevel \tag{7}$$

In the curve 3 (experiment results), we used all the data from the experiments, so the curve is the most precise one. The curve in the Fig.3-3 and Fig.3-4 we just copy it from Figure 3-2, which got it from the real situation experiment.

Via the Fig 3-3 and Fig 3-4, we think each line of real situation can very close to the line of theoretical prediction, but never cross it.

Another conclusion from the graph is real situation span long transmission power range, and always has bad performance.

Through the compare between the theoretical result and result of measurement, we found the packet delivery ratio with different transmission power level can not be predicted by the theoretical calculation. The relation between PDR and Txpower is scenario dependent, that means different environment, different condition, the cure will be quiet different. Our method is when we want to use energy saving method, we need to smartly select a transmit power that save the most of energy in a certain particular scenario. And the power level is only can get via the present situation. In the meantime, it will keep on observing of correlation between PDR and transmission power level , the best transmit power will changed parallel. In the following section, we will discuss how to find the best transmission power level and how to update it simultaneously.

3.3.1 Basic algorithm and the definition of best transmit power

Since we identified the theoretical estimation is unconvincing, we need to use our method to saving energy. For instance, if delivery ratio equal to 50%, this means that each packet we need to transmit twice. So through the delivery ratio, we get the total packets we expect to transmit (include retransmission packets). Use the function of (8), (9), (10) we can get the minimum consume energy with transmission power level from 1 to 15dBm, that is what we want (best power level);

$$txpower(mW) = 10^{txpower(dBm)/10} \tag{8}$$

$$E = P \times N_{expected} \times T \tag{9}$$

$$N_{expected} = N_{received} / Delivery \tag{10}$$

P is the transmit power level, N is the expected transmitted times, T is the duration for one transmission.

We did three experiments in different scenario. All the three experiments use the above formula can select a power level that consumes the least energy. The result is depicted in Fig. 3-5.

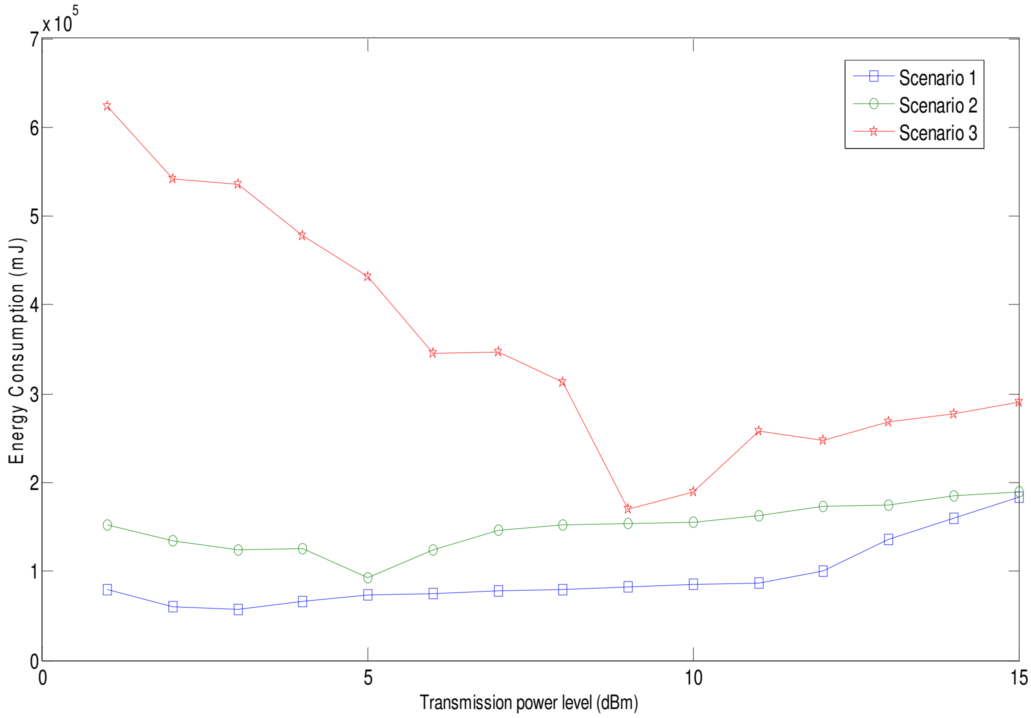

Figure 3-5. Best power level of different scenarios.

Through the graph 4-6, firstly let us analysis the blue curve. This one got from the lunch room 8m. The minimum energy consumption happens when we use 2dBm to transmit, so the best transmission power is 2dBm. The reason why the best value is so low it's because this scenario is in Ground floor 8m, which has a good link quality, and the distance is not so large. So the algorithm selected 2dBm instead of 15dBm (default one). It is proof our first ideal, in short distance or good link quality, we can use lower transmission power to saving energy.

Secondly, let us see the green one. This one is in most scenarios; we did it in lunch room of 16m. The minimum energy consumption happens when we use 5dBm to transmit, so the best transmission power is 5dBm. However, we did in the same scenario like first experiment, but this time we have large distance. So implement our algorithm, the 5dBm can saving more energy than 2dBm.

Finally, we will analysis the red curve. In this experiment, the environment is not light insight, and the distance is quiet large (24m). Through the red curve, we found the channel is varied frequently. And our algorithm selected 13dBm as best value. This experiment also identified our algorithm can work in some bad scenarios.

3.3.2 The Condition of Best Power

Of course, in this algorithm we only focus on the energy consumption, we don't consider the retransmission or delay. Because in some applications like sensor network. We only consider two things.

First is whether received or not, another is energy consumption. This means that as long as we received, we don't mind how many times retransmission or how long the delay. In my thesis energy consumption is a very important factor. For example, a message we need to transmit several times (due to low packet delivery ratio), but we only consume half energy than use default transmission power transmit one times, we choose the first one.

3.3.3 Two Phases of Our Method

For a certain channel, if the correlation of Txpower and N and T is known, the best consumption can be easily selected. However, the real channel correlation can be quite different. Therefore, a good method of learning this correlation is required. Meanwhile, this correlation may change due to several reasons, such as environment change, multi-path, interference. The method should not only use one correlation learned from beginning or heritage from the past, a self updating mechanism is also required. We divide the proposed method to be two phases, initial and updating phase. The initial phase use a certain method to learn the correlation of transmit power level to PDR in different scenarios when the communication link is established between two nodes. The updating phase keep on update this correlation during the whole communication period.

3.4 Different Energy Saving Methods for Initialization Phase

We proposed five algorithms for the Initialization phase and they are describe as following. The default algorithm is to transmit the all the packets with default power level (15dBm)..

3.4.1 Our Proposed Algorithm of Fix

In this algorithm, we just use this default algorithm to make a comparison with our algorithm.

The advantage of Fix is we do not need waste time on initial period. We can go to updating period directly. Because we directly select the best value of 15dBm (default one).

The disadvantage is that we skipped the initial period, so we do not know the best value and because we use the maximum one, it will waste lots of energy.

3.4.2 Our Proposed Algorithm of Theory

In this algorithm, first we use formula 6.1 to calculate the path loss and through function (12), we get the SNR with different transmit power levels.

$$L_p(d) = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) + 10n\log_{10}\frac{d}{d_0} \tag{11}$$

$$SNR = -L_p(d) - Noiselevel - transmitpower \tag{12}$$

Through Fig 3-4, and use our proposed method, we get a best transmit power for initial period.

The drawbacks of this algorithm, we already proved in section 3.3. We found the theoretical predict is unconvincing. That means we cannot use the theoretical model to calculate the best transmission power level.

3.4.3 Our Proposed Algorithm of Knowledge

In this algorithm, we use a history table (delivery with 15 levels of transmission power level and their SNRs). Firstly, we send ten packets (each packet included RSSI, which can convert to SNR later). We get an average of the SNR for the present situation. Secondly, we compare with the last SNR record. Through the difference value, we shift the original table to left or right with the difference value. Then, we use our algorithm get a best transmission power level for start.

The advantage of this algorithm is we can use the history table to get the best value directly. If the channel quality is just the same like last time, we only need to send one packet. The drawback is if we change location or the link quality is quiet different compared to the history result, which means we use a wrong best value to transmit, it will cost more energy.

3.4.4 Our Proposed Algorithm of Probing

In the start period of this algorithm, we do not consider history table. We learn the channel again. We send packets with all kinds of transmission power levels. Then, using the collected values, calculate the best transmission power level and go to the updating period.

This algorithm is more precisely compare to above three algorithms. Because each time in the initial period we need to learn the channel, we can guarantee the best value is correct. The disadvantage is that we consume some extra energy for the purpose of finding the best value.
Based on the method proposed above, to select the best data rate and transmission power level automatically by the communication node themselves, we proposed following flow chart as

this figure.

3.4.5 Our Proposed Algorithm of Combine

Combined: Based on difference of "Knowledge" and "Probing" algorithm, take advantage of both and always use the better one. This algorithm works like this , we first read the RSSI, if the value is the same like history table, we used the algorithm of Knowledge, if the value changed, this means that history result can not trust anymore, so we need to learn the channel again, at this situation, we choose the algorithm of Probing.

3.5 How to update best transmission power

Due to the dynamics of the channel, if we found an best transmission power at present, it is not mean next moment will have the same best value. So we need keep touching with the packet delivery ratio. Our algorithm is set up a table, which included all levels of transmission power's packet delivery ratio, every minute it will use our algorithm to calculate the minimum power level. If the value changed, we will get a new best one. Otherwise, keep the old best value.

In general, we first ask sender to send packet use 15 transmission power levels for the purpose to find the best transmission power use function (8),(9) and (10). Due to the varied of the channel, we can't always hold the best we got before, we need to get the best transmit power update. So our algorithm operated after we first got the best transmission power level. We use best transmission power to send 90% of packets, order to avoid the channel varied causes best power changed. We let 10% of packets as sensor information which send from 1 to 15dBm power level in order. We set up 10s as a time interval, so every interval receiver will give a feedback. It updated the database, and so we can get the precise best transmission power level all the time.

We divided our algorithm into two parts. One is the initialization period. In this period, we need to get the first best value. The second is the updating period. In this period, we update the value of best transmission power level and transmit information.

3.5.1 How to decide smoothing factor of in the updating phase

In the updating period, we estimate the packet delivery ratio using an Exponential Weighted Moving Average (EWMA), which considers the history of link quality as function (13)

$$E_{tt} = (1-\alpha)E_t + \alpha S_t \tag{13}$$

$E_{tt} = estimated\_PDR \quad E_t = old\_PDR$

$S_t = current\_PDR$ (It gets from the interval of 5 seconds).

The EWMA method is used to control the speed of this updating. Parameter α is the filter parameter. Smoothing factor alpha is used to tune the speed. If the PDR changes very fast, a large alpha may timely update the estimated PDR, However, when PDR changes slowly, a large alpha value would result in deviation of the estimated PDR from the actual one.

3.5.2 Our flow chart of program

Based on the method proposed above, to select the best data rate and transmission power level automatically by the communication node themselves, we proposed following flow chart as this figure.

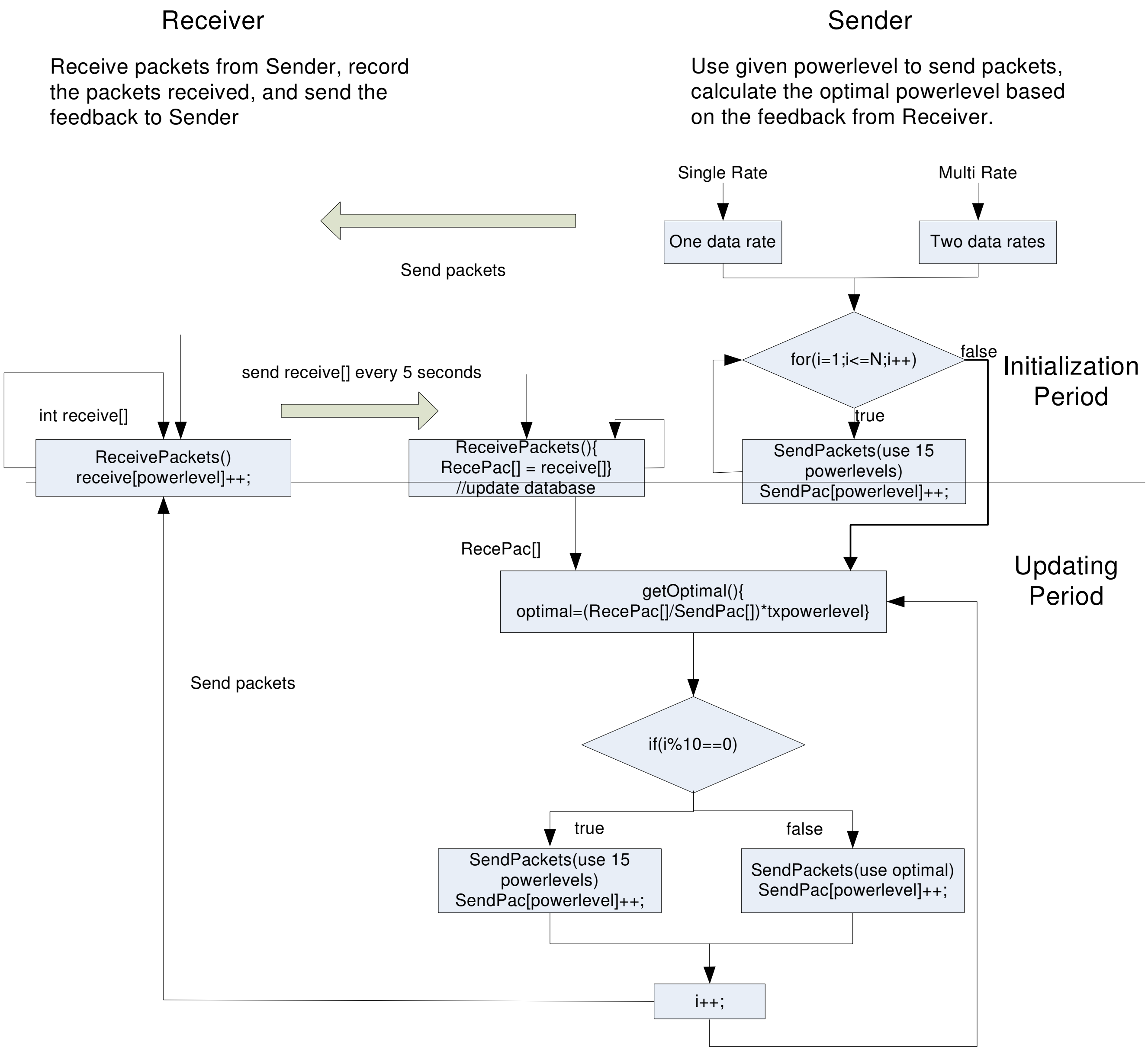

Figure 3-6. The flow chart of our program.

4

Evaluation

We used real test-bed to evaluate the performance of our designed method. In this chapter we first introduce the hardware and software of our test-bed. Then, we present our measurement result of performance evaluation.

4.1Test-Bed Implementation

Based on comparison in section 3.2, we known that simulation model which use math equation from the theoretical model is not accurate, therefore, we use real devices to carry out the measurement campaign. Two Hp laptops are used. The 3Com PC wireless cards are used in the laptops. The madwifi driver with version 0.9.4 is used.

We specially wrote a one hop communication program which has a sender and receiver part. The node using the sender program can control the data rate and power level for each packet transmission. Fixed packet size 1500Bytes are used during all experiments. We use broadcast packet to generate uniform packet sending interval during the experiment. The sender kept on sending broadcast packets with a speed of 10 packets/second. Since the sender need the instantaneous packet delivery ratio information from the receiver, we let the receiver to communicate with the sender in fixed interval. (We set this interval to be 5s).

4.1.1 Our Code in Experiment

4.1.1.1 How can we change the Txpower

We used command of “system” and “execl” to change the transmission power level. For each interval, our method selected the best transmission power based on the PDR and apply this power level for most of packets in next interval, we used the command of “execl ifconfig ath0 Txpower n” for each packet. if transmission power level for the next packet is the same as current one, this command is skipped.

4.1.1.2 How Can We Get the Best Value

We set three arrays, one is named Send[], it's length is 15. We use Send[0] to Send[14] to record the number of packets sent with different transmission power level, which we send. Another array named Receive[], it's length also is 15. We use Receive[0] to Receive[14] to record the received packets in different transmission power level. The last array is named Delivery[], it used to calculate the delivery ratio for each transmission power level. For (n=1;n<=15;n++),we defined m, m=(1.0/delivery[n])*(10^(n/10)); if m smaller than minimum value, the minimum equal to m, and the best value is n. So after execute fifteen transmission power levels, we will get the precise best transmission power level. Then we return the best value to the main program.

Each time, when we execute the function of send to, we are invoking the function of "get_best" to get the transmission power level.

4.1.1.3 How Can We Update the History Table

In the sender part, we set 0.1 seconds of the time interval, And in the receiver part, we set 1 or 5 seconds of the time interval. This means that every fixed interval, we will give a feedback to the sender part. The sender part added these information to the history table. Then, the sender use the get_best ( ) function to get the new best transmission power level.

4.1.2 Operational system and experimental condition

In our project, all experiment environment under the operation system of Fedora [34].

The experiment is carried out in an indoor environment in the cafeteria of our department building which is a big open indoor space environment. All the experiment are done in the night when there is very few people walking around the experiment laptops. We use channel 7 during the experiment and in the testing period, long duration observation is done to the noise level for this channel and the value is always -96dBm, the maximum variance of noise level is 2dBm. Different distances and locations in the cafeteria are used in experiment to generate different channel conditions.

We have 6 scenarios in our experiment, the detail of all the scenarios have discussed in section 3.1.1.

4.2 Measurement Results of Our Proposed Methods in Initialization Phase

In the initialization phase, our mission is get the best transmission power based on our proposed algorithms. Different algorithms will consume different packets for initialization phase. The algorithm of Fix only need one packets, the algorithm of Theory don't need packet in the initialization phase, because the best transmission power level we used theoretical equation to calculate in advance. For the algorithm of Knowledge, we need 10 packets to read the SNR, algorithm of probing, we need 150 packets. Because we have 15 transmission power levels, each level we need to probe 10 packets to build the table. In the algorithm of Combine, due to we take the advantage of Probing and Knowledge, so we need 160 or 10 packets in the initialization phase.

We first carried out experiment for Scenario 1 [detail of scenario in section 3.1.1] with 3000 packets for all the algorithms. We plot the sent packets distribution on each transmission power level for different algorithms. Through Fig 4-1, we can get a rough view of how the different methods choose different transmission power levels. Via Fig 4-2, we compare the energy consumption of these algorithms. Our result shows all the algorithms which we proposed can saving energy compare to the default algorithm.

In Fig 4-1, we put the four algorithms' delivery ratio together. We found at most times, these four algorithms selected 5dBm as the best value (because they use 5dBm transmission most of the times), but there still are some differences. For example, the algorithm of Fix choose 4dBm as its secondary best transmission power level. The algorithm of Theory selected 13dBm as its secondary best transmission power.

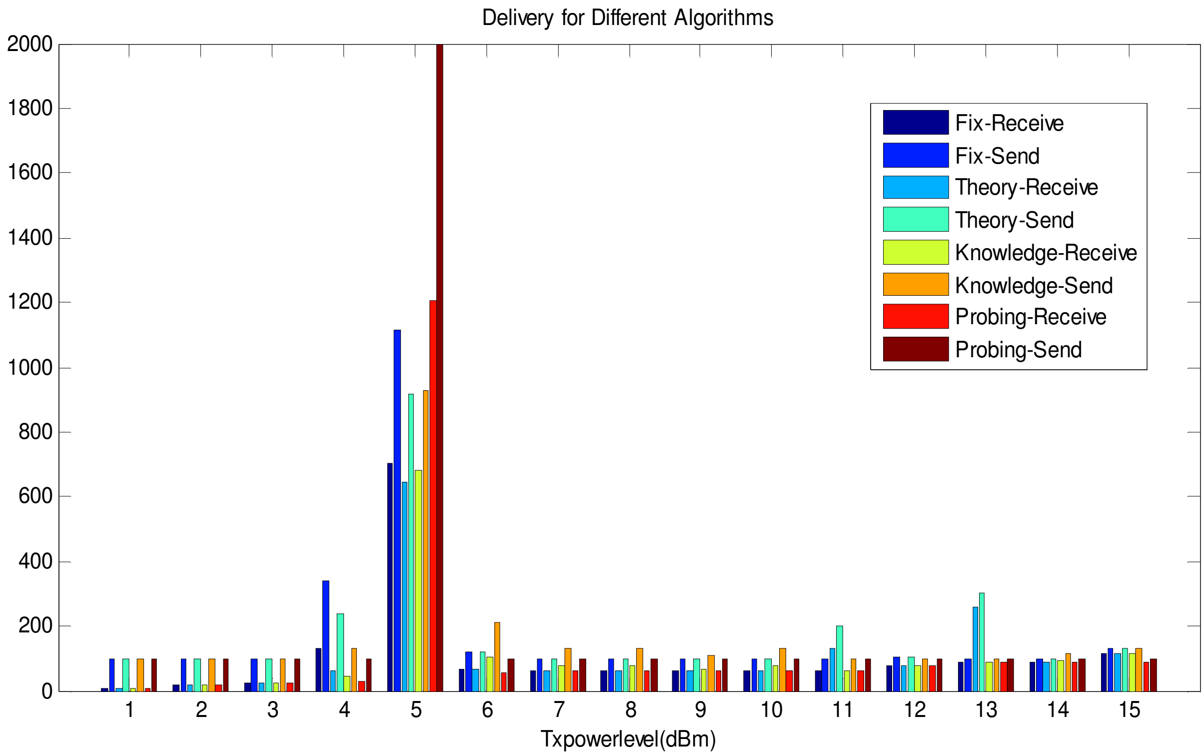

Fig 4-1. Delivery ratio of all algorithms.

Because we use energy consumption as our metric to evaluate the performance of our five algorithms, we plot the expected energy consumption in Fig 4-2.

Via the Fig 4-2, we can see that the algorithm of Knowledge and Probing achieved better performance.

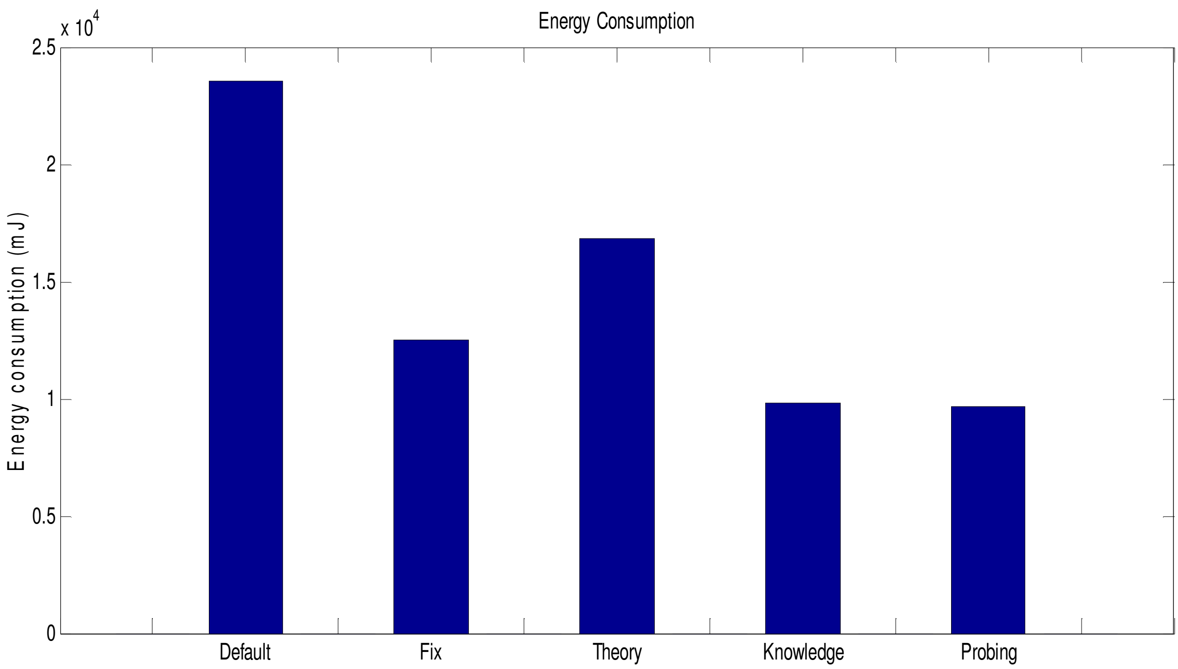

Fig 4-2. Energy consumption of all algorithms.

4.2.1 Analysis Our Algorithms Drawbacks

We need to analysis a special case of Knowledge algorithm. Because since we did several experiments use the algorithm of previously knowledge, we found the result is obviously difference.

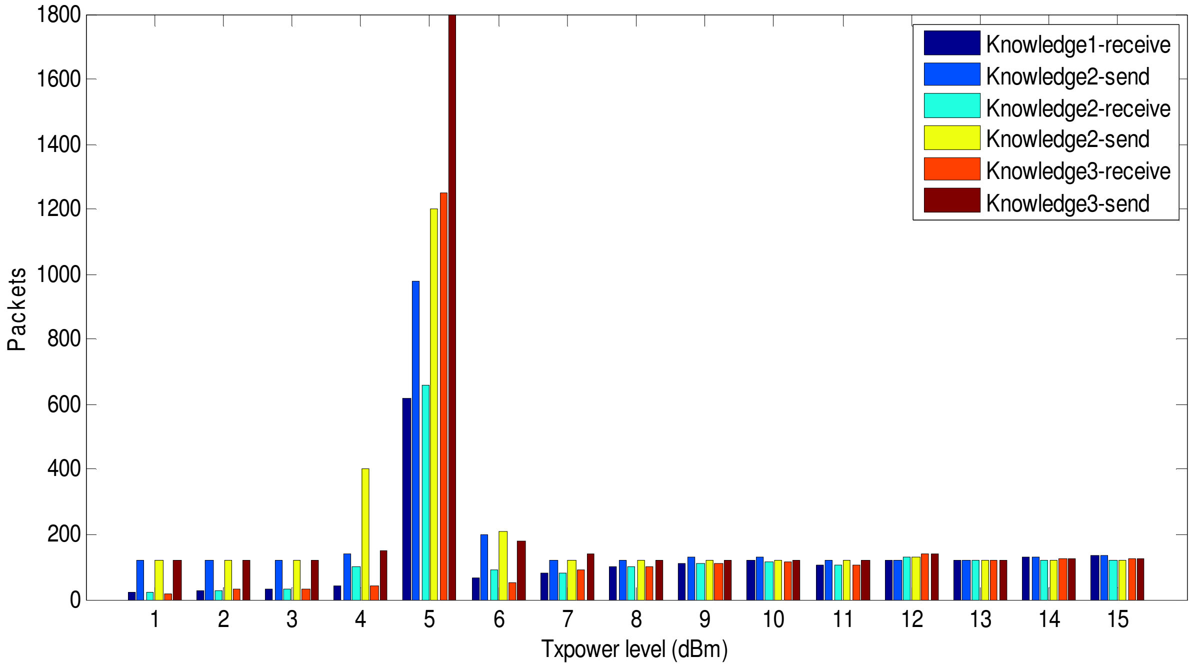

Fig 4-3. Different scenario of previously knowledge algorithm.

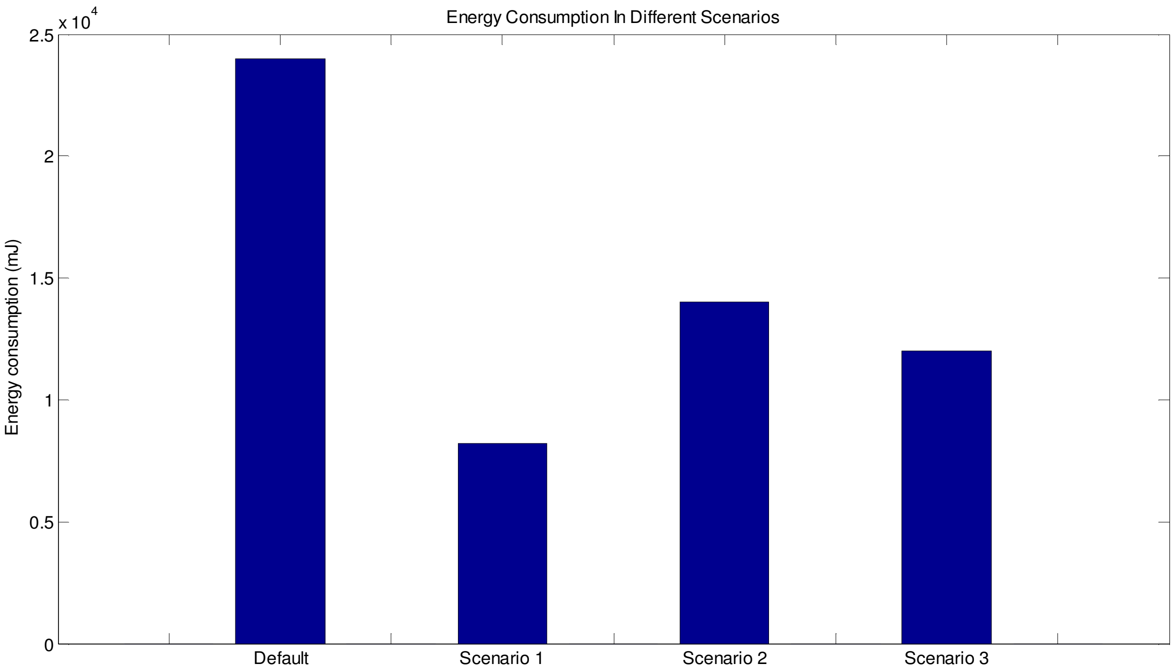

Fig 4-4. Same algorithm in different scenario with different energy consumption.

Via Fig 4-3, we did the experiment in the same scenario; we did the measurement three times, which used the same algorithm of Knowledge, but it selected different best transmission power level at beginning. Then we compare the energy consumption, we found also has a big differences.

Our conclusion is because the algorithm of previously knowledge is strongly dependent on the history table. If the scenario' channel did not change, then we can get the best power level directly, that will be the best way in our design. But if the channel changed a bit, then we need to shift the table and find a new best value. It also can acceptable. However, the best power level selected by this less accurate history table may not be very accurate. The bad situation is when the channel changes a lot, the current correlation table will be totally different from the previous record. In this case, our history table does not work anymore. We need to learn the channel again.

4.2.2 Analysis the Algorithm of Combine

Based on the advantage and disadvantage of Knowledge and Probing algorithm, we designed the Combine algorithm. For example, when channel is unchanged, or the scenario we choose is the same as last time, if we used the algorithm of Knowledge, we can direct get the best transmission power level based on the history table. But the algorithm of Probing need to learn the channel again, which means consume extra waste. In other situation, when the environment changed, if we still use Knowledge algorithm, we will get a wrong best transmission power level, in this case, we need to learn the channel again, build a new table, so the algorithm of Probing will be the best choice.

Through the experiment, I think we should to separate our algorithm into two parts, we first read the SNR, to check whether the channel is varied or unchanged compared to the previous experiment record. If SNR identify the channel is the same as our history, we use the algorithm of previously knowledge. In this case, we find that the SNR has a large variance. We manage to the Probing algorithm.

We did the same kind of experiments in some different scenarios. We set up our experiment in 5 different scenarios. Which include good link quality and bad link quality. The good link quality means if we use default 15dBm to transmit, the packet delivery ratio will close to 100%. The bad link quality is the packet delivery ratio less than 50%. We use the algorithm of Probing, Knowledge and our improvement algorithm (Combine) did the experiment in all the scenarios, through the Fig 4-5, we found the performance of Probing and Knowledge fluctuated. However, with our improved algorithm (combine) the variation is very small, that mean the improved algorithm (Combine) has a good stability.

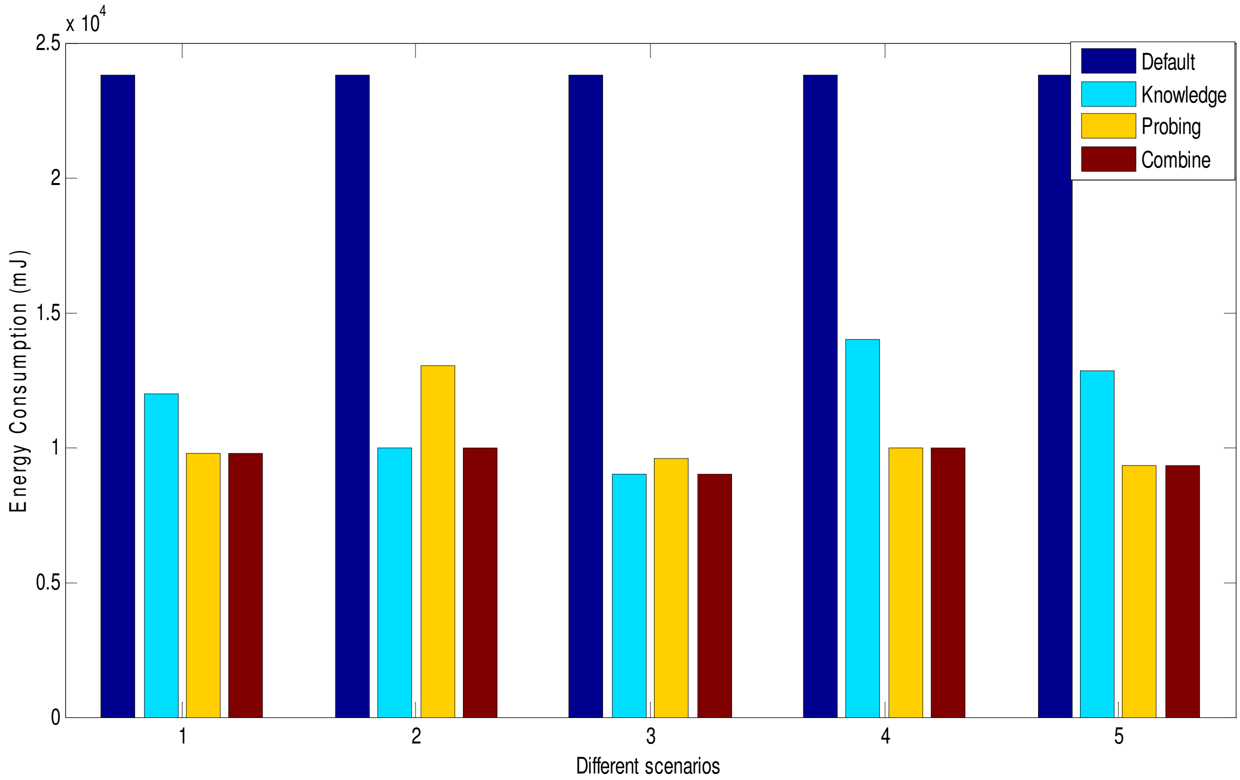

Fig 4-5. 5 scenarios with four different energy saving algorithm.

Through the table, we can compare the different algorithms in two aspects (delivery ratio and energy consumption).

Table 4-6 Compare different algorithms.

Scenarios	Scenario 1	Scenario 2	Scenario3	Scenario 4	Scenario 5
Default (mJ)	22000	22000	22000	22000	22000
Knowledge (mJ)	12000	10000	9500	14900	13500
Percentage	45%	54%	57%	32%	39%
Probing (mJ)	9800	13500	9800	10200	9900
Percentage	56%	39%	54%	54%	55%
Combine (mJ)	9800	10000	9500	10200	9900
Percentage	56%	54%	57%	54%	55%

In some of the sensor application, the delivery ratio or number of transmissions is not the first concern, also if for the Non-real time application, the delay is not strict. In those situations, the energy can be the first issue and the Combine algorithm will be the best choice for the initialization phase.

4.2.3 Analysis the Process of Best Transmission Power Level selection

One thing also interesting for us is how to find the best power level in our algorithm. Because the best value changed all the time, we are quite curious about process of best values' selection. Fig 4-7 illustrated the procedure. Through the figure, we found in first 100 packets the best values changes fluently. At the start period, we used 15dBm to transmit. Because the first 1dBm transmission successfully arrived, the algorithm chooses 1dBm as best value. Next, because the low delivery ratio of 1dBm; the best value changes to 3 instead. When we transmit more packets, the best value will be stability due to the more history data. After 500 packets, it will keep the best value until the environment changed.

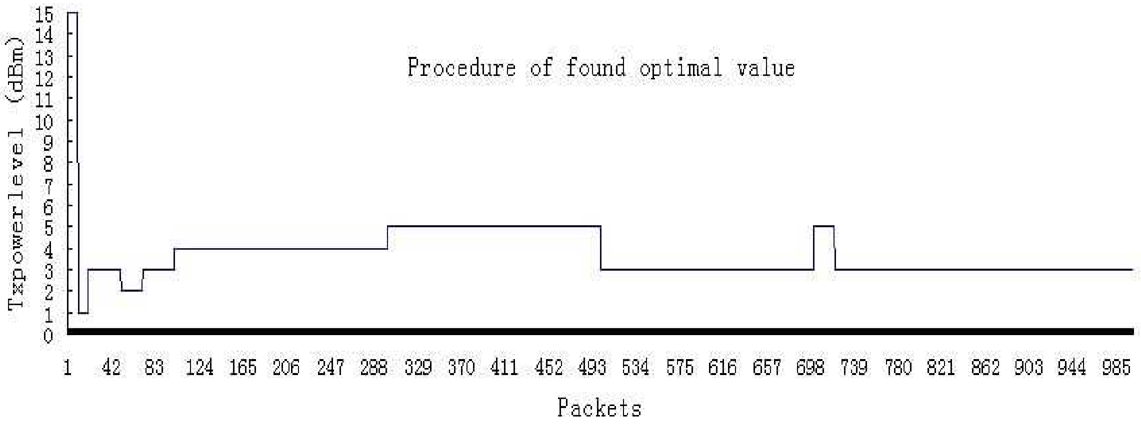

Fig 4-7. Procedure of find best value.

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Through the Fig 4-7, we found when system start to transmit, the best value at the beginning part is always not precise in the algorithm of Fix. If we only transmit less than 500 packets, what result will it have? Is our algorithm still saving energy? The table 4-13 gave the answer.

Table 4-8. Compare different algorithm just for start period.

Algorithm	Packets be to transmitted	Expected packet transmissions (including retransmissions)	Energy consumption (mJ)
Default	500 packets	500 packets	15811
Fix	500 packets	2013packets	11234
Theory	500 packets	2361 packets	12672
Knowledge	500 packets	2417 packets	11678
Probing	500 packets	2398 packets	13192
Combine	500 packets	2312 packets	11131

Through the table, we found if we just transmit less than 500 packets, the Combine algorithm is still the best algorithm. It can save 24% energy consumption compare to the default algorithm which use 15dBm to transmit or the packets, but we need to transmit four times the number of packets compared to the original one.

4.3 Measurement Results of our Proposed Method in Updating Phase

4.3.1 Decide the Smoothing Factor in Updating Phase

There are two parameters to decide for our updating phase (see Section 3.5.1). Our first step is to decide the value of α which decide the updating speed of new PDR to the old history table. We did experiment four scenarios with 20 values of α (0 to 0.95, with the step of 0.05). We found different link have different α.

Through the figure 4-9, we found different α value result in different energy consumption, so we can't get a best α value for all the scenarios. Our solution is we also need to learn the value of α.

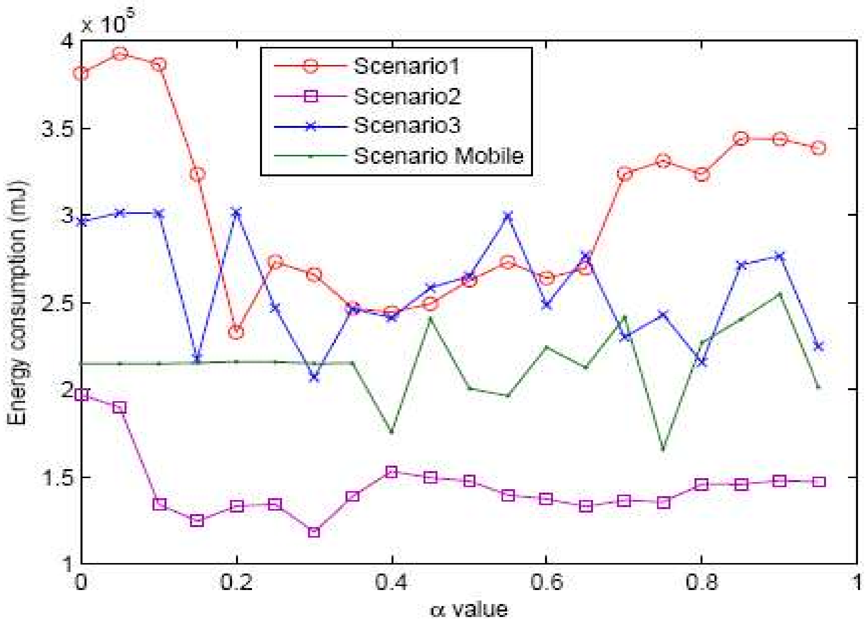

Fig 4-9. The best alpha value selection for each scenario.

Based on the fact that the best α is different for each links, another question is when we learned the α value, we need to update or not, the α value will change with the time in the same scenario? In order to find the best α value variance with time, we segment the experiment time into 10 different pieces and use the same algorithm as previous to select the best α for each part and plot them in Fig. 4-10.

Via figure 4-10, in the seario1, 2 and 3, the α value is almost stable. But in the Scenario of Mobile, the α value is changed frequently with the time. We can see the lowest point is 0.15, in the period of 2-3, the highest happened in the period of 8-9 with the value of 0.45.

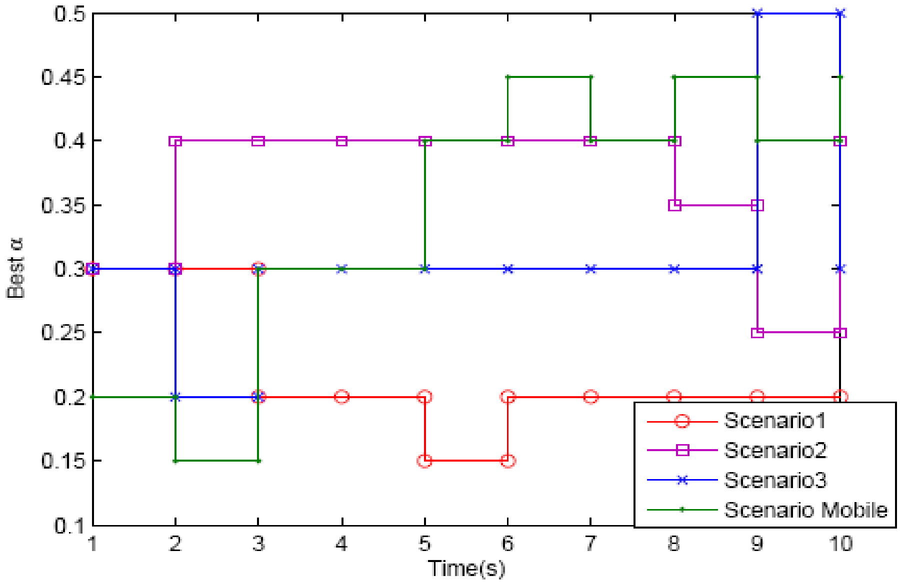

Fig 4-10. The best alpha value in different time interval.

4.3.2 Decide the Proportion of Probing Packets in Updating Phase

Another parameter to decide is how much percentage of packets should be send in the transmission power levels other than the currently selected best one. In the Figure 4-11, we find the probing packets between 0 to 10% achieved better performance.

Through the graph, in all the four scenarios, when we use more than 15% packets to probe the channel, the energy consumption is arise with the proportion of probing packets, the conclusion is we don't need to use more than 15% packets to keep learning the channel. Also in the graph, we found when we use 5% to10% packets to probe the channel will achieve better performance. In scenario 1 and scenario 2, 8% in the best choice. In scenario 3 and scenario 4, use 5% packets to probe will save more energy.

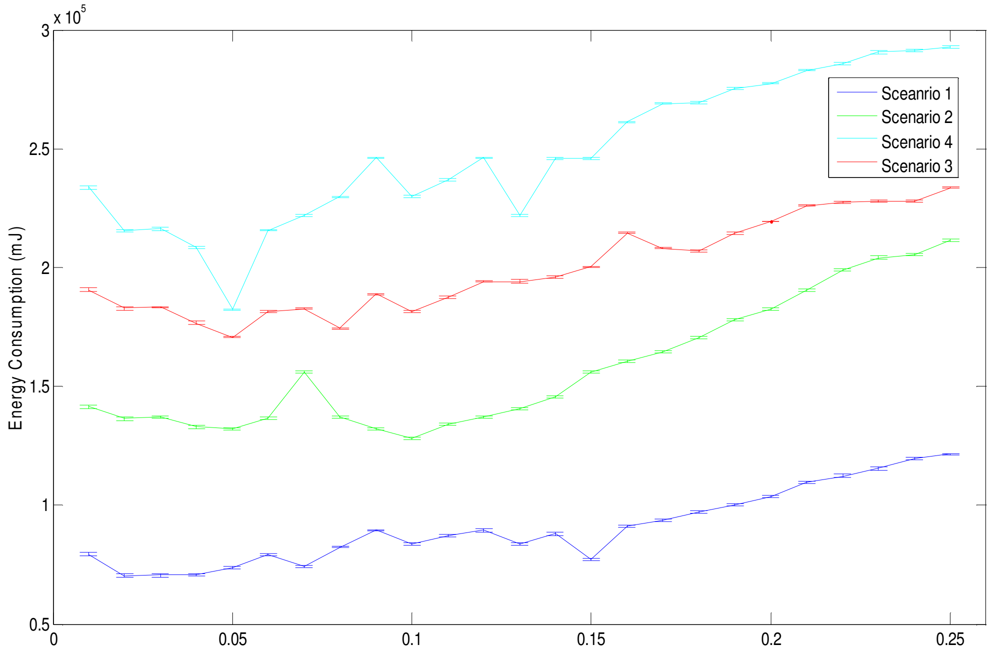

Fig 4-11. The performance of different percentage probing.

4.4 Measurement Results of Integration Data Rate and Txpower

Previously we described how we can save energy by adapting transmission power in single data rate,, in this section, we discuss the energy saving in multi-data environment..

4.4.1 The Relation between Data Rate and PDR In 802.11b

We set up our experiment as usual. In IEEE 802.11b, we have four kinds of data rate; 1Mbps, 2Mbps, 5.5Mbps and 11Mbps. Firstly, we investigate whether the relation between data rate and delivery ratio has the same phenomenon like the transmission power level and packet delivery ratio. We send 10000 packets in total for each scenario, averaged divided into four data rate. We did this experiment six times in six different scenarios. We show the results in Fig 4-12.

In the Fig 4-14, the X axis is the different scenario, we selected scenario through the SNR. Scenario 1 has the highest SNR. Scenario 6 has the lowest one. Because when the SNR goes down, that means link quality declined, so the PDR dropped. The four curves in the graph are four different data rates in 802.11b. We can see these four curves are very close to each other, so we think in 802.11b, the different data rate only a few influence on PDR in our scenario.

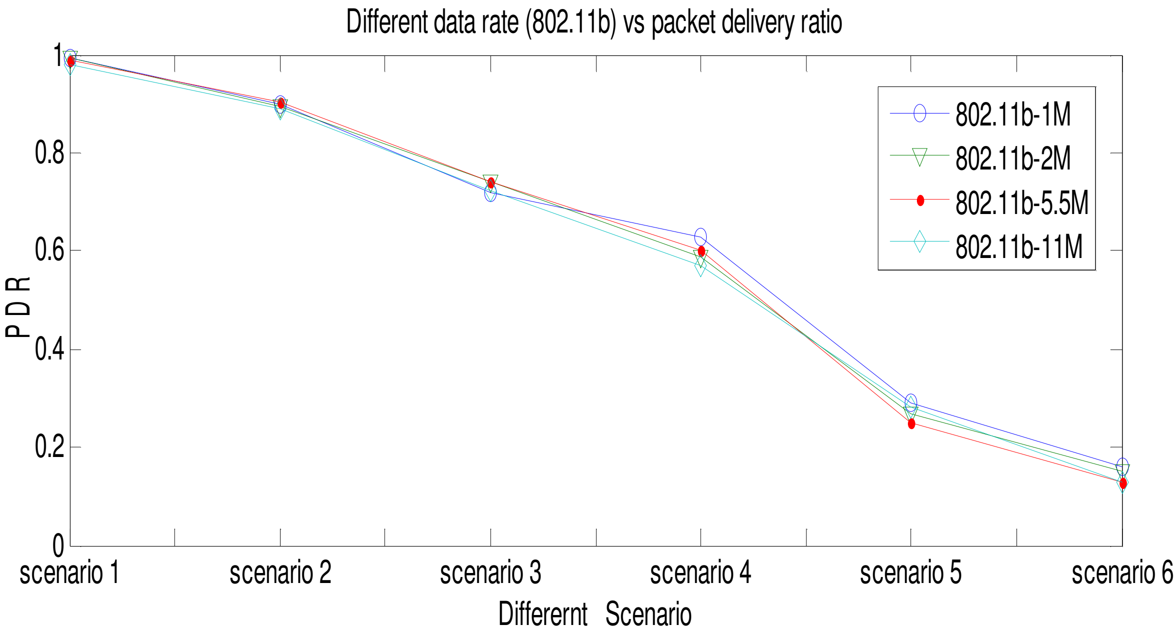

Fig 4-12. Different data rate (802.11b) vs PDR.

4.4.2 The Best Data Rate In Our Energy Saving Algorithm

In chapter 3.4, we gave the definition about how we select the minimal energy consumption as,

$$E = txpower \times N_{expected} \times T \tag{9}$$

In chapter 3, the T is constant for single data rate system. Now we suppose we can change the data rate. Which data rate is more efficient, if we only consider energy consume. First, as we analysis in the Fig 4-12, in 802.11b, the four data rates have nearly the same PDR in different scenario. Secondly, from the function (9), we found if we want to the least E, the smaller T, the better. Taking all factors into consider, we believe the best transmission date rate in 802.11b is 11M in our scenario.

4.4.3 The Relation between Data Rate and PDR in 802.11g

We set up this experiment as usual. In IEEE 802.11g, we have eight kinds of data rates; 6Mbps, 9Mbps, 12Mbps, 18Mbps, 24Mbps, 36Mbps, 48Mbps, 54Mbps. In order to simplify the experiment, we only select four data rates in 802.11g (6M, 18M, 36M, 54M). We also did this experiment six times in six different scenarios. We show the results in Fig 4-13.

Via the Fig 4-13, we found the four data rate in 802.11g also have the same PDR in all scenarios. So as we discussed before, in order to save energy, we select 54Mbps.

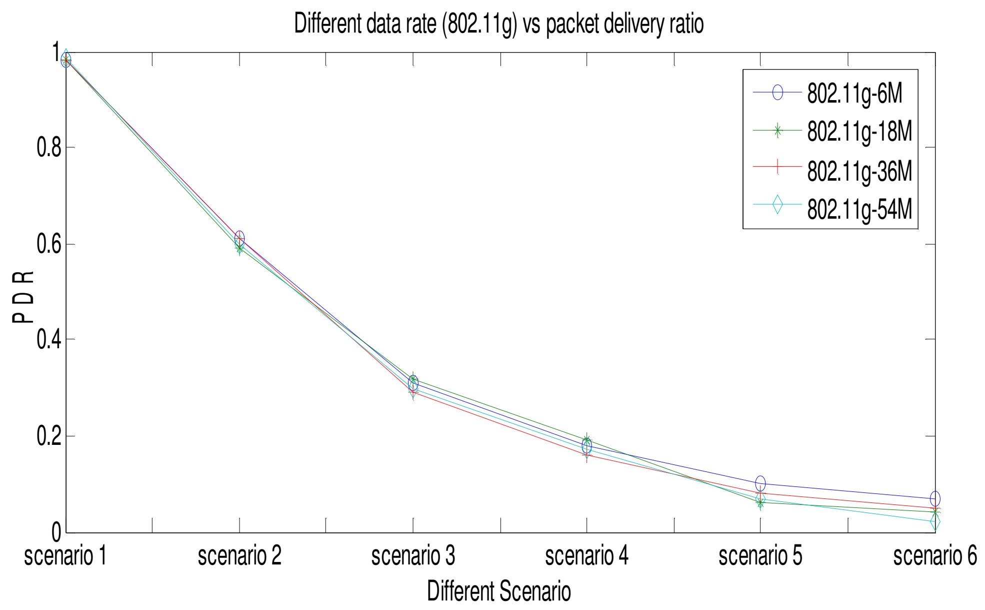

Fig 4-13. Different data rates (802.11g) vs PDR.

4.4.4 Select Data Rate between 802.11b and 802.11g

In section 4.4.3, we selected the highest data rate for the purpose of saving energy. So we wondering if we can select data rate between 802.11b and 802.11g, which data rate is optimize.

We did an experiment use two data rates (11Mbps in IEEE 802.11b and 54Mbps in IEEE 802.11g). The reason why we choose these two data rates is because 11Mbps is the best one in IEEE 802.11b, and 54Mbps is the best one in IEEE 802.11g. So if we decide to use IEEE 802.11b, we select 11M. So does IEEE 802.11g. This experiment results are shown in the Fig 4-14.

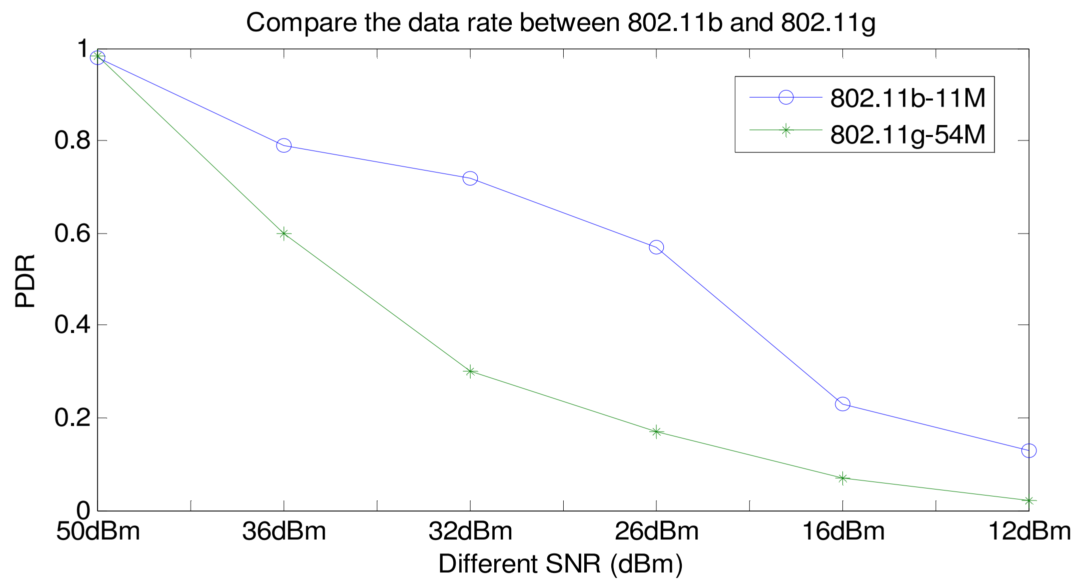

Fig 4-14. Different PDR for 11Mbps and 54Mbps in different scenarios

In Fig 4-14, the blue curve is 11Mbps PDR for all the scenario. The green curve is 802.11g of 54Mbps. The X axis is the different scenarios. Our first conclusion from the result is that the two data rates have a great difference. Therefore, we want to make a trade off between these two data rates:

1. Compare the transmission time: 11Mbps data rate is roughly 5 times bigger than 54Mbps.
2. The maximum difference of PDR of these two is 12%, which happens in scenario 6.
3. The minimum difference of PDR of these two is 0.3%, which happens in scenario 1.

Our ideal is we need make a trade off between 1 and 2 for the purpose of selecting the best data rate in different scenario.

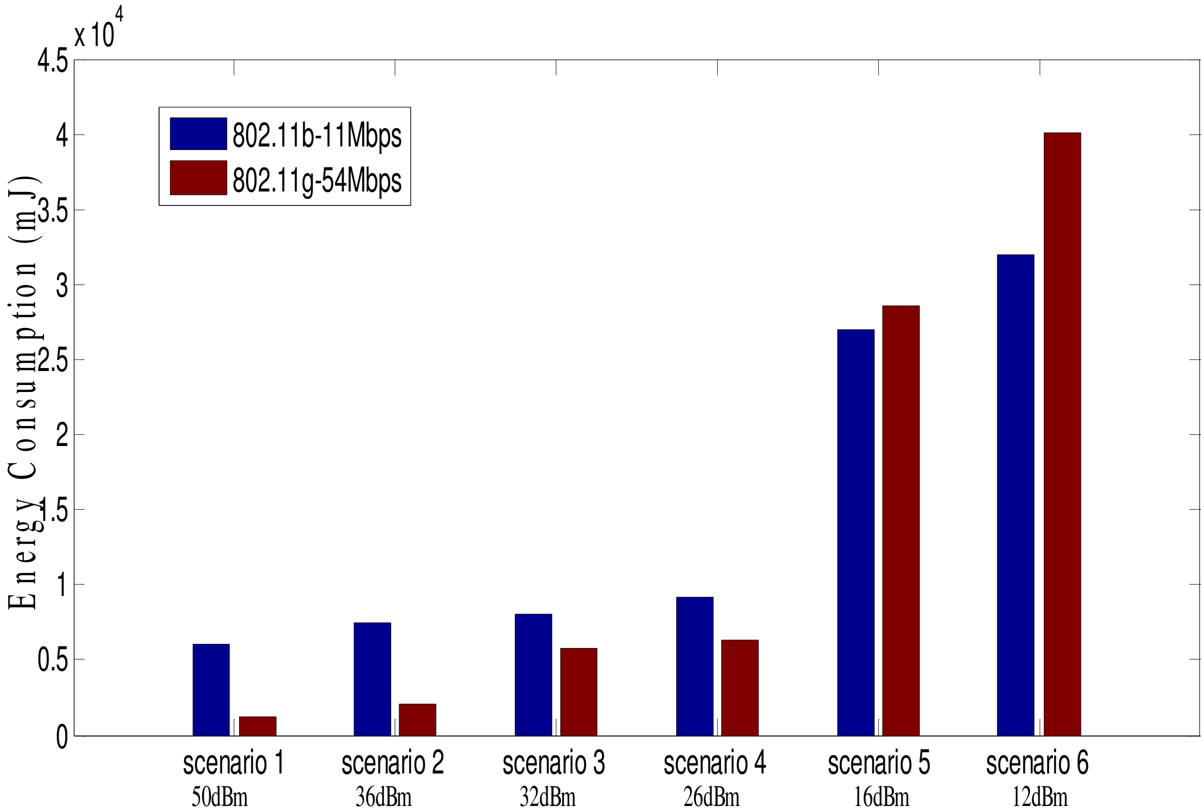

Fig 4-15. Compare the energy consumption between 802.11b and 802.11g.

Through the Fig 4-15, we found in some scenario the 802.11b achieved better performance, and in some scenario the 802.11g have. So how can we choose the best one?

In order to find the way to select the best choice: We compare 802.11b and 802.11g in three different scenarios.

Scenario 1 is an indoor environment and has short distance. We suppose this scenario has good link quality. Through scenario 1, we found a good link quality; the 802.11g achieved better performance. IEEE 802.11g's energy consumption only 25% of 802.11b, the reason is 802.11g have a high data rate (54M), but 802.11b only have the max value of 11M.

Scenario 2 is an indoor environment and has medium distance. We call this scenario has normal link quality. Through scenario 2, we found in most scenarios, IEEE 802.11g also has better energy saving performance compared to 802.11b.

Scenario 3's is in indoor environment but Non-Line of sight, which has a large distance. This scenario has bad link quality. Through the figure, we found 802.11b has a better energy saving performance. The reason is although 54Mbps has four times PDR than 11Mbps for transmitting the packet data , but in Fig 4-16 we can seen in bad link quality, 802.11g's PDR is very low. We make a trade off between data rate and PDR, in the experiment of scenario 3, we found 802.11b has better energy saving performance.

Our conclusion is if we want to compare the energy consumption between 802.11b and 802.11g, it depends on the link quality. Through the experiment results, we found in some scenario that the link quality is low, because 802.11g's PDR is quite low, which means we need to retransmit a lot of times. So in that kind of situation, 11Mbps achieved better performance.

4.4.5 Our Proposed Method for Selecting the Data Rate

We improved the algorithm of Compare, which we proposal in above chapter. Our new way is first we read the SNR, if the link quality is good, we choose 54Mbps in 802.11g, otherwise we choose 11Mbps in 802.11b.

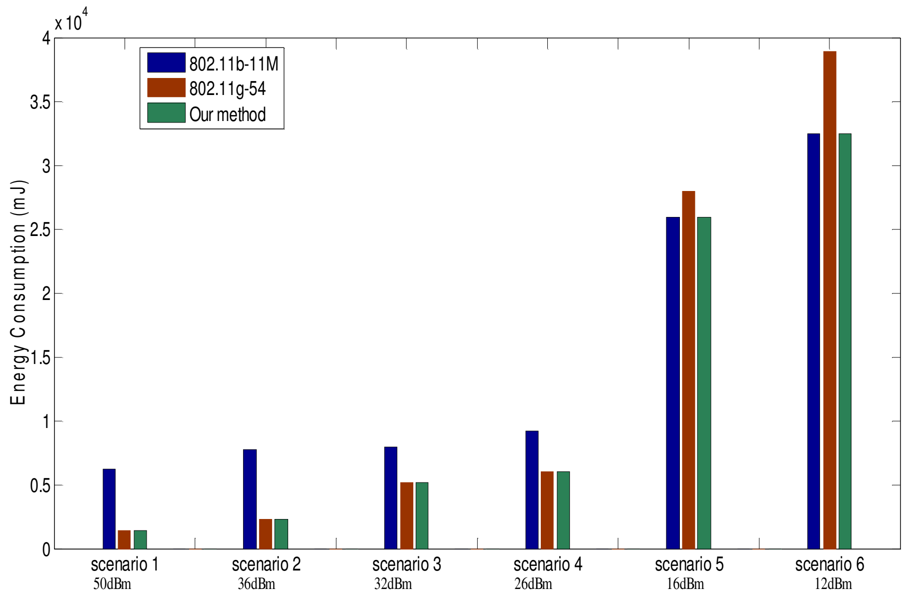

Figure 4-16. Our algorithm for different data rates.

In our experiment, we think SNR equal to 11dBm is a good point for divided the good and bad link quality. Via the Figure 4-16, in the Scenario 1, 2, 3, 4, we can find which consume less energy than scenario 5 and 6. In these scenarios, the SNR is higher than 16dBm, so we have a good link quality. Then our algorithm will choose 54Mbps. In the Scenario 5 and 6, we found the SNR is quality lower, which means the link quality is bad, so we choose 11Mbps to transmit.

5

Conclusion

5.1 Conclusion

In this master thesis, we presented the relation between the packet delivery ratio and the transmission power level. Firstly, we expect to use theoretical model to predict the relation between PDR and SNR. Through the comparison with measurement results and theoretical values, we got our first conclusion that the theoretical prediction is unconvincing.

Based on the fact that PDR and transmission power relation is keep on changing, we proposed a general transmission power adaptation method, which is divided into two phases, the initialization phase and updating phase. We proposed three algorithms for the initialization phase, Knowledge, Theory and Probing. We found these three algorithms can save approximate 50% of energy in most scenarios, but it caused more retransmissions. Following, we analyze the results deeply. We found that when the link quality is the same as the history result; the algorithm of Knowledge achieved better performance. When we changed experiment location, which means the correlation between PDR and SNR changed, the Probing has better performance. We improved our algorithm, we call it Combine. In this algorithm, it first read the SNR and compared to the history table. If the SNR is the same like record, we believe we can use last times' best transmission power level. Then we have skipped the initiation part, and go to the updating period directly. If the SNR changed a lot, we cannot trust the history results anymore. We have used the algorithm of Probing; learn the channel again, to get a new and precisely best transmission power level. Through experiments, we found this method has the best performance.

In the updating phase, we discussed the smoothing factor α and the proportion of probing packets, for the value of α, we found its depend on the scenario, for the proportion of probing packets in the updating phase, we think 5% to 15% will achieve better performance through our experiment.

We have also integrated the data rate into our algorithm. In our experiment scenarios, we found that if we used 11Mbps in IEEE 802.11b, it can save 82% of energy compare to 2Mbits/s. If we used 54Mbps in IEEE 802.11g, it can save 89% of energy compare to 6Mbits/s. Through experiments, we found all the data rate of IEEE 802.11b has the same packet delivery ratio, so did IEEE 802.11g. So the high data rate will cause a low delay, consider the energy consumption, we choose the maximum data rate in IEEE 802.11b and

IEEE 802.11g.

Later, we put IEEE 802.11b and IEEE 802.11g together. We found IEEE 802.11g's packet delivery ratio is lower than IEEE 802.11b in our measurement scenario. Hence, there is also a potential trade off between IEEE 802.11b and IEEE 802.11g. Through the experiment results, we found that when the link quality is not very bad; the IEEE 802.11g achieved much better performance than IEEE 802.11b. After all, the maximum data rate in IEEE 802.g is 4 times higher than IEEE 802.11b (54Mbps in IEEE 802.11g, 11Mbps in IEEE 802.11b). However, in some very bad scenarios, the IEEE 802.11g's packet delivery ratio is less than one-quarter of IEEE 802.11b's, so we selected the IEEE 802.11b as the best value.

Due to the algorithm of Combine, which we have discussed above, we think the SNR value has more functions. Through the SNR, we not only can compare to the history table, but also can examine the link quality. If SNR is quite low, we'd better use 11Mbits/s instead of 54Mbits/s.

5.2 Future work

A lot of extension work can be done as future work for extension of this project. Firstly, we used SNR to distinct the link quality. Through the experiment result, we used approximate 16dBm as a dividing line, but maybe 15 dBm or 17 dBm is more precisely. Maybe the dividing line depends on the environment or the equipment, so we should find a more precise way to select this line.

For the updating phase, we only found the smoothing factor α depended on different scenarios, a good method to learn and updating the smoothing factor also can be researched.

Secondly, we did this energy saving method mainly in stationary scenarios. If these algorithms be implemented in mobile applications, it may not achieve the best performance. We believe the algorithm of Knowledge and Theory will not perform as good as in our results. We need to find an algorithm that can be implemented in both stationary and mobile scenarios.

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Abbreviations and Acronyms

ACK	Acknowledge
ATIM	Announcement
AP	Access
BER	Bit
BPSK	Binary
CCK	Complementary
CTS	Clear
CSMA/CA	Carrier
CSMA/CD	Carrier
DSSS	Direct-Sequence
DBPSK	Differential
DQPSK	Differential
EWMA	Exponentially
GPS	Global
IP	Internet
OFDM	Orthogonal
PAN	Personal
PCMA	Power
PDA	Personal
PDR	Packet
Madwifi	Multiband
MFR	Most
QPSK	Quadrature
RTS	Request
RSSI	Received
RX	Receive
SNR	Signal
TCP	Transport
TX	Transmission
Txpower	Transmission
UMTS	Universal
WLAN	Wireless