

# Analysis of Energy Efficiency for Wi-Fi 802.11b Multi-Hop Networks

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**Abstract**— Wireless local area network (WLAN) is growing popularly day by day. A common WLAN application is Wi-Fi technology, where it is easy to find in public areas and has a great interest of internet access users, particularly those who use mobile devices (nodes) such as notebooks and mobile phones. The phenomenon has impact on the energy consumption in Wi-Fi networks. Nowadays, the consumption, management and energy efficiency of indoor wireless networks are important issues. Therefore, this paper analyses the energy efficiency for Wi-Fi 802.11b multi-hop networks. The Wi-Fi 802.11b multi-hop network is simulated using Network Simulator 3 (NS-3), in which the network consists of a line sequence of 5 wireless nodes that are a source, three relays and a destination. In the simulation, several energy parameters are considered such as the number of nodes, grid spacing, packet size and data rate. Moreover, several important energy efficiency factors are analyzed including energy consumption, effective energy utilization, bit energy, throughput and energy efficiency. The simulation results show that the number of the packet size and throughput have impact on energy consumption and energy efficiency in the network. While effective energy utilization decreases as the throughput of the network increases. Therefore, the Wi-Fi 802.11b multi-hop network can be an alternative green communication method which has a higher energy efficiency.

**Keywords**— Wi-Fi 802.11b, energy consumption, energy efficiency, multi-hop network, network simulator.

## I. INTRODUCTION

Currently, the development of information and communication technology has shown rapid progress to fulfill user requirements for real-time communication system at anytime and anywhere. Moreover, the connectivity of mobile communication with easy access that is supported by a wireless local area network (WLAN) has increased the number of its users and predicted continued to grow more in the future. WLAN provides mobility for the infrastructure of the access layer from the edge of the wire to the end-user. Nowadays, one of successful WLAN technology is Wi-Fi standard IEEE 802.11 [1]. This technology allows some clients to share a connection through one access point that can be implemented quickly, easily and inexpensively. Wi-Fi standard IEEE 802.11b has widely used as an alternative solution for data communication as well as a local area network using a high radio frequency in transmitting data and replacing the function of cables on conventional network that

operated at a frequency of 2,4 GHz. The standard refers to layer physical (PHY) network and Media Access Control (MAC) layer [2].

One of the major issues to access data using Wi-Fi is the limited source of energy for mobile devices. The battery is also projected to be used more than its capacity that is being lower than the energy needed to provide wireless access to the Internet [3]. Therefore, the source of energy for mobile devices becomes significant factor in the Wi-Fi network. Both consumption and energy efficiency of wireless indoor network and management of energy are currently crucial issues [4]. Furthermore, energy consumption of wireless interface for a mobile device could reach 50% of total available energy [5]. By the increasing number of users to access data through Wi-Fi, then the energy consumption will also be increased. The limited source of energy on mobile devices and the wasteful energy would lead to CO<sub>2</sub> emissions that can cause the damage environment. So the analysis of energy efficiency in the design of telecommunication systems is very significant by putting attention in power saving used on terminal (node) to reduce the carbon footprint leading to green communication [4]. The previous research has studied the energy efficiency on Wi-Fi network based on traffic route for constant willingness as well as energy aware willingness versions of OLSR [6]. The experimental investigation on energy consumption of the 802.11 devices has conducted in [7], but it was only modeled and analyzed the power consumption of WLAN devices. In [8], a power saving strategy for IEEE 802.11 has proposed without considering the impact of packet sizes, effective energy utilization and energy efficiency as well. Moreover, the energy efficient protocol was introduced in IEEE 802.11b by combining the transmit power control and adaptive rate in [9], where the data rate is a main influenced factor to the energy. Therefore, the several energy efficiency parameters of Wi-Fi 802.11b multi-hop network is also important to analyze.

This paper analyses the energy efficiency for Wi-Fi 802.11b multi-hop network that is implemented through Network Simulator 3 (NS-3). In the simulation, the network topology is considered as a line network of a sequence of nodes equally spaced node, which consists of 5 nodes that are a source node, three relay nodes and a destination node. The topology is simple and flexible to be realistically implemented. Moreover, the influenced parameters of energy efficiency should be analyzed including energy consumption, effective energy application, throughput and bit energy. The

network variables such as several wireless nodes, the distance between nodes, packet sizes and data rates are taken into account for analysis of energy efficiency of the Wi-Fi 802.11b multi-hop network. The simulation results indicated that packet size and throughput have major influenced to the energy consumption and efficiency energy on the Wi-Fi 802.11b multi-hop network.

The rest of the paper is organized as follows. Section II provides a research method for simulating and analyzing of energy efficiency for Wi-Fi multi-hop network. A simulation system; network simulator, simulation scenario and energy efficiency parameters are presented in Section III. In Section IV, simulation results and several energy efficiency factors are analyzed and discussed. Finally, we conclude with a brief summary of results.

## II. RESEARCH METHOD

The method used in this paper is computer simulation in order to analyze the energy efficiency for Wi-Fi 802.11b multi-hop network. It starts with identify the system requirements of the simulation for Wi-Fi network through Network Simulator 3 (NS-3). NS-3 provides the code for energy module of Wi-Fi network and quite closely the IEEE 802.11b standard. Besides the NS-3 software, the other software applications are needed to analyze the efficiency energy on NS-3 such as Net-Anim to visualize the simulated network and C++ programming for coding and further analyzing the energy efficiency. Then, the network topology is defined which consists of 5 wireless nodes in the network that are a source, three relays and a destination. Furthermore, the simulated network is implemented using NS-3 and visualizes the network through Net-Anim. Then, energy parameters of the Wi-Fi multi-hop network is obtained in the simulation. In the simulated network, we assumed a specific distance between source (S) and destination (D). Finally, we analyze the level efficiency energy based on energy consumption, energy effective utilization, throughput and bit energy.

## III. SIMULATION SYSTEM

### A. Network Simulator 3

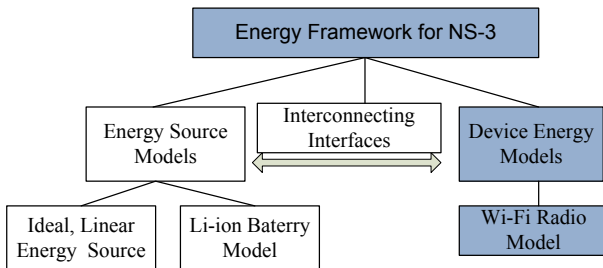


Fig. 1. Framework structure of energy for NS-3 [6].

A simulation framework of energy efficiency on Wi-Fi network has been designed by using NS-3 [6]. The framework provides energy models for energy source and also device

energy. Obviously, the energy source model represents some kind of energy source such as Li-ion battery, whereas device energy model represents components of the node, such as Wi-Fi radio. The relationship between energy source and device energy models can be seen in Fig. 1, where it can be realized that the energy device model consumption come from energy sources. Furthermore, it will be notified by the energy device models when capacity is completely drained of energy. In this research, computer simulation is applied in order to lead the device energy and Wi-Fi radio model as well.

### B. Simulation Scenario

Realistic simulation scenario is crucial to correctly analyze the energy efficiency of Wi-Fi 802.11b multi-hop network. This scenario can be defined by choosing a basic network topology for the simulation as shown in Fig. 2. The topology is considering as a line network of a sequence of nodes equally spaced node on a line. Each pair of nodes will connected by a link. Based on the network in Fig. 2, there are 5 wireless nodes that consist of a source (blue color), three relay nodes (grey color) and a destination (red color) in the simulation. Moreover, the simulation scenario has been designed on the NS-3 and was written using C++ programming language.

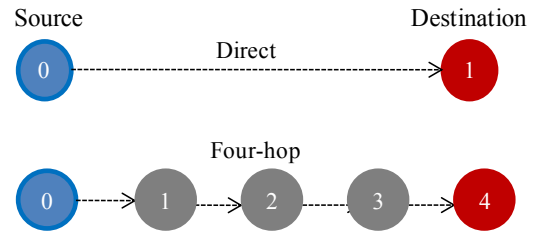


Fig. 2. Multi-hop network topology.

The Wi-Fi multi-hop network can be visualized by NetAnim which is simulated the flow of data packet transmission as shown in Fig. 3. Based on the simulated network, the energy efficiency is calculated by considering the energy parameters and the flow of data packet from source (node 0) to the destination (node 4).

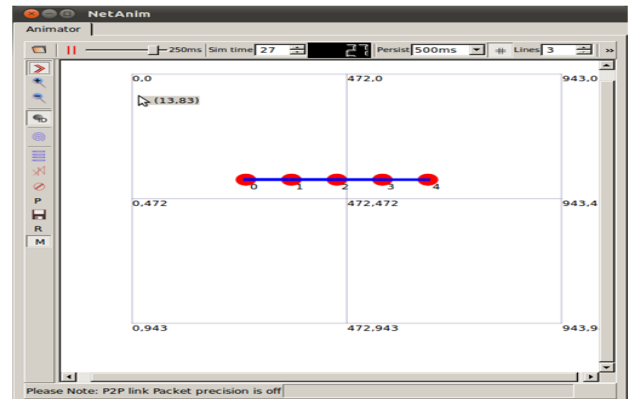


Fig. 3. Multi-hop network visualization via NetAnim.

### C. Energy Efficiency Parameters

Energy efficiency is an important issue in the field of wireless networks where varieties of mechanisms and protocols are developed and also evaluated in order to reduce energy consumption [10]. In addition, optimization of energy consumption in Wi-Fi devices also have significant impact on carbon emissions [1]. Thus, energy efficiency at the node or access point is needed to decrease carbon emissions and to create a sustainable communication. The average energy efficiency can be calculated by the following equation:

$$\eta = \frac{P}{T \cdot (1 - \varepsilon)}, \quad (1)$$

where  $\eta$  is the energy efficiency (J/b),  $P$  is the power (watts),  $T$  is the traffic rate (b/s) and  $\varepsilon$  is the probability of error messages received by the destination.

Several important parameters that affected the energy efficiency on Wi-Fi network are as follows:

#### - Energy Consumption

Effective energy usage can be calculated using the following equation:

$$E_A = \frac{P_A - P_I}{T_A}, \quad (2)$$

where effective application-specific energy usage ( $E_A$ ) is defined as the use of energy in the unit of J/Mb,  $P_A$  is the average power consumption during the data flow of transmission in the unit of W, the power consumption for the  $P_I$  is the power of an idle node in the unit of W, and  $T_A$  is mean-average throughput flow that occurs during transmission [11].

#### - Energy Bit

Energy bit is the energy dissipation by the corresponding data rates. It is also used to compare the energy efficiency of the system by employing a different transmission scheme. The energy bit of a communication system can be formulated as follows [12].

$$Eb = \frac{P}{R}, \quad (3)$$

where  $Eb$  is the energy bit which is measured in J/b, the bit rate  $R$  is expressed in the unit of b/s and  $P$  is the power level that is measured in watts or J/s.

#### - Throughput

Throughput is the number of data packets that can be passed through a network node for every second on the wireless access point [13]. It is usually expressed in units of bits per second (bps). The main aspect that range in throughput is sufficient availability of bandwidth for an application as it passes through the network. The other important aspects are the error (usually associated with the link error rate) and losses (generally related to the buffer

capacity) [14]. The average throughput of a network can be calculated as

$$\text{Average throughput} = \frac{\text{Received Packet} \times 8}{\text{Simulation time} \times 1000} (\text{kbps}) \quad (4)$$

#### - Data Rate

Data rate is the rate at which data is transmitted through a communication channel. It is usually corresponding to the necessary time to transmit the data. It is also related to the speed of the data signal through the wireless network, which can effectively identify the amount of bandwidth on the media in order to supply and to support the presence of a digital signal. Wi-Fi 802.11b was designed using two data rates at the PHY layer, 1 Mbps and 2 Mbps. Shortly after the first standard, Wi-Fi 802.11b has a raw maximum data rate of 11 Mbps.

### D. Simulation Parameters

Simulation parameters that are used to simulate the energy efficiency of Wi-Fi 802.11b multi-hop network are shown in Table I.

TABLE I. SIMULATION PARAMETERS OF WI-FI 802.11B MULTI-HOP FOR EFECIENCY ENERGY

Parameter	Value
Wi-Fi Standard	802.11b
Initial energy	1 J
Dsss rate	1, 2, 5.5, and 11 Mbps
Prss	-80 dBm
Distance between nodes	50 m
Packet sizes	1024, 4096 and 8192 bytes
Number of packet	10,000
Number of nodes	5
Source node	1
Relay nodes	3
Destination node	1

## IV. RESULTS AND DISCUSSIONS

In this section, several overviews will be presented and also will be discussed as the results on analysis of energy efficiency for Wi-Fi 802.11b multi-hop network using NS-3. First of all, energy consumption is going to be presented, followed by effective energy utilization. There will be discussion about the energy bit and energy efficiency as well. Lastly, the average energy efficiency is shown in order to gain energy efficiency for Wi-Fi 802.11b multi-hop network.

### A. Energy Consumption

There are three of packet sizes that are considered in the simulation to obtain energy consumption: 1024, 4096 and 8192 bytes, respectively. The simulation time is set to 50 s and the initial energy is given by 1 J. As depicted in the Fig. 4, it shows the result of energy consumption using three different packet sizes. It clearly illustrated that the greater of the given

variable value of packet size, so the generated energy consumption is increasing significantly.

Furthermore, based on the result, the difference of energy consumption between 1024 and 4096 bytes of packet size is around 0.071 J. However, differentiation of energy consumption is produced by 0.194 J between 1024 and 8192 bytes of packet sizes. So, the bigger packet sizes will consumption more energy.

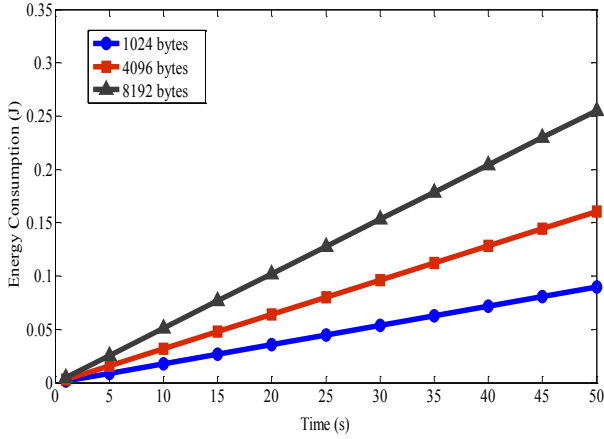


Fig. 4. Energy consumption by varying packet sizes.

### B. Effective Energy Utilization

The relationship between effective energy utilization and throughput can be seen in the Fig. 5. Energy utilization values are obtained by using the Eq. (2), while the throughput values are obtained using Eq. (4). The result clearly shows that the lower value of energy utilization is generated at the higher throughput. When the throughput of 8 Mbps, the effective energy utilization is 0.00106 J/Mb. Moreover, the effective energy utilization is 0.00046 J/Mb when the throughput size is 40 Mbps. Then, it decreases significantly at throughput value of 80 Mbps, which produces the effective energy utilization approximately to 0.00039 J/Mb.

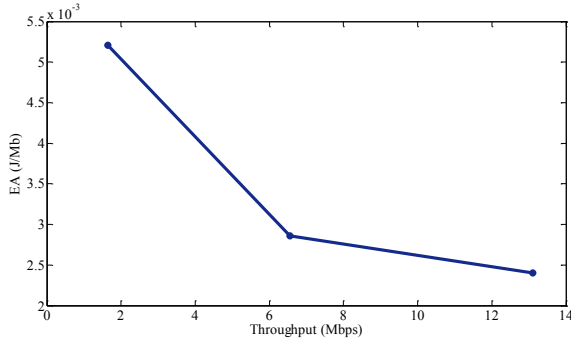


Fig. 5. Relationship between effective energy utilization versus Throughput.

### C. Energy Bits

In the energy bits discussion, the received power that generated in the simulation can be used to calculate the energy bit for each node by using Eq. (3). Thus, the result of bit energy can be seen in the Fig. 6. As highlighted in the Fig. 6,

it shows a comparison between data rate and bit energy when a given grid spacing between nodes in the network is 50 meters. Based on the results, node 1 at data rate of 1 Mbps, the generated energy bit is  $4.325 \times 10^{-13}$  mJ/b, and continued to decline until energy bit reaches  $3.932 \times 10^{-14}$  mJ/b at a data rate of 11 Mbps. Similarly, at node 2, the energy bits at a data rate of 1 Mbps is  $1.081 \times 10^{-13}$  mJ/b and also decrease gradually until data rate of 11 Mbps is  $9.831 \times 10^{-15}$  mJ/b. Furthermore, the result indicates quite the same for node 3 and 4. It is going to be decreased gradually as bit rate increases. Whereas, energy bit at data rate of 1 Mbps is  $4.808 \times 10^{-14}$  mJ/b and  $2.704 \times 10^{-14}$  mJ/b, respectively. While other bit energy of 11 Mbps, they are produced to  $4.371 \times 10^{-15}$  mJ/b and  $2.458 \times 10^{-15}$  mJ/b, respectively. Therefore, the energy bit will decrease as data rates and the number of hops are increased.

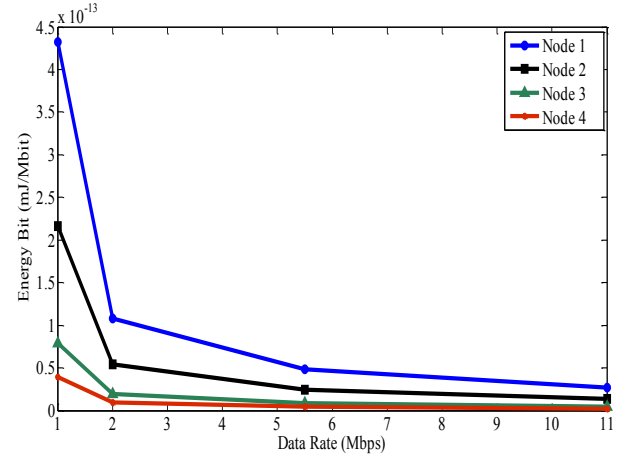


Fig. 6. Energy bit and data rates for each node.

### D. Energy Efficiency

Using energy consumption data and residual energy in the simulations, it can be known the value of energy efficiency by using the following equation:

$$\text{Energy Efficiency}(\%) = \frac{\text{Energy Total (J)} - \text{Energy Consumption(J)}}{\text{Energy Total (J)}} \times 100\% \quad (5)$$

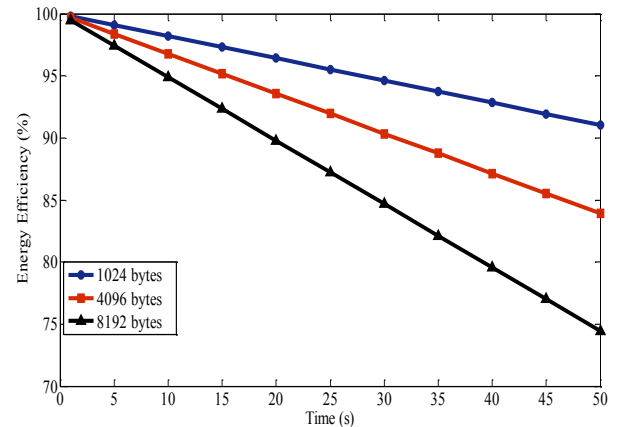


Fig. 7. Energy efficiency based on packet sizes.

In addition, the result of the comparison data between energy efficiency and three sizes of packets (1024, 4096 and 8192 bytes) are going to be illustrated in the Fig. 7. Figure 7 shows energy efficiency for three different types of packets sizes. They produce a different percentage of energy efficiency at 1 second and 50 second. For example, for 1024, 4096 and 8192 bytes, at 1 s, they are going to produce the energy efficiency of 99.82%, 99.68% and 99.49%, respectively. Contrastly, there are different results in 50 s. They produce a lower percentage than that of at 1 second. The result of the energy efficiency for three different sizes at 50 second are 91.04 %, 83.93 % and 74.46 %, sequentially.

#### E. Average of Energy Efficiency

Average energy efficiency can be calculated by using Eq. (1). Assuming that the probability of error messages of  $\epsilon$  is 0.05 or there are 5% error messages during transmission on the network, then the graph is obtained as shown in Fig. 8.

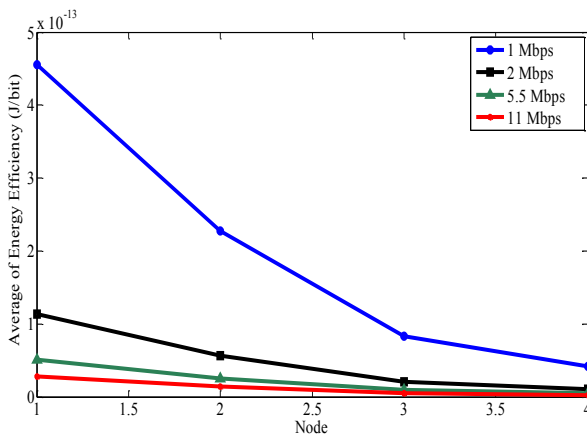


Fig. 8. Average of energy efficiency with  $\epsilon = 0.05$ .

Figure 8 shows the average of energy efficiency for each node. Based on the result, it is noticeable to say that the greater of data rate is given, the lower of the average energy efficiency is generated. This phenomenon can be seen from the difference of the average of energy efficiency at node 1 for different data rates. Moreover, 1 Mbps and 2 Mbps data rates, the difference in the average value of energy efficiency that occurs is  $2.277 \times 10^{-13}$  J/b. Then the difference between the average energy efficiency at 2 Mbps and 5.5 Mbps data rates is approximately  $1.449 \times 10^{-13}$  J/b. Finally, when the data rates of 5.5 Mbps and 11 Mbps, the difference of average of energy efficiency is equal to  $4.139 \times 10^{-14}$  J/b. So the data rates of Wi-Fi 802.11b multi-hop network has impacted the average of energy efficiency in the network.

#### V. CONCLUSIONS

This paper has analyzed the energy efficiency for Wi-Fi 802.11b multi-hop network using Network Simulator 3 (NS-3). The computer simulation scenario has been implemented by using NS-3 in which the Wi-Fi 802.11b multi-hop network topology is a line network of a sequence of 5 wireless nodes that are a source, three relays and a destination. The simulated

network provides flexible and more suitable to the real world condition. Then, some programming codes have developed to visualize and to analyze the energy efficiency parameters of the network. Simulation results show that the given number of packet sizes have impact to energy consumption on a Wi-Fi multi-hop IEEE 802.11b. While energy effective utilization decreases on the Wi-Fi multi-hop network as the throughput of the network increases. Moreover, energy efficiency decreases as the size of the transmitted packet is getting bigger because the value of energy consumption will grow in line with the increase of the size of the packets that are sent. Finally, the simulation is obtained also the average of energy efficiency with the assumption of the error packet  $\epsilon = 0.05$  is decreased when data rates and number of hop are increased. Therefore, the Wi-Fi multi-hop topology may be an alternative green communication method for implementing the Wi-Fi IEEE 802.11b multi-hop network.

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