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Impact of Frequencies on IEEE 802.15.4 WPANs for Wireless Sensor Networks

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***Abstrac* — This paper analyzes the impact of frequency band on the performance of IEEE 802.15.4 for Wireless Sensor Network (WSNs).Three scenarios were considered with frequency band of 2.4GHz, 915MHz and 868MHz.The results were compared and analyzed on the performance parameters like: traffic sent and received, retransmission attempts, end to end delay and number of hops. Choosing a suitable frequency band impacts the performance WSNs as this paper concludes that depending upon the parameter under focus the particular frequency band yields the better results.**

***Keywords*— WSNs, Wireless Personal Area Networks (WPANs), IEEE 802.15.4, Traffic Received, Traffic Sent, Retransmission Attempts, End to End Delay.**

I. Introduction

WPANs are slowly becoming part and parcel of our life as they provide a variety of applications such as environment sensing, health care, manufacturing industry, transportation industry, education space and military etc. Also the growing use is due to the convenience it provides by removing the limitations of wires. Zigbee is one such WSN protocol which uses the Physical and Media Access Control (MAC) layer of IEEE standard 802.15.4.This standard was actually designed for low rate WPANs with the target of low data rate, low power consumption and low cost wireless networking which are the main requirements of WSNs. IEEE 802.15.4 WSN generally consists of tens or hundreds of simple battery powered sensor nodes which periodically transmit their sensed data to one or several data PAN Coordinators. Architecturally, it consists of four different layers: Firstly, the physical layer - which performs modulation and demodulation on outgoing and incoming signals respectively; Secondly, the MAC layer - to access the network by using CSMA/CA technique in order to provide reliable transmission; Thirdly, the network layer - which initializes the WPAN and handles routing. Fourthly, the application layer which interacts with the user.

The WPANs are affected by parameters such as the frequency band used, the packet size used and these factors impact the traffic received, performance, efficiency, end to end delay, battery energy consumption etc. So it needs to be focused upon that what are main requirement of the network and thus accordingly decide the parameters which affect these requirements.

The main aim of this paper is to study and observe the impact of the change in frequency band on various key parameters, which directly affect the network performance, such as throughput, end to end delay, traffic received, traffic sent, retransmission attempts, number of hops, packets dropped, delay, load per PAN, data dropped etc. It is achieved by simulation and then analyzing the observations.

II. Simulation Structure

In order to carry out this research, an OPNET simulation model for the Zigbee has been used as a means to compare experimental and simulation results, for three identical scenarios which differ only in the frequency band used. The simulation tool used OPNET, provides a comprehensive development environment to support modeling of communication networks and distributed systems. OPNET is a general-purpose application level network simulator. It uses a hierarchical model to define each aspect of the system. The top level consists of the network model, where topology is designed. The next level is the node level, where data flow models are defined. A third level is the process editor, which handles control flow models. Finally, a parameter editor is included to support the three higher levels. The simulator aids users in developing the various models through a graphical interface. The interface can also be used to model, graph, and animate the resulting output. These simulations show the behaviour of the system based on its simulation model under three different frequency bands. This version of simulation supports cluster topology, where communication takes place between a central controller – PAN coordinator, routers and devices.

III. Scenarios

The basic setup for all three scenarios is the same as only one ZigBee Coordinator (ZC) in each topology, four ZigBee routers (ZR) and twenty ZigBee End devices (ZED). All ZR’s and ZED’s are immobile. PAN Coordinator is a Fully Functional Device (FFD) which manages the functioning of the whole network. It is the root of the network tree and bridges other networks. It sets up the parameters for establishing a network. It stores information about the network, e.g. radio-channel, repository for security keys, etc. Then there are routers which act as an intermediate device, passing data from other devices. The main purpose of the routers is to extend the range of the network by acting as relays. Lastly, ZED are quite basic devices; They require very limited resources and their basic functionality is to talk to their parent node (either the coordinator or a router), they cannot relay data from other devices.

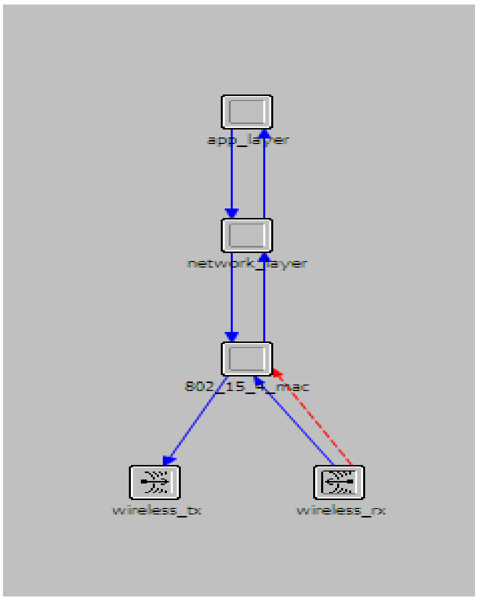

Fig. 1

Fig. 1 represents the node model for the PAN coordinator, router and the end device. Physical layer has a wireless transmitter and a receiver which conforms to the ZigBee protocol specifications operating at specified frequency as in three different scenarios. MAC layer implements CSMA/CA scheme and on top is the application layer.

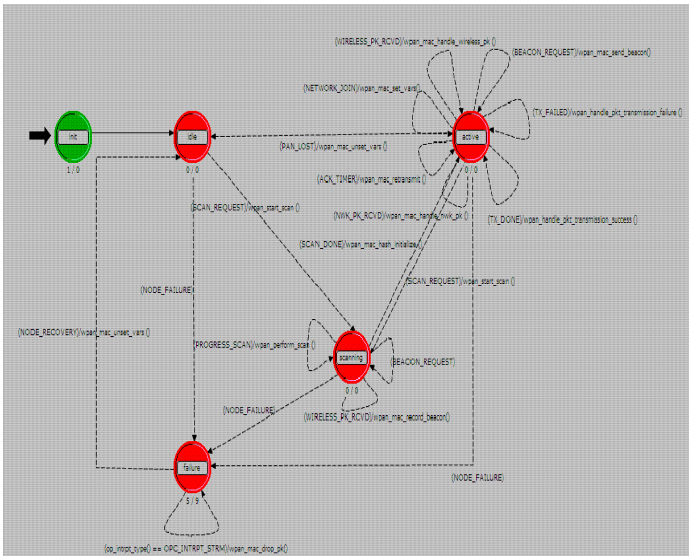

Fig. 2

Fig. 2 shows the process model for the PAN Coordinator, router and the end device. It consists of the various states: Init whose function is to initialize MAC ; Idle which is responsible for introducing delays in order to make the maximum use of the resources; active deals with the packet handling , sending beacon requests, handling packet transmission failures & successes and also setting & changing various MAC variables; Scanning is responsible for the beacon requests it receives from active stage, it also deals with scanning and sending node failure instructions to the failure stage of the process model which further deals with the node failure and recovery.

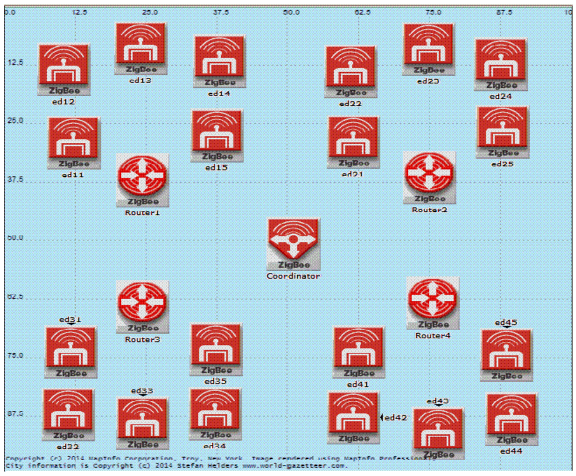

Fig. 3(a)

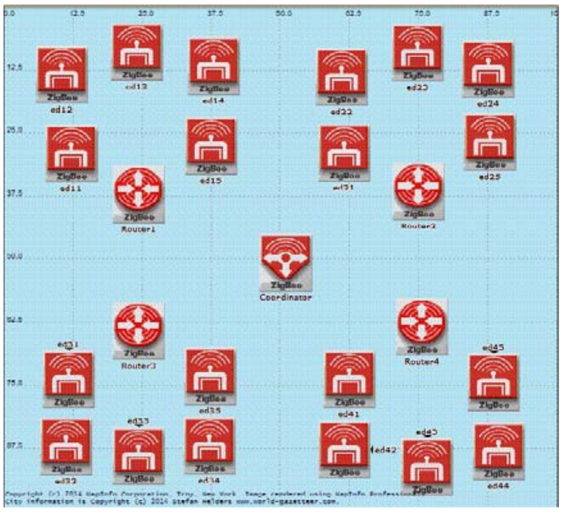

Fig. 3(b)

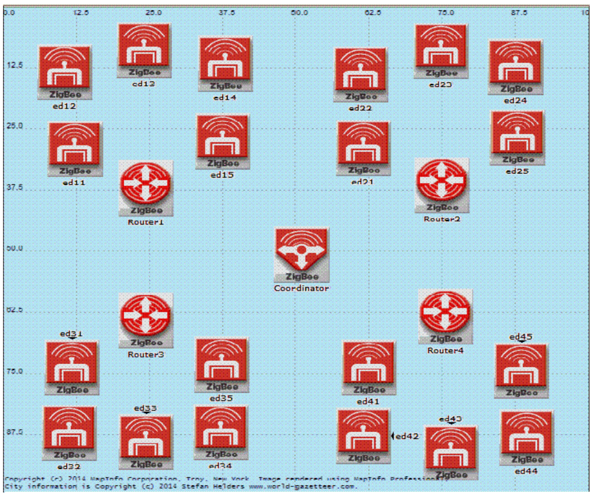

Fig. 3(c)

In Scenario 1: all the devices operate at 2.4GHz frequency band and the scenario is shown in Fig. 3(a). Similarly Scenario 2: operates at 915MHz frequency band for the devices and is shown in Fig. 3(b). Lastly, Scenario 3 operates at 868MHz frequency band as shown in Fig. 3 (c).

IV. Results And Discussions

A. Control Traffic Received and Sent

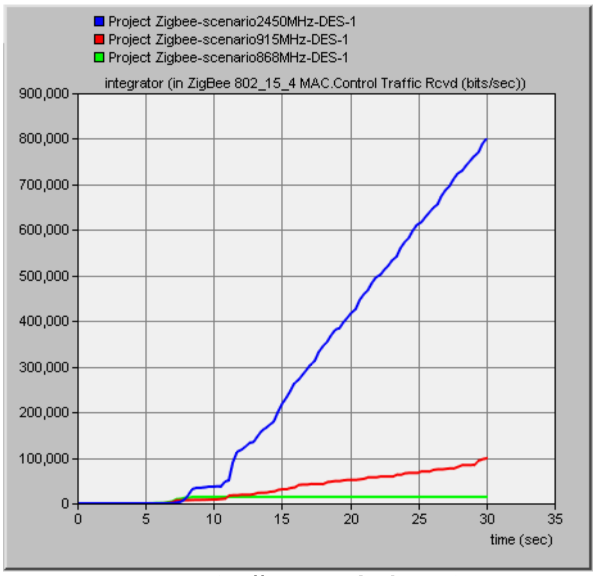

Fig. 4 (Traffic Received in bits/sec)

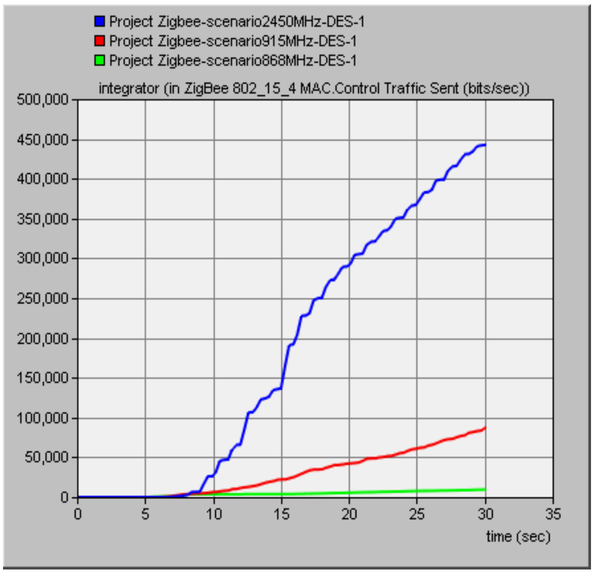

Fig. 5 (Traffic Sent in bits/sec)

Fig. 4 and Fig. 5 depicts that the Traffic Received is: 7744.0, 7040.0, 12056.00 bits/sec for 2.4GHz, 915MHz, 868MHz respectively. And the traffic sent is 442463.99, 87032.00, 9504.00 bits/sec for 2.4 GHz, 915 MHz, 868 MHz respectively. It is observed that traffic received and sent is maximum in case of 2.4 GHz frequency band and least in case of 868MHz frequency band because IEEE 802.15.4 makes use of the spread spectrum techniques which lowers the interference. There are 16 channels corresponding to the 2.4 GHz and each is 2 MHz wide and 5 MHz apart and 10 for the 915MHz which are 2 MHz apart and 1 for 868 MHz. Since the number of channels are maximum in case of 2.4 GHz therefore the traffic received and sent is maximum and also there is lesser collision in 5Mhz apart channels of 2.4GHz band as compared to others which increases the number of bits received and sent per sec.

Also when a device plans to transmit a message, it first goes into receive mode to detect and approximate the signal strength in the desired channel and energy of a wave is:

Energy=planks_constant*frequency (1)

(1) implies that energy is directly proportional to frequency , so higher the frequency ,higher is the energy ,more easily it is detected and more is the number of bits transmitted/received per second. Moreover, the packets with a power less than a threshold value are not decoded by the receiver and are treated as noise. These packets can cause interference and bit errors if they collide with valid packets at the receiver. Packets with a received power higher than the threshold are treated as valid packets and are decoded by the receiver unless they get bit errors from interference, background noise or collisions with valid packets. To ensure a packet's received power is above this threshold, its transmission power must be large enough to accommodate for the path loss between the transmitter and receiver. Path Loss (PL) is:

PL = 20 log(4*Pi*d/ λ) (2)

Where: d is the distance between transmitter and receiver¸ **λ** is the wavelength of the signal.

We also have: **λ=c/f;** (3)

Where c is speed of light and f is frequency of signal.
The received signal power at distance d:

Pr= Ae Gt Pt/4*Pi*d*d (4)

where Pt is transmitting power, Ae is effective area, and Gt is the transmitting antenna gain assuming that radiated power is uniformly distributed over the surface of the sphere.
Gr is given by:

Gr= 4 * Pi *Ae / λ* λ (5)

Using (5) equation (4) becomes:

Pr= Pt * Gr * Gt / (4 * Pi * d / λ)^2 (6)

(2) & (3) implies that path loss is directly proportional to frequency. So, higher frequency means higher path loss. (3) & (6) implies that the transmitted power is directly proportional to square of the frequency i.e. higher the frequency more shall be the transmitted power. From (2 - 3) & (6), it is concluded that frequency has more rapid effect on transmitted power, So this means that higher frequency signals can accommodate path loss effectively on account of higher transmitting power and hence the number of packets received and sent are maximum in case of 2.4 GHz frequency range.

B. Retransmission Attempts

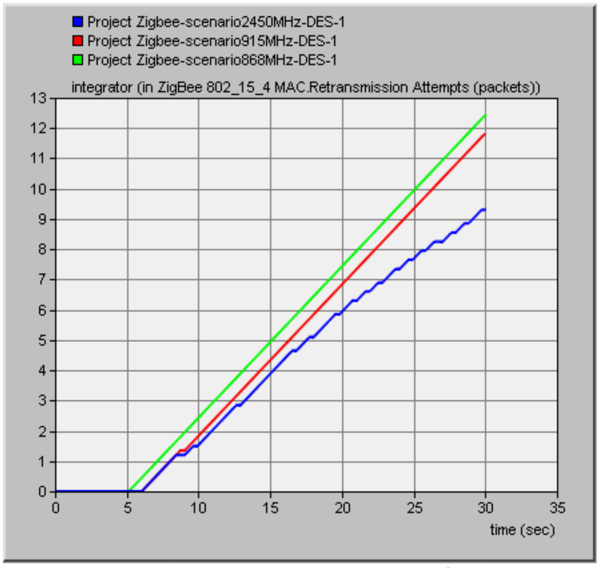

Fig. 6 (Retransmission Attempts in packets)

Fig. 6 shows that the Retransmission attempts (packets) observed are 9.3, 11.85, 12.45 packets for 2.4 GHz, 915 MHz, 868 MHz respectively. It is observed that retransmission attempts observed are maximum in case of 868 MHz and least in case of 2.4 GHz because if the packet is not transmitted successfully due to some error the MAC retries to transmit is again according to the following relation:

Retransmission attempts α 1/(1- Pe) (7)

Where Pe is the packet error rate which depends upon: transmission channel noise, interference, distortion, bit synchronization, attenuation, wireless multipath fading etc. These factors contribute to higher Pe in case of 868 MHz, for instance there is higher attenuation in this case due to higher number of collisions and thus leads to highest number of retransmission attempts in case of 868 MHz. So (7) proves that if higher is the packet error rate more shall be the retransmission attempts.

C. End to End Delay

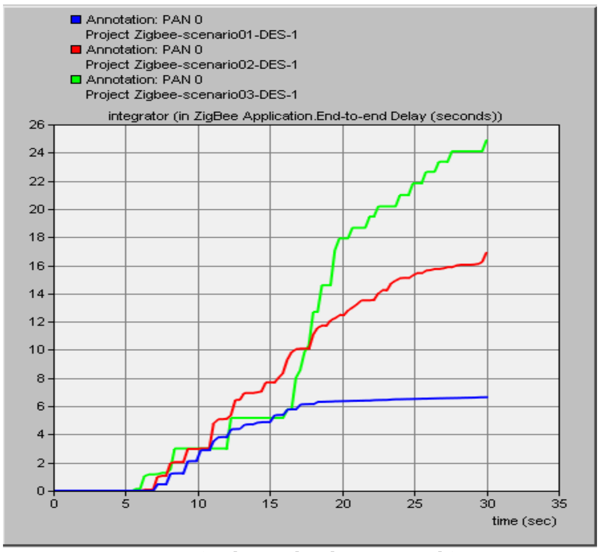

Fig. 7 (End to End Delay in seconds)

In Fig. 7 End to End delay in seconds is: 6.63, 16.95, 24.90 seconds for 2.4 GHz, 915 MHz, 868 MHz respectively. It is observed that end to end delay observed is maximum in case of 868 MHz and least in case of 2.4 GHz because the end to end delay is given by:

$$\mathbf{d_{end\text{-}end} = N[\, d_{trans} + d_{prop} + d_{proc}]} \qquad (8)$$

where:
$d_{end\text{-}end}$ = end-to-end delay
d_{trans}= transmission delay
d_{prop}= propagation delay
d_{proc}= processing delay
N= number of links (Number of routers + 1)

The N is fixed, considering other three factors d_{trans}, d_{prop}, d_{proc}. It is observed that d_{proc} is same for all the three cases as it accounts for the delay that occurs due to the routers, Secondly the d_{prop} delay which is calculated as the distance between the sender and receiver divided by the speed of propagation, Since the distance and speed is same in all three cases so it does not account for the differences in $d_{end\text{-}end}$ observed in the graph. Lastly we have the d_{trans} which depends on the data rate of the link which further depends on the frequency band chosen. Since the 915MHz and 868 MHz ISM bands are very narrow as compared to 2.4 GHz and this limits the maximum data rates which leads to more d_{trans} and hence more $d_{end\text{-}end}$ (end to end delay).

D. Number of Hops

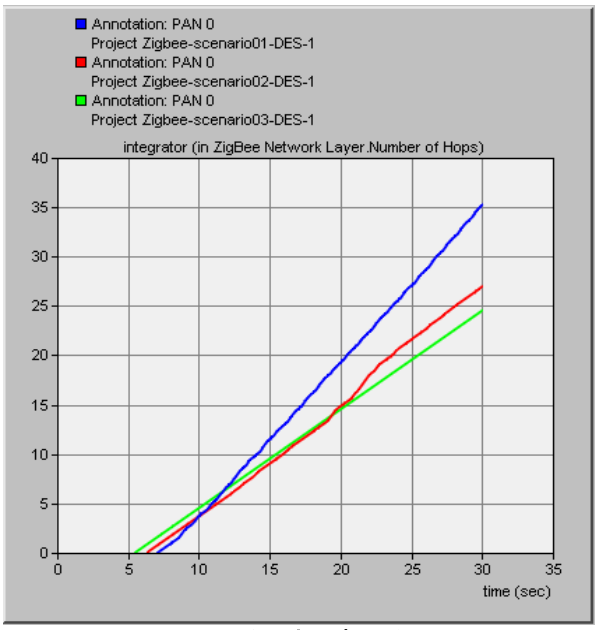

Fig. 8 (Number of Hops)

Fig. 8 shows that the Number of hops observed are: 35.28, 26.99, 24.563 for 2.4GHz, 915 MHz, 868 MHz respectively. It is observed that number of hops are maximum in case of 2.4 GHz and least in case of 868 MHz because using higher data rates as is the case of 2.4Ghz decreases the air time of a packet, which in turn decreases the power consumption. But the higher data rates generally have a shorter maximum transmission distance, and thus may increase the hop count for data transmission. Also, the hop count between the source and destination is usually a function of the transmission power at each node. Additionally, higher transmission power at each node can be used to reach nodes farther away, thereby reducing the hop count from the source to the destination but this reduces the data rate. So, the 868 MHz uses higher transmission power and has lesser data rate and thus has the least number of hops and vice versa for the 2.4GHz case. Also, more the number of hops more will be the delay. So, even if the hop count of the path is low, the total delay experienced by the message might be large due to the channel access delays i.e. lesser number of hops do not correspond to smaller end to end delay. Channel access delays are usually functions of load on each node, the node density or the number of nodes in the network and the transmission power. Conclusively, the hop count is maximum in case of 2.4 GHz because of the higher data rate which reduces the maximum transmission distance and thus the hop count, but the delay added due to more hops is not very significantly dependent on hop count.

V. CONCLUSIONS

Three different scenarios identical in all respects except the frequency band of 868 MHz, 915 MHz and 2.4 GHz were used for simulation. The results were analyzed and it was observed that the frequency band affects the network performance considerably. It was observed that for lesser end to end delay and for more number of hops, the higher frequency bands should be preferred. But if the focus is on the traffic received/sent and the retransmission attempts, then the lower frequency bands should be considered as far as the IEEE 802.15.4 WSNs are concerned. So, it can be concluded that frequency band should be chosen depending upon the parameter under focus.

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