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Performance Evaluation of IEEE 802.15.4 PHY based Sensor Networks with MCTA

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Abstract: IEEE 802.15.4 is the standard that is specially developed for low cost, low data rate and low power consumption wireless network. IEEE 802.15.4 is a standard which specifies the physical layer and media access control for low-rate wireless personal area networks (LR-WPANs). This paper provides a description of the performance evolution of IEEE 802.15.4 PHY based sensor network with multi capacity transmitter algorithm. In this paper, we want to work to improve the efficiency and performance of data transmitter. Presently IEEE 802.15.4 standard based device works with single transmitter that transmits and receives data in one to one manner. In proposed device, all three transmitters are kept in many to many transmission manners but transmit and receive data in one to one manner and automatically switch from first transmitter to second and second to third and so on as required. Existing transceiver device can be failed some time due to data load and power failure. To overcome this problem, we propose multiplicative capacity transmitter device. In this mechanism, we propose three transmitters in a single device and all the three transmitter have double and triple capacity to sense and transfer data to work in proper manner from previous one. If first transmitter is not working properly then second transmitter, which is having double capacity from its previous one, will be automatically active and will work smoothly. This is specially designed for future purpose in which transmitter failure problem can be occur.

Keywords: Transmitter Device, LR-WPAN, Physical layer, MAC layer, data rate, IEEE standard, Sensor network, Transmission, wireless network.

1. Introduction:

In present scenario we are seeing many of IEEE 802.15.4 standard based application around of us. All the applications are designed with the single transceiver device that transmit and receive data. A promising wireless sensor network (WSN) helps to facilitate efficient communications .Such type of devices can be fail down sometimes when data transmission load is increased. To overcome from this situation we want to improve such devices with the help of multiplicative capacity transceiver that provides a mechanism in which transceiver will be activated as per network requirement.

A. An Overview on Zigbee

The IEEE 802.15.4 Standard introduced zigbee network, is intended for Low Rate Wireless Personal Area Network (LR-WPAN) which defines low-power, low-cost and short-range wireless networking. ZigBee has spread spectrum techniques in the 2.4 GHz band, which is unlicensed in most countries and known as the industrial, scientific, and medical (ISM) band. ZigBee uses direct sequence spread spectrum (DSSS) with 16 channels and 2 MHz bandwidth at physical layer. Operational frequency bands are: 868 MHz, 915 MHz and 2.4 GHz with supported data rate of 20 kbps, 40 kbps and 250 kbps respectively. The 2.4 GHz frequency band has the most potential for large-scale WBAN applications, because of its high radio data rate reduces frame transmission time. The protocol supports star; tree and mesh topologies. In star topology, all devices communicate directly with the coordinator. Tree and mesh topologies allow to increase the range of the network by introducing routers that relay the traffic from the end devices (EDs).

B. WPAN

Wireless Personal Area Networks (WPAN) is having radio devices with low data rate, low power, short communication range and low cost. WPAN performs exchange of information over the short distances. Connection in WPAN involves little or no infrastructure that offers a reliable data transfer and reasonable battery life [1][2][3][4].

C. IEEE 802.15.4 Model

IEEE 802.15.4 standard is specially designed for Low Rate WPAN (LR-WPN) that enables the Wireless Sensor Network (WSN). It gives low data rate, low power and low cost wireless networking communication [11]. A ZigBee protocol stack is based on PHY and MAC layers of IEEE 802.15.4 defines the upper-layer (network and application layers) specifications [6]. A Zigbee network supports star, mesh and cluster-tree network. This network comprises of Full Function Device (FFD) and Reduce Function Device (RFD). Some of the applications of IEEE 802.15.4 devices are industrial control, environmental and health monitoring, home automation, entertainment, security, and disaster response [5][7][8].

IEEE 802.15.4 defines three data transfer models: 1) data transmission to a coordinator, 2) data transmission from a coordinator, and 3) data transmission between peers. The first two models are for star networks and the last one is for peer-to-peer networks. In the following, we introduce these three data transfer models[9].

1. *Data transmission to a coordinator*: In a beacon-enabled network, devices that have data to send use the slotted CSMA/CA mechanism to contend for channels after receiving beacons. In a non-beacon-enabled network, devices contend for channels using the unslotted CSMA/CA mechanism. In both kinds of networks, after successfully obtaining a channel, a device can send data to its coordinator directly. A coordinator that receives a data frame from a device may reply an acknowledgement (optional). Fig. X.4 shows the procedures of data transfer to a coordinator.

2. *Data transmission from a coordinator*: Data transmission from a coordinator is based on requests from devices. In a beacon-enabled network, a coordinator should notify devices that it has buffered packets by its beacons, instead of directly sending data frames to devices. A device that receives a beacon first checks whether its ID appears in the *pending data fields* in the beacon. If so, this device sends a data request command to the coordinator. The coordinator, after receiving the data request, will reply an acknowledgement and forward the data frame to that device. On the other hand, in a non-beacon-enabled network, a device should periodically send data request frames to query the coordinator if there are buffered packets for itself. The coordinator, on receipt of a data request frame, should check if there are frames for the sender. If so, the coordinator will reply an acknowledgement and then send a data frame to the corresponding device. The procedures of data transmission from a coordinator are shown in Fig. 1.2

3. *Data transmission between peers*: In a beacon-enabled network, peers cannot send data to each other directly. However, peers can directly transmit data to each other in a non-beacon-enabled network. The unslotted CSMA/CA mechanism is used to contend for channels.

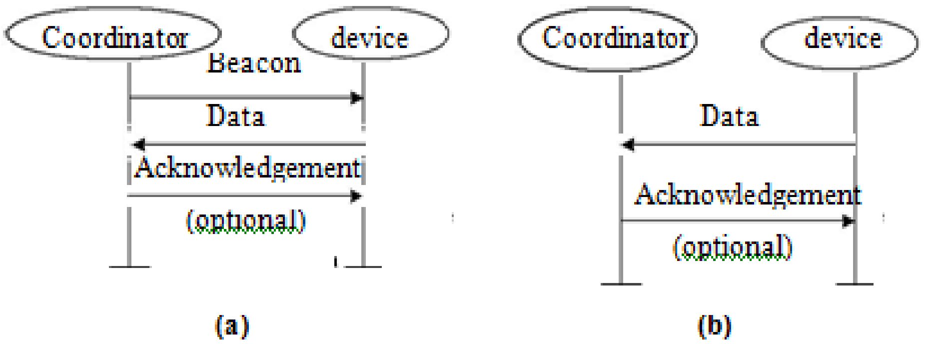

Fig. 1.1 (a) Data transmission to a coordinator in a beacon-enabled network.
(b) Data transmission to a coordinator in a non-beacon-enable network.

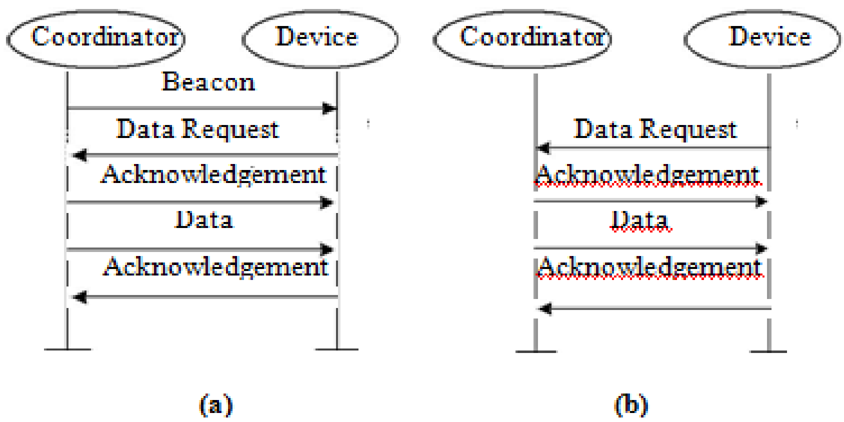

Fig. 1.2 (a) Data transmission from a coordinator in a beacon-enabled network.
(b) Data transmission from a coordinator in a non-beacon-enable network.

D. ***Protocol architecture:***

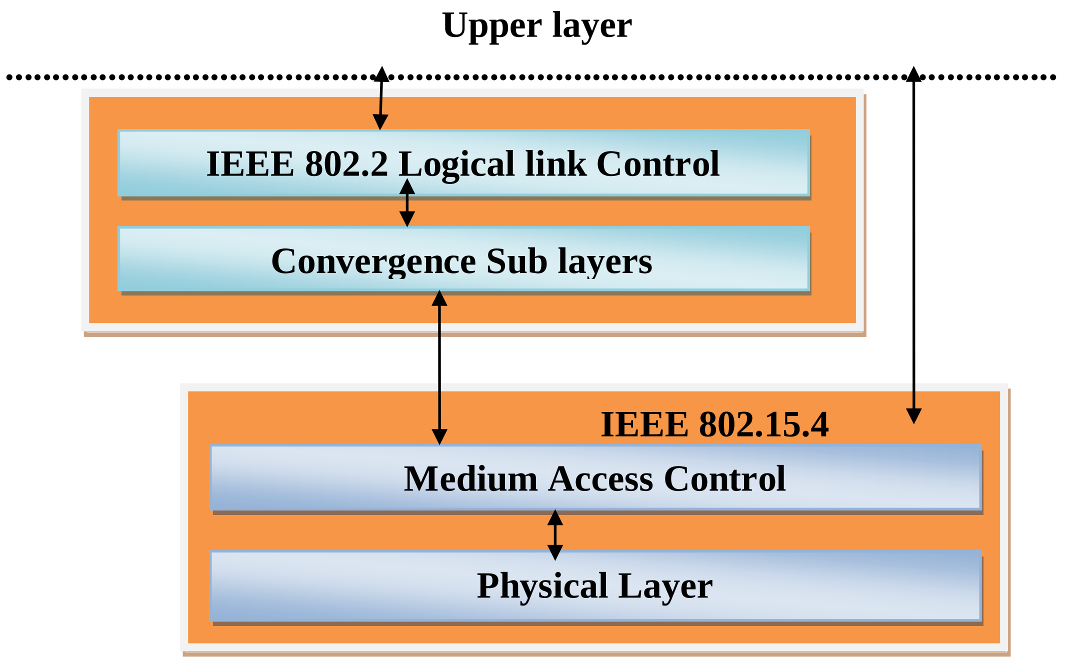

Figure 1.3 IEEE 802.15.4 Protocol Stack

Devices are conceived to interact with each other over a conceptually simple wireless network. The definition of the network layers is based on the OSI model; although only the lower layers are defined in the standard, interaction with upper layers is intended, possibly using an IEEE 802.2logical link control sub layer accessing the MAC through a convergence sub layer. Implementations may rely on external devices or be purely embedded, self-functioning devices.

2. IEEE 802.15.4 Basics

The physical layer and data link layer protocols for low-rate wireless personal area networks (LR-WPAN) is specified by IEEE 802.15.4, which emphasize on simple, low-cost applications. In such networks, devices normally have less communication capabilities and limited power, but are expected to operate for a longer period of time. As a result, 3 energy-saving is a critical design issue., There are two basic types of network topologies in IEEE 802.15.4, the star topology and the peer-to-peer topology. Devices in a LR-WPAN and can be classified as full function devices (FFDs) and reduced function devices (RFDs). One device is used and designated as the PAN coordinator, which is responsible for maintaining the network and managing other devices.

A FFD has the capability of becoming a PAN coordinator or associating with an existing PAN coordinator. A sending or receiving data is performed by RFD from a PAN coordinator that it associates with. Each device in IEEE 802.15.4 has a unique 64-bit long address. After associating to a coordinator, a device will be assigned a 16-bit short address. Then packet exchanges between the coordinator and devices will use short addresses. In the following, the IEEE 802.15.4 physical layer and data link layer protocols are introduced.

2.1 Physical Layer (PHY):

There are three operating frequency bands in IEEE 802.15.4 PHY with 27 radio channels. These bands are 868 MHz, 915 MHz, and 2.4 GHz. The channel arrangement is shown in Fig.2.1. In frequency 868.0~868.6 MHz has Channel 0 , which provides a data rate of 20 kbps. Channels 1 to 10 work in frequency 902.0~928.0 MHz and each channel provides a data rate of 40 kbps. Channels 11~26 work in frequency 2.4~2.4835 GHz and each channel provides a data rate of 250 kbps. Fig. 2.1 shows arrangement of channels in IEEE 802.15.4. The binary phase shift keying (BPSK) is used by Channels 0 to 10 as their modulation scheme, and channels 11 to 26 use the offset quadrature phase shift keying (O-QPSK) as their modulation scheme. The required receiver sensitivity should be larger than -92 dBm for channels 0 to 10, and larger than -85 dBm for channels 11 to 26. The transmit power should be at least -3 dBm (0.5 mW). The transmission radius may range from 10 meters to 75 meters. Targeting at low-rate communication systems, in IEEE 802.15.4, the payload length of a PHY packet is limited to 127 bytes.

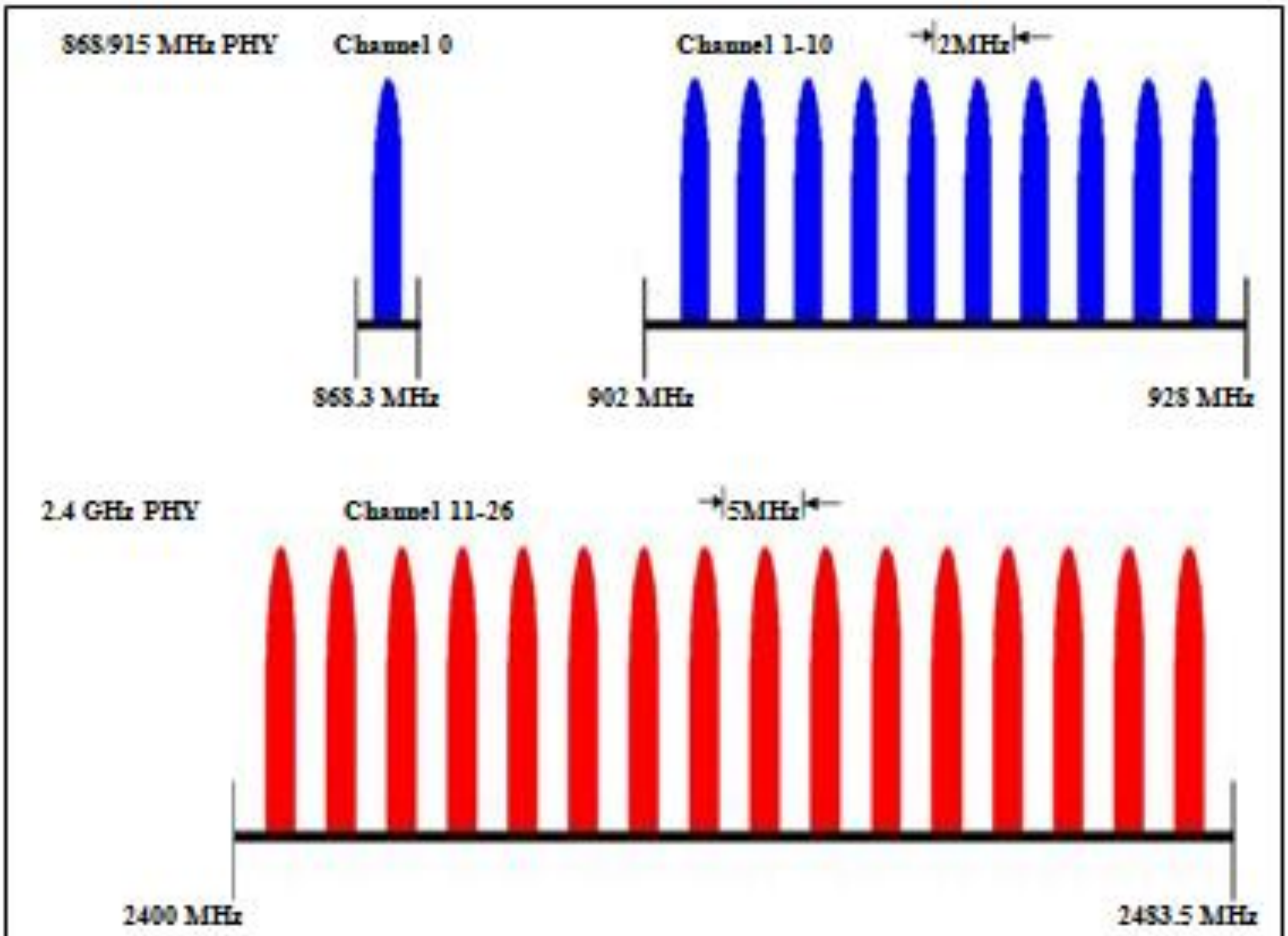

Fig. 2.1. Arrangement of channels in IEEE 802.15.4.

2.2 Data Link Layer:

In all IEEE 802 specifications, the data link layer is divided into two sub layers: logical link control (LLC) sub layer and medium access control (MAC) sub layer. The LLC sub layer in IEEE 802.15.4 follows the IEEE 802.2 standard. The MAC sub layer manages super frames, controls channel access, validates frames, and sends acknowledgements. The IEEE 802.15.4 MAC sub layer also supports low power operations and security mechanisms. In the following subsections, we introduce the MAC layer protocols in IEEE 802.15.4. The MAC layer defines two different operation modes: a non-beacon-enabled mode, which uses

an unslotted CSMA-CA (Carrier Sense Multiple Access - Collision Avoidance) algorithm, and a beacon-enabled mode, which defines a superframe structure and uses a slotted CSMA-CA algorithm. The MAC layer provides also an optional guaranteed time slot (GTS) scheme, which allows the allocation of dedicated bandwidth for devices; however, this scheme is limited to a maximum of seven GTS allocations[10].

3. Old Approach for IEEE 802.15.4

Presently we are using many of the applications based on the IEEE 802.15.4 standard. The working can be understood with the help of following example.

<u>Zigbee SIM Card:</u>

Information Delivery: Mobile phones equipped with a ZigBee SIM card may receive a variety of information provided by network operators including:

- Weather
- Public safety
- Traffic status
- Other municipal notice
- Advertisements
- Sports News
- Stock Market
- Indoor location

<u>Mobile Payment:</u> Mobile phones equipped with ZigBee SIM card be used to pay for services, with the charges authenticated by the network operator, in a variety of areas including:

- Shops
- Restaurants
- Parking
- Movie theaters
- Toll stations
- Doctor offices

Location Based Services: Devices equipped with a ZigBee SIM card can calculate distances and determine location in an indoor setting without using GPS. This helps people find their way in new areas like airports or malls, plus know what services are available. It also provides retailers, public transport and amusement parks with more information on areas that attract more traffic.

4. New Approach

In this new approach we proposed a new method to increase the performance of IEEE 805.15.4 standard device. In this we propose a algorithm to develop multiplicative capacity transceiver. This approach provides auto switch mechanism by which it can give high performance in data overload condition and in failure condition. In proposed device, all three transmitters are kept in many to many transmission manners but transmit and receive data in one to one manner and automatically switch from first transmitter to second and second to third and so on as required. Existing transceiver device can be failed some time due to data load and power failure. To overcome this problem, we propose multiplicative capacity transmitter device. In this mechanism, we propose three transmitters in a single device and all the three transmitter have double and triple capacity to sense and transfer data to work in proper manner from previous one. If first transmitter is not working properly then second transmitter, which is having double capacity from its previous one, will be automatically active and will work smoothly. This is specially designed for future purpose in which transmitter failure problem can be occur.

4.1 Algorithm:

MULTI CAPACITY TRANSMITTER ALGORITHM BASED ON IEEE 802.15.4

Step-1: First of all we will define the parameters necessary to create IEEE 802.15.4 standard architecture. In which we are defining sampling frequency range of signal to Noise Ratio for which we are calculating error rate then No of Bytes per symbol, Data rate, chip rate no. of transmitters, No. of frame repetitions etc.

Step-2: Start simulation for first transmitting frame.

Step-3: Now generate random data (Bit Sequence) called as PSDU (Public Service Data Unit). Defined Preamble after that set SFD (Start Frame Delimiter) Defined frame length and Reserved bit. These all parameters produce one frame.

Step-4: One Single frame in IEEE 802.15.4 standard known as (PPDU Presentation Protocol Data Unit)

Step-5: Now in this step we are performing DSSS (Direct Sequence Spread Spectrum) Which is a kind of digital modulation technique in where we spread the digital data by multiplying it with a chip sequence know as PN sequence.

Step-6: In this step the resulting bit stream from previous step divided in two parts Even & Odd that is the starting of OQPSK Modulation. After OQPSK Modulation the signal is ready to transmit.

Step-7: Now this point is the changing point where we can improve the performance of existing system by using multiple transmitters instead of one transmitter.

Step-8: After transmission signal travels through wireless channel which introduce some noise in signal which distort or create errors here the characteristics of wireless channel is considered as AWGN channel. AWGN channel is the prototype of wireless channel considering all the possible noises in the media.

Step-9: Now continue simulation for first value of SNR that is -20 dB.

Step-10: Now receive signal that is combination of transmitted signal and noise signal.

Step-11: Demodulate received signal.

Step-12: Perform dispreading of the sequence (Inverse Direct Sequence Spread Spectrum)

Step-13: Now calculate Bit error rate form received data and go to step 9 and keep repeating for all the values of SNR. This is complete simulation of one frame.

Step-14: To get the precise result repeat above steps for your convenience. Here we have simulated above proposed methodology for 25, 50, 75, 100, 125,150,175 and 200 frame repetition with one, two and three transmitter of multi capacity as 2nd transmitter has the double capacity of first transmitter and 3rd transmitter has triple capacity of 1st transmitter. Each and every transmitter works separately means that if 1st is working then 2nd and 3rd are off and so on for 2nd and 3rd transmitter.

4.2 Flow Chart:

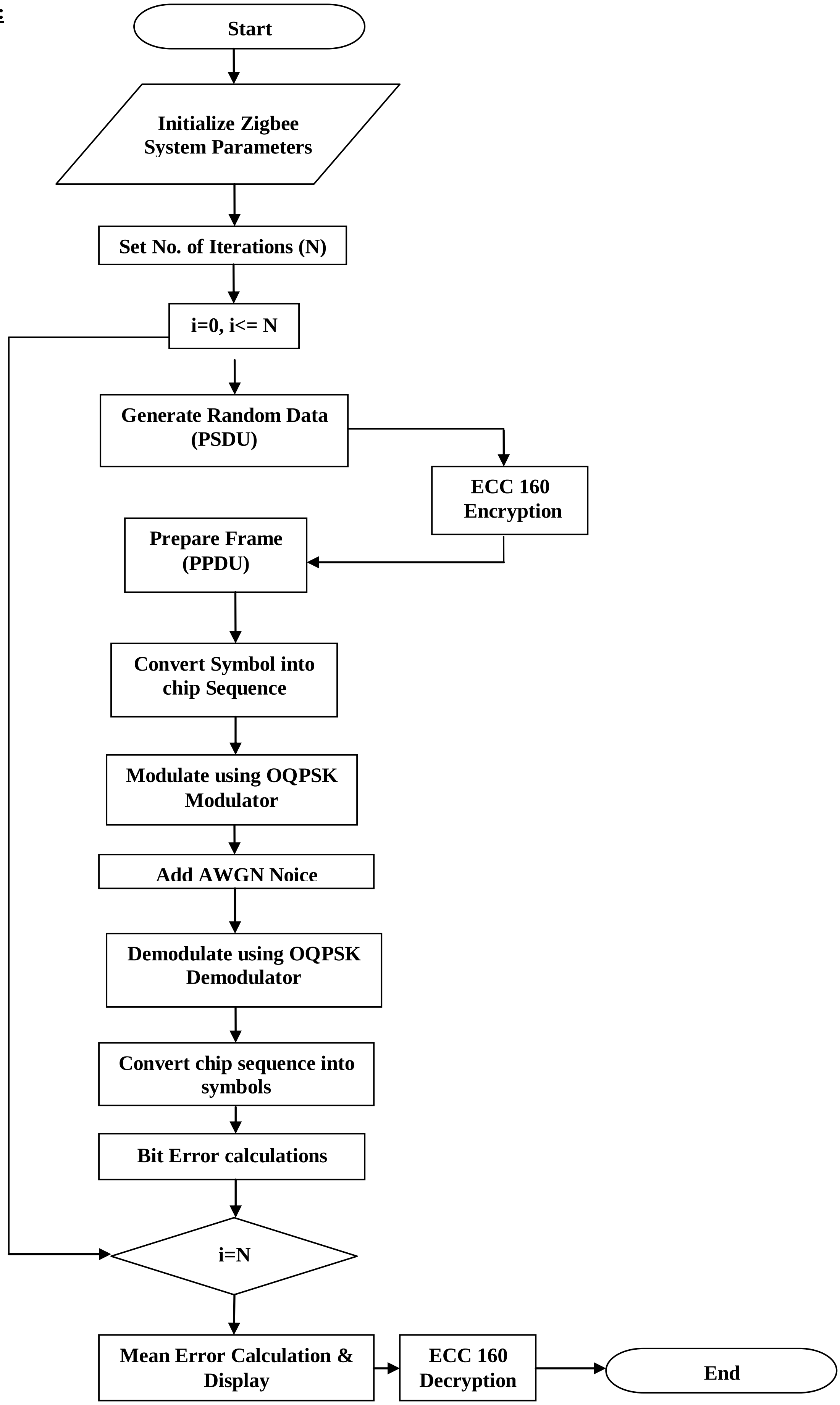

Fig: 4.2 Flow chart for Multi Capacity Transmitter Algorithm based on IEEE 802.15.4

4.3 Results

We worked on METLAB 2012 to generate result.

To get result we use 3 transmitter to improve performance of IEEE 802.15.4 physical based sensor network. We got following results when we use different iteration with 3 Tx.

i. When we use Transmitter (Tx) = 3 with iteration =5, get improvement in performance of Bit error rate(BER) in the comparison with SNR. Figure (a) shows BERvsSNR with 3 transmitter(s) and 5 iterations. When we use 3 multi capacity transmitters, no of channels is increased and bit error rate is decreased.

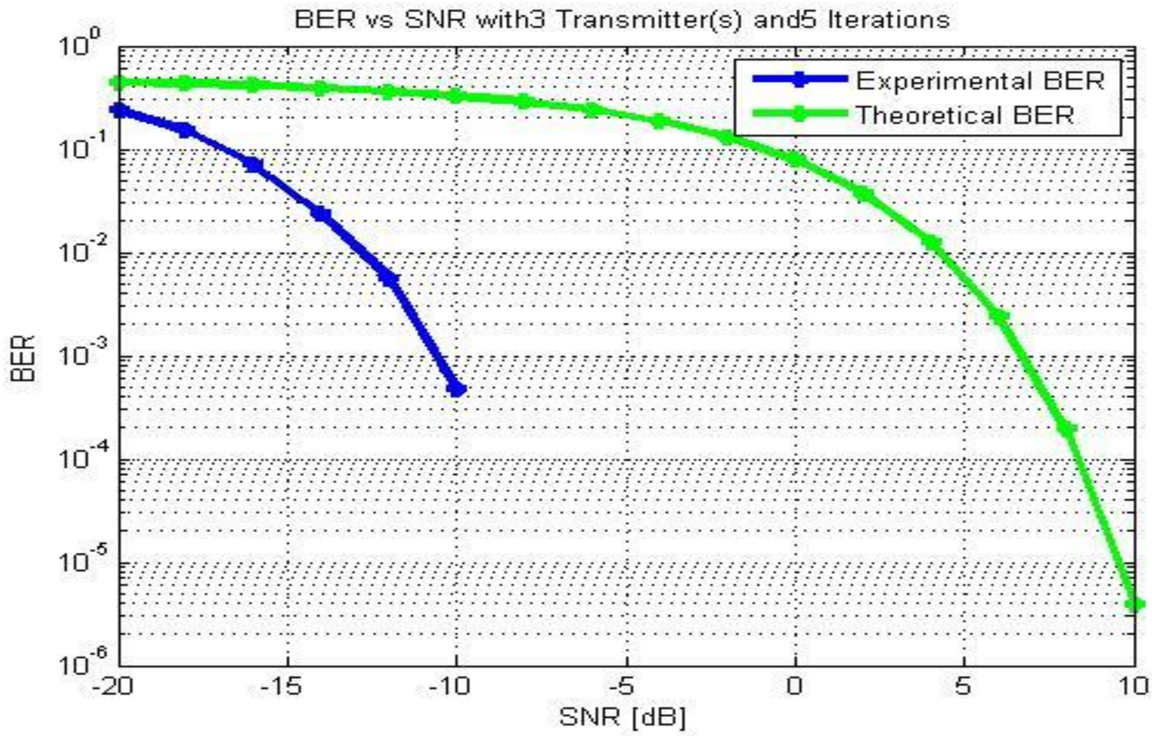

Fig.(a) BER vs SNR with 3 transmitter(s) and 5 iterations.

ii. When we use Transmitter (Tx) = 3 with iteration =10, get improvement in performance of Bit error rate(BER) in the comparison with SNR. Figure (b) shows BER vs SNR with 3 transmitter(s) and 10 iterations.

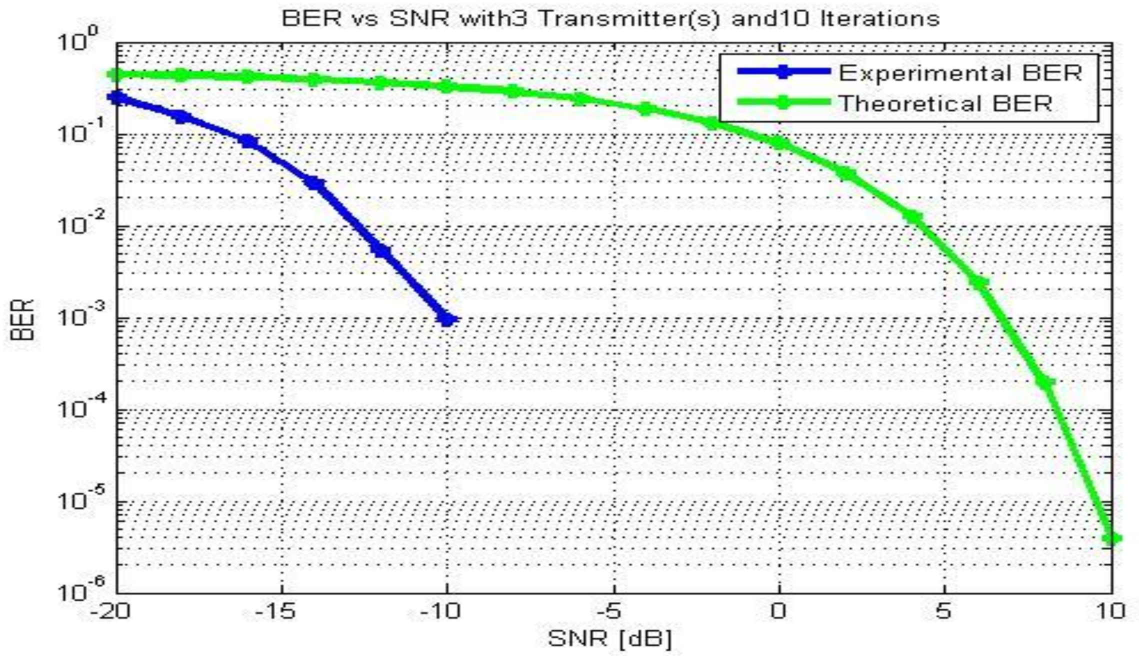

Fig.(b) BER vs SNR with 3 transmitter(s) and 10 iterations.

iii. When we use Transmitter (Tx) = 3 with iteration =15, get improvement in performance of Bit error rate(BER) in the comparison with SNR. Figure (c) shows BER vs SNR with 3 transmitter(s) and 15 iterations.

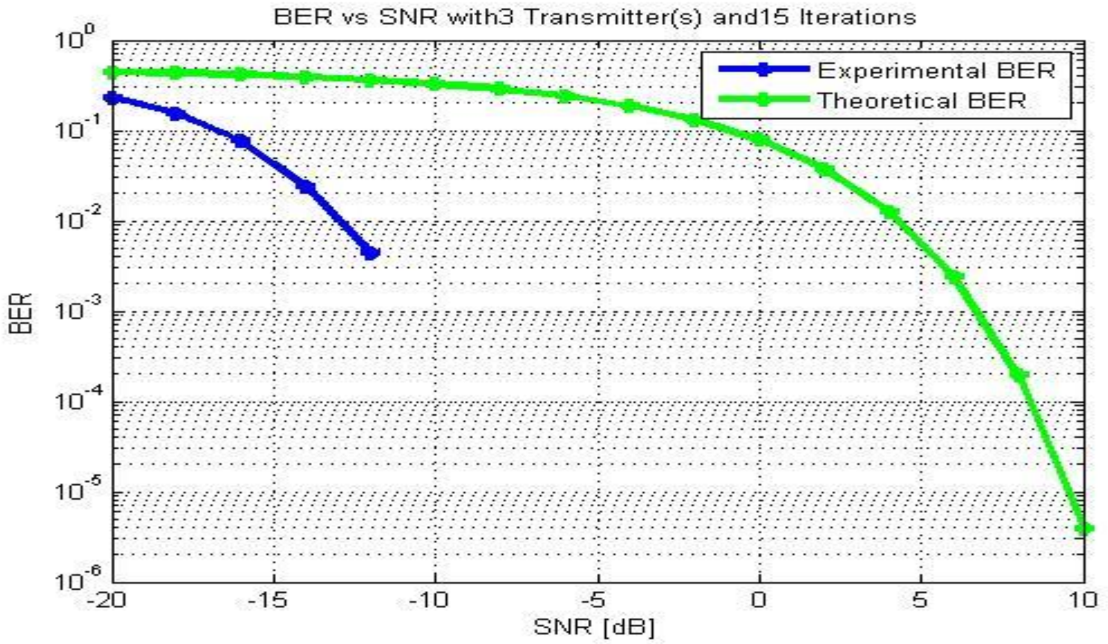

Fig.(c) BER vs SNR with 3 transmitter(s) and 15 iterations.

iv. When we use Transmitter (Tx) = 3 with iteration =20, get improvement in performance of Bit error rate(BER) in the comparison with SNR. Figure (d) shows BER vs SNR with 3 transmitter(s) and 20 iterations.

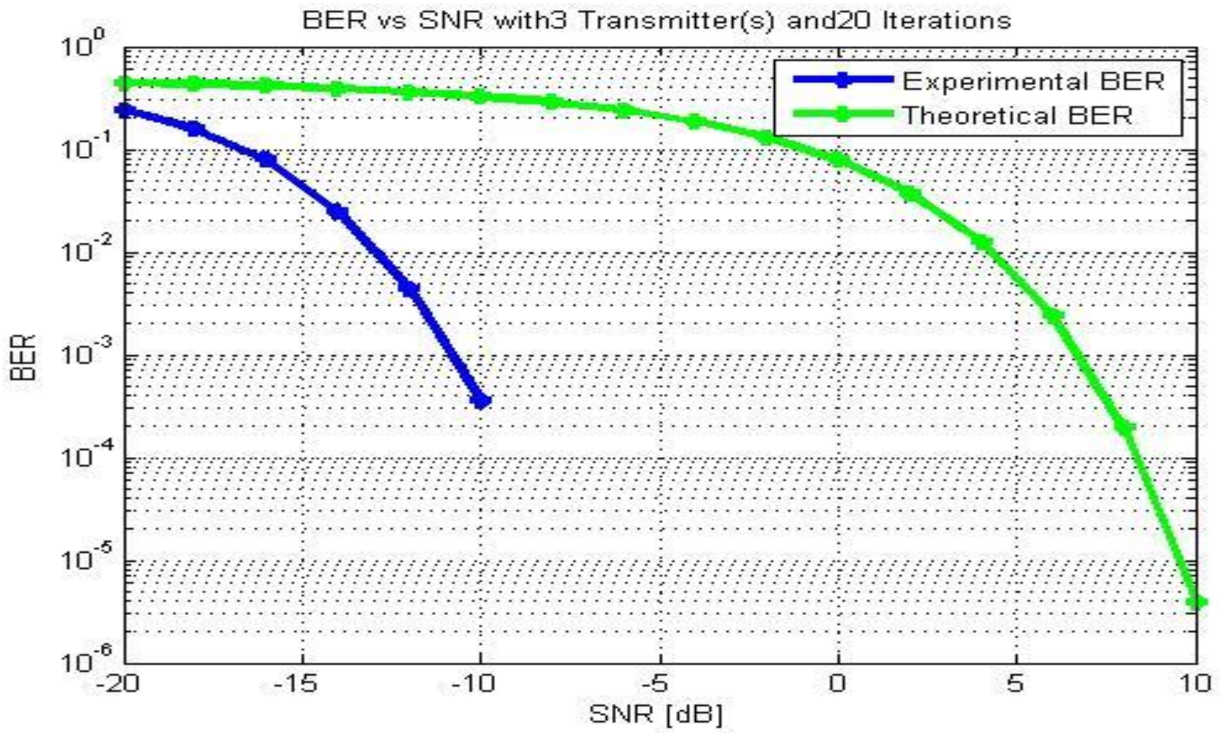

Fig.(d) BER vs SNR with 3 transmitter(s) and 20 iterations.

The Factors are:

1. Capacity of ZigBee MISO System.
2. Battery Life Compression.
3. Performance of Probability of Error with various digital modulation techniques.
4. Data Rate
5. Power Spectrum Density.

These all factors are one by one described with the graph supporting to our work of MISO and ECC 160 based ZigBee Wireless network.

1. Capacity of ZigBee MISO System.

The channel capacity is given by Shannon Capacity Theorem:

$$C = B\, log_2\left(1 + \frac{S}{N}\right)$$

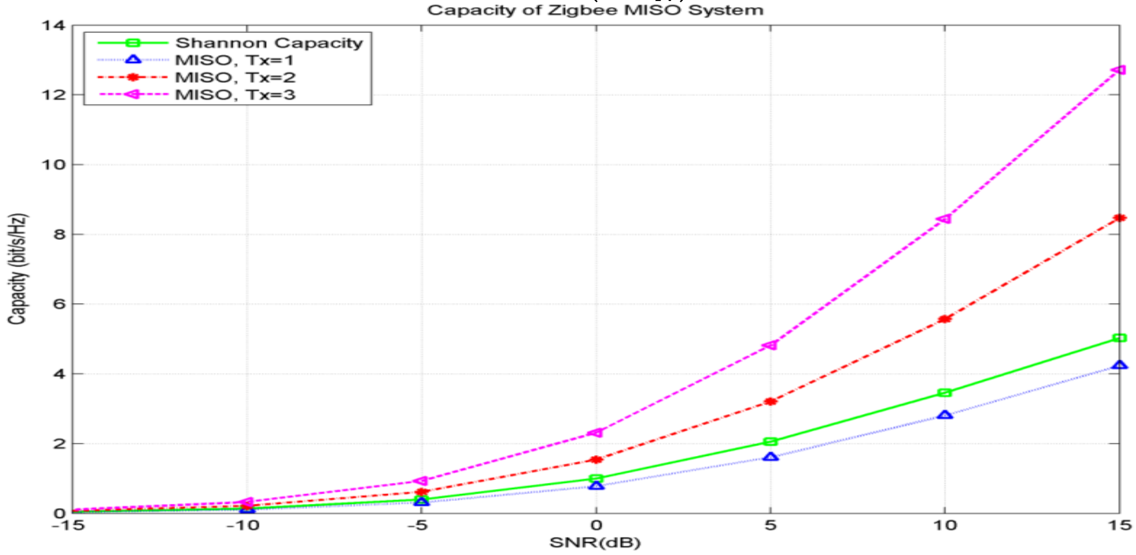

Figure 4.3 Capacities of ZigBee MISO System Vs SNR Characteristics.

As per the result we can see that on increment of the transmitter in the ZigBee Based wireless Network the channel capacity is going up according to follow with Shannon channel capacity theorem. The purple line of 3 transmitters is showing maximum capacity for the MISO system. Hence this factor support to our work that to increase the transmitter is beneficial to get higher capacity (bits/Hz).

2. Battery Life Compression

As per IEEE 802.15.4 standard specifications the battery life for the system in years which includes the sleep time of the system i.e. idle condition, figure 4.3 (a) is given below.

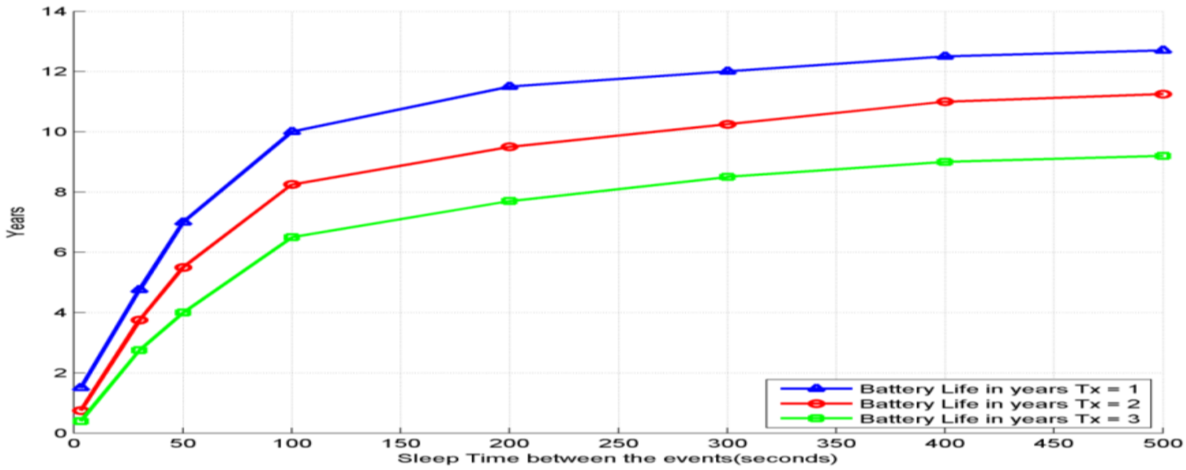

Figure 4.3 (a) Battery Life vs Sleep time for ZigBee System

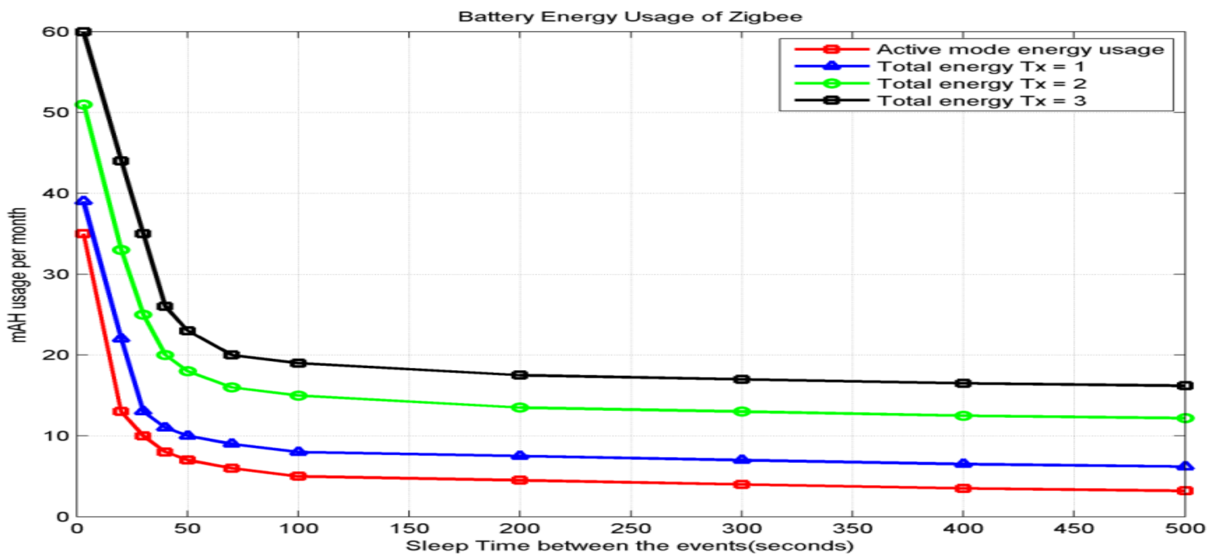

Fig. 4.3 (b) Battery mAH usage of ZigBee System.

Figure 4.3 (b) shows Energy Usage Breakdown (Battery Usage per month). This has characteristics Active Energy usage and Total Energy Usage. This characteristic helps us to analyze the battery performance in various conditions. Battery Life can vary according to the duration of data transmission and interval between active modes and sleep modes. The switching from sleep mode to active mode or active mode to sleep mode also causes battery power consumption.

3. Performance of Probability of Error with Various Digital Modulation Techniques.

The Error Probability of IEEE 802.15.4 System for existing system and multiple transmitter systems are shown in figure 4.3 (c), figure 4.3 (d) and figure 4.4 (e) for various digital modulation techniques. The error probability we have taken for the various modulation techniques BPSK, QPSK, O-QPSK , 16-PSK , 32-PSK, D-BPSK, D-QPSK. From the result of this factor we analyzed.

Digital modulation techniques give different performance with IEEE 802.15.4 device. Speed (or data rate) and distance (or range) are inversely proportional. That is, other things being equal, a higher data rate system will not transmit as far as a lower data rate system. Radio frequency (RF) signals of a given carrier frequency, such as 2.4 gigahertz (GHz), lose power as they propagate. Called path loss, this is similar to the way a sound is softer the farther it is from the source. Path loss in decibels (dB) increases with the square of the distance and is relatively easy to estimate when the path is unobstructed.

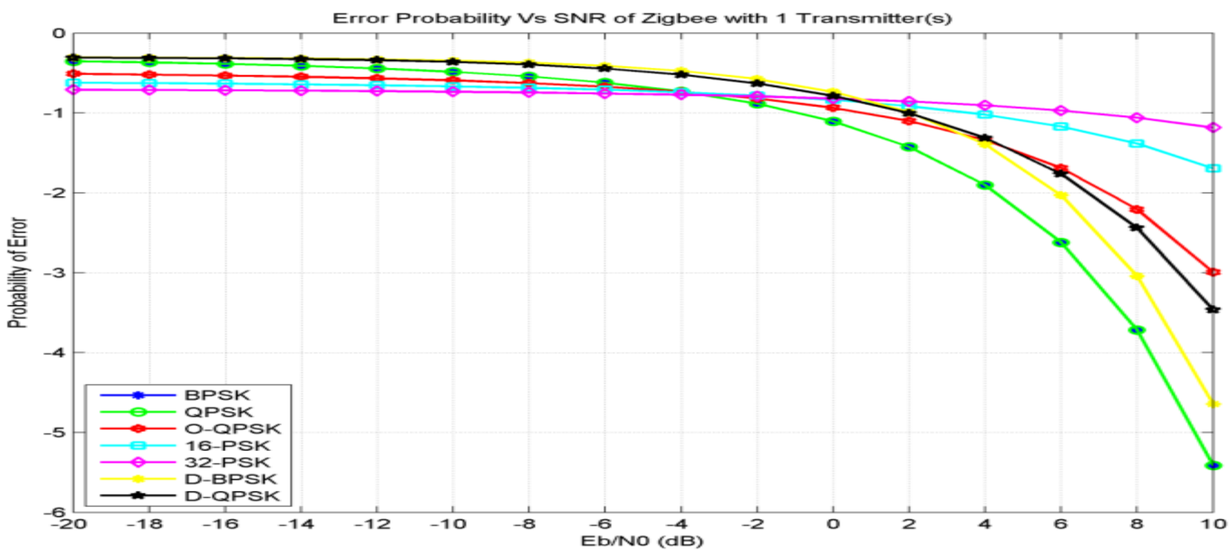

Fig.4.4 (c) Probability of Error of ZigBee System with 1 Tx and Digital Mod. Techniques

The free space loss equation at 2.4 GHz is simply this path loss in dB = 40 dB + 20 log (distance in meters)Digital modulation techniques give different performance with IEEE 802.15.4 device

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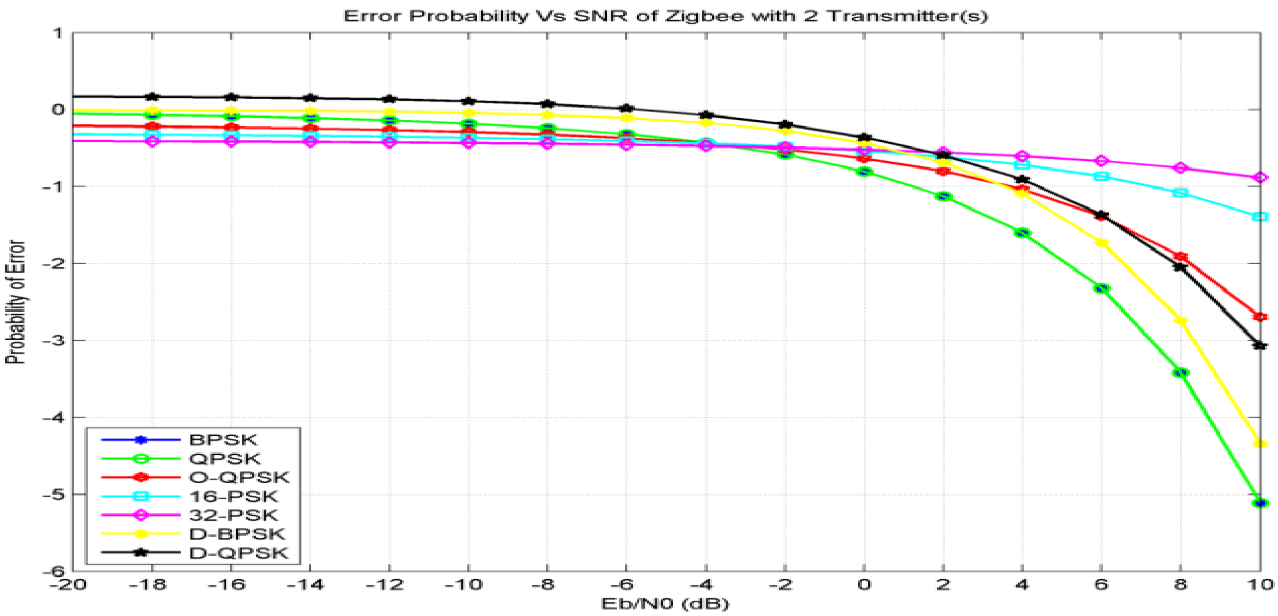

Fig4.3 (d) Probability of Error of ZigBee System with 2Tx and Digital Mod. Techniques

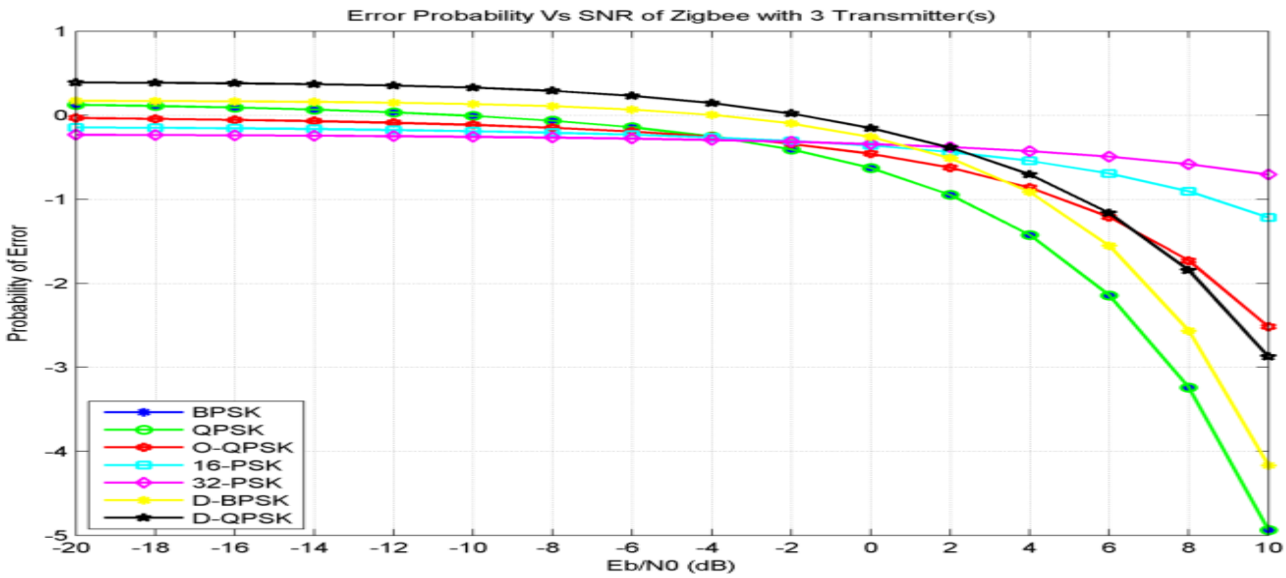

Fig.4.3 (e) Probability of Error of ZigBee System with 3Txs and Digital Mod. Techniques

4. Data Rate

The following table illustrates the impact of distance on path loss. Notice each time distance in kilo meters (km) doubles, path loss increases 6 dB (this applies only in the 2.4-GHz band).Here we have shown data rate performance for 1 transmitter (Existing System), 2 transmitters and 3 transmitters with the proposed MISO architecture & ECC 160 Encryption Based ZigBee Wireless Network. This shows that multi transmitter scheme is very effective on varying the distance. Now if we use more than one transmitter instead of one (existing system) then the performance of ZigBee (IEEE 802.15.4) system will improve.

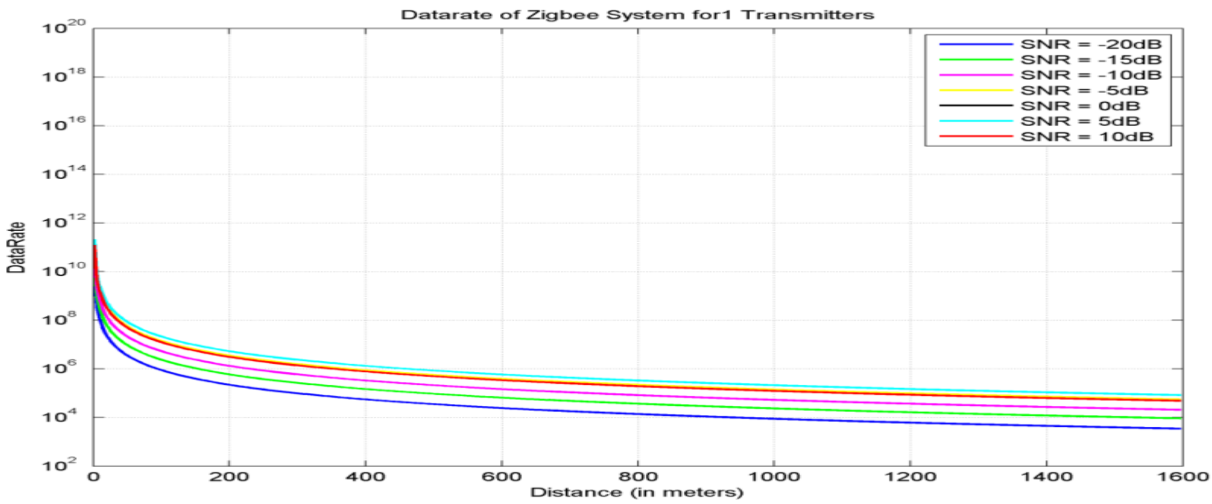

Fig.4.3 (f) Rate Vs Distance for Various Values of SNR for 1 Transmitter

Figure 4.3 (f), figure 4.4 (g) and figure 4.3 (h) showing the data rate of ZigBee for distance and for various values of Signal to Noise ratio respectively. The data rate performance increases with the increase in number of transmitters. Here we have shown data rate performance for 1 transmitter (Existing System), 2 transmitters and 3 transmitters with the proposed MISO architecture & ECC 160 Encryption Based ZigBee Wireless Network. This shows that multi transmitter scheme is very effective on varying the distance. Now if we use more than one transmitter instead of one (existing system) then the performance of ZigBee (IEEE 802.15.4) system will improve.

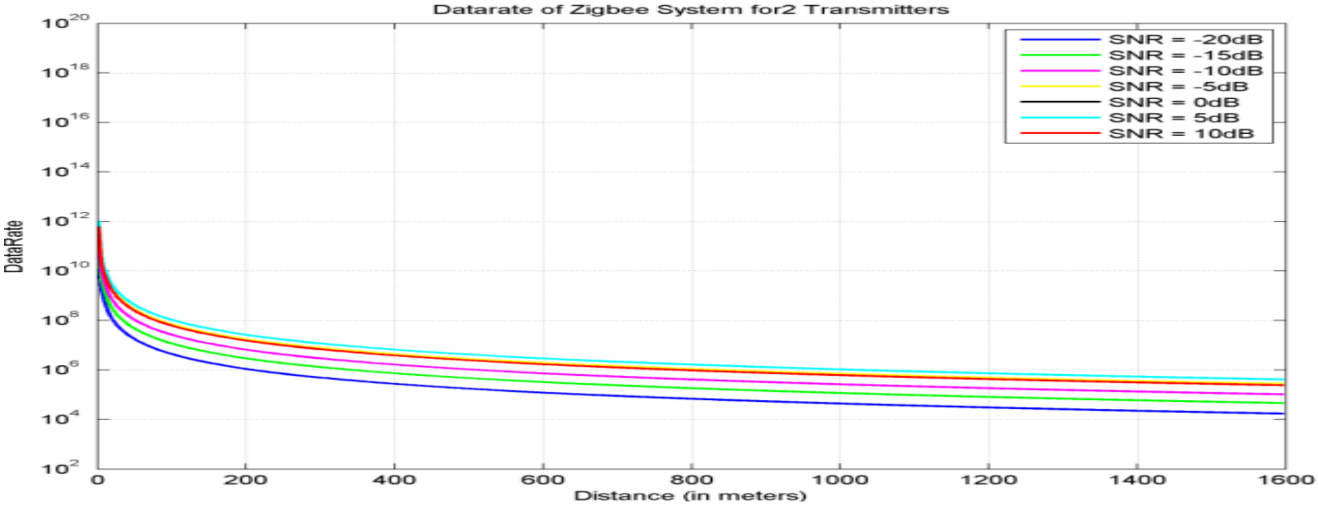

Fig.4.3 (g) Data Rate Vs Distance for Various Values of SNR for 2 Transmitters

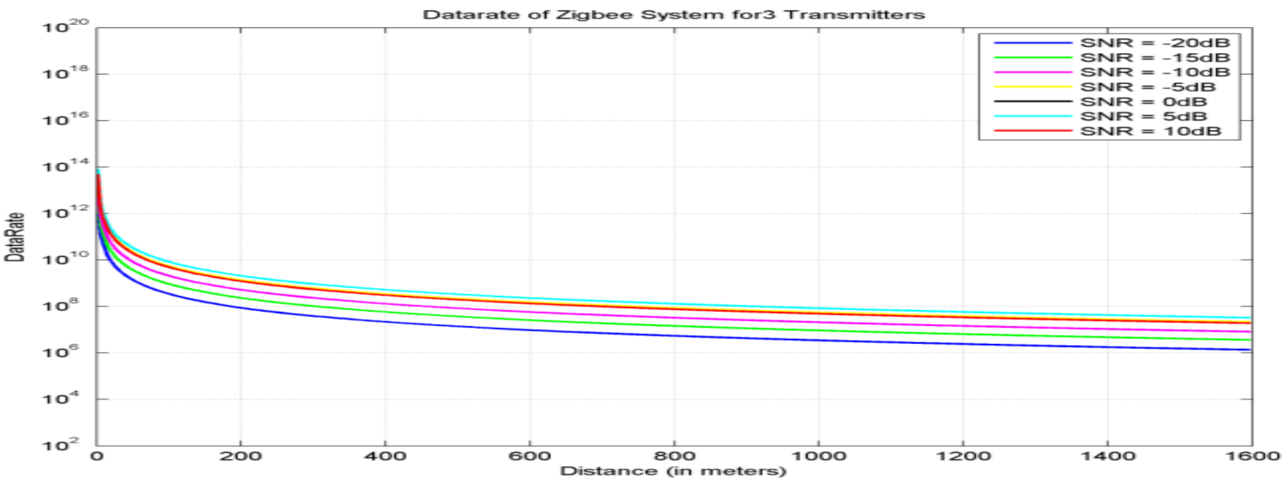

Fig4.3 (h) Data Rate Vs Distance for Various Values of SNR for 3 Transmitters

5. Power Spectrum Density.

Power spectral density (PSD) refers to the amount of power per unit (density) of frequency (spectral) as a function of the frequency. The power spectral density, PSD, describes how the power (or variance) of a time series is distributed with frequency. By knowing the power spectral density and system bandwidth, the total power can be calculated. Power spectral density (PSD) shows the strength of the variations (energy) as a function of frequency. In other words, it shows at which frequencies variations are strong and at which frequencies variations are weak.

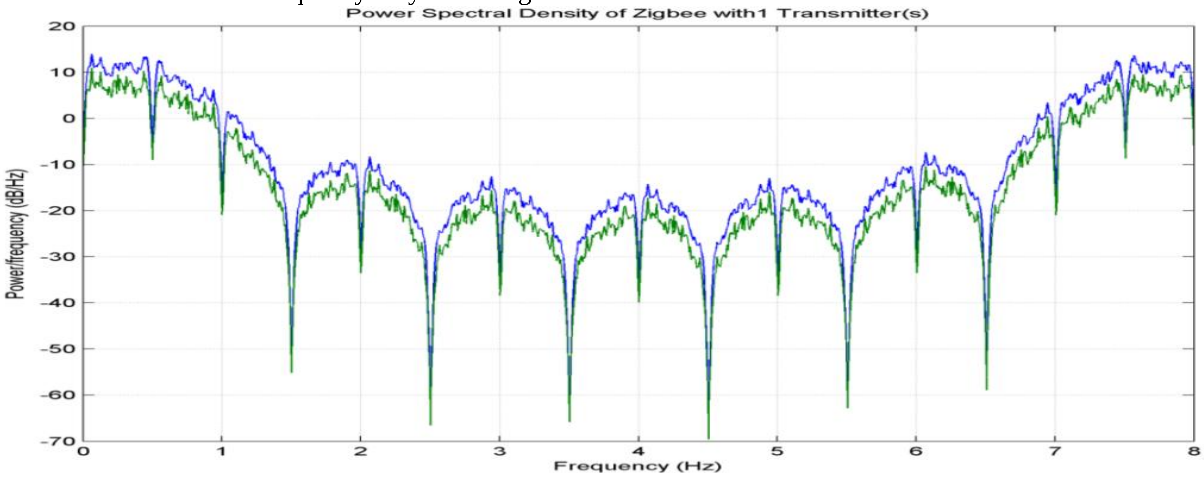

Fig.4.3 (i) Power Spectral Density of ZigBee System with 1 (one) Transmitter

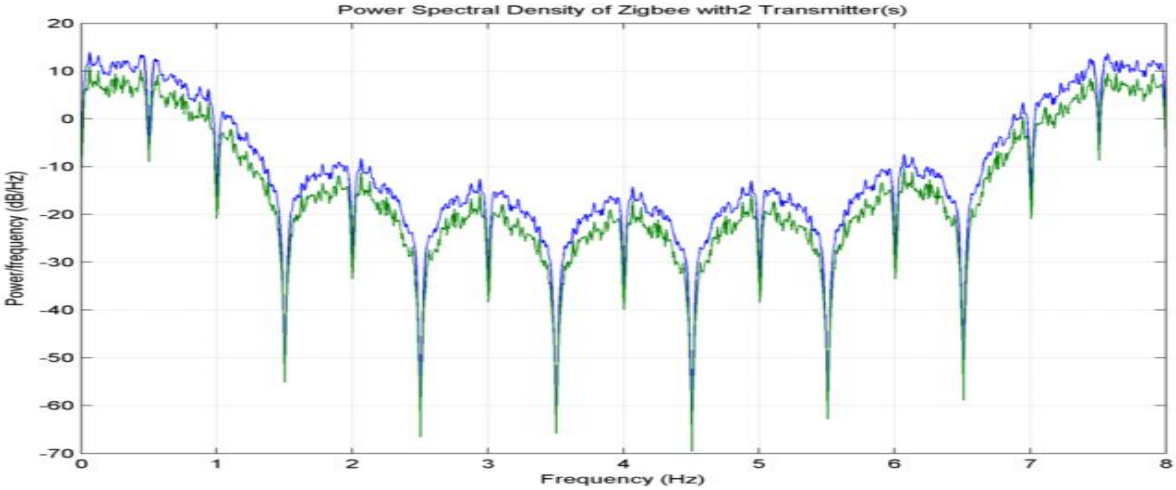

Fig. 4.3 (j) Power Spectral Density of ZigBee System with 2 (Two) Transmitters

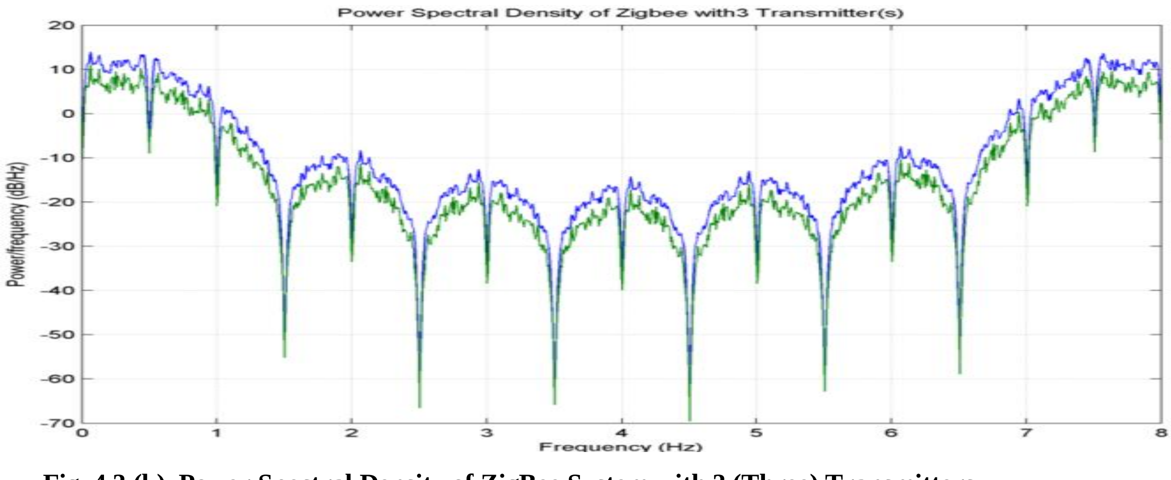

Fig. 4.3 (k) Power Spectral Density of ZigBee System with 3 (Three) Transmitters

The unit of PSD is energy per frequency (width) and you can obtain energy within a specific frequency range by integrating PSD within that frequency range. Computation of PSD is done directly by the method called FFT or computing autocorrelation function and then transforming it. The power spectral density for existing system of ZigBee (1 Transmitter), and Proposed Approach (i.e. multiple transmitters) are calculated and shown in the figure 4.4 (i), figure 4.3 (j) and figure 4.3 (k) respectively. From the result it is clear that the PSD for multiple Transmitters is slightly more than that of existing system. And it is not doubled as number of transmitters goes double. That's why the proposed approach gives better result than existing system.

5. Benefits of Our New Approach:

i. ***Performance:*** This approach gives performance because multiplicative capacity will give the proper transmission of data in high speed.

ii. ***Speed:*** This approach will also increase the speed of data transmission.

iii. ***Robust System:*** Due to multiplicative capacity transceiver will transmit and receive data in high speed, this provides robustness system.

iv. ***Low battery consumption:*** When multiplicative capacity transceiver installed, battery consumption is also divided according to the data load. When device start working it behaves like existing device but according to data load and auto shifting mechanism it reduce battery consumption.

v. ***Low Bit Error Rate:*** Data transmission rate will be increased due to new approach and low bit error rate will be decreased.

vi. ***High Capacity:*** Multiplicative transceiver increase the capacity of device and increase the performance of its.

vii. ***Chanel Increase:*** When multiplicative transceiver installed no of channel increased to transfer noiseless data over medium.

viii. ***Reliability:*** New approach uses three transmitters that provide reliability in this system.

6. Drawbacks of New Approach:

1. **Cost of the Hardware to design**: As we know that existing IEEE 802.15.4 standard device using single transmitter but when we apply three multi capacity transmitters, its cost will be increased.
2. **Battery Consumption on High Load :** When data load increased transmitter will continuously work and battery consumption will be increased.

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