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Evaluating Performance of Beacon Enabled 802.15.4 Network with Different Bit Error Rate and Power Models

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Abstract— This research finds the most suited Bit Error Rate (BER) and Power Model for IEEE 802.15.4 network. A total of three BER models and three Power Models were used for testing purposes. Their respective algorithms have been developed as well. alt_ber was found to be most suited as BER model and dra_power was found to be most suited for power model for 802.15.4 based networks. The relationship between BER and throughput has been established and the same has been confirmed by simulating the network. The most suited BER and power model settings were confirmed from the graphs obtained from network performance. This research paper can further be used for future references by all the researchers who aim to study this particular aspect of 802.15.4 based networks.

Keywords- Bit Error Rate, Beacon Order, IEEE 802.15.4, Power Model, Superframe Order.

I. INTRODUCTION

Standard IEEE 802.15.4 was introduced with the predefined specifications for Physical and MAC (Media Access Control) layers for the WPANs - Wireless Personal Area Networks [1] and the rest of the layers were left to the solution provider to design it for the client, thus making it more flexible. The standard was designed with the purpose to provide the low rate data transfers at minimum power consumption in WPANs. IEEE 802.15.4 is compatible with many other standards, as such forms the backbone for a large number of standards and is therefore far more used than may be apparent at first sight. Bit Error Rate or BER is an essential parameter for evaluating the performance of different channels in terms of data rates. When data is transmitted from source to destination, via a medium, BER is used to determine how many errors would appear at the destination. IEEE 802.15.4 has been the desired topic for various researchers, many have studied this network under various different test beds using various different tools to study its behavior [2-20]. Many researchers have tried to custom code the pipeline stage model files to fit the requirements of theirs [2 - 4]. Most of the researches focus on simulating the network through various test beds by changing various parameters of the network nodes such as Beacon Order (BO) and Superframe Order (SO) or minBE and maxBO [5]. Researchers have implemented automated position system over mobile Ad-hoc networks in 2-dimension space [6]. Researchers have modelled the throughput in IEEE 802.15.4 under effects of interference as well [7]. Some have compared the QoS of the IEEE 802.15.4 & 802.15.6 in WBAN based health monitoring systems [8]. Researchers have also tried to develop enhanced modified GTS scheduling algorithms of 802.15.4 for use in different industry applications [9]. Some researchers have also researched on jamming of the signals in an IEEE 802.15.4 network [10]. Researchers due to the suitability of IEEE 802.15.4, have also developed Tele-Medicine Protocol using CSMA/CA (slotted) 802.15.4 with low duty-cycle optimization in Wireless Body Area Sensor Networks [11]. Researchers have also tried to prepare technical reports on study of CSMA/CA (slotted) in IEEE 802.15.4 for WSNs [12]. Researchers have also presented the architecture for an IEEE 802.15.4 receiver that provides battery free operation [13]. Some have recommended better link adaptation strategies for 802.15.4 [14]. Researchers have tried to investigate many performance issues such as Delay and throughput evaluation of the GTS mechanism [15]. Researchers have also amended the existing 802.15.4 by providing extension to Low Power Wide Area Network (LPWAN), which uses PHY layer based on infrastructure monitoring (LECIM) to cover the cellular network cell of radii 10-15 km in rural areas [16]. Researchers have also developed interference classification algorithm on the basis of k-means clustering which is compatible with low-cost available commercially IEEE 802.15.4 transceivers [17]. Researchers have also developed a markov model for TSCH MAC mode to compare the energy costs of 802.15.4e and 802.15.4 [18]. Researchers have also used machine learning for handling

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channel access mechanisms efficiently using a reinforcement learning (RL) mechanism [19]. For improving network lifetime and to detect wormhole attacks in 802.15.4 WSNs, researchers have designed a MCRP - centralized MAC routing protocol to help enhance the performance of 802.15.4 embedded networks [20]. The requirements are mostly, either to design real world scenario as good as it could get or to get model files to work as required by the protocol. Also, in the field of 802.15.4 lots of researches have been done in the past and have continued till now. Very less considerations have been given to edit the pipeline stage model files and simulate how the network behaves under the changed pipeline stage files. In this paper we aim to study various network parameters for different settings of BER model and power model in pipeline stages.

We have organised the paper in nine sections where section I is introduction to the IEEE 802.15.4 WPANs followed by Section II which gives system description where it describes the superframe structure. Section III Explains the data transfer models. Further Section IV describes models pipeline stages, understanding of which is crucial for improving the performance of the existing standard. Section V studies BER and Power Models and establishes mathematical relationship between BER and throughput. Section VI explains the modifications implemented for enhancing the performance. In section VII, test bed and the various parameters used have been explained. Section VIII elaborates the results obtained. Finally, the section IX concludes this research.

A. Abbreviations and Acronyms

Abbreviations and Acronyms embedded in this research are: Media Access Control (MAC), Wireless Personal Area Networks (WPANs), Beacon Order (BO), Superframe Order (SO), Quality of Service (QoS), Bit Error Rate (BER), Fully Functional Device (FFD), Reduced Functional Device (RFD), Personal Area Network (PAN), Contention Access Period (CAP), Contention Free Period (CFD), Superframe Duration (SD), Beacon Interval (BI).

II. SYSTEM DESCRIPTIONS

IEEE 802.15.4 is known for its minimal power usage, and is suited for the applications in which the remote sensors require to be operational on battery power for years without any external attention. We are introducing the 802.15.4 protocol here in this section. A more detailed explanation can be found in [1]. The main feature of 802.15.4 which makes it most flexible and most suited for wide range of applications is:

A. Structure of Superframe

In 802.15.4 standard of IEEE, network devices are categorized as FFDs – fully functional devices and RFDs - reduced-functional devices. A FFD is a node that has extended level of functionality. It by itself can send and receive data and can route data from other nodes as well. RFD on the other hand can only communicate with FFDs. FFDs can act as a coordinator of the PAN, or an end device. The devices use very less power when they are in sleep mode. The figure 1 below represents the different topologies present in 802.15.4 [25].

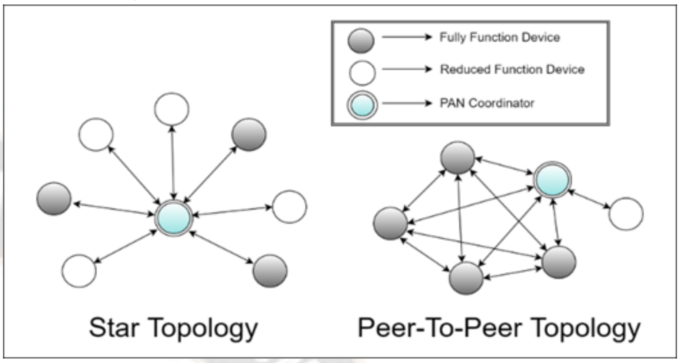

Figure 1: Basic topologies in 802.15.4 [25]

The concept of "superframe" structure implemented in IEEE 802.15.4 standard for supporting WSNs is a communication architecture based upon time division multiplexing consisting of active and inactive periods marked by beacons. If 802.15.4 adopts active period of this architecture, it is known as a beacon-enabled network. Else, it is a non-beacon network.

The active and inactive periods collectively form a Beacon Interval as shown in Figure 2 [25]. In active period, the nodes that want to communicate with each other can do so and are in sleep mode in inactive period for saving the energy. The superframe has 16 equal duration time slots which are divided into CAP - Contention Access Period and CFP - Contention Free Period. PAN coordinator generates the beacon frame containing the information such as structure of frame and next Beacon.

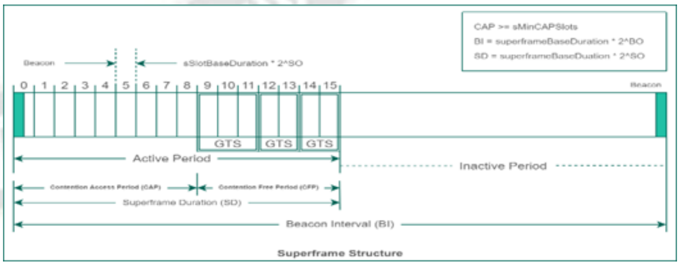

Figure 2: Superframe Structure [25]

Beacons are intended at synchronizing the coordinator with the nodes in the network to transmit data. CSMA/CA is used as channel accessing medium to avoid any collision of frames during transmission while the CAP. During the CFP nodes with GTS enabled contest for data communication.

SO - Superframe Order and BO - Beacon Order in combination determines the superframe duration. SO

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determines duration of superframe and the beacon interval is determined by BO. They are computed using (1) and (2).

$$SD = superframeBaseDuration*2^{SO} \quad (1)$$

$$BI = superframeBaseDuration*2^{BO} \quad (2)$$

SO & BO should be the integer values ranging from 0 to 14, and also the value of SO should be smaller or equal to the value of BO. The *superframeBaseDuration* constant has a value of 960 (symbols).

III. DATA TRANSFER MODELS

Beacon enabled data transfer mode of IEEE 802.15.4 occurs either as a transfer initiated from the end device to Coordinator, or from the Coordinator to end device.

Data transfer to the PAN Coordinator: During this transmission the end device first of all synchronizes with PAN coordinator. Then using CSMA/CA mechanism as channel access mechanism, transfers the data to the Coordinator. The complete procedure is explained in Figure 3 [19].

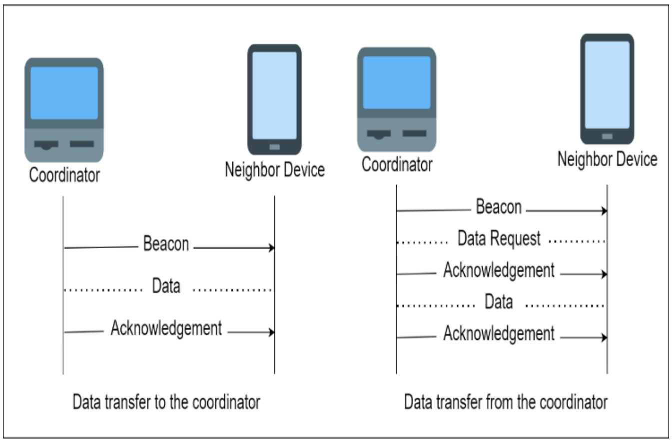

Figure 3: Data Transfer Model in 802.15.4 [25]

Coordinator Data transfer. When data has to be broadcasted to the end devices by the coordinator, it places in its buffer that packet, and then adds the data pending status through beacon frame. Thereafter, the target device receives and parses the beacon frame, by using slotted CSMA/CA mechanism to send coordinator the Data-Request. The Coordinator upon receiving the receiving the request sends back an acknowledgment, and then to the end device(s) it sends the buffered data packet. The complete mechanism is pictorially shown in Figure 3.

IV. MODEL PIPELINE STAGES

For modelling, the effect of transmission in the network stage has divided the process into 14 calculation stages, and finally checks if the packet can be received. The pipeline stage process consists of 14 different processes which are executed as the transmission occurs. These 14 stages are divided based on the pipeline they are executed, six stages are executed in transmitter pipeline and 8 in receiver's pipeline. These stages are nothing but C language codes. The diagrammatical representation of the above concept is shown in Figure 4 [6]. The user can modify the default pipeline stages to suit the type of channel required by the user: the user can define his own TDA in the pipeline, and can also call the kernel process (KP) in the system kernel that supports the operation of TDA for programming own channel model. The default suffix of the pipeline stage model file is .ps.c, and the suffix of the object file formed after compilation is .ps.o . The default pipeline stage files for all three channels are stored n <model directory >/< version_directory >/models/std/links/ folder. If the user wants to write a pipeline stage instead of the default model, he needs to first write a .ps.c suffix c or c ++ file, and then compile to form a .ps.o target file.

Stage 1 - Receiver Group

The Receiver Group basically determines which receivers will be able to receive the signal that is about to be broadcast. Receivers are accepted by default based on the assumption that they are all valid. You can limit which receivers can receive particular signals based on their power or distance, but by default, all receivers are considered genuine.

Stage 2 - Delayed Transmission

This is the second stage and is used to determine how long will it take the packet to get through the transmitter. This determines this based on data rate and duration of the packet being sent.

Stage 3 - Link Closure

This stage excludes some of the receivers based on line of sight computation. This allows model to determine if the transmitter can see the receiver or whether transmission is possible due to the curvature of the Earth.

Stage 4 - Channel Match

Channel match compares from both Transmitter & Receiver the number of characteristics. These includes the frequency (transmission), bandwidth used, data rate achieved, spreading code used, and modulation scheme implemented. In case of transmission frequency is not exactly matched, the stage determines the bandwidth of the receiver and the transmitted signal overlapping. For no overlapping, the transmission is considered as invalid, and is thus ignored. The signal is

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considered as interference when there is overlapping. This interference is utilized in noise stages.

Stage 5 - Antenna Gain (Transmitter)

The gain stage of transmitter antenna is the following stage, and it does precisely what its name says. Model calculates the gain in the receiver's direction by looking at the antenna model (which the user can change).

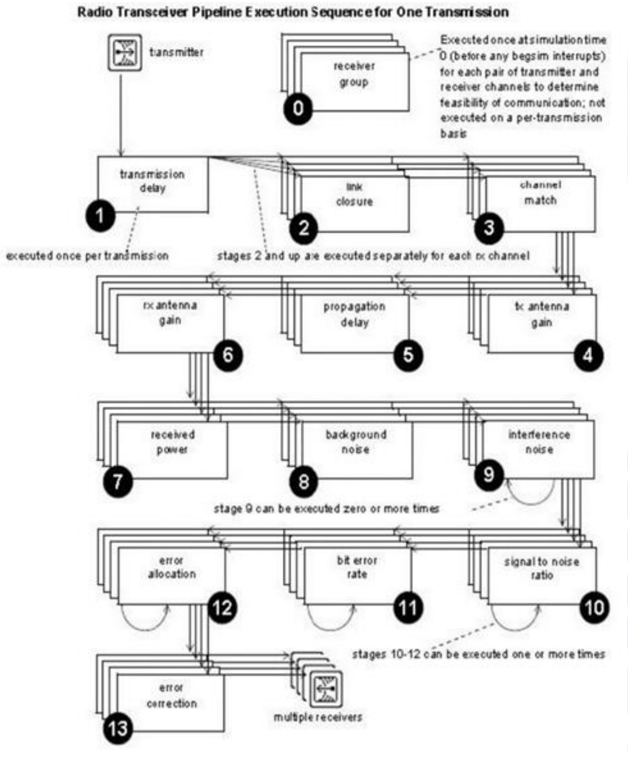

Figure 4: Model pipeline stages [6]

Stage 6 - Propagation Delay

This stage works similar to the transmission delay stage in a way that the time is calculated based upon the distance between the transmitter & the receiver as well as the propagation speed.

Stage 7 - Receiver Antenna Gain

This stage is same as transmitter gain stage, but here the receiver is used as the calculation's starting point. Any incoming signal, genuine or interference, can be amplified by the receiver antenna gain.

Stage 8 - Received Power

This stage determines the power of the incoming signal, whose value will further be used to calculate SNR in stage 11. It performs two functionalities 1) calculating the power of incoming signal 2) checking validity of incoming signal.

Stage 9 - Background Noise

This stage determines the background noise. Galactic, urban, and thermal noise are all factors in background noise. Boltzmann's constant is used to compute aggregate thermal noise at 290° K.

Stage 10 - Interference Noise

Interference noise originates due to receiver being unable to decode some signal in transmission band. A sent signal is classified as invalid, valid or interference when the channel match stage is completed.

Stage 11 - SNR (Signal to Noise Ratio)

The SNR calculates the ratio of powers calculated in previous stages. This number is then converted to decibels. This stage is run during the execution of interference noise and background noise stage.

Stage 12 - Bit Error Rate (BER)

This stage calculates the bit error rate for the incoming signal, by using the SNR calculated in the previous stage and adding the process gain to it as well. This effective SNR value is then passed to a Kernel Procedure which finds the BER value using the predefined modulation curves.

Stage 13 - Error Allocation

The BER and packet length are used in this stage to determine, if any, errors in the packet. This stage is executed many times, since there could happen to be many SNR values for the transmission of a single packet.

Stage 14 - Error Correction

The final stage, checks if the signal's encoding power has enough capabilities to overcome the amount of packet defects. Users can specify the maximum number of bit errors that a packet can contain while being considered legitimate. The stage determines whether a packet is correct or incorrect by comparing a user defined number against number of bit-errors.

V. BER AND POWER MODELS

Radio connectivity and radio communications systems are more closely related with SNRs and E_b/N_o statistics. The Bit Error Rate (BER), is usually expressed as a probability of error, or PErr. Three other criteria are utilised to determine this. These are the Q function(Q), the Energy per bit (E_b), and the Noise Power Spectral Density Number.

It should be noticed that the error function has a different value for each type of modulation. The energy per bit, E_b, is a unit of energy that is calculated by the division of carrier power with the bit rate. It is measured in Joules. N_o is the power per

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Hertz, hence it has as its dimensions the power (Joules per second) divided by seconds. Looking at the dimensions of the E_b/N_o, it will be noticed that they all cancel out, resulting in a dimensionless ratio. It's vital to remember that POE is a SNR that is proportional to E_b/N_o.

The value for PErr or BER for QPSK modulation is found using:

$$\mathrm{PErr} = Q\left(\sqrt{\frac{2E_b}{N_o}}\right) \tag{3}$$

$$\text{Where } Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-\frac{x^2}{2}}\,dx$$

Usually for solving numerical problems people refer to Q-function table. The predefined modulation curve for QPSK modulation in the network model is described in Figure 5:

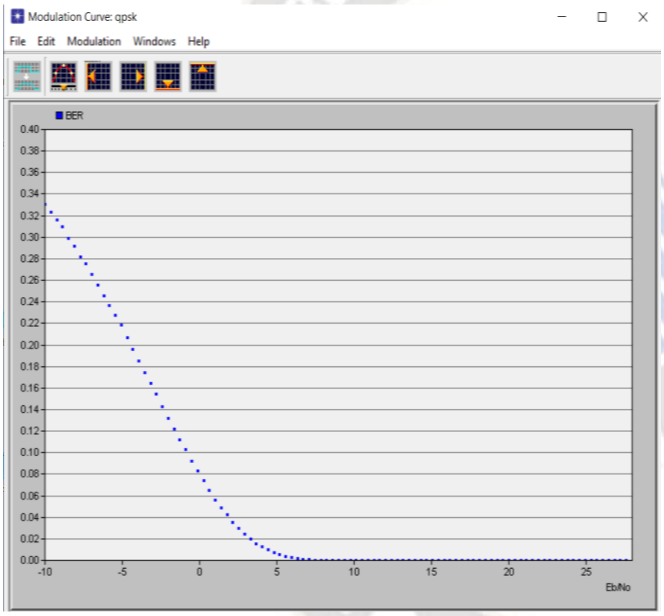

Figure 5: Modulation curve for QPSK Modulation

Now to relate throughput and BER [8]

Let the data getting through the network is data_sent × (1-BER)

If any error occurs at all then you need a resend and In case of an error Throughput reduces as:

data_sent - (packets (error per second) = err_pktsps) × (packet length)

For converting BER to err_pktsps, it can be assumed either every single occurring error destroys a packet or there should be grouping of errors (statistical).

If every occurring error bit loses one packet and if (say) data rate (error free) is D while the packet length is P, then due to occurring errors, lost data is BER × P bits/sec. So data rate simplistically reduces to ~= (D - BER × P) / D of previously.

If we drop every packet with single bit error at least, and let the net error free data rate be dFree and packet length is L. Then due to occurring errors, lost data is BER × L bits/sec so throughput reduces to ~= (dFree – BER x P) / dFree.

Hence

$$\text{Throughput} \propto (1 - \text{BER}) \tag{4}$$

Basically, when Bit error rate grows, the throughput is expected to decrease.

For Power models they calculate incoming power, each one of them have different way to calculate it. The incoming power calculation effects the SNR and SNR in turn is inversely related to BER.

We know,

$$\frac{E_b}{N_0} = \frac{\text{SNR}}{b} \quad \text{where} \quad b \text{ is spectral efficeincy}$$

Or

$$\frac{E_b}{N_0} \propto \text{SNR} \tag{5}$$

From (5) one can infer that E_b/N_o is inversely related to BER and thus making SNR directly proportional to throughput. Which is also very obvious since SNR measures the transmission channel quality or an audio signal over a network channel. Greater the value of SNR, better the quality of transmission. Thus, better the throughput.

VI. MODFICATIONS

In this paper we will be focusing on trying three different BER models and three different Power models, and study their effects on the throughput of the network. Two of the BER models are inbluilt and one is custom defined and will be discussed later. All the three power models are predefined. Ber model and power model can be changed by expanding the transceiver properties from the node model of the wpan_node, refer to Figure 6 & 7.

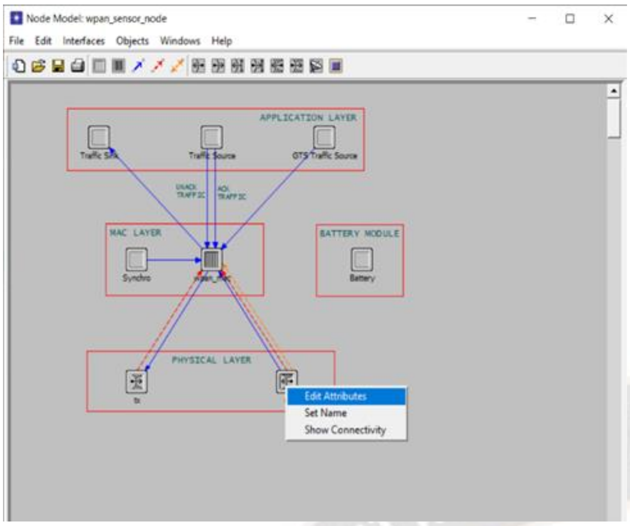

Figure 6: Node Model of Wpan_Node

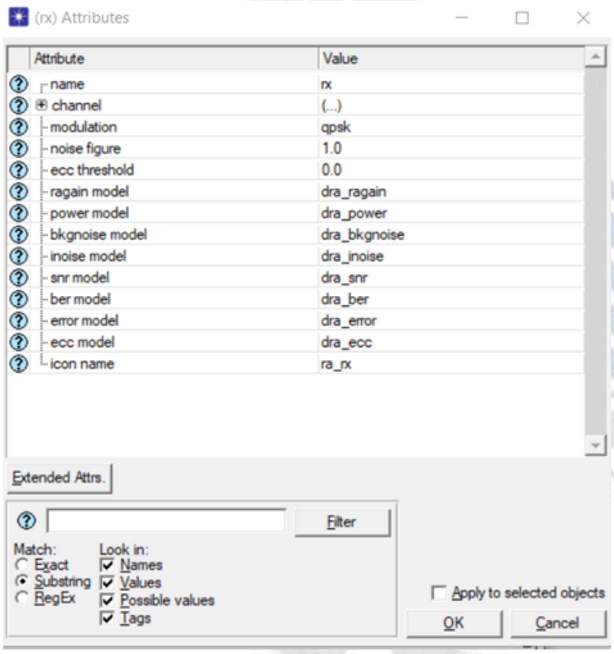

Figure 7 : Transceiver Attribute Values

A brief description of the algorithms behind the various pipeline stage model files taken into consideration in this paper are as follows:

A. BER Model Files

1) dra_ber.ps.c

This algorithm calculates default BER for wireless links. This stage calculates the BER for the incoming signal, by using the SNR calculated in the previous stage and adding the process gain to it as well. This effective SNR value is then passed to a Kernel Procedure which finds the BER value using the predefined modulation curves.

a) Algorithm

1. Obtain signal to noise ratio from SNR TDA
2. Obtain processing gain from PROC_GAIN TDA
3. Compute effective SNR

$$\mathrm{SNR_{effective}} = \mathrm{SNR_{actual}} + \mathrm{G_p}$$

$$\mathrm{G_p} = \text{Processing gain}$$

4. Call the system KP op_tbl_mod_ber () to calculate the bit error rate or ber and write it into the TDA of the package.

2) wlan_ber.ps.c

In contrast to dra_ber.ps.c Bit Error Model, modified model instead of using the value calculated by kernel computes the processing gain by itself. As the kernel makes use of the data rate settings of the receiver for computing processing gain which may or may not be equal to data rate (actual) used for the transmission of data packet. In WLAN bit error models, transmissions of all supported data rates makes use of same channel while the actual data rate for transmission is given with the transmitted packet itself. Using this information TDA OPC_TDA_RA_TX_DRATE is implemented or updated in wlan_txdel stage. Hence the modified model uses this data rate value to identify the modulation scheme to be implemented and to calculate the processing gain of received signal.

a) Algorithm

1. Obtain signal to noise ratio from SNR TDA
2. Obtain data rate from DRATE TDA
3. Get the modulation curve based on the data rate obtained in step 2.
4. if data rate < = 6000000.0 or data rate = = 11000000.0

   then processing_gain =

   10 * log10 (WLANC_11b_CHIP_RATE / data_rate)
5. else processing_gain = 0.0
6. Compute effective SNR

$$\mathrm{SNR_{effective}} = \mathrm{SNR_{actual}} + \mathrm{G_p}$$

$$\mathrm{G_p} = \text{Processing gain}$$

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7. Call the system kernel process op_tbl_mod_ber () to calculate the bit error rate ber and write it into the TDA of the package.

3) alt_ber.ps.c

We have custom coded this ber model file, we have made some slight changes to dra_ber model file in that we will discard the packets having effective snr values less than equal to 3. Since from Figure 5 the BER starts to grow rapidly. Hence discarding these packets would be helpful in getting better packets.

a) Algorithm

1. Obtain signal to noise ratio from SNR TDA
2. Obtain processing gain from PROC_GAIN TDA
3. Compute effective SNR
   $\mathrm{SNR_{effective}} = \mathrm{SNR_{actual}} + \mathrm{G_p}$
   $\mathrm{G_p} = \text{Processing gain}$
4. If effective SNR<=3.0
   Then set BER in TDA to 1 since we are discarding this packet.
5. Else
   Call the system KP op_tbl_mod_ber () to calculate the bit error rate ber and write it into the TDA of the package.

The approach to calculate bit error rate can be summarized using the flow chart in Figure 8.

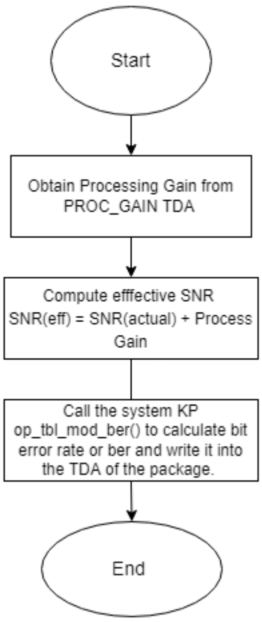

Figure 8: BER Algorithm

B. Power Model Files

1) dra_power.ps.c

This is the default received signal power calculation stage for wireless links. This supports the default "signal lock" concept, meaning that the packet that arrives first should be received. The signal lock attribute is set to 1 when this packet is received and any other incoming packet is set to be interference.

a) Algorithm:

1. Fetch the "match" flag of the packet using the TDA, perform the next steps only if the match flag is valid.

2. Read the channel identification number (ID).

3. Read the "signal lock" mark of the channel.

4. For already locked channels the packet is marked as Noise in TDA, for idle channels "signal lock" is set to 1, regardless of the package, if the "match" flag is valid the received power is calculated as:

5. Read the transmission power of the packet.

6. Read the transmitter reference frequency and bandwidth.

7. Get the overlapping bandwidth of the transceiver.

8. Read the gain of transmitting antenna and the receiving antenna;

9. Calculate the transmission wavelength using frequency. Also calculate the path loss in free space using:

$$\text{Path Loss} = \frac{\lambda^2}{16\pi^2 \text{propagation\_distance}^2}$$

10. Calculate received power using

$$\text{Reveived Power} = (\text{in\_band\_tx\_power} \ * \text{tx\_ant\_gain} \ * \text{path\_loss} \ * \text{rx\_ant\_gain})$$

Set the received power in the TDA by calling the KP op_td_std_dbl

2) dra_power_no_rxstate.ps.c

Alternative Received Power Model for radio link. Transceiver Pipeline. In contrast to the default model. This model uses the built-in "signal lock" attribute for checking and updating the signal lock status of the channel instead of the receiver channel state information. The algorithm is similar to that of dra_power, except in step 3 it uses inbuilt signal lock attribute.

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3) tdma_power.ps.c

This power model does not support "signal lock (Signal Lock)" concept. It fetches MATCH_STATUS value from the TDA, based on the status of MATCH_STATUS the value for "in-band transmitter power" is decided.

a) Algorithm

1. Read the transmission power of the packet;
2. Read the transmitter reference frequency and bandwidth;
3. Get channel match status from TDA
4. If (chanmatch_status == VALID)
   in_band_tx_power = tx_power
5. Else
6. Get the overlapping bandwidth of the transceiver
7. Read transmitter gain and receiver gain.
8. Calculate the transmission wavelength using frequency. Also calculate the path loss in free space using:

$$\text{Path Loss} = \frac{\lambda^2}{16\pi^2 \text{propagation\_distance}^2}$$

9. Calculate Received Power using

$$\text{Reveived Power} = (\text{ in\_band\_tx\_power } * \text{tx\_ant\_gain} * \text{path\_loss } * \text{rx\_ant\_gain })$$

10. Set the received power in the TDA by calling the KP op_td_std_dbl

The approach to calculate received power of incoming signal using power model can be summarized using the flow chart in Figure 9.

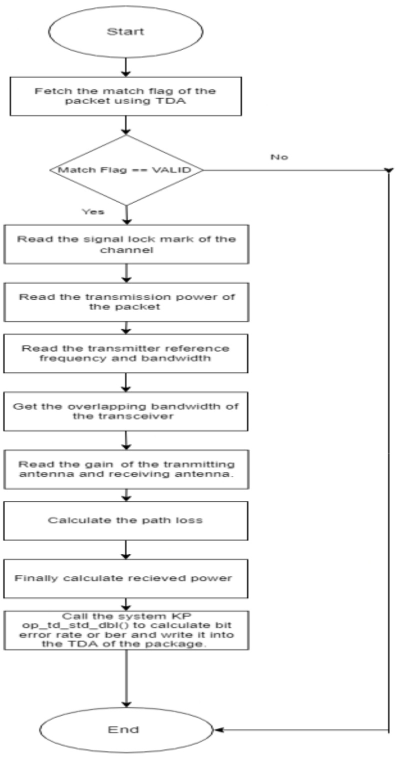

Figure 9: Power Model Algorithm

VII. TEST BED

IEEE 802.15.4 implements multiple types of networking topologies in distinct application environments including star & peer to peer [1]. As depicted in Figure 1, Star topology has been employed in test beds in this article. Although the topology utilized by a specific network may vary in practice, this topology is the most fundamental and have been used extensively in various different research papers.

Wireless IEEE 802.15.4-compliant Transceiver (Rx for reception and Tx for transmission) operates at 2.4 GHz frequency in the Physical layer (PHY), with bandwidth for each channel is 2 MHz. The transmission power is set to 1 mW, using Quadrature Phase Shift Keying as the modulation technique (QPSK). Slotted CSMA/CA is implemented by the MAC sublayer. When utilized in a PAN coordinator node, it is also in charge of generating beacon frames and synchronizing the network. The battery module calculates the amount of energy that has been utilised and how much energy is left. Current draws' default values are set to those of the mote MICAz.

For experimentation a WSN in a surface of 100m * 100m with 01 PAN Coordinator and 50 in number the transmitting nodes are spread randomly. Each transmitting node has distinct address and a data frames can be transmitted between these nodes and PAN Coordinator with PAN Coordinator being the destination node. The network is experimented in a superframe enabled setup, in which end nodes receive the beacon frame from the PAN Coordinator and synchronise with it before transmitting a frame. The beacon order (BO) and superframe order (SO) are set to 7 meaning there is no inactive period. MinBE and MaxBO are set to 4 and 3 respectively.

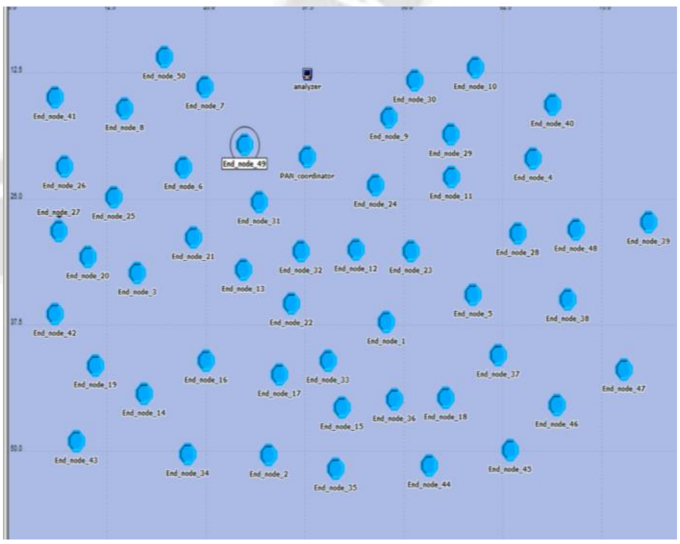

Figure 10: Test Bed

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The project consists of 5 such test beds similar to Fig 10, they share common properties except they all use different BER and power models. Their specifications are described in Table I.

Table I: Test Beds Setup

Test Bed Number	BER Model Used	Power Model Used
Test Bed 1	dra_ber	dra_power
Test Bed 2	wlan_ber	dra_power
Test Bed 3	alt_ber	dra_power
Test Bed 4	dra_ber	dra_power_no_rxstate
Test Bed 5	dra_ber	tdma_power

VIII.RESULTS AND DISCUSSIONS

Test bed's: 1 – 3 are tested for time of 30 seconds each with BER model and power model attributes set accordingly as per Table I.

For the above simulation throughput and bit error rate of network statistics were recorded by the analyser node [15]. Figure 11 & 12 represents the graph for throughput and network output load throughout the whole simulation time of 30 seconds for test beds 1-3.

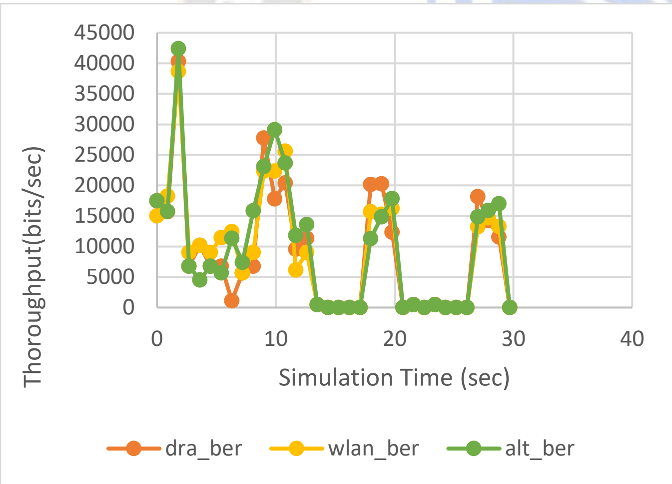

Figure 11: Throughput (bits/sec)

In figure 11 the throughput for the test bed's 1,2,3 is obtained. Model alt_ber shows the highest throughput, around 42,000 bits/sec, this higher throughput is due to the fact that in the algorithm of alt_ber model file the packets having SNR value lower than 3.0 dB are dropped hence from the modulation curve one can infer that probability of getting better $\frac{E_b}{N_0}$ value.

From (3), for better $\frac{E_b}{N_0}$ the PErr reduces.

From (4) $\text{throughput} \propto (1 - \text{BER})$.

Prob(PErr) decreases hence increasing the throughput. Opting to this reason the model alt_ber performs better than other bit error rate model files.

In Figure 12 below, network output load for the test bed's 1,2,3 is analysed. Clearly the model wlan_ber shows highest load.

if data rate < = 6000000.0 or data rate = = 11000000.0 then

Processing Gain = 10 * log10 (WLANC_11b_CHIP_RATE / data_rate)

Hence the load on network varies with data_rate varying. Due to this the wlan_ber model gives more load.

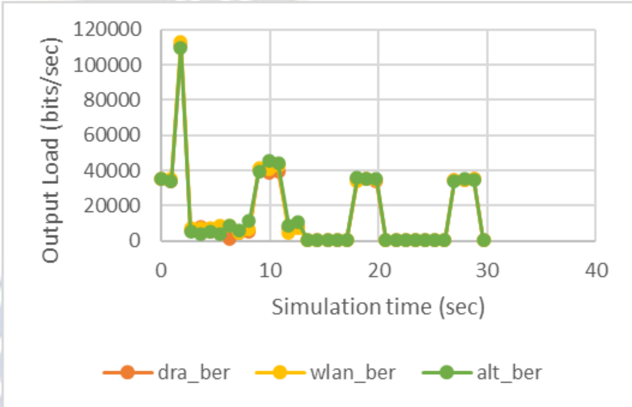

Figure 12: Network Output Load (bits/sec)

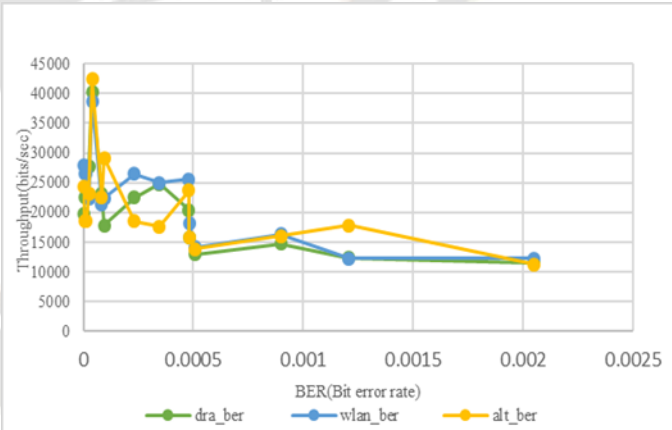

Figure 13: Throughput vs BER

From figure 13 it is observed that the bit error rate behaviour of dra_ber and alt_ber is almost similar, since the code for these two is almost similar except that alt_ber will set BER for packets having SNR less than or equal to 3 to 1.

Moreover in (4) we derived that $\text{throughput} \propto (1 - \text{BER})$

Meaning that when bit error rate grows throughput decreases and when bit error rate decreases throughput has to grow. Every

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bit error rate model file is expected to follow this behaviour as well. In Figure 13 every bit error rate model file follows this behaviour that is they show inverse trend in Throughput vs Bit Error Rate. BER model file alt_ber shows highest throughput as explained above.

Further, Figure 14 depicts the bit error rate values for all the three different ber models throughout the simulation of our model. Every Ber model has different BER values due to different approaches to calculate Bit error rate. One may notice that the graphs for dra_ber and alt_ber are roughly similar hence they can be used alternatively for 802.15.4 based netoworks. The average bit error rates shown by dra_ber, alt_ber and wlan_ber are 0.000676067, 0.000619081 and 0.000526979 respectively. The lowest average is shown by wlan_ber but the throughput for alt_ber is higher and not much of a difference is there in the average bit error rates of alt_ber and wlan_ber. Hence alt_ber is a choice for bit error rate models.

Test bed's 1,4, 5 are run for simulation time of 30 seconds each with BER model and power model attributes set accordingly as per Table 1. For the above simulation throughput and received power and snr of network statistics were recorded by the analyser node [15].

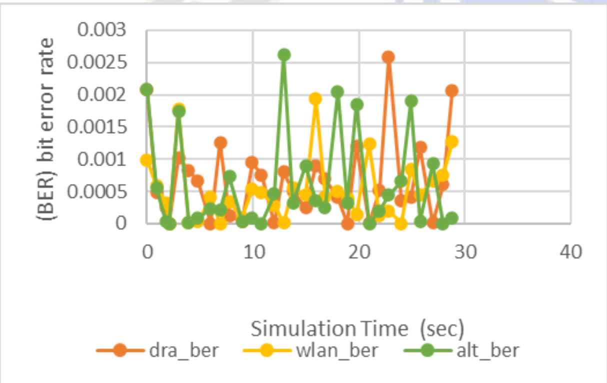

Figure 14: BER vs Simulation Time

Figure 15 & 16 represents the graph for throughput and network output load throughout the whole simulation time of 30 seconds for test bed's 1,4,5.

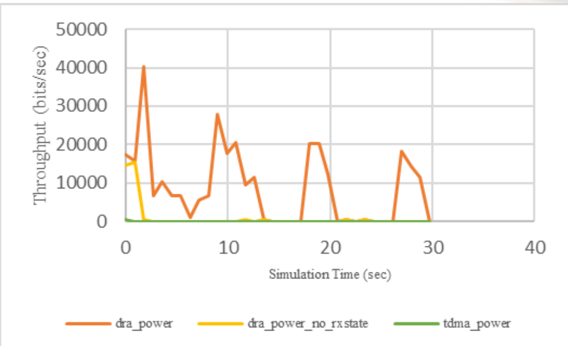

Figure 15: Throughput

It is clear from Figure 15 that throughput for dra_power is highest, tdma_power model and dra_power_no_rxstate power model have shown very poor performance. This could be explained by (5)

From (5) we know that

$$\frac{E_b}{N_0} \propto \text{SNR}$$

dra_power model has signal locking capability allowing it to differentiate between noise and valid signal, thus allowing better quality of signal to pass through the network. This makes SNR better hence making throughput better. Low SNR value results in poor throughput, and models like tdma_power do not have signal locking capabilities and due to this the model could not differentiate between a valid signal and noise and thus result in poor SNR. Hence dra_power performs better comparative to other models.

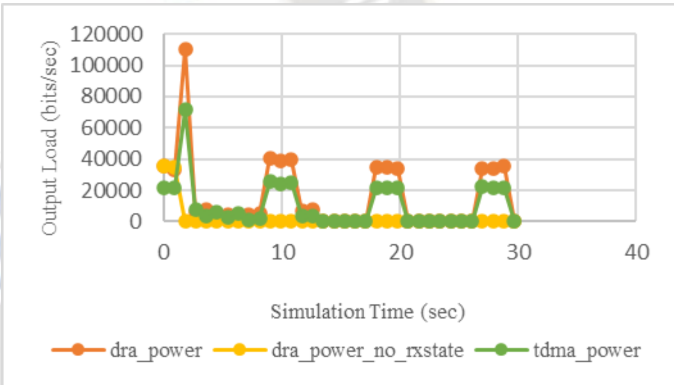

Figure 16: Network Output Load

In Figure 16 dra_power model file gives the highest network output load. Thus, it may be concluded that for getting better network output load dra_power can be used for power model setting in 802.15.4 based networks. Whereas tdma_power is somewhere near 70,000 bit/sec, dra_power_no_rxstate is very low around 35,000 bits/sec as shown in figure 17 below.

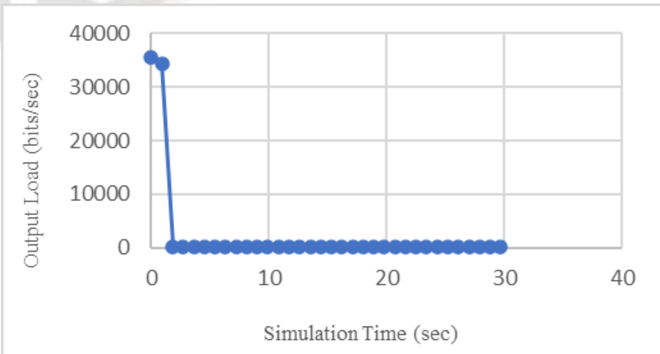

Figure 17: Network Output Load for dra_power_no_rxstate

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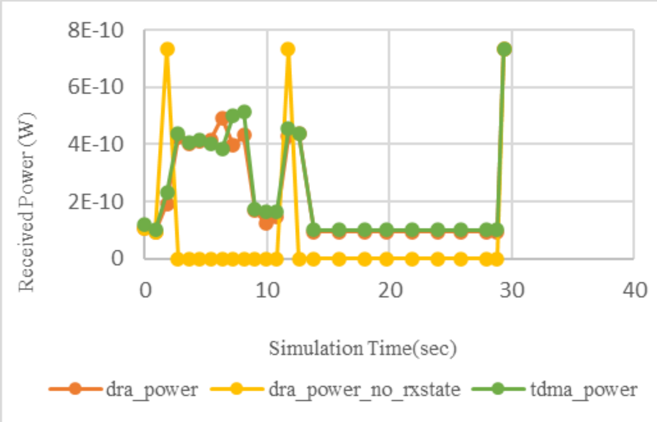

Figure 18: Received Power (W)

In Figure 18 the graph shows Received Power in watts vs the Simulation Time in sec throughout the whole simulation. dra_power_no_rxstate shows 0 received for most of the time, tdma_power performs poorly as well. dra_power models have varied range of received power, dra_power model has signal locking capability allowing it to differentiate between noise and valid signal, thus allowing better quality of signal to pass through the network. This makes SNR better hence making received power better.

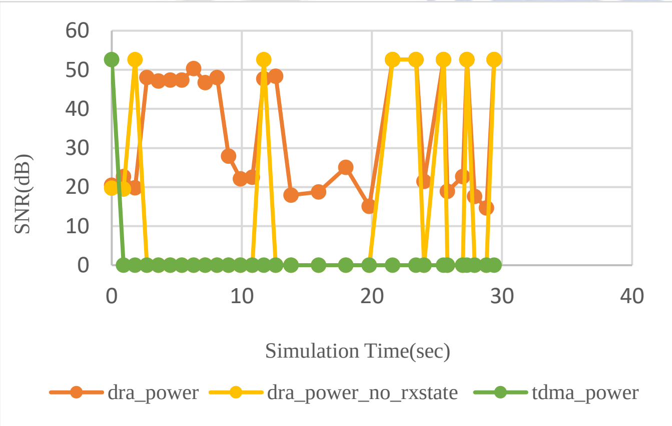

Figure 19: SNR(dB) vs Simulation Time (sec)

In Figure 19 the graph shows SNR in dB vs the Simulation Time in sec throughout the whole simulation.

From (5) we know that

$$\frac{E_b}{N_0} \propto \text{SNR}$$

In section II, we studied the relationship between received power and SNR value. Better the received power better the SNR. tdma_power shows 0 SNR vlaue for most of the time, dra_power_no_rxstate performs poorly as well. dra_power models has varied range of SNR. Low SNR value results in poor throughput, and models like tdma_power do not have signal locking capabilities and due to this the model could not differentiate between a valid signal and noise and thus result in poor SNR.

IX. CONCLUSION

IEEE 802.15.4 protocol was created in response to the requirement for a low-cost, low-power wireless network. It has characteristics such as a low transmission rate, a short communication range, and ease of installation, among others. This excellent model has been released as open source. In this paper, a model of 802.15.4 wpan network is studied and the performance is analysed under different parameters. In this paper, a total of 3 different Bit error rate and Power Models were taken. From the results obtained in section VIII. It can be concluded that for better throughput alt_ber and dra_power can be used for ber and power models respectively. For getting better network output load wlan_ber and dra_power can be used for ber and power models respectively. wlan_ber has shown the lowest average bit error rate out of all three ber models. In section V mathematical relationships between BER and throughput was followed by studying relationship between received power (for the purpose of studying power models) and SNR and relating SNR to Eb/No. The algorithms behind these BER models and power models were described in the same section as well. Throughput of the network was analysed by analyser node (since it captures global statistical data from whole PAN) and network output load for all six different pipeline stage model files. The simulation results also confirm that Throughput decreases when BER increases.

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