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ADVENT OF PHY AND MAC LAYER OPERATIONS IN WIRELESS AND LOCAL PERSONAL AREA NETWORK

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Abstract
Carrier sense multiple access with collision avoidance (CSMA-CA) algorithm is implemented on AT86RF230 Trans-receiver, which is done in Physical layer. As the number of nodes is increased, power efficiency of CSMA-CA algorithm is decreased. Power efficiency is improved in terms of Throughput and Block acknowledgement. Fragmentation increases the reliability of correct transmission. Both high and low data rate can be supported through multirate design. Data Scrambler and Data Whitener is implemented. Finally the transmitted and received information is analyzed using Analyzer.

Keywords:
Stack, CSMA-CA, Packet size, Data Scrambler, Data whitener, Block Acknowledgement, Throughput

1. INTRODUCTION

Wireless Personal Area Networks (WPAN) defines the physical layer (PHY) and medium access control (MAC) sub-layer specifications for low-data-rate wireless connectivity with fixed, portable, and moving devices with no battery or very limited battery consumption requirements typically operating in the personal operating space (POS).The PHY provides an interface between the MAC sub-layer and the physical radio channel, via the RF (Radio frequency) firmware and RF hardware. The Physical layer (PHY) is responsible for performing Clear channel assessment (CCA) for carrier sense multiple access with collision avoidance (CSMA-CA).Wireless Local Area Networks (WLAN) defines several PHY signaling techniques and interface functions that are controlled by the IEEE 802.11 MAC.The features are designed and implemented using C programming language. The platform used is Ubantu Linux, edited using VIM Editor and complied using AVR GCC complier and finally tested using Simulator.

2. BACKGROUND AND RELATED WORK

The IEEE 802.15.4 is a low data rate wireless standard for wireless personal area network and application developments. This standard has MAC and PHY layers as defined by IEEE and higher layers are to be developed by the user to support various applications in 2.4GHz band. The details about the IEEE 802.15.4 PHY and MAC layers [1], explains the features of these layers and also the flow of primitives between the layers. It also gives a hint for the design of higher layers. The design steps of the transceiver and the different operating modes explained in [3], helps in better understanding of the communication procedure, also the register descriptions guides in utilizing the available options to the best. The communication between the transceiver and microcontroller [3], also the explanation about various modules like SPI, Timer, Interrupts, helped in obtaining necessary details during the design.

3. THROUGHPUT ANALYSIS

In case of IEEE 802.15.4, PHY shall be able to transmit or receive Maximum Data packet size of 127 bytes. However the Packet length may vary from 0 to 127 bytes. Header includes Preamble, Start of frame delimiter (SFD), Frame Length which includes the length of the payload and Auxiliary security header. So the Total Header length is 40b as in standard [1]. When the data packet is to be transmitted, the Transceiver is in the Transmitting mode. After the transmission of the data packet, the Transmitter switches its mode to Reception, so that it can receive the Acknowledge (ACK) for the data transmitted.

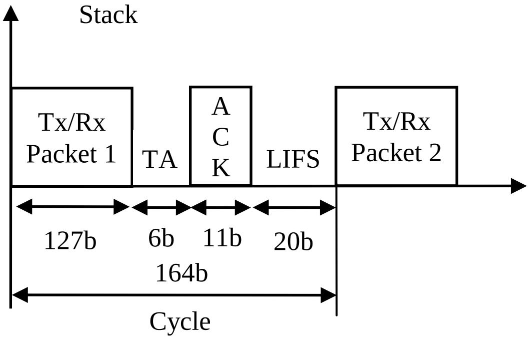


Fig.1. Throughput analysis for IEEE 802.15.4

$$\begin{aligned}
&\text{Data Packet Size} = 127 \text{ bytes}\\
&\text{Header} = 40 \text{ bytes}\\
&\text{Payload} = \text{Data Packet Size - Header}\\
&\text{Payload} = (127 - 40) \text{ bytes}\\
&\text{Payload} = 87 \text{ bytes}\\
&\text{Throughput} = (87/164)*100 = 53.04\% \approx 50\%
\end{aligned} \tag{1}$$

Similarly, in case of IEEE 802.11,

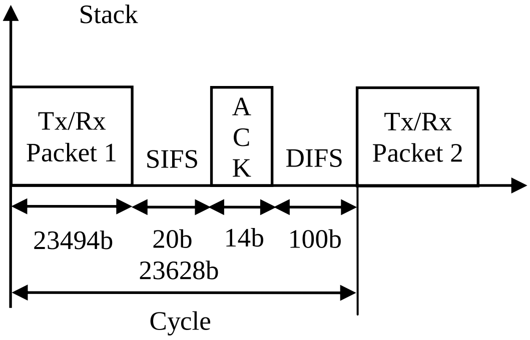


Fig.2. Throughput analysis for IEEE 802.11

$$\begin{aligned}&\text{Data Packet Size} = 23494 \text{ bytes}\\&\text{Header } = 70 \text{ bytes}\\&\text{Payload} = \text{Data Packet Size - Header}\\&\text{Payload} = (23494 - 70) \text{ bytes}\\&\text{Payload} = 23424 \text{ bytes}\\&\text{Throughput} = (23424/23628) * 100 = 99.1\%\end{aligned} \tag{2}$$

The Time taken by the Transceiver to switch on from Transmission to reception state is Turnaround time (TA). TA requires 6 bytes. Acknowledge frame consumes 11Bytes as in standard [1]. Long Inter Frame Spacing (LIFS) is the separation between the present acknowledgement frame and next data packet transmission. LIFS is 20 bytes long. Fig.1 shows Throughput Analysis for IEEE 802.15.4.

Short Inter Frame Spacing (SIFS) is the separation between data packet and acknowledgement frame of the current transmission. SIFS is 20 B long. The DIFS (Distributed Inter-frame Spacing) shall be used by Stations operating under the DCF (Distributed co-ordination function) to transmit data frames and management frames. DIFS is 100 B long as in standard [2]. Fig.2 shows Throughput Analysis for IEEE 802.11.

Data rate of IEEE 802.15.4 is 250Kbps (kilo bits per sec). It is very power efficient as in [1] but has low data rate, throughput is just 50 %, Refer to “(1)”. Hence it is used for applications with less data rate and applications which require long battery life.

Data rate of IEEE 802.11 ranges from 1 Mbps (Mega bits per sec) to 54 Mbps, but consumes very high power as in standard [2]. Throughput analysed has per standard IEEE 802.11, refer to “(2)” is 99.1%. Throughput of IEEE 802.11 is very high when compared to IEEE 802.15.4. Company is on the process of implementing the advantages of both IEEE 802.15.4 and IEEE 802.11. So that high data rate is obtained on low data rate hardware.

4. MULTIRATE SUPPORT

IEEE 802.15.4 is very power efficient but has low data rate [1]. IEEE 802.11 has high data rate but consumes more power [2]. The proprietary stack is developed in such a way that it supports both low data rate hardware and high data rate hardware. To support different data rates, additional functionalities are added to Physical layer, thus enhancing Medium Access Control layer accordingly. Block diagram of multirate support is as shown in Fig.3.

Hardware comprises of Microcontroller (or processor), Transceiver, counter, registers, buffers and many other components. Antenna is mounted on Transceiver. Microcontroller & transceiver is driven by drivers. PHY and MAC of IEEE 802.15.4 has been modified to support IEEE 802.11 and called as Hybrid PHY and Hybrid MAC. Different types of interrupts are observed between Microcontroller and Transceiver.

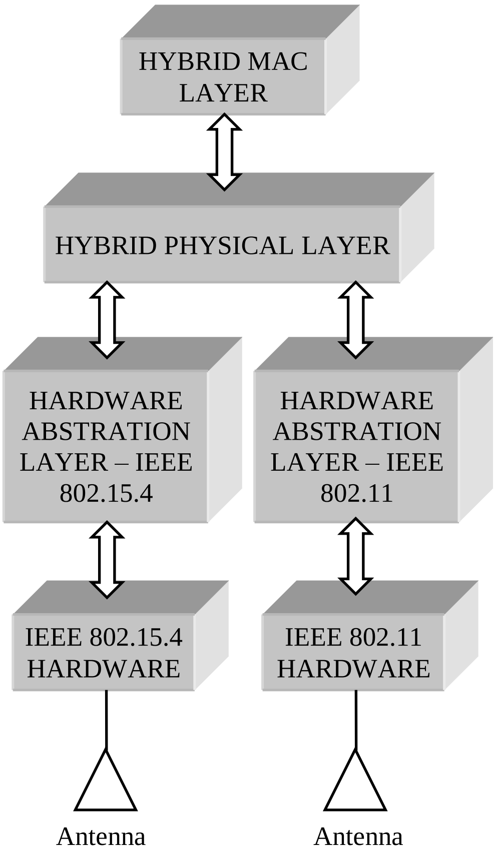


Fig.3. Diagram of Multirate Support

Hybrid PHY layer handles the transmission and reception functions for data propagation through the channel. Controlling the states of the transceiver for performing CSMA-CA is also the main responsibility of the PHY layer [14].It also holds the Personal Area Network (PAN) Information Base (PIB) related to the functions of this layer.

Hybrid MAC layer mainly performs the data and management services by handling the corresponding primitives. The MAC Management Service processes the management requests and responses through PHY and Hardware Abstraction Layer (HAL) and if applicable invokes the respective confirm function implemented in the Network Layer. Generation of beacon frames and management of its timings is the main managerial responsibility which is handled by the MAC layer [15]. The MAC Data Service transmits data using the frame transmission services of the HAL and invokes the confirmation function. It has MAC sub Layer Management Entity (MLME) and MAC Common Part Sub layer (MCPS) as service access points for management and data services. The MAC sub-layer then handles all access to the physical radio channel.

The parameters such as modulation, code rate, length, transmit power level, Transmit antenna is defined as part of the TXVECTOR parameter list in the PHY transmit start (PHYTXSTART).request service primitive [2]. The parameters such as modulation, code rate, length, received signal strength indicator, antenna for reception are defined as part of the RXVECTOR parameter list in PHY receive start (PHYRXSTART).indication, service primitive. Packet error rate (PER) is defined as ratio of Number of error packets transmitted or received to the Number of actual packets transmitted or received. Header is transmitted at a default data rate. Default data rate mentions default channel access, default modulation, default code rate. First or the initial transmission is by default data rate. Then it updates channel access performance table accordingly, as transmission is in progress. If packet error rate is less, data rate is increased to next higher level. If packet error rate is more, data rate is decreased to next lower level. The process is repeated and transmissions and receptions are managed by Transmit-Receive Queue.

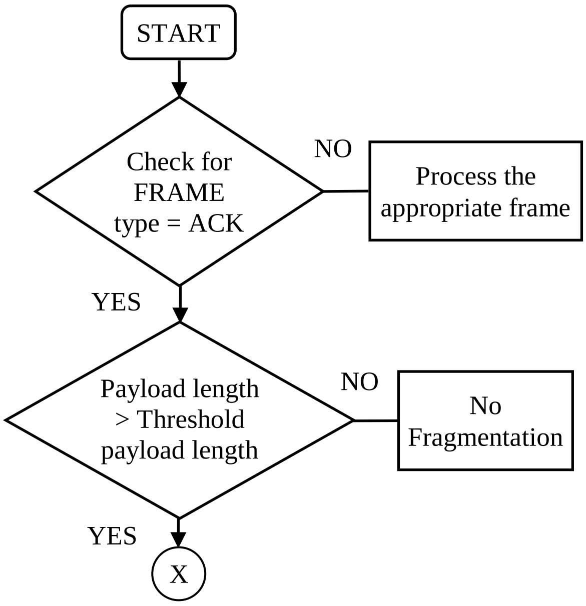
5. FRAGMENTATION AND DEFRAGMENTATION

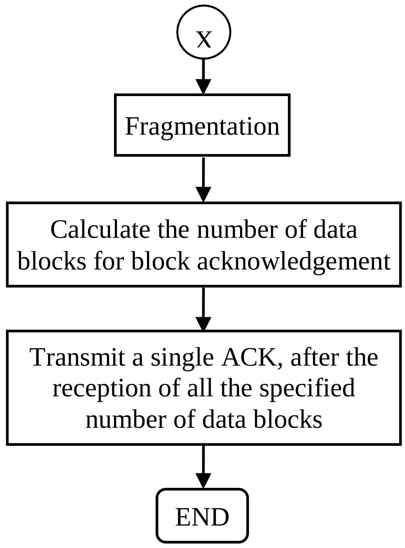
Fragmentation creates data packets smaller than the original data packet length to increase reliability, which increases the probability of successful transmission of the data packets as in standard [2]. Fragmentation is done at the Transmitter and Defragmentation is done at the Receiver. If the data Payload length is greater than the Threshold payload length then the data is fragmented else fragmentation is not preferred. Once the data is fragmented, Defragmentation is processed at the receiver. This is also advantages where channel characteristics, limit reception reliability for longer frames. Concept of Block Acknowledge (ACK) is used in Fragmentation. Single ACK is transmitted for a specified number of blocks received. This is applicable for IEEE 802.15.4, which increases the reliability but consumes more power. Company is on the process of implementing this for IEEE 802.15.4.

5.1 BLOCK ACKNOWLEDGEMENT IMPLEMENTATION

Usually Acknowledge is received after each single block is transmitted. But in case of Block ACK (acknowledgement), an ACK is received after predetermined number of blocks. In case of both IEEE 802.15.4 and IEEE 802.11 standards, implementation of Block ACK minimises the power consumption.

5.1.1 Flowchart for Block ACK:





5.1.2 Algorithm to calculate the number of data blocks:

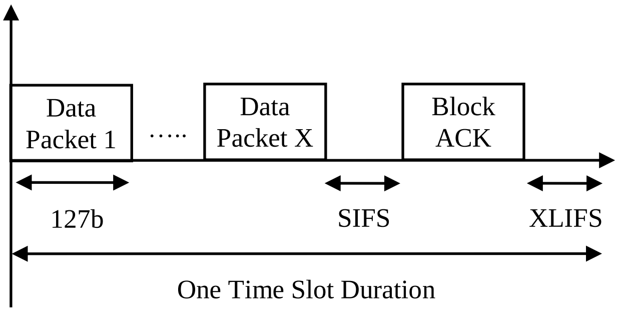


Fig.4. Frame Format of Block Acknowledgement

- Calculate the Maximum payload size of the data packet. In case of WPAN hardware, register size is restricted to 127 bytes. Hence Maximum payload size of each data packet in case of IEEE 802.15.4 is 127 bytes.
- The spacing between two data packet is 1 byte. Let "X" be the total number of blocks for which an acknowledgement is to be sent.
- As last data packet X, [(Maximum packet size + 1) * X], gives the size of all the data packets.
- SIFS is Short Inter frame Spacing, is the time interval between last data packet X and the acknowledgement frame.
- XLIFS is the Extra Long Inter Frame Spacing is the time interval between Block ACK and next data packet.
- Fig.5 shows Frame format of Block Acknowledgement. Block ACK consumes (5+X) octets. PHY header includes 4 bytes of preamble, 1 byte of SFD (Start of Frame Delimiter) and 1 byte of frame length. Totally Block ACK consumes (5 + 4 + 1 + 1 + X) Octets.

Octets: 1	**0/1/2**	**1**	**1**	**1**	**1**	**1**
Frame Control	DstEP	ASL Counter	Count X	Packet No. 1	…..	Packet No. X

Fig.5. Frame format of Block Acknowledgement

- So the duration of Single Block ACK Time Slot is given by,

$$\text{BLK\_ACK\_TS\_LEN} = \left[\begin{array}{l}\left(\begin{array}{l}X * (\text{MAX\_PAYLOAD\_SIZE} + 1) + \\ (\text{T\_SIFS} - 1) + (11 + X) + \text{T\_XLIFS}\end{array}\right) \\ * \text{UNIT\_OCTET}\end{array}\right] \tag{3}$$

- Duration of the regular Time Slot length, can be represented by the formula,

$$\text{REGULAR\_TS\_LEN} = \left[\begin{array}{l}\left[\begin{array}{l}\text{No. GTS length} * \\ \left(\begin{array}{l}\text{MAX\_PAYLOAD\_SIZE} \\ + \text{T\_ACK} + \text{ACK\_FRAME\_LEN} \\ + \text{T\_LIFS}\end{array}\right)\end{array}\right] \\ * \text{UNIT\_OCTET}\end{array}\right] \tag{4}$$

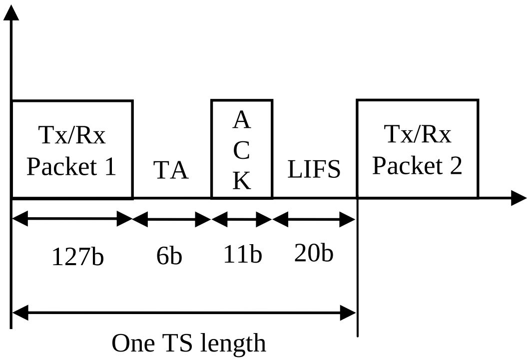


Fig.6. Format of Single Acknowledgement

Equating Eq.(3) and Eq.(4) and calculating the value of X,

$$X = \left[\begin{array}{l}\left[\text{BLK\_ACK\_TS\_LEN} - \left[\begin{array}{l}(\text{T\_SIFS-1}) \\ + \text{T\_XLIFS} + 11\end{array}\right]\right] / \\ \left[\text{MAX\_PAYLOAD\_SIZE} + 2\right]\end{array}\right]$$

- X should be in between the constants, i.e. Minimum and Maximum Block ACK count.
- Check the ED level, if it is greater than the threshold predetermined ED level, then ACK for X blocks. If not, then ACK for a single block.
- After the reception of ACK, finally process the request to the lower layers.

Transmitting ACK, after the reception of each data frame, consumes more power. Hence by the implementation of Block ACK reduces the power consumption.

6. DATA SCRAMBLER AND WHITENER IMPLEMENTATION

In IEEE 802.11, Scrambler is followed by a 32/33 bias suppression encoding to randomize the data and to minimize the data dc bias. Data to be transmitted is first passed to Scrambler, which randomizes the data then to the whitener which minimizes the dc bias. At the reception, the received data is passed through the De-whitener followed by a De-Scrambler as in [2].

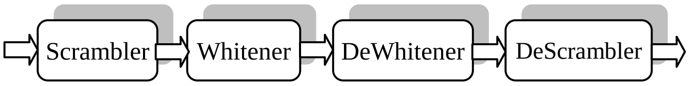


Fig.7. Data flow diagram

Before the data is transmitted, data-in is processed through the Scrambler, which randomises the data. Output of the Scrambler is given to the Whitener, DeWhitener and Descrambler is used at the receiver. Each data is of 32 symbol blocks. After 32 symbol blocks a stuff symbol is inserted. If stuff symbol is 1, then next block is inverted. If stuff symbol is 0, then next block is not inverted. Scrambler provides adequate security in hiding vital data with realistic values. Data Whitener randomizes the data and avoids redundant patterns.

6.1 ALGORITHM FOR DATA WHITENER

Each bit is a Symbol .The weights assigned to each value of the symbol. For example under channel access FHSS, modulations schemes are 2GFSK and 4GFSK. Weights are mentioned in table below.

Table.1. PLCP field bit descriptions

2GFSK	4GFSK	Weight
--	10	3
1	--	2
--	11	1
Center	Center	0
--	01	-1
0	--	-2
--	00	-3

- Read the symbol and accordingly sum the weights.
- Calculate the total number of blocks.
- Get the bias of the current block.
- If number of zero's is greater than number of one's, stuff symbol is zero, which implies do not invert the next block.
- If the number of one's is greater than number of zero's, stuff symbol is one, which implies invert the next block.

Test results are shown below which implies that the data at the input of Scrambler is same as output at the De-Scrambler.

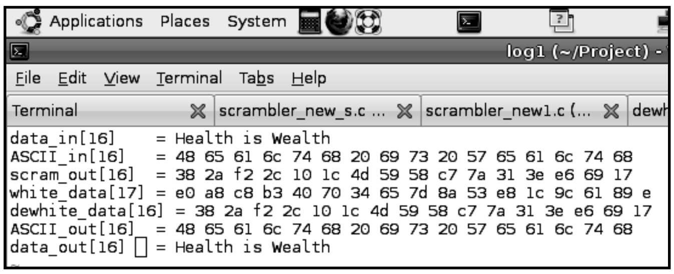


Fig.8. Test result of Scrambler and Whitener

The Fig.8, explains the test result as follows,

Data_in[16] = Input to the scrambler with total characters of 16. Next line represents the ASCII values.

Scram_out = Output observed at the scrambler, which is a randomized data, which is an input to the data whitener.

White_data = Output observed at whiter with minimized dc levels.

Dewhite_data = Output of dewhitener is given to descrambler.

Data_out = It represents the ASCII values. In next line original data is been recovered.

The code is written in C programming language edited using VIM Editor and debugged using AVR debugger. The platform used is ubantu linux.

7. CSMA-CA IMPLEMENTATION

In IEEE 802.15.4 standard the nodes make use of CSMA-CA algorithm to access the channel to communicate with the coordinator or other devices. If superframe structure is used in the PAN, then slotted CSMA-CA shall be used.

7.1 TRANSCEIVER

CSMA-CA algorithm is implemented on AT86RF230 Trans-receiver. It is a low power; 2.4GHz radio Trans-receiver specifically suitable for IEEE 802.15.4 applications. During Active state transceiver is enabled. The entire radio transceiver is disabled in sleep state. No circuitry is operating in this state. Thus AT86RF230 current consumption is reduced to only leakage current, thus saving power.

Special IEEE 802.15.4 Hardware Support include Clear Channel Assessment, Energy Detection / RSSI (Receive signal strength indicator) Computation, Automatic CSMA-CA, Automatic Frame Retransmission, Automatic Frame Acknowledgement, Automatic Address Filtering.

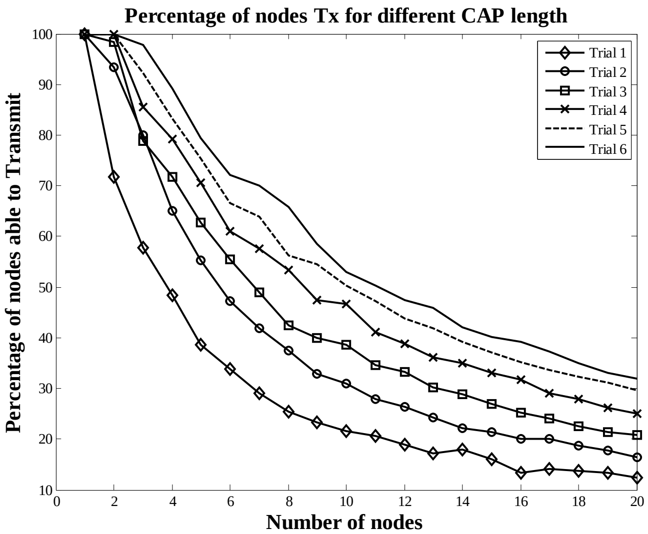


Fig.9. Graph of Percentage of nodes transmitted for different CAP (Contention access period) length

The Fig.9 explains the graph of number of nodes v/s percentage of nodes able to transmit. As the number of nodes is increased transmission opportunity of the nodes is decreased. This is tested for different CAP (contention Access Period) length.

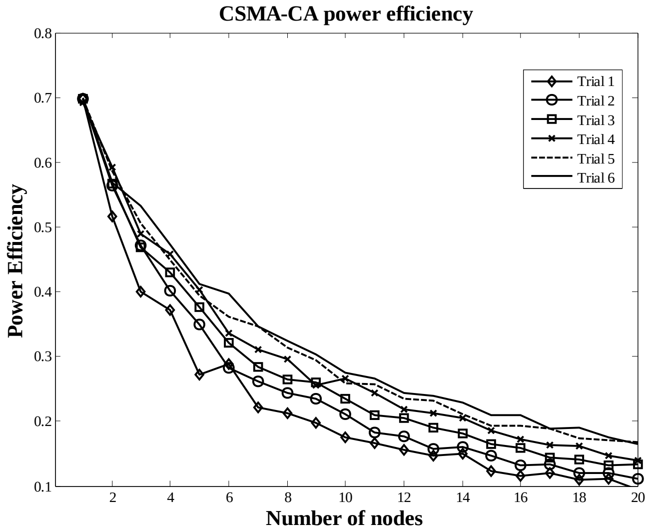


Fig.10. Graph of CSMA-CA Power efficiency

The Fig.10 shows the graph of number of nodes v/s power efficiency. Different colours indicate different trails. This work is simulated for nearly 30 trials, only 6 trails has appeared, Rest of the trails overlap because, random backoff generated is same. Red, blue, green colours indicate different trails. Above graph implies that First node has a power efficiency of the 70 %. As the number of node increases the power efficiency decreases. At 10th node power efficiency is just approximately 30%. So for a larger network CSMA-CA is not power efficient. Company has developed a patent on Data transfer in large networks in efficient manner referred to [4]. The code is written in Matlab, simulated using RF230 Transceiver (RF230 Transceiver is by Atmel company) to implement CSMA-CA Algorithm.

8. ANALYSER

Analyser analyses the commands transmitted. As soon has the transceiver receives any commands or information, it is in hexadecimal numbers. If this information has to be analysed, as which frame is been transmitted and other details regarding the frame, the received commands is pasted in the command window. Total Number of commands is printed and called length. Then based on the commands, data is analysed.

Meta data is the data which is appended before PHY header. This is required for transmission of data packet. Then PHY header is printed. Then MAC header is analysed. Depending on the frame type in frame control field, details of each frame is analysed, and as per TYStack standard.

Table.2. Description of frame type

Frame type value $b_2b_1b_0$	Description
000	Beacon
001	Data

010	Acknowledgement
011	MAC command
100	Sync frame
101-111	Reserved

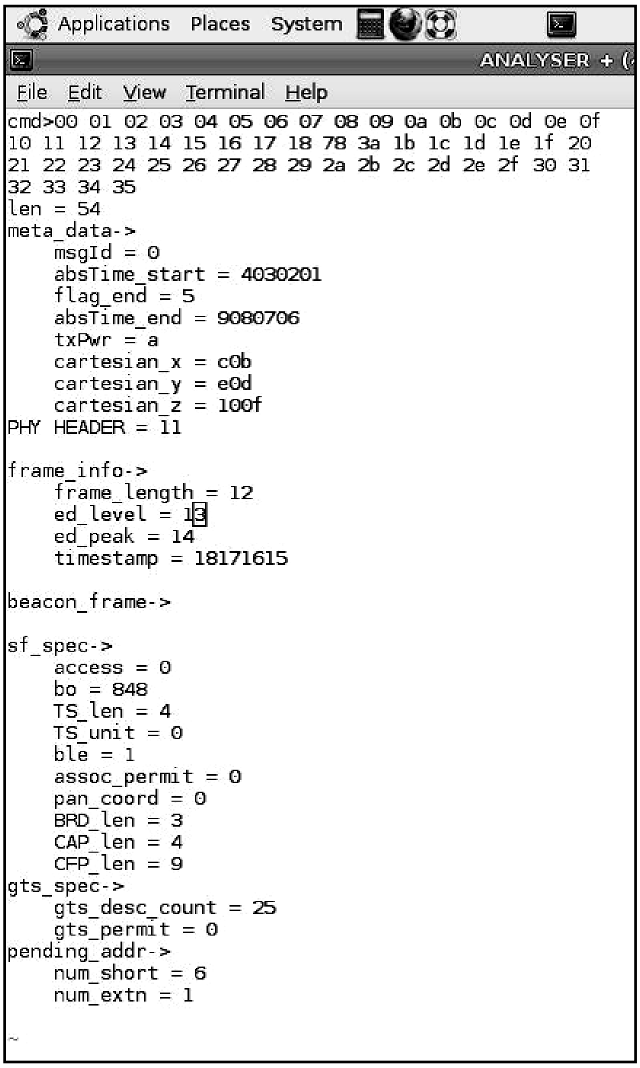


Fig.11. Test result of Analyser for Beacon frame

The Fig.11 explains the test result of an analyser. If fcf is 000, then frame transmitted is beacon frame. Analyser prints all the information regarding beacon frame, i.e., superframe specification, guaranteed time slot information, pending address specifications are printed.

8.1 READING AND WRITING THE PAN INFORMATION BASE

The user has the option to read the attribute or when there is a necessity even user is able to write the current value into that attribute.

Reading the attribute is called as GET. Writing the attribute is called as SET. These attribute has a set of requests and confirm parameters.

8.1.1 Algorithm for reading and writing the PAN information base:

- User has to request to read or write the required attribute
- Copy the received request to the buffer
- Check if the request is within Current layer PIB range
- If Yes, Read or write the requested PIB.
- Then send Confirmation to the higher layer has SUCCESS / FAILURE / INVALID PARAMETER / UNSUPPORTED ATTRIBUTE
- If NO, Process the request to the next lower layer
- Then append the request to the current layer to the next layer queue and cycle repeats.

9. CONCLUSIONS

In this work, the specific functions of PHY and MAC layer has been implemented.

CSMA-CA is not Power efficient, as the number of nodes is increased power efficiency is decreased, which implies CSMA-CA is not suitable for larger networks. As the nodes are increased, nodes get very less opportunity to transmit, which is not desirable.

By implementation of Throughput and Block ACK, Power efficiency is increased. Block ACK and Fragmentation increases the reliability of correct transmission. This is also advantages where channel characteristics, limit reception reliability for longer frames. Scrambler provides adequate security in hiding vital data with realistic values. Data Whitener randomizes the data and avoids redundant patterns.

Analyser is used to analyse the commands which is transmitted or received.

As a future work, simulations can be done for more number of nodes with real time examples

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