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Analysis of Slotted CSMA/CA OF IEEE 802.15.4

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Abstract - *IEEE 802.15.4 standard is specifically intended for low Rate Wireless Personal Area Network (LR-WPAN) with low information rate and low power capacities. Because of extremely low power utilization with obligation cycle even under 0.1, the standard is as a rule generally connected in Wireless Sensor Networks applications. It works in Beacon and Non Beacon empowered modes. During Beacon empowered mode, it has Contention Access Period (CAP) and discretionary Contention Free Period. We have broke down its exhibition during CAP where opened CSMA/CA calculation is utilized. The presentation investigation incorporates channel access occupied, transmission disappointment risks alongside unwavering quality and throughput against every one of the three recurrence groups with burden variety.*

Key Words: CAP, CSMA/CA/ IEEE 802.15.4

1. INTRODUCTION

As research in the field of low-power embedded systems (or micro-electro mechanical systems) such as Bluetooth [1], IEEE 802.11 [2] etc was done, new networking concepts were thought of which led to the creation of new concepts such as Wireless Personal Area Networks (WPANs), Low Powered Wireless Personal Area Networks (LR-WPANS). For higher data rates wireless applications, IEEE802.11 and IEEE802.16 are used. IEEE802.15.4 standard [3] is specifically designed for those applications where low data rate with higher reliability and less power consumption is required.

Wireless Personal Networks were earlier designed to be used for defense purposes but due to the availability of the industrial, scientific and medical (ISM) band these networks came to be used for civilian purposes also. WSNs can provide a reliable network because of the following features: self-*organization, low power, low memory, low bandwidth, self-configurable, wireless and infrastructure less. Therefore, if these features are* kept in mind during the design of a network, a reliable communication medium can be created.

The performance of the slotted CSMA/CA MAC protocol is evaluated and analyzed for different network configurations

to understand the impact of the protocol parameters such as super frame order, beacon order, back off exponent, frame size and CSMA/CA overheads on the network performance, namely in terms of throughput, average delay and energy consumed by the network. Overview of ieee 802.15.4 STANDARD IEEE 802.15.4 standard is designed for Low Rate Wireless Personal Area Network (LR-WPAN). It operates at both Physical and MAC layer with duty cycle of less than 0.1. In LR- WPAN, two types of wireless nodes called as Fully Functional Device (FFD) and Reduced Functional Device (RFD). FFD may be a PAN Coordinator, a Coordinator or a simple node whereas RFD can only act as simple wireless node. FFD has capability to exchange its information both with FFD and RFD whereas RFD can not exchange its information with other RFD that's why RFD only placed as end node of any wireless network. LR-WPAN operates in star as well as in peer-to-peer fashion. Nodes associated with coordinator can communicate with coordinator in star pattern where as two or more coordinators exchange their information by following peer-to-peer topology. Fig.1 shows nodes communicating in Star as well as in Peer-to- Peer.

TABLE I REQUENCY BANDS WITH DATA RATE

Frequency Band (MHz)	Modulation Scheme	Symbols / sec	Bits/ sym-bol	Symbol Du-ration (sec)	bits/sec	channels sup-ported
868 - 868.6	BPSK	20000	1	50*e-6	20000	1
902 - 928	BPSK	40000	1	25*e-6	40000	10
2400 -	O-QPSK	62500	4	16*e-6	250000	16

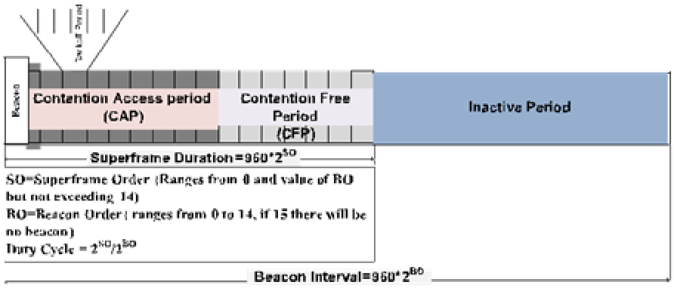

Fig. 1. *Superframe Structure with CAP and CFP.*

The standard operates in three different frequency bands as 868MHz, 915MHz and 2.4GHz by offering data rates of 20Kbps, 40Kbps and 250Kbps respectively. These frequency bands uses 27 frequency channels from 0 to 26 as channel 0 at 868MHz, 1-10 at 915MHz and 11-26 at 2.4GHz frequency bands. Different frequency bands with respective data rates are shown in table 1.

IEEE 802.15.4 supports beacon enabled and non-beacon enabled modes. The later uses un-slotted CSMA/CA algorithm and earlier applies Superframe structure and consists of two parts called active period and inactive period. Active period consists of beacon frame followed by the Contention Access Period (CAP) and optional Contention Free Period (CFP) as shown in fig.2. Slotted CSMA/CA algorithm is used during CAP of beacon enabled mode.

Coordinator disseminates beacon frame on the network after regular intervals and all the associated nodes listen to it to follow these instructions. Beacon frame is also used to synchronize all the associated nodes so that all nodes must awake up just before start of next beacon from coordinator. All requests along with some data packets from nodes to coordinator are transferred during CAP. Information relating to Length of active superframe duration, next Beacon arrival time and Slot duration for each slot can be attained from the superframe specs field of the beacon frame as shown in figure

4 and can be determined from equations 8, 9 and 10 respectively.

A. Calculations from super frame

Information about Beacon Intervals (BI) and Superframe Duration (SD) depends upon a constant value of aBaseSuperFrameDuration (BSFD) as well as the values of Beacon Order (BO) and Superframe Order (SO) as mentioned in superframe specs shown in figure 4. Whereas BSFD depends upon the fixed values of aNumSuperframeSlot (NSS) and aBaseSlotDuration (BSD). BI and SD can be calculated as follows.

$$BI = BSFD * 2^{BO} \text{ (Symbols)} \quad (1)$$

Where value of BO ranges from 0 to 14 and

$$SD = BSFD * 2^{SO} \text{ (Symbols)} \quad (2)$$

Here value of SO ranges from 0 to BO Where as BSFD is calculated as

$$BSFD = NSS * BSD \text{ (Symbols)} \quad (3)$$

According to IEEE 802.15.4 standard, default value of NSS is 16

$$BSD = 3 * aUnitBackoffPeriod \quad (4)$$

Default value of aUnitBackoffPeriod is 20 Symbols

$$BSD = 60 \text{ (Symbols)} \quad (5)$$

$$BSFD = 960 \text{ (Symbols)} \quad (6)$$

$$SD = 960 * 2SO \text{ (Symbols)} \quad (7)$$

$$BI = 960 * 2BO \text{ (Symbols)} \quad (8)$$

In SD there are 16 slots, so each slot duration (SlD) is calculated as

$$SID = (960 * 2^{SO}) / 16 \text{ (Symbols)} \quad (9)$$

If Number of Backoff Period against one slot is mentioned by BPS then these are calculated as

$$BPS = \frac{960 \times (2^{SO})}{16} / (20) \quad (10)$$

$$TotalBackoffPeriods\ inSD = BPS \times 16 \quad (11)$$

$$bits/slotin868MHz = 960 \times (2^{SO})/16 \quad (12)$$

$$bits/slotin915MHz = 960 \times (2^{SO})/16 \quad (13)$$

$$bits/slotin2.4GHz = 4 \times [960 \times (2^{SO})/16] \quad (14)$$

2. SLOTTED CSMA/CA MECHANISM

During the CAP, to achieve all the hub fight through reducing CSMA / CA system. This calculation is essentially dependent on three parameters such as backoff (nb), backoffience exponent (BE) and the number of concession window (cw).The initial estimates of NB, BE and CW are individually 0,3 and 2. At the point when the medium is captured, NB estimates increase in 1, except that it receives the most extreme form of maximum 4 as Max CSMA Backoffs are in. Channel access is for the inability of the upper layer when NB crosses its stimulus as Max CSMA Backoffs.

BE parameter defines the range of Backoff slots that is how many Backoff Slots node has to wait before going to assess.

The channel availability. The random number of backoff period ranges from 0 to 2 – 1. Estimation of BE augmentations when the medium access was discovered occupied up till amacMaxBE estimation of 5. This builds the arbitrary backoff span from 0-7 to 0-31. CW parameter identifies with Clear Channel Assessment (CCA) and its default worth is 2 which means hub should guarantee two successive inactive channels before transmitting the edge to medium. The channel detecting is finished during initial 8 images of the backoff period.

The stream graph of CSMA / CA shows that when the hbbs need to transmit some casing, it is initially consistent with the beginning of the backoff limit and later tightens for the opening of the irregular backoff period. After the expiry of the backoff period, the hub detects the channel by performing CCA on its backoff period limit. Occupancy is detected on the off-spot of the channel, the CCA value is reinvested at its default value, and the estimates of NB and BE are enriched with 1, except that they obtain their most extreme breaking point. As the BE is the extreme number 5, which means that every time the channel is captured, arbitrary backoff salary increases. The most extreme scope of the backoff span is 0 to 620 symbols.

A most extreme number of backoff cutoff is 4. By surpassing this point of confinement, the calculation reports a channel get to disappointment. On the off chance that, the channel is detected inactive after backoff commencement, the estimation of CW is decremented by 1. On the off chance that its worth methodologies 0, at that point bundles are transmitted at next backoff opening limit as appeared in fig.4. This outcomes in two back to back channel access inactive. The backoff period commencement ends if superframe length winds up and continues toward the beginning of the following superframe.

After effectively fighting the channel access inactive, the hub figures whether its transmitting outline with information affirmation and interframe separating can be finished inside remaining superframe length. On the off chance that remaining superframe span is bigger than the figured casing transmitted time, at that point the edge is transmitted generally hub needs to sit tight for the beginning of the following superframe so as to transmit its information. All out time required to send information can be determined as appeared in fig.5.

Total time required to send data can be calculated as shown in fig.5.2.Total Delay (TD) required to transmit data with acknowledgement

TD=Tbackoff + Tdata + 2Tprop + Tta + Tack + Tifs (5.15)

Tbackoff= node's waiting time during Backoff Tdata= Time required to transmit frame Tprop= propagation delay

Tta= Turnaround Time

Tack= Acknowledgement time Tifs= Time for interframe space

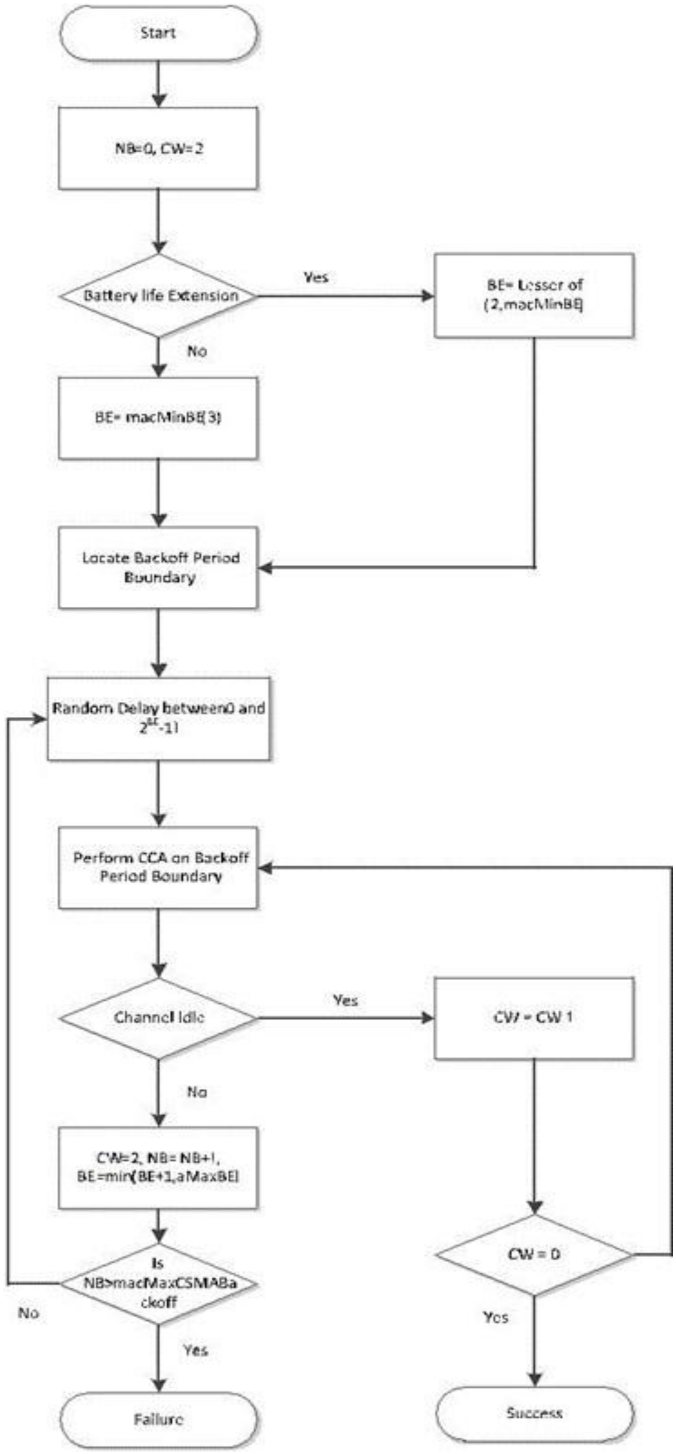

Fig. 2. *Flow diagram of Slotted CSMA/CA*

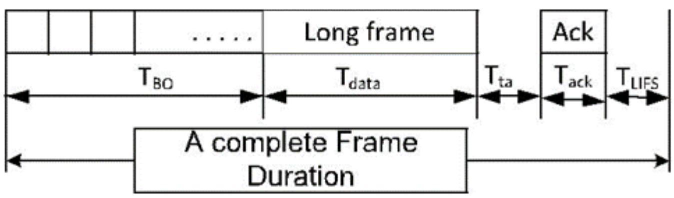

Fig. 3. *Complete frame length including Acknowledgement and Inter frame Space*

TABLE II Input Parameter Values

Parameters	868MHz	915MHz	2.4GHz
Number of Nodes	10	10	10
Data Rate	20Kbps	40Kbps	250Kbps
Bits/Backoff Slot	20	20	80
Offered Load	484 to 6776 bits	484 to 6776 bits	484 to 6776 bits
aunitBackoffPeriod	20*50*e-6	20*25*e-6	20*16*e-6
Turnaround time	12*50*e-6	12*25*e-6	12*16*e-6
macAckWaitDuration	120*50*e-6	120*25*e-6	120*16*e-6
Sensing Time	8*50*e-6	8*25*e-6	8*16*e-6
LIFS	40*50*e-6	40*25*e-6	40*16*e-6
SIFS	12*50*e-6	12*25*e-6	12*16*e-6
macMinBE	3	3	3
macMaxBE	5	5	5
MaxCSMABackoff	4	4	4
macMaxFrame re-tries	3	3	3

3. ANALYSIS WITH RESULTS

Our examination involves CSMA / CA execution when it is being worked under various recurrence channels. Includes correlation dependence, the transmission of the channel gets frustrating, throughput investigation and transmission disappointment probability. Apart from this, the CCA1 and CCA2 incorporate the general hold of the hub before transmitting the framework along with the possibility of detection of occupied channels during the activity. Keeping the estimates of the criteria the default, the conduct is examined by expanding the stack on different recurrence groups. The MATLAB retrain tool is used so that the results can be searched. Prospects are determined by following the General Markov series model depicted by Parkins [12].

A. Probability of Assessing Channel Busy During CCA1:-

After sitting tight for an arbitrary back-of-period, the hub transporter understands that it is occupied or is inactive. Chances are determined by portraying the Markov Chain model

$$\alpha = (1-\alpha)(1-\beta)\left(1-(1-\tau)^{N-1}\right)\ldots.. \quad [L + \frac{L_{ack}\left(N_T(1-\tau)^{N-1}\right)}{1} - (1-\tau)^{N-1}]$$

Where α = probability of busy channel during CCA1

L = Length of data frame in slots

L_{ack}= Length of Acknowledgement frame

τ= Node attempting to sense carrier during CCA1

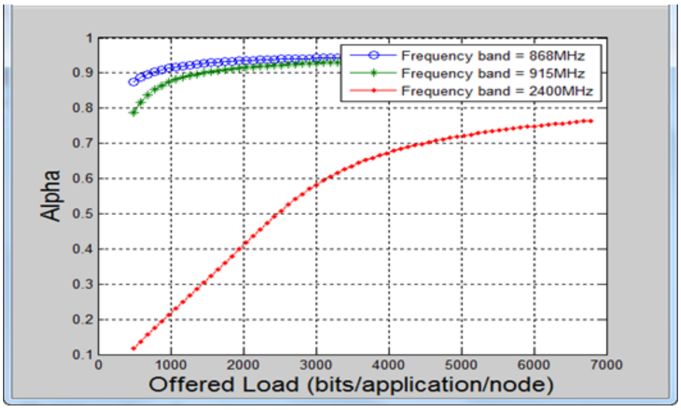

Fig 4: Busy channel probability during CCA1

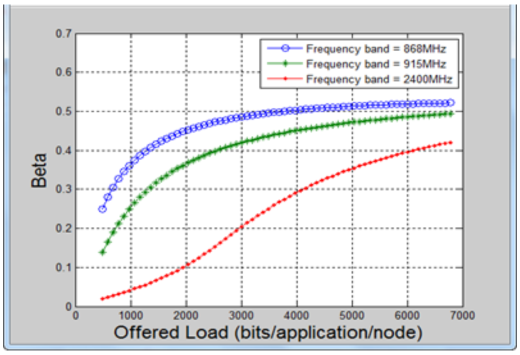

Fig. 5. *Busy channel Probability during CCA2*

Is higher with the expansion in burden as channel will be occupied for more often than not. It can be seen very well that the results appeared in Fig. 7 that the chances of channels being caught during CCA1 are more likely to be those hubs which are working in low repetition groups. The probable capture of the channel is the most in circulation against the 868MHZ channel, the probability of 915 MHz at that point and the probability of the channel being surveyed is the lowest when the hub has a similar load and 2.4GHz at 2.4GHz Working on the recurring band This is because for the possession of the channel, the equivalent burden requires more opportunity, where the rate of information is low.

B. Probability of Assessing Channel Busy During CCA2

After effectively detecting the channel in an idle way, the hub detects the channel for the second time as it is shown in field III. The probability of detection of CCA2 has been determined as follows.

$$\beta = \frac{1-(1-\tau)^{N-1} + N_T(1-\tau)^{N-1}}{2-(1-\tau)^{N-1} + N_T(1-\tau)^{N-1}}$$

Here β is Probability of busy channel during CCA2

Results in fig. 6.2 indicates that the discovery of medium

inertia during CCA2 is low when compared to CCA1. It is in this way because during the CCA2 hub the backoff is not tight for opening and the medium is to find out the location. Again, the effect of high information rates can not be thought of more about that which has similar effect during CCA1 investigation.

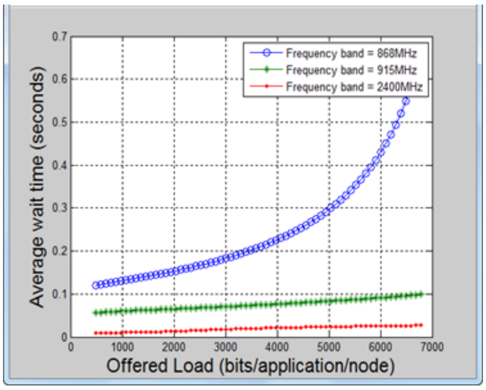

Fig 6: Average waits time of node before transmitting frame

During CCA2 as compared to CCA1. This is due to the fact that during CCA2 node need not to wait for backoff slots and sensing of medium is done in the next slot. Again the effect of higher data rate can easily be compared which has the same influence as during CCA1 analysis.

C. Average Wait time before transmitting

In order to hold a parcel, the usual hangtime time is determined according to the timing of the time that the hub holds bundle due to the means of possession. It has been seen that catching time is low where the rate of information is high because a unit back of opening is a 2.4GHz repetition bandlet, the Unit Backoff Space is more against the 915MHz recurring band and the 8MMHz recurring band. The most happens against. In figure 8

D. Channel Access Failure Probability

Channel access is accounted for disappointment when hub could discover the channel inert for two sequential occasions inside its most extreme permitted backoff stages (maxcsmabackoff) as depicted in area II. It very well may be determined as pursues.

$$P_{ef} = \frac{x^{m+1}(1-y^{n+1})}{(1-y)} \qquad (6.3)$$

P_{ef} = Probability of channel access failure

m = macMaxcsmabackoff

$$x = \alpha + (1-\alpha)^{\beta} \qquad (6.4)$$

$$y = P_{fail}(1-x^{m+1})$$

the equation shows that channel access failure probability mainly depends upon the values of, and macMaxcs-mabackoff. Higher the probability of carrier sensing busy, higher will be the probability of channel access failure. As these values increases with the increase in load so the same trend is being reflected here. The results shown in fig.9 verifies it.

E. Packet Failure due to retry limits

When transmitting node does not receive acknowledgement against its transmitting packet within the macAckWaitDuration then it retransmit the frame again. The transmission is reported

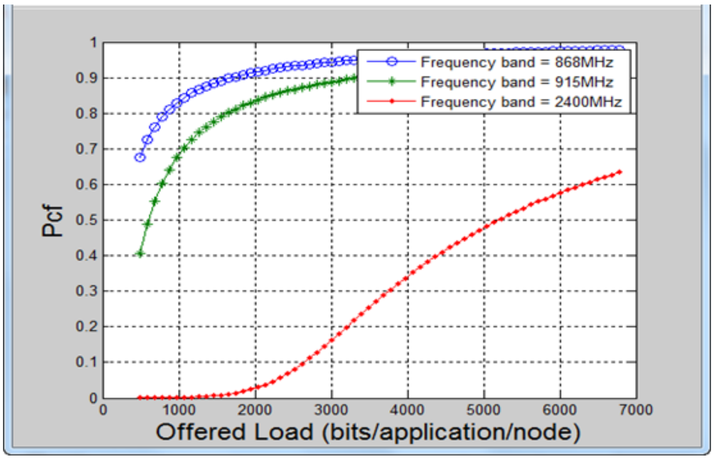

Fig. 7. *Channel access Failure Probability*

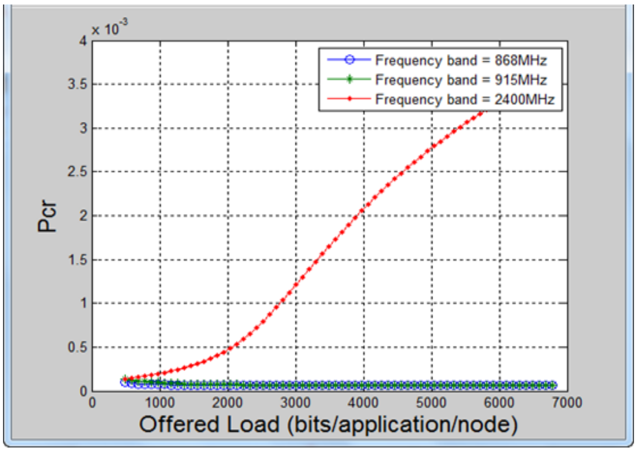

Fig. 8. *Failure Transmission due to retry limits*

failure when number of retries limit increases the value of macMaxFrameRetries. Chances of transmission failure are very low as can be seen from the fig.10.

F. Packet Failure by Exceeding Retry Limits: -

When the transmission hub does not get confirmation against its transmitting bundle within MacAckWaitDuration, then it changes the cover once again. Transmission is considered to be responsible for the disappointment when the various retreat points of Confidence expands the estimation of

Macmaxfremitrates. Transmissions of despair are less like odds, as can be seen from Fig.

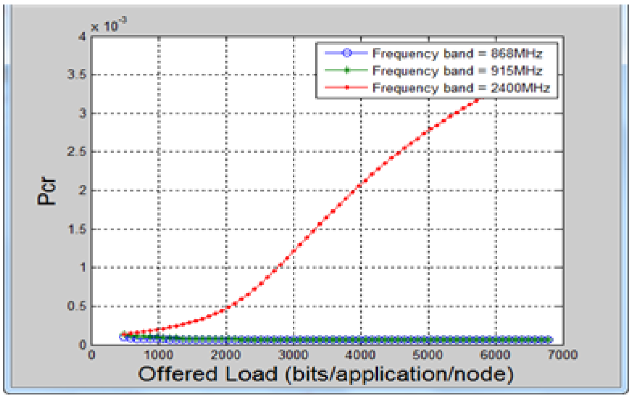

Fig 9: Failure transmission due to retry limits

Throughput against each Frequency Channel: -

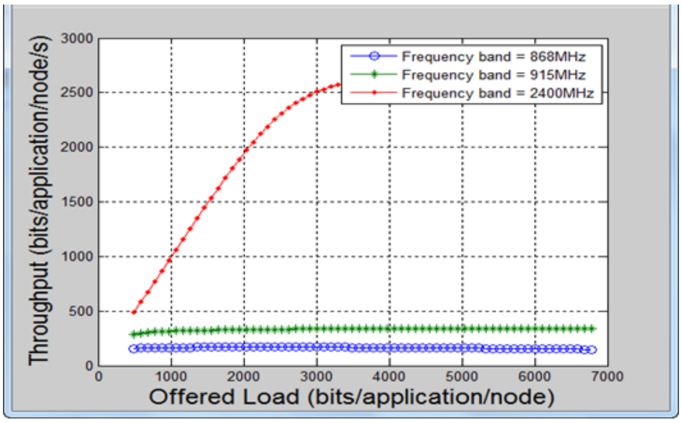

Fig 10: Throughput of different frequency bands

G. Throughput against each Frequency Channel

Throughput is periodically depicted as the time required for effective transmission of bundles. The throughput against the associated load is determined by increasing the probability of effectively transmitted parcel with only 10 hubs connected stacks. Results in fig .12 show that the throughput against the 2.4GHz repetition band is much higher than the other two repetition groups.

4. CONCLUSION AND FUTURE WORK

In this paper, we have assessed the presence of content access period of IEEE 802.15.4 standard in three diversified repetition modes. The effect of the same burden diversity in different recurrence groups has been disrupted in relation to finding chaotic channel chances during CCA1, CCA2, frustration prospects, dependence and throughput. Reproductive results show that during the 2.4GHz band the exhibition is better for any other two repetition groups, seriously affecting dependence during the cap through the extension of the burden.

In future work, we need to check the exhibit ratio of IEEE802.15.4 standard when we change the default parameters and need to break the best parameters for different loads.

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