A Collaborative Framework for Avoiding Interference Between Zigbee and WiFi for Effective Smart Metering Applications

Vikram. K. and Sarat Kumar Sahoo

***Abstract*—Energy management is one of the foremost priorities of research in many countries across the world. The introduction of modern information and communication technologies (ICT) are transforming the existing power grid, towards a more distributed and flexible "Smart Grid" (SG). The wireless sensor networks (WSN) are considered for data communication and are generally, incorporated with actuators to implement the control actions remotely. The wireless technologies like ZigBee (for automation), WiFi (for internet) and Bluetooth (entertainment) work in the 2.4GHz band. The coexistence of different wireless technologies working in the common area is unavoidable. Hence, this phenomenon degrades the performance of each other, due to the interference phenomenon. The wireless nodes with high energy had a great influence on the performance of the nodes working with low energy. Under the influence of interference, the low-power nodes experience the uncertain sleep-wake scheduling and increased delays in channel occupation. Interference also results in, high packet error rates (PER), decreased throughput, and high energy consumption. Hence for overcoming the above problems, A collaborative framework for an effective interference management and its avoidance is proposed in this paper. The framework proposed assures the effective ZigBee communication by systematic channel scheduling operating even under the influence of Wi-Fi. The work proposed performs better even under extreme interference conditions and the results obtained shows enriched performance.**

***Index Terms*—Advanced data communications, Home area networks, Interference, Smart meter, The 2.4GHz frequency band, Wi-Fi, ZigBee.**

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I. Introduction

THE energy management using advanced metering infrastructure (AMI) employs WSN for monitoring the power usage of the end-user [1]. The monitoring and control areas for smart grid applications is an important research area. Smart meters will allow the consumers to interact with the utility companies and allow to monitor the power consumption on an hourly basis towards consumer side. Thus, with the introduction of Smart metering, every building should become smart and should adapt the better communication system for transmitting the data. The Internet of Things (IoT) plays a prominent role in the information transfer and controlling the load. This allows the consumer to decrease electricity usage bills and on the utility side, they can properly assess the load supply the demand [2]. There is need for research in terms of collaborative communication between different networks so as to form network of networks and SG communication system demands this integration of networks [3]. The implementation of IoT is based on IEEE 802.15.4 standard [4]. The networks operating in same frequency band (2.4GHz unlicensed) effects each other's performance. The networks with different standards like IEEE 802.15.4 (IoT based on ZigBee communication) and IEEE 802.11(WiFi) need to coexist with each other and the issue is addressed in this paper.

In many applications of SG, the WSN has already replaced wired data communication systems [5]. WSN, in general, refers to the wireless network based on ZigBee nodes effectively employed for data communication. The important characteristics of the WSN include low cost, ease of deployment. WSN supports the smart grid in decision making through the remote management, data collection, querying abilities [6]. The wireless technologies like ZigBee, WiFi, and Bluetooth operate in the 2.4GHz unlicensed frequency band is shown in figure 1 below. The channel operating in 2.4GHz is distributed between frequencies 2400MHz to 2483.5MHz. The ZigBee operation is defined by IEEE 802.15.4 standard. The ZigBee technology consists of 27 channels for data communications. Among the available channels, one channel operates in the 868MHz frequency band, 10 channels operated in the 915MHz band and remaining 16 channels (channel 11 to channel 26) operates in the 2.4GHz frequency band [7]. The WiFi (Wireless Fidelity) operates based on the IEEE 802.11 standard in the 2.4GHz band. The WiFi generally has 11 channels (in the USA), 13 channels (in Europe) and 14 channels (in Japan). But among the available, only channels 1, 6 and 11 are useful for data communication [8]. The WiFi access points and clients (Laptop's) are usually very near to continuous power supply and shall maintain high link strength a with high data speed. Because of high link strength the channel 1 of WiFi overlaps with the channels 11, 12, 13 and 14 of ZigBee, channel 6 of WiFi overlaps the channels 16, 17, 18, and 19 of ZigBee, and finally, channel 11 of WiFi overlaps the channels 21, 22, 23, and 24 of ZigBee. Though channels 15, 20, 25 and 26 of ZigBee node are affected partially or remains unaffected (free from interference) the network programmer cannot opt for these channels [9].

The Bluetooth technology operates based on IEEE 802.15.1 technology. The Bluetooth has 79 channels operating in the 2.4GHz band. But the data communication using this technology will not be much affected because of the interference. It is because data communication is based on Frequency hopping spread spectrum (FHSS) technology. As soon the data transmission is initiated it keeps on changing the frequencies until it reaches the destination [10]. Hence it has fewer effects of interference from WiFi. But disadvantage Bluetooth is it consumes more energy and covers less distance when compared to ZigBee nodes [11].

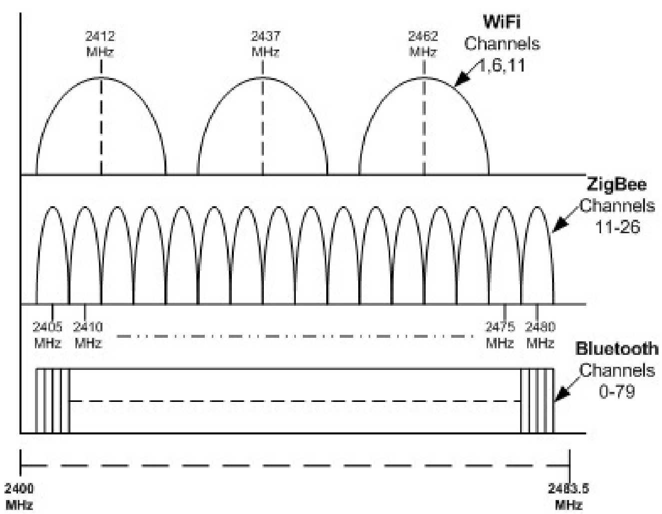

Fig. 1. Channel distribution of different technologies in 2.4GHz frequency band.

Though ZigBee is considered as a prominent technology for modern automation applications including IoT, it has certain difficulties in the coexistence mediums and research must be done to overcome the problems [12] [13]. The domestic applications like microwave ovens and cordless phones also emanate the electromagnetic radiation in the 2.4GHz band [14]. The coexistence of different wireless technologies in the vicinity of each other and working in the same frequency band affects the performance of each other. The performance of ZigBee in terms of packet delivery gets highly affected under the influence of WiFi when compared to Bluetooth. The electromagnetic radiation from the Microwave oven when switched ON will affect almost all the channels of ZigBee [15].

One of the best and emerging applications of WSN is monitoring the power system assets aimed at increasing the reliability of smart grid [16]. The prototype was developed for smart homes for monitoring the power usage and controlling purposes based on ZigBee communication [17]. The SecureHAN is based on ZigBee [18], employed for data communication about power usage between the appliance and the smart meter. Secure HAN emphasizes and addresses the complications raised due to the coexistence environment.

The Section II shows the background of the related works. Section III presents the mathematical model and algorithms. The mathematical results are presented in Section IV and the conclusion is given in Section V.

II. Related Works

The CCS algorithm is proposed for improving the performance of ZigBee operating under the influence of WiFi (IEEE 802.11b) operating in a 2.4GHz frequency [19]. The CCS comprises a scheduler to coordinate the signaling with temporary channel hopping for ZigBee data transformation operating in the vicinity of WiFi. The successive interference cancellation (SIC) to avoid the interference at physical layer level and improves the packet reception at the receiver side of ZigBee. In addition to SIC, the work also proposes the optimization model for the identification of accurate channel [20].

The advanced multichannel clustering algorithm aims for determining the interference and avoids it substantially. The algorithm proposed is aimed at improving the performance of ZigBee based cluster tree networks affected by WLAN access points (AP) and resolves the issues of channel utilization within the cluster [21]. The effects of interference on ZigBee communication in the coexistence model is based on the transmitter and receiver distance. The experimental setup based on distance and variation of distance for decreasing the interference has decreased the effect considerably [22]. The channel selection is a very significant parameter for better network performance. The algorithm ReSIST [23] is aimed for better channel selection and decreases the packet error rate (PER) significantly. The experimental evaluation of interference on IEEE 802.15.4 (ZigBee) in [24] by corresponding 2.4GHz frequency-based technologies like WLAN (IEEE 802.11b), Bluetooth (IEEE 802.15.1) and Microwave oven and the cordless phone is evaluated. It is discovered that the effect of Bluetooth on Zigbee results in PER of around 4%. The impact of WLAN on Zigbee can be avoided by better channel selection strategies and can limit the PER<10% can be achievable. Based on station assessment and determination of spectrum utility near cordless phone can only reduce the interference effects on ZigBee. Microwave oven radiation on 2.4 GHz WSN can be avoided by safer channel selection. The PER can be expected around 8% if the Zigbee node is placed at least 1.5m away from Microwave oven.

The work in [25] assessed the ZigBee propagation under WiFi interference for the applications of the smart grid. ZigBee may be to a great degree interfered by WiFi but if an “Ensured Distance” and “Safe Offset Frequency” is identified then it can be a better solution. It is exhibited that 8 meters between ZigBee and WiFi is considered as "secured" partition that can guarantee the better throughput for ZigBee. A multi-channel architecture in [26] was proposed for defeating the issue of concealed hubs and WLAN interference with the point of expanding packet delivery ratio (PDR). The Multi-Channel Cluster Tree (MCCT) convention with Adaptive Channel Access (ACA) calculation was proposed to decrease the effects of interference. Every sensor hub inside the system continuously examines each of the 16 channels by performing PDR measurements with a specific end goal to decide their inhabitance level. The facilitator performs counts for every channel to assure that every hub adds to the determination of the ideal channel as per set up needs.

The smart grid requirement for monitoring and control [27] have defined the necessity of the wireless sensors and actuator networks (WSAN). The WSAN is used for regulating the smart grid assets and calls for the prioritization of critical data. Two MAC layer-based algorithms were proposed. Firstly, delay aware cross layer algorithm (DRX) deals with delay estimation and prioritization of data. Secondly, the FDRX introduces the fairness into DRX and avoids few dominating nodes from occupying the communication channel. The work in [28] evaluates the performance of ZigBee based IoT aimed for smart homes under the close proximity of WLAN it is observed that because of coexistence the response time is getting affected. Hence the work carried will guarantee the delay experienced by ZigBee while maintaining the data rate of WLAN. The cross- layer multichannel MAC protocol was introduced in [29] for interference avoidance between WiFi and ZigBee operating in the 2.4GHz frequency band. Based on the present state interference calculation, the forthcoming interference is estimated based on hidden Markov model and based on the estimation the channel with low interference is assigned. Then when the packet reaches near the destination it will be processed by CMCMAC-FEC algorithm to recover the data lost because of collisions occurred during the transmission process.

III. Proposed Work

In our previous works, we have proposed a WSN protocol CMCMAC, aiming for strengthening the wireless data communication keeping in the view for smart metering applications [13]. The CMCMAC works efficiently for external interference and assures improved performance of IEEE 802.15.4 based network working in the vicinity of IEEE 802.11b. Initially, it estimates the delay and Received signal strength indicator (RSSI) values for all the possible linkages between the nodes in the network. After obtaining the initial values, the Hidden Markov Model (HMM) based prediction is employed for anticipating the channel with no interference. Then, clear channel assessment (CCA) period was adjusted to obtain the specified channel with in stipulated time based on the estimation from HMM. The fairness offered was obtained by adjusting CCA that was again dependent on MAC layer and Physical (PHY) layer regulations. In [27] a new forward error correction algorithm was added to the above work (FEC-CMCMAC). This algorithm mainly aims to improve the performance of above work so as to restore the collided data (partially lost) due to the data collision occurred because of external interference or internal interference. Though it notices the interference systematically, the channel shifting process is not practical and hence consuming a substantial amount of delay. Hence, for surpassing the above problem in 2.4GHz ISM band, the PSOLACES (Particle swarm optimization-based load aware channel estimation and channel scheduling for Zigbee networks under the influence of WiFi) was proposed [9]. The PSOLACES based collision-free multichannel super frame scheduling was employed to communicate the data without any collision. The channel with best energy function was selected for data transmission.

A. *The Collaborative Framework for Avoiding Interference between Zigbee and WiFi networks.*

A collaborative framework for avoiding the interference (CFAI) between the ZigBee and the WiFi nodes is proposed in this paper. The efficient and improved ZigBee communication under the interference conditions from WiFi is an important research problem considered in this paper. When compared to our previous works, in this paper we have proposed an improved mathematical analysis for avoiding interference. The block diagram of proposed work is pictorially represented in figure 2.

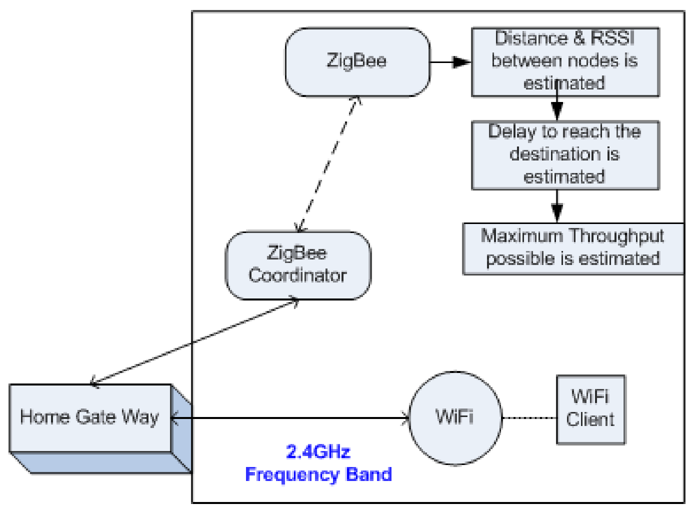

Fig. 2. Block diagram of the proposed work.

The architecture considered for the implementation of CFAI is as shown in figure 3. The modern smart home considering ZigBee for automation, WiFi for accessing internet and Home Gate Way (H\GW) acts as Smart meter for SG based energy management. The figure 3, consists of 4 ZigBee coordinators, connected through a wireless connection to about 17 ZigBee nodes. Where Each ZigBee coordinator is connected to about 4 to 5 ZigBee nodes. There are 4 WiFi access points (AP) and about 5 WiFi clients, each AP is connected to 1 to 2 WiFi clients. The position of all the nodes is assumed and placed such that they fall under each other's influence. The Zigbee coordinator and WiFi access points are connected to Home Gate-Way

(HGW) through wired network as shown in the figure. The HGW can be considered as Smart Meter.

CFAI helps in finding the best channel, based on minimized delay, and assures high throughput by effective channel utilization by maintaining good link strength. The CFAI allots ranking for the channels based on the chances for effective bandwidth utilization. When source node (ZigBee) is ready for data transmission, it estimates the quality of the channel for effective communication in the coexisting environments. Based on the quality of channel it transmits the information as early as possible. All the communication between ZigBee sensors and HGW is accomplished through the ZigBee coordinator. The CFAI is based on the arrangement as shown in the Fig. 2. CFAI reduces the interference based on the realization of distance and (RSSI) between two nodes, delay estimation, and throughput estimation. Initially, when the WSN node is ready for data communication to the destination (ZigBee coordinator), the source node estimates the distance and RSSI parameters for understanding the link strength.

1) Realization of the Distance and RSSI

Consider the reference node (WLAN) $b_n = (b_{n1}, b_{n2} \ldots b_{nN})$ is focusing on path loss that can be expressed as a function of distance

$$P_L(\bar{d}_{hi}) = P_L(d_0) + 10n\log\left(\frac{\bar{d}_{hi}}{d_0}\right) \tag{1}$$

Where $\bar{d}_{hi}$ is the distance among the node *h* and anonymous node *i*, d_0 is the reference distance (for ZigBee typically the value of d_0 is taken to below 10m), *n* is considered as path loss exponent (the rate at which the signal/decay). The RSSI value $\mathrm{P^r}$ at a distance $\bar{d}_{hi}$ is

$$\mathrm{P^r}(\bar{d}_{hi}) = p^t - P_L(\bar{d}_{hi}) \tag{2}$$

For each pair of *nodes (h, i)* which is in transmission range(*r*), we can measure the received signal strength (P^r_{hi}). The set of such pair is as follows.

$$\Psi = \{(P^r_{hi}, \bar{d}_{hi}) : \|S_k - S_i\|^2 < r\} \tag{3}$$

The activity of AP in a node *i* and *h* can be represented by. It describes the activity of the node S_i seen by the node S_k that means distance, RSSI and path loss of the nodes. It depends on the transmission activity of node S_k and S_i. The activity of $A_{k,i}$ is a relative value between one and zero.

$$A_{k,i} = t_i(|Channel(S_k) - Channel(S_i)|) \tag{4}$$

Where t_i is the time that node S_i is active (measured between one and zero).

The arithmetic means of the transmission time of busy slots, denoted by *T*

$$T = (T_s \times (1 - P_c)) + (T_f \times P_c) \tag{5}$$

where P_c is the probability of unsuccessful transmission because of the collision.

The slot admittance probability of a node *i,* to the adjacent node *h,* computed at the position of node *k* and it represented by $\tau_i^{(k)}$. The arithmetic means of channel utilization of a node *i* from $\tau_i^{(h)}$ denoted by U_h, that is not disturbed by changes of neighboring nodes, U_h can be expressed as,

$$\mathrm{U}_h = \frac{c_n T(t)}{t} \tag{6}$$

where c_n is the number of occupied slots and *T(t)* is the average broadcast time of *node i* for the duration of *t*.

Let S_i be the set of all the nodes near to node *i.* The average busy slot size of node S_i is T_i. The average channel utilization of set S_i denoted by U_{Si}

$$U_{S_i} = \frac{(1 - \prod_{i\grave{o}S_i}(1 - \tau_i^{(h)}))T_i}{P_i^{(t)}T + P_n\sigma} \tag{7}$$

Since, $P_i^{(T)} : \tau_i^{(h)} = U_{S_i} : U_t$, we get $\tau_i^{(h)}$ with equation (6)

$$\tau_i^{(h)} = U_h \frac{P_i^{(T)}T_i + P_n\sigma}{T_i},$$

$$\tau_i^{(h)} = \frac{U_h\sigma}{(1 - U_{S_i})T_i + U_{S_i}\sigma} \tag{8}$$

In the steeped condition, slot admission probability is extended. From [9], we can achieve the comprehensive value of $\tau_i^{(h)}$ measured at its location as

$$max(\tau_i^{(h)}) = \frac{2(1 - 2P_{hi}^{(f)})}{(1 - 2P_{hi}^{(f)})(W' + 1) + P_{hi}^{(f)}W'(1 - (2P_{hi}^{(f)})^{BF})} \tag{9}$$

Where, W' is initial window size, *BF* is maximum back off stage, $P_{hi}^{(f)}$ be the probability of communication failure caused by the packet collisions is given by,

$$P_{hi}^{(f)} = 1 - (1 - P_{hi}^{(I)})(1 - P_{hi}^{(C)}) \tag{10}$$

The probability of communication failure initiated by interference and data packet collisions, indicated by $P_{hi}^{(I)}$ and $P_{hi}^{(C)}$, is given by

$$P_{hi}^{(I)} = 1 - \prod_{i\in S_i}(1 - \tau_i^{(h)}) \tag{11}$$

$$P_{hi}^{(C)} = 1 - e^{(-\gamma/\lambda k)} \tag{12}$$

where, γ be the collision period and λk be the average packet arrival rate of the *node k* in the set of *AP's*. Equation (13) demonstrates the throughput of node *i* once correlated with an *AP* is denoted as

$$T(S_k) \mid A_{h,i} = \frac{\mathrm{P^r}(\bar{d}_{hi})}{T_i} \sum_{i\in S_i}(1 - P_{hi}^{(f)})U_{S_i} \tag{13}$$

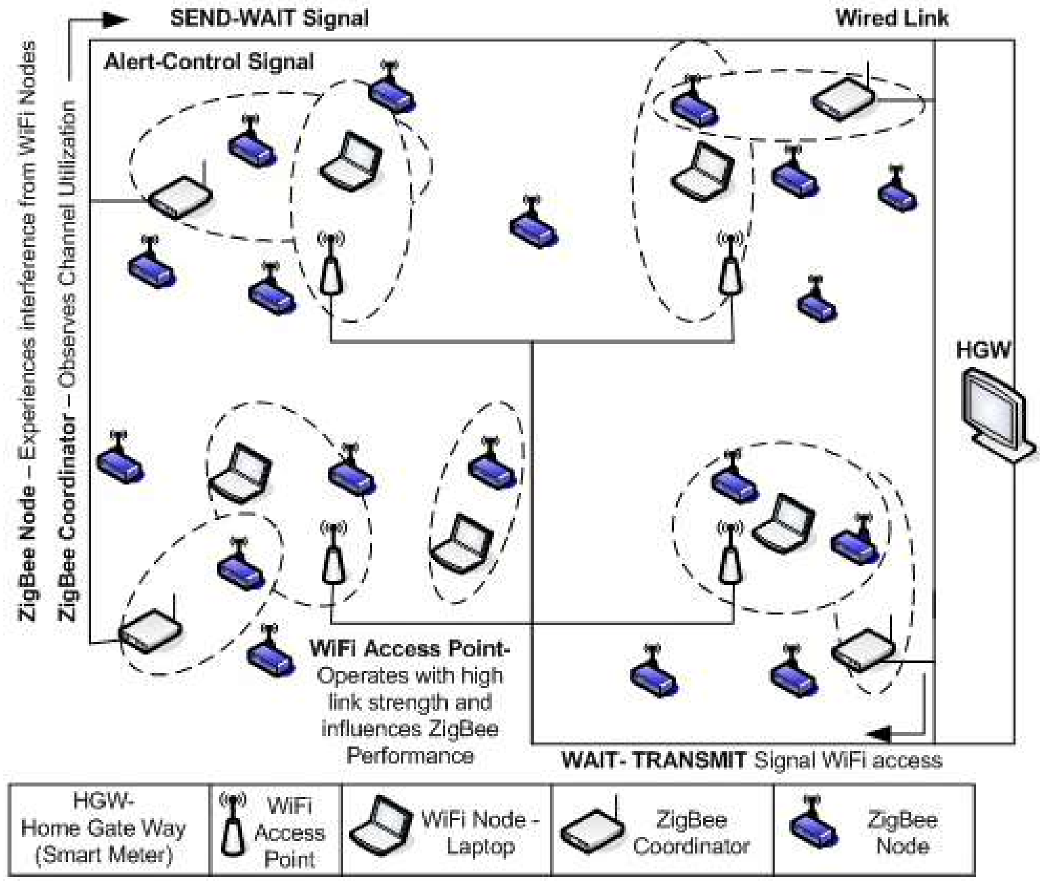

Fig. 3. The architecture of smart home environment.

After the distance and RSSI values are estimated then the delay is estimated for increasing the fairness for assuring the data communication within the time.

2) Delay Estimation

Let $Z = (z_{1a}, z_{1b})$ denotes the coordinates of ZigBee nodes that experience interference from the WiFi node. The arithmetic means of interference strength accepted at the ZigBee coordinator, *z* is

$$P^{\text{int}}_{z,i} = \frac{\sum_{i \in S_z} \tau_i^{(z)} T_i P_{z.i}}{U_z} \tag{14}$$

Where, $P_{z.i}$ is the beacon power obtained by the Zigbee coordinator, z.

The small difference in the delay may introduce the errors in the data due to the collision at the receiver side, because of the interference, the estimation of the Bit error rate (BER) value for the ZigBee sensor is as given below,

$$BER^{(k)}_{z,s}(P_{z,i}) = \frac{1}{2} - \phi\left(\sqrt{\frac{2P_{z,i}}{P_z^{(n)} + P_{z,i}}}\right) \tag{15}$$

Where, $\phi(\gamma) = \frac{1}{\sqrt{2\pi}} \int_0^{\gamma} e^{\left(-\frac{u^2}{2}\right)} du$ is the standard distribution function. from (14), the PER for the packet communicated from the ZigBee sensor, *s* to the Zigbee coordinator, *z* is given as

$$P^{(e)}_{s,z} = (1 - BER^{(k)}_{z,s}(0))^{L_p(1-U_c)} (1 - BER^{(k)}_{z,s}(P^{\text{int}}_{z,i}))^{L_p U_z} \tag{16}$$

where, L_p be an average size of a ZigBee packet and U_z is the WLAN channel utilization detected at the coordinator, z.

In (16), $BER^{(k)}_{z,s}$ is the ‘zero’ if WiFi is ideal, doesn’t communicate but ZigBee sensor *s* is ready to communicate a packet to coordinator *z*.

Let S_z be the group of ZigBee sensors that are within transmission range of the coordinator, z. Using (16), we discover the PER of the coordinator, z as

$$P_z^{(e,s)} = \frac{\sum_{s \in S_z} \varphi_s P^{(e)}_{s,z}}{\sum_{s \in S_z} \varphi_s} \tag{17}$$

where, φ_s be the average packet arrival rate from WiFi node

$$U_z = \frac{T_i}{T_i + a\sigma} \tag{18}$$

Where, *a* is the number of empty slots between WiFi packet transmissions.

By means of (18), the probability that any WLAN packet is not communicated in the empty time slots is given as

$$P_a = 1 - \frac{T_i + 2T_{slot}}{T_i + a\sigma}, \quad P_a = 1 - U_z - 2U_z \frac{T_{slot}}{T_i} \tag{19}$$

Let *BF* and *R* denote the max. a permissible number of Back-Off stages and the highest number of retransmissions allowable just after a communication failure. Then, we have the frame failure probability due to collisions with the WLAN packets $P_z^{(f)}$ as follows:

$$P_z^{(f)} = 1 - (1 - c_z^{(f)})^R \tag{20}$$

Where is the probability that the only packet communicated by the Zigbee node which is given by

$$c_z^{(f)} = (1 - P_n)^{BF} + (1 - (1 - P_n)^{BF}) P_z^{(e,s)} \tag{21}$$

Using (19) and (20), $\overline{A}_{BF}$ can be expressed as

$$\overline{A}_{BF} = P_a \frac{W' + 1}{2} + \sum_{S_i = 1}^{BF} (2(1 - P_n)) S_i \frac{W' + 1}{2} \tag{22}$$

The arithmetic mean delay for a single transmission attempt $[D]_s$ is a combination of [sleep period, Back-Off, and frame communication time],

$$[D]_s = \frac{\overline{A}_{BF}}{N_{SF}} (T_{bi} - T_{sf}) + \overline{A}_{BF} T_{slot} + \{1 - \left(U_z + 2U_z \frac{T_{slot}}{T_i} \right)^{BF} \tag{23}$$

where, T_{bi} is beacon interval and T_{sf} denote the superframe duration, in the ZigBee network, and N_{SF} is the no. of slots in a superframe.

From Eq. (23), the average successful transmission delay for a ZigBee packet is obtained as:

$$Delay, D = \frac{1 - (P_z^{(f)})^R}{1 - (P_z^{(f)})} [D]_s \tag{24}$$

3) Throughput Estimation

In WSN, let us consider the set of sensor nodes S_k, where *k=1, 2, 3…, n* with known and unknown positions in the area considered, expressed as m-dimensional coordinates. Let, T_s and T_f be the mean time duration of successful and unsuccessful transmissions correspondingly is given as below,

$$T_s = H_{phy} + \frac{H_{mac} + \mathrm{P_r}}{d} + SIFS + ACK + DIFS \tag{25}$$

$$T_f = H_{phy} + \frac{H_{mac}}{d} + ACK_{timeout} + DIFS \tag{26}$$

Where P_r is the signal strength of the data frame, H_{PHY} & H_{MAC} is the PHY and MAC header respectively and *d* is the distance between the nodes.

The probability of collision due to transmissions by any one of *n* active nodes and other nodes is given by,

$$P_c = \tau'(1 - (1 - \tau)^n) \tag{27}$$

Where, τ and τ' denoted as transmission probabilities of slot per *n* active nodes and other nodes.

The average slot duration is given by,

$$T_{slot} = P_s T_s + P_f T_f + P_{idle}\sigma - P_c \min(T_f) \tag{28}$$

where P_s be the probability of successful transmission appears in a slot for n^{th} active node. P_f is the probability of unsuccessful transmission occurs in a slot for n^{th} active node. σ is the duration of empty slots, P_c is the probability of collision among nodes. P_{idle} is the probability that a slot is idle, which is given by $P_{idle} = (1 - \tau')(1 - \tau)^n$.

Let us consider node *j* is interferer with *h* retrieves the channel at the location of node *i* transmits.

Let $P_i^{(t)}$ denote the probability of transmission for estimating the interference that at least one among the available nodes can interfere with node *i*. The probability is given

$$P_i^{(t)} = 1 - \prod_{h \in S_i} (1 - \tau_i^{(h)})^{n_i} \tag{29}$$

where is the set of all the *i* number of nodes and n_i is the active nodes among set S_i. The transmission probability $\tau_i^{(h)}$ of channel at *h* retrieves the node *i* through the particular *AP*. The value of the distance and received signal strength and channel quality of each node at the allocated time slot are derived in (1) and (2).

The probability that the node in a set S_k transmits in the considered slot for the particular AP

$$P_s = \sum_{S_i \in S_k} \tau_{S_i} \sum_{i \in S_i, i \neq h} (1 - \tau_i^{(h)}) \tag{30}$$

The probability that no node in a set S_i communicates in the considered slot (idle),

$$P_n = 1 - P_i^{(t)} \tag{31}$$

IV. Performance Evaluation

The ns 2.34 simulation tool is enhanced for simulation results by extending the libraries of IEEE 802.15.4 and IEEE 802.11 based on the requirements, by analyzing the interference between the ZigBee and WiFi networks. The area considered is 500*500 sq. meters. The parameters considered for simulation are considered in Table I.

TABLE I
Parameters and values for simulation

Parameters	Values
ZigBee protocol	IEEE 802.15.4
WiFi	IEEE 802.11b
HGW (Server)	1
WiFi Access Points	4
WiFi clients	5
ZigBee Coordinator	4
ZigBee Sensors	17
Simulation time	300 secs
Routing Protocol	AODV
Bit rate	250 Kbps
ZigBee Node Energy	10 J
ZigBee Tx Power	0.5mW
ZigBee Rx Power	0.3mW

The proposed is architecture is carried based on the smart home architecture proposed in Fig. 3. The typical network is considered consists of 17 ZigBee nodes, 4 ZigBee coordinators, working the in the influence of the 4 WiFi AP's, and about 5 WiFi clients. The CFAI model proposed in this paper aims for controlling the traffic of WLAN which tolerate continuous transformation of ZigBee and the highest tolerable delay is avoided as a result of the WLAN interference. The CFAI assures the efficient ZigBee based operation, by the assessment of distance between source and distance based on the RSSI parameter. Then CFAI assures for Channel availability based on the delay and channel weight (T_S, T_F & P_s) calculations. The evaluation of CFAI is carried based on the comparison to the following works. The K. Hong et al. [28] have proposed the algorithm for the efficient operation of the ZigBee working under the influence of WiFi. The authors have focused on the channel utilization but have not considered the traffic generated in the network due to the overhead and this has a serious impact on the network life time. The work proposed in [9] was for the indoor environment based on Wireless HAN having ZigBee and WiFi that are coexisting in the same area. This work has considered the load scheduling effectively but have not considered the Channel utilization parameter. The CMCMAC-FEC [29] was proposed for coexisting mechanism environment and have considered efficient packet delivery towards receiver side and also arrangement was there for finding the low interference effected channel. But could not assess the channel utilization effectively. The CFMSS [30] have proposed a systematic algorithm for assuring the efficient ZigBee performance. But the authors have not considered the coexisting environment with WiFi nodes

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The information from WiFi (AP) is downloaded from each node of WiFi. For each and every WiFi node, the packet entry follows a neighbor strategy along with a mean value. The ZigBee network works with constant bit rate (CBR) runs at the data rate of 27Kbps for every second. WiFi node receives the data from the AP. The WiFi node receives the data at a maximum rate up to 12Mbps for every second. The simulation runs for 300sec. The ZigBee node has to wait, until Back-off period to occupy the channel for the transmission of the data, when interference occurs this is considered as delay (D). The value of '*D'* is Considered by taking the two scenarios 10ms and 50ms. The simulation is carried for channel utilization by considering different data delays like D=10ms in Fig. 4 and D=50ms in Fig. 5 for evaluation of CFAI.

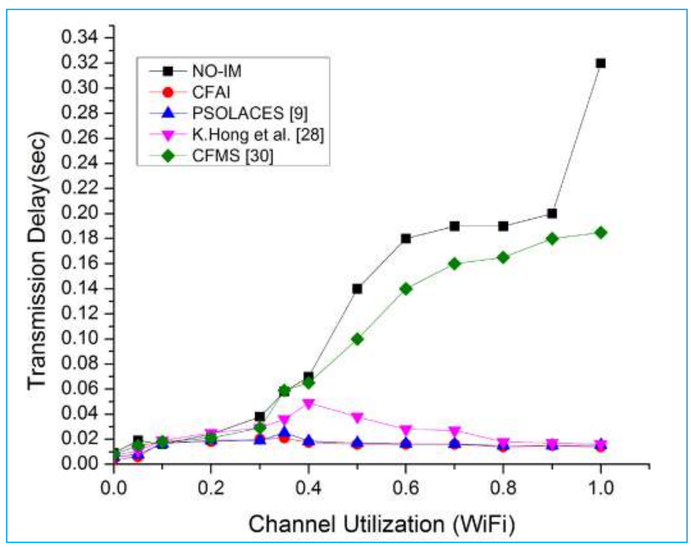

Fig. 4. Transmission delay in Zigbee network. (Delay D=10ms).

From the Fig. 4 and Fig. 5, it can be inferred that the ZigBee network works better considering CFAI methodology when the volume of data transmission from WiFi is increased. CFAI performs better compared to the existing method as in [28], [9], [30] and when there is no interference mitigation methodology (NO-IM). Fig. 4 delay D is considered as 10ms and in Fig. 5 delay D is considered as 50ms.

The Fig. 6 evaluates the performance of CFAI in terms of an average number of packets generated per second when different number of nodes is considered. The CFAI performance is compared to the existing works like [9], [28]-[30]. The average number of packets generated by ZigBee network based on CFAI is very economical compared to the others. The ZigBee network performance is also evaluated for 4 nodes, 8 nodes, 12 nodes and finally 17 nodes based on network sizes. In all the scenarios for various network sizes, the CFAI performance is very better compared to the other works.

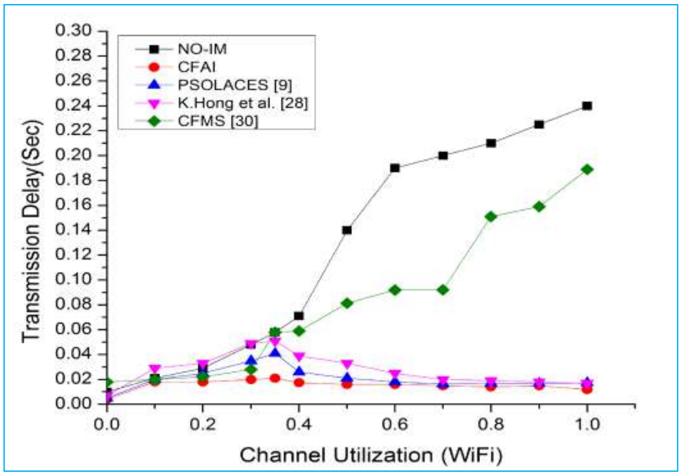

Fig. 5. Transmission delay in Zigbee network. (Delay D=50ms).

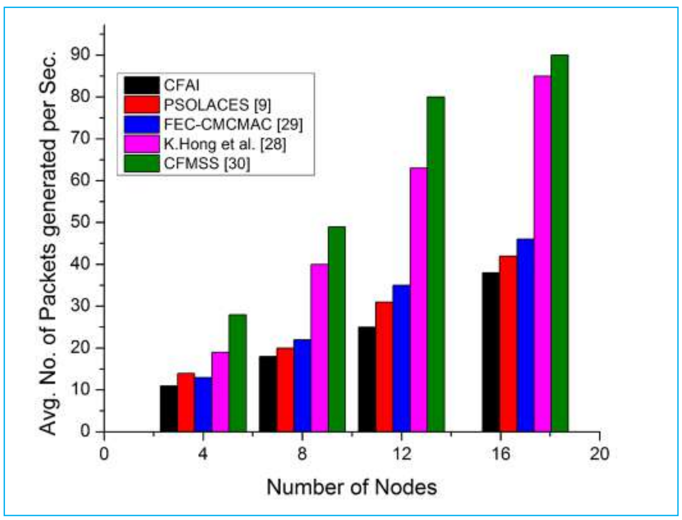

Fig. 6. Average Number of Packets Generated per Second.

The Fig. 7 below represents the number of acknowledgements received by the respective source nodes that have generated packets transmitted to the destination. In this scenario the ZigBee network varied by 4, 8, 12, and 17 nodes respectively. From the graph above it can be inferred as the CFAI methodology works better when compares to other works considered [9], [28]-[30]. The number of acknowledgement messages received by ZigBee nodes shows 100 percent when network size is 4 and 8. The number of Acknowledgement messages received when network size with 12 and 17 nodes considered is above 90 percent. The results obtained in various scenarios strengthens the CFAI model as the most suitable for the Coexisting environment.

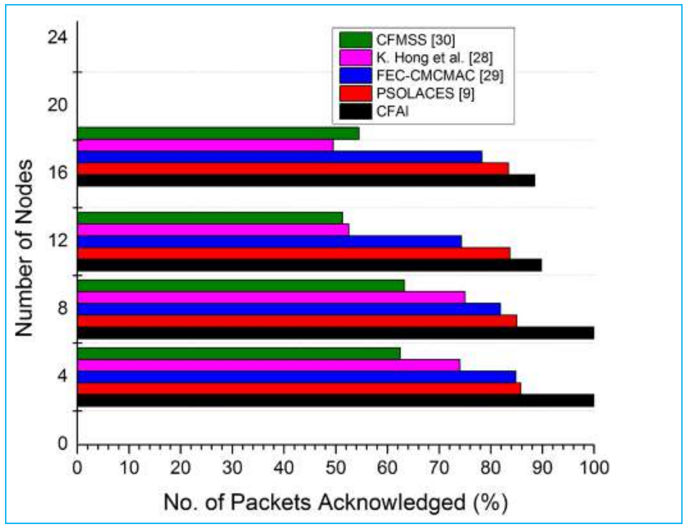

Fig. 7. Number of Acknowledgements received by Source Nodes.

Based on the above results when compared to other works CFAI is working much better and has improved the performance of ZigBee network working under the influence of the WiFi.

V. Conclusion

The employment of wireless networks like Zigbee and WiFi for data communication in the HAN premises is unavoidable. Both the networks considered are operating in 2.4GHz frequency band. It is considered as no radio is immune to the occurrence of interference. This interference occurs is because of overlapping of the frequency channels in the same band and it exactly occurs when ZigBee node and WiFi desires to transmit at the same instance. In general, the WiFi node with high energy shall occupy the channel. To carry out the efficient operation of IEEE 802.15.4 based ZigBee network there is a need for a coexisting mechanism for managing the operation of low-power network in particular. In this paper, CFAI methodology is proposed for improving the performance of ZigBee network which is operating in the vicinity of WiFi. From the results obtained it can be inferred that CFAI performs better when compared the existing methodologies like PSOLACES [7], K. Hong et al. [26], FEC-CMCMAC [27] and CFMSS [28]. and when no interference mitigation is present. The CFAI based ZigBee network shows better channel occupancy, and other network parameters considered as shown in the results and also assures better data rate with good throughput even under the coexistence of WiFi.

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