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Energy Procedia 117 (2017) 847–854

Energy Procedia

www.elsevier.com/locate/procedia

1st International Conference on Power Engineering, Computing and CONtrol, PECCON-2017, 2-4 March 2017, VIT University, Chennai Campus

Forward Error Correction based Encoding Technique for Cross-layer Multi Channel MAC protocol

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Abstract

The advancements in the home area networks call for wireless data transmission for continuous monitoring and taking control decisions to strengthen the smart grid technologies. The wireless sensor networks (WSNs) using Zigbee, WiFi operating in 2.4GHz frequency band play a key role in the data transmission. Because of coexistence in the same frequency band, there is a need for research to develop a mechanism for avoiding interference and proper encoding for precise data retrieval. In our prior work, we have presented a cross-layer multi-channel MAC (CMCMAC) [25] protocol for WSNs for estimation and avoiding interference. In this paper we propose an algorithm, Forward Error Correction (CMCMAC-FEC) encoding technique for improving the performance of CMCMAC in order to enhance reliability in communication of the data by ZigBee nodes to the specified destination under the influence of WiFi environment. In this paper, the CMCMAC-FEC model estimates the corrupted Zigbee packets and recovers the corrupted data packets at the destination accordingly maximizing the packet delivery ratio and throughput. The results attained illustrate the enhanced network performance.

Peer-review under responsibility of the scientific committee of the 1st International Conference on Power Engineering, Computing and CONtrol.

Keywords: Home area networks; Smart Grid; Interference; Wireless sensor networks; WiFi; ZigBee; Error correction;

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Peer-review under responsibility of the scientific committee of the 1st International Conference on Power Engineering, Computing and CONtrol.
10.1016/j.egypro.2017.05.202

1. Introduction

With the integration of communication and control technology, the traditional power grid is getting renovated as the smart grid to make intelligent decisions according to the fluctuations that take place in any part of power systems (i.e., generation, transmission and distribution systems) [1]. Great attention is required in case of distribution systems because it involves with the interoperability between various technologies working together and requires consumer participation [2]. The information is generated and communicated in a timely manner by employing the wireless sensor and actuator networks (WSAN) coordinating various electrical equipment's, for their condition monitoring enabling smart grid to take critical decisions assuring high reliability [3]. The technical review in [4] is focused on the communication requirements of advanced metering infrastructure (AMI) for home area networks (HAN) of smart grid and compared the functioning of various wireless network providers like WLANs or WiFi (IEEE 802.11), Zigbee (IEEE 802.15.4), 6LoWPAN, Bluetooth, Ultra Wide Band (UWB), etc., and recommended ZigBee radio communication for HANs. The HAN preferably employee the Zigbee based wireless network for smart home automation and AMI purposes because it is available at low cost, works efficiently with low data rates and less power consumption [5].

Based on IEEE 802.15.4 regulations [6] Zigbee communication standards were defined. The continuous revisions of the standard IEEE 802.15.4 regulation [7] signifies the essence of standardizing the quality of service (QoS) parameters based on the latest technological advancements depending on the area of application. When two or more different networks (Zigbee, WiFi or Bluetooth, etc.,) operate in the close proximity of each other interference occurs and degrades the overall performance of the WSN[8]. Though ZigBee networks are extensively employed for HAN's their usage in the vicinity of WiFi (IEEE 802.11) is unavoidable resulting in the coexistence difficulties causing in failing to fulfill the latency requirements of applications [9]. The interference occurs mainly because of coexistence in the same frequency band (2.4GHz) and is specifically because of channel overlapping of Zigbee (channel 11 to channel 26) with the WiFi (channels 1, 6, 11 in general) this results in the substantial service degradation because the transmission power of ZigBee is extreme lower than WiFi [10]. The work presented in [11] described the performance of WSN getting degraded due to the presence of noise and interference. The bandwidth of the link at receiver depends on various parameters like bit error rate, packet reception rate and the quality of the link based on signal strength [12].

The paper is structured as follows. The section 2 deals with the related works. The details of CMCMAC-FEC protocol and the algorithms used for implementation are given in section 3. The details of simulation parameters and graphical representations are presented in section 4. Finally, section 5 concludes the paper.

2. Background of Related Works.

The idea behind implementation of smart grid is for increased monitoring technology through prioritizing the data by the maintenance of the low latency levels by enhancing the network parameters is highly anticipated [13]. The delay-response (DRX) transmission of data [14] and fairness (FDRX) in data transmission [15] were introduced to MAC (medium access control) based on the cross-layer architecture. The operation of the DRX is for MAC sub-layer on the basis of the delay estimation as well as the data prioritization procedure which is executed by the application layer, along with handling the service needs of the smart grid application. Fairness is included into DRX by FDRX by avoiding some sensor nodes from controlling the involved channels. A WSN based cross layer protocol was presented in [16] by estimation of link quality at PHY layer, MAC layer maintains QoS parameters and appropriate channel resources are planned by network layer thus making this work more suitable for smart grid applications. A cognitive communication based cross-layer framework was implemented for mitigating the noise in congested spectrum bands, by proper channel allocation with high link quality to overcome the high data traffic scenarios of smart grid conditions [17].

A model was presented to enhance the performance of WSN based on the effects caused on the data propagation in the indoor environments using 2.4GHz frequency bands and analyzed the effects by considering the reliability of network in terms of PER and active times of sensor in dynamic environments [18]. The work in [19] developed interference avoidance algorithm identifies the ZigBee channels overlapped by WLAN channels in the coexistence environment and avoids interference by switching Zigbee nodes to safe channel based on the safe distance and safe offset frequency parameters and also decreasing the PER and improving overall performance. The work in [20] evaluates the effects of electromagnetic interference on Zigbee nodes in 2.4GHz environment and analyzed the effects on the energy consumption of node for estimating the life time of a battery.

To expedite the Zigbee data packets to be magnificently communicated under WiFi channel there are two distinctive ways collision avoidance [21] based approach and collision recovery based approach [22]. In the coexistence environment under WiFi and Zigbee for data transmission can only be possible when the WiFi channel is in idle duration time (white space) the Zigbee has to utilize this time to transmit the packets with suitable size with less collision probability so as to adjust the white space. Collision recovery based approach is useful if minor part of data packet is getting collided, then it can be recovered by error correction based approach [22] [23]. A real- time transmission scheme [24] improves the performance of Zigbee under WiFi interference environment by employing proper encoding algorithm for recovering the corrupted Zigbee packets and thus improving packet delivery ratio by maintaining low latency. The CMCMAC protocol in [25] was proposed to avoid the interference between the channels, the future interference is predicted using the Hidden Markov Model (HMM), then based on the prediction, a channel with the minimum interference is selected for data transmission to enhance the network performance.

3. Forward Error Correction based Encoding Technique for Cross-layer Multi Channel MAC protocol.

The CMCMAC protocol for avoiding interference was developed aiming for coexistence environment operating in 2.4GHz frequency band. Implementation of CMCMAC involves, firstly the existing interference approximation is done, secondly future interference is anticipated based on hidden Markov model (HMM), thirdly channel with least interference is assigned for Zigbee transmission and additionally in this paper we are introducing an algorithm called as the forward error correction (FEC) encoding technique(CMCMAC-FEC) for the recovery of collided packets that are corrupted due to the collision during completion of idle time (white space) of WiFi. The employment of this technique has shown significant improvement in parameters like the packet delivery ratio and throughput.

3.1. Estimation of Interference Level.

Interference depends on the combination of the intensity and density of channel traffic. Hence, to determine the interference level in the channel, it is necessary to estimate intensity level as well as the density value around the channel. The RSSI depicts the received signal strength in the surrounding. Thus, RSSI can be used an intensity indicator. The COR is defined as a time ratio utilized by the interference. Thus, the COR is used as the density indicator. Based on the RSSI and COR value, the interference is estimated. Then on the basis of the HMM, the future interference level is predicted. This process is described in algorithm 1.

Algorithm I – Estimation of delay and interference.

1. Let D_{avg} be the average delay in data transmission from source till destination, P_T be the probability of n packets reaching the destination within time interval T, D Delay in transmitting n packets from source in time interval T, then the average delay in the network is estimated according to equation (1),

$$D_{avg} = P_T * D \tag{1}$$

2. The *RSSI* (received signal strength indicator) value is estimated according to equation (2), d is the distance between source node and destination, q is the propagation path loss exponent and A is the received signal strength at one meter of distance,

$$RSSI = 10.q.\log_{10}(d) + A \tag{2}$$

3. The *RSSI* value is estimated for *N* number of rounds taken to collect *W* number of *RSSI* readings taken in each round within *TI* time interval.
4. Then $RSSI_{avg}$ is estimated according to equation (3),

$$RSSI_{avg} = \frac{(Total\ sum\ of\ RSSI\ readings)}{(Total\ number\ of\ RSSI\ readings)} \tag{3}$$

5. The channel occupancy rate *COR*, is calculated according to equation (4),

$$COR = \frac{N}{W} \tag{4}$$

6. The estimated interference level I_{est} is estimated by the two tuple $(RSSI, COR) = (RSSI_{avg}, N/W)$ represents the interference level.

In this way, the interference in the network at the current time is determined, based on the intensity and density of the network traffic.

3.2. Prediction of future interference based on HMM.

The HMM (Hidden Markov model) is an analytical Markov model in which the system being modeled is assumed to be a Markov process with unobserved (hidden) states. This model defines a system if it satisfies the following Markov properties as follows: given the present state event, then future and past events are independent. The estimated interference level gives us the information of the present interference. Based on the current interference information, the future interference value can be predicted this is performed using the HMM. The HMM is a stochastic technique for selecting among available channels and subsequently the process of estimating an output sequence. But, the series of state alterations are hidden. These states can be detected only through the classification of symbols. Majorly, it involves the persistent finite-state Markov chain variables depicting the output and a selection of every transition for the variable in the chain. The process of predicting the future interference is defined in algorithm 2.

Algorithm 2 – Interference prediction.

1. The transmitting node passes the I_{est} estimated interference levelvalue to the HMM.
2. The fixed sequence of the duration *TI* is given by equation (5)

$$TI = TI_1,\ TI_2, \ldots\ldots\ldots TI_L \tag{5}$$

3. The sequence of the hidden states *HS* is given by equation

$$HS = \{HS_1,\ HS_2,\ \ldots\ldots\ldots\ldots HS_n\} \tag{6}$$

4. The probability of interference prediction, I_{pred} for the given *TI* is given by equation (7) is based on V_{ni} observation state probability,

$$X(I_{pred} \mid TI, \delta) = \prod_{t=1}^{L} P(I_{est(t)} \mid n_t, \delta) = v_{n1}(I_{est(1)}) * v_{n2}(I_{est(2)} * \ldots . * v_{nL}(I_{est(L)}) \tag{7}$$

5. The probability of the interference level sequence is given by equation (8) where π_{ni} is the probability of initiating in state I for n hidden states and n_t is the observation sequence,

$$P(TI \mid \delta) = \Pi_{n1} u_{n1} u_{n2} u_{n3} \ldots u_{n(L-1)} u_{nL} \tag{8}$$

6. On the basis of fixed sequence and hidden sequence depicted in equation (5) and (6), the probability of correct prediction of the future interference is given by equation (9), Where Iest(t) is the estimated interference value for time t,

$$\sum_{TI} P(I_{\Pr ed} \mid TI \mid \delta) P(TI \mid \delta) = \sum_{n_1 \ldots n_L} \Pi_{n1} v_{n1}(I_{est(1)}) u_{n1n2} v_{n2}(I_{est(2)}) \ldots . u_{n(L-1)nL}(I_{est(L)}) \tag{9}$$

Thus, the future interference is predicted on the basis of this prediction, the channels with higher interference can be determined prior to data transmission and hence it can be avoided accordingly.

3.3. Data transmission through channel with least interference.

When transmission of data is initiated, the source node ready to transmit analyzes the predicted interference at each channel and compares it with a threshold value. On the comparison and the value of the predicted interference, at each channel the value of interference is decided as low or high. This process is described in algorithm 3.

Algorithm 3 – Least interference data transmission.

1. The D_{avg} is the average delay in data transmission is compared with D_{Th} threshold delay.
2. If D_{avg}>D_{Th}, then the MAC sub-layer appeals the physical layer to decrease the CCA (Clear channel assessment) duration by half. Hence, the physical layer senses the channel in half the duration of the original CCA duration.
3. This reduces the delay considerably
4. Simultaneously, the predicted interference level I_{pred} is compared with the threshold interference level I_{Th}.
5. If $I_{Pred} < I_{Th}$, then it indicates that the interference at the channel is low, and hence data is transmitted through this channel.
6. If $I_{Pred >} I_{Th}$, then it indicates that the interference at the channel is high.
7. So, the MAC sub layer initiates the channel switching process.
8. In the channel switching process, the $I_{Pred\ (i)}$ >I_{Pred} of all the neighboring channels are estimated.
9. The channels with $I_{Pred\ (i)} < I_{Pred}$ are taken into consideration.
10. Out of all the channels in consideration, the channel with lowest $I_{Pred(i)}$ is selected.
11. Then the $I_{Pred\ (i)}$ is compared with the $I_{Th.}$
12. If $I_{Pred\ (i)} < I_{Th}$, then this channel is selected for data transmission.
13. If $I_{Pred\ (i)} > I_{Th}$, then the channel switching process is reinitiated.
14. In this way, the data transmission occurs only through the channel with least interference.

3.4. Transmission Scheme using (CMCMAC-FEC) Encoding.

In addition to previous algorithm-3(least interference data transmission) not only recognizes the least interfered channel in order to transmit the data in the ZigBee packet successfully but also use CMCMAC-FEC encoding technique. In this technique, data will be encoded in the group by group manner. An encoded ZigBee packet can be effectively delivered only when each encoded group in the packet can recover the data. Else the data will not pass the cyclic redundancy check (CRC). This is described using the following Algorithm 4. Consider the size of encoded group as z-bits.

Algorithm 4- Forward Error Correction Encoding.

1. Initially the data packet undergoes bit interleaving spreads bursting approach. The entire Q byte encoded data in the packet = $z*[8Q/z]$, where z is the data groups.

2. The bit interleaving extends each bit in a group in the whole packet and separate them by *[8Q/z]* bits.
3. After bit interleaving, if the errors are uniformly spread in the packet, then the probability that each encoded group can recover *(P_r)* the data is given using the following equations,

$$P_r = P\{(Z_w / X) < t\} \tag{10}$$

$$P_r = P\left\{\frac{W.Y.BER}{X} < t\right\} = \int_0^{t.X} f_w(x)dx \tag{11}$$

where X = encoded groups count in the ZigBee packet, W= interfering time, BER = bit error rate.
4. If a portion of encoded group fails, then we apply a segment based CRC technique. This involves partitioning of un-encoded data in ZigBee packet into a number of fragments.
5. The optimum number of fragment-based CRC is estimated using the following equation:
   Let U bytes in Zigbee packets are split into V fragments. Each fragment includes [8(U-2V)/V_z] encoded groups and each encoded group contains k-bits raw data.
6. The correct raw data count obtained by the receiver is estimated using the following equation:

$$V_c = P_H \sum_{i=0}^{V} ij.\frac{8(U-2V)}{V_z}.K_v^i P^{\frac{i.8(U-2V)}{V_z}} (1-P^{\frac{8(U-2V)}{V_z}})^{V-i} \tag{12}$$

   It is assumed U bytes data in the ZigBee packet in the portioned in to V segments. Each of encoded group consists of j bits raw data. P_H= probability that the packet header persists from the interference.
7. The optimal fragment based CRC count V_z is given as follows:

$$V_z = \arg\left\{\max_v Z(V)\right\} \tag{13}$$

8. The communication efficiency of Zigbee packet is given using the following equation:

$$\gamma = \frac{Z(V')}{t_{en} + t_{de} + t_{at} + t_{act} + t_{tr}} \tag{14}$$

t_{en} = encoding time, t_{de}= decoding time, t_{at} = air-in time of the packet, t_{act} = air in time of the acknowledgment packet, t_{tr} = transmission and reception state switch time.

4. Results

4.1. The Simulation Parameters

The software we used for analysis is ns2.34 for simulation of our proposed CMCMAC-FEC protocol. The network layer is notified about link breakage by MAC layer. The number of nodes is varied as 20,40,60,80 and 100 in our simulation. The CMCMAC-FEC performance is compared with CMCMAC and FDRX protocol. Using the following parameters, the area size is 50 meter x 50 meter square region, the simulated traffic is CBR (Constant Bit Rate), MAC considered is IEEE 802.15.4, simulation time is 50 sec to 300 sec, traffic source considered is CBR, propagation considered is two ray ground, the antenna considered is Omni antenna, initial energy is 10 Joules (J), transmission energy is 0.3mJ and receiving energy is 0.3mJ.

4.2. Analysis of network parameters based on number of nodes

The analysis of interference and its effects on the size of network is analyzed in the first set of results. Figures 1 to 2 demonstrate the results of packet delivery ratio and throughput by varying the number of nodes from 20, 40, 60, 80 and 100for the CBR traffic in CMCMAC-FEC, CMCMAC and FDRX protocols.

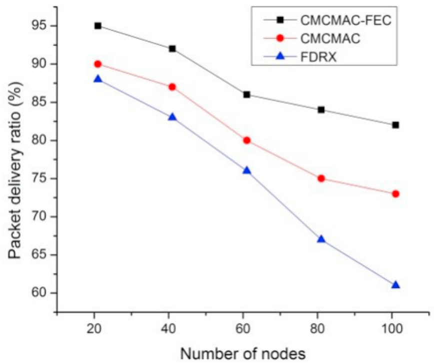

Fig. 1. Comparison of packet delivery ratio (%) to number of nodes.

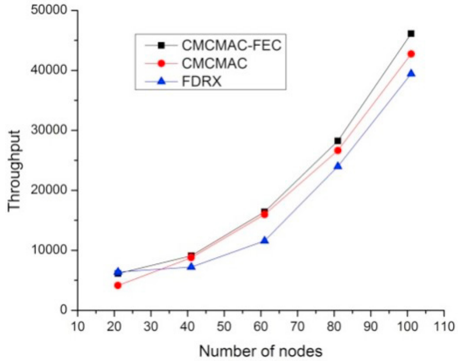

Fig. 2. Comparison of throughput to the number of nodes.

When the performance of the protocols is compared by varying the number of nodes, it is inferred that CMCMAC-FEC outperforms CMCMAC and FDRX by 7% and 13% in terms of packet delivery ratio. CMCMAC-FEC outperforms CMCMAC and FDRX by 8% and 16% in terms of throughput.

4.3. Analysis of network parameters based on number of flows

The analysis of interference and its effects on increased data traffic are analyzed in the second set of results, based on the number of data flows are varied as 2,4,6,8 and 10 for fixed 20 nodes. Figures 3 to 4 demonstrate the results of packet delivery ratio and throughput by varying the number of flows from 2 to 10 for the CBR traffic in CMCMAC-FEC, CMCMAC and FDRX protocols.

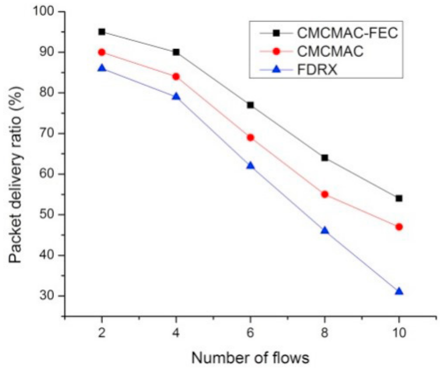

Fig. 3. Comparison of packet delivery ratio (%) to the number of flows.

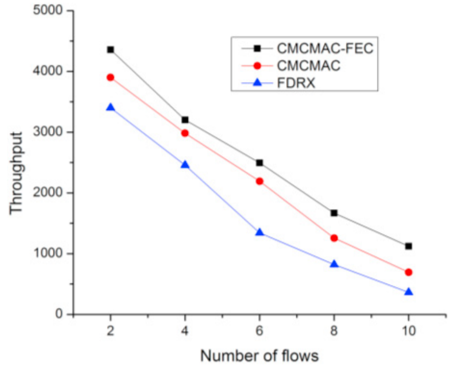

Fig. 4. Comparison of throughput to the number of flows

When the performance of the protocols is compared by varying the number of flows, it is inferred that CMCMAC-FEC outperforms CMCMAC and FDRX by 9% and 20% in terms of packet delivery ratio. CMCMAC-FEC outperforms CMCMAC and FDRX by 14% and 34% in terms of throughput

5. Conclusion

In the coexistence medium particularly when the Zigbee and WiFi networks are working under the influence of each other, the Zigbee packets have to be transmitted from source to destination only when WiFi channel is in idle mode (white space). If the Zigbee data is not transmitted within the time gap then a part of the data is getting corrupted because of collision. In order to overcome the above mentioned case we have developed an algorithm CMCMAC-FEC encoding technique, using this technique data will be encoded in the group by group mode for data repossession mainly when a part of Zigbee packet is collided before it's reaching to the destination. The encoded Zigbee packet can be magnificently delivered only when each encoded set in the packet can recover the data. The algorithm-1 estimates the RSSI (intensity indicator) and COR (density indicator), based on these values algorithm 2 estimates the interference levels using HMM model. Then based on prediction algorithm 3 compares with the predefined threshold values to confirm the channel interference is low enough to transmit data successfully. If it is not confirmed then the channels are switched until a channel with low interference value is determined. Then ensuring the transmission of data packets through the channel with minimum interference and assuring complete packets of data to reach the destination.

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