Priority Aware Interference Mitigation Techniques For Coexistence Of Wireless Technologies In Smart Utility Networks

Badrun Nahar
Institute of Information and Communication Technology
Bangladesh University of Engineering and Technology
Bangladesh
tanjina84@gmail.com

Mohammad Shah Alam
Institute of Information and Communication Technology
Bangladesh University of Engineering and Technology
Bangladesh
smalam@iict.buet.ac.bd

Shamim Ara Shawkat
Dept. of Electrical Engineering and Computer Science
University of Tennessee Knoxville
USA
mshawkat@vols.utk.edu

Mohammad A Hoque
Department of Computing
East Tennessee State University
USA
hoquem@etsu.edu

ABSTRACT

In recent years, Smart Grid (SG) is envisioned to be the next generation electric power system by replacing traditional power grid due to its advantage of using two way communications. To implement reliable SG wireless communication networks, IEEE introduced a new wireless standard (IEEE802.15.4g) for Smart Utility Networks (SUNs). However, SUN operates on 2.4 GHz unlicensed band which is overlapped with Wireless Local Area Networks (WLANs) that leads to coexistence in Smart Utility Networks. In this paper, the coexistence problem of SUN is addressed in terms of homogeneous and heterogeneous interferences. To mitigate the homogeneous interference, Contention Access Period (CAP) and Contention Free Period (CFP) of a super frame of IEEE 802.15.4g is used to access the channel using slotted CSMA/CA algorithm by modifying the Backoff Period (BP) and Clear Channel Assessment (CCA) period for different priority data. An analytical model is developed using Markov chain, through which we demonstrate the accuracy of the proposed model in terms of throughput, channel access delay, probability of successful transmission and collision for nodes with different priority data. Performance evaluation is further investigated by comparing the proposed scheme with the existing PA-MAC. A channel switching mechanism is explored to mitigate the heterogeneous interference by the prediction of Naive Bayes Classifier. Predicted result shows that proposed mechanism effectively mitigates the heterogeneous interference by choosing the non-overlapping and non-coexisting channel.

CCS CONCEPTS

• **Networks → Wireless personal area networks**; • **Hardware → Smart grid**; *Wireless integrated network sensors*;

KEYWORDS

smart utility networks; coexistence; IEEE 802.15.4g; interference mitigation

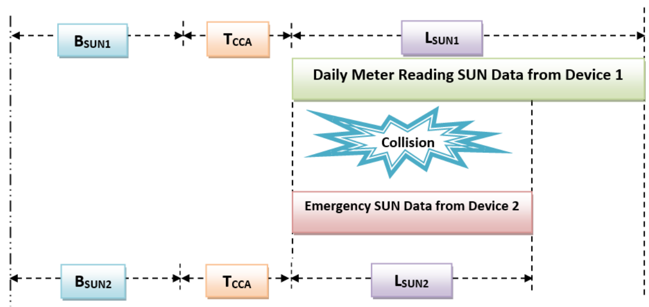
Q2SWinet'17, November 21–25, 2017, Miami, FL, USA

ACM ISBN 978-1-4503-5165-2/17/11…$15.00
https://doi.org/10.1145/3132114.3132124

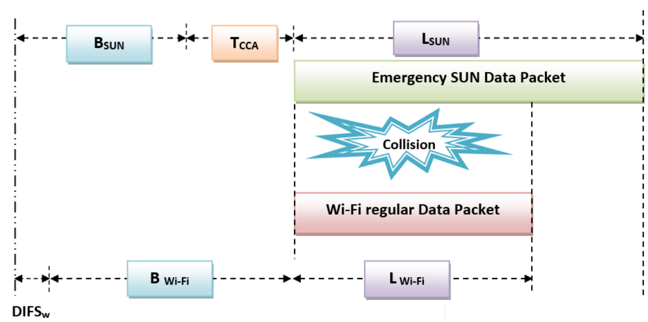
1 INTRODUCTION

In Smart Grid (SG), Advanced Metering Infrastructure (AMI) is one of the core components. It covers SG Neighborhood Area Networks (NANs) and Home Area Networks (HANs) under which a low-cost heterogeneous wireless network architecture is the only choice [1–4]. To facilitate the implementation of AMI using wireless technologies, IEEE introduces a new wireless network standard IEEE 802.15.4g for Smart Utility Network (SUN) for data transmission in SG NANs. SUNs were proposed by modifying physical (PHY) layers of IEEE 802.15.4 standard, which was designed for outdoor, low power and low rate multi-hop wireless networks, which may cover thousands of communication nodes distributed in a large geographical area [5].

However, SUN was designed to operate only in unlicensed bands, shared by many other wireless technologies, such as Wireless Local Area Networks (WLANs), ZigBee, and Bluetooth etc. [6]. These wireless technologies are commonly working in the vicinity of SG Home Area Networks (HANs). Thus a study of coexistence issues between SUNs and other wireless networks in SG NANs and HANs are extremely important [7] as homogeneous and heterogeneous coexistence problem surely will arise in SUNs that is shown in Fig. 1. Here B_{SUN}, B_{Wi-Fi}, T_{CCA}, L_{SUN}, L_{Wi-Fi} stands for back off period of SUN and Wi-Fi node, CCA period (Clear Channel Assessment) and SUN and Wi-Fi data packet length. When devices in SUNs use same wireless technology in same frequency band, it creates homogeneous coexistence Fig. 1 (a). Heterogeneous coexistence, on the other hand, creates when devices using different wireless technology operate in the same frequency band Fig. 1 (b). To overcome these coexistence problem in SUN, we propose interference mitigation techniques that will mitigate both homogeneous and heterogeneous coexistence problem in addition with priority data service. For homogeneous interference, this paper proposes how contention access period (CAP) and contention free period (CFP) period of IEEE 802.15.4g superframe will use by reducing backoff period and clear channel assessment period based on priority for data



(a) Homogeneous System



(b) Heterogeneous System

Figure 1: Interferences in Smart Utility Network.

transmission. An analytical model is established to demonstrate the accuracy of the channel access mechanism for homogeneous interference and the performance evaluation is investigated by comparing the proposed mitigation scheme with the existing PA-MAC in terms of performance parameters such as throughput, channel access delay, probability of successful transmission and collision. On the other hand, a channel switching mechanism is used to mitigate the heterogeneous interference. In this case a Naive Bayes Classifier is used to make the prediction of channel switching based on channel availability. Predicted result shows that the proposed techniques will significantly reduce the heterogeneous interference if the node switches channel based on prediction of channel availability.

The rest of the paper is organized as follows. Section 2 presents the related works. Section 3 describes the proposed technique. Section 4 covers the analytical model and section 5 discusses on performance evaluation. Finally, section 6 concludes the paper.

2 RELATED WORKS

Coexistence problem has been actively researched for SUNs, which necessitate transmission reliability. Several studies have been proposed to mitigate the coexistence problem. In [8], a segmented Packet Collision Model is proposed, through which collision probability for each time segment can be calculated to identify the Packet Error Rate (PER) of an affected SUN receiver during coexistence. A major drawback of this scheme is, it increases latency while transmitting SUN packets by breaking into multiple segments to mitigate interference.

On the other hand , in [9], different cases of packet transmission has been considered when SUN device acts like transmitter and WLAN device acts like an interferer in heterogeneous interference systems. The authors proved that no additional interference avoidance algorithm is required for SUN data packet transmission even if the interferer WLAN device exists for two conditions. First one is if the addition of SUN device back off and CCA is less than the back off of WLAN device and the second one is if the addition of SUN device back off and CCA is greater than the back off of WLAN device. But the drawback of this paper is the transmission link is usually not symmetric in reality, so the first condition will not work.

An analytical model is applied to evaluate the Bit Error Rate (BER) performance of a SUN in case of heterogeneous interference with WLAN/Zigbee. Then a calculation model is established to analyze the Packet Error Rate (PER) performance in order to determine the minimum separation distances between a SUN receiver and WLAN/ZigBee transmitters. The limitation of this model is, the transmission delay becomes longer due to time offset [10].

A dynamic spectrum sharing (DSS) coexistence scheme working with cognitive radio techniques is proposed in [11]. In this articles, a channel detection and channel allocation mechanism are proposed based on unlicensed band 's (2.4 GHz) frequency availability, to be used by SUN and WLAN. Then a Markov chain model is used for fair and unfair channel assignment. The problem with this scheme is, new services will be blocked if the channel is occupied by WLAN or SUN service in case of fair assignment. This is also applicable for unfair assignment, resulting into less reliability of transmission.

In PA-MAC [12] data traffic prioritization and backoff value are considered but the problem is GTS (Guaranteed Time Slot) slots are assigned for both medical data and consumer electronics traffic. As the number of GTS slots are limited, the substantial high collision ratio result in significant performance degradation, especially in case of heavy and high data traffic.

3 PROPOSED TECHNIQUES

As discussed in the previous section, there are two kinds of interferences in smart utility networks— homogeneous and heterogeneous. Thus our challenge is to mitigate these two types of interference problems. The proposed schemes are explained below with some scenarios:

3.1 Homogeneous Interference Mitigation

Homogeneous interference arises when two or more SUN nodes simultaneously attempt to transmit data corresponding to different priority, using the same wireless technology under the same unlicensed band (2.4 GHz). To mitigate homogeneous interference, we are using IEEE 802.15.4g super frame shown in Fig. 2 where CAP and CFP/GTS time slots will be used to transmit SUN data on priority basis. A super frame structure is imposed in beacon enabled mode, which begins with a beacon followed by an active and an optional inactive period. All communication takes place in active period. On the other hand, during inactive period, nodes are allowed to cut off the power to conserve energy. Active period consists of CAP (9 slots) and CFP/GTS (7 slots) period. The length

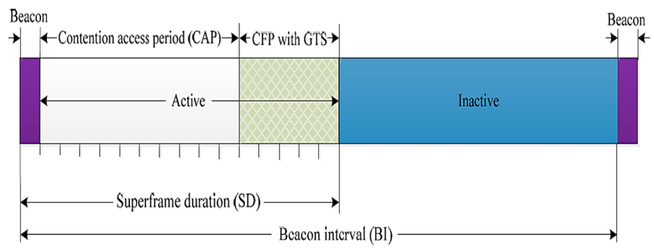


Figure 2: IEEE 802.15.4g Superframe structure.

Table 1: Contention period modification for SUN priority data

Modified values used in IEEE 802.15.4g for CSMA/CA			
Priority Type	**MinBE**	**aMaxBE**	macMaxCSMA(NB)
Priority 1 (P1)	0 ∼ 2, default 2	3	0 ∼ 3, default 2
Priority 2 (P2)	0 ∼ 3, default 3	4	0 ∼ 4, default 3
Priority 3 (P3)	0 ∼ 4, default 4	5	0 ∼ 5, default 4
Default values used in IEEE 802.15.4 for CSMA/CA			
All data are of same priority	0 ∼ 3, default 3	5	0 ∼ 5, default 4

of the superframe (called the beacon interval, BI) and the length of its active part (called the superframe duration, SD) are defined as follows:

$$BI = aBaseSuperframeDuration \times 2BCO$$
$$SD = aBaseSuperframeDuration \times 2SFO$$

Here,$aBaseSuperframeDuration$ = 960 symbols or 15.36ms. The parameters BCO and SFO denote the beacon order, and the superframe order respectively. These values are determined by the network coordinator and are restricted to the range $0 \leq SFO \leq BCO \leq 14$.

Based on the priority, at first we divide SUN data into three priority types as mentioned in Table 2. As P1 data will get first chance to transmit, so the backoff period and CCA period will keep small in size for P1 and gradually increase for P2 and P3 data. That means a SUN node which has data to send will first backs off for a random number of backoff slots, chosen uniformly between 0 and 2^{BE}-1 before sensing the channel, where $MinBE$ (Minimum Backoff Exponent), $aMaxBE$ (Maximum Backoff Exponent), $macMaxCSMA(NB)$ (Maximum Backoff Stages) for each priority type data are shown in Table 1.

That means a node can choose a random number of back off slots from 0 to 3 for P1 ($0 \sim 2^{BE}$ - 1=0 ∼ 2^2 - 1=0 ∼ 3) , 0 to 7 for P2 ($0 \sim 2^{BE}$ - 1=0 ∼ 2^3 - 1=0 ∼ 7) and 0 to 15 for P3 ($0 \sim 2^{BE}$ - 1=0 ∼ 2^4 - 1=0 ∼ 15) data. Let P1 data randomly choose 2, P2 choose 3 and P3 choose 5 as backoff. For convenience we consider unit backoff slot = 320 μs (20 symbol duration) and duration of performing CCA= 240 μs for P1, 440 μs for P2 and 640 μs for P3 as static value because our target is to serve the P1 data first by reducing the backoff period as well as CCA. Then the contention period will be (random backoff x unit time slot of a backoff period + duration for performing CCA) which is shown in Table 2.

Table 2: Contention period modification for SUN priority data

Priority Type	Description	Contention Period
Priority 1 (P1)	Emergency Data	(2 × 320)+240=880 μs
Priority 2 (P2)	Demand Response Data	(3 × 320)+440=1400 μs
Priority 3 (P3)	Periodic Meter Reading	(5 × 320)+640=2240 μs

If the node with P1 data randomly choose 2 as backoff slots (0 ∼ 2^{BE}-1=0 ∼ 2^2-1=0 ∼ 3) as per mentioned in Table 1, then it will start backoff count from 2 to 0, and after that node will perform first CCA for about 120 μs. After 120 μs if the node find the channel is free then it will perform second CCA for about 120 μs again. That means after performing total 240 μs of CCA in addition with 640 μs (2 × 320) of backoff if the node find the channel is free then after waiting total 880 μs (mentioned in Table 2) the node will send the data. Otherwise the backoff exponent is incremented by one and a new number of backoff slots is drawn for the node to wait, until the channel can be sensed again. This process is repeated until either BE equals to the parameter $aMaxBE$ (which has a default value of 3 for P1 as per Table 1) or until a certain maximum number of permitted random backoff stages (NB) is reached, at which point an access failure is declared to the upper layer. This process is same for all type of data (P2 and P3).

Fig. 3 illustrates the mitigation of homogeneous interference if emergency (P1), demand response (P2) and daily meter reading (P3) SUN data wants to access 2.4 GHz band at a time. As per proposed scheme, the mitigation can be done by differentiating backoff and CCA period mentioned at Table 2 on priority basis.

Besides CAP period, CFP/GTS (Guaranteed Time Slot) is basically used for real-time periodic traffic flows such as periodic meter reading. But it can also be used when CAP periods are completely occupied and no slots are available for P1, P2 or P3 data transmission. For an example suppose all CAP periods are occupied by P1 and P3 data. In this situation if any P2 data is arrived, it will found the channel busy after contending for about 1400 μs as per Table

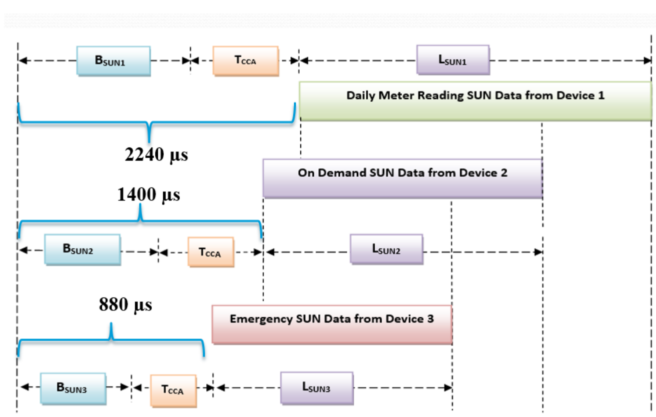


Figure 3: Homogeneous Interference Mitigation.

2. In that case CFP/GTS slots (7 slots) can be used for P2 data transmission by requesting to Network Coordinator (NC) that some slots can be allocated for P2 data. After getting slots, node with P2 data will directly transmit data to the allocated slots.

3.2 Heterogeneous Interference Mitigation

To mitigate heterogeneous interference, we establish a channel switching mechanism. Initially network coordinator will scan all the channels of SUN and creates a channel status table. After that all the channels is categorized into three Pools (Pool 1, Pool 2 and Pool 3). Pool 1 contain channels of SUN those are non-overlapping and non-coexisting of Wi-Fi channels and that is channel 15, 20 and 25 shown in Fig. 4. Pool 2 contain channels those are not used yet say channel 11-14, channel 16-17, channel 21-22 and Pool 3 contain channels those are used once say channel 18, 19, 23, 24 (Fig. 4). After that if a node with P1 data arrives, it will first sense the channel from Pool 1 using RSSI (Received Signal Strength Indicator). If the channel is not busy it will directly send the data. If the channel is busy it will send a request to network coordinator for channel switching. Network coordinator will then assign the node a available channel based on the output of the Naive Classifier so that it will get the access of non-coexisting SUN channel. In this way node with P2 and P3 data will also sense Pool 2 and Pool 3 channel using RSSI to get available channel for data transmission. If such a situation arises that no channel is available for P1 data transmission in that case to mitigate heterogeneous interference, we reserve channel 26 of SUN so that P1 data can be transmitted without any interferences with Wi-Fi data. If node with P2 data is not get any available channel at Pool 2, then it will search channel from Pool 3 and if P3 data doesn't get any channel at Pool 3 then it will search channel from Pool 2. The pseudo-codes of Algorithm 1 and 2 summarizes the heterogeneous interference mitigation techniques.

Algorithm 1 Channel Categorization

```
1:  /*NC perform channel categorization*/
2:  NC will scan all channels, categorized channels into Pool 1,
    Pool 2 and Pool3
3:  Create channel status table
4:  if sender wants data to send then
5:      perform CSMA/CA
6:      if current channel is busy then
7:          perform channel switching using Algorithm 2
8:      else
9:          transmit data
10:     end if
11: end if
```

As one channel of Wi-Fi is interfered 4 channels of SUN (Fig. 4), so in case of heterogeneous interference, say a node using Wi-Fi technology is transmitting data through channel 4 that is interfered channel 13 to channel 16 of SUN. In this situation, if the SUN node wants to transmit emergency (P1 type) data, then it will scan Pool 1(channel 15, 20, and 25) and found that channel 15 is interfered by channel 4 of Wi-Fi. So P1 data will search channel from 20 and 25, select one of them and switch to that channel. If the SUN packet is P2 type data, then it will scan Pool 2 (channel 11-14, channel 16-17, channel 21-22) and identified that channel 13 and 16 is coexisting with channel 4 of Wi-Fi. So it will search among channel 11-12, channel 17 and channel 21-22, select one and switch to that channel.

Algorithm 2 Heterogeneous Interference Mitigation Technique

```
1:  /* Channel Switching Mechanism*/
2:  for all packet from Algorithm 1 do
3:      if Packet_Type= P1 then
4:          sense the channel of Pool 1 using RSSI mentioned at
    section 3.2
5:          if find any available channel then
6:              switch to that channel
7:              transmit data
8:              update channel status table
9:          else switch to Channel 26 and repeat step 7 to 8
10:         end if
11:     else if Packet_Type= P2 then
12:         sense the channel of Pool 2 using RSSI mentioned at
    section 3.2
13:         if find any available channel then
14:             repeat step 6 to 8
15:         else sense the channel of Pool 3 using RSSI mentioned
    at section 3.2
16:             if find any available channel then
17:                 repeat step 6 to 8
18:             else repeat step 12 to 14
19:             end if
20:         end if
21:     else if Packet_Type= P3 then
22:         sense the channel of Pool 3 using RSSI mentioned at
    section 3.2
23:         if find any available channel then repeat step 6 to 8
24:         else sense the channel of Pool 2 using RSSI mentioned
    at section 3.2
25:             if find any available channel then
26:                 repeat step 6 to 8
27:             else repeat step 22 to 24
28:             end if
29:         end if
30:     end if
31: end for
```

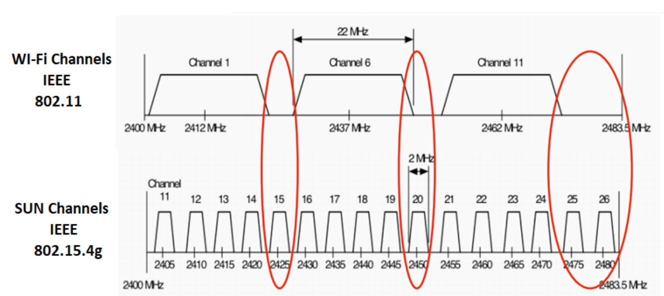


Figure 4: Frequency spectrum of Wi-Fi and SUN.

Finally, if the SUN packet is P3 type data then it will scan Pool 3, select available one and then switch. The channel status table should be updated after each channel scanning to maintain the updated status of each channel so that it can improve the efficiency of finding available channels. Each time channel switching decision will be taken by the classifier 's prediction output.

4 ANALYTICAL MODEL

In this paper, we consider a SUN network consisting of a network coordinator and n smart devices. We define (i =1,2,3) to represent the priority of SUN data in a homogeneous network. The states of the Markov chain for node with priority-i is formed by $\{S(i,t), B(i,t)\}$. Here, $S(i,t)$ represents the value of the Number of Backoff stages (NB) at time t. $B(i,t)$ represents the value of the backoff counter at time t. Let, α_i denote the probability that the channel is busy when node with priority-i performs the first CCA. Let β_i denote the probability that the channel is busy when node with priority-i performs the second CCA. $P_{i,w}$ denotes the probability that node with priority-i accesses the channel after twice CCA. Therefore, the state of each node can be described by i, j, k, where i stands for the priority of data, j stands for the backoff stage, and k stands for the value of the backoff counter. Therefore, the Markov chain could be constructed for nodes with different priorities data which are shown in Fig. 5.

For analytical model, we consider our network is saturated. Based on the models shown in Fig. 5, let $b_{i,j,k}$ be the stationary distribution of the Markov Chain. So in steady sate, we can derive following relations through chain regularities represent through $b_{i,0,0}$ mentioned in Eq (1). In Eq (1), $W_{i,o}$ defines initial window size and m stands for Number of backoff stages.

$$b_{i,0,0} = \frac{2(1-\alpha_i)(1-2\alpha_i)}{(1-\alpha_i)\left\{1-(2\alpha_i)^{m+1}\right\}W_{i,0} + (1-2\alpha_i)\left(1-\alpha_i^{m+1}\right) + 2(1-\alpha_i)(1-2\alpha_i)\left(1-\alpha_i^{m+1}\right)} \quad (1)$$

We get Eq (1) by solving the normalized condition shown below:

$$\sum_{j=0}^{m}\sum_{k=0}^{W_{i,j,-1}} b_{i,j,k} + \sum_{j=0}^{m} b_{i,j,-1} = 1 \quad (2)$$

Let, ω_i be the probability that node with priority-i performs the first CCA. τ_i denotes the probability that node with priority-i perform the second CCA, and γ_i denotes the probability that node with priority-i accesses the channel successfully. When the value of backoff counter is equal to zero, node performs the first CCA. Therefore, we have the probability of the first CCA performed by the node is

$$\omega_i = b_{i,0,0}\left[\frac{1-\alpha_i^{m+1}}{1-\alpha_i}\right] \quad (3)$$

Then the probability of the second CCA performed by the node is,

$$\pi_i = \sum_{j=0}^{m} b_{i,j,-k} = (1-\alpha_i)\omega_i \quad (4)$$

Since Node can transmit the data frame only after that the channel is accessed to be idle after the twice consecutive CCA. So the probability of a node to access the channel successfully is shown in Eq (5) which is derived with the help of Eq (4):

$$\gamma_i = \sum_{j=0}^{m} P_{i,w}(1-\beta_i)\, b_{i,j,-k} = (1-\alpha_i)(1-\beta_i)P_{i,w}\omega_i \quad (5)$$

Suppose α_i and β_i are independent of the backoff stage, and are equal to each other. A transmitted frame collides when one or more nodes also transmit during a slot time. Therefore collision probability is

$$\alpha_i = 1-(1-\gamma_i)^{n_i}(1-\gamma_2)(1-\gamma_3) \quad (6)$$

Here n_i represents the number of nodes with priority (i =1,2,3).

Let S be the normalized system saturation throughput, defined as the fraction of time the channel is used to successfully transmit payload bits. Let P_{tr} be the probability that the channel is busy when there is at least one transmission in the slot time where each node transmits with probability γ_i,

$$P_{tr} = 1-(1-\gamma_1)^{n_1}(1-\gamma_2)^{n_2}(1-\gamma_3)^{n_3} \quad (7)$$

So the probability that the node performs a successful data frame transmission on the channel, conditioned on the fact that at least one node transmits, i.e.

$$P_{i,s} = \frac{n_i\gamma_i(1-\gamma_i)^{n_i-1}(1-\gamma_2)^{n_2}(1-\gamma_3)^{n_3}}{P_{tr}} \quad (8)$$

So we can now express S as the ratio of

$$S = \frac{E[payload\ information\ transmitted\ in\ a\ slot\ time]}{E[length\ of\ a\ slot\ time]} \quad (9)$$

Let S_i represents the fraction of system throughput for nodes with priority-i [13]. Hence Eq (9) becomes,

$$S_i = \frac{P_{i,s}P_{tr}E[P]}{P_{i,s}P_{tr}T_s + P_{tr}(1-P_{i,s})T_c + (1-P_{tr})P_{i,b}\sigma + (1-P_{tr})P_{i,CCA1}T_{CCAi} + 2(1-P_{tr})P_{i,CCA2}T_{CCAi} + (1-P_{tr})P_{i,w}T_w} \quad (10)$$

The corresponding probabilities used in Eq (10) can be calculated from the following equations,

$$P_{i,CCA1} = \frac{\omega_i\alpha_i}{1-\pi_i(1-q_i)} \quad (11)$$

$$P_{i,CCA2} = \frac{\pi_i q_i}{1-\pi_i(1-q_i)} \quad (12)$$

$$P_{i,b} = 1 - P_{i,CCA1} - P_{i,CCA2} \quad (13)$$

With the help of all equations so far written from (1) to (10), we can calculate Normalized Throughput, S_i for each priority data where (i =1,2,3).

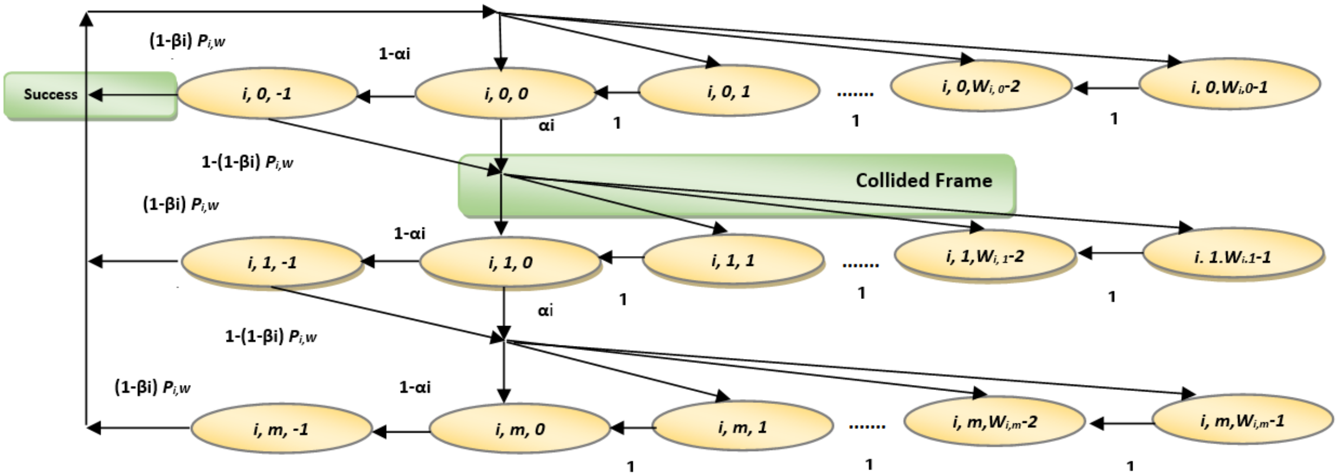


Figure 5: Markov Chain for data with Priority-i (i=1,2,3).

5 PERFORMANCE EVALUATION

In this paper, we evaluate the performance of the proposed technique by comparing with existing PA-MAC using MATLAB for homogeneous interference mitigation. For evaluation, we consider throughput, channel access delay, probability of successful transmission and collision as performance metrics. Assume that n^{th} no. of smart devices works under our priority based SUN networks. Parameters used for the simulations are listed in Table 3.

Table 3: Parameter Settings

Packet Payload	70 bytes	T_{CCA}	40/symbols
MAC Header	13 bytes	T_{ACK}	22 symbols
PHY Header	6 bytes	$T_{ACKtimeout}$	54 symbols
SIFS	21.5 symbols	$T_{turnaroundtime}$	12 symbols
Slot time σ	20 symbols	T_w	20 symbols

In Fig. 6, the overall performance of the network throughput is illustrated as a function of the number of nodes with different priorities. With the increased number of nodes, the throughput of priority 1, 2 and 3 decreases slowly because of a high contention complexity. In Fig. 6, throughput is measured in terms of maximum backoff period for both proposed scheme and conventional PA-MAC, where for PA-MAC, we consider maximum backoff period (BP_{max}=10 for priority 1, BP_{max}=20 for priority 2 and BP_{max}=30 for priority 3) used in IEEE 802.15.4 for all priority data. In the proposed scheme maximum backoff period is set differently for different priority data (BP_{max} =3 for priority 1, BP_{max} =7 for priority 2 and BP_{max} =15 for priority 3) that means smaller backoff period for priority 1 and larger backoff period for priority 3, which leads higher throughput in comparison with conventional PA-MAC as contention complexity for accessing channel is low for priority 1 data. So from Fig. 6, it is clearly shows that, priority 1 and 2 data of the proposed scheme have significant performance (36% and 26%) than priority 1 data of PA-MAC (16%). Again priority 3 data of proposed scheme performs better than priority 2 and 3 of the PA-MAC. Thus in case of prioritization of data traffic, the proposed scheme performs better than conventional PA-MAC.

Fig. 7 shows the access delay for successfully transmitting one packet in a saturation condition. The result shows that, delay increases as the number of nodes increases. Moreover its being noticed that when the number of nodes and backoff period is small (Proposed scheme backoff period < PA-MAC backoff period), the access delay is low. Because lower the presence of nodes, probability of collision is less, thus less time is need to spend in a backoff period, which leads to lower delay. On the other hand, with large backoff period, channel access delay is getting longer as the nodes has to spent more time in a backoff period and thus collision probability is also low. Therefore the access delay under large contention is

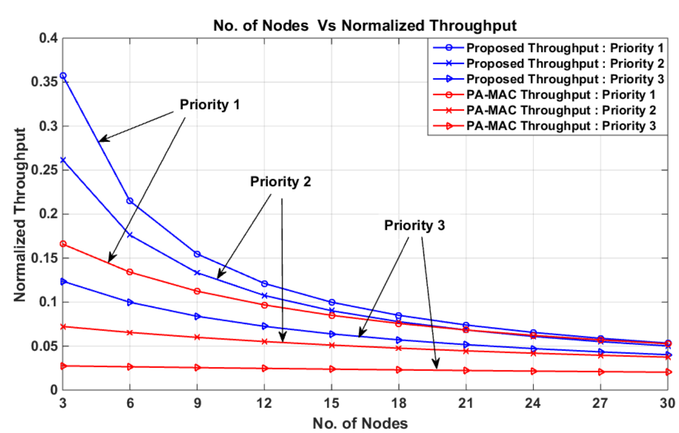


Figure 6: Normalized Throughput.

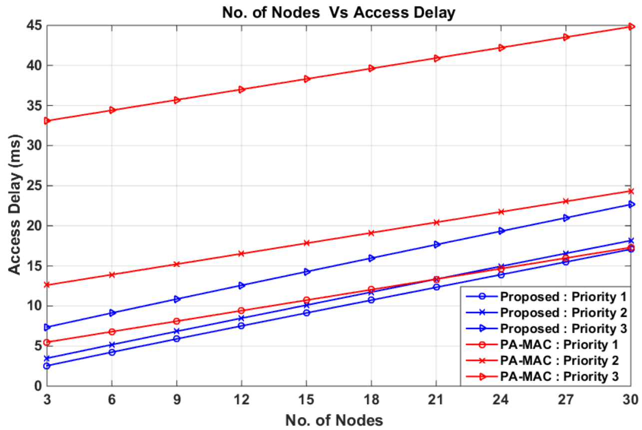


Figure 7: Access Delay.

higher. However, when the number of nodes increases, the collision probability is so high that, a small backoff period cannot guarantee successful transmission and triggers a new backoff stages which again opens a new chance to win the channel for priority 1 data which provides QoS. From Fig. 7 we can say that in proposed scheme, high priority data is always leading in comparison with PA-MAC as we also consider small CCA period in addition with small backoff period which helps to get channel access by contending for less time.

Fig. 8 shows the probability that nodes with different priorities perform successful transmission. As the number of nodes increases, the channel access probabilities of all nodes decrease, due to the number of collision increases. As shown in Fig. 8, node with high priority always has higher successful transmission probability than node with low priority. The reasons is as the backoff and CCA periods are lower for high priority in our proposed scheme, so channel access delay is also lower than low priority data and thus probability of channel access is higher which ultimately results to high probability of successful transmission. On the other hand, in our contention mechanism, the value of backoff period for node with low priority is larger than the high priority. This makes the node with low priority have to be backoff more backoff slots which decreases the channel access probability and thus results low probability of successful transmission. In both cases, proposed scheme performance is better than PA-MAC as PA-MAC do not consider backoff period and CCA period minimization to provide QoS.

In Fig. 9 we can see the collision probability of the proposed scheme is higher than the conventional PA-MAC. This is due to the fact that we consider maximum backoff period in both cases. That means PA-MAC consider traditional backoff period (BP_{max} = 10 for priority 1, BP_{max} = 20 for priority 2 and BP_{max} = 30 for priority 3) used in IEEE 802.15.4 for all priority data whereas the proposed scheme backoff period is set differently for different priority data (BP_{max} = 3 for priority 1, BP_{max} = 7 for priority 2 and BP_{max} = 15 for priority 3). In this situation due to small window size, compare with PA-MAC, proposed scheme will suffer more collision, because nodes will contend less and thus with the increased number of nodes, probability of collision will be higher and the node will triggers a new backoff stages. But as the backoff stages has dependency on the number of Backoff Exponent (*BE*), so this *BE* is also limited to *maxBE*=3 for priority 1, 4 for priority 2 and 5 for priority 3 whereas PA-MAC *BE* is limited to 5 as per Table 1. So for Fig. 9 if we consider priority 1 data of the proposed scheme, node with priority 1 will try up to 3 times (as per Table 1, *aMaxBE* for Priority 1 is 3) if collision occurs, and after that it will discard the packet.

On the other hand, to predict the channel status (available or busy) a naive bayes model is needed to create where several parameters are used as input parameters and output is calculated based on input parameters. Signal to Noise Ratio (SNR), Received Signal Strength Indicator (RSSI) are used as the input parameters to identify the state of the channel. There are three types of variables are applied such as SNR=0, 0<SNR<SNR_{th} and SNR>SNR_{th} in the SNR node. Similarly, in the RSSI node two types of variable is applied like RSSI>$RSSI_{th}$ and RSSI<$RSSI_{th}$. A training data is mapped with network model using batch queries. Simulation is run for 100 test cases on network model based on training data and we get Histogram and Lift chart as prediction output. From Fig. 10, we

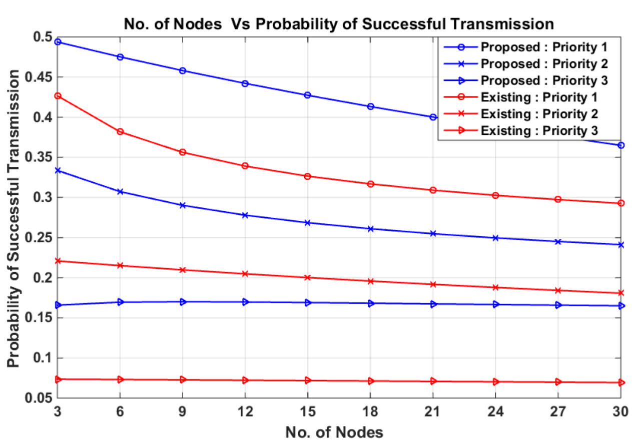


Figure 8: Probability of Successful Transmission.

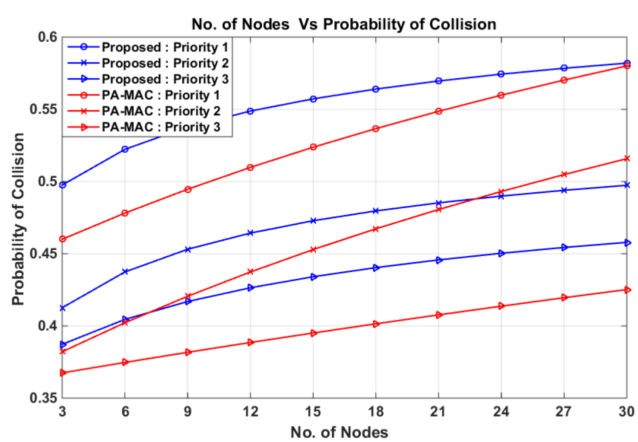


Figure 9: Collision Probability.

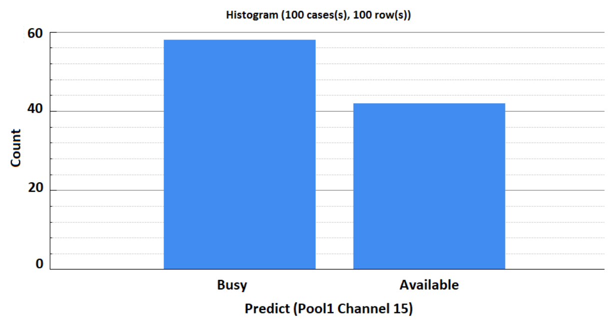


Figure 10: Histogram of Channel 15 availability prediction.

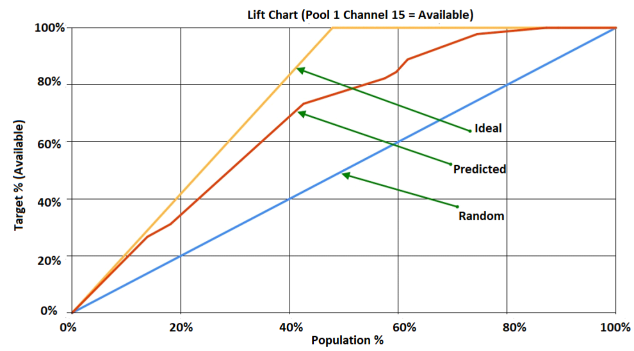


Figure 12: Lift Chart of Channel 15 Available prediction.

can say that the availability prediction of Channel 15 of Pool 1 is 58% busy and 42% is available.

The lift chart shows in Fig. 11 and Fig. 12 are used to evaluate the effectiveness of a model when predicting a particular discrete state (e.g. Busy=True or Available= True) . If the expected value for a case was indeed unavailable or available, then the chart will increase on the y-axis (% of total Busy) or y-axis (% of total available). In this way, for every channel of every Pool, we can predict the availability of channel before channel switching.

6 CONCLUSIONS

In this paper, we proposed two mitigation techniques for homogeneous and heterogeneous coexistence arises in SUN networks due to multiple wireless technologies uses. The proposed work adopts an efficient priority differentiation scheme and contention resolution scheme which serves the priority 1 data first with improved network throughput in homogeneous networks. Simulation results shows that the proposed technique achieves improved throughput of about 36%, 26% and 16%, respectively in a homogeneous networks. Furthermore, the proposed work also uses a channel switching mechanism based on Naive Bayes Classifier which predicts the probability of channel availability before switching channel to avoid heterogeneous interference. Availability prediction of a single channel in Pool 1 (say channel 15) is 58% busy and 42% available in heterogeneous networks. Thus we can conclude that our proposed techniques for homogeneous interference mitigation performs better than PA-MAC in terms of throughput, access delay, successful transmission. In addition with this channel status prediction is another part of enhancing QoS of the SUN networks for heterogeneous interference mitigation. Finally the evaluation of channel switching mechanism for heterogeneous system and collision probability reduction for homogeneous system is our future work.

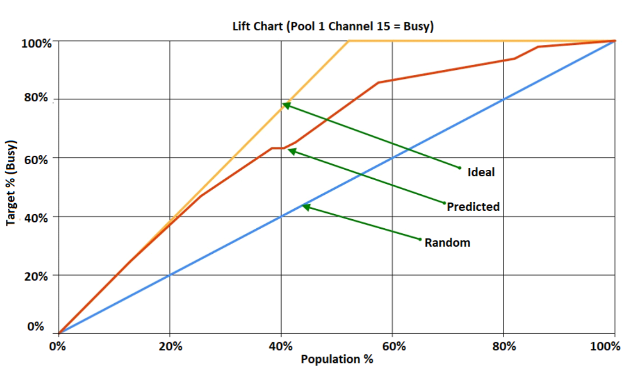


Figure 11: Lift Chart of Channel 15 Busy prediction.

REFERENCES

[1] Ruofei Ma, Hsiao-Hwa Chen, Yu-Ren Huang, and Weixiao Meng. Smart Grid Communication: Its Challenges and Opportunities. *IEEE transactions on Smart Grid*, 4(1):36–46, 2013.

[2] Weixiao Meng, Ruofei Ma, and Hsiao-Hwa Chen. Smart grid neighborhood area networks: a survey. *IEEE Network*, 28(1):24–32, 2014.

[3] Rong Yu, Yan Zhang, Stein Gjessing, Chau Yuen, Shengli Xie, and Mohsen Guizani. Cognitive radio based hierarchical communications infrastructure for smart grid. *IEEE network*, 25(5), 2011.

[4] Agustin Zaballos, Alex Vallejo, and Josep M Selga. Heterogeneous communication architecture for the smart grid. *IEEE Network*, 25(5), 2011.

[5] Thilo Sauter and Maksim Lobashov. End-to-End Communication Architecture for Smart Grids. *IEEE Transactions on Industrial Electronics*, 58(4):1218–1228, 2011.

[6] Chun-Hao Lo and Nirwan Ansari. The Progressive Smart Grid System from Both Power and Communications Aspects. *IEEE Communications Surveys & Tutorials*, 14(3):799–821, 2012.

[7] Chin-Sean Sum, Fumihide Kojima, and Hiroshi Harada. Coexistence of homogeneous and heterogeneous systems for ieee 802.15. 4g smart utility networks. In *New Frontiers in Dynamic Spectrum Access Networks (DySPAN), 2011 IEEE Symposium on*, pages 510–520. IEEE, 2011.

[8] Shuyi Chen, Ruofei Ma, Hsiao-Hwa Chen, and Weixiao Meng. A Segmented Packet Collision Model for Smart Utility Networks Under WLAN Interferences. *IEEE Transactions on Wireless Communications*, 15(5):3506–3517, 2016.

[9] Teng-Hui Wang and Hsiao-Hwa Chen. Channel discovery algorithms for interference avoidance in smart grid communication networks: a survey. *Wireless Communications and Mobile Computing*, 16(4):427–440, 2016.

[10] Ruofei Ma, Weixiao Meng, Hsiao-Hwa Chen, and Yu-Ren Huang. Coexistence of smart utility networks and WLAN/ZigBee in smart grid. In *Smart Grid Communications (SmartGridComm), 2012 IEEE Third International Conference on*, pages 211–216. IEEE, 2012.

[11] Ruofei Ma, Hsiao-Hwa Chen, and Weixiao Meng. Dynamic Spectrum Sharing for the Coexistence of Smart Utility Networks and WLANs in Smart Grid Communications. *IEEE Network*, 31(1):88–96, 2017.

[12] Sabin Bhandari and Sangman Moh. A Priority-Based Adaptive MAC Protocol for Wireless Body Area Networks. *Sensors*, 16(3):401, 2016.

[13] ZHAO Lu, Guang-wei BAI, SHEN Hang, and Zhen-min TANG. Priority-based IEEE 802.15. 4 CSMA/CA mechanism for WSNs. *The Journal of China Universities of Posts and Telecommunications*, 20(1):47–53, 2013.