RESEARCH THESIS

“Prevention of Beacons Collision in IEEE 802.15.6 under Coexistence”

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DECLARATION OF AUTHENTICATION

I state that the research work presented in this thesis is the superlative of my own knowledge. All causes used and any help established in the research of this study have been acknowledged. I hereby verify that I have not yielded this material, either in whole or in part, for any other degree at this or any other institution.

Signature……………………..

ACKNOWLEDGEMENT

I thank Allah who provided me with strength and caliber to bring this thesis work to its successful completion.

I am deeply obliged to my supervisor, Dr. Faisal Bashir Hussain, for his guidance, unwavering support and confidence in me throughout the course of this thesis work. His time and efforts were very valuable.

I offer my regards and blessings to all of those who supported me in any respect during the completion of this work. Last but not the least; I am grateful to those people without whom I could never have accomplished my aim; my family, especially my father, and friends. I thank them all for their constant prayers and unfaltering support throughout this journey.

May Allah bless them all with eternal happiness!

DEDICATION

To My Father, Mother, Family and friends.

Abstract

IEEE 802.15.6 standard is designed for Wireless Body Area Network (WBAN). WBAN connects wireless sensor nodes in/on or around the human body. WBAN is specially designed for monitoring e-health applications like temperature, blood pressure and fever etc. One of the basic concerns in IEEE 802.15.6 networks is coexistence of multiple BANs. This is a natural phenomenon as multiple BANs while coexisting can be within the transmission range of each other. For example, in a sitting room, conference room, stadium and hospital BANs attached with different peoples can be within the radio range of each other. When multiple BANs coexist then the performance of an individual BAN is degraded due to interference with neighboring BANs. Interference causes unsuccessful transmission of data, thus lowering the throughput, and energy of devices is wasted which is an important resource for WBAN devices. This work is amid at studying the coexistence issues within the WBANs. IEEE 802.15.6 proposes different solutions including beacon shifting, channel hoping, and superframe interleaving for solving the issue of coexistence. In beacon shifting the collision of beacons is avoided by transmitting the beacons at different offsets in a superframe instead of start of every superframe. Beacon shifting defined by IEEE 802.15.6 allows BANs to select a sequence index that is not being used by another BAN. As only eight different sequence indexes are defined so it can supports only eight BANs. In this study, a beacon shifting scheme is proposed to solve the issue of beacons collision under coexistence by adding a beacon phase to the superframe of IEEE 802.15.6. The scheme adjusts the transmission time of beacons in the beacon phase for all coexisting BANs and allows BANs to transmit their beacons in allocated time slot in the beacon phase. Hence, instead of assigning different sequence indexes which has overlapping patterns, the proposed scheme allocates time slots in beacon phase to avoid beacon collision. Detailed simulation analysis using OPNET, concludes that proposed scheme provides greater beacon delivery ratio and higher throughput than beacon shifting technique used in IEEE 802.15.6.

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ABBREVIATIONS

ACK	Acknowledgement
B2	Beacon 2
BDR	Beacon Delivery Ratio
BP	Blood pressure
CAP	Contention Access phase
CCA	Clear Channel Assessment
CFP	Contention Free period
CIFS	Coexistence Inter Frame Space
EAP	Exclusive Access Phase
ECG	Electrocardiography
EEG	Electroencephalogram
EMG	Electromyogram
GPS	Global Positioning System
GTS	Guaranteed Time Slot
I-ACK	Immediate Acknowledgement
LR-WPAN	Low Rate Wireless Personal Area Network
MAC	Multiple Access Control
MAP	Management Access Phase
NB	Narrowband
PER	Packet Error Rate
PRR	Packet Reception Ratio
RAP	Radom Access Phase
R-ACK	Response Acknowledgement
RIC	Random Incomplete Coloring
SD	Super-frame Duration
SINR	Signal Interference Noise Ratio
UWB	Ultra-wideband
WBAN	Wireless Body Area Network
WMSN	Wireless Multimedia Sensor Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

Chapter 1

Introduction

1.1 Overview

The wireless communication is meant to exchange data without any wire. The wireless technologies allow wireless devices to connect and transfer data without any expensive cabled infrastructure forming the foundation for its rapid and expediting advancement. It is the wireless technologies that make it portable for people to carry and use the necessary technologies. In the wireless technologies, various improvements have been made and it has revolutionized the user connectivity to internet in last two decades. These wireless technologies are used for the benefits, welfare and improvement of living standards in every walk of life, ranging from entertainment to health care. The Wireless technologies are receiving increasing interest as compared to its wired counterpart.

In the beginning, Wireless Local Area Network (WLAN) was the first popular wireless networking technology. WLANs allow devices to connect in a building, or home to internet without any wire. The WLANs are suitable for proving internet connectivity to hand held devices but it utilize considerable amount of battery power. With the advent of miniature sized low power device for environment science and information gathering, need was felt to improve the power hungry medium access of wireless LANs. This led to the introduction of IEEE 802.15.4 Wireless Personal Area Network (WPAN). WPANs provide limited transmission range and data range but are more suitable for resource constrained devices as compare to IEEE 802.11 (WLAN). The WPANs are used for providing physical and medium access capabilities in Wireless Sensor Networks (WSNs) and Wireless Sensor and Actor Networks (WSANs). The aforementioned networks are used for monitoring and controlling different physical environment including habitat monitoring, surveillance, asset management system, building structure checking and automobiles etc.

In the last few years low power networks are increasingly used in health care for remote monitoring of various health parameters [45]. The existing technologies such as WLANs and WPANs were considered for designing of health care networks. But they were more resource hungry and the transmission range was not suitable for human health care systems. However in 2012 IEEE 802.15.6 standard is introduced for Wireless Body Area Network (WBAN), which is more resource constrained and has smaller transmission range as compared to WLAN and WPAN. It provides data rates ranging up to 10 Mbps. WBAN consists of sensors attached on, in and around human body to sense and monitor a range of conditions in a verity situation of human body and actuator to perform appropriate action. The WBAN introduced a portable health care system that can handle emergency situation [1]. WBAN captures various health critical measurements and now has a very huge market in medical field. Besides, health care the WBAN is extensively utilized in various other fields such as gaming, identification system, fitness etc. [2]. Collectively WLANs, WPANs and WBANs can be termed as Low Power Lousy Networks (LLNs). Although LLNs have constrained resources such as battery power, memory, speed, and transmission range but all of these wireless networks have numerous applications for society from entertainment, health-care, agriculture, forests and roads etc. sectors.

In a Wireless Body Area Network (WBAN) sensors/nodes are attached on the whole body, these sensors are energy efficient, inexpensive and very light in weight e.g. ECG (Electrocardiogram) sensor, blood pressure sensor, blood glucose sensor and heartbeat sensor etc. These sensors expand over the whole body and are connected to a central Hub/coordinator wirelessly as depicted in figure 1. Sensors collect data which can be of priority ranging from 0-7 and forward it to the hub/coordinator. Hub is further responsible for the processing and forwarding of data to the desired destination.

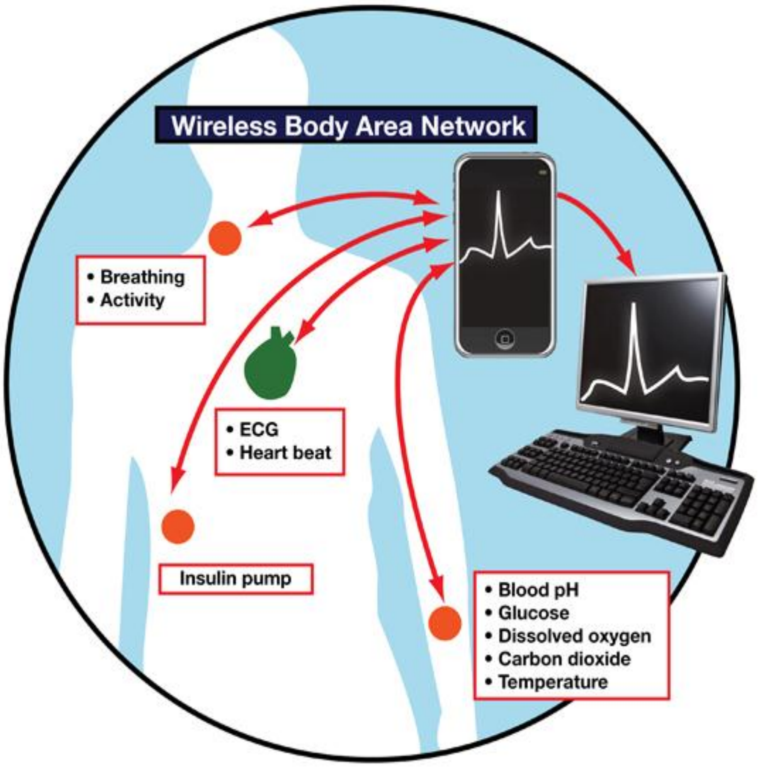


Figure 1: Wireless Body Area Network

1.2 Motivation

Hundreds and thousands of patients in advanced hospitals are shifting to use the WBANs to monitor and observe the conditions of patients. These patients have sensor devices attached to or implanted in their bodies. The sole purpose of the WBANs sensors is to check various health parameters such as EEG, ECG, blood pressure, heart beat, temperature, and glucose etc. When the sensors report any of the vital signs cross the threshold, then the actuator acts accordingly such as it may automatically provide first aid or an alert is generated in the hospital and the medical staff is immediately called to help. For example, when the sugar level reaches highest threshold, it is reported by sensor to the hub/actuator. The actuator may inject insulin to the patient or it may alert the concerned medical staff.

In hospital various patients are equipped with WBANs and their BAN communication can interfere with each other causing hindrance in the transmission of a WBAN. For example, when multiple patients come close, then the WBAN of one patient is being interfered by the transmission of another patient's WBAN. This type of interference is termed as homogeneous interference. The interference results into collision of beacons and data which consequently leads to low throughput and wastage of bandwidth and energy. Since beacons are generated and sent by Hub towards nodes, it carries synchronization information, superframe parameters, BAN identifiers and other necessary information. Hence, solutions are required to avoid beacons collision in homogeneous networks.

1.3 Problem Statement

To enhance the network performance by minimizing the effects of interference that arises due to the coexistence of multiple BANs in IEEE 802.15.6. Three techniques proposed by IEEE 802.15.6 for mitigating coexistence are; beacon shifting, superframe interleaving, and channel hopping. Beacon shifting is an efficient technique to prevent homogeneous interference as it avoids beacons of neighboring BANs to collide. However, the beacon shifting technique proposed in IEEE 802.15.6 standard is not efficient enough to eliminate beacon collision. Focus of our research is to solve beacons collision problem that arises due to the coexistence of multiple BANs on a single channel using a centralized hub.

1.4 Thesis Organization

The thesis is organized as: Chapter 2 describes the detailed overview of IEEE 802.15.6, its applications and the coexistence techniques described by the IEEE 802.15.6 standard [3]. Chapter 3 presents the existing work done on interference mitigation techniques in different wireless homogeneous and heterogeneous networks. Chapter 4 relates to the detailed operation of proposed technique that avoids beacons collision and mitigates the interference in WBANs. Chapter 5 presents the simulation analysis of proposed technique. Last chapter concludes this work and provides future directions.

Chapter 2

Overview of IEEE 802.15.6

2.1 Introduction

Although the existing IEEE standards for wireless networks are considered for implementation of WBAN but they are not best suited for WBANs application due to the different nature of WBAN's application. Because of lengthy startup time for nodes association and nodes dissociation, high bandwidth requirements, non-support for multi-hope communication and high power consumption of IEEE 802.15.1 (Bluetooth) standard cannot be adopted for WBANs applications [4,5,6]. The IEEE 802.15.4 (Zigbee) standard has high delay in transmission due to fades [7], lacks adequate Quality of Service (QoS) which is essential for WBANs application [6]. The WBAN is a very special type of low power network also differencing from WPAN (WSN) in deployment and density, data rate, latency and mobility. Flexibility, cost, effectiveness and efficiency are the special requirements of WBAN over other low power networks [8]. Therefore, the IEEE developed a special standard in 2012 for WBAN to meet the requirements of WBAN. The IEEE 802.15.6 standard network layout of the WBAN can be one-hope star where nodes directly communicate with hub or two-hope extended star in which communication is done between nodes and hub via a relay-capable node as portrayed in figure 2.

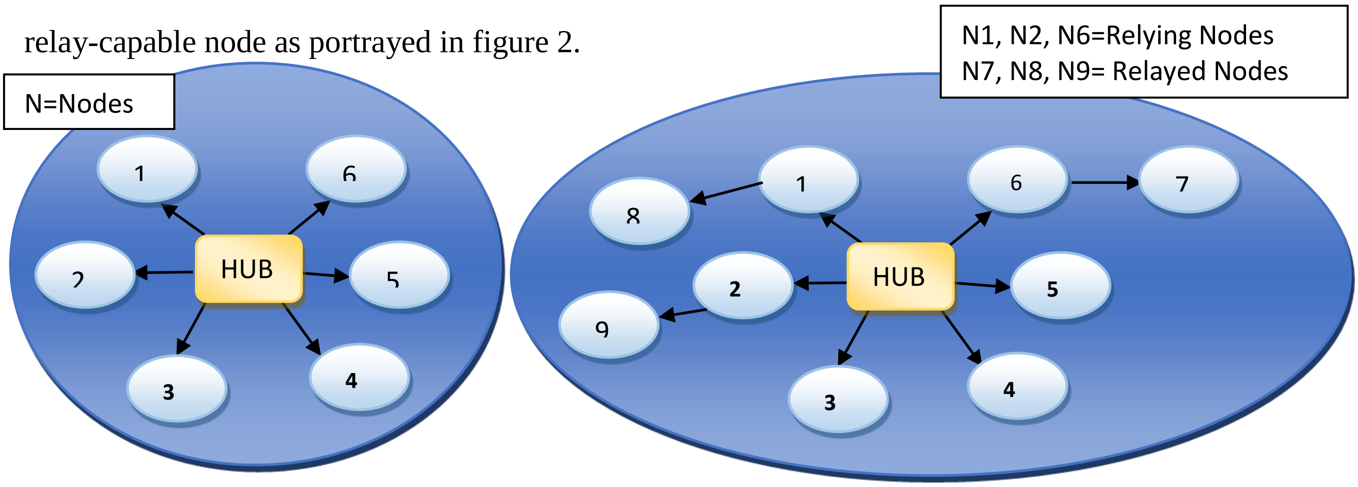


Figure 2: Star topology (left) and extended star (right) of IEEE 802.15.6

The frequency bands for data transmission defined by the IEEE 802.15.6 standard are; Narrowband (NB), Ultra Wideband (UWB) and Human Body Communication (HBC). The NB includes 400 MHz, 800MHz, 900MHz, 2.3GHz and 2.4GHz frequency bands. The UWB make use of 3.1GHz to 11.2GHz frequency. The HBC utilizes frequency band range of 10-50 MHz. The selection of each PHY depends on the application requirements. The 2.4 GHz band has 79 frequency channels with 1 MHz for the bandwidth and with only 1 MHz for the channel spacing. Hence, the 79 channels are tightly adjacent. Since WBAN is for only a single human body therefore, it is a short-range (1-5 meter) communication depending on sensor type [9].

In IEEE 802.15.6 standard, a hub may either use time referenced allocation or it may use timeless referenced allocation in WBAN. In prior type, hub and all nodes create time reference and medium access is scheduled in time and beacon period (superframe) of WBAN is divided into equal length time as illustrated in figure 3. Further each superframe is decomposed into slots (allocation slots) numbered as 0, 1, 2….255 whereas the maximum slots of a superframe can be 256. The hub may or may not transmit a beacon frame in every beacon period [3].

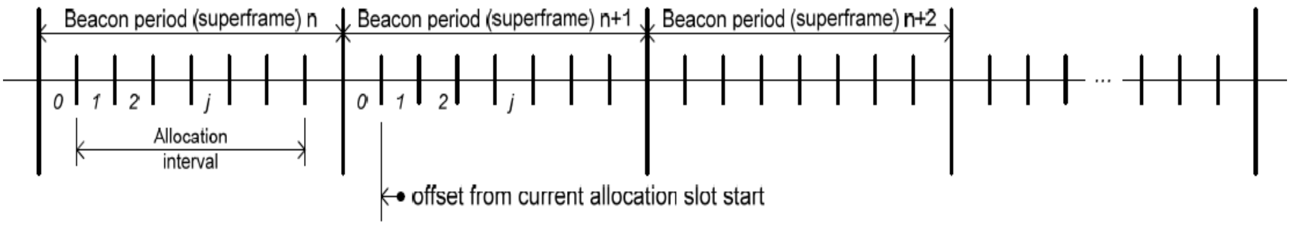


Figure 3: IEEE 802.15.6 based WBAN Time Reference base [3]

In later type, the WBAN operates without a time reference or beacon period and therefore no transmission of beacon is required. Based on aforementioned details, there are three access modes of operation of WBAN which are beacon mode with superframes, non-beacon mode with superframes and non-beacon mode without superframes. In this study, our main focus is on beacon mode with beacon period and superframe boundaries. Different phases included in this mode are Exclusive Access Phase 1 (EAP1), Random Access Phase 1 (RAP1), EAP2, RAP 2, Managed Access Phase (MAP) and Contention Allocation Phase (CAP) that are depicted in figure 4 below.

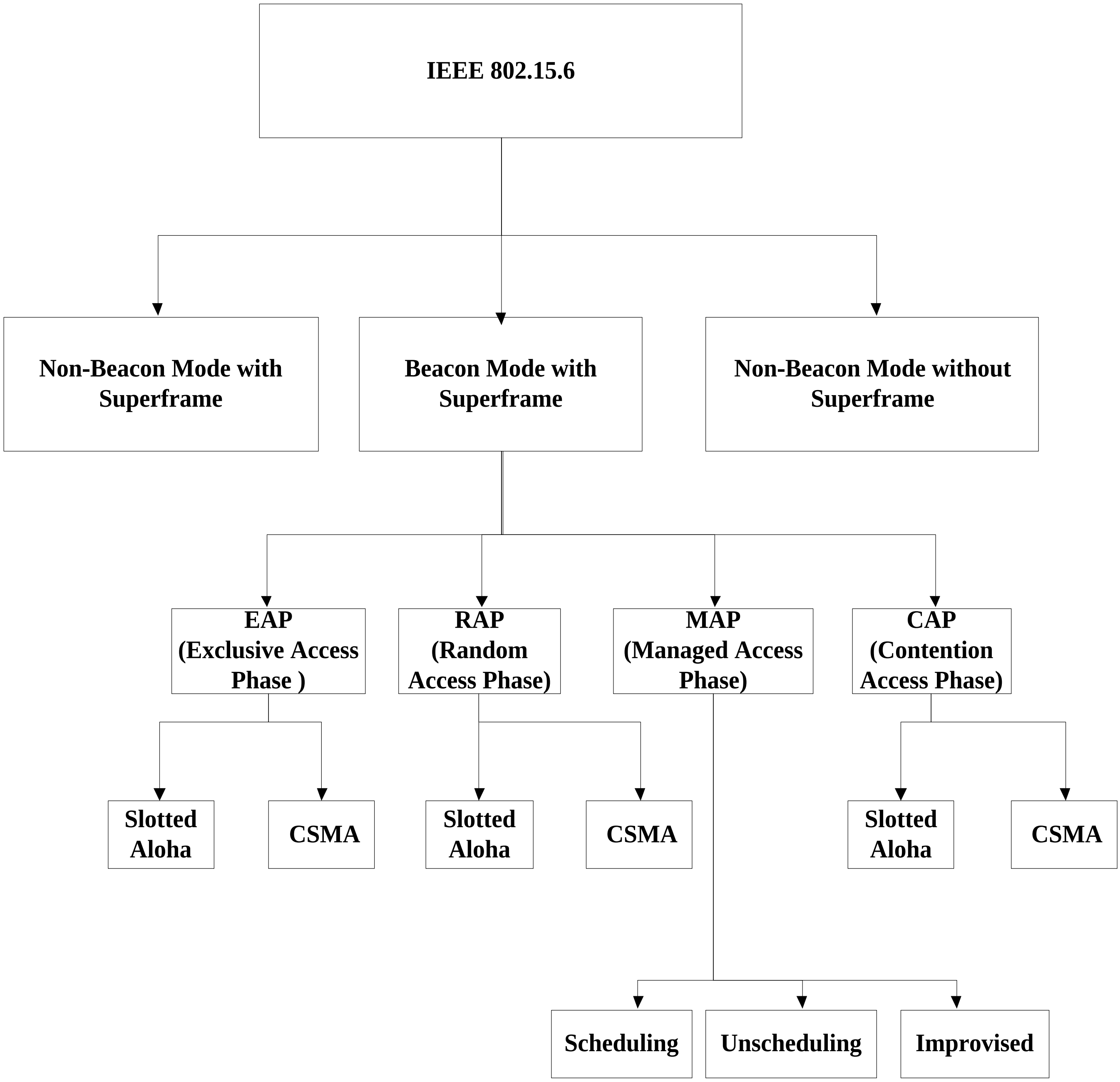


Figure 4: IEEE 802.15.6 Operational Modes

2.1.1 Beacon Enabled Mode

In this mode all the devices are in coordination with the hub that leads to better efficiency, high throughput and less consumption of energy. On the basis of contention and contention free access various intervals for medium access are provided by beacon frame. The IEEE 802.15.6 superframe comprises of EAP1/EAP2, RAP1/RAP2, MAP and CAP phases as shown in figure 5. EAP phase is employed for high priority traffic i.e. emergency traffic and is based on Slotted ALOHA or CSMA/CA. Random Access Phase (RAP) is used for regular traffic which is also based on CSMA/CA or Slotted ALOHA. The nodes can access the channel to hub in RAP phase. Managed Access Phase (MAP) is used for polling: uplink, downlink, bi-link, and scheduling. Contention Access Phase (CAP) is used for coexistence. A hub shall transmit a B2 frame if the CAP is of non-zero length.

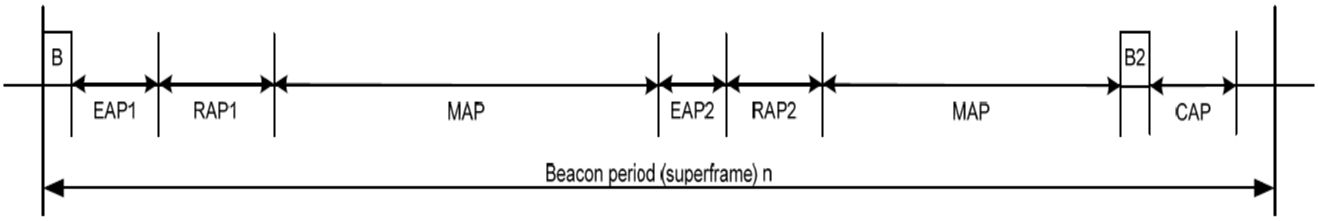


Figure 5: Beacon enabled mode with Superframe [3]

2.2 Coexistence in IEEE 802.15.6

In the presence of more than one BAN as shown in figure 6, the interference arises due to overlapping of the neighboring BAN's radio ranges leading to the wastage of the energy and decreasing the efficiency of the devices as the packets are dropped. To solve the problem of interference due to the coexistence, IEEE 802.15.6 has proposed three techniques that are beacon shifting, superframe interleaving and channel hopping.

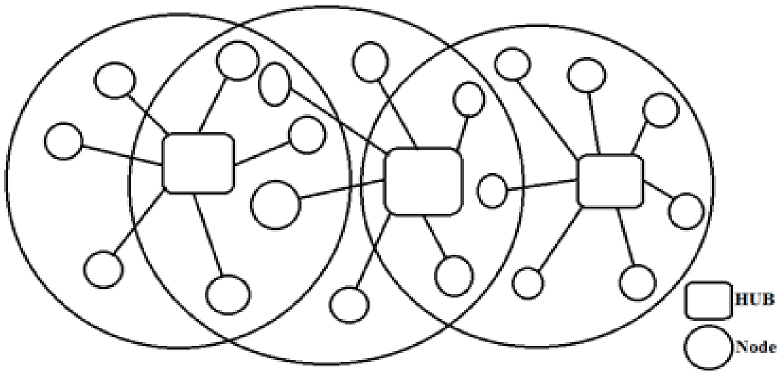


Figure 6: Coexistence among multiple BAN

Interference is mainly of two types. One is homogeneous interference and the other one is heterogeneous interference. When two alike wireless networks interfere with each other's communication it is termed as homogeneous interference, for e.g. one WBAN's communication interfering another WBAN's communication. The type of interference which involves two different types of systems or networks is called heterogeneous interference, e.g. interference between IEEE 802.15.4 and IEEE 802.15.6 based networks. The Standard has provided three optional techniques for homogeneous coexistence / interference mitigation among WBAN with its neighbors.

2.2.1 Beacon Shifting

In this mechanism, the beacon is transmitted at different periods inside a superframe, instead at start of beacon period. There are four possible start positions for a beacon to be transmitted in a superframe. The transmission of beacon at different time offsets is performed using beacon shifting sequence which is chosen by the hub and the same sequence is not being selected by neighbors to alleviate data and especially beacon collisions. There are eight (08) beacon shifting sequences defined by the standard as listed in table 1.

Beacon Shifting Sequence Index *m* in decimal value	**Beacon Shifting Sequence as function of Beacon Shifting Sequence Phase *n* = 0, 1, 2, …, 15**	**Beacon Shifting Sequence pattern ("…" denotes pattern repeat)**
0	$PN_0(n) = n \bmod 2$	$PN_0(n)$ = 0, 1, 0, 1, …
1	$PN_1(n) = 2 \times PN_0(n)$	$PN_1(n)$ = 0, 2, 0, 2, …
2	$PN_2(n) = n \bmod 4$	$PN_2(n)$ = 0, 1, 2, 3, …
3	$PN_3(n) = [PN_0(n) + PN_2(n)]/2 \bmod 2 + [PN_0(n) + PN_1(n) + PN_2(n)] \bmod 4$	$PN_3(n)$ = 0, 1, 3, 2, …
4	$PN_4(n) = [PN_0(n) + PN_1(n) + PN_2(n)]/2$	$PN_4(n)$ = 0, 2, 1, 3, …
5	$PN_5(n) = \{PN_2(n) + [PN_0(n) + PN_2(n)]/2\} \bmod 4$	$PN_5(n)$ = 0, 2, 3, 1, …
6	$PN_6(n) = PN_1(n) + \{[PN_0(n) + PN_2(n)]/2 \bmod 2\}$	$PN_6(n)$ = 0, 3, 1, 2, …
7	$PN_7(n) = [PN_1(n) + PN_2(n)] \bmod 4$	$PN_7(n)$ = 0, 3, 2, 1, …
8–15	Reserved	Reserved

Table 1: Beacon Shifting Sequence field encoding [3]

"BP" is length of Beacon period, "m" is the beacon shifting sequence index that hub selects and "n" is the beacon shifting sequence phase (n = 0,1,2,……). The beacon is transmitted at time t = PNm(n)×BP/4 relative to the start of beacon period by the hub [3]. The superframe structure with PN4(n) is illustrated in figure 7:-

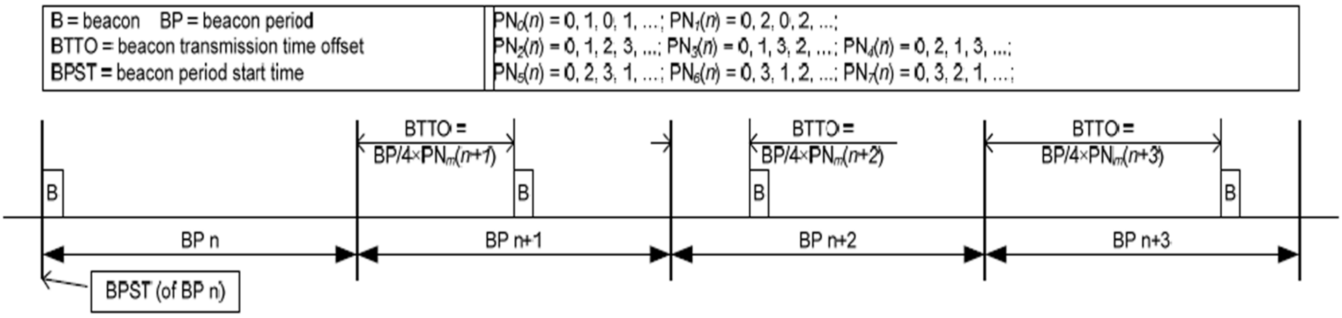


Figure 7: Beacon shifting illustration with PN4 [3]

The EAP1, RAP1, EAP2, RAP2, CAP and Scheduled allocation intervals phases are referenced to numbered allocation slots and alter around with the beacon in the beacon period as shown in figure 8. When beacon shifting sequence is used the aforementioned access phases cannot be split into two parts except the scheduled allocation interval in a beacon period, which may be split into two portions. But the aggregate length remains the same [3].

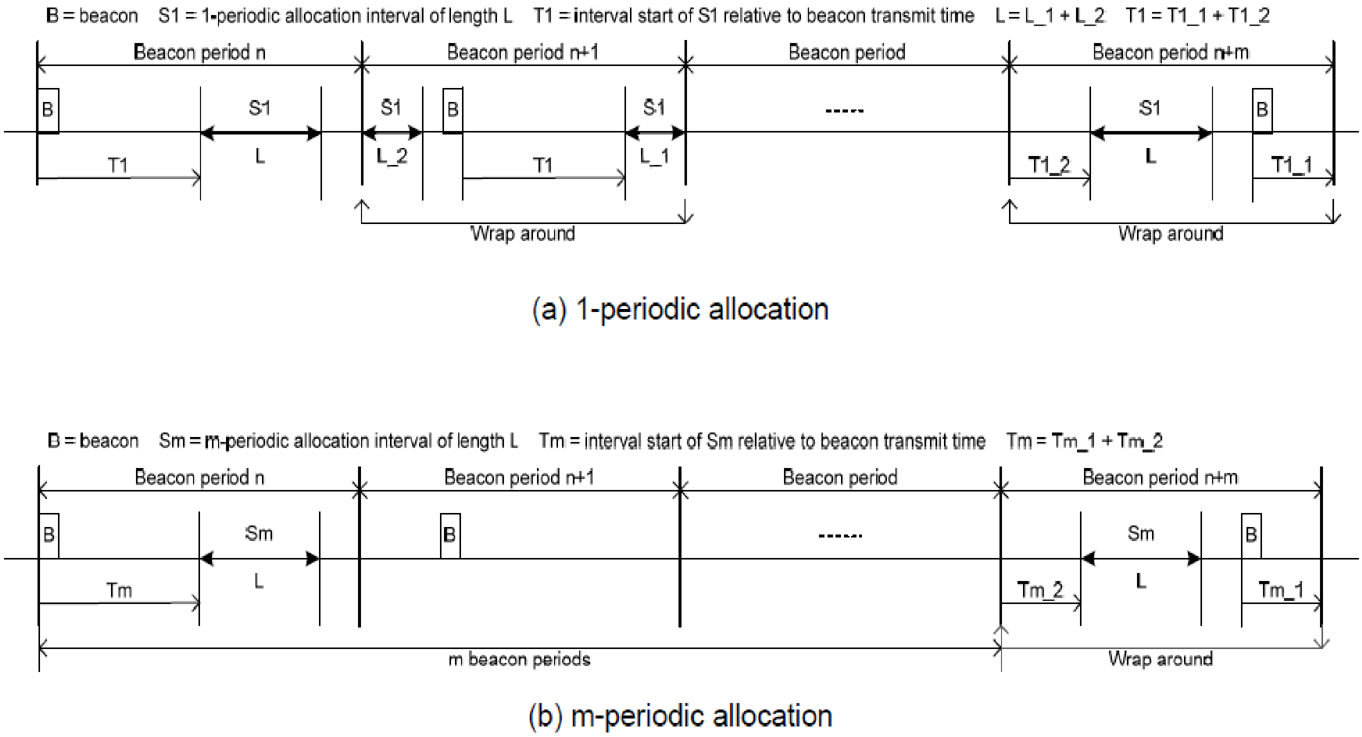


Figure 8: Beacon and scheduled allocation interval shifting [3]

2.2.2 Channel Hopping

The channel hopping technique is not permitted for Medical Implant Communications Service (MICS) from 402 MHz to 405 MHz band and frequency modulation ultra-wideband (FM-UWB) PHY but only allowed for a hub operating in narrow band (NB) PHY. In this technique the hub changes its operating channel/frequency band periodically. The information about the channel hopping is propagated by hub using Channel Hopping State and Next Channel Hop fields in beacons or/and in its Connection Assignment frames of Superframe Parameters IE. The hub shall change its operating channel after a fixed number of beacon periods in the same channel. The hub shall switch to channel that is not being used by its neighbor hubs. A 16-bit Galois linear feedback shift register (LFSR) is used by hub for generating the channel hopping sequence.

2.2.3 Active Superframe Interleaving

The third method provided by the IEEE 802.15.6 standard for interference mitigation is active superframe interleaving depicted in figure 9. In this method, a BAN operates in the same frequency band / channel without interrupting the active superframe of another BAN. A hub operating in non-beacon mode with superframes shall transmit a B2 frame in every active superframe if it supports active superframe interleaving [3].

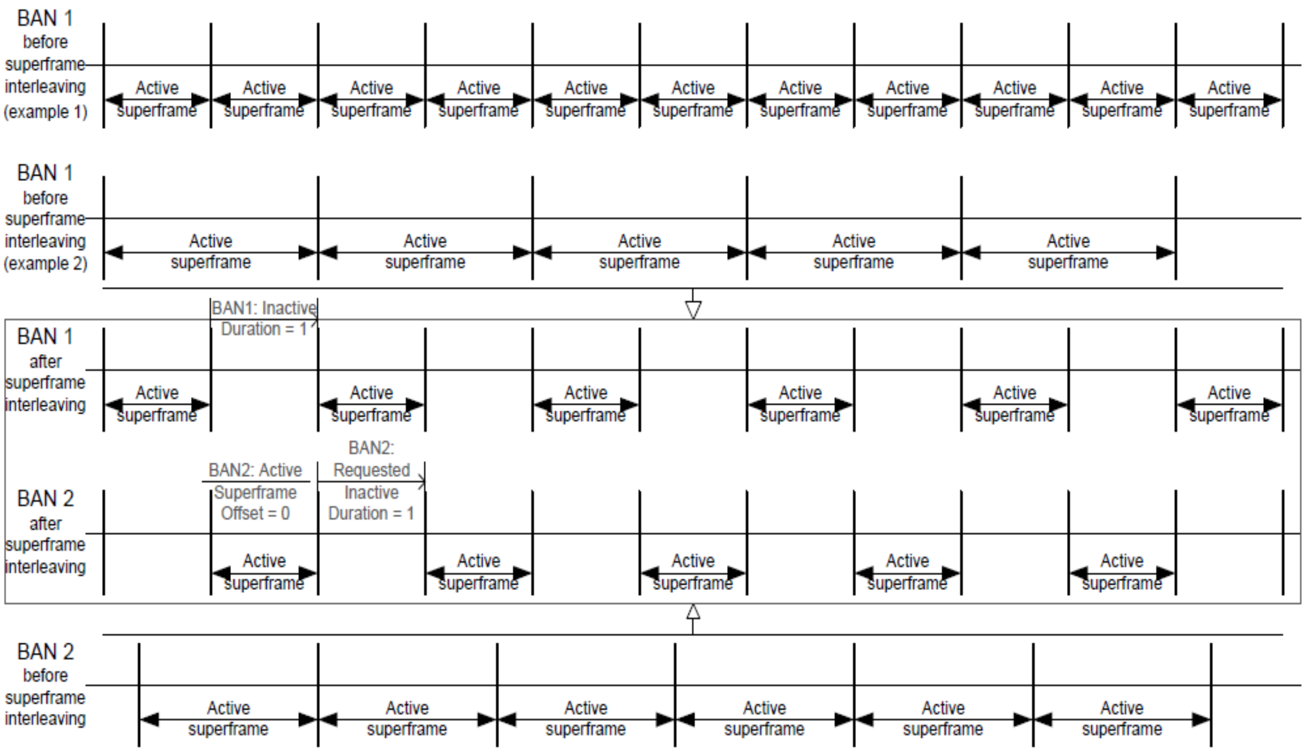


Figure 9: Active superframe interleaving Adjustment [3]

Command–Active Superframe Interleaving Request and Command–Active Superframe Interleaving Response are the two control frames utilized by the standard for allowing coexisting WBANs to utilize active superframe interleaving. The prior command is optionally transmitted by hub to request channel sharing through active superframe interleaving. Frame format of Command–Active Superframe Interleaving Request is depicted below in Figure 10.

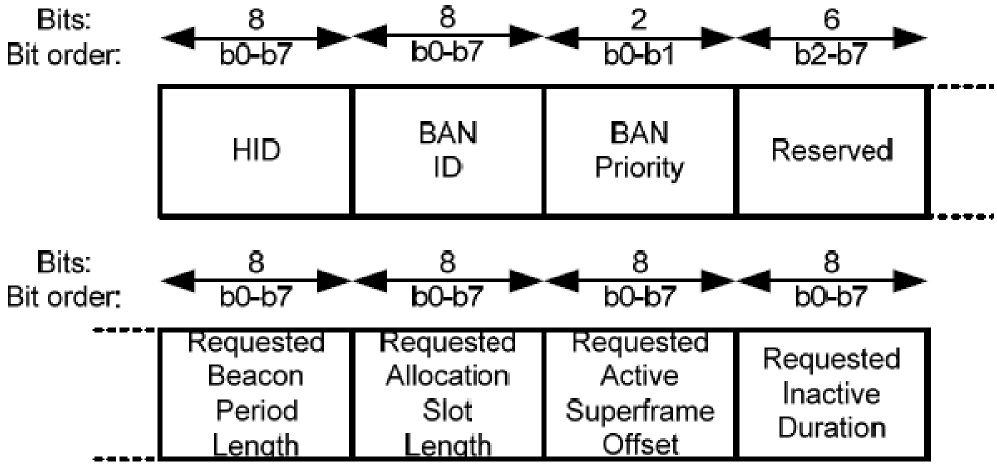


Figure 10: Command Frame Superframe Interleaving Request [3]

The later command is optionally transmitted by a hub, in response to the Command–Active Superframe Interleaving Request for active superframe interleaving [3]. The frame layout of Command–Active Superframe Interleaving Response is shown in Figure 11.

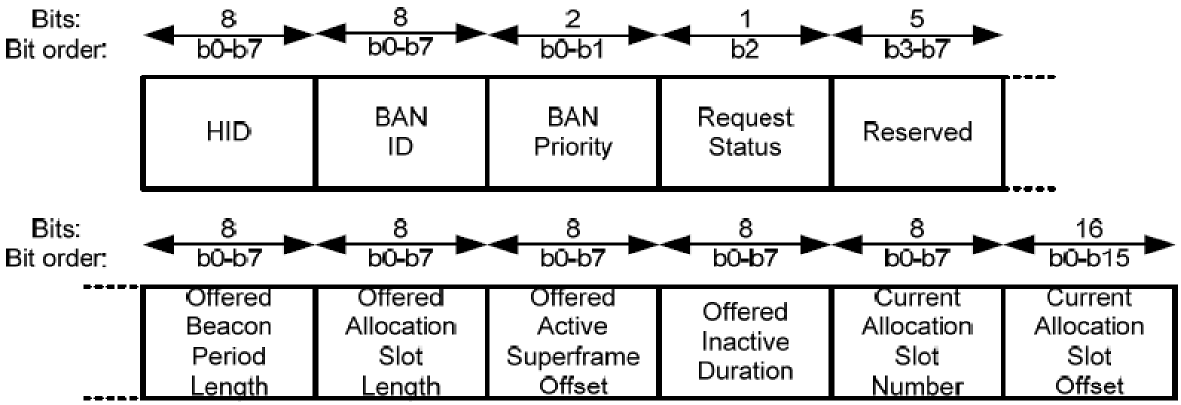


Figure 11: Command-Active Superframe Interleaving Response

In complete superframe interleaving there is no beacon collision or data collision. One of the biggest disadvantages of this inherent scheme by IEEE802.15.6 is that superframe adjustment is performed according to the number of WBANs. Also the active superframe interleaving is static in nature, as the duration allocated to each WBAN is not changeable.

For interference mitigation between coexisting WBANs no time synchronization and information exchange is required for beacon shifting and channel hopping. It means that beacon shifting and channel hopping are non-collaborative approaches. On the other hand, the active superframe interleaving demands synchronization and information exchange between coexisting hub, to mitigate or limit interference. This makes active superframe interleaving a collaborative approach. Dynamic, semi-dynamic and static are the three categories of the mobility levels defined by the IEEE 802.15.6 standard. From standard it is clear that active superframe interleaving is used for static mobility state and beacon shifting and channel hopping are used for dynamic and semi-dynamic mobility levels of WBANs.

Chapter 3

Related Work

3.1 Introduction

The issue of coexistence is an integral part of the wireless networks including WLAN, WPAN and WBAN, due to the use of same frequency band i.e. 2.4 GHz ISM band. This research will focus on the issue of interference produced due to coexistence in WBAN. On the basis of the underlying wireless networking technology used, WBANs can be categorized into; IEEE 802.15.4-based WBAN, IEEE 802.15.6-based WBAN, and low-power Wi-Fi based WBAN [9]. This related work will cover coexistence mechanisms of WBAN in 802.15.4 and IEEE 802.15.6 standards. Various categorizations of the coexistence mechanisms are rendered, such as homogeneous and heterogeneous interference and these interferences are differently treated. Furthermore, collaborative and non-collaborative coexistence mechanisms are other classification of the coexistence [10].

In [11], the author has provides taxonomy of different types of coexistence mechanisms in IEEE 802.15.4 based WBANs as shown in the figure 12. The coexistence mechanisms are divided into homogeneous which is between WBANs and heterogeneous which is between WBAN and other wireless network. The homogeneous coexistence mechanisms are further divided into distributed and centralized. In distributed coexistence, each WBAN try to handle coexistence independently and in centralized coexistence, central mechanism is used for solving the issue. The distributed is further divided into collaborative and non-collaborative. In former the Base Stations (BS)/hubs coordinate with each other for handling the coexistence and in later WBANs have their own solution for mitigation of interference and do not share information with other.

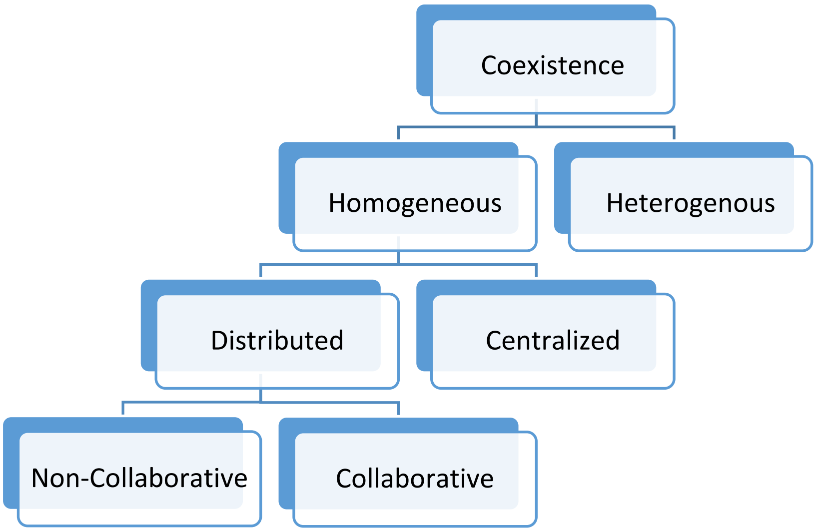


Figure 12: Coexistence mitigation techniques hierarchy [11]

In order to mitigate interference, the coexistence and the issues raised because of interference need to be explored. Researchers have exploited various techniques to explain the problems faced by communication in the presence of interference. In [12] the coexistence of homogeneous WBANs with same number of sensors and data rates is studied. The author presents an in-depth investigation of the situations where the dynamic coexistence may severely affect their performances and analytically studies the effect of coexistence on the operation of WBANs. To precisely obtain the probabilities of successful communication a mathematical analysis is also rendered. In [8], the coexistence effects of IEEE 802.15.4 with IEEE 802.11b, Bluetooth and microwares working on the same 2.4GHz has been discussed. In [13], the author has given details of the coexistence of the IEEE 802.15.4 with IEEE 802.11b wireless networks.

In [14] the authors, propose a technique for the assessment of the of IEEE 802.15.4 performance under different cross-channel interference conditions. A case study based on applying the methodology on the IEEE 802.15.4 devices is presented in a real scenario and discuss the results obtained with one or multiple interferers and varying some MAC level parameters. Another similar study [15] analyzes and demonstrates the dynamic interactions between the IEEE 802.15.4 and IEEE 802.11 on relevant devices. CCA is main reason of IEEE 802.15.4 transmission failures rather than corrupted data packets. The author proposed new LQE by merging the Clear Channel Assessment count with the Packet Reception Rate. Results show that the new estimator distinguishes persistent IEEE 802.11 traffic more robustly. In [16] the author rendered the impact of the IEEE 802.11b/g networks on the ZigBee and vice versa on the basis of bit error rate (BER) and error vector magnitude (EVM). In [17] significant 802.11 performance degradation frequently occurs due to unequal slot sizes between the IEEE 802.11 and 802.15.4. This is one of the first papers studying the listen-before-send performance for heterogeneous networks with substantial measured data.

In the remaining of this section the interference mitigation in LLNs is elaborated. First some schemes about the homogeneous and heterogeneous coexistence mechanism in WLANs are studied. Then the literature about the interference mitigation schemes of WPAN is elaborated. IEEE 802.15.4 based WBAN interference mitigation related work is explored next. And finally the IEEE 802.15.6 based WBAN coexistence mechanisms proposed by various researchers are explained.

3.2 Coexistence of IEEE 802.15.4 based WBAN

Authors in [18] mitigate the effects of the homogeneous and dynamic coexistence of IEEE 802.15.4 based WBANs by using a distributed and collaborative mechanism called Dynamic Coexistence Management (DCM) mechanism. In this method a coordinator/hub works as a Coexistence Manager when it detects a harmful coexistence, the Coexistence Manager collaborates with other Coexistence Manager. Two techniques beacon replacement and channel switching are the core techniques used by the DCM for solving beacon collision and the data collision respectively. In the Beacon replacement, when the coordinator does not detect a data frames in the CFP of two consecutive superframe or frames from a coexisting WBANs are detected then coordinator assumes that the beacon is interfered by beacon of a coexisting WBANs. Upon detection of beacon loss, the hub will monitor the channel for a complete beacon interval and will reschedule the beacon at the start of the largest gap available in the beacon interval. Thus the superframe of the WBAN is adjusted to avoid interference. When data loss is detected by the hub, it either performs full beacon interval scan or inactive period scan for possible channel switch. In former method, complete information about the preexisting WBANs as the scan is comprised of entire beacon period whereas in the later method scan consists of only the inactive period of the beacon interval and therefore does not gathers complete information. But the later method does not miss a beacon while finding a free gap. The main drawback of this method is overhead for channels switching, re-arrangement of superframe and synchronization after the superframe is re-arrangement.

In [19] BAN-BAN Interference Reduction System (B2IRS) for mitigation of interference of IEEE 802.15.4 based WBANs is proposed. In B2IRS, when a hub detects interference from coexisting WBANs, it reschedules the active period at the inactive period of the interfering WBANs and transmit beacon at start of its active period. The rescheduling is performed in such a way that the active period starts at the end of the active period of the coexisting WBAN. This prevents WBANs active periods from interference still operating in the same channel. But if the number of coexisting WBANs is high, then this technique leads to extensive delay. Therefore, the protocol is not applicable to applications with real-time requirement.

Authors in [20] propose an Interference-Aware Channel Switching algorithm (Inter-ACS) which mitigates the homogeneous interference of IEEE 802.15.4 based WBANs. The WBAN switch channel when multiple WBANs coexist on a channel. The WBANs interference is based on the Signal-to-Interference Ratio (SIR) value. The SIR value is divided into LOW, MODERATE and HIGH at coordinator. The channel is switch into next 2-hop channel, next 3-hop channel and next 4-hop channel on the basis of SIR value. But with increase in the densities of the WBANs the performance of the Inter-ACS decreases.

As a summary, table no. 2 presents the IEEE 802.15.4 based WBAN coexistence mitigation schemes. The table contains details about the interference mitigation protocols such as whether the coexistence is homogeneous or heterogeneous, type of coexistence, interference detection, medium access strategies, and interference mitigation technique used. The type of coexistence explains that collaborative or non-collaborative approach is used for interference mitigation. The parameters that detect the presence of interference are rendered in interference detection column. Polling, CSMA/CA, slotted Aloha and TDMA are the common medium access techniques rendered in the medium access strategies. The table also provides details of some of the protocols.

Protocol	Homogeneous/Heterogeneous	Type of Coexistence	Interference Detection	Medium Access strategies	Interference Mitigation	Detail
DCM [18] 2014	Homogeneous	Non-Collaborative	Interference traffic	CSMA/CA Channel scan	Beacon Replacement and channel switch	Mitigation of homogeneous and dynamic coexistence effects
[11] 2012	Homogeneous	Collaborative	Throughput	CSMA/CA	Message Exchange & Superframe arrangement	Detects Coexistence & rearranges the communication for interfering BANs
[21] 2012	Homogeneous	Collaborative	Average Waiting Time	TDMA	TDMA based	Seamless communication by creating common schedule
B2IRS [19] 2012	Homogeneous	Collaborative	Packet receive ratio	TDMA	Superframe Adjustment	Reschedules beacons to avoid active frame overlapping
[22] 2014	Homogeneous	Non-Collaborative	Interference landscape	CSMA/CA	Frequency Adjustment	Discusses a number of adaptation schemes and assess performance
Inter-ACS [20] 2012	Homogeneous	Collaborative	SIR	TDMA	Switching channel	Interference aware channel switching algorithm (Inter-ACS) for WBANs
[23] 2014	Heterogeneous	Collaborative	SINR	CSMA/CA	Multi-Hop Routing	Adaptive transmit power, packet Size, time interval between transmissions
[24] 2013	Heterogeneous	Non-collaborative	-	Heuristic	Heuristic	Cross technology Interference
[25] 2014	Heterogeneous	Collaborative	-	CSMA/CA	Contention Window	Contention window adaptation scheme for achieving channel sharing.
DIAop [26] 2014	Heterogeneous	Non-Collaborative	Congestion	-	Channel switch	dynamic channel assignment policy

Table 2: Summary of the coexistence mechanisms for IEEE 802.15.4 based WBANs

3.3 Coexistence of IEEE 802.15.6 based WBAN

Besides, the inherent solution for interference mitigation provided by the IEEE 802.15.6 based standard, various researchers have worked on reduction of homogeneous and heterogeneous coexistence of WBANs. A lot of research has been conducted by researchers on the interference mitigation of IEEE 802.15.4 based WBANs but very less exploration has been carried out so far on IEEE 802.15.6 based WBAN as it is a new standard developed in 2012. In the remaining of this section the research work carried out for detection and mitigation of the effects of homogeneous and heterogeneous interference of coexisting IEEE 802.15.6 based WBANs is discussed.

In [27] the author explains the effects of interference on IEEE 802.15.6 based WBANs and develops a model for the interference. The performance of the model is evaluated using the parameters such as energy, delay, packet error rate and packet reception rate. The work then evaluates the performance of the collaborative and non-collaborative interference mitigation techniques. Results shows that in non-collaborative technique channel hopping performs much better, whereas in collaborative, CSMA/CA is effective.

Research in [28] proposes an adaptive channel allocation technique for alleviating homogeneous interference of IEEE 802.15.6 based WBANs. In this technique each coexisting WBAN creates and broadcast a table of the coexisting nodes to inform its neighbor WBANs of the interfering nodes in vicinity. These interfering nodes are assigned orthogonal channel, whereas, other nodes are allowed to communicate in the same channel using TDMA. This scheme increases the channel reuse. However, it only considers node level interference and not deals with WBAN level interference.

As a summary, table no. 3 presents the IEEE 802.15.6 based WBAN coexistence mitigation schemes sorted by year of publication. The table contains details about the interference mitigation protocols such as whether the coexistence is homogeneous or heterogeneous, type of coexistence, interference detection, medium access strategies, and interference mitigation technique used. The type of coexistence explains that collaborative or non-collaborative approach is used for interference mitigation. The parameters that detect the presence of interference are rendered in interference detection column. Polling, CSMA/CA, slotted Aloha and TDMA are the common medium access techniques rendered in the medium access strategies. The table also provides details of some of the protocols.

Protocol	**Homogeneous/ Heterogeneous**	**Type of Coexistence**	**Interference Detection**	**Medium Access strategies**	**Interference Mitigation**	**Detail**
Adaptive - CSMA/CA [29] 2015	Homogeneous	Non-collaborative	Delay/CCA	CSMA/CA	Adaptive superframe length	Hub Back-off before CCA and then poll to sensor & Adaptive superframe length
Ali et al. [30] 2015	Homogeneous	Collaborative	SINR	TDMA and slotted CSMA/CA	Orthogonal channel	Dynamic Orthogonal channel assignment
WBAN-DC [31] 2015	Homogeneous	Non-collaborative	SNIR	TDMA	Graph coloring	Common schedule and Distributed Graph coloring
Dakun et al. [32] 2015	Homogeneous	Non-collaborative	Power consumption	TDMA	Game theory and power control	distributed power control algorithm and Nash equilibrium
Meharouechet al. [33] 2015	Homogeneous	Non-collaborative	Signal-to-Interference Ratio (SIR)	Channel switch	Game theory	Two stage approach. Game theory, channel allocation.
2L-MAC[34] 2014	Homogeneous	Non-collaborative	delivery rate and latency	Polling	Channels switching	Polling for intra-BAN and CCA for inter-BAN interference mitigation
Movassaghi et al. [35] 2014	Homogeneous	Collaborative	SINR	TDMA	Graph coloring & orthogonal channel	Graph coloring for TDAM with cooperative communication for orthogonal channel

Movassaghi et al. [28] 2014	Homogeneous	Collaborative	SINR	TDMA	Orthogonal channel	orthogonal channel to interfering nodes
FTMH[36] 2014	Homogeneous	Collaborative	interference signal strength (ISS)/SIR	TDMA	Heuristic	Fairness-based Throughput Maximization Heuristic (FTMH) And analytical model
Dong et al. [37] 2014	Homogeneous	Non-collaborative	SINR	TDMA	Hybrid	Relay Selection and Power control
Zou et al. [38] 2014	Homogeneous	Non-collaborative	SINR	TDMA	Game theory	Bayesian model Game theory and power control
Jamthe et al. [43] 2014	Homogeneous	Collaborative	ED and SIR	TDMA	Fuzzy logic	fuzzy inference engine and scheduling algorithm
RIC[39] 2013	Homogeneous	Collaborative	time-complexity/no Interference Detection	TDMA	Graph coloring	Two channels. Both used for inter and intra ban communication
Dong et al. [40] 2013	Homogeneous	Collaborative	SINR	TDMA	Opportunistic Relay	two-hop relay-assisted cooperative communications using opportunistic relaying
Yang et al. [41] 2012	Homogeneous	Non-collaborative	SINR	TDMA	Adaptive modulation, data rate and duty cycle	interference mitigation factor (IMF)
Smith et al. [42] 2012	Homogeneous	Collaborative	SINR	TDMA	Opportunistic Relay	The sensors request time slots after receiving beacon from hub.

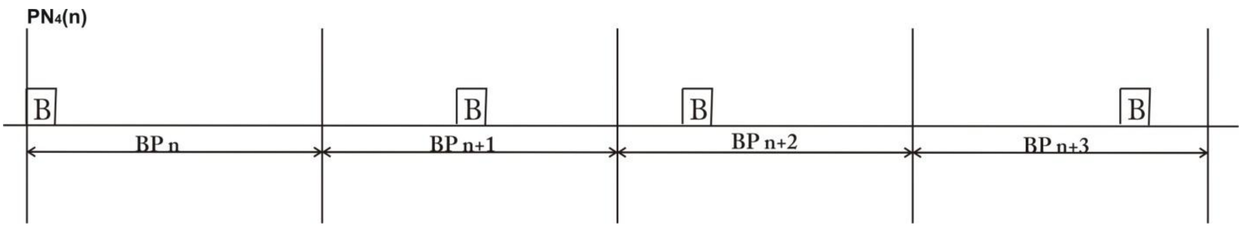
Table 3: Summary of the coexistence mechanisms for IEEE 802.15.6 based WBANs

Chapter 4

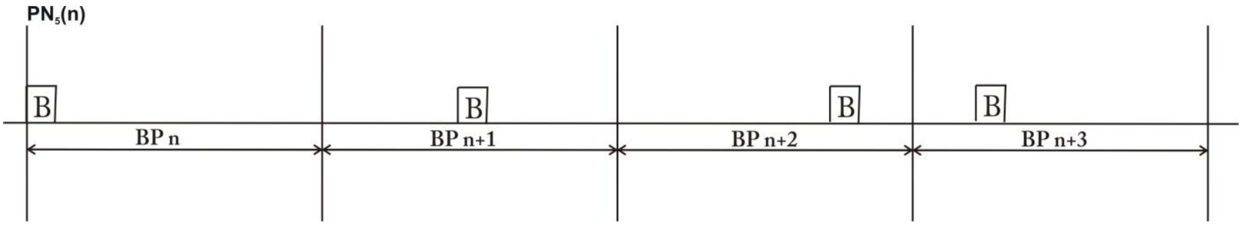
Proposed Beacon Shifting Scheme

4.1 Introduction

The objective of the proposed scheme is to avoid the collision of beacons among multiple BANs. When more than one BANs become active simultaneously in vicinity, their radio ranges overlaps with one another and the BANs are said to be coexisting. Due to this coexistence the communication within a BAN between hub and nodes face interference. The beacons that are generated by a BAN's hub for carrying critical network information to the sensors/nodes connected to it collide with the beacons/data from other BAN's hub. To overcome coexistence issue IEEE 802.15.6 introduces beacon shifting technique as shown before in figure 7. During beacon shifting of IEEE 802.15.6 BAN 1 and BAN 2 selects a beacon shifting sequence from the 8 sequences defined, which is not being used by the other. Even by choosing different sequence indexes i.e. PN_4 and $PN_{5,}$ the chances of beacons collision exists as shown in figure 13 below. Beacons at phase 0 and 1 still collide.



(a) Beacon shifting sequence pattern - PN_4



(b) Beacon shifting sequence pattern - PN_5

Figure 13: Beacon Shifting Sequences

In our proposed scheme a beacon phase is introduced to send all the beacons in different time slots to avoid beacons collision when several BANs coexist.

4.2 Network Model

The proposed algorithm operates in a single hop star topology based IEEE 802.15.6 network. Star topology has a disadvantage of dependency of whole network on a single hub, though it gives better performance results, it is easy to connect new nodes without affecting the network, also its centralized management helps monitoring the network. IEEE 802.15.6 offers three modes of communications but the proposed algorithm works in beacon enabled mode i.e. beacon mode with superframe boundaries. Beacon-enabled mode is a coordinated and synchronized communication mode of IEEE 802.15.6. It supports relatively high data rates and consumes less energy of the devices. The proposed scheme allows the use of all superframe specifications included in IEEE 802.15.6, such as EAP1, RAP1, MAP1, CAP and B2.

All network devices directly communicate with the HUB. HUB is responsible for network establishment and maintenance. Nodes generate events and have different content requirements based on the traffic priority type. Nodes are located at a fixed distance from hub and mobility is not considered. The proposed algorithm is designed to mitigate the interference in star topology based WBAN and to solve the coexistence problem by shifting the beacons in a synchronized and coordinated manner.

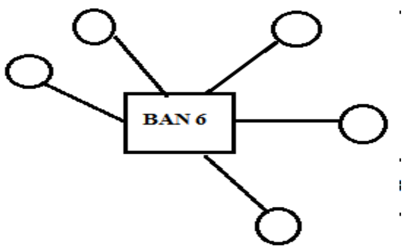
Few assumptions are considered for the operation of proposed scheme. Those assumptions are mention below:

Assumptions

- The nodes are static, mobility is not considered in this scheme.
- This scheme is only applicable to homogeneous networks.

- As selection of cluster head hub is not our main focus therefore BAN 1 is assumed to be the cluster head BAN.
- Superframe length is same for all BANs.

In our proposed solution, the coexisting BANs (Hubs / Coordinators) create a cluster with a head BAN/Hub. Cluster is a set of interfering BANs and one of the hubs is selected as cluster head. When multiple BANs become active at same time in a channel, a Hub from one BAN receives beacons from other BANs; it realizes the coexistence of other BANs in the vicinity and communicates with their Hubs to collaboratively declare a cluster head hub, for example; suppose BAN1 is active in a communication channel, in the mean while BAN2 activates in the same channel and broadcast its beacon. Upon receiving beacon from BAN2, BAN1 sends a command frame to BAN2, declaring itself as a cluster head Hub as BAN1 was first to start working in the specific channel. In figure 14, five BANs are active and these BANs lie within the transmission range of each other, from these multiple BANs one is declared as a cluster head (BAN5) and other BANs (BAN1, BAN2, BAN3, and BAN4) join the cluster



head hub through a response acknowledgement frame (R-ACK) and become the members of the cluster. As BAN6 is out of the radio range of other BANs so it does not join the cluster and works separately without causing any interference. These multiple BANs use the proposed beacon shifting technique to mitigate the coexistence which occurs when these BANs start working at the same time in a channel. Coexistence among members of different clusters and between nodes of different BANs with in a cluster is not considered in this work. The focus of this scheme is mainly on shifting beacons to avoid beacons collision instead of cluster formation or head hub selection.

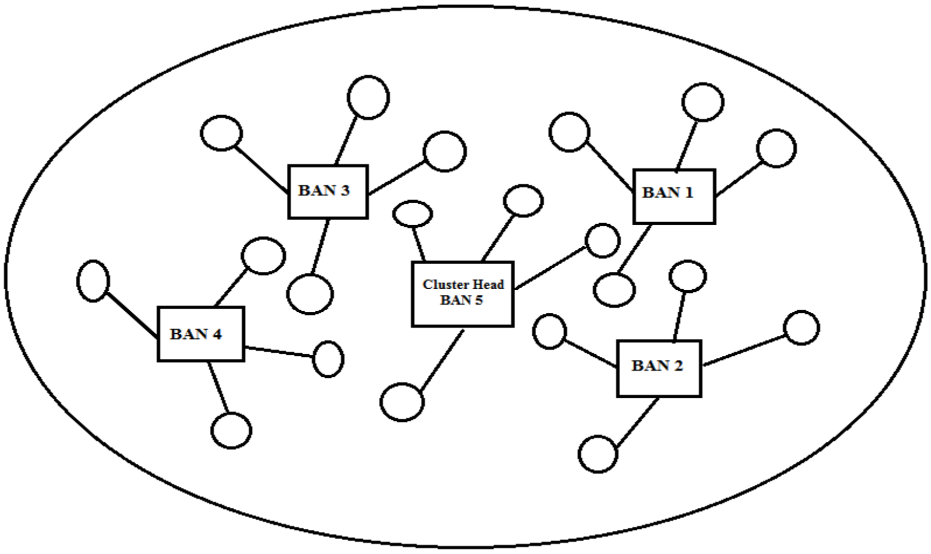


Figure 14: Coexistence scenario

4.3 Operation of the proposed Beacon Shifting scheme

In cluster formation and selection of the cluster head Hub, some important frames are exchanged. We consider the size of superframe to be same for all BANs. The cluster head Hub generates a command frame containing information about its BAN ID, Sender ID, ACK policy to be used, frame type and some other essential information depicted in figure 15.

Bits:	8	8	8	2	4	2
	Recipient ID	Sender ID	BAN ID	ACK Policy	Frame Subtype	Frame Type

Figure 15: Command Frame

This command frame is broadcasted to BANs in the surrounding that coexist. Upon reception of command frame by other BANs, they retrieve the desired information about the cluster head Hub and its BAN and sends a response acknowledgement (R-ACK) to let the head Hub know about the successful reception of the command frame. When R-ACK is received, the head Hub extracts the BAN ID of the sender hub and store it to calculate the duration of beacon phase. Beacon phase is the duration defined/calculated by head BAN given by equation 4.1, in the start of superframe that is shared by all interfering BANs for transmission of their beacons.

$$BeaconPhase = \sum_{i=0}^{n} BANs \times SlotLength \qquad (4.1)$$

SlotLength is the duration of a single slot in the IEEE 802.15.6 superframe. Maximum number of slots in the IEEE 802.15.6 superframe can be up to 255. The beacon packet in each superframe lists the length of L and the number of Slots that are to be used in the superframe. IEEE 802.15.6 defines L and number of slots before the network deployment and the aforementioned values do not change. The length of a single slot and superframe duration is calculated using equation 4.2 and 4.3. These values are fixed and defined by IEEE 802.15.6. SlotLength is the length of single slot in seconds and depends on a minimum value (pAllocationSlotMin) and slot resolution (pAllocationSlotResolution) as defined in table 4.

Symbols	**Description**	**Values**
$P^{AllocationSlotMin}$	Length of single slot in seconds and depends on a minimum value	500μs
$p^{AllocationSlotResolution}$	Length of the single slot resolution	500μs
nSlot	Number of Slots	1-255
L	Slot Length	0-255

Table 4: Symbols and their description

$$SlotLength = (\, pAllocationSlotMin \, + L \, \times pAllocationSlotResolution \,) \qquad (4.2)$$

$$SuperframeDuration = nSlot \times SlotLength \quad (4.3)$$

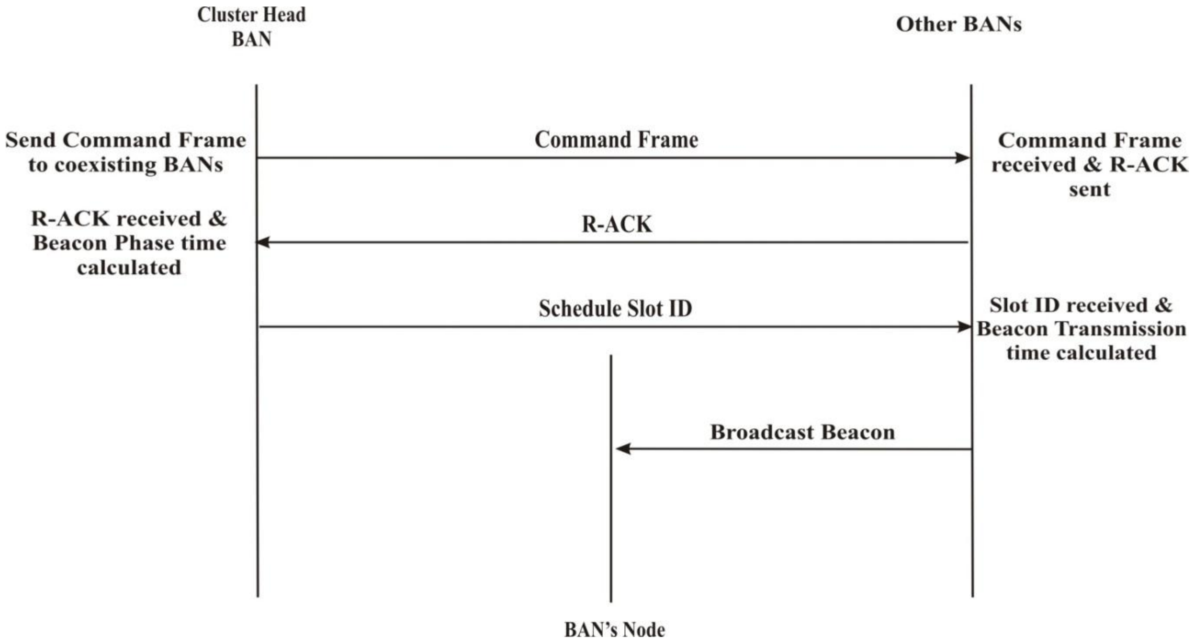


Figure 16: Cluster Head BAN coordination with other BANs

After the beacon phase duration is calculated, the head hub conveys this information to all BANs as depicted in figure 16 and they set their superframes accordingly. Let us assume the time duration of the beacon phase comes out to be ‘x’ seconds. All BANs will add ‘x’ seconds in start of their superframes before EAP and adjust all other phases accordingly. Head Hub, along with beacon phase duration also sends the Slot ID. The Slot ID is basically the location ID where the head Hub has stored the BAN IDs of all BANs that sends the R-ACK. Using this slot ID the BANs calculates time to send beacon in the beacon phase given by equation 4.4.

$$SendBeaconTime = SlothLength * Slot\ ID \quad (4.4)$$

Using this proposed scheme BANs sends its beacons in the beacon phase with the help of a cluster head hub deducing the chances of beacon collision and avoiding necessary synchronization information to be lost as shown in figure 17. The IEEE 802.15.6 beacon shifting solution provides only eight sequence indexes which can support only eight BANs furthermore there is overlapping of patterns in different sequences causing beacons to transmit at same time and increases the chance of its collision.

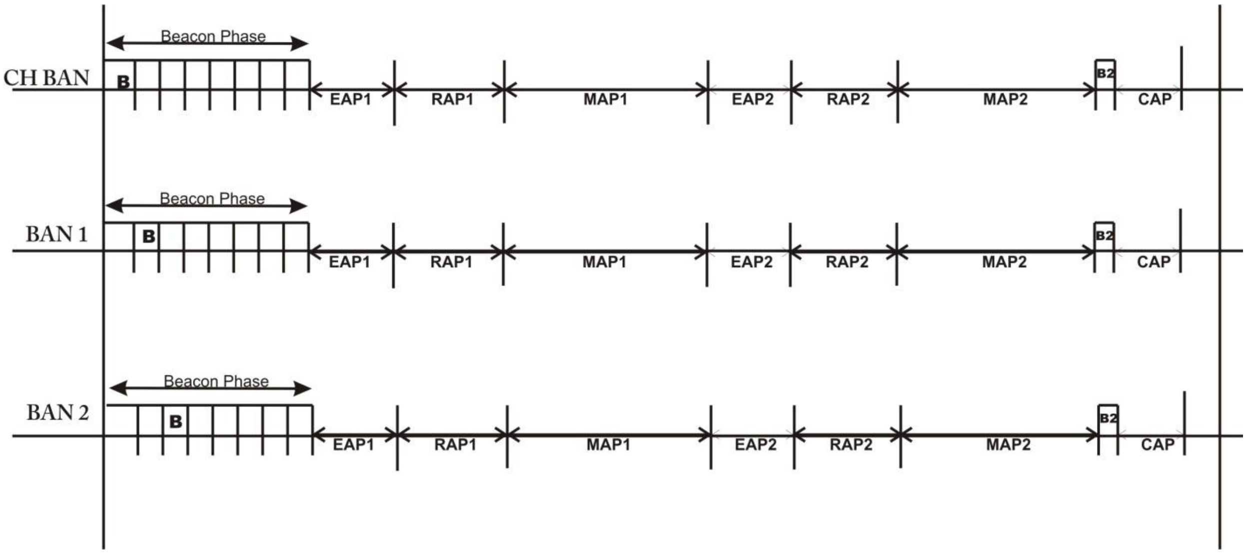


Figure 17: Proposed Beacon Shifting scheme with Beacon Phase

Chapter 5

Results and Analysis

5.1 Introduction

In this chapter, detailed simulation analysis and performance evaluation of proposed scheme is discussed and compared with standard beacon shifting proposed by IEEE 802.15.6. The IEEE 802.15.6 beacon shifting solution provides only eight sequence indexes which can support only eight BANs furthermore there is overlapping of patterns in different sequences causing beacons to transmit at same time and increases the chance of its collision, whereas in proposed scheme beacon phase is dynamically adjusted according to number of coexisting BANs. Hence, we can compare proposed algorithm results with standard beacon shifting by IEEE 802.15.6. Comparison is based on end-to-end latency, beacon delivery ratio, and throughput. The simulation analysis is performed using OPNET Modeler 14.5 [44]. We have analyzed different simulators (NS-2) for the implementation of IEEE 802.15.6, but only OPNET and OMNET++ supports the IEEE 802.15.6 implementation. OMNET++ only supports the DRAFT of WBAN; it doesn't provide complete superframe implementation.

Star topology based WBAN network is used for simulation analysis, in which all nodes can communicate directly with HUB. A BAN's Hub is placed in center of the network topology, whereas nodes surround the hub. For simulation, we have considered four BANs. Beacon-enabled mode of communication is used by all HUBs and each HUB broadcasts periodic beacon for its network devices. Each beacon contains superframe duration which is supposed to be constant along with information about EAP, RAP and MAP intervals.

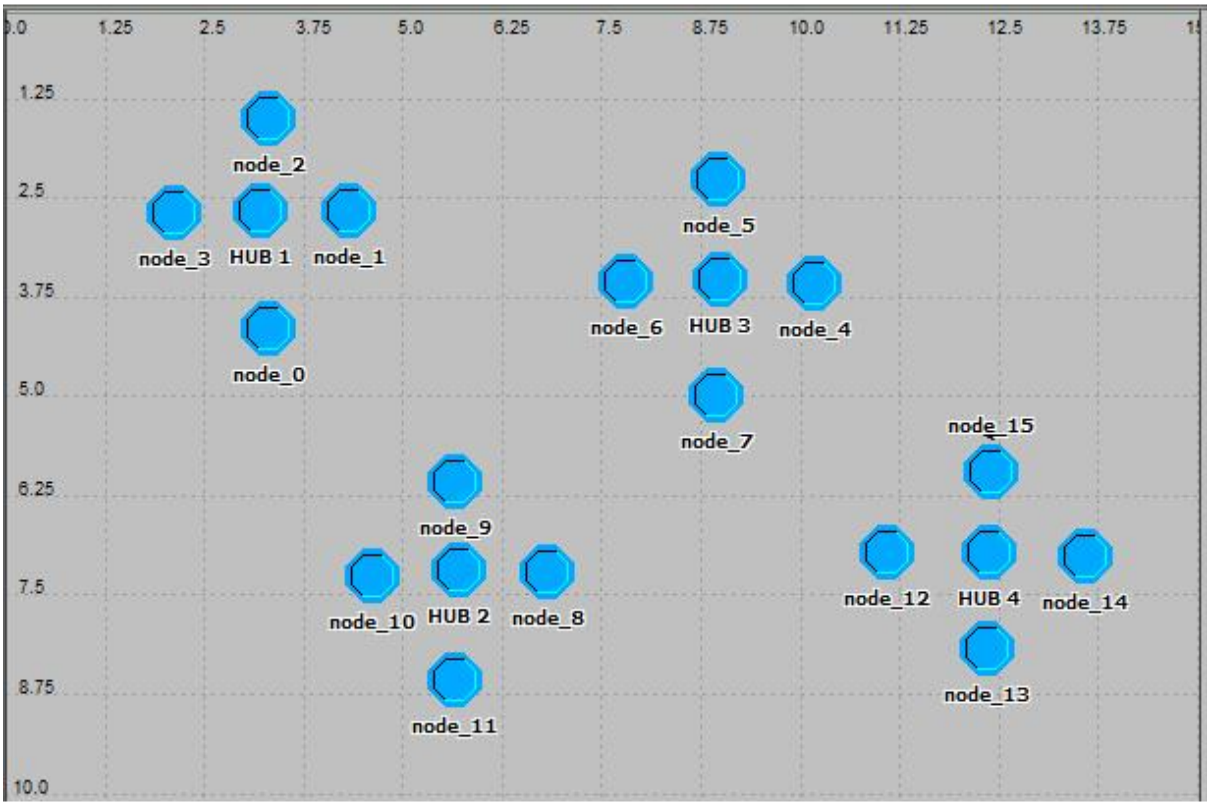


Figure 18: Simulation Network Topology

Figure 18 shows four different BANs. All these BANs are within the transmission range of each other. Node_0 – Node_3 are connected with HUB 1, node_8 – node_11 are connected with HUB 2, node_4 – node_7 are connected with HUB 3 and node_12 – node_15 are connected with HUB 4. The maximum link capacity supported by each WBAN is 971.4 kbps. Frequency band used for operating is 2.4 GHz.

In the remaining of this section, simulation results of proposed algorithm are compared and analyzed with IEEE 802.15.6 beacon shifting technique. Two types of data reporting are used i.e. continuous and periodic. First, we will discuss continuous data reporting results and later on periodic data reporting results will be discussed.

5.2 Continuous Data Reporting

In this section, continuous data reporting is used with constant rate and results from proposed scheme are analyzed and compared with that of the standard IEEE 802.15.6. In continuous data reporting both emergency and non-emergency data traffic is used. Table 5 shows the simulation parameters for continuous data reporting.

Parameter	Value
Simulation time	600 seconds
Frequency band	2.4 GHz
Traffic Type	Emergency / Non-Emergency
Packet Size (bytes)	100
Number of BAN's	10
Link Capacity (kbps)	971.4
Data Rate (kbps)	312.5
Initial energy	34560 Joules
Transmit mode	17.4 mA
Receive mode	24.8 mA

Table 5 : Simulation parameters for Continuous data

We have taken different number of BANs with varying number of nodes to achieve the appropriate results and maximum output of our proposed scheme. Continuous data reporting parameters are shown in table 6.

	Non-Emergency Traffic	Emergency Traffic
MSDU Interval Time (seconds)	0.0025 (400 pkts/sec)	
MSDU Size (bits)	800 (100 bytes)	
HUB1		
Starting Time	250 Second	50 Second
Ending Time	550 Second	250 Second
HUB2		
Starting Time	250 Second	50 Second
Ending Time	550 Second	250 Second
HUB3		
Starting Time	250 Second	50 Second
Ending Time	550 Second	250 Second
HUB4		
Starting Time	250 Second	50 Second
Ending Time	550 Second	250 Second

Table 6: Continuous Data Reporting Parameters

5.2.1 Beacon Delivery Ratio with two nodes per BAN

Beacon Delivery Ratio (BDR) is the ratio of number of beacons successfully received to number of beacons sent. Figure 19 shows the beacon delivery ratio of the proposed beacon shifting scheme and standard beacon shifting scheme using continuous data reporting. Number of nodes associated with hub in a BAN is kept dynamic for different results. In this case two nodes per BAN are considered. The square symbol line denotes proposed beacon shifting scheme which indicates better BDR as compared to round symbol line denoting standard beacon shifting. BDR is dependent on number of beacons collided. If more beacons collide BDR gets dropped and vice versa. Proposed beacon shifting gives better BDR when compared to standard beacon shifting because number of beacons collision in standard beacon shifting is more. In standard beacon shifting when number of BANs reaches nine, BDR drops more because of reuse of the sequence index. More beacons are dropped when they are transmitted at same time in a channel.

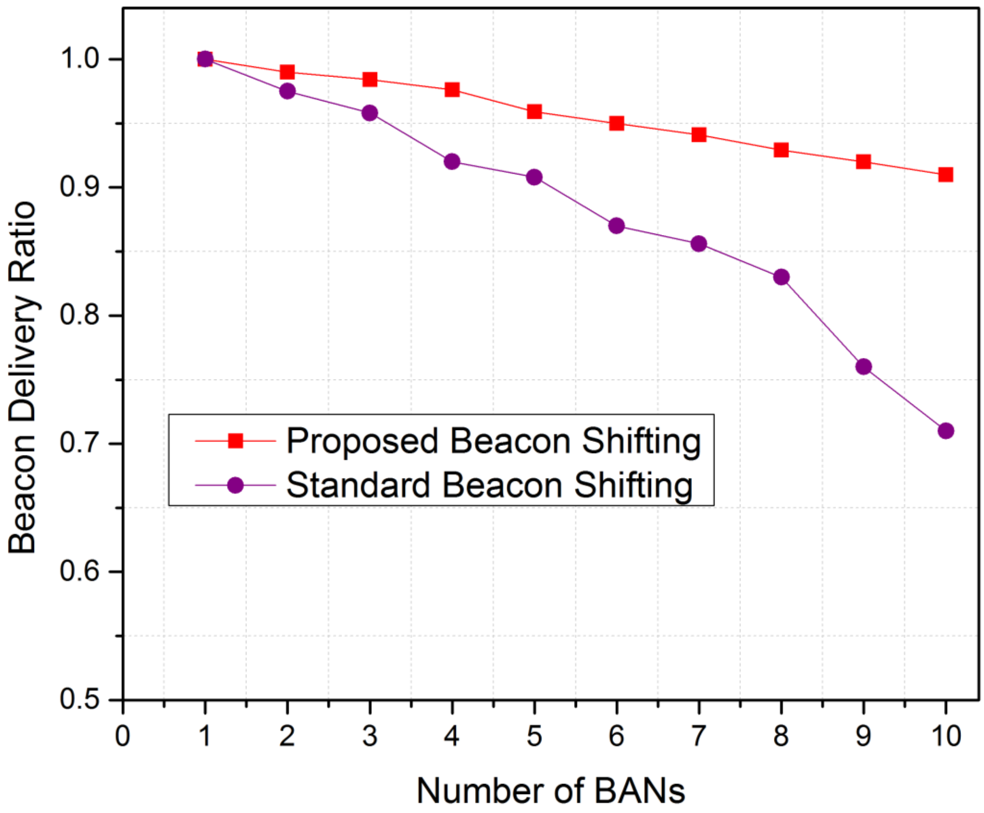


Figure 19: BDR of continuous data reporting with 2 nodes per BAN

5.2.2 Beacon Delivery Ratio with four nodes per BAN

BDR is shown in Figure 20 with 4 nodes per BAN in proposed beacon shifting scheme and standard beacon shifting scheme of IEEE 802.15.6. BDR seems to decrease as number of nodes per BAN increases. With increase in number of nodes, beacon collision increases causing decrease in BDR. However it has unnoticeable effect in the proposed beacon shifting scheme.

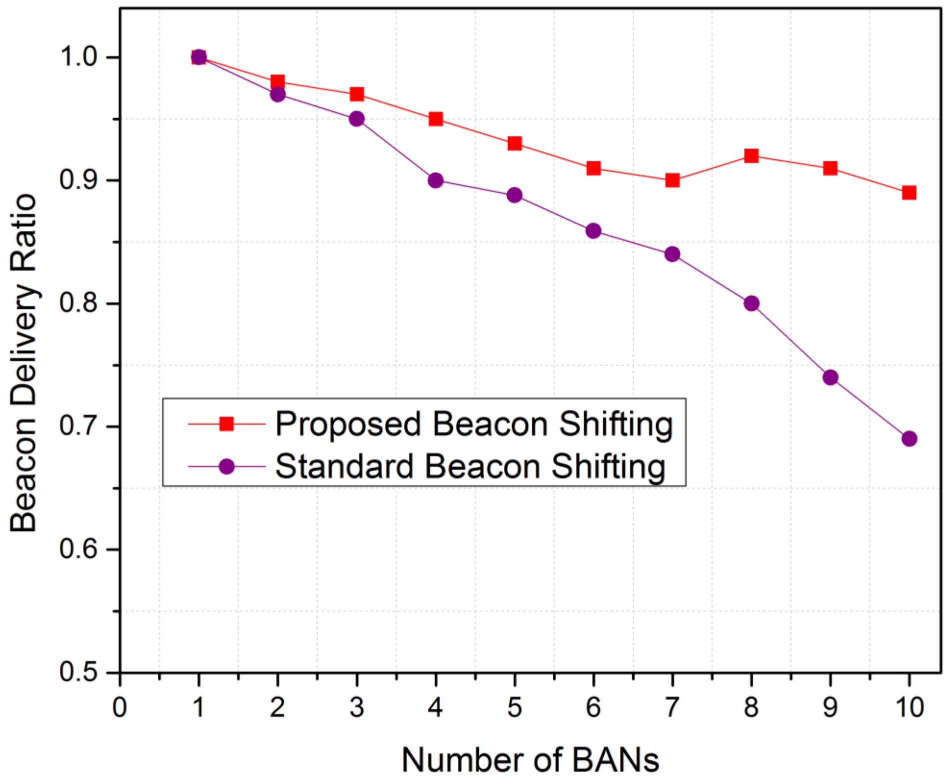


Figure 20: BDR of continuous data reporting with 4 nodes per BAN

5.2.3 Beacon Delivery Ratio with six nodes per BAN

Beacon delivery ratio is shown in Figure 21 and provides the comparison between proposed beacon shifting scheme and beacon shifting scheme of IEEE 802.15.6. BDR of the two schemes is calculated by increasing the number of nodes. Hence increasing nodes per BAN, affects the BDR.

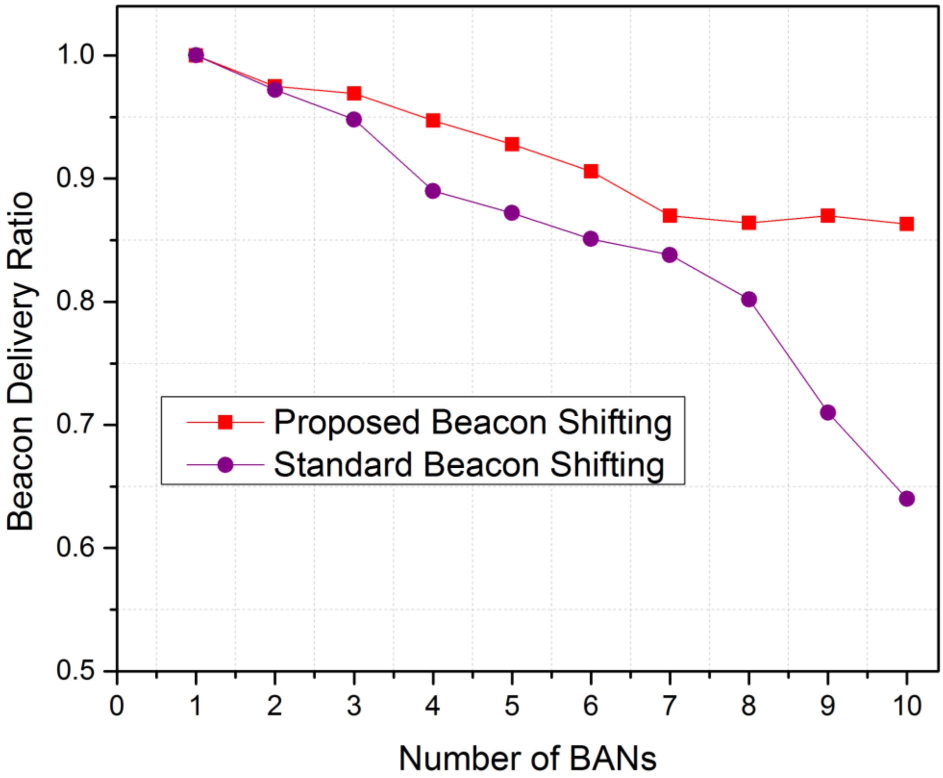


Figure 21: BDR of continuous data reporting with 6 nodes per BAN

5.2.4 Throughput of proposed Beacon Shifting scheme

Figure 22 shows throughput of the two schemes i.e. proposed beacon shifting and standard beacon shifting technique of IEEE 802.15.6. Proposed scheme gives much higher throughput than standard scheme after the number of BANs increases from eight. It is because the standard scheme reuse the sequence pattern causing different BANs to use same pattern which increases the number of collisions, and as a result throughput of the standard scheme reduces.

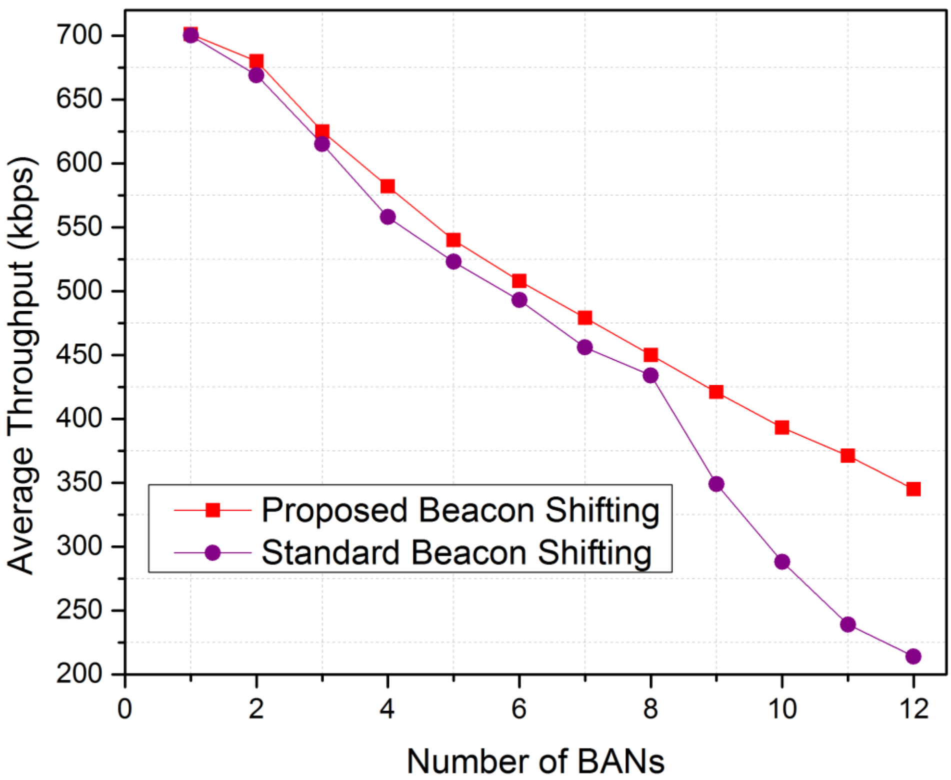


Figure 22: Throughput with continuous data reporting

5.2.5 Delay of proposed Beacon Shifting scheme

Delay of the proposed scheme is compared with that of the standard scheme and is shown in Figure 23. Average delay of the proposed scheme comes out to be much less than that of standard technique, taken that number of BANs are same with same other parameters. Delay increases due to the retransmission of the beacons. When beacons collide, it takes more time to retransmit the beacons and synchronize the nodes with hub. Figure 23 shows that the delay increases in standard beacon shifting technique as the number of BANs is increased.

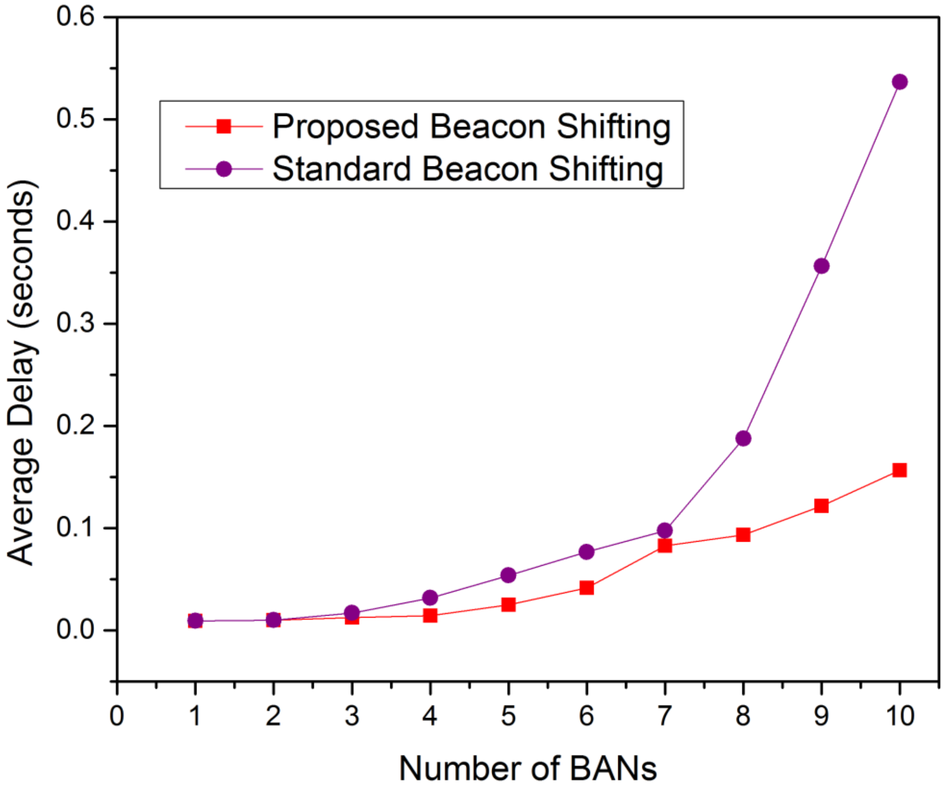


Figure 23: Delay with continuous data reporting

5.2.6 Energy of proposed Beacon Shifting Scheme

Figure 24 represents the remaining energy of the BANs at start of simulation and then at different instances of the simulation. The proposed scheme utilizes more energy in the beginning because it sends some extra management frames for the formation of a cluster and then declaring a cluster head. After some period of time as obvious from the graph the proposed scheme shows efficient energy consumption than the standard technique.

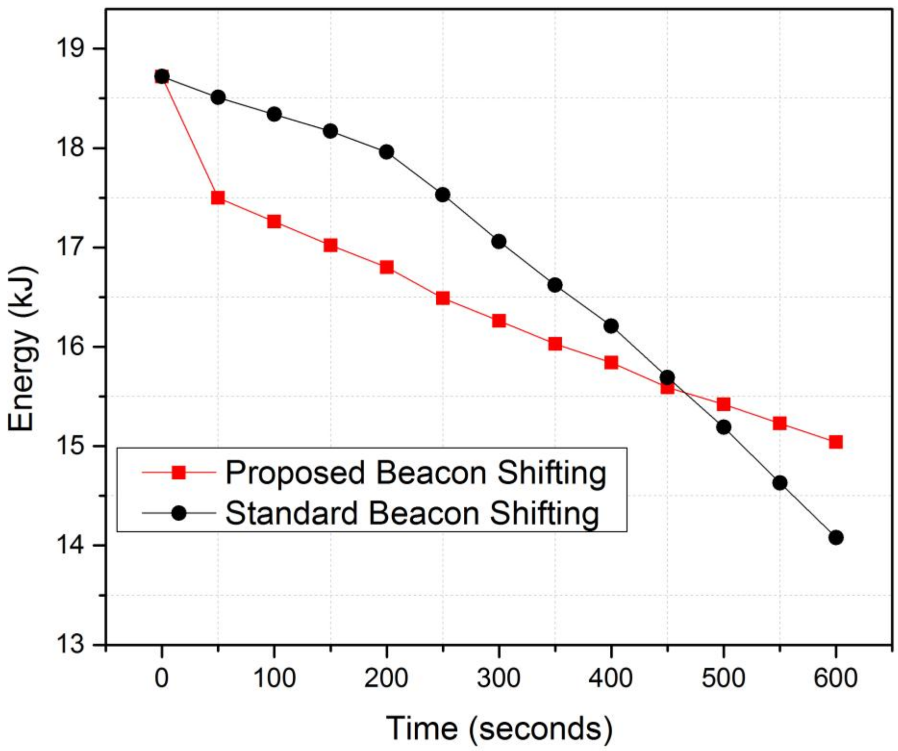


Figure 24: Residual Energy with continuous data reporting

5.3 Periodic Data Reporting

Periodic data reporting means transmitting data for a certain interval then stopping data generation, to observe the performance of standard and proposed scheme. The two types of traffics used are Emergency and Non-Emergency. Emergency traffic is transmitted in EAP whereas in RAP both types of traffics can be transmitted. The general simulation parameters used are shown in table 7.

Parameter	Value
Simulation time	600 seconds
Frequency band	2.4 GHz
Traffic Type	Emergency and Non-Emergency
Packet Size (bytes)	150, 200
Number of BAN's	10
Link capacity	971.4 kbps
Initial energy	34560 Joules
Data Rate (kbps)	34.36, 312.5
Transmit mode	17.4 mA
Receive mode	24.8 mA

Table 7: Simulation parameters

Table 8 shows the periodic data reporting pattern of different HUBs with respect to time.

	Non-Emergency Traffic	**Emergency Traffic**
MSDU Interval Time (seconds)	0.005 (200 pkts/sec)	0.005 (200 pkts/sec)
MSDU Size (bits)	1200 (150 bytes)	1600 (200 bytes)
HUB 1		
Starting Time	200 Second	50 Second
Ending Time	300 Second	150 Second
HUB 2		
Starting Time	300 Second	50 Second
Ending Time	500 Second	250 Second
HUB 3		
Starting Time	400 Second	150 Second
Ending Time	600 Second	350 Second
HUB 4		
Starting Time	200 Second	50 Second
Ending Time	300 Second	150 Second

Table 8: Periodic Data Reporting Parameters

5.3.1 Throughput of the proposed Beacon Shifting scheme

Figure 25 shows the throughput comparison of proposed beacon shifting scheme with standard beacon shifting technique of IEEE 802.15.6 in periodic data reporting mode. Throughput reduction in standard beacon shifting technique is more than the proposed beacon shifting scheme. The proposed schemes overall gives better throughput than the standard scheme as the number of BANs increases. Due to increase in the number of BANs more beacons are generated and broadcasted. As a result more beacons are collided which seems to have a direct affect in reducing the throughput of the standard beacon shifting technique. Periodic data's throughput is less as compared to continuous data's throughput because of difference in data rates of the two.

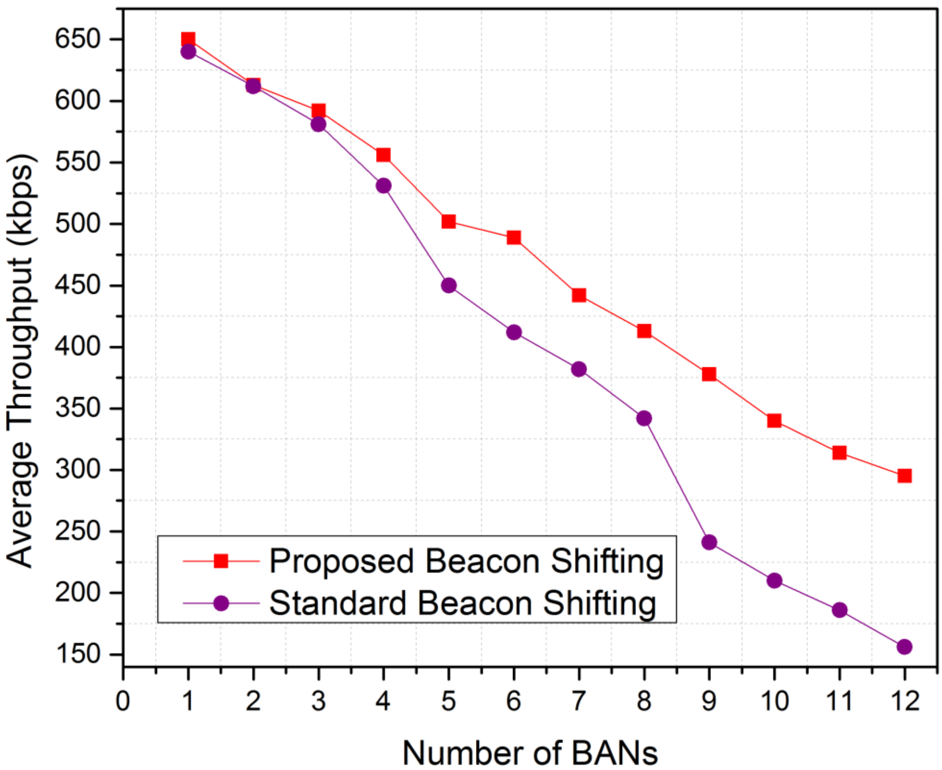


Figure 25: Throughput during periodic data reporting

5.3.2 Delay of the proposed Beacon Shifting scheme

The term delay is used to indicate how much slower the data has arrived to its destination. Delay in both schemes is calculated periodically and is shown in figure 26. Delay is caused do to the interference between the coexisting BANs. Delay increases as the number of BANs and interference between them is increased. With increase in number of BANs the proposed scheme faces less delay than the IEEE 802.15.6 standard beacon shifting technique.

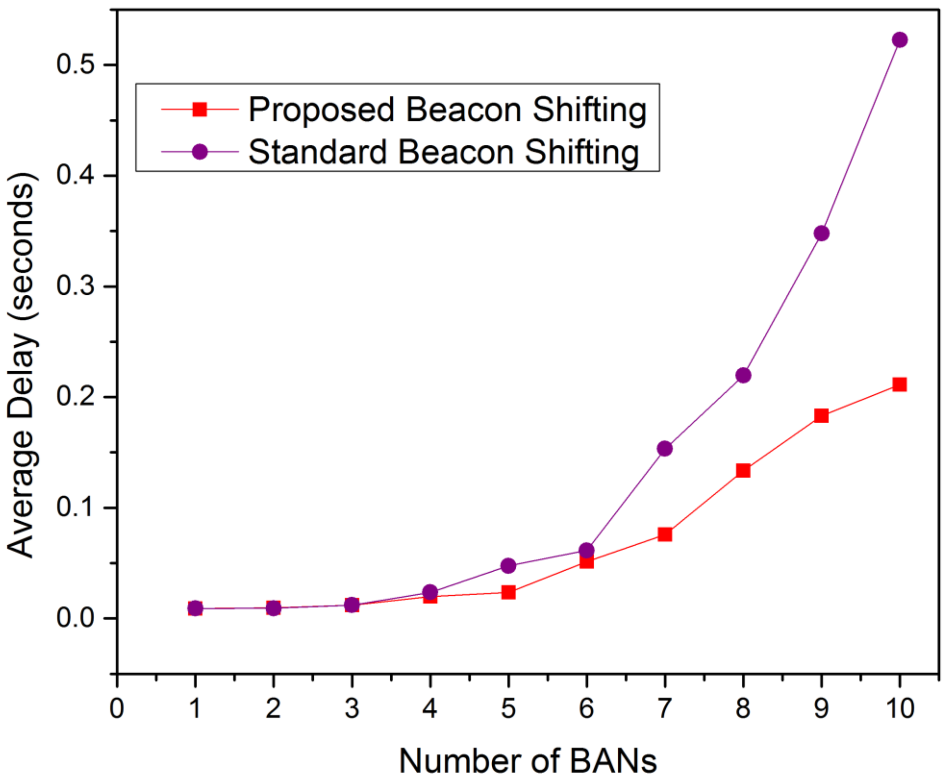


Figure 26: Delay during periodic data reporting

5.3.3 Beacon Delivery Ratio with two nodes per BAN

Figure 27 shows the beacon delivery ratio of the proposed beacon shifting scheme and standard beacon shifting scheme using periodic data reporting. Performance of the proposed scheme is better than the standard even with periodic data reporting. Variation in results of continuous data reporting and periodic data reporting can be observed

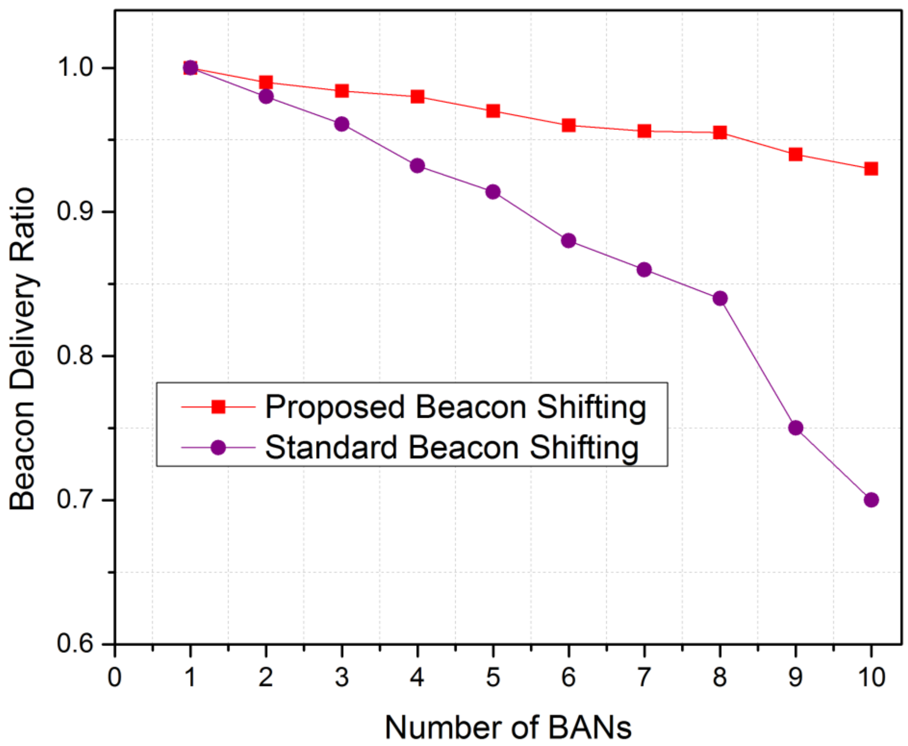


Figure 27: BDR of periodic data reporting with 2 nodes per BAN

5.3.4 Beacon Delivery Ratio with four nodes per BAN

BDR of periodic data reporting is shown in Figure 28 with 4 nodes per BAN in proposed beacon shifting scheme and standard beacon shifting scheme of IEEE 802.15.6. BDR seems to decrease as number of nodes per BAN increases. With increase in number of nodes, beacon collision increases causing decrease in BDR. However it has very little effect in the proposed scheme.

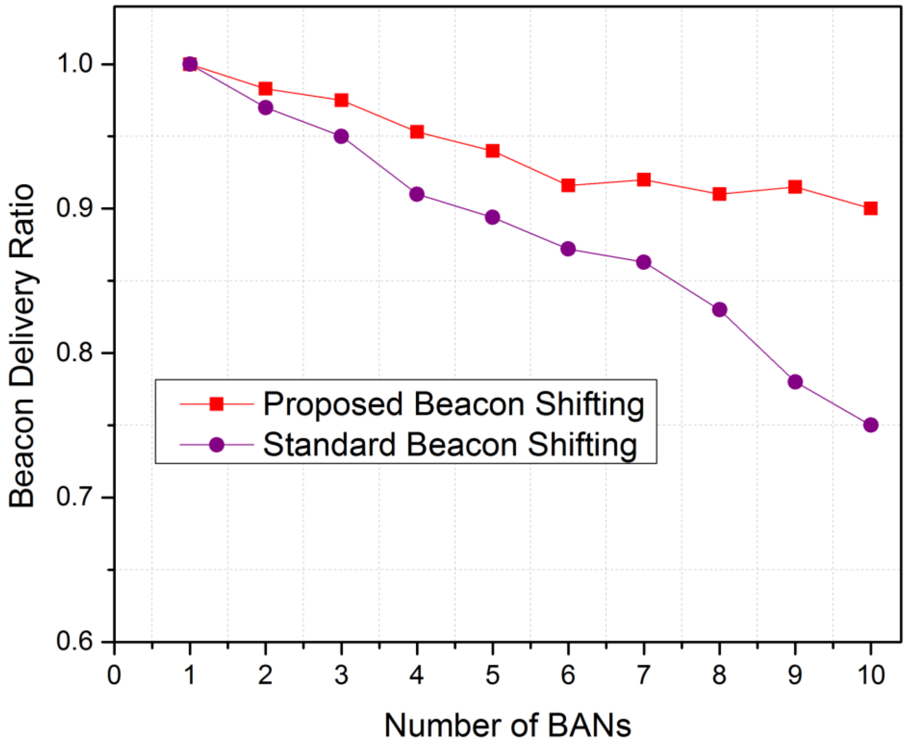


Figure 28: BDR of periodic data reporting with 4 nodes per BAN

5.3.5 Beacon Delivery Ratio with six nodes per BAN

Beacon delivery ratio is shown in Figure 29 and provides the comparison between proposed beacon shifting scheme and beacon shifting scheme of IEEE 802.15.6. Six nodes per BAN are taken to calculate the BDR. Graph shows that by increasing nodes per BAN, BDR is affected.

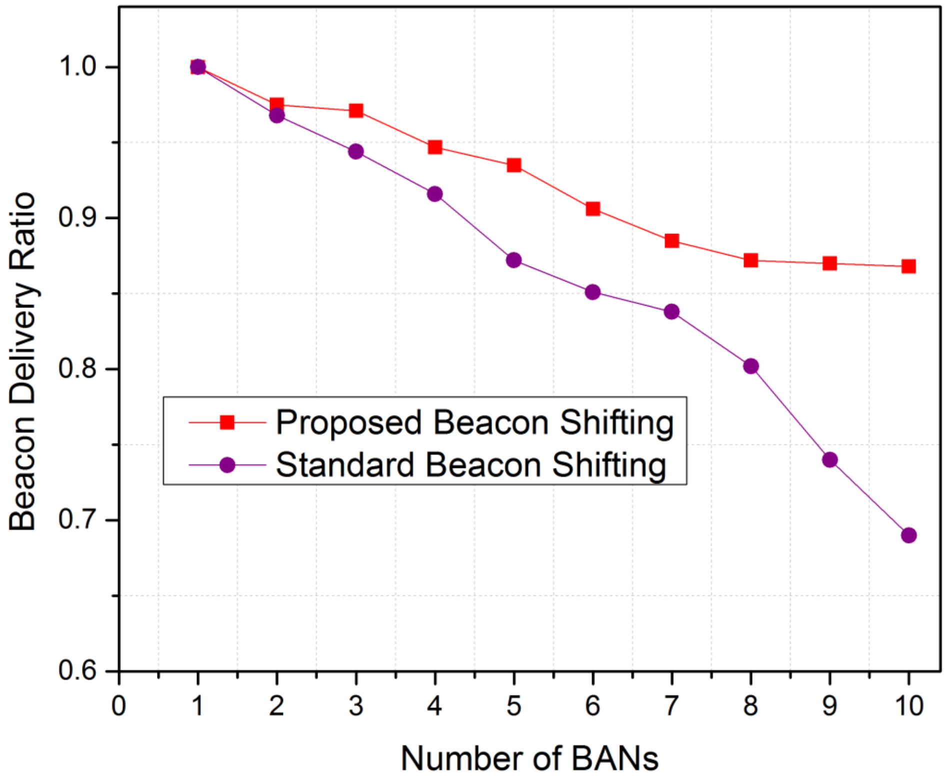


Figure 29: BDR of periodic data reporting with 6 nodes per BAN

Chapter 6

Conclusion

The problem of coexistence is well known and studied in wireless networks for more than two decades. However, IEEE 802.15.6 is a relatively new standard for WBANs and due to the nature of short distance communication in BANs interference is imminent in these networks. In IEEE 802.15.6 three techniques are proposed to avoid coexistence between BANs. First technique is beacon shifting in which multiple sequence patterns of beacon shifting are introduced and these patterns are assigned to individual BANs. Second technique is channel hopping in which BANs constantly change communication channels. The last technique is superframe interleaving that mitigates the interference between multiple BANs by adjusting and sharing the communication channel on turns.

Proposed algorithm plays a vital role in improving the performance of wireless body area networks by mitigating the chances of beacons collision while coexisting with other homogeneous WBANs. In this work, we have developed a beacon shifting scheme in which collision of beacons is prevented under coexistence by shifting the beacons in a timely, organized and coordinated manner using a centralized hub. The work assumes a cluster of BANs in which the head hub performs beacon shifting among neighbouring BANs. The head hub dynamically adjusts the duration of beacon phase according to the number of BANs in its cluster. Thus proposed beacon shifting is performed to avoid beacons collision while having a coexisting environment.

Detailed simulation analysis is performed in OPNET and the performance of the proposed beacon shifting scheme is found better than the existing IEEE 802.15.6 beacon shifting technique. The proposed scheme is able to substantially increase the overall beacon delivery ratio of interfering BANs.

In our proposed scheme, we assume that the first BAN in a communication channel is the cluster head. In future work, selection of cluster head can be made more efficient by considering multiple parameters for cluster head selection. Also, algorithms for cluster head rotation and tackling changes in the cluster with mobility are interesting areas for future research in WBANs. Another, important aspect for future research is the application of beacon shifting in heterogeneous networks as the proposed scheme only addresses the interference problem in homogeneous WBANs.

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