



**Selective Packet Discarding for Effective Congestion  
Control in Medical Data Transmission of Remote  
Healthcare Monitoring System**

by

**Wan Aida Nadia binti Wan Abdullah  
(1540211894)**

A thesis submitted in fulfillment of the requirements for the degree of  
Doctor of Philosophy

**School of Computer and Communication Engineering  
UNIVERSITI MALAYSIA PERLIS**

2020

## ACKNOWLEDGMENT

In the name of Allah, the Most Gracious, the Most Merciful: “So which of the favors of your Lord would you deny? (Ar-Rahman)”. Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this thesis.

First and foremost, I would like to express my special appreciation to my beloved and dedicated PhD supervisor, Dr Naimah binti Yaakob and co-supervisor, Prof. Ir. Ts. Dr. R. Badlishah Ahmad for their continuous support and invaluable constructive comments and suggestions that contributed to this success. Special thanks to Dr Mohamed Elshaikh for his knowledge and guidance in using OMNeT++ simulator.

Secondly, my deepest gratitude and indebtedness goes to my beloved parents; Wan Abdullah bin Wan Mamat and Mariam binti Che Lah, my little brother; Wan Fakrul Rizal bin Wan Abdullah and other family members for their endless love, prayers and encouragements in whatever I pursue.

My sincere thanks to all my friends for the kindness and moral support especially on the sleepless nights we were working together before deadlines and most importantly for all the fun we have experienced throughout this journey. Thanks for the memorable friendship and memories.

Last but not least, thanks to MyBrain15 for the sponsorship throughout this period of study. This appreciation also goes to my beloved adopted family in Perlis and members of Embedded Network and Computer (ENAC) lab. Also, thank you to the individuals who have been there for me during my ups and downs and to those who indirectly contributed in this research, your kindness means a lot to me. Thank you very much.

## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION OF THESIS</b>	<b>i</b>
<b>TABLE OF CONTENTS</b>	<b>iii</b>
<b>LIST OF TABLES</b>	<b>viii</b>
<b>LIST OF FIGURES</b>	<b>xii</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xv</b>
<b>LIST OF SYMBOLS</b>	<b>xviii</b>
<b>ABSTRAK</b>	<b>xx</b>
<b>ABSTRACT</b>	<b>xxii</b>
<b>CHAPTER 1 : INTRODUCTION</b>	<b>1</b>
1.1 Overview	1
1.2 Research Background	1
1.3 Problem Statement	5
1.4 Research Questions	9
1.5 Research Objectives	10
1.6 Research Motivation	11
1.7 Research Contributions	12
1.8 Scope of Research	13
1.9 Thesis Organization	14
<b>CHAPTER 2 : LITERATURE REVIEW</b>	<b>16</b>
2.1 Overview	16

2.2	Integration of WBAN in Remote Health Monitoring System (RHMS) towards IoT	17
2.2.1	Classification of Health Monitoring Systems (HMS)	18
2.2.2	Architecture of Wireless Body Area Network (WBAN)	20
2.2.3	Standard Wireless Communication in WBAN	22
2.2.4	Bio-sensors and their signals characteristics in WBAN	24
2.3	Characteristics of ECG and its network features	26
2.4	Requirements and Challenges in WBAN	29
2.5	Protocol Stacks in WBAN	32
2.6	Overview of Data Congestion in WBAN	35
2.6.1	Congestion Control mechanisms in WBAN	38
2.7	Related Works	43
2.7.1	Congestion Avoidance in WBAN	43
2.7.2	Packet Discarding (PD) mechanism	49
2.7.3	Packet Prioritization based Congestion Control mechanisms in WBAN	56
2.7.4	Packet Fragmentation in MAC 802.15.4 protocol for WBAN	61
2.7.5	Research Gap	71
2.8	Summary	72
	<b>CHAPTER 3 : METHODOLOGY</b>	<b>74</b>
3.1	Overview	74
3.2	Phases of PSPT-MAC congestion avoidance mechanism in WBAN	75
3.2.1	Phase 1: ECG Packet Classification and Prioritization (ECG-PCP) mechanism (Objective 1)	76
3.2.2	Phase 2: Prioritized Selective Packet Discarding (P-SPD) mechanism (Objective 1)	82
3.2.3	Phase 3: Fragmentation-based Slot Time Medium Access Control (FST-MAC) mechanism in slotted CSMA/CA of MAC IEEE 802.15.4 protocol (Objective 2)	89

3.3	The integration of PSPT-MAC congestion avoidance mechanism in WBAN	102
3.4	Network Test-bed Design and Implementation through OMNeT++ simulator tool	106
3.4.1	Protocol Stack of Network in INET 3.6.2 framework	107
3.5	Network Performances Evaluation	109
3.6	Settings of WBAN simulation environment	113
3.7	Results Validation and Verification Method	117
3.7.1	Comparison and Validation with Existing Works (Objective 3)	117
3.7.2	Simulation Model Validation	118
3.8	Summary	119
<b>CHAPTER 4 : RESULTS AND DISCUSIONS</b>		<b>120</b>
4.1	Introduction	120
4.2	Preliminaries analysis on the effects of congestion in WBAN	122
4.2.1	Overall Network Performances of IEEE 802.15.4 protocol against Number of Nodes for preliminaries analysis on the effects of congestion in WBAN	124
4.3	Evaluations on the effectiveness of the proposed Prioritized Selective Packet Discarding (P-SPD) mechanism in alleviating congestion in WBAN	127
4.3.1	Number of Nodes	128
4.3.1.1	Overall Network Performances between P-SPD mechanism and IEEE 802.15.4 protocol against Number of Nodes	129
4.3.2	Packet Sizes	134
4.3.2.1	Overall Network Performances between P-SPD mechanism and IEEE 802.15.4 protocol against Packet Sizes	134
4.3.3	Traffic Generations	138
4.3.3.1	Overall Network Performances between P-SPD mechanism and IEEE 802.15.4 protocol against Traffic Generations	139

4.4	Evaluations on the effectiveness of Fragmentation-based Slot Time Medium Access Control (FST-MAC) mechanism based on MAC IEEE 802.15.4 protocol in alleviating congestion in WBAN	143
4.4.1	Number of Nodes	144
4.4.1.1	Overall Network Performances between FST-MAC mechanism and IEEE 802.15.4 protocol against Number of Nodes	145
4.4.2	Packet Sizes	149
4.4.2.1	Overall Network Performances between FST-MAC mechanism and IEEE 802.15.4 protocol against Packet Sizes	149
4.4.3	Traffic Generations	153
4.4.3.1	Overall Network Performances between FST-MAC mechanism and IEEE 802.15.4 protocol against Traffic Generations	154
4.5	Performances Comparisons and Validations between PSPT-MAC, standard MAC IEEE 802.15.4 and FCA-MAC mechanism	158
4.5.1	Number of Nodes	160
4.5.1.1	Comparison of Network Performances between PSPT-MAC, FCA-MAC and IEEE 802.15.4 mechanisms against Number of Nodes	161
4.5.2	Packet Sizes	165
4.5.2.1	Comparison of Network Performances between PSPT-MAC and IEEE 802.15.4 mechanisms against Packet Sizes	165
4.5.3	Traffic Generations	169
4.5.3.1	Comparison of Network Performances between PSPT-MAC and IEEE 802.15.4 mechanisms against Traffic Generations	170
4.6	Summary	174
	<b>CHAPTER 5 : CONCLUSION</b>	<b>176</b>
5.1	Introduction	176
5.2	Achievements of Research	177
5.3	Limitations and Future Works	179

<b>REFERENCES</b>	<b>180</b>
<b>APPENDIX A PSPT-MAC CODING</b>	<b>190</b>
<b>APPENDIX B SNAPSHOTS OF CODING FOR ECG-PCP, P-SPD AND FST-MAC MECHANISMS IN OMNET++ SIMULATOR TOOL</b>	<b>199</b>
<b>APPENDIX C WBAN SCENARIO CODING IN OMNET++ SIMULATOR TOOL</b>	<b>201</b>
<b>LIST OF PUBLICATIONS</b>	<b>206</b>

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## LIST OF TABLES

		<b>PAGE</b>
Table 2.1	Characteristics of different classes of HMS Source: Baig & Gholamhosseini (2013)	19
Table 2.2	Wireless communications in WBAN Source: Arbia et al. (2017)	23
Table 2.3	Characteristics of biosensors and their signals Source: Masud (2013)	25
Table 2.4	Features in ECG waveform Source: Singh & Bilandi (2015)	27
Table 2.5	Range of intervals for RR and QRS complex of ECG for Normal Heart Rate Source: Ravish et al. (2014)	28
Table 2.6	Specifications on each layer in protocol stack of WBAN	34
Table 2.7	Features of network traffics Source: Kafi et al. (2014)	36
Table 2.8	Performances comparison of SPD methods	55
Table 2.9	Criteria in each strategies of congestion control in the selected protocols	59
Table 2.10	Comparison of network's performances in the selected congestion control protocols	60
Table 2.11	PHY layer specifications of IEEE 802.15.4 Source: Ghayvat, Mukhopadhyay, & Gui (2016)	63

Table 2.12	The differences between beacon and non-beacon modes in MAC IEEE 802.15.4 protocol Source: Yadav, Brar, & Kaur (2014)	63
Table 2.13	Criteria in the selected modification of superframe for MAC IEEE 802.15.4 protocol	69
Table 2.14	Comparison of network's performances in the modification of superframe in MAC IEEE 802.15.4 protocol	70
Table 3.1	Range of RR-interval for packet classification of ECG in the WBAN	78
Table 3.2	Category of ECG medical data for ECG-PCP mechanism	80
Table 3.3	Role and value of parameters in the slotted CSMA/CA of MAC IEEE 802.15.4 protocol	101
Table 3.4	Sub-modules of INET 3.6.2 framework and their functionalities	108
Table 3.5	Setting of parameters in WBAN Source: Dharshini & Tamilarasi (2014)	117
Table 4.1	General simulation parameters of WBAN scenario Source: Dharshini & Tamilarasi (2014), Nepal et al. (2017)	121
Table 4.2	Preliminary results of network performances during congestion in the WBAN	123
Table 4.3	Overall network performances between P-SPD mechanism and IEEE 802.15.4 protocol against number of nodes in the WBAN	133
Table 4.4	Overall network performances between P-SPD mechanism and IEEE 802.15.4 protocol against packet sizes in the WBAN	137
Table 4.5	Value of packet generation based on Send Interval (SI)	138

Table 4.6	Overall network performances between P-SPD mechanism and IEEE 802.15.4 scheme against traffic generations in the WBAN	142
Table 4.7	Values of slot time for FST-MAC and IEEE 802.15.4 protocol	144
Table 4.8	Overall network performances between FST-MAC mechanism and IEEE 802.15.4 standard against number of nodes in the WBAN	148
Table 4.9	Overall network performances between FST-MAC mechanism and IEEE 802.15.4 standard against packet sizes in the WBAN	152
Table 4.10	Overall network performances between FST-MAC mechanism and IEEE 802.15.4 standard against traffic generations in the WBAN	157
Table 4.11	General simulation parameters for performance comparisons and validations of WBAN	160
Table 4.12	Overall network performances between PSPT-MAC mechanism, FCA-MAC and IEEE 802.15.4 protocol against number of nodes in the WBAN	164
Table 4.13	Overall network performances between PSPT-MAC mechanism and IEEE 802.15.4 protocol against packet sizes in the WBAN	168
Table 4.14	Value of packet generation based on Send Interval (SI) for the comparison and validation purposes	169
Table 4.15	Overall network performances between PSPT-MAC mechanism and IEEE 802.15.4 standard against traffic generations in the WBAN	173

Table 4.16 Summary of the average percentage improvement between PSPT-MAC, FCA-MAC and IEEE 802.15.4 standard for WBAN

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## LIST OF FIGURES

		<b>PAGE</b>
Figure 1.1	Integration of WBAN in RHMS Source: Dinkar, Gulavani, Ketkale, Kadam, & Dabhade (2013)	4
Figure 2.1	Block diagram of components in sensor node	20
Figure 2.2	Architecture of communication system in WBAN Source: M. Chen et al. (2011)	21
Figure 2.3	ECG cycle Source: Ramli, Ahmad, & Abdollah (2013)	26
Figure 2.4	Overview of protocol stacks in the network	32
Figure 2.5	Node and link level congestion Source: Rezaee et al. (2014)	37
Figure 2.6	Layers of congestion control mechanisms in the network's protocol stack	39
Figure 2.7	Stages of congestion control and their techniques	40
Figure 2.8	Taxonomy of congestion control mechanisms in WBAN	43
Figure 2.9	Packet Discarding (PD) mechanisms	51
Figure 2.10	Structure of superframe in MAC IEEE 802.15.4 protocol Source: Toscano & Lo Bello (2012)	64
Figure 3.1	Phases of PSPT-MAC congestion avoidance mechanism	76
Figure 3.2	QRS complex and RR-interval in a complete ECG cycle Source: Baldoumas et al. (2018)	77
Figure 3.3	Flowchart of ECG-PCP mechanism	80

Figure 3.4	Algorithm of ECG-PCP mechanism	81
Figure 3.5	Flowchart of P-SPD mechanism	85
Figure 3.6	Algorithm of P-SPD mechanism	88
Figure 3.7	Data collision scenario in MAC 802.15.4 protocol	90
Figure 3.8	Structure of frame in MAC IEEE 802.15.4 protocol Source: Ranjit & Shin (2013)	92
Figure 3.9	Structure of medical frame in MAC IEEE 802.15.4 protocol for WBAN	92
Figure 3.10	Structure of superframe in MAC IEEE 802.15.4 protocol	93
Figure 3.11	Flowchart of the proposed FST-MAC mechanism in the superframe of MAC IEEE 802.15.4 protocol	97
Figure 3.12	Algorithm of FST-MAC mechanism under slotted CSMA/CA of MAC IEEE 802.15.4 protocol	98
Figure 3.13	A data fragmentation mechanism in slotted CSMA/CA of MAC IEEE 802.15.4 protocol	99
Figure 3.14	A successful packet transmission in MAC IEEE 802.15.4 protocol	100
Figure 3.16	Algorithm of PSPT-MAC mechanism	104
Figure 3.17	Internal Structure of a running wireless WBAN node with the PSPT-MAC mechanism	107
Figure 3.18	Simulation environment of WBAN in OMNeT++ simulator tool	113
Figure 3.19	Illustration of clinical ward for WBAN	114
Figure 4.1	Performances of (a) throughput (b) delay (c) packet loss and (d) PDR for IEEE 802.15.4 protocol against number of nodes	124

Figure 4.2	Graphs of (a) throughput (b) delay (c) packet loss and (d) PDR between P-SPD mechanism and IEEE 802.15.4 standard against number of nodes in WBAN	129
Figure 4.3	Graphs of (a) throughput (b) delay (c) packet loss and (d) PDR between P-SPD mechanism and IEEE 802.15.4 standard against packet sizes in WBAN	134
Figure 4.4	Graphs of (a) throughput (b) delay (c) packet loss and (d) PDR between P-SPD mechanism and IEEE 802.15.4 standard against traffic generations in WBAN	139
Figure 4.5	Graphs of (a) throughput (b) delay (c) packet loss and (d) PDR between FST-MAC mechanism and IEEE 802.15.4 standard against number of nodes in WBAN	145
Figure 4.6	Graphs of (a) throughput (b) delay (c) packet loss and (d) PDR between FST-MAC mechanism and IEEE 802.15.4 standard against packet sizes in WBAN	149
Figure 4.7	Graphs of (a) throughput (b) delay (c) packet loss and (d) PDR between FST-MAC mechanism and IEEE 802.15.4 standard against traffic generations in WBAN	154
Figure 4.8	Graphs of (a) throughput (b) delay (c) packet loss and (d) PDR between PSPT-MAC, FCA-MAC and IEEE 802.15.4 standards against number of nodes in WBAN	161
Figure 4.9	Graphs of (a) throughput (b) delay (c) packet loss and (d) PDR between PSPT-MAC and IEEE 802.15.4 standards against packet sizes in WBAN	165
Figure 4.10	Graphs of (a) throughput (b) delay (c) packet loss and (d) PDR between PSPT-MAC and IEEE 802.15.4 standards against traffic generations in WBAN	170

## LIST OF ABBREVIATIONS

ACD	Automata based Congestion Detection
ACK	Acknowledgement
ADC	Analog to Digital Converter
ADL	Activity of Daily Life
A-MPDU	Aggregated MAC protocol
AODV	Ad-hoc On Demand Vector
AP	Access Point
AQM	Active Queue Management
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BI	Beacon Interval
BLE	Bluetooth Low Energy
BO	Beacon Order
BPM	Beat Per Minute
bps	bits per second .
CAP	Contention Access Period
CCA	Clear Channel Assessment
CFP	Contention Free Period
CL	Congestion Level
CN	Congestion Notification
CODA	Congestion Detection and Avoidance
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
DTP	Data Transmission Period
DTS	Data Time Slot
ECG	Electrocardiogram
ECG-PCP	ECG Packet Classification and Prioritization
E-CODA	Enhanced Congestion Detection and Avoidance
EEG	Electroencephalogram
EL	Engineering Level
EPD	Early Packet Discarding
ESPD	Early Selective Packet Discarding
FIFO	First In First Out
FST-MAC	Fragmentation based Slot Time Medium Access Control

GTS	Guaranteed Time Slot
HMS	Health Monitoring System
IFS	Inter Frame Space
IoT	Internet of Things
kbps	kilobits per second
LA	Learning Automata
LACAS	Learning Automata-Based Congestion Avoidance Scheme
LIFS	Long IFS
MAC	Medium Access Control
Mbps	Megabits per second
MHMS	Mobile Health Monitoring System
MPDU	MAC Protocol Data Unit
NAV	Network Allocation Vector
NIC	Network Interface Card
ORA	Optimized Rate Adjustment
PC	Personal Computer
PCCP	Priority based Congestion Control Protocol
PD	Packet Discarding
PDA	Personal Digital Assistant
PDR	Packet Delivery Ratio
PHTCCP	Prioritized Heterogeneous Traffic-oriented Congestion Control Protocol
POS	Personal Operating Space
PPD	Partial Packet Discarding
PQ	Priority Queue
PRA	Priority Rate Adjustment
PSDU	Payload Segment Data Unit
P-SPD	Prioritized Selective Packet Discarding
PSPT-MAC	Priority Selective Packet Timeslot Medium Access Control
PTA	Priority Timeslot Allocation
QoS	Quality of Service
RED	Random Early Detection
RHMS	Remote Health Monitoring System
RT-MMF	Relaxation Theory with Max-Min Fairness

RTT	Round-Trip Time
SD	Superframe Duration
SIFS	Short IFS
SO	Superframe Order
SPD	Selective Packet Discarding
S-TDMA	Statistical frame based TDMA
SUDAS	Superframe Duration Adjustment scheme
TCP	Transmission Control Protocol
TD	Tail Drop
TDMA	Time Division Multiple Access
TTL	Time-to-Live
UDP	User Datagram Protocol
WBAN	Wireless Body Area Network
WBSN	Wireless Body Sensor Network
WFQ	Weighted Fair Queuing
WHMS	Wearable Health Monitoring System
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WRED	Weighted Random Early Detection
WSN	Wireless Sensor Networks

## LIST OF SYMBOLS

$\lambda_{gen}$	Traffic generation in the network
$BER_{ECG}$	Bit Error Rate of ECG
$Bit_{err}$	Number of bits in error
$Bit_R$	Bit rate of a transceiver
$Delay_{diff}$	Difference between the received and creation time of the packet
$Delay_{proc}$	Processing delay
$Delay_{prop}$	Propagation delay
$Delay_{queue}$	Queueing delay
$Delay_{trans}$	Transmission delay
$D_{rateSTD}$	Data rate of IEEE 802.15.4 standard
$L_{macfooter}$	Size of MAC footer
$L_{macheader}$	Size of MAC header
$L_{phy}$	Size of PHY header
$n$	Length of packet in bit
$ND_{rateECG}$	New Data Rate of ECG
$NE$	Number of Experiments
$N_{nodes}$	Number of nodes
$np$	New priority
$NP_{received}$	Number of received packets
$NP_{sent}$	Number of sent packets
$NP_{total}$	Total number of packets
$P_{ecg}$	Generation of ECG packet
$P_{high}$	High priority
$P_{low}$	Low priority
$P_{med}$	Medium priority
$pr$	Priority
$ps$	Packet Size
$P_{T\_creation}$	Time of packet created
$P_{T\_received}$	Time of packet received
$SI$	Send Interval between two consecutive packets
$Slot\_T$	Slot Time
$S_{payload}$	Size of payload packet
$SR_{ECG}$	Sampling rate of ECG
$SRES_{BIT}$	Sampling bits resolution
$T_{RR}$	RR interval

$T_{rbit}$	Total number of received bits
$T_{simulation}$	Simulation time
$T_{trans}$	Transmission time of a packet

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# **Pembuangan Paket Terpilih untuk Kawalan Kesesakan yang Berkesan dalam Penghantaran Data Perubatan untuk Sistem Pemantauan Penjagaan Kesihatan Kawalan Jauh**

## **ABSTRAK**

Kemajuan pesat dalam teknologi Internet dan pengesanan telah membolehkan pembangunan Rangkaian Kawasan Badan Tanpa Wayar (WBAN) yang disasarkan untuk Pemantauan Penjagaan Kesihatan Kawalan Jauh (RHMS). Teknologi ini membantu pesakit dengan terus memantau dan mengesan status kesihatan mereka melalui melekatkan atau menanamkan beberapa pengesan bio yang pintar dan ringan ke dalam badan mereka. Kemudian, data perubatan terkumpul akan selanjutnya diproses oleh pihak perubatan. Sekiranya terdapat ketidaknormalan yang dikesan, tindakan perubatan akan segera akan dilakukan untuk mengelakkan sebarang akibat kepada pesakit. Walau bagaimanapun, penghantaran data perubatan berterusan boleh menyebabkan trafik berat yang boleh meningkatkan masalah kesesakan di rangkaian. Ia boleh merosakkan prestasi rangkaian dari segi kelewatan lebih tinggi dan kehilangan paket serta kadar penghantaran bit dan nisbah penghantaran paket yang lebih rendah (PDR). Ini boleh mengakibatkan kemudaratan kepada pesakit kritikal. Oleh itu, kesesakan perlu dielakkan seawalnya untuk memastikan RHMS boleh dipercayai dan cekap. Satu mekanisme iaitu Prioriti Pemilihan Paket Slot Masa Kawalan Akses Perantara (PSPT-MAC) dicadangkan untuk menangani isu yang dinyatakan ke atas data perubatan Elektrokardiogram (ECG) di dalam thesis ini. Mekanisma yang dicadangkan ini merangkumi tiga teknik iaitu Klasifikasi dan Pengutamaan ECG-paket (ECG-PCP), mekanisme Prioriti Pembuangan Paket Terpilih (P-SPD) dan Pemecahan berdasarkan Slot Masa Kawalan Akses Perantara (FST-MAC). PSPT-MAC dimulakan oleh ECG-PCP untuk mengklasifikasikan dan mengutamakan data berdasarkan nilai selang RR. Data perubatan ini diklasifikasikan ke dalam data kritikal (keutamaan tinggi), luar biasa (keutamaan sederhana) dan biasa (keutamaan rendah). Kemudian, satu mekanisme Prioriti Pembuangan Paket Terpilih (P-SPD) akan dijalankan untuk membuang paket perubatan yang rosak di kalangan data normal dan tidak normal dalam WBAN. Ini kerana jenis data ini tidak memerlukan kelewatan yang ketat berbanding dengan data kritikal. Untuk menegaskan, paket yang rosak tidak bernilai untuk dihantar kerana mereka mempunyai peluang yang lebih tinggi untuk dijatuhkan yang mungkin menyebabkan penghantaran semula. Ini boleh menyebabkan kelewatan yang lebih panjang dalam rangkaian yang menjejaskan penyampaian data perubatan kritikal dan mungkin membazirkan sumber-sumber rangkaian yang terhad seperti lebar jalur dan tenaga. Fasa terakhir iaitu FST-MAC membantu dalam pemecahan paket perubatan melalui slot masa yang sesuai sebanyak 0.2 milisaat dalam protokol CSMA / CA MAC IEEE 802.15.4 untuk mengurangkan kelewatan dalam rangkaian. Keberkesanan mekanisme PSPT-MAC telah diuji dan disahkan melalui proses simulasi menggunakan alat simulasi acara diskrit iaitu OMNeT++ dengan integrasi rangka kerja INET 3.6.2. Penemuan menunjukkan bahawa cadangan mekanisme PSPT-MAC selalu mengalahkan kedua-dua kaedah sedia ada yang mana IEEE 802.15.4 dan FCA-MAC. Mekanisma PSPT-MAC berjaya mencapai pengurangan kelewatan ketara kira-kira sehingga 78.67% dan 74.42% berbanding dengan protokol

IEEE 802.15.4 dan mekanisma FCA-MAC. Juga, mekanisma PSPT-MAC berjaya menurunkan kadar kehilangan paket sebanyak 48.99% yang menyumbang kepada kadar penghantaran bit dan PDR yang tinggi berbanding dengan protokol IEEE 802.15.4 di bawah senario bilangan nod yang berbeza.

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## **Selective Packet Discarding for Effective Congestion Control in Medical Data Transmission of Remote Healthcare Monitoring System**

### **ABSTRACT**

A rapid advancement in Internet and sensors technology have enabled the development of Wireless Body Area Network (WBAN) technology which is targeted for Remote Healthcare Monitoring System (RHMS). This technology assists patients by continuously monitoring and detecting their health's status through attaching or implanting several intelligent and lightweight bio-sensors into their bodies. Later, the collected medical data would be further processed by the medical authorities. If any abnormalities are detected, immediate medical actions would be carried out to avoid any consequences to patients. However, continuous transmission of medical data could lead to heavy traffics which can raise the issue of congestion in the network. It could degrade network performances in terms of higher delay and packet loss as well as lower throughput and packet delivery ratio (PDR). The consequences of these performances might be severed to the critical patients. Therefore, congestion should be avoided at the first place to ensure a reliable and efficient RHMS. In this thesis, a mechanism namely Priority Selective Packet Timeslot Medium Access Control (PSPT-MAC) is proposed to handle the aforementioned issues with regard to the Electrocardiogram (ECG) medical data. This proposed mechanism integrates three techniques which are ECG Packet Classification and Prioritization (ECG-PCP), a Prioritized Selective Packet Discarding (P-SPD) and Fragmentation based Slot Time Medium Access Control (FST-MAC) mechanisms. The PSPT-MAC is initiated by ECG-PCP to classify and prioritize the medical data based on the value of RR-interval. These data are classified into critical (high priority), abnormal (medium priority) and normal (low priority). Then P-SPD is carried out to discard the corrupted medical packets among normal and abnormal data. This is because these types of data do not pose a strict delay compared to critical data. To emphasize, the corrupted packets are not worth to be transmitted as they have higher chance of being drop which might cause retransmission. This could result in longer delay which affects the delivery of critical medical data and might waste the scarce network resources such as bandwidth and energy. The last phase which is FST-MAC helps in fragmentation of medical packets through a suitable slot time of 0.2 millisecond in the slotted CSMA/CA MAC IEEE 802.15.4 protocol in order to reduce delay in the network. The effectiveness of PSPT-MAC mechanism has been tested and validated through simulation processes using a discrete event simulator tool namely OMNeT++ with the integration of framework INET 3.6.2. The findings have shown that the proposed PSPT-MAC always outperforms the two existing methods which are IEEE 802.15.4 and Fast Channel Assignment Medium Access Control (FCA-MAC) mechanisms. The PSPT-MAC has managed to achieve a significant reduction in delay approximately up to 78.67% and 74.42% compared to the standard IEEE 802.15.4 protocol and FCA-MAC mechanism respectively. Also, PSPT-MAC mechanism has successfully decreased packet loss rate by 48.99% which has contributed in higher throughput and PDR compared to the standard IEEE 802.15.4 protocol under different number of nodes scenario.

## CHAPTER 1 : INTRODUCTION

### 1.1 Overview

This chapter covers general information on Wireless Body Area Network (WBAN) that includes its characteristics, advantages and limitations to be adopted in designing a reliable Remote Health Monitoring System (RHMS). In addition, this chapter also describes about congestion phenomena which is one of the key challenges in WBAN in providing seamless RHMS. Apart from that, problem statement, research questions, objectives, motivations, contributions and scope of this research are also discussed.

### 1.2 Research Background

The estimation of increasing number in aging population around the world are up to 761 million in 2025 (Vo, Nghi, Tran, Mai, & Le, 2015) which may lead to a higher number of patients suffering to chronic diseases such as heart attack and diabetes. Precisely, nearly 17.5 million of dead people has been recorded annually due to heart attacks and 246 million diagnosed with diabetes (Masud, 2013). These issues are further extended with the limited capabilities of the current global healthcare systems. For instance, the traditional healthcare system is still facing consultation issue in the sense that the patients and doctors need to have a face-to-face medical consultation. This will be time consuming since patients have to wait a long queue for the available medical practitioners before they can be checked. Patients with chronic diseases will be more suffered if they receive late medical attention and response. In addition, infants and elderly people could also be affected by the traditional consultation system. Therefore, it

is essential to develop an efficient and reliable RHMS to enable continuous monitoring patient's health status and also advance detection of chronic diseases at anywhere and anytime. This is to avoid any occurrence of unwanted incident that might increase mortality rate.

The realization of RHMS can be made possible by exploiting special characteristics of WBAN and the advancement in the current wireless communication technology such as Internet. In (Fatema & Brad, 2014), the term WBAN can be interchangeable with Wireless Body Sensor Network (WBSN). A WBAN is an enhancement of Wireless Sensor Networks (WSN) technology which is categorized into wearable computing devices (Devapriya & Sudha, 2014). In (Chiuchisan, Costin, & Geman, 2014), this progress of technology is one of the Internet of Things (IoT) applications where many devices are connected and capable to self-configure in order to interact with physical and virtual components within standard communication protocols.

However, in (Barakah & Ammad-uddin, 2012) and (Srinidhi & Mangala, 2016), WBAN is slightly different compared to WSN in terms of its coverage scale, mobility, and consequences of lost data. Sensor nodes in WBAN or also term as bio-sensor nodes are restricted to cover only few centimetres of human body. Conversely, WSN has a large coverage area which is up to several kilometres. Other perspective is on mobility. Users with WBAN sensors might pose high mobility and can move around freely compared to a stationary WSN. The other difference is type of data rates which is homogeneous and heterogeneous for WSN and WBAN respectively. Furthermore, the correct placement of sensors is vital for WBAN to measure vital body signals. Additionally, the loss of any significant data in WBAN can cause severe impact that will threaten patient's life while

the loss of redundant data may not have significant impact in WSN. Hence, WBAN enforces high Quality of Service (QoS) requirements to be fulfilled in designing any application particularly in real-time healthcare applications.

The deployment of WBAN in RHMS consists of a number of tiny and intelligent bio-sensor nodes which are wearable or implanted on/inside the patient's body. These sensors generate massive amount of data continuously while collecting various vital physiological signals such as heart rate, body temperature and blood pressure. All the readings will later be forwarded to the sink node (gateway) to be used for further processing and diagnosis by the physicians. Finally, the processed data is wirelessly transmitted via Internet to patients' relatives to notify them on the current condition of the patient. A prompt emergency procedure will be carried out immediately if any abnormalities are detected in the collected signals. An integration of WBAN in RHMS can be depicted as in Figure 1.1.

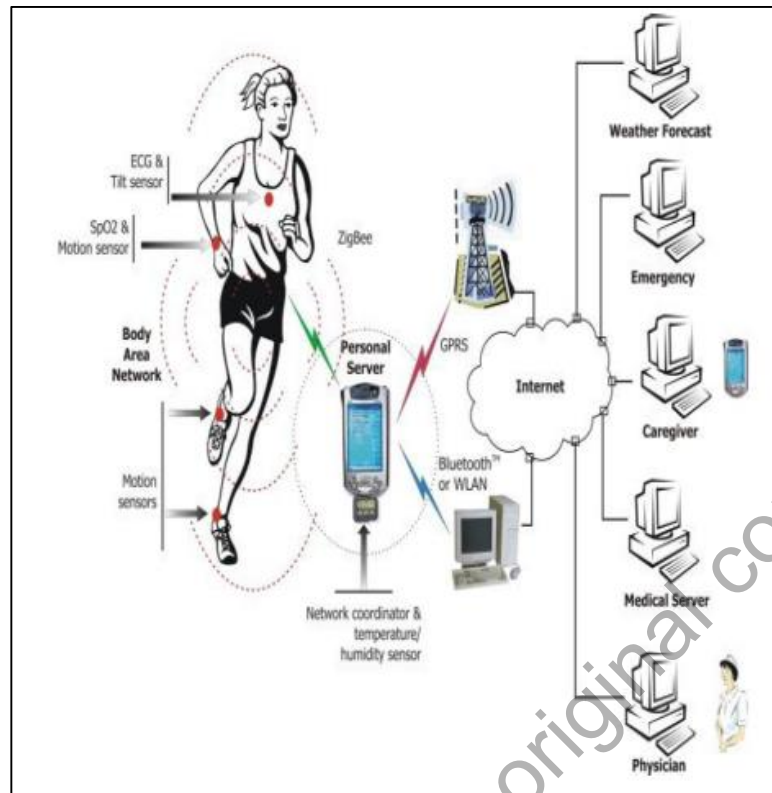


Figure 1.1 Integration of WBAN in RHMS  
 Source: Dinkar, Gulavani, Ketkale, Kadam, & Dabhade (2013)

Although WBAN contributes numerous advantages on RHMS, there are still various challenges to be overcome in order to evade from any service interruptions during continuous monitoring session. For examples, common issues such as delay (should be less than 250 milliseconds) and packet loss during data transmission are still unresolved (Akbar, Yu, & Cang, 2016). In typical RHMS situation, multiple bio-sensor nodes are attached to multiple patients' bodies. This could result in formation of high data traffic which lead to congestion. Such a burden of traffic burst cannot be afforded by the limited network resources in WBAN such as bandwidth and energy supply. Thus, congestion has severe negative impact to the network performances specifically on delay and packet loss. Consequently, transmission delay and loss of packet should be avoided when handling critical medical data transmission in RHMS since it will degrade the quality of received information on the receiver's side (Yusuf Khan, Yuce, Bulger, & Harding, 2012). In fact,

longer transmission delay can lead to obsolete information that create late delivery of emergency response to the patient (Yaakob & Khalil, 2016). Hence, a reliable and efficient congestion avoidance mechanism should be crucially designed with minimum delay and packet loss to ensure high performance of WBAN.

### **1.3 Problem Statement**

Several issues are identified when conducting this research and are explained as follows.

#### **i. Scarce resources and limited capacities in bio-sensor nodes**

Generally, bio-sensor nodes in WBAN are tiny, battery-operated and communicate with each other using IEEE 802.15.4/ZigBee (Pathak, Kumar, Mohan, & Kumar, 2015), (Yena Kim, Lee, & Lee, 2016). Due to these characteristics, they are facing resources' constraints such as bandwidth, processing power and buffer storage. The deficiency of available bandwidth will hinder transmission of emergency signal to healthcare providers. This could be worst when there is congestion in the network as these resources will be quickly depleted due to high possibility of packets retransmission. This retransmission could lead to extra energy consumption that can reduce the longevity of nodes and cause to poor performance of sensor nodes. Also, retransmission brings to longer delay in delivery the packets to the base station.

Moreover, continuous sending of bulk packets without classification and prioritization would lead to higher usage of scarce resources in WBAN. This is a crucial

issue in transmitting medical data which contains different types of information such as normal, abnormal and critical data. Critical data should have the highest priority for allocation of limited network resources so that they would not suffer from high packet loss and delay. Although a priority mechanism to control the congestion in WBAN have been proposed (Yaghmaee, Bahalgardi, & Adjeroh, 2013), (Manfredi, 2014), but they only considered assignment of priority for different types of bio-sensor nodes. However, there would be a situation in which same type of bio-sensors are used in WBAN. For instance, placement of ECG sensor to multiple bodies might generate various readings of heart rate. Thus, the highest priority should be assigned to the patients with abnormality readings in the ECG. From the aforementioned problems, an effective classification and prioritization mechanism should be designed according to their level of importance. This could avoid congestion at the very first place which will directly reduce the use of scarce resources in the network.

**ii. High data generation in bio-sensor nodes results in congestion which would increase delay and packet loss rate thus degrade the overall network performance**

Continuous monitoring and sensing of vital body signals from multiple bodies would produce huge amount of data. For instance, one lead of ECG can generate up to 360 samples/second (Ramli, Ahmad, & Abdollah, 2014). In fact, placement of ECG leads on a single body could be reach up to 12 leads that would yield data around 500 Megabyte for 24 hours continuous monitoring (Kang, 2014). Thus, this amount of data will be significantly increased during the sensing and data collection from multiple bodies. Furthermore, a sudden surge of data production will occur because of detection of

abnormalities during data sensing. This situation happens in order to alert and update the medical authorities regarding the emergency situation. These heavy traffic might result in contention among bio-sensor nodes in accessing the shared wireless medium. This could lead to congestion.

In addition, high buffer occupancies due to congestion will lead to buffer overflow. Such an event will result in higher number of packets drop and packets loss. The dropped and lost packets might carry critical data and valuable information of patient's health status. This issue could lead to false diagnosis of the diseases. A separate virtual buffers on a single physical buffer to store the receiving packets to avoid congestion has been proposed (Rezaee, Yaghmaee, & Rahmani, 2014). However, it is not efficient to increase size of buffers as it will lead to longer delay in the network. Consequently, this longer transmission delay will bring to obsolete and stale packet arriving at the base station. As a result, these packets are no longer useful and could negatively impact the performance of WBAN. This could be worst if these packets carried significant information on the health's status of the patients. Hence, a new mechanism to avoid congestion during transmission of a bulk packets should be designed which could prevent longer delay and high packet loss in the network of WBAN.

**iii. Critical data poses a strict delay during data transmission in order to be timely arrived at the base station**

As stated earlier, WBAN deals with different types of data which are critical, abnormal and normal data. Critical data carries significant features of physiological signals compare to other types of data. This critical data will help medical practitioners

to early diagnose the symptoms of chronic diseases to prevent any severe impact that could risk the life of patients. Thus, this critical data need to face less delay (less than 125 milliseconds) to be timely arrived at the base station (Tabish, Ben Mnaouer, Touati, & Ghaleb, 2013). However, sending large packet size of critical data could bring to longer transmission time which lead to longer delay. Hence, critical data should be fragmented into smaller size to pose less delay to arrive at the destination. This would lead to shorter time of transmission. Frame fragmentation has been done in (Akbar, Yu, & Cang, 2017) by combining several frames from different types of data under same PHY header in the WBAN. This is done to reduce overhead in the packet. However, this work does not consider importance of data during combination of frames. Thus, this would affect the transmission of critical data which might violate the requirements of low delay for critical data. Hence, an effective frame fragmentation should be designed to handle this issue with regard to the critical data in the WBAN.

## 1.4 Research Questions

Based on the aforementioned issues, several research questions have been outlined.

- i. How effective is the combination of proposed techniques namely ECG Packet Classification and Prioritization (ECG-PCP) mechanism in classifying ECG medical packets according to their priority with the proposed Prioritized Selective Packet Discarding (P-SPD) mechanism to preserve the limited network resources and permit high Quality of Service (QoS) network performance in order to avoid congestion in WBAN?
- ii. How effective is the proposed Fragmentation based Slot Time Medium Access Control (FST-MAC) mechanism to provide lower delay during data transmission in order avoid congestion in WBAN?
- iii. How effective and efficient is the Priority Selective Packet Timeslot Medium Access Control (PSPT-MAC) mechanism which is designed by integrating the proposed ECG-PCP, P-SPD and FST-MAC mechanisms in IEEE 802.15.4 protocol to prevent congestion occurrence which will ensure reliability and promote high QoS in WBAN?

## 1.5 Research Objectives

Based on the above problems and research questions, several research objectives are highlighted as follows.

- i. To design a new mechanism of Prioritized Selective Packet Discarding (P-SPD) in accordance to the significance of medical packets through ECG Packet Classification and Prioritization (ECG-PCP) mechanism to avoid congestion in WBAN.
- ii. To design a Fragmentation based Slot Time Medium Access Control (FST-MAC) mechanism for medical data in MAC IEEE 802.15.4 protocol in order to minimise the delay in the network.
- iii. To enhance, evaluate, and validate the network performances of integrated proposed congestion avoidance mechanism namely Priority Selective Packet Timeslot Medium Access Control (PSPT-MAC) against Fast Channel Assignment (FCA-MAC) mechanism and standard IEEE 802.15.4 protocol for WBAN.

## 1.6 Research Motivation

By implementing technique of ECG-PCP mechanism for packet classification and prioritization of ECG, important or critical packets that need immediate response and attention from healthcare providers can be delivered first. This mechanism could ensure those important packets would not loss and thus experience less delay and timely delivery at the destination while maintaining high QoS of the system. Also, by lowering possibility of packet loss in the network could avoid retransmission of packets which would reduce the consumption of scarce resource under IEEE 802.15.4 protocol.

In addition, the many-to-one traffic's pattern between sensor nodes and sink node increases the chance of congestion due to generation of massive data during continuous and simultaneous sensing of patients' physiological signals. Also, there is a high possibility that the amount of the sensed data might suddenly increase and be overloaded due to the incoming data from other nodes as well as the sensed data of the node itself. Hence, discarding some unimportant packets such as corrupted packets through P-SPD mechanism can greatly help in reducing the amount of data that can overwhelm the limited resources. Therefore, congestion can be automatically controlled in the network.

After data have been classified, prioritized and selectively discarded, medical data would undergo frame fragmentation namely FST-MAC mechanism in the MAC IEEE 802.15.4 protocol to minimise transmission delay. A long packet size results in time consuming in order to be processed and served which may lead to higher delay in the network. Thus, FST-MAC mechanism helps these medical data especially the critical one

to arrive in a timely manner so that medical staffs can provide quick and appropriate action to avoid any severe impact to the patient's health which may bring to mortality.

The network performances of PSPT-MAC mechanism in avoiding congestion would be evaluated, compared and validated with Fast Channel Assignment (FCA-MAC) mechanism by (Nepal, Pudasani, & Shin, 2017) and IEEE 802.15.4 protocol in terms of throughput, delay, packet loss and packet delivery ratio (PDR) in order to ensure its reliability and QoS are achieved for WBAN.

### **1.7 Research Contributions**

The contributions of this research which is intended to curb the congestion phenomenon at earlier stage in WBAN are listed as follows.

- i. The design of ECG-PCP mechanism which taken into account the value of RR-interval in the reading of ECG to classify and prioritize the ECG medical data into normal, abnormal and critical as to increase level of awareness among medical practitioners so that appropriate medical action can be performed quickly.
- ii. The design of P-SPD mechanism that helps in the disposal of valueless data such as corrupted packets which can help in reducing the number of packets for transmission that will utilizes the usage of limited resources in the nodes. Hence, congestion can be mitigated due to reduction in number of unimportant packets during transmission.

- iii. The design of FST-MAC mechanism which would fragment the frame of medical data that is carried out in MAC IEEE 802.15.4 protocol which take place right after ECG-PCP and P-SPD mechanisms to prevent longer transmission time.
- iv. The integration of ECG-PCP, P-SPD and FST-MAC mechanisms into PSPT-MAC mechanism to reduce the delay and packet loss as well as promoting to higher throughput and PDR for the network performances in alleviating the congestion of the WBAN.

## **1.8 Scope of Research**

The scope of this research is targeting on Priority Selective Packet Timeslot Medium Access Control (PSPT-MAC) mechanism to cater congestion in WBAN under IEEE 802.15.4 protocol. In PSPT-MAC mechanism, the packet with high (critical) priority assignment is considered to be first transmitted. Then, corrupted packets among medium (abnormal) and low (normal) priority packets are discarded before transmission. Implementation of frame fragmentation on the medical data before transmission to the destination is done to minimize packet's delay. Precisely, this research is carried out using OMNeT++ simulator tool by assuming stationary patients with ECG sensors attached to their bodies. In addition, the ECG sensors are assumed to be well functioning and there is no loss of wireless connection during data transmission in the network of WBAN. The network performances of the proposed mechanism are tested and analysed in terms of throughput, delay, packet loss and PDR. On top of that, the performances of PSPT-MAC mechanism are compared and validated through simulation results with existing FCA-

MAC mechanism and standard IEEE 802.15.4 protocol in WBAN. The PSPT-MAC mechanism is chosen to be compared with FCA-MAC because this work caters similar issue involving the transmission of ECG critical packets to avoid longer delay as well as to reduce the risk of congestion in WBAN.

## 1.9 Thesis Organization

The rest of the thesis are structured as follows:

Chapter 2 presents a brief description on the concept associated to WBAN, RHMS, characteristics of the bio-sensors and their signals, as well as details of features in ECG signal, requirements and challenges in developing the WBAN and network protocol stacks of WBAN. Furthermore, an extensive review is done on the previous and existing congestion control mechanisms specifically for WBAN. The established mechanisms on packet prioritization, packet discarding and packet fragmentation are also provided as well.

Chapter 3 presents overall systematic phases of the proposed congestion avoidance mechanisms namely ECG-PCP, P-SPD and FST-MAC mechanisms which are explained in detail with the support of algorithms, equations and illustrations. In addition, the integration of aforementioned three designs into PSPT-MAC mechanism in avoiding congestion is further elaborated. Last but not least, the simulation setups in designing and validating these mechanisms under OMNeT++ simulator tool is also elaborated in this chapter.

Chapter 4 presents the results obtained in evaluating, analysing and validating the effectiveness of P-SPD, FST-MAC and PSPT-MAC mechanisms in solving the issue of congestion in the network of WBAN. Their performances are measured in terms of throughput, delay, packet loss and PDR by varying number of nodes, packet size and traffic generation. The average of percentage improvements of PSPT-MAC mechanism compared to FCA-MAC mechanism and standard IEEE 802.15.4 protocol are also provided.

Finally, the conclusion of the thesis is drawn in Chapter 5. Several suggestions for future work are also highlighted in this chapter.

## CHAPTER 2 : LITERATURE REVIEW

### 2.1 Overview

The emergence of Wireless Body Area Network (WBAN) technology has enabled Remote Health Monitoring System (RHMS) to be developed which is one of the successful and recognized applications in Internet of Things (IoT) nowadays. However, simultaneous sensing of vital body signals from various sensor nodes and multiple bodies could generate heavy traffic. This situation is likely to cause congestion since this bulk of data may not be well processed as WBAN faces constraint in network resources such as bandwidth and energy. Hence, this would lead to severe consequences such as higher delay, packets loss and energy usage due to the retransmission process of loss packets. Therefore, it is crucial to detect this problem at an early stage through congestion avoidance mechanism. In addition, the classification and prioritization of sensed data according to their importance would help to minimise the probability of congestion. If the congestion still persists, the congestion control mechanism which comprises of detection, notification and mitigation will take place. At the same time, the successful delivery of the sensed data to the destination or termed as data reliability should be achieved in order to establish a seamless and efficient system. With the help of effective processing data mechanism, the data would be delivered with less delay especially for critical data so that medical practitioners would alert and give accurate medical response to the patients.

This chapter generally conveys a comprehensive review on state-of-art of WBAN in RHMS towards the concept of IoT especially in solving the issues of congestion. The first section covers classification and architecture of WBAN, standard wireless

communication in WBAN and characteristics of their bio-signals. Next, characteristics of every features in ECG signals are reviewed. In addition, the requirements and challenges in creating WBAN as well as details of protocol stacks in WBAN are also discussed. Most importantly, this chapter extensively analysed several previous studies on congestion avoidance and control mechanisms during data dissemination in WBAN.

## **2.2 Integration of WBAN in Remote Health Monitoring System (RHMS) towards IoT**

As mentioned in Chapter 1, WBAN is a branch of advancement in WSN that comprises of many specialities to be particularly exploited in any healthcare application such as monitoring patients and supports rehabilitation (Filipe, Fdez-riverola, & Costa, 2015). The integration of components in RHMS such as intelligent sensors, database and alert systems evolve to become part of IoT application (Li, Xu, & Zhao, 2015). This development has a remarkable significance towards improvement of quality of healthcare in community. This section comprises the classification of Health Monitoring System (HMS), architecture of WBAN, the standard wireless communication of WBAN with their respective bio-signals characteristics to be applied in WBAN.

### 2.2.1 Classification of Health Monitoring Systems (HMS)

Typically, HMS can be divided into three categories which are Wearable Health Monitoring System (WHMS), Mobile Health Monitoring System (MHMS) and RHMS which are generally used to sense and collect vital bio-signals (Baig & Gholamhosseini, 2013). WHMS is specifically concerned with sensors that can be worn on the body and garments or implanted in the body which is different from MHMS. MHMS refers to the usage of handheld devices such as smartphones and Personal Digital Assistant (PDA). Meanwhile, RHMS is a combination of WHMS and MHMS with the existence of wireless technology such as Internet to send the collected data to the medical authorities which will record the data into the database.

Each of these HMS has their own domains or roles in the architecture of WBAN. In addition, this trio HMS can be identified as a smart system as they do not need any human's intervention during collection of various types of body signals at any time. Furthermore, any enhancement in WHMS and MHMS would bring significant effects towards more efficient and seamless RHMS. The characteristics in terms of their functions, advantages and limitations for HMS are listed in the Table 2.1 as follows.

Table 2.1 Characteristics of different classes of HMS  
Source: Baig & Gholamhosseini (2013)

Specification	Wearable Health Monitoring System (WHMS)	Mobile Health Monitoring System (MHMS)	Remote Health Monitoring System (RHMS)
Function	Biosensors are worn by patients or attached in the textile to collect the vital signals of the body.	Modules of main processing are made up of mobile phones, PDA, or personal computer (PC) to measure and transmit physiological signals to the system.	Combination of WHMS and MHMS that ease doctors to access the current health status of patients remotely at any location in a real-time system.
Advantages	Measure the vital signals of a person continuously and if any abnormality is detected, a responsive alarm will be triggered to alert physicians.		
Limitation	The size of the biosensors should be tiny and non-invasive to the patient. It should not constraint the movement and Activity of Daily Life (ADL) of the patients.	The device is hand-held, but it causes inconvenience to the people as they always need to carry the mobile phone in order to monitor their body signals.	The connection of Internet should be secure and failure avoidance to avoid any problem to the system.

Based on the Table 2.1, it can be deduced that every HMS implements intelligent medical sensors in order to sense and detect the presence of abnormalities in the physiological signals of the patients. Typically, these sensors are battery powered and consist of several major components such as Analog to Digital Converter (ADC), micro-controller, transceiver and memory. Combination of these components have enable these medical sensors to perform sensing and gathering of physiological signals as well as processing and communicating with other medical sensors in WBAN. Precisely, the sensed and collected physiological data from sensors are converted into electrical signals through ADC. Then, these electrical signals undergo pre-processing by micro-controller and communication between sensor nodes is established via wireless network such as ZigBee. A battery is used as power source in order to supply energy for data

communication and data dissemination among sensor nodes. This internal operation is illustrated in Figure 2.1 as follows.

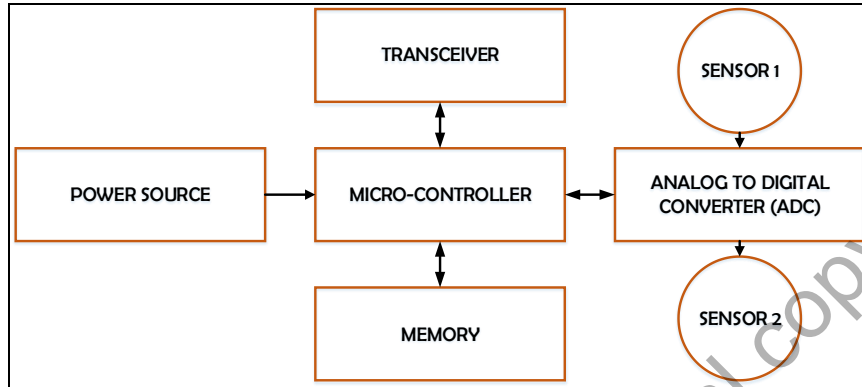


Figure 2.1 Block diagram of components in sensor node

However, the use of various bio-sensors among multiple bodies either they are attached or implanted in the body would produce huge or burst data which consume high energy consumption. As a consequence, high energy consumption would deplete the node's resource and reduce the node's lifetime. This is especially true for implanted nodes that require longer support of battery which can be reached up to several months or years without recharging or replacing. In short, energy is one of the scarce resources in WBAN. Thus, it is vital to well handling this resource to prolong battery lifetime and achieve high performance of the system.

### 2.2.2 Architecture of Wireless Body Area Network (WBAN)

The architecture of WBAN can be divided into 3-tiers communication components which are intra-BAN (Tier-1), inter-BAN (Tier-2) and beyond-BAN (Tier-3) according to (M. Chen, Gonzalez, Vasilakos, Cao, & Leung, 2011) as illustrated in Figure 2.2.

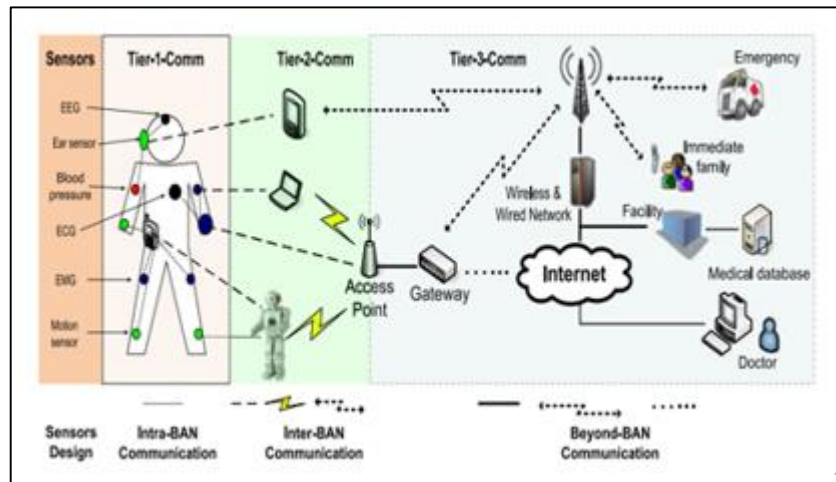


Figure 2.2 Architecture of communication system in WBAN  
 Source: M. Chen et al. (2011)

There are two types of communication in Tier-1 which are among sensor nodes (sensor-sensor) and between sensors and local gateway such as PDA (sensor-gateway). These communications cover about 2 metres around human body. In Tier-2, the scope of communication is wider due to involvement of gateway and multiple Access Points (AP) to boost the system during managing emergency conditions (Ali & Khan, 2015). This tier is also classified into two classes such as infrastructure-based and ad-hoc-based architectures. The former architecture offers high bandwidth with centralized control and flexibility. The latter promotes fast deployment within dynamic surroundings specifically when any medical emergency is encountered. Nevertheless, most of WBAN applications choose infrastructure-based architecture due to benefit of centralized and security control. Lastly, Tier-3 represents communication that improve the application and range of coverage in the healthcare system via permitting authorized medical practitioners to retrieve any medical information of the patient through Internet. Hence, a medical database is a vital agent to the provision of this tier since it helps to record the patients' personal information and their medical history. Briefly, all these communication tiers should be designed properly to establish a robust and efficient RHMS.

### 2.2.3 Standard Wireless Communication in WBAN

The transmission of collected data can be sorted into two classes which are short-range and long-range communication (Ghamari et al., 2016). A short-range communication occurs between bio-sensors and central's node. The second type of communication happens between central's node and remote station. In WBAN, choosing an appropriate and suitable wireless communication to be implemented are crucial in order to achieve low power consumption which can extent network's lifetime of the system. Additionally, WBAN can also be integrated with other technologies such as video surveillance system, Wireless Local Area Network (WLAN) and other cellular networks to make more autonomous and intelligent system.

The typical wireless communications in WBAN are Bluetooth (IEEE 802.15.1), Bluetooth Low Energy (BLE), ZigBee (IEEE 802.15.4) and Wireless Fidelity (Wi-Fi IEEE 802.11). Bluetooth (IEEE 802.15.1) is the first choice in the early development of WBAN (Arbia, Alam, Moullec, & Hamida, 2017), (J. F. Zhao, Chen, Liang, & Chen, 2017). Yet, it has limitation since it can only connect to small amount of devices. The extension to Bluetooth is BLE which is more power saving but still not widely deployed in other devices. Apart from that, ZigBee (IEEE 802.15.4) supports large coverage area and use low power compared to Bluetooth. However, Wi-Fi (IEEE 802.11) covers larger area and provides security which is not offered by ZigBee (IEEE 802.15.4). However, it consumes more power and high bandwidth compared to ZigBee.

The detail features such as operation, advantages and limitations of the available wireless communications to be adopted in WBAN are listed in Table 2.2.

Table 2.2 Wireless communications in WBAN  
Source: Arbia et al. (2017)

Type	Wireless Technology	Frequency	Data rates	Transmission range	Advantages	Limitations
Short range	Bluetooth (802.15.1)	2.4 GHz on frequency hopping technique (FHSS) over 79 channels in the ISM band	Offers up to 1 Megabits per second (Mbps)	Up to 10 metres	-Low latency -Low cost	-High power usage -Prone to potential attacks and risks -Low scalability
	Bluetooth Low Energy (BLE)		Offers up to 3 Mbps		-Ultra low power usage -Shorter set up time (in millisecond) compared Bluetooth (in second)	-Not support by many devices
	ZigBee (802.15.4)	2.4 GHz in 16 channels	Low data rate up to 250 kilobits per second (kbps)	Covers until 75 meters	-Low cost -Wider network coverage based on enabled multi-hop routing -Low power consumption	-Interferences with other WLAN
Long range	Wi-Fi (802.11)	2.4 GHz	High data rates up to 54 Mbps	Large coverage	-Offers secure, reliable and fast connection	-High energy usage

Based on the advantages and limitations of each wireless technology in Table 2.2, it can be concluded that ZigBee is a promising technology that is suitable to be chosen for inter-BAN communication. This is due to its low power consumption which is one of the essential requirements in WBAN to extend network's lifetime. Generally, Wi-Fi is used in Tier-3 communication of WBAN since it can act as a backbone access to end users and allows interference of different equipment within same frequency range.

#### **2.2.4 Bio-sensors and their signals characteristics in WBAN**

With the help of dynamics and positive advancements of technologies nowadays, various types of bio-sensors have been realized. Although they are light and tiny in size, they have capabilities to sense and collect vital bio-signals (body signals) of a person such as heart rate, temperature, blood pressure and others. To date, these bio-sensors can be placed in the garments, directly wear or implanted inside human body (Zou et al., 2017). Hence, in order to develop an efficient RHMS, it is essential to determine the patterns and characteristics of bio-sensors since the collection of the measured vital bio-signals will assist in evaluating and diagnosing overall health's performances of a patient. Table 2.3 summarises the existing several biosensors with respect to their characteristics to be adopted in RHMS.