Relay node selection in Two Hop Extended Star Topology based Wireless Body Area Network

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CERTIFICATE

We accept the work contained in this report as a confirmation to the required standard for the partial fulfilment of the degree of MS(CS).

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DEDICATION

To My Family and Friends.

DECLARATION OF AUTHORSHIP

I declare that the research work presented in this thesis is to the best of my knowledge my own. All sources used and any help received in the research of this dissertation have been acknowledged. I hereby certify that I have not submitted this material, either in whole or in part, for any other degree at this or any other institution.

Signature……………………..

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May Allah bless them all with eternal happiness.

ABSTRACT

A Wireless Body Area Network (WBAN) is a special purpose sensor network designed to operate autonomously to connect various medical sensors and appliances, located inside and outside the human body. These medical sensors are capable of measuring, processing, and forwarding important physiological parameters. To facilitate the development of WBAN, IEEE 802.15.6 Task Group 6 (TG6) that released IEEE 802.15.6 standard in 2012. The standard provide physical and medium access for wireless BAN. IEEE 802.15.6 creates star topology based network that is established and maintained by central device preferred as hub. An important aspect of the standard is that it can support two hop extend star topology. The aforementioned topology is created using relay node. The multi-hop (two hop) topology is especially useful for extremely low power in-body and around-body implanted devices that can decrease energy consumption by transmitting to hub through near-by relay node(s). IEEE 802.15.6 define the message exchange necessary for the announcement and selection of relaying node. However, the standard does not define the metrics based on which the relayed node should select the relaying nodes. In this thesis we propose and use packet drop, packet service time and packet retries as the basic metrics for the selection of relaying node. Also, another novelty of this work is that the decision of node selection is mode by the relayed node based on the feedback provided by relaying node. On the other hand, IEEE 802.15.6 suggests that the decision should be made by relayed node without the involvement of relaying nodes. Detailed simulation analysis using OPNET is conducted in this thesis which reveals that the relaying node selection based on the feedback of different metrics results in better throughput and low latency of communication.

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ABBREVIATIONS

ACK	Acknowledgement
BI	Beacon Interval
BM	Broadcast Message
BOP	Back Off Period
CAP	Contention Access Phase
CCA	Clear Channel Assessment
CSMA/CA	Carrier Sense Multiple Access with Collison Avoidance
CE	Consumer Electronics
DC	Duty Cycle
EAP	Emergency Access Phase
ECG	Electrocardiography
IFS	Inter frame spacing
MAP	Managed Access Phase
RAP	Random access phase
RTT	Restricted tree topology
RN	Relaying node
SD	Super-frame duration
SIFS	Short inter frame spacing
SN	Sensor node
Patent	Two Hop Extended Star Topology U.S. Patent
WBAN	Wireless Body Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network
WMSN	Wireless Multimedia Sensor Network

Chapter 1

INTRODUCTION

1.1 Overview

The IEEE 802.15.6 [4] is a standard for short range wireless communication in the vicinity of human body. A wireless body area network (WBAN) is a special purpose sensor network design to operate independently to connect sensor inside or outside the human body. WBAN will offer flexibilities and cost saving options in healthcare and patients. WBANs are used to critical human body parameters like blood pressure, oxygen saturation, sugar level, heart diseases and cancer which can be measured using sensors nodes that are attached on human body.

WBANs aim to provide attractive and efficient alternate for conventional medical care system. In early 1990’s the idea of developing and implement communications with human body as center was gaining popularity. This led to the birth of short range communication using IEEE 802.15.4 Wireless Personal Area Networks (WPANs) [1] to execute communications on, near and around human body. Later, the term "BAN" was used to reflect communication within, on, and in the immediate proximity of a human body. A WBAN system can use WPAN wireless technologies as gateways to reach longer ranges. Through gateway devices, it is possible to connect the wearable devices on the human body to the internet. As a result, medical professionals can access patient data online irrespective of the patient’s location.

WBAN supports a variety of real-time health monitoring and consumer electronics applications. The latest international standard for WBAN is the IEEE 802.15.6 standard which aims to provide low power, short range, and extremely reliable wireless communication within the surrounding area of the human body, supporting a vast range of data rates for different applications. *Figure 1.1* represent the WBAN overall structure, nodes are shown as circle over the human body and is connected with central device known as hub. Hub can be placed on or outside the body depending on application's requirement. Hub is the central device of the WBAN, responsible for establishing the network and receives the information from body devices and forwards information to external network.

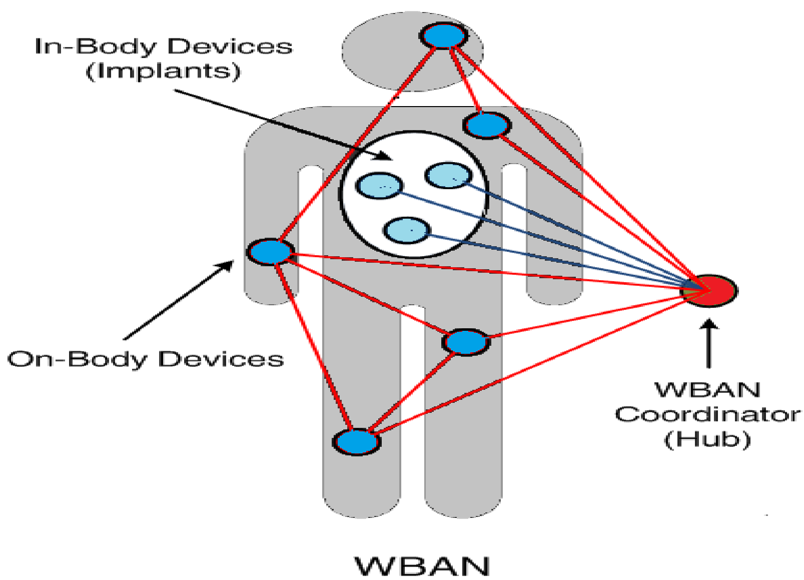

Figure 1.1: Wireless Body Area network.

IEEE 802.15.6 has great potential to revolutionize the future of healthcare technology. It has attracted a number of researchers both from the academia and industry in the past few years. WBAN supports a wide range of medical and Consumer Electronics (CE) applications. For example, WBAN provides remote health monitoring of a patient's state for a long period of time without any restriction on his/her normal activities [2,3].

1.2 Extended two hop star topology

IEEE 802.15.6 supports both star and extended star topologies as shown in *Figure 2.7*. In the extended star topology the node requesting for the relay facility is referred as relayed node, whereas the node providing this facility is relaying node. The node can request for a relaying node because either it is unconnected or cannot directly reach hub or it wants to ensure its energy by transmitting through relaying node. In the latter case, the distance between relayed node and relaying node is less than the distance between relayed node and hub. In the remaining of this section, the relay node discovery procedure both for connected and unconnected cases is briefly discussed.

1.2.1 Relay discovery procedure for connected node

A sensor node discovers a relaying node as follows: when the sensor node overhears an Acknowledgement frame (ACK) for data or management frames originated from relaying node and destined to the hub within the same BAN. This implies two things:

1) Relaying node is within the range of both hub and the relayed node.

2) The link between the relaying node and the hub is a fairly reliable link.

Therefore, the node will initiate the establishment of a new link with the discovered relaying node by sending a connection request to the relaying node. Then, if relaying node accepts the connection request from the node, it relays the connection request to the hub.

1.2.2 Relay discovery procedure for unconnected node

In case of an unconnected relaying node acts as a micro-hub and can provide synchronization to the relayed node. This is achieved when relaying node sends a Broadcast Message (BM) which includes a time stamp and resource allocation specification in which sensor node can communicate with the relaying node. The purpose of this broadcast message is two-fold:

1) To provide synchronization to new node, or a sensor node having a bad connection.

2) To provide an opportunity for establishing a connection to relayed node in order to relay their transmission to hub.

How often the relaying node will send the broadcast message is a policy issue and should not violate the power consumption constraint of the relaying node and the availability of resource allocation in the network. The broadcast message will assist the sensor node to discover a relaying node and to wake up at the resource allocation advertised by the relaying node BM, to establish connection with the relaying node. A relaying node has option to exercise admission control over connection requests from nodes to restrict the number of nodes that can support relaying taking into account its power consumption, link quality and other policies such as security policy to prevent third party attack etc.

1.1 Motivation

IEEE 802.15.6 BAN hub is responsible for controlling the whole traffic and synchronizing the sensors nodes through beacons or other control frames. Initially, only beacon is send or broadcasted to the nodes in the same BAN in which full detailed information of superframe is present to all connected nodes. During the communication a node may require two hop connection with the hub. The two hop extended star topology in IEEE 802.15.6 is supported with the help of relaying node. The standard define mechanism for announcement of relaying node and association of relayed node. However, it does not specify on what metrics the relayed node should select the relaying node. A few research effort including [11,13,14] have been proposed for extended star topology. In [11] the basic issue of when and how to relay is discussed. The work suggest that RSSI should be used to decide when and to which node the information should be relayed. In [13] the relayed node uses relaying node for transmission of data to the hub but the hub directly communicate with the relayed node. In [14], network layer base solution for the selection of relaying node is proposed that is independent underline medium access protocol. Similar upper layer solution is suggest for IEEE 802.15.6 but in cooperating a network in resource constraint and devices for the purpose of path establishment is not an energy efficient solution. Therefore the basic innovation of this work is to define new mechanism or metrics that can lead to a better relay node selection in IEEE 802.15.6.

1.2 Problem Statement

Dynamic relay node selection in IEEE 802.15.6 to enhance network performance in terms of throughput and latency. Currently, IEEE 802.15.6 only provides a mechanism for relay node selection but on what metrics the relay node should be selected is not addressed by the standard. Existing work is more focused on WPANs using IEEE 802.15.4 because it’s a relatively old and mature standard. Relay node selection in IEEE 802.15.6 is discussed in only a few existing works that use upper layer (network) solutions.

1.3 Thesis organization

The thesis is organized as follows: chapter 2 describes the detailed overview of IEEE 802.15.6. chapter 3 describes the existing work on relay node selection in two hop extended star topology. chapter 4 presents the proposed metrics for relay node selection. chapter 5 presents the results and simulation analysis of two hop relaying node selection using proposed schemes and IEEE 802.15.6 and Patent [22]. Last chapter concludes this work and provides future directions.

Chapter 2

IEEE 802.15.6

2.1 Introduction

In this chapter, the detailed overview of IEEE 802.15.6, is a communication standard optimized for low-power (in-body/on-body or around the body) nodes for monitoring the health issues like temperature, blood pressure etc. The current IEEE 802.15.6, defines three PHY layers, i.e., Narrowband (NB), Ultra-wideband (UWB), and Human Body Communications (HBC) layers. On the top of it, the standard defines a sophisticated MAC protocol that controls access to the channel. For reference of time resource allocations, the hub (or the coordinator) divides the time axis (or the channel) beacon periods of equal length and each superframe is composed of allocation slots of equal length. Communication in WBAN is possible by the use of superframe structure. Superframe structure can be between 0 – 255 fixed slot lengths. *Figure 2.1* shows multiple superframes and each superframe is divided into fixed length of slots. The boundaries of the superframe is selected by hub and thereby selects the allocation slots. The hub may also shift the offsets of the beacon period. Generally, transmission of beacon take place in each beacon period except in Inactive superframes.

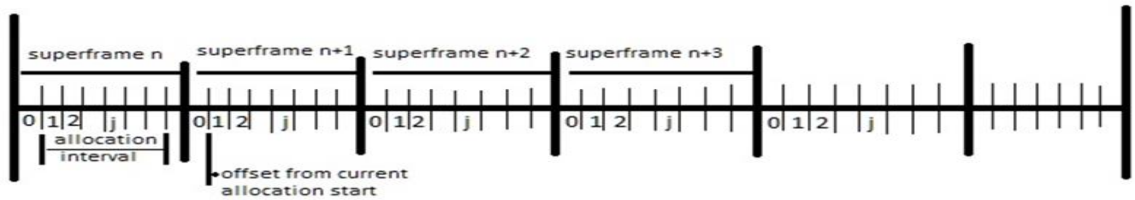

Figure 2.1: Super frame allocation Structure.

To ensure high level security [23], the standard defines three levels:

A) Level 0: unsecured communication.

B) Level 1: authentication only.

C) Level 2: both authentication and encryption.

At the MAC sub-layer, IEEE 802.15.6 supports two different types of access mechanisms including: contention access and contention-free access. The contention access phase supports either a slotted ALOHA based access mechanism or CSMA/CA based access mechanisms. The contention-free access phase supports a scheduled downlink/uplink access scheme as well as an improvised posting/polling based access scheme. The operation of IEEE 802.15.6 network take place in one of the following modes. Beacon mode with beacon period superframe boundaries, non-beacon mode without superframe boundaries, non-beacon mode with superframe boundaries. Work of our research is based on beacon mode with beacon period superframe boundaries as shown in *Figure 2.2*.

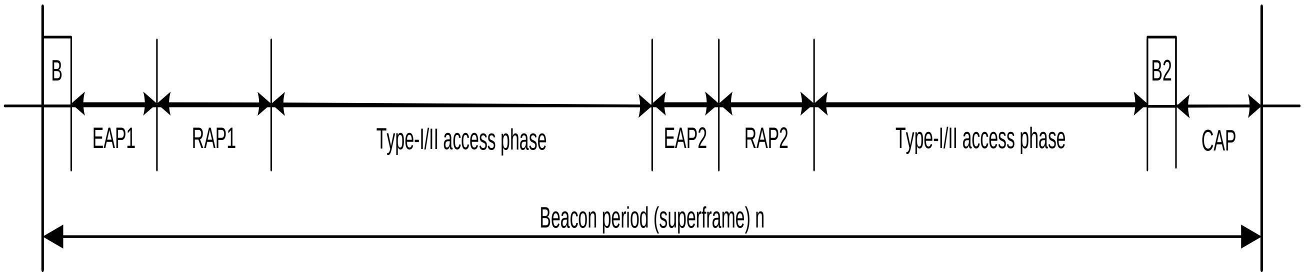

Figure 2.2: MAC frame format (beacon mode with super frame).

2.2 Beacon mode with beacon period (superframe)

This mode is coordinated mode in which all the devices are synchronized with the hub and can provide higher throughputs with reduced energy consumption. Beacon frame format defines different duration for medium access based on contention and contention free access. The superframe is comprised of EAP1/EAP2 (Exclusive Access Phase1/2), RAP1/RAP2 (Random Access Phase1/2), MAP (Managed medium Access Phase) and CAP (Contention Allocation Phase) as shown in *Figure 2.2: MAC frame format (beacon mode with super frame).* EAP phase is used for emergency traffic and based on CSMA/CA or Slotted ALOHA. RAP phase is used for regular traffic and based on CSMA/CA or Slotted ALOHA. MAP phase is used for polling, uplink, downlink, bi-link, and scheduling. CAP phase is used for coexistence if the CAP is non-zero length the hub shall transmit a B2 frame.

2.3 Non-beacon mode with superframe

In this mode of access, beacon frames are not periodically transmitted by the hub. The medium is accessed only through polling and is termed as managed access period as shown in *Figure 2.3*.

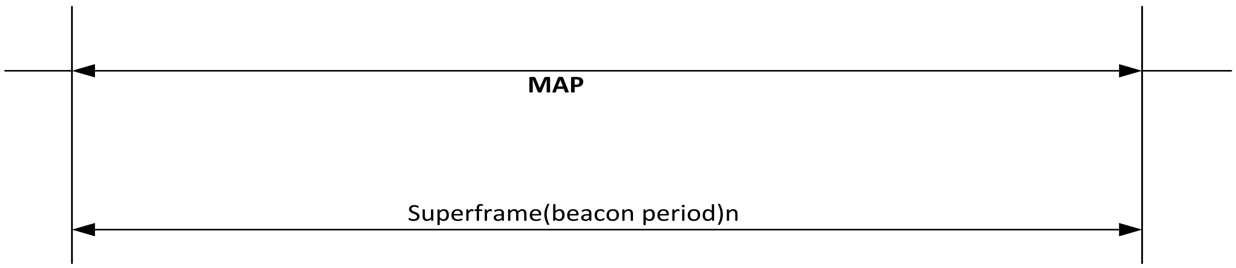

Figure 2.3: Non-beacon mode with super frame.

2.4 Non-beacon mode without superframe

In this access mode, beacon frames are not periodically transmitted by the hub. Also, there is no fixed superframe structure and the devices access the medium as using contention based access technique. IEEE 802.15.6 establishes a star topology based network, which is controlled and maintained by a device termed as hub and data is directly exchanged between nodes and the hub, as shown in *Figure 2.4*.

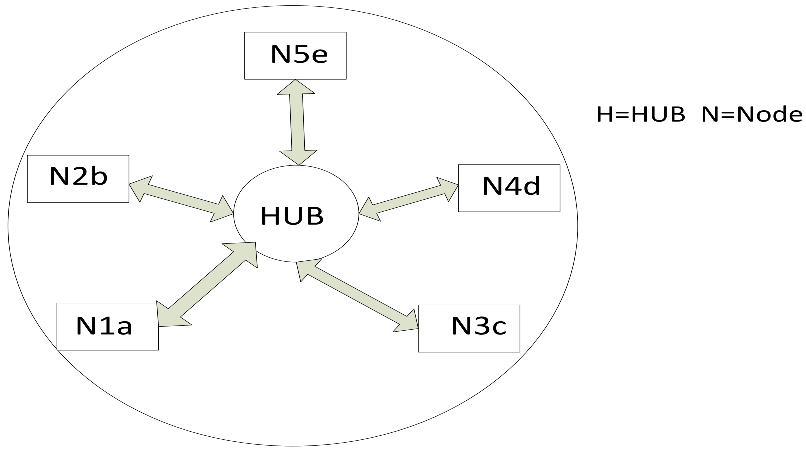

Figure 2.4: Architecture of WBAN.

2.5 User priority in IEEE 802.15.6

User priority (UP) values, transmission of data and management types frames is prioritized by the user priority value describe in Table 2.1. User priority 7 can only transmitted in EAP period of superframe, whereas other periods support all kind of data.

Table 2.1: User priority [4].

Priority	User priority	Traffic designation	Frame type
Lowest	0	Background (BK)	Data
	1	Best effort(BE)	Data
	2	Excellent effort (EE)	Data
	3	Video (VI)	Data
	4	Voice (VO)	Data
	5	Medical data or network control	Data or management
	6	Higher priority medical data or network control	Data or management
Highest	7	Emergency or medical implant event report	Data

2.6 Coexistence in IEEE 802.15.6

When multiple BANs coexist as shown in *Figure 2.5* then the radio range of neighboring BANs overlap due to which interference increases, throughput decreases and the energy of devices is wasted as the packets are dropped. IEEE 802.15.6 proposes different mechanism for solving coexistence issues including: channel hopping, beacon shifting and superframe interleaving.

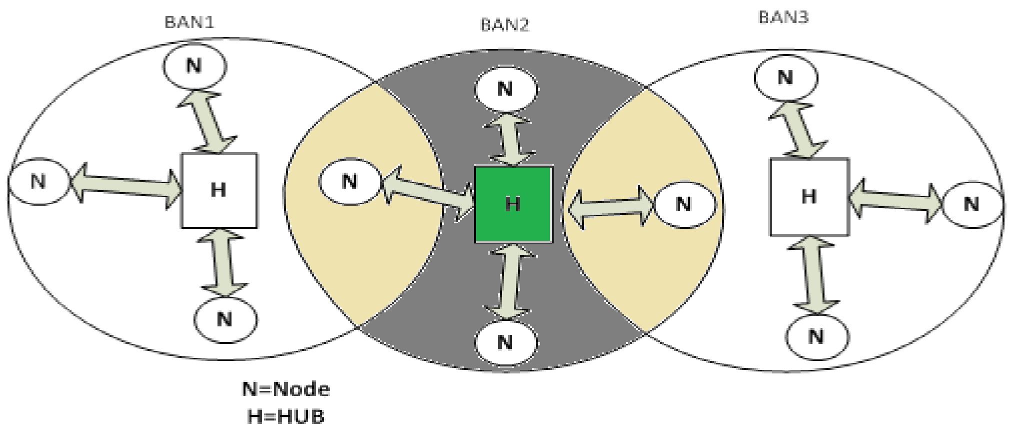

Figure 2.5: Co-existence in 802.15.6.

2.7 Overview of Two Hop extension mechanism of 802.15.6

The main objective of our work is finding a node that needs a relay as a relaying node, and a node that helps relayed node with frames transmission as a relaying node. IEEE 802.15.6 supports a two-hop star topology extension, as shown in *Figure 2.7*, in which the data frame from a relayed node can be transmitted to the hub through a selected relaying node. The relaying node selection can be done through pre-arrangement or overhearing/receiving ACK/T-Poll frames sent/broadcast by relay-capable nodes.

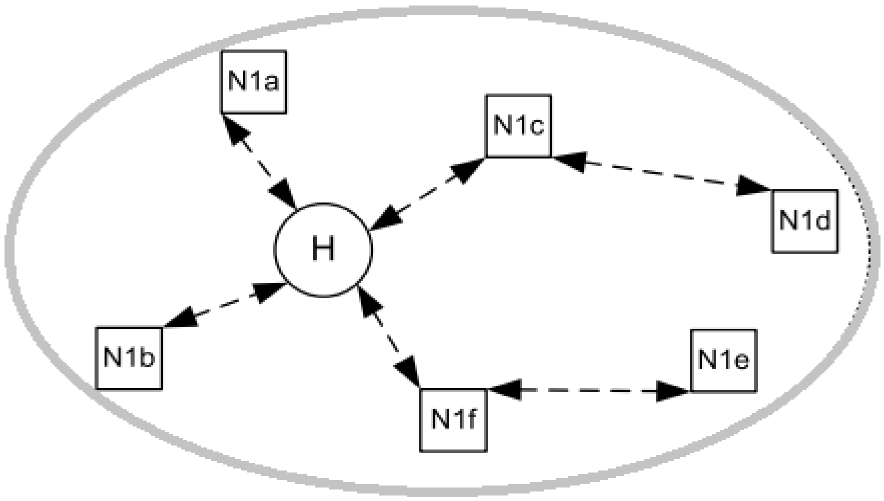

Figure 2.6: IEEE 802.15.6 two-hop extended star topology.

To establish the two-hop connection, the relayed node first sends out a connection request frame to the hub through the relaying node. The hub then returns a connection assignment frame to the relayed and relaying nodes. The connection assignment frame contains the scheduled allocation in the MAP so that data relaying from relayed node to the hub via the relaying node can be carried out. The two-hop connection establishment can be carried out in the RAP if it is initiated by overhearing the ACK frame, or in MAP if it is initiated by receiving the T-Poll frame, whereby the data relaying is carried out in the next MAP. Once the connection is established, during the data relaying in MAP, the relayed node cannot send the frame directly to the hub even if the one-hop communication is possible unless a request in exchange for an equivalent one-hop scheduled allocation is granted by the hub prior to the schedule allocation [6]. In summary, the relay mechanism supported in the standard can be divided into three processes:

1) Channel assessment by overhearing/receiving, ACK/T-Poll frames from others.

2) Relaying node election by connection request/assignment frames exchange.

3) The data relaying in the scheduled allocation in MAP.

2.8 Simulation analysis of relay node performance IEEE 802.15.6

IEEE 802.15.6 standard suggests transmission of data of relayed node in MAP only. This allows normal EAP and RAP traffic to proceed without any contention from relay nodes. But, the relayed node traffic suffers a lot of delay as it can only be transmitted by relayed node during MAP. In [22], a modified superframe structure of IEEE 802.15.6 is presented in which relayed node traffic can be transmitted in all superframe modes EAP, RAP and MAP. However [22] does not suggest strategy for relaying node selection.

In order to evaluate the performance of relay node communication, we have conducted simulation in OPNET [21] and the network setting are shown in Figure 2.7. Node N1 is the relayed node whereas N2, N3 and N4 are relaying nodes.

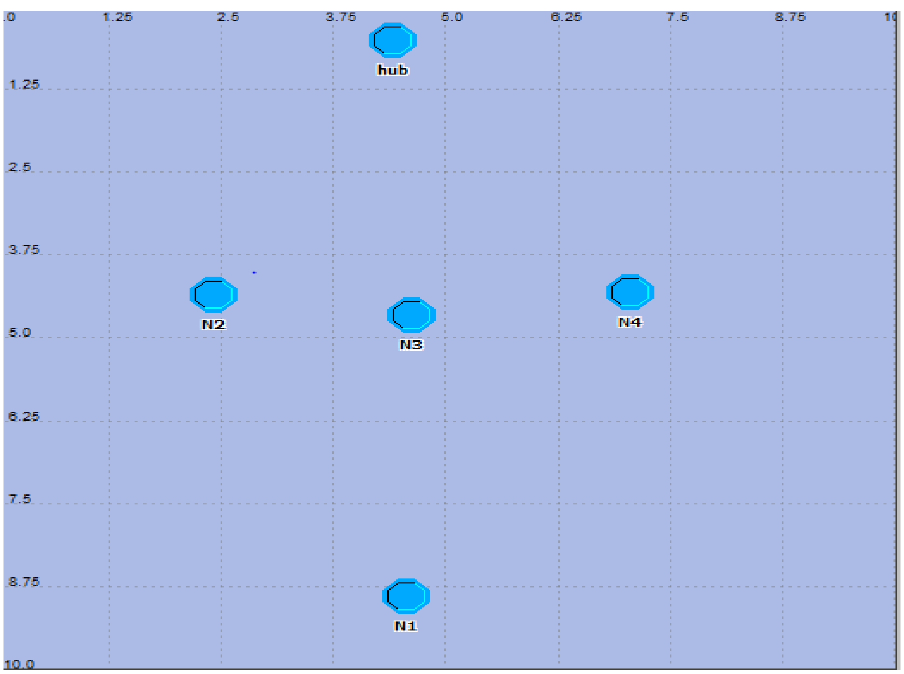

Figure 2.7: Two hop extended Star topology based beacon enabled superframe network.

Simulation settings used in the performance evaluation are listed in *Table 2.2*.

Table 2.2: Simulation parameters.

Parameter	**Value**
Simulation time	500 s
Frequency band	2.4 GHz
Traffic Type	UP6 and UP7
Packet Size	153 B with 100B of application data
Number of nodes	4
Data Rata (kbps)	971.41
Initial energy	34560 Joules
Transmit mode	17.4 mA
Receive mode	24.8 mA
Sleep mode	6.1 µA
Idle mode	26.1 µA
IEEE 802.15.6 slot length	0.128s
EAP1 duration	14 slots
RAP1 duration	17 slots
MAP1 duration	08 slots
EAP2,RAP2,MAP2	Not used
Buffer Size	25

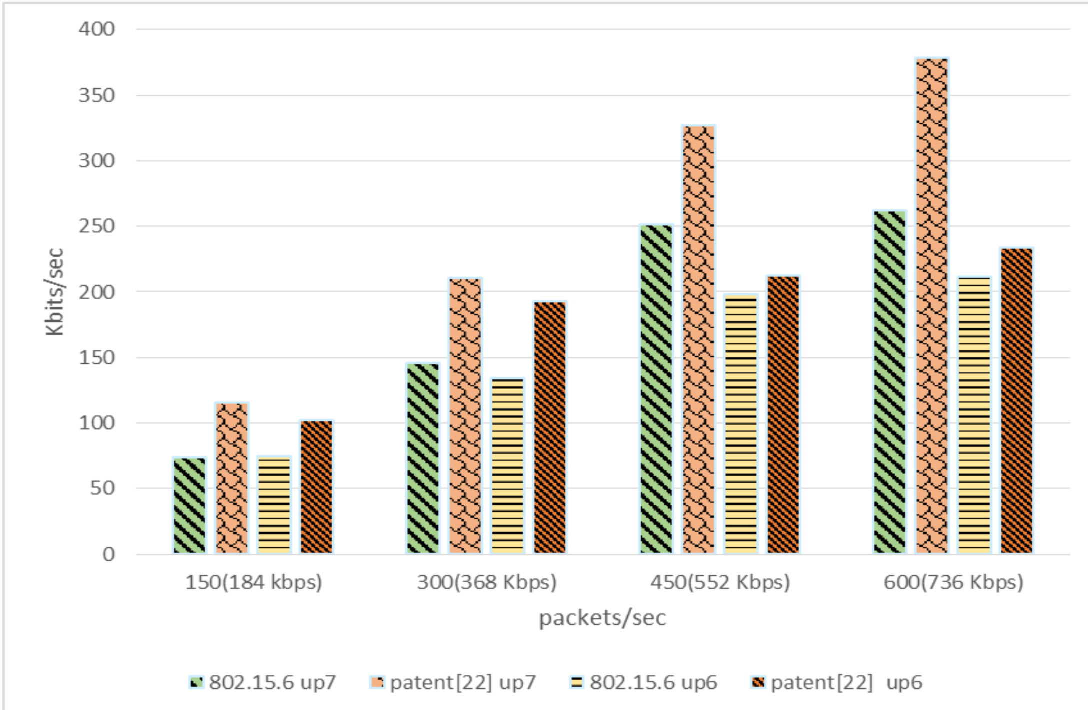

Figure 2.8: Average throughput at 150, 300, 450 and 600 packet/sec of periodic transmission.

The average throughput of relaying nodes and relayed node observed at different data generating rates (150,300,450 and 600 packet/sec) is shown in *Figure 2.8*. The generated traffic consists of User Priority (UP) six and seven traffics.UP7 is the highest priority traffic whereas UP6 has lower priority compared to UP7.In EAP only UP7 is transmitted and all other priority traffics have to wait for RAP or MAP for communication . Hence, UP7 is exclusively communicated in EAP but in RAP and MAP it is communicated along with lower priority traffics. The graph clearly illustrate that the throughput of Patent [22] is much better than IEEE 802.15.6 because it sends data of relayed node in all periods of superframe (EAP, RAP and MAP). According to graph the UP7 data has more throughput with respect to UP6 it’s because the UP7 data can communicated in all periods of superframe.UP6 packets are buffered during EAP and due to buffer overflow more UP6 packets are dropped compared to UP7 traffic

RELATED WORK

This section presents the existing literature on two hop relaying mechanism. The related work on two hop extension mechanism of IEEE 802.15.6 and related articles are presented in this section.

Table 3.1: Related work.

Title/ published year	***Objective***	***Metric***	***Layers***	***Solution***
Reliable Body Area Networks Using Relays: Restricted Tree Topology, [7], 2012	Increasing connectivity	Relay link indicator, And Control frames	MAC layer	Restricted tree topology and path loss model is proposed and is compared with star topology, different position.
Network Lifetime Improvement by Relaying Node Re-Selection in the IEEE 802.15.6 BAN, [8], 2012	Re-selection of relay node	residual energy and active state indication	MAC layer	The wake-up schedule control procedure that enables a node to re-select its relaying node
Low-SAR Path Discovery by Particle Swarm Optimization Algorithm in Wireless Body Area Networks, [9] 2015	The optimal placement of the relay node	Low specific Absorption rate (SAR)	Network layer	Send packets via the relay node to the hub through a path with the lowest specific absorption rate (SAR) and higher packet delivery rate.

An Opportunistic Relay Protocol with Dynamic Scheduling in Wireless Body Area Sensor Network, [10] 2015	Improvement in selection of rally node.	Network lifetime and PDR	Network and MAC layer	A dynamic scheduling algorithm is proposed to optimize slot allocation in the superframe for all nodes
Prediction-based Dynamic Relay Transmission Scheme for Wireless Body Area Networks, [11], 2013	Relay node selection	Beacon broadcasting	MAC layer	(PDRT) scheme that makes use of the correlation characteristics of on-body channels
BANMAC: An Opportunistic MAC Protocol for Reliable Communications in Body Area Networks, [12], 2012	Monitors and predicts channel fluctuations and schedules transmissions	Co-channel interference	MAC layer	MAC protocol is capable of providing differentiated service and resolves co-channel interference in the event of multiple co-located BANs in a vicinity.
Energy-efficient two-hop extension protocol for wireless body area networks, [13], 2013	Less energy consumption, direct transmission of ACK	Energy consumption and overhead for relaying nodes	MAC layer	Node to sink via relay node and sink to node direct communication.
Adaptive Routing for Dynamic On-Body Wireless Sensor Network, [14], 2015	Minimizes the energy cost per bit	Instantaneous channel gain and threshold is used to select either two hop or one hop	Network layer	The source node will switch between direct and relayed communication based on the quality of the link

In [8] the relaying node re-selection problem in the IEEE 802.15.6 standard is studied for the BAN in order to enhance the network lifetime is studied. The major contribution of [8] is the wake-up schedule control procedure that enables a node to re-select its relaying node even though nodes in the network have different wake-up schedules.

In [9] research divides the body into several parts and assigns different weight values for each to show the impact of Specific Absorption Rate (SAR) on human body. By using the Particle Swarm Optimization (PSO) algorithm, [9] calculates the optimal placement of the relay nodes on the body. The objective is to send packets to the hub through a path with the lowest SAR and higher packet delivery rate.

In [10], a relay mechanism with predefined relaying nodes are introduced and evaluated against the relay mechanism proposed in IEEE 802.15.6 standard. [10] claims that proposed relay mechanism is able to achieve reduction in data relaying failure rate. Also, algorithm with dynamic scheduling solution is proposed to optimize slot allocation in the superframe for all nodes. The proposed relay protocol achieves improvements in network lifetime and in PDR.

In [7] the position of optimal relay nodes is studied using real testbed. Sleeping positions of patients in hospital were studied to observe the link loss and disconnection between body sensors. Later, based on observed positions the optimal positions of relay nodes are suggested in [7].

In [11], Prediction-based Dynamic Relay Transmission (PDRT) scheme that makes use of the correlation characteristics of on-body channels is implemented. In the PDRT scheme addresses “when to relay” and “who to relay” in a WBAN on the last known channel states. The PDRT scheme achieves significant performance improvement in terms of energy efficiency, as well as ensuring the transmission reliability.

In [12], a BANMAC protocol is proposed that monitors and predicts the channel fluctuations and schedules transmissions opportunistically when the Received Signal Strength (RSS) is likely to be higher. The work concludes that [12] is capable of providing differentiated service and resolves co-channel interference in the event of multiple co-located BANs in a vicinity.

In [13], to reduce the energy consumption and overhead of relaying nodes, the authors introduce a new two-hop extension protocol which lets hub directly transmit packets to the downlink relayed nodes. On the other hand, in 802.15.6 standard hub can transmit packets through relaying nodes.

In [14], an adaptive routing protocol is developed and analyzed which minimizes the energy cost per bit of information. It uses the channel information to choose the best strategy for routing data. In this approach, the source node switches between direct and communicate via relaying node. If the channel quality is below certain threshold relay facility is used, otherwise direct communication with hub is carried out.

Chapter 4

PROPOSED RELAY NODE SELECTION METHODOLOGY

4.1 Introduction

Star topology wireless BAN can have different types of sensors installed on-body and in-body to monitor events such as; blood pressure, temperature, ECG and Implantable Cardiac Defibrillator (ICD) to observe the patient. In all these events the nature of data is different and reporting rate of each event is different from each other. Due to movement of body, sensors node can get far from sink or hub. The connection get weak or disconnected, then the sensor node select another path through relaying node for data transmission to hub. The *Table 4.1* illustrates the differences between single hop and multi hop. The main objective of proposed work is to select relaying node among all possible relaying node based on relaying node status in order to increase throughput and decrease delay of communication.

Table 4.1: Comparison of one-hop star network and multi-hop network [19].

Comparison criteria	**Star Networks**	**Multi-Hop Networks**
Energy Consumption	For nodes in close proximity to the hub, the power used to transmit to the hub will be low. The nodes further away, however, will consistently require more power to be able to transmit information	The nodes that are closest to the hub consume more energy as they will have to forward not only their own information but also information from other nodes.
Transmission Delay	The star network presents the least possible delay present in transmission from any sensor to the hub, as there is only a single hop.	Dependent on how the network is configured. In terms of delay, the nodes closest to the hub can get their information through quickly, without any intermediate relay.
Interference	Sensors that are farther away from the hub require	Since each node is only transmitting to its neighbor

	transmission with higher power, increasing the amount of interference.	nodes, the energy of transmission is kept low and hence mitigates the effects of interference.
Node Failure and Mobility	Only the failed node will be affected and the rest of the network can perform as needed.	The part of the network that involves the failed node has to be reconfigured. Overheads are involved.

4.2 Network model

In this section basic assumptions, definitions and network model used by proposed algorithm are explained. The proposed algorithm works in a two hop extended star topology based IEEE 802.15.6 in beacon enabled mode. We considers only EAP1, RAP1 and MAP1 period in superframe and EAP2, RAP2, MAP2 and CAP is not used. According to standard IEEE 802.15.6 it is not necessary to use all modes of communication.

A node decides to use relay facility if its connection with hub is weak or it needs to conserve its energy. It discovers the relaying node using standard procedures available in the standard. We have used explicit notification in the MAP for this purpose. The relaying capable nodes send broadcast message for potential relayed nodes. In the proposed scheme the relaying nodes communication their network status to the potential relayed nodes in the broadcast message.

The status of node define the basic metric based in which the relayed node can selected the relayed node. We have used three different metrics which can calculate at the relaying nodes. These metrics include number of packets drops, number of retries made for successful transmission of data packet and packet service time of relaying node. In this study, we have used the aforementioned metrics and each relaying node calculates the moving average of these metrics in each beacon interval. All the metrics are node based and are independently calculated by each relaying node without the assistance or feedback of either neighboring nodes or hub. The moving average is calculated using equation 4.1

$$status = \alpha * status + \beta * current\_status \qquad (4.1)$$

Where, current_status the value of any metric observe in the last beacon interval, whereas status represents the predicted value for the next beacon interval. α and β are weights which are assigned to previous status values and currently observed value respectively.

Three different schemes proposed to get *current_status* is.

Packet drop are the total number of packet drops at beacon interval at the relaying node. it is the standard metric numerous protocol for measuring congestion over a node. The basic idea of using this metric is to avoid relaying packet through a congested node.

Another metric used is packet service time. It is the time a packet is received or generated by the application and placed in the buffer for future transmission. As soon as the medium is available, a packet from the queue is schedule for transmission by the medium access layer. Therefore, it represents the waiting time of the packet at any node. Hence, service time is another metric reflecting the load over a node and the level of contention around any node.

Retries represent the number of unsuccessful attempt a node has made to transmit a packet. It is a good measure of contention faced by a node in a busy medium.

4.3 Operation of proposed algorithm

In proposed algorithm the relayed node is responsible for the checking of link quality between hub and relayed node, between relaying node and relayed node and between relaying node and hub. In every beacon interval or superframe the relaying node observe the metric i.e. drop packets, service time and retries. The currently observe value of metric, a value obtain is the current status of relaying node. The nodes that are currently using relaying nodes or want to use them receive this packet, others just dropped the packet including hub.

The next step is to select the proper relaying node by checking the *minimum value* of each possible relaying node. Information is updated after each beacon interval or superframe. Relayed node check minimum value and made decision after energy or appropriate beacon intervals. The selection criteria is to find the minimum (min) value of all possible relaying nodes in relayed node which is being updated in every map (schedule slot allocated to every nodes). If the min status value found is that of the relaying node that is currently used by the relayed node then it continuous with old relaying node. Otherwise, the new relaying node with min value is selected and encapsulated connection request frame is send to hub, according to frame reception and sending rule of 802.15.6 standard [4].

The flow chart of relayed node for proposed algorithm is presented in *Figure 4.2* and relaying node is presented in *Figure 4.3*, the symbols used in the algorithm are listed in *Table 4.2*. The relaying node algorithm is triggered in MAP after each beacon interval at all possible relaying nodes. Whereas, relayed node algorithm is triggered after every beacon or after specific number of intervals according to settings provided by superframe.

Proposed algorithm for IEEE 802.15.6 two hop extended star topology is shown in *Figure 4.1*.

```
RN  : RelayedNode
R_yNode :RelayingNode
LS: Link Status
if (SNR_node < threshold)
{
        LS = weaker
        SET: RN = TRUE;
        SET: RN = LISTENING;
        if (Pkt_rcv = ACK)
        {  SET R_yNode }
}
Repeat: After each beacon interval in ( MAP)
{
        Status of  R_yNode ;
        if(BS > 0);
        {  Broadcast BM;  }
        if (RN == TRUE)
        {   SET: BUCKET [NID] [BS] = BufferStatus   }
}

if (Beacon_Count == beacon interval)
{       for(i = 1; i ≤ No.R_yNode; i + +)
       {  Select Min_status Value from BUCKET ;}
}
if (Min_status == CurrentR_yNode)
{
  SET Beacon_count = 0;
  FOUT;
}
else
  {
SET Beacon_count = 0;
            Send Connection Request
}
```

Figure 4.1: Proposed algorithm

Table 4.2: Symbols in proposed algorithm flow chart and their description

Symbols	**Description**
RN	Relayed node
Min val	Minimum value of status (metrics)
Current	Current value of status (metrics)
LS	Link quality
RYN	Relaying node
Cur_slct	Already being connected
Set Conn.	Connection request is send through selected relaying node to hub and get connected
Obtain status	Obtain status refers to the dropped packets, service time, retries of packet.
NS	It is the node status of each node as in proposed scheme.
BM	Broadcast message
$Recv_{Ratio}$	Packet receive ratio at coordinator during a BI
$Delay_{Observed}$	Average end-to-end delay observed in the last beacon interval at BAN hub
$Delay_{Req}$	Application defined deadline associated with delivery

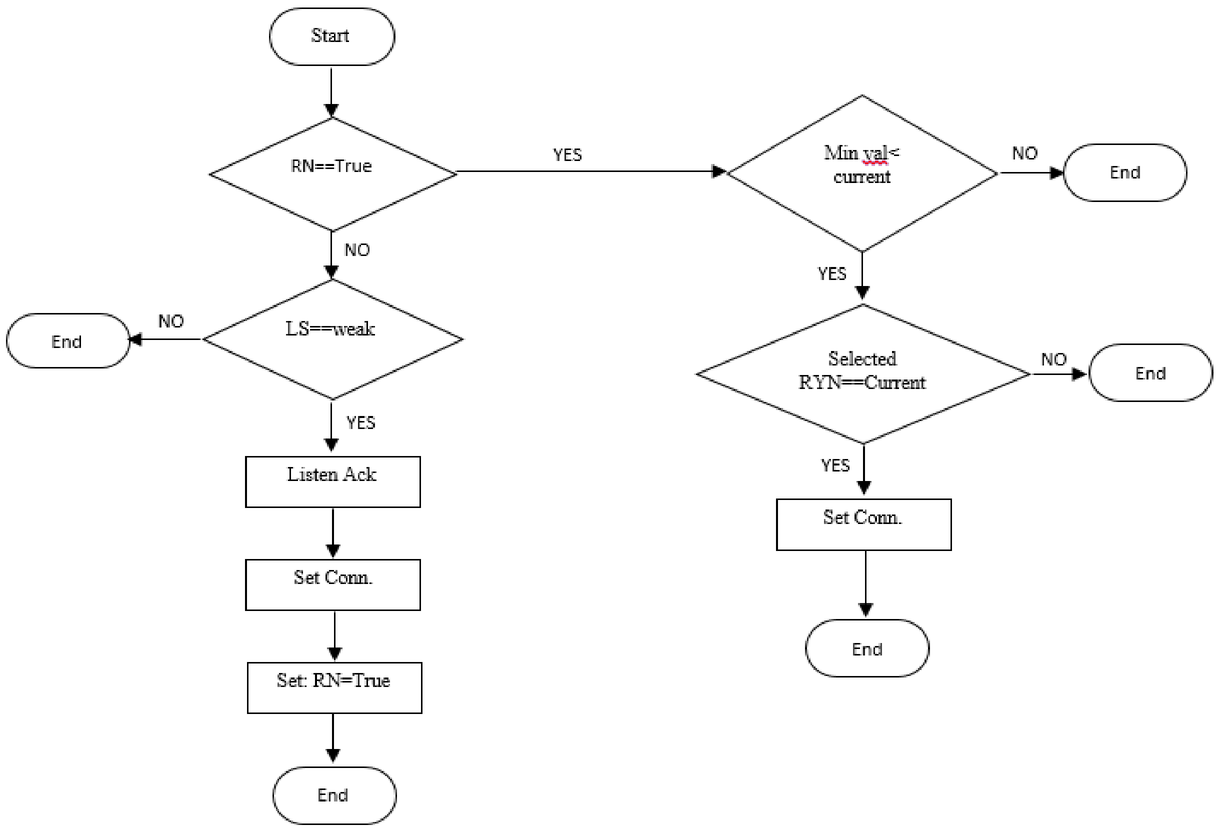

Figure 4.2: Flow chart of proposed relaying node selection algorithm executed at relayed nodes

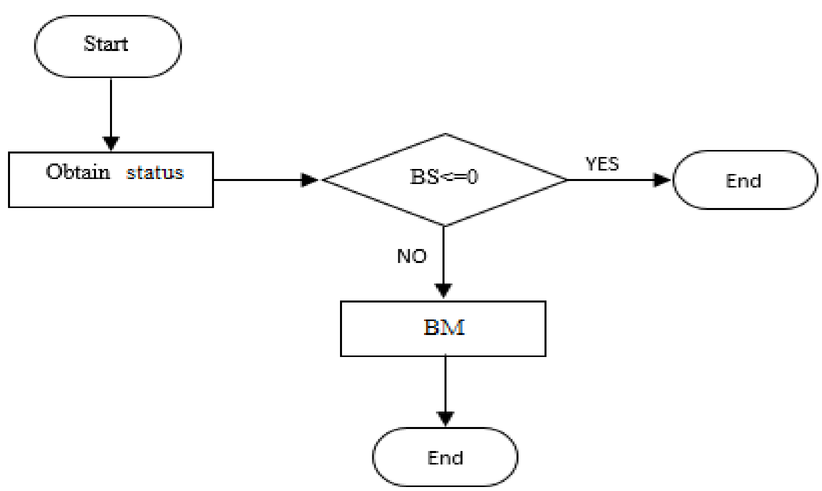

Figure 4.3: Flow chart of proposed algorithm at relaying nodes

Chapter 5

RESULTS AND ANALYSIS

5.1 Introduction

In this chapter, detailed performance evaluation of proposed algorithm is done based on simulation analysis in comparison with IEEE 802.15.6 and Patent [22]. Comparisons are based on packet delivery ratio, throughput and end-to-end latency. The simulation analysis is performed using network simulator OPNET 14.5 [21]. We surveyed a number of simulators for the implementation of IEEE 802.15.6 but only OPNET 14.5 supports the complete WBAN implementation.

The network was configured based on star topology and was extended to two hop star topology for relaying node selection. The WBAN hub is place in middle of the network topology whereas the relaying nodes are placed around the hub in circular fashion. Relayed nodes are placed outside the circle and away from transmission range of hub, in transmission and receiving range of relaying nodes as shown in *Figure 5.1*. Node1 is possible relayed node and node2, node3 and node4 are possible relaying nodes. In the start of each super-frame WBAN hub sends beacon to the network nodes, in order to access the channel in the active period of super-frame based on EAP1, RAP1 and MAP1. Then, nodes get connected and send data in EAP1 if its emergency, both regular data and emergency data send in RAP1 and MAP1 periods. In MAP each node has dedicated slots for transmission of data. Relayed node select possible relaying node, possible relaying nodes which send ACK frame to hub is listened by relayed node according to IEEE 802.15.6 standard. In IEEE 802.15.6 ACK frame which is received first at relayed node from the any possible relaying node is selected as relaying node and then send encapsulated and encapsulating connection request frame through it to hub in order to get two hop connection.

In case of proposed solution, after the transmission of packets from all relaying node to hub a current status is estimated by each relaying node. Current status (obtain either from drop packets or retries or service time) is sent in broadcast message in MAP period of superframe by each relaying node and is received by relayed node. Relayed node update its current information about the relaying nodes, in the updated information if current relaying node has better metric value than others than it remains the same else the node which has better metric value is selected and connection request frame is sent through it to hub. New two hop connection is establish between hub and relayed node through new relaying node.

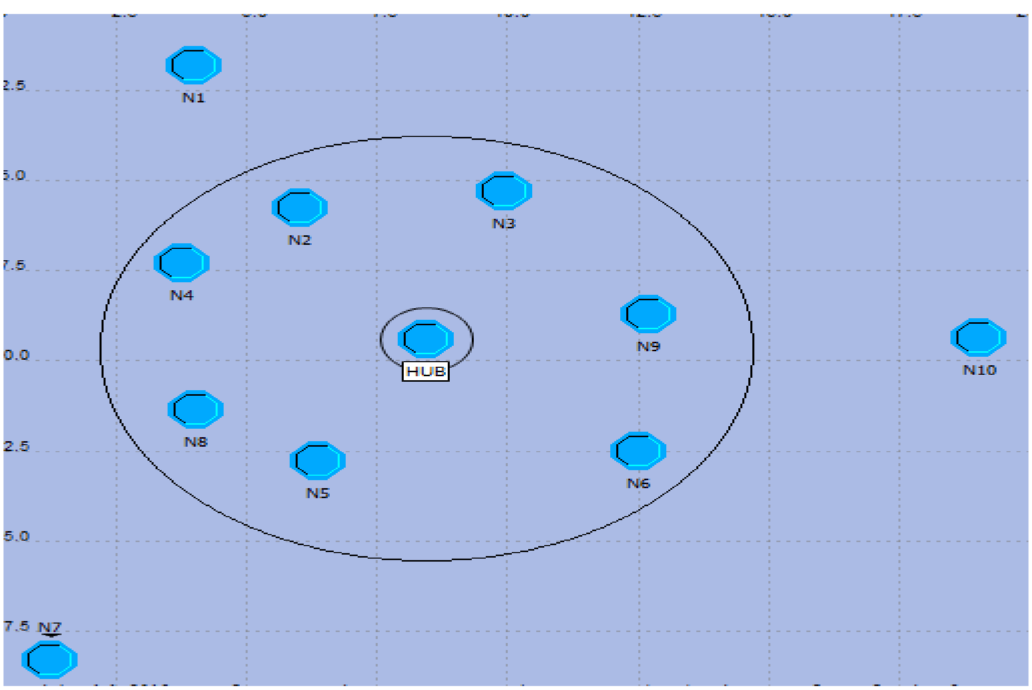

Figure 5.1: Two hop extended Star topology based beacon enabled superframe network.

The simulation parameters used for simulation analysis are shown in *Table 5.1*. Two different UP (UP6 and UP7) are used for data reporting. Data reported in both periodic (without contention) and continuous (with contention) manner. In case of periodic reporting the relaying node periodically after certain intervals generate data to the hub. At one time only one relaying node is transmitting data to the hub. Therefore, it is not facing any contention from neighboring relaying node. In case of continuous reporting more than one relaying nodes are transmitting data to the hub and they content for medium using CSMA/CA technique as specify by IEEE 802.15.6. The implementation used in the simulation for the selection of relaying node using IEEE 802.15.6, Patent [22] and the proposed algorithm are shown in *Table 5.2*.

Table 5.1: Simulation parameters.

Parameter	Value
Simulation time	500 s
Frequency band	2.4 GHz
Traffic Type	UP6 and UP7
Packet Size	100 B
Number of nodes	10
Number of hubs	1
Data Rata (kbps)	971.41
Initial energy	34560 Joules
Transmit mode	17.4 mA
Receive mode	24.8 mA
Sleep mode	6.1 µA
Idle mode	26.1 µA
Data reporting	With and without contention
IEEE 802.15.6 slot length	0.128s
EAP1 duration	14 slots

RAP1 duration	17 slots
MAP1 duration	08 slots
EAP2,RAP2,MAP2	Not used
Buffer Size	25

Table 5.2: IEEE 802.15.6 and proposed schemes with data transfer mechanism.

Protocols Names	**Relaying node selection**
IEEE 802.15.6 standard	Only in MAP, selection of relaying node through first listening of ACK frame and reselection based on observed load at relayed node.
Proposed algorithm	EAP, RAP and MAP, selection of relaying node through metrics i.e. packets dropping, retries and service time in relaying node.
Patent [22]	Reselection of relaying node based on observed load at relayed node.

In the remaining of the section the performance analysis of the relaying node selection scheme is carried out against throughput, PDR and latency.

5.2 Throughput

Figure 5.2 shows the throughput observed at hub using proposed schemes and IEEE 802.15.6. Performance of IEEE 802.15.6 is severely degraded, as there is no dynamic selection of relaying node and the transfer of data in MAP period only for relayed node, hence packets are dropped due to no dynamism and small transmission portion. Proposed algorithm uses dynamic selection of relaying node by relayed node after checking the status of every possible relaying node. Therefore, its performance is better than IEEE 802.15.6 and Patent [22]. *Figure 5.2* shows that proposed algorithm's relayed node outperforms 802.15.6 even in the presence of high contention.

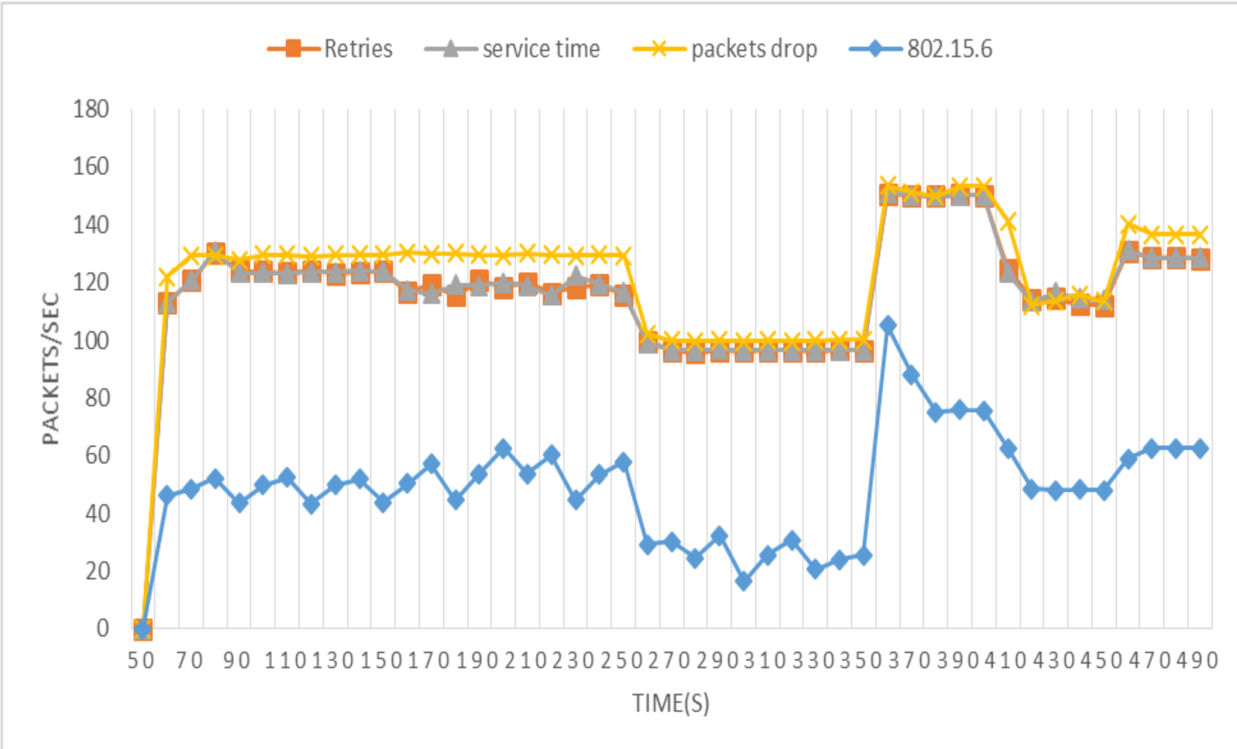

Figure 5.2: Throughput of relayed node of proposed schemes and IEEE 802.15.6

Average throughput of proposed algorithm, IEEE 802.15.6 and patent at different data rates and source nodes is shown in *Figure 5.3*. The overall data rate is used in these simulations are 50, 100 and 150kbps. Increasing source nodes traffic speed contention increases and throughput is decreased. Since IEEE 802.15.6 uses MAP period in two hop topology of relayed node and no dynamism in selection of relayed node, its performance is severely affected. Patent and proposed algorithm schemes uses EAP and RAP but in proposed solution dynamic Selection of relaying node is implemented. Therefore, proposed schemes out performs IEEE 802.15.6 and Patent in all cases as shown in *Figure 5.3* and the average throughput with data generating rate is shown in *Table 5.3*.

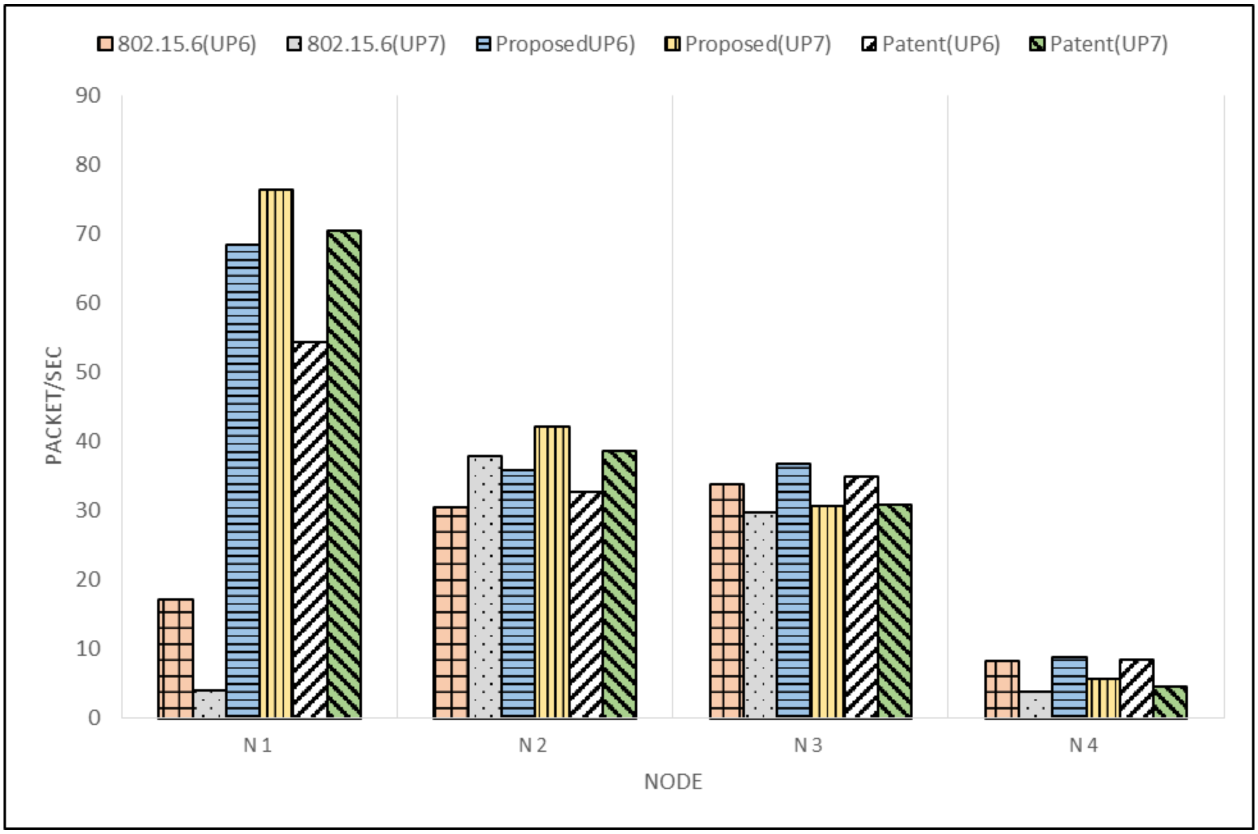

Figure 5.3: Average throughput (UP6 &UP7) of Proposed scheme, 802.15.6 and Patent.

Table 5.3: Achieved average throughput.

Protocol	**Application data rate for periodic (Packets/s)**	**Avg. Throughput achieved**	**Expected Throughput in packets**
Proposed algorithm	N1=90, N2=40,N3=40 and N4=10	153.36	180
IEEE 802.15.6	N1=90, N2=40,N3=40, N4=10	93.835556	180

Patent	N1=90, N2=40,N3=40, N4=10	143.47	180

In *Figure 5.4*, it is observed that using proposed schemes packet delivery ratio is higher than IEEE 802.15.6 and Patent [22] of each node. This outcome is explained by the fact that the delivery ratio is directly related to the packet drop status. While, in IEEE 802.15.6, and Patent [22] no proper relaying node is selected so performance is decreased.

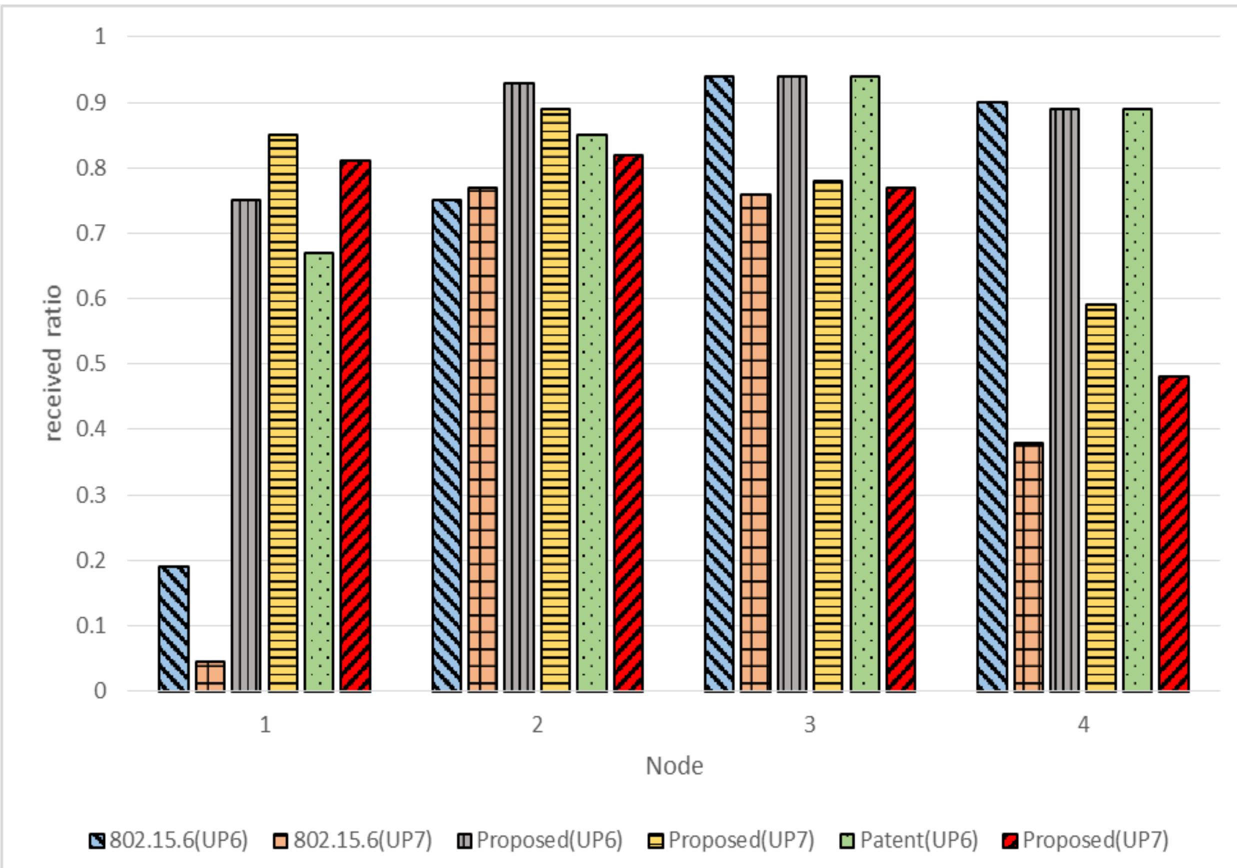

Figure 5.4: Packet delivery ratio (UP6 &UP7) of Proposed algorithm, IEEE 802.15.6 and Patent [22].

Figure 5.5 shows the average over all throughput of proposed algorithm of different scheme like drop packet, service time, retries and compare with Patent [22] of two hop extended star topology, simulation is run on different data rate 150, 300, 450 and 600. Performance of patent is severely degraded as because of no proper selection of relaying node as it select randomly or in a sequence. Proposed algorithm uses formula and according to which proper relaying node is selected, thus its performance is better than IEEE 802.15.6 and Patent [22].

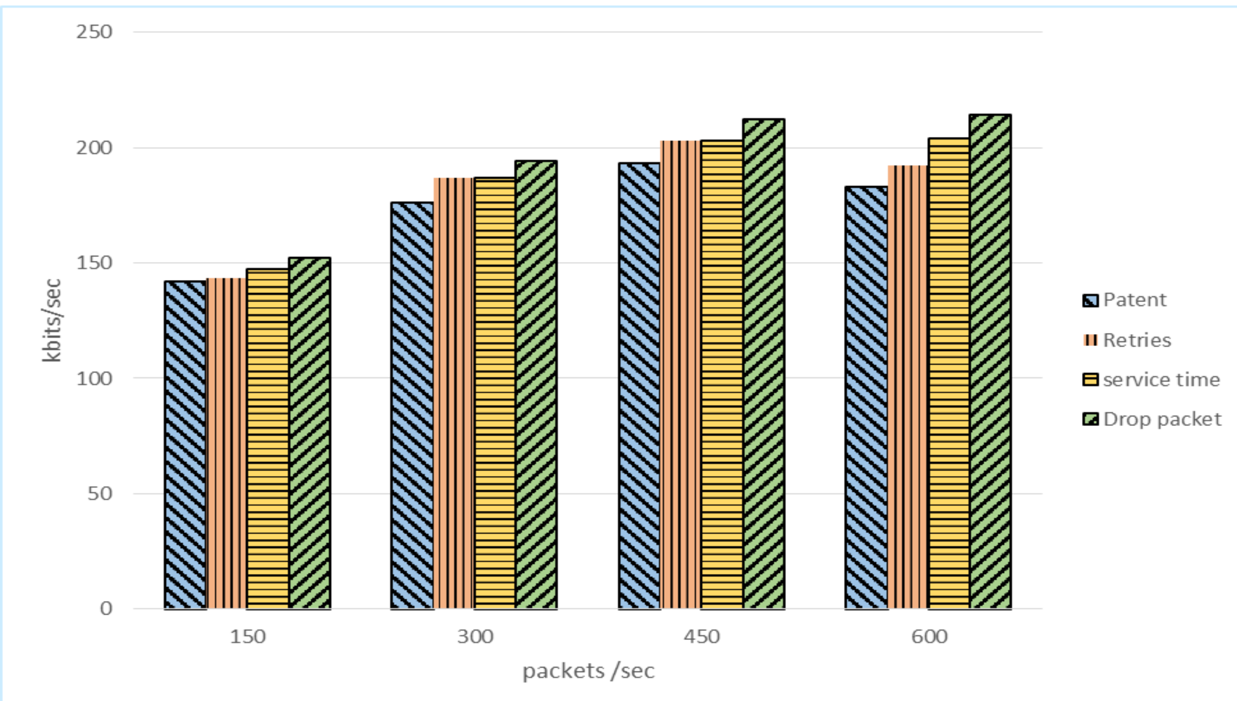

Figure 5.5: Average overall throughput of different protocols at different data rate.

Figure 5.6 shows the selection of relaying node during simulation time from 0 to 250 sec, using the proposed scheme. In this scenario, only packet drop metric is used as other metrics have similar behavior. The *Figure 5.6* shows that proposed relaying node selection methodology result in switching of relaying nodes based on best possible relaying node according to used metric.

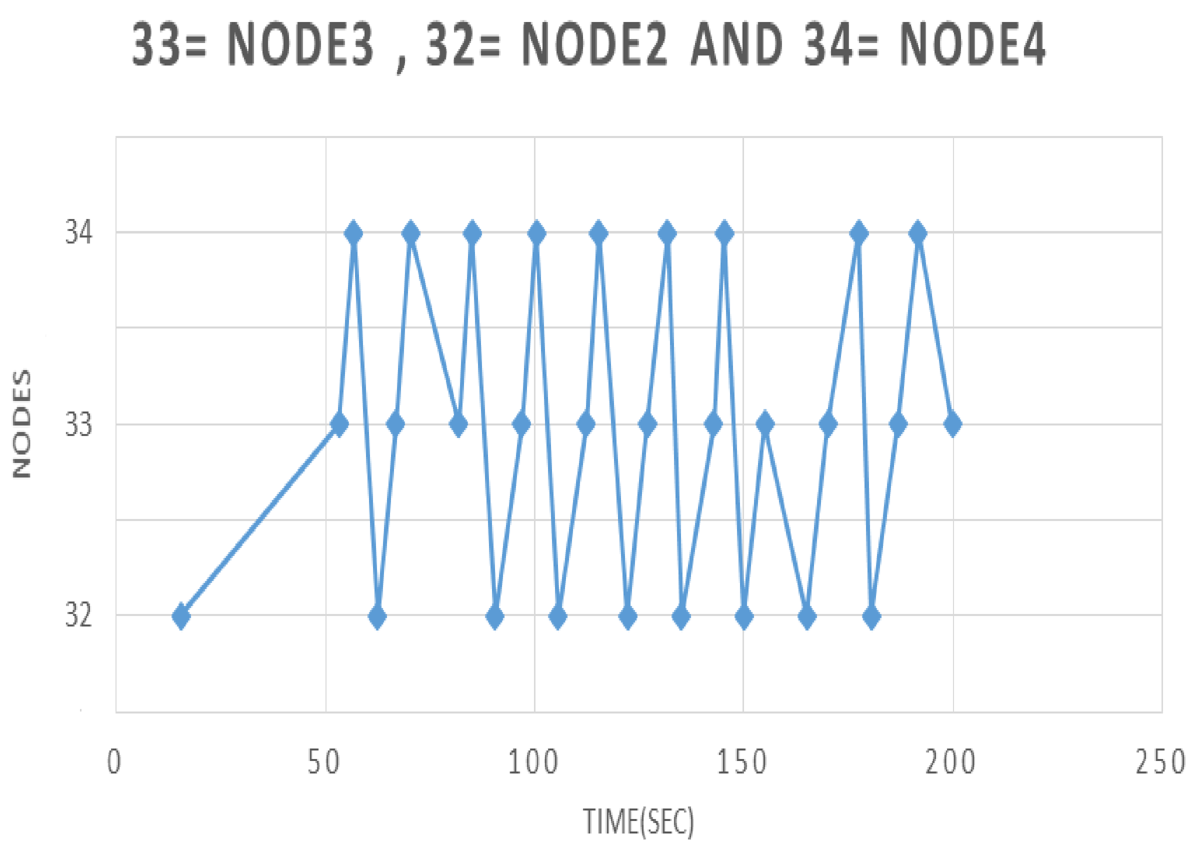

Figure 5.6: Selection of relaying node during simulation.

An important optimization problem for the proposed relaying node selection methodology is the duration of decision interval that is the interval after which a relayed node decides to switch or not to switch the current selected relaying node. *Figure 5.7* shows the impact of using different decision interval using packet drop as relay node selection metric. The best results are obtained for the decision interval 3 with superframe duration approximately 5 seconds.

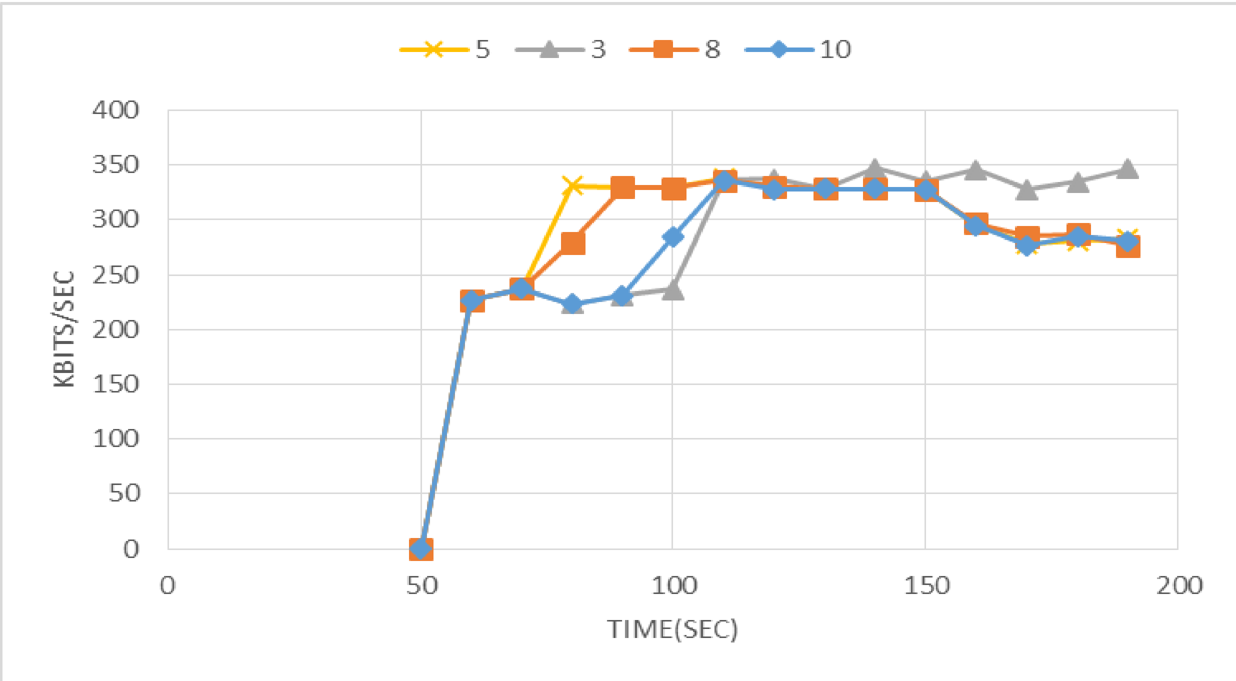

Figure 5.7: Average Throughput (UP6 & UP7) of proposed algorithm with different decision interval.

5.3 Latency

The average end-to-end delay of proposed algorithm and 802.15.6 standard is shown in *Figure 5.8*. It is evident from the figure that results in lower latency, as it efficiently select relaying node and the impact of EAP and RAP of proposed algorithm.

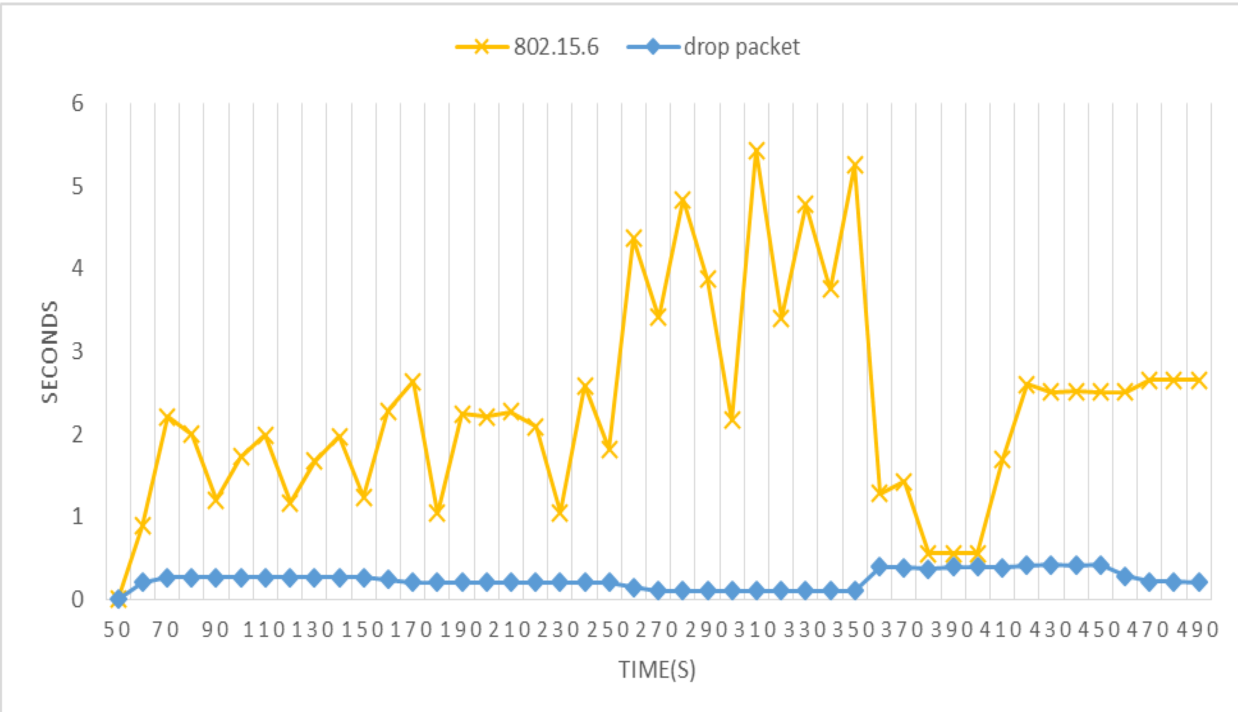

Figure 5.8: Data latency of proposed algorithm and 802.15.6.

Figure 5.9, shows the simulation result between the proposed schemes and according to simulation result and in the given scenario, drop packet scheme outperforms the packet retries and service time scheme.

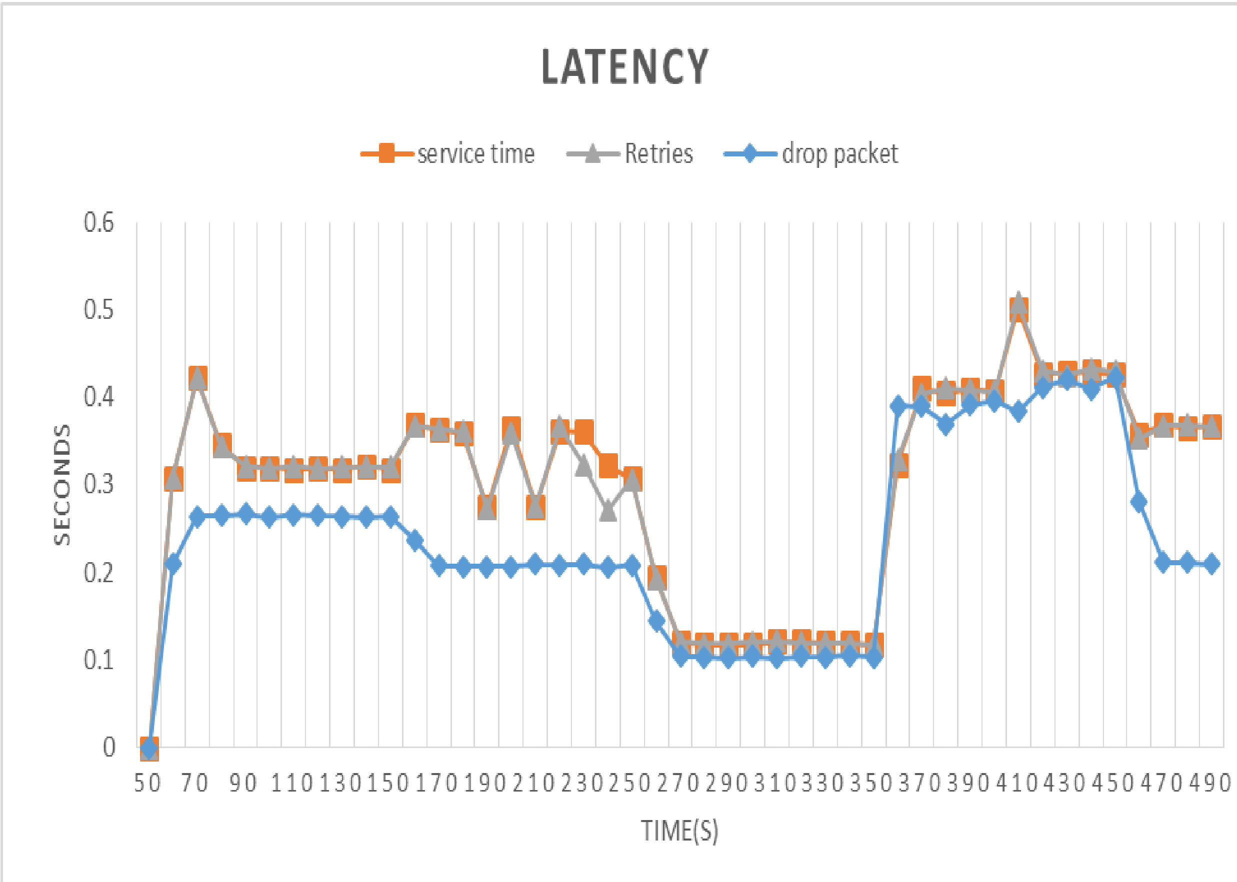

Figure 5.9: Data latency of service time, retries and drop packet.

Figure 5.10 presents end-to-end delay observed at hub, which makes clear that using more buffer in node 4 can produce a higher end-to-end delay. IEEE 802.15.6 and Patent too produce a higher end-to-end delay than the result obtained through dynamic adaptation of relaying node. Proposed algorithm shows the significance of looking for the stability by showing smaller end-to-end delay in relation with IEEE 802.15.6 and Patent [22].

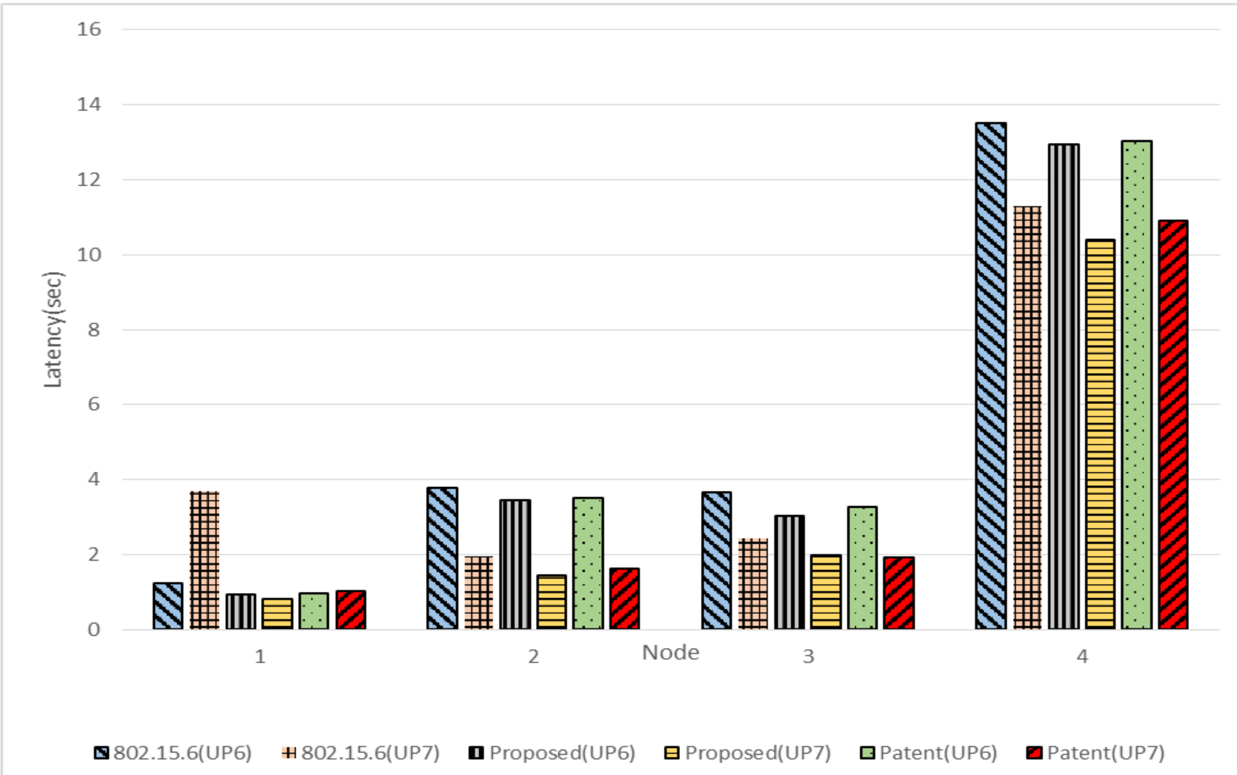

Figure 5.10: Average end-to-end delay (UP6 & UP7) of Proposed, IEEE 802.15.6 and Patent.

Figure 5.11 shows the average latency of proposed algorithm and Patent at different data rate. The graph clear shows proposed algorithm out performs IEEE 802.15.6 and Patent at different data rate. Proposed algorithm optimally select relaying node resulting in better performance.

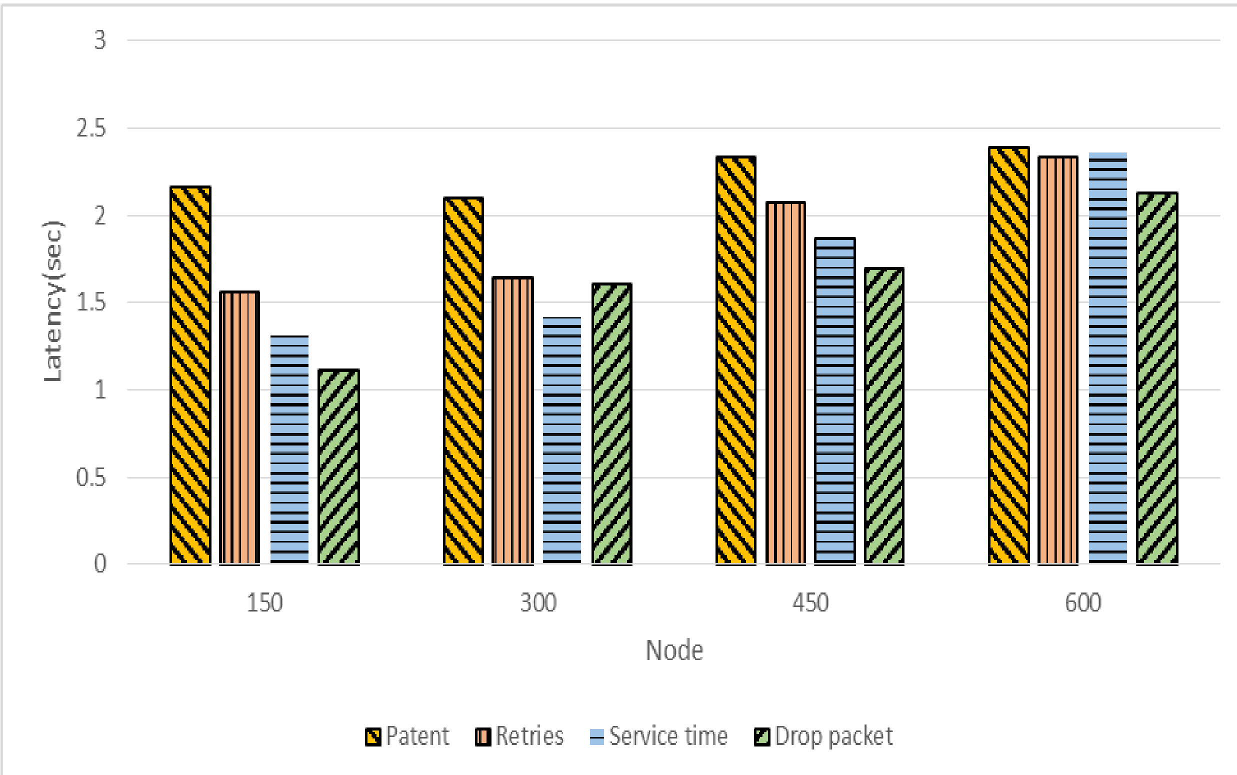

Figure 5.11: Average latency of different protocols at different data rate

Chapter 6

CONCLUSION AND FUTURE WORK

IEEE 802.15.6 supports extended two hop star topology with the help of relaying node. The standard specify message exchange necessary for the announcement and selection of relaying nodes by the relayed node. In this thesis, we have proposed different metrics (packet drops, retries and service time) for the selection of relaying node. The aforementioned metrics are calculated by the relaying node during a beacon interval and communicated to the relayed node after every beacon interval. As a result, propose relaying node selection schemes are able to dynamically select appropriate relay node depending upon network condition. On the other hand, IEEE 802.15.6 standard recommend the use of first available relaying node for data relaying to the relayed node.

Detail simulation analysis of the proposed schemes and IEEE 802.15.6 standard reveal selection of relaying node based on proposed metrics gives better results than the IEEE 802.15.6 standard. Using both periodic and continuous data reporting scenarios in different data node arrangements. It is observed that the average throughput can be increased to 51 % using EAP, RAP and a simple metrics like packet drops for relaying node selection. Likewise, latency of communication for the aforementioned scenarios can be decreased to 49 % at compare to IEEE 802.15.6.

In future this work can be further extended to support dynamic relaying node selection in terms of energy, latency and Signal to Noise Ratio (SNR). Furthermore, the schemes such as retries, drops packet and service time can also be integrated and optimize in order to select best relaying node.

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