I, Sahithi Chintapalli, hereby submit this original work as part of the requirements for the degree of Master of Science in Computer Science.

It is entitled:
Transmission Scheduling Using Adaptive Neuro-Fuzzy Inference System For Minimizing Interference in Wireless Body Area Networks (WBANs)

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Transmission Scheduling Using Adaptive Neuro-Fuzzy Inference System For Minimizing Interference in Wireless Body Area Networks (WBANs)

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ABSTRACT

Wireless Body Area Networks (WBANs) comprise of small sensors implanted on or inside the human body. WBANs are applied in various health care areas, including medical care for the elderly, and athlete health management system. WBANs are helpful in saving patient’s life by monitoring the human body signals and sending collective response to a collector node in case of an emergency. In addition to their advantages, there are several problem areas that need to be addressed before WBANs can be widely used for commercial purposes.

Interference is one of the major concerns that impacts availability of data. In this thesis, we propose a transmission scheduling scheme that helps minimize interference. This scheme uses Fuzzy Logic Inference System that considers network link quality parameters to decide if the transmission needs to take place or not. We use MATLAB Fuzzy Logic ToolBox to determine this decision. In order to augment the decision strength, Transference Belief Model is applied to the result of the Fuzzy System, using Adaptive Neuro-Fuzzy Modeling. We include resulting graphs to demonstrate that transmission scheduling using adaptive neuro-fuzzy system is an effective method so as to minimize intra-WBAN interference in WBANs.
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I would like to dedicate this thesis to my father, who is not with us anymore but I am sure he is looking and showering his blessings upon me. Also, I would like to dedicate this thesis to my mom who is my role model. Hopefully, as I grow I’ll be able to handle situations in life with the same strength as she does. I would like to thank my sister for being a funny and responsible older sister.

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CHAPTER 1
INTRODUCTION

1.1 Background

Monitoring health by periodic health check ups, maintaining proper diet, and engaging in physical activities have been of great importance these days. People are taking measures to identify health problems at an earlier stage than later. As per US Census Bureau [1], by 2020 healthcare expenditure is going to go up to 20% of the nations GDP. The Allied Business Intelligence study has suggested an annual market increase of 41 percent between 2011 and 2017 to $169.5 millions [2].

With the increasing costs of health care, there is a need for reliable and cost effective way of reducing the expenses. With the advancements in sensor networks world, wireless networking, and mobile computing enables us a mechanism to improve the healthcare network. Wireless Body Area Networks (WBANs) provide cost effective and reliable personal network for patients that need 24 x7 constant health monitoring. The main advantage of using WBANs is the flexibility of providing to the patients (especially elderly people who live alone and are in need of constant monitoring for chronic diseases).

There are several other applications of Body Area Networks besides from the health industry such as military, sports, etc. In addition to their advantages, there are a many challenges while designing and implementing Body Area Networks. Extensive research is being done in order to help overcome these challenges.
WBAN is a network consisting of several small, light weight, low powered sensors implanted in/on human body. Figure[1.1] shows the multi-tiered architecture with human body sensors in tier-1. The sensors communicate with each other and also with the coordinator node which is responsible to transmit the data to Base station (BS). Each sensor in the network is responsible for monitoring only one vital parameter, reducing potential redundancy of data. Tier-2 has a personal server which can be a mobile phone that controls the sensors. Tier-3 has the medical servers as BS that receive parameter data from the sensors.

![Figure 1.1 MULTI-TIER ARCHITECTURE](image)

A major responsibility of WBANs is to monitor body signals and transmit them to the server. In order to monitor a patient’s health, vital signals from the body need to be transmitted via a server to the healthcare provider. Vital signals can be heart rate, blood pressure, breathing rate, etc. When any of the vital signals are abnormal, an alarm is sent to the healthcare provider via the
server. By monitoring the human body in this manner, there is a better chance of identifying the symptoms in an earlier stage than later.

1.2 History of WBANs

The medical telemetry device could utilize vacant television channels which would face some interference due to the primary users of the band. In the year 2000, Wireless Medical Telemetry Service (WMTS) was defined specially for the transmission of data related to the patient’s health. The bands defined for this purpose are 608-614 MHz, 1395-1400 MHz and 1427-1432 MHz. Channel interference and, restrictions on the bandwidth are the limitations of WMTS. In 2003, Medical Implant Communication Service (MICS) has been defined for the communication of medical implants. The frequencies assigned to this standard are 402 and 405 MHz. MICS is a standard with low bit rate and, consumes low power.

WBANs were first proposed by T. G. Zimmerman and were known as Wireless Personal Area Networks (WPANs) [3]. Later, they have been redefined as WBANs. WPANs are used in many areas like continuous patient monitoring, mass casualty incident areas, etc., [4]. The main technology used by WPANs is Bluetooth, also known as 802.15.1, which was launched by Ericsson in 1994. The other technology used by WPANs is Zigbee, also known as 802.15.4. For example, in a casualty incident area, tiny sensors are placed on the patient to form a network using Bluetooth and the signals are relayed to multiple receiving systems.

WBANs were developed based on the idea of WPANs. In 1995, the work on developing WBANs started and in 2001, the term Body Area Network(BAN) came into existence. BANs implied that the communication was within the communication range of a human body. A study group 802.15.BAN (SG-BAN) has been formed to work on establishing an IEEE standard for
medical and healthcare services [5]. In 2011, IEEE has specified 802.15.4 standard for low-rate WPANs. Later 802.15.4 standard was proposed with improvements like 802.15.4e, 802.15.4f, 802.15.4g, 802.15.4j, 802.15.4k, 802.15.4m and 802.15.4p. In 2012, IEEE introduced 802.15.6 standard for WBANs. This standard concentrates on communication within or inside the human body range. Several other technologies like RFD, cellular system have also been used for medical applications.

1.3 Current and Future of WBANs

WBANs are being utilized in several areas including healthcare, military, sports, and security. Currently, they are in the initial stages and a lot of research work is being pursued in many areas for improvement. According to [6], WBANs are expected to develop into a multi-million dollar industry in the coming years.

![Figure 1.2 PROJETED GROWTH OF WEARABLE TECHNOLOGY IN DIFFERENT AREAS](image_url)
Figure [1.2] shows the growth of revenue for wearable systems in different applications. Adoption of disposable body sensors is increasing in the healthcare industry. As per AIB research, it is projected that the shipments of disposable body sensors will increase up to 5 million by 2018 [7]. In 2012, Federal Communications Commission approved a separate frequency spectrum for Medical Body Area Networks (MBANs). The MBAN spectrum ranges from 2360MHz to 2400MHz. Since Aeronautical Mobile Telemetry (AMT) is the primary user of the band, the spectrum has been divided into two sub-bands : 2360MHz-2390MHz and 2390MHz-2400MHz. The MBAN communications are restricted within an indoor environment.

In the military area, a project is under progress to develop wearable sensors for body to body communication between troops in the field. According to Dr. Simon Cotton of CSIT’s Radio Communications Research Group, the objective of the project is to provide awareness of the situation to the troopers by monitoring and sharing field information with helmet monitors and antennas [8]. A lot of research is being done in the medical and non medical industries to come up with breakthrough inventions.

1.4 Challenges in WBANs

In spite of all these advantages, WBANs have a few challenges that are preventing them from being commercially accepted worldwide. Listed below are a few:

**Sensor Placement**

Each sensor node in WBANs is used to monitor one vital sign of the human body which reduces redundancy of data. The placement of sensors ought to make sure that a sensor covers the required body parts that need constant monitoring.
Security
The data handled by WBANs contains sensitive patient information. One of the major challenges in WBAN implementation is keeping the patient data secure and not combine with data coming from different WBANs. IEEE 802.15.6 standard does provide data security, but some enhancements are still needed to address different situations.

Data Consistency
The human body parameters are sensed by the sensors and transmitted to the coordinator and personal server. The data from the server is sent to the medical server. Each sensor is responsible for monitoring only a single parameter. All data need to be aggregated and then condensed data is to be sent to the medical assistant. It is a challenge to send correct and aggregated data sensed by the sensors.

Interference
Having several WBANs in the same area will cause interference which could affect monitoring of the human body signals. Thus, interference is a major challenge in keeping the WBANs monitoring the vital parameters. Several scheduling schemes are proposed to avoid or suppress the interference between WBANs.

Cost
The cost of implementing a WBANs can be a challenge while deploying them in real world.

1.5 Thesis Study
In this thesis, interference in WBANs is considered as the scope of the study. There are two kinds of WBAN interference; Inter-WBAN interference, and Intra-WBAN interference. Inter-WBAN interference occurs during communication between the coordinator node and the
medical network. Intra-WBAN interference occurs during communication between the sensor nodes and the personal server.

It is very important to mitigate interference to make the communication in WBANs more reliable and secure. Implementing a proper transmission scheduling scheme has been considered an effective method to mitigate interference in WBANs. Scheduling techniques like color based scheduling, channel switching, etc., have been proposed to mitigate interference.

In this thesis, we propose a scheduling scheme to avoid Intra-WBAN interference. We chose fuzzy logic inference to come up with a decision for scheduling and further applied transference belief model to strengthen the decision made.
CHAPTER 2

WBAN OVERVIEW

2.1 Health Monitoring WBAN Architecture

The architecture shown in Figure [2.1] is the system architecture of a medical WBAN. It is a multi-tiered architecture with the sensors forming the BAN in the lower tier. The second tier consists of the personal server and the third tier consists of the medical servers.

[Diagram showing WBAN architecture with various sensors and network connections]

The signals sensed by the sensors are transmitted to the medical servers via personal servers that make use of the internet for communication. The human body has several sensors to monitor signals like ECG, blood pressure, pulse, etc. The signals from the sensors are aggregated at the personal server which can be a smart phone or Personal Digital Assistant (PDA). The personal server transmits signals via WLAN/Cellular network (3G, 4G) to the caregiver. If there is an emergency, an alarm is generated at the Emergency services.
The sensors should be light weight and low powered such that monitoring can be done for longer time. They sense, process, store, and forward data to the collector node periodically. The personal servers are responsible for monitoring the sensors in the WBANs, integrating the data received from different sensors, communicating received data to the health servers, and providing graphical interface to the user. The personal server communicates with the WBAN nodes using ZigBee or Bluetooth standard. The medical servers integrate the data received with the patient data already in the database. Based on received data, the caregiver might give appropriate recommendation. If the data range is out of sync, emergency services might be alerted and location of the patient is removed from the network from which the data came in [9].

Figure 2.2 PERSONAL SERVER AND SENSOR NODES
Figure [2.2] is an example of personal server and the sensor nodes that are used to monitor the human body signals. There are several different types of sensors used to monitor these signals. Selection of the sensors depends on the application as sensors are categorized as chemical, thermal, mechanical, and acoustic. For example, accelerometer measures the acceleration, blood pressure measures the systolic and diastolic, temperature uses silicon integrated circuits to measure the temperature changes, etc.,.

2.2 Requirements of WBANs

WBANs have unique characteristics compared to other Wireless Sensor Networks (WSNs). Below are a few of them:

- WBANs operate in low-range environments. The range of WBANs can be between 3m-6m, depending on the application requirement.
- The data rate supported by WBANs varies from 1 kbps for vital parameters to 10Mbps for video transmission.
- WBANs are known to operate with low powered sensors and actuators. The amount of power consumed for transmission depends on the type of application. For applications that don’t require constant monitoring, the sensors can go to sleep mode when they don’t have any data to share. Power consumption should not exceed 1mW.
- Interoperability is one of the essential features of WBANs. With several applications using the same frequency band for transmissions, it is essential for WBANs to co-exist with such other systems.
- Security is a major concern when it comes to sensitive patient data or military data. Effective authentication and encryption methods should be performed to maintain the integrity of data.
- Specific Absorption Rate (SAR) is the energy absorbed by human body when exposed to Electromagnetic fields. FCC has posed restrictions on the SAR to be 1.6 W/kg in 1g of body tissue. This SAR requirements should be met.
- Since the sensor nodes are either implanted inside or worn on the human body, the antennas and batteries should be flexible in a way that it doesn’t affect the comfort of the person wearing it.

2.3 Deployment of WBANs

The wearable WBANs can be used for medical or non-medical applications. The implanted WBANs are used only for medical applications. A wearable WBAN called “Smart Vest” has been introduced in [10] to monitor different parameters like electrocardiograms, heart rate, blood pressure, temperature etc. Figure [2.3] illustrates the architecture of a smart vest.

Figure 2.3 SMART VEST – WEARABLE WBAN SYSTEM – TAKEN FROM [10]
Sensors generate physiological parameters and send it to the server via a BS using 802.15.4 communication standard. There are several other applications that utilize wearable WBAN deployment method.

An implantable WBAN is the deployment of sensors inside the human body. Few important human body signals need continuous monitoring, even when the patient is sleeping. Once the sensors are implanted inside the body, they keep monitoring the signals at all times and process the data accordingly. Examples of applications of implantable WBANs include a pacemaker for the heart and an automatic insulin injection for diabetes patients. The pacemaker is an actuator controlled by commands and it will adjust the heart rate based on the heart rate parameters being monitored. Similarly, based on the glucose parameter being monitored an automatic insulin injection is given to the diabetes patient. Figure [2.4] shows a bio sensor pill implanted inside the human body to sense the glucose levels and pump insulin whenever required.

Figure 2.4 GLUCOSE SENSOR AND INSULIN PUMPING UNIT – TAKEN FROM [10]
As per [11], the topology used in WBANs can be one-hop or multi-hop star topology with the coordinator as a root. When all the nodes can be directly connected to a coordinator node in one hop, then the topology is said to be one-hop. When the nodes are connected to the coordinator node via other nodes, then the topology is said to be multi-hop. There are different types of topologies WBANs can use like star, mesh, point-to-point and, tree, etc.

- In point-to-point topology, one node is directly connected with another node.
- In star topology, there is one root and several other slave nodes. All the slave nodes only communicate with the root coordinator or sink node. The slave nodes cannot communicate with each other.
- In mesh topology, all the nodes are in the same hierarchy and communicate with each other as long as they are in one hop distance. Nodes that are not in the communication range cannot communicate.
- In tree topology, the nodes follow a parent-child relationship for communication. Each node has only one parent node that is used to transfer the data. The data is ultimately sent to the root coordinator node. There is only one path of communication between two nodes.

### 2.4 WBANs Communication

There are two ways WBANs can communicate. The communication can be among sensor nodes on the body which is called Intra-body communication. The communication can be between the sensor nodes on the body to the external data center which is called Inter-body communication. Figure [2.5] shows inter and intra BAN communication in WBANs.
On-Body or Intra-WBAN network

In On-Body or Intra-WBAN networks, the sensors communicate with each other and the personal coordinator.

Body-to-Body or Inter-WBAN network

In a Body-to-Body or an Inter-WBAN network, a single WBAN communicates with other WBANs through its coordinator nodes. This communication is used when the a WBAN cannot transmit the data to its server through its own coordinator.

There are several standards that WBANs can use for communication as follows

Bluetooth (802.15.1)

This standard has been approved in 2002 by the IEEE for short range communications. It defines MAC and PHY layer for communication between devices and can network up to 8 devices. The range of this standard is up to 10 meters.

ZigBee (802.15.4)
This standard has been developed by ZigBee Alliance developed on top of 802.15.4 in 2004. It has low rate and low power requirements and can network up to 256 devices. The range of this standard is 10-100 meters.

**UWB**

This standard is applicable in short range and indoor environments. The range of this standard is 2 meters. It has been modelled as a part of the standards 802.15.4 and 802.15.6.

### 2.5 802.15.6 Standard

IEEE 802 group has been working on defining communication standards for WBANs. In 2011, IEEE standard draft was approved for WBANs. In 2012, the 802.15.6 standard was finalized with its aim to provide a communication standard for low powered operating on/in/around human body to serve different applications. This IEEE standard defines Medium Access Control (MAC) and Physical (PHY) layer for communication in WBAN. Figure [2.6] shows the architecture of this standard.

![Figure 2.6 IEEE STANDARD 802.15.6 ARCHITECTURE](image)

It has 3 PHY layers- Narrowband (NB), Ultra-Wideband (UWB), and Human-Body Communications (HBC), and one common MAC and Security layers. Of the 3 PHY layers, UWB and HBC layers are mandatory and NB PHY is optional.
The NB PHY layer uses Differential Binary Phase-shift keying (DBPSK), Differential Quadrature Phase-shift keying (DQPSK), and Differential 8-Phase-shift Keying (D8PSK) modulation technique. This PHY layer is responsible for activation/deactivation of radio transceiver and data transmission/reception. The frame structure consists of Physical Layer Convergence Procedure (PLCP) preamble, PLCP header, and PHY Service Data Unit (PSDU). The preamble helps in time synchronization and carrier-offset recovery. The header carries the information for a successful decoding of a packet to the receiver. The PSDU consists of MAC header, frame body, and Frame Check Sequence (FCS) after PLCP header. Any of the available data rates are used for the PSDU transmission. The UWB PHY layer operates in low and high frequency bands. The low band consists of 1-3 channels with channel 2 being a mandatory channel. The high band consists of 4-11 channels with channel 7 being a mandatory channel. The UWB PHY Protocol Data Unit (PPDU) has a Synchronization header (SHR) with a preamble and Start Frame Delimiter (SFD), PHY Header (PHR) to convey information about the data rate of PSDU and length of the payload that are used to decode PSDU by the receiver. The HBC PHY layer operates at two frequency bands, with the first one centered at 16MHz and the second one centered at 27MHz. This layer uses Electrostatic Field Communication (EFC) specification. The UWB PPDU consists of a preamble, SFD, PHY Header, and PSDU. The preamble and SFD employ pre-generated fixed data patterns. The SFD is used by the receiver to detect the start of the frame.

The MAC layer of 802.15.6 has a MAC frame structure as shown in Figure [2.7]. The frame structure has a 56 bit MAC header, 0-255 MAC frame body, and 18 bit Frame Check Sequence (FCS).
The frame header indicates frame control which tells us what type of a frame is being transmitted; 8 bit Recipient ID has the address information of the data recipient; 8 bit Sender ID has the address information of the data sender; and 8 bit WBAN ID which has information about the WBAN where the transmission is taking place.

In 802.15.6 standard, the channel is divided into beacon period or super frames of the same length [12]. Each superframe in turn has many allocated slots for data transmission. Beacons are transmitted at the start of the superframe to allocate transmission slots. The inactive superframes have no beacon transmitted. To shift the allocation of the slot, the offsets of the beacon periods are shifted.
Figure 2.8 shows superframe structure of a beacon mode. The frame consists of several phases: Exclusive Access Phase (EAP), Managed Access Phase (MAP), Random Access Phase (RAP), and Contention Access Phase (CAP). EAP1 and EAP2 are used for higher priority data and RAP1, RAP2, CAP phase are used for normal data. MAP are used for uplink, downlink and bi-link allocation. EAP1, EAP2, RAP1, RAP2, CAP use CSMA/CA or slotted aloha for resource allocation where as TypeI/II uses polling.

2.5.1 802.15.6 MAC Access Modes

This standard supports the following three communication modes:

1. Beacon Mode with Superframe Boundaries,
2. Nonbeacon Mode with Superframe Boundaries, and

In Beacon Mode with Superframe Boundaries mode, beacons are transmitted in the active superframes. The active frames are followed by inactive superframe with no transmissions. In Nonbeacon Mode with Superframe Boundaries, the transmission takes place only in the Managed Access Phase (MAP). In Nonbeacon mode without Superframe Boundaries, only Type II polled allocation is provided.
2.5.2 802.15.6 MAC Access Mechanisms

In order to allocate the resources for data transmissions to each node in a specific superframe phase, there are few mechanisms that can be used. As mentioned earlier, the phases use CSMA/CA, slotted aloha, and polling as access mechanisms.

Carrier Sense Multiple Access (CSMA/CA) Mechanism

In CSMA access mechanism, the node maintains a backoff counter and sets it to a random integer called Contention Window (CW). The minimum and maximum values of the contention window depend on the priority of the data. For each idle CSMA slot of a given length, a random delay called “backoff” between 0 and (CW-1) is generated. Then the backoff counter is decremented. Once the backoff counter reaches 0, the node starts transmitting the data. If the channel is busy with another transmission, the backoff counter is locked until the channel is empty. The contention window is doubled for each transmission.

Slotted Aloha Mechanism

In slotted aloha, the node maintains a contention probability. The standard 802.15.6 defines 8 user priorities that are used to classify high and low priority data. The channel is divided into slots and only one packet is transmitted in a given frame. The transmission is initiated at the start of the slot only. The packets either overlap completely or they don’t. There is no chance of interference in slotted aloha which makes it more efficient.
**Polling Mechanism**

In a polling mechanism, the coordinator node sends a polling packet to the node that is being polled. Once the polling packet is done, the assigned node transmits the data and once the transmission is complete it sends a poll finished packet to the coordinator. The coordinator node then sends a polling packet to the node next in the list. Similarly, the coordinator node gives a chance to all the nodes to transmit their data and repeat the process.

**2.6 Interference in WBANs**

In wireless networks, the channel communication is through radio frequency which can be used by more than one network at a time. When more than one WBAN is trying to utilize the channel for transmission, there is a chance for interference to occur. In WBANs, possibility of interference increases in both intra-WBAN and inter-WBAN networks.

**Inter-WBAN Interference**

In inter-WBAN interference, the interference exists due to more than one controller trying to access the network to transmit the patient data available to the medical server. This kind of interference can occur when there is more than one patient wearing monitoring sensors in the close proximity.
Intra-WBAN Interference

Intra-WBAN interference occurs when all the sensor nodes in the WBAN trying to access the channel to transmit the patient’s data to the controller node.
Due to interference, there is a chance of important patient information being uncommunicated that needs immediate assistance. Interference can cause loss of data which cannot be tolerated in biomedical application. Several techniques have been adopted in the wireless network world. But, unfortunately these techniques are not applicable to WBANs. WBANs have unique features like limited sensor power, low range environments, mobility, and energy constraint makes it difficult to adopt existing strategies [13]. WBANs communication using 802.15.6 standard have high chances of interference due to sharing of the same ISM bands.
CHAPTER 3
TRANSMISSION SCHEDULING USING ADAPTIVE NEURO-FUZZY SYSTEM TO MINIMIZE INTERFERENCE IN WBANs

3.1 Literature Review

In [14], 802.15.6 standard has been used to address the interference problem in both inter-WBAN and intra-WBAN. For inter-WBAN, a QoS based preemptive scheduling method has been proposed. For intra-WBAN, a fuzzy inference method has been introduced.

In QoS based scheduling method, priority of the data is taken into account while scheduling the transmission. The transmission schedule is generated by the coordinator node in descending order of priority and published to all the sensors in the communication range. During the slot allocation, the higher priority data is assigned the first slot and so on. In case there are two transmissions scheduled in the same slot, the priorities are evaluated. The transmission with the lower priority is preempted from that slot. Hence, interference is minimized by considering the priorities of the data transmitted.

In Fuzzy Inference System method, the decision to schedule the transmission in the upcoming slot is decided based on Fuzzy Inference System output. The inputs to the system are three network quality parameters, and the output is whether to schedule, forward, or defer the transmission for the current slot. The 3 parameters considered are sensor signal to noise ratio, bit error rate, energy per bit to noise power spectral density ratio. Triangular membership function has been used in the Fuzzy logic system to map the inputs to either of the three possible outputs.
3.2 Proposed Scheme

In order to avoid or minimize the intra-WBAN interference, there is a need for good scheduling schemes. Intra-WBAN scheduling refers to scheduling the transmission of data from sensors within a single WBAN.

In this thesis, we propose a scheduling scheme to avoid intra-WBAN interference. The scheduling scheme is based on Fuzzy logic Inference system and Adaptive Neuro-Fuzzy Modeling system. We consider four network quality parameters to make a decision on scheduling. The decision is either to schedule, forward, or defer the transmission. We apply transference belief model to the decision obtained through fuzzy inference, so as to optimize the decision made.

3.3 Fuzzy Inference Modeling

As discussed earlier, Fuzzy Inference System is used to decide if the transmission needs to be scheduled or not on the current slot. The main advantage of using fuzzy logic is to solve the problem with linguistic as well as numerical data [15]. Fuzzy Inference Modeling is based on fuzzy logic to formulate input/output mappings. The idea of fuzzy logic is to consider the interval between true or false instead of using values true or false. Figure [3.1] shows the Zadeh’s fuzzy logic model.
We use the Mamdani Fuzzy Inference Model [16] in our work. In Mamdani model, the crisp inputs are fuzzified by mapping them to the degree of membership function. Once we have the fuzzy input sets, we apply fuzzy operators to form the rule base. Based on the inputs we give, an implication is applied to the rules which results in an output fuzzy set. Once we have all the output fuzzy sets, we aggregate the output to get the final result.

3.3.1 Fuzzy Inference Model for 4 parameters

For the 4 parameter model, we built a Mamdani 4 inputs and 1 output fuzzy system. With the help of this model, we give network quality parameters as input and obtain a decision to schedule the transmission or not. The inputs are delay, packet generation, SINR, and BER. The output can be any one of schedule, defer, or forward. Figure [3.2] is the model for 4 parameter fuzzy inference system.
In our model, we used triangular membership function which is the basic membership function. To form the rule base we used min AND and, max OR method. For the implication process, we used MIN implication method which is applied to all the rules we formed. To aggregate the output we have all the output fuzzy sets, we aggregate the output using MAX aggregation. Each parameter has a range of values or degree of truth assigned. The fuzzy input set for each parameter is as below:

Delay $\in \{\text{Low, Medium, High}\}$
Packet Generation $\in \{\text{Few, Less, More}\}$
SINR $\subseteq \{\text{VeryLow, Moderate, Required}\}$

BER $\subseteq \{\text{Least, Okay, VeryHigh}\}$

According to [14], the linguistic crisp output fuzzy set is as below. We are considering the same set of output decision in our work.

Decision $\subseteq \{\text{Schedule, Forward, Defer}\}$

Triangular membership functions are used to map the input value range to the fuzzy input set. For example, delay has 3 triangular membership functions for its input set, namely Low, Medium, and High. Figure [3.3] shows the 3 triangular membership functions for delay. Each membership function has 3 values a, b, c (a < b < c) that determine the bottom and peak of the triangle [17].

Once we have the membership functions set for all the inputs, we formed the rules using the AND, OR, or NOT operators. Fuzzy rules are formed based on IF-THEN statement logic that considers the linguistic input variables. For example, rules formed to decide if the transmission can be schedule, defer or forward using the 4 parameters can be written as below:

*If (Delay is Low) and (PacketGeneration is not More) and (SINR is not VeryLow) and (BER is Least) then (Decision is Schedule)*
Figure 3.3 MEMBERSHIP FUNCTIONS

If (Delay is Medium) and (PacketGeneration is not More) and (SINR is not Required) and (BER is Okay) then (Decision is Forward)

If (Delay is High) and (PacketGeneration is not Few) and (SINR is not Required) and (BER is VeryHigh) then (Decision is Defer)

These fuzzy rules are formed for all the combinations of input-output we have. The rules have an implication that results in an output set. All the outputs of the rules are aggregated at the end that gives us the desired single value output. The output is displayed as a graph plot with the inputs on X and Y axes mapped to the output. By using the fuzzy inference system process, we make sure that the decision made to schedule the transmission or not will help us in avoiding interference.
3.4 Transference Belief Model (TBM) using Adaptive Neuro-Fuzzy Inference System (ANFIS)

TBM is a variation of Dempster Shafer Theory of evidence. It doesn’t consider probability functions to model the uncertainty. The aim of TBM is to quantify the degree of belief [18]. In the process, TBM initially assigns masses to the belief, obtains belief function from the mass assigned and at the end it combines the belief functions by applying Dempster’s rule of combination. TBM is used in our work to strengthen the decision obtained using fuzzy logic.

As stated in [19] by Phillippe Smets in the process of conditioning, when a mass is allocated to a proposition and once there is a new evidence available and true for a subproposition B of A in future, then the mass m will be allocated to both A & B. The model gets m transferred from A to both A & B. The two major parts of TBM are allocating masses to the beliefs, and applying the rule of combination so as to combine two beliefs with different evidence. For example, given two belief functions bel₁ and bel₂, the belief function bel₁₂ resulting in the combination of the functions using Dempster’s rule of combination results in the equation below:

\[ m_{12}(A) = \sum_{X \& Y = A} m_1(X) \times m_2(Y) \]  

(3.4)

There are few axioms proposed by Phillippe Smets that lead to Dempster’s rule of combination. They further prove that in order to prove the Dempster’s rule of combining to be wrong, few of the axioms ought to be proven wrong.
3.4.1 Adaptive Neuro-Fuzzy Inference System (ANFIS)

ANFIS is an inference system which is a combination of neural networks and fuzzy logic. It has the ability to model the uncertainty of FIS and learning capability of neural network [20]. The framework is based on fuzzy logic, fuzzy rules and fuzzy reasoning. It has a layered architecture that has fixed and adaptive nodes in each layer. Below is the Figure [3.4] showing the architecture of ANFIS.

![ANFIS Architecture](image)

**Figure 3.4 ANFIS ARCHITECTURE**

**Layer 1**: In this layer, the nodes adapt the inputs to the membership functions. They can adapt to any of the membership functions. We have used triangular membership function in our work.

\[
\mu_{A_i}(x) = 1,2 \\
\mu_{B_i}(y) = 3,4
\]
Layer 2: In layer 2, the nodes act as a multiplier to calculate the firing strength of the rules. The output of this layer is
\[ w_i = \mu_{A_i}(x) \cdot \mu_{B_i}(y) \quad i = 1, 2 \]  

Layer 3: In this layer, the firing strengths calculated in the previous layer are normalized. The output of this layer is
\[ w_i' = w_i / (w_1 + w_2) \]  

Layer 4: In layer 4, the output is product of normalized firing strength and a polynomial.
\[ w_i'f_i \]  

Layer 5: In this layer, all the incoming outputs of layer 4 are summed up to get a single output.
\[ \sum_{i=1}^{2} w_i'f_i \]  

ANFIS makes use of an algorithm to tune the inputs to get the required output during the learning process. The output of ANFIS is always single. ANFIS is trained until a criterion is reached or until maximum allowable epochs is reached. In our work, we used ANFIS to optimize the output based on the input parameters.

We modeled 3 ANFIS models as a part of our work. The first model is for 2 input parameters delay and packet generation. The second model is for 2 input parameters SINR and BER. The third model is for 4 input parameters of delay, packet generation, SINR, and BER. For the 2 input parameter model, we considered 3 data pairs with 2 inputs and 1 output columns. For the 4 parameter model, we considered 81 data pairs with 4 inputs and 1 output column. Each input value is the mass assigned to the belief, the output is the weighted average of the input data pair. We used grid partition method to Generate FIS and Back propagation algorithm optimization to tune the input and output parameters for each model.
Grid Partitioning: The number of membership functions are 3 for all the inputs. The type of membership function selected is triangular membership function. The output membership function type selected is constant.

Hybrid Algorithm: The hybrid algorithm is a combination of least-squares and back propagation gradient descent method. It has forward and backward pass in each epoch of the training. This learning process uses least squares method in the forward pass and gradient descent method in the backward pass [21]. The consequent parameters in the layer 4 of ANFIS are updated in the forward pass using least squares method and the premise parameters in the layer 1 are updated using the gradient method. Thus the input parameters and their outputs are optimized using the hybrid learning process. We consider the decision we obtained using Fuzzy logic and optimize it using ANFIS modeling.
CHAPTER 4

SIMULATION & RESULTS

This chapter contains results that have been obtained in our decision making process. We used MATLAB Fuzzy Logic Tool box for the fuzzy inference system and MATLAB Adaptive Neuro-Fuzzy Inference Modeling for implementing TBM. The plots obtained are MATLAB graphs, depicting the process of decision making. We will also discuss in detail the network quality parameters that have been considered as the inputs to the system and the possible decision as an output.

4.1 Input Parameters and Output Decision

4.1.1 Delay

Network delay is a major parameter to be considered while transmitting data in a network. The more delay the network has, the longer it takes for the data to reach destination. Network delay is calculated by considering transmission, queuing, processing and propagation delay. Delay in transmitting data can be a major hurdle, especially in WBANs as delay in sending critical body signals can be dangerous while motinoring a patient.

\[
\text{Network Delay} = D_T + D_Q + D_P + D_{Pr} \quad \text{.............................................(4.1)}
\]

where \( D_T \) = Transmission Delay,

\( D_Q \) = Queuing Delay,

\( D_P \) = Processing Delay, and

\( D_{Pr} \) = Propagation Delay.

We have considered transmission delay in our scheduling scheme.
4.1.2 Packet Generation

More the packets are generated, more will be the probability of re-transmission due to packet loss. Packet generation is directly proportional to payload. The higher the payload the less is the packet generation for re-transmission [22].

4.1.3 Signal to Noise Ratio

SINR is one of the link quality parameters used to evaluate the quality of the link. The more the SINR value, better will be the quality of the link. As SINR decreases, there is a chance of having packet loss and bit error rate. It is defined as a ratio of Power of the signal divided by sum of power of Interference and background noise.

\[ S = \frac{P}{I + N} \]  
(4.2)

Where \( P = \) power of the signal \( I = \) Interference and \( N = \) background noise

In WBANs, not having required signal strength will affect the body signals to reach the coordinator node at the right time. Hence, SINR is a very important link quality parameter to be considered.

4.1.4 Bit Error Rate

Bit Error rate is the number of bits that have error from the bits that have been transmitted. It is affected by the signal strength of the network. More is signal strength, less will be the error bits in any transmission. In WBANs, transmitted data cannot be erroneous while monitoring a patient. There can be high priority body signals that need immediate attention.
Output Parameters

These input parameters were supplied to the fuzzy inference system and the output for transmission scheduling follows one of the three options below:

4.1.5 Schedule

If all the parameters are satisfactory which implies that the link quality is good, then the transmission is scheduled in the upcoming superframe.

4.1.6 Forward

If the input parameters are not very satisfactory which implies that the link quality is average, then the transmission is scheduled in the subsequent superframes whichever is available.

4.1.7 Defer

If the input parameters are below average satisfactory levels which implies that the link quality is poor, then the transmission is deferred to a later or unknown superframe.

4.2 MATLAB Fuzzy Logic ToolBox

For the implementation of fuzzy inference system and adaptive neuro-fuzzy modeling, we use MATLAB Fuzzy Logic ToolBox. It helps creating and modifying fuzzy inference system. The toolbox contains Fuzzy Inference System Modeling, Adaptive Neuro-Fuzzy Modeling, Data Clustering, Simulation and Deployment.
The Fuzzy Inference System Modeling helps us build Mamdani Inference System. Graphical User Interface tools in the below Figure [4.1] are used to build and view the inference system.

![Figure 4.1 GRAPICAL TOOL TO CREATE INference SYSTEM](image)

**FIS Editor**

FIS editor helps us to add/edit the input and output parameters.

**Membership Function Editor**

The membership function editor helps us to model each input and output parameter through the membership function plots. Triangular membership function has been used in our work.
Rule Editor

Rule Editor helps us to form IF-THEN rules to define the behavior of the system.

Rule Viewer

The rule viewer helps us to view and verify if the inference system is behaving as anticipated.

Surface Viewer

Once we are done creating the inference system, we can view the input vs output plot using the surface viewer.

Table [1] shows the numerical value range and the associated fuzzy level considered for each input parameter

<table>
<thead>
<tr>
<th>Input Parameter</th>
<th>Parameter Range</th>
<th>Fuzzy Range</th>
<th>Fuzzy Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>SINR</td>
<td>[0 20]</td>
<td>[-4.985 3.015 11.02]</td>
<td>Very Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[2.04 10 18]</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[9.05 17.1 25.1]</td>
<td>Required</td>
</tr>
<tr>
<td>Delay</td>
<td>[0 0.016]</td>
<td>[-0.004318 0.002082 0.008432]</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[0.001045 0.007445 0.01384]</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[0.008245 0.01465 0.02105]</td>
<td>High</td>
</tr>
<tr>
<td>BER</td>
<td>[0 6]</td>
<td>[-2.394 0.0003848 2.406]</td>
<td>Lowest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[-0.06377 0.07 4.736]</td>
<td>Okay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[3.6 5.85 8.4]</td>
<td>Very High</td>
</tr>
<tr>
<td>Packet Generation</td>
<td>[0 400]</td>
<td>[-115 25.1 165]</td>
<td>Few</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[-11.59 128.4 268.4]</td>
<td>Less</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[124 264 404]</td>
<td>More</td>
</tr>
</tbody>
</table>
4.3 Results

4.3.1 Fuzzy Logic Inference System

Initially, we worked on considering only 2 input network quality parameters to the fuzzy inference to come up with a decision for scheduling. Below are the results showing the fuzzy logic applied to come up with the decision.

**SINR vs BER**

![Figure 4.2 SINR VS BER (2 PARAMETERS)](image)

As per Figure [4.2], as SINR increases, the BER decreases. The decision of scheduling is to have the transmission.
Delay vs Packet Generation

![Figure 4.3 DELAY VS PACKET GENERATION (2 PARAMETERS)](image)

The Figure [4.3] shows the relation between delay and packet generation, and as packet generation increases the delay increases.

Once we have the 2 input parameter inference system, we modeled the inference system with all the 4 parameters. Below are the results of the decision after applying fuzzy logic. For 4 input parameter, the input to the FIS is a four dimensional vector with 2 inputs having NaN (Not a number) value which takes the linguistic variable as the input and the other 2 inputs are fixed numbers. Hence, the output shows 2 inputs and 1 output while it considers all 4 inputs to define the output.
**SINR vs BER vs Delay vs PacketGeneration**

The Figure [4.4] shows the inference system for 4 parameters, with 4 input parameters of Delay, Packet Generation, SINR and BER. The output is the decision to schedule, defer, or forward the transmission. The surface viewer in this case shows the plot for 2 parameters at a time. The drop down helps us select the parameters we need to select for the plot.
SINR vs Delay

As obvious from the plot in Figure [4.5], as SINR increases, delay decreases. SINR and delay has NaN, as the inputs which implies that the values for those two inputs are not a number. Varying linguistic variables are taken as inputs for those two inputs. The other two inputs BER and packet generation have numerical values as inputs which are fixed. 4 parameter inputs are considered with 2 numerical values and 2 linguistic fixed variables.
SINR vs BER

As you can see in the plot in Figure 4.6 when SINR increases, BER decreases. SINR and BER has NaN as the inputs which implies that the values for those two inputs are not a number, varying linguistic variables are taken as inputs for those two inputs. The other two inputs delay and packet generation have numerical values as inputs which are fixed. 4 parameter inputs are considered with 2 numerical values and 2 linguistic fixed variables.
Packet Generation vs BER

As seen in the Figure 4.7, as the packet generation decreases, BER decreases. Packet generation and BER has NaN as the inputs which implies that the values for those two inputs are not a number, varying linguistic variables are taken as inputs for those two inputs. The other two inputs delay and SINR have fixed numerical values as inputs. 4 parameter inputs are considered with 2 numerical values and 2 linguistic fixed variables.
Delay vs Packet Generation

![Figure 4.8 DELAY VS PACKET GENERATION](image)

As seen in Figure [4.8], as packet generation decreases, the delay decreases. Packet generation and delay have NaN as the inputs which implies that the values for those two inputs are not a number, varying linguistic variables are taken as inputs for those two inputs. The other two inputs BER and SINR have fixed numerical values as inputs. 4 parameter inputs are considered with 2 numerical values and 2 linguistic fixed variables.
Delay vs BER

As seen in Figure [4.9], as the delay decreases, BER decreases. Delay and BER have NaN as the inputs which implies that the values for those two inputs are not a number, varying linguistic variables are taken as inputs for those two inputs. The other two inputs SINR and packet generation have fixed numerical values as inputs. 4 parameter inputs are considered with 2 numerical values and 2 linguistic fixed variables.
4.3.2 Adaptive Neuro-Fuzzy Inference System Results

In ANFIS, we initially trained the data with 2 inputs and 1 output and then trained the data with 4 inputs and 1 output. Below are the results after the data has been trained accordingly.

Delay vs Packet Generation

For training the data, we considered 3 data pairs of 2 input and 1 output columns.

Figure 4.10 ANFIS DELAY VS PACKET GENERATION

The plot in Figure [4.10] above depicts the ANFIS surface viewer for 2 input parameters Packet generation and delay.
SINR vs BER

For training the data, we considered 3 data pairs with 2 input and 1 output columns.

![Figure 4.11 BER VS SINR](image)

**Figure 4.11 BER VS SINR**

The plot in Figure [4.11] depicts the ANFIS surface viewer for 2 input parameters SINR and BER.

**Delay vs Packet Generation vs SINR vs BER**

While training the data for 4 parameters, we have 4 input columns and 1 output column. The input to the fuzzy inference system is a four dimensional vector. The plots are for 2 parameters at a time. Hence we have many graphs for 4 parameter ANFIS. We considered 81 data pairs with 4
input columns and 1 output column. ANFIS automatically maps the data to membership functions and generates a FIS as per the data provided. The training dataset is as shown in Figure [4.12].

Figure 4.12 ANFIS TRAINING DATA SET FOR 4 PARAMETERS
Delay vs PacketGeneration

The plot in Figure [4.13] describes the output when packet generation and delay are selected as inputs. ANFIS also considers 4 dimensional vector as input with two fixed values and varying linguistic variable inputs for packet generation and delay.
Delay vs BER

The plot in Figure [4.14] depicts the output when BER and delay are selected as inputs. ANFIS also considers a 4-dimensional vector as input with two fixed values for SINR, Packet generation and varying linguistic variable inputs for BER and delay.
Packet Generation vs BER

The plot in Figure [4.15] demonstrated the output when BER and Packet generation are selected as inputs. ANFIS also considers 4 dimensional vector as input with two fixed values for SINR, delay and varying linguistic variable inputs for BER and Packet generation.
Packet Generation vs SINR

The plot in Figure [4.16] shows the output when SINR and Packet generation are selected as inputs. ANFIS also considers 4 dimensional vector as input with two fixed values for BER, delay and varying linguistic variable inputs for SINR and Packet generation.
SINR vs BER

Figure 4.17 ANFIS SINR VS BER

The plot in Figure [4.17] represents the output when SINR and BER are selected as inputs. ANFIS also considers 4 dimensional vector as input with two fixed values for Packet generation, delay and varying linguistic variable inputs for SINR and BER.
SINR vs Delay

Figure 4.18 ANFIS SINR VS DELAY

The plot in Figure [4.18] portrays the output when SINR and Delay are selected as inputs. ANFIS also considers 4 dimensional vector as input with two fixed values for Packet generation, BER and varying linguistic variable inputs for SINR and Delay.
4.4 Results Summary

The graphs shown in Figure [4.5] – Figure [4.18] illustrate the results generated using Mamdani Fuzzy Inference System and Adaptive Neuro-Fuzzy Inference System. Since the decision whether the transmission should be scheduled or not, is made based on the important network quality parameters, the chance of the transmissions colliding with each other reduces. Fuzzy logic has been used in our work as it is very flexible and is based on linguistic variable input and output. In addition to the fuzzy logic, transferable belief model has been used to model the input and output data to obtain improvised decision. The graphs show the decision made based on the input parameters.
CHAPTER 5
CONCLUSION AND FUTURE WORK

5.1 Conclusion

In our work, we addressed interference which is one of the major issues of WBANs. We approached resolving the issue by considering a transmission scheduling scheme to mitigate associated interference. Our work concentrates on providing a scheme to mitigate intra-WBAN interference. The proposed scheduling scheme uses fuzzy logic to deduce a decision for transmission scheduling. Important network link quality parameters like Delay, Packet Generation, SINR, BER have been considered as the source to come up with the decision. Transference belief model has been applied to the fuzzy logic part in order to strengthen the decision made. The fuzzy logic results show the scheduling decision based on the link quality which will help us reduce the interference with other co-existing sensor nodes. The ANFIS results show the input data trained using membership functions and back propagation algorithm. Fuzzy logic and ANFIS together have proven to be a great way to deal with uncertainty.
5.2 Future Work

The proposed scheduling scheme in our work considers important network quality parameters as signal to noise ratio, delay, packet generation rate and bit error rate. While these being major quality of service (QoS) parameters of the network, there can be important parameters of the sensors monitoring the data that require attention during scheduling. Sensor power and energy can be important factors to be considered.

In the present work, we depicted the relation between the input and output by training the data. A variation to the present work can be to predict the range of a third parameter, given the range of two parameters using ANFIS.

In our work, we considered mamdani inference system to keep the process simple. The method can also be implemented by using sugeno inference method. For the membership functions, we considered triangular membership function to assign the degree of membership to the input parameters. Other membership functions such as bell shaped, Gaussian, trapezoidal, etc can be used as membership functions.

The proposed scheduling scheme is only for intra-WBAN interference. In inter-WBAN, the interference is due to more than one WBAN existing in close proximity of each other. This approach can be extended to inter-WBAN interference.
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