Ant-Colony based Energy Efficient Routing Technique for Wireless Body Area Networks

THESIS

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CERTIFICATE

This is to certify that the thesis entitled **"Ant-Colony based Energy Efficient Routing Technique for Wireless Body Area Networks"** and submitted by **Rakhee** ID.NO. **2009PHXF0042H** for award of Ph.D. degree of the institute embodies original work done by her under my supervision.

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Dedication

To

To Almighty God, who is the source of life, strength of knowledge and wisdom.

My Late Grand Parents, who always wished me to reach the sky.

My Mother, for her over-decades cultivating and enduring love.

My Father, who always takes me as his best pride.

My Husband, who always encouraged in his best.

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Abstract

Wireless Sensor Networks (WSNs) have applications in a range of fields as wide as military, environment and health monitoring, etc. A typical sensor network can have a few or several nodes deployed in a region for remote monitoring of events or parameters and send the same to a base station. They are usually ad-hoc in nature and have constraints in terms of processing power, memory and energy etc. Wireless Body Area Networks (WBANs) are a type of WSN where sensors (such as for temperature, pulse rate etc.) are mounted on the body of the patients and the corresponding data is acquired and monitored remotely. This may happen either within or outside a hospital setting. The aggregated data thus collected is sent to a base station (typically a server) for further processing.

The parameters of interest in WBANs are energy consumption, network lifetime, latency and throughput. A significant amount of work has been done to improve one or more of these parameters to increase overall functioning of the WBANs. Efficient routing protocols and methods have been proposed, primary objective of which is to conserve the energy leading to increased lifetime of the network. Results reported in the literature indicate that these protocols have achieved their objective of reducing the energy consumption during the data transmission to some extent. Their limitations, however, are that the load distribution among the nodes is not effective as well as recovery from route failures due to the presence of dead nodes was limited.

In this thesis, we propose a technique based on ant-colony algorithm for data routing in Wireless Body Area Networks for improved energy efficiency leading to a better network lifetime. The adaptive nature of the ant-colony algorithm also helps in route maintenance in the routing table of a given node. During the route

discovery, the algorithm ensures that it balances the load at every node so that congestion doesn't occur at the base station.

Further, the proposed technique is extended by including a modified cluster based approach to achieve improved energy efficiency in WBANs. In this method, clusters of devices are formed and data is routed through the cluster heads to minimize the load on the intermediate nodes. This helps in reducing the routing overhead in the network by minimizing the number of transmissions and duplication of the packets sent to the base station. A cluster head probability function is defined and shortest path is calculated using a cost function.

Additionally, the well-known Breadth First Search (BFS) method is employed to avoid trapping situations within the network and also search level by level in order to check if all the nodes have been visited at least once, by checking the quality of the ant's trip.

A series of simulations have been performed on the popular WSN simulator OMNeT++ to prove the effectiveness of the proposed approach.

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Chapter 1

Introduction

Wireless Sensor Networks (WSNs) have been proposed during the last decade with the main objective of creating intelligent technology by sensing, processing and communicating remote sensors data further to a central node, frequently called the base station. Body Area Networks (BANs), a special realization of WSNs, is a network of small wireless devices that are mounted/implanted on/inside a human body. These devices transmit their data to a sink device called a Body BAN Coordinator which is responsible for delivering the sensor data information to the destination i.e. the base station.

WBANs have been deployed in a variety of scenarios and their performance has also been studied. However, there have been very few instances where they have been evaluated in a hospital environment. In this work, we extend the scope of WBANs to include hospital scenario which involves patients whose vitals may need to be monitored and sent to a nursing station server wirelessly. Such a situation is more important in an ICU where vitals of a large number of patients need to be monitored, displayed locally and also communicated in real time.

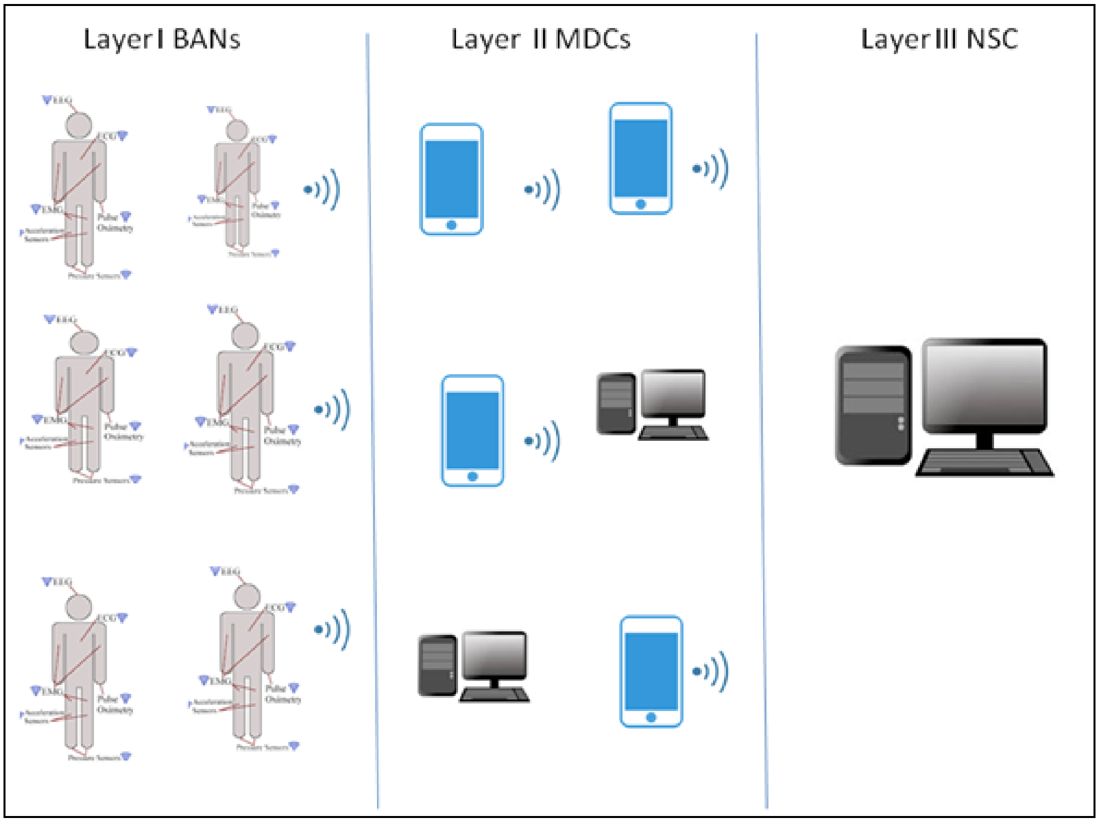


Figure 1.1: WBAN in a Hospital Environment

Figure 1.1 illustrates a typical scenario in a hospital environment. Layer I consists of WBANs while layer II has MDCs (Medical Device Coordinators). Layer III is NSC (Nursing Station Coordinator) where the data needs to be sent. While WBAN is mounted on patient's body and powered by batteries, MDCs are also powered by batteries since they may move with the patient. Only the NSC is powered by the ac power.

Data collected by the WBANs is sent to NSC through the MDCs which need to find an appropriate route through their network to reach the NSC. Since MDCs are also battery powered, it is important that routing of data should be such that the network consumes as little energy as possible while also ensuring that its throughput and latency are not affected.

In this work, we explore the application of Ant-colony algorithm for data routing in WBAN in indoor hospital environment in an attempt to minimize the network energy thereby possibly increasing the network lifetime. Soft computing techniques like ant-colony algorithm is used to search for an optimal path in a network. These techniques may help in finding solutions that are closer to optimal if not completely optimal. Ant-colony algorithm has been successfully applied for routing in WSN and in this work we attempt to apply the same for data routing in WBAN in a hospital environment.

1.1 Neighbor Discovery, Data Routing and Shortest path in WBANs

Body Area Networks (BANs) provide a variety of services in different applications which include medical and consumer electronics. It is possible with a set of tiny sensors that are connected in-body or on-body. The major feature of WBAN is that it can provide real-time un-interrupted monitoring of vital as well as other parameters with the help of these sensors. Various applications of BAN are depicted in Figure 1.2.

BAN communication has very limited range of transmission and non-interference with other electronic or medical devices. It also has low data rate in order to ensure low energy consumption for reliable transmission of data with low delay. Also, numerous routing protocols have been proposed from time to time to improve the reliability and energy efficient communication between the sensor nodes in a WBAN.

Figure 1.2: Various Applications of WBAN

1.2 Major Issues and Challenges in Neighbor Discovery and Data Routing in WBANs

In WBAN, due to its size and limited energy resources, the effects of noise, interference and fading limit the bandwidth. Thus it sends the data to the central node/coordinator through other nodes that are capable of doing multi-hop to the desired destination. Therefore, any energy efficient routing protocol should attempt to find and manage alternate routing paths in case of node failure.

Different techniques are used for sending the data from sensor nodes to the coordinators/destination node. Hello Packets are typically used by the routing protocols to maintain the routing table of the nodes. Since broadcasting of Hello Packets can cause consumption of energy in the network, reduced energy consumption is a basic requirement for any routing protocol. Also, the routing protocol needs to consider the location and available energy of the neighbor node for the selection of a route which has the shortest path. Thus, energy efficient routing protocols have been designed to improve data aggregation, reduce redundant transmissions at the node and minimize the traffic load.

Existing protocols address routing by controlling who broadcasts the Hello Packets thereby reducing the number of Hello Packets broadcast. A majority of the transmissions in a network however are due to Hello Packets that provide neighbor discovery information and routing paths for data transmission. This process is continued until the packets find the destination node. It however requires a large number of computations and does not provide the shortest path or minimum hop distance from a sensor node to reach the base station.

Further when a node in a network fails due to, say, lack of power, alternate paths need to be found for data routing in an adaptive fashion. Otherwise, node failures result in a high end-to-end delay in networks such as WBAN. Cluster based techniques for data aggregation have evolved to ensure that there will be load balancing among the nodes. These techniques help to connect to the base station without level by level processing in case of node failures.

Finally, while finding a minimal route in a network, it is also important to ensure that complete coverage of the network is effected. BFS (Breadth First Search) is one algorithm which helps to check if all the nodes in a network are covered while the shortest path is being explored from source node to the destination node.

1.3 Motivation

Routing in WBAN is a challenge that needs to be addressed for practical realization of the network. It is compounded due to the complexity of a large scale network with its dynamic nature, resource constraints and so on. Finding the shortest path in WBAN during routing can help to optimize the communication and computation overhead. Any efficient routing algorithm based on a soft computing technique like ant-colony for heterogeneous architecture helps in solving adaptive to varying environment as well as able to learn and evolve itself whenever network conditions are varied. Such a technique will also be able to self organize in a fully distributed fashion.

1.4 Scope of the work

The scope of WBAN work extended to indoor hospital environment where more number of patients exists and they are continuously monitored by the sensors mounted on human body and further transmit the data to the central device called base station. Such a situation is more useful in an ICU where more patients monitored real time data continuously and sent to base station in a coordinated way. Routing in WBAN is most important for uninterrupted monitoring of data transmission. The proposed routing algorithm using ant-colony technique addresses the issues pertaining to the route discovery of the node during construction phase while checking its reliability and intensity of the path from source to destination by achieving increased network lifetime and reduced energy consumption by using ant-colony technique and also clustering method for less consumption and reduced participation of the nodes in the network which outer performs better than the existing algorithms.

1.5 Contributions of the Thesis

This thesis tries to address the issues pertaining to data routing in WBANs operating in a hospital environment.

1. The first contribution of the thesis is the application of ant-colony algorithm for data routing in WBANs. It involves neighbor discovery, workload balancing among the nodes, etc. while finding the shortest path from the source node to the destination node. Unlike other techniques, our approach computes only the probability of choosing the next hop node based on pheromone value (explained in Chapter 3) and energy of the node. The route selected is based on the value returned by a cost function.

2. The second contribution is the modification of ant–colony algorithm to include clustering of the nodes on lines similar to LEACH algorithm. This approach helps to handle node failures that lead to link failures during data routing. A function called cluster probability function is introduced to form clusters of nodes and choose a cluster head as explained in Chapter 4.

3. The third contribution of the thesis is to combine the Breadth First Search (BFS) technique with ant-colony algorithm to ensure complete network coverage while the ants traverse from source node to the destination node. BFS technique helps to avoid trapping during the route discovery based on quality of ant's trip as described in Chapter 5.

   Network performance has been studied in all the above instances and detailed comparisons with existing work have been made, as reported in subsequent chapters.

1.6 Thesis Outline

In this thesis,Chapter 2 briefs about the state-of-the-art in WBAN related to the work. Chapter3 explains how the ant-colony algorithm is employed initially to find the shortest path for data routing in WBAN in a hospital environment. This algorithm is then modified to include the clustering technique and its effect on data routing is studied in Chapter 4. Finally, BFS is included in the modified ant-colony algorithm to ensure complete network coverage and influence of the same on data routing in WBAN is investigated in Chapter 5. A detailed comparison of these techniques with those reported in literature in terms of their effect on network performance is also provided. Conclusions are drawn and directions for future work are given in Chapter 6.

Chapter 2

Literature Survey

This chapter reviews the state-of-the-art in WBANs as related to the work reported in this thesis. Several routing protocols have been proposed for data routing in WBANs deployed in hospital environment that use conventional methods for achieving energy efficiency of the overall network operation. The major function of WBAN is that it can provide real time uninterrupted monitoring of vitals transmitted to the base station. Routing of data should be such that the network consumes a little energy as possible while also ensuring that it has high throughput and less latency etc. Typically network lifetime, latency, energy efficiency and reliability of data transmission are the most important criteria in these networks. An energy efficient routing protocol should attempt to find and manage alternate routing paths in case of route failure.

2.1 Routing Protocols in WBAN

Authors in [1] presented a review on going research WBAN in terms of system architecture, address allocation, routing issues, channel modeling, physical layer, MAC layer, security and applications. In this difference between WBAN/WSN and other technologies were presented.

In [2], authors propose a priority-based routing protocol for normal and critical data transmission by considering both single and multiple-hop communications. Routes are selected on the basis of minimum-hop count which reduces the delay in transmission. Authors in [3] designed a thermal-aware energy efficient routing protocol based on mobility. It finds an alternate path in case of hot-spot detection. They incorporated direct communication for real time or on-demand data while choosing multi-hop communication for normal data transmission. Incremental cooperative communication proposed in [4] was found to be more reliable than direct communication. Simulations carried out in OMNeT++ have shown to find optimal distance from source to destination. A survey carried out in [5] explains in detail the investigation of sensor nodes, physical layer, data link layer of WBAN.

An energy efficient routing protocol for WBANs is proposed in [6] that utilizes threshold approach to preserve the energy of sensor nodes. Authors in [7] proposed an energy preserving protocol that utilizes multi-hop communication in WBAN. In this protocol they formulated a cost function to select intermediate nodes with high residual energy and minimum distance from sink. WBAN is usually a single-hop star network but work reported in literature shows multi-hop cooperative relaying improves the performance of WBANs. In [8], authors focused on cooperative transmission for implanted sensors. Spatial diversity of multiple terminals is exploited to reduce total power consumed by the implanted sensors.

Opportunistic Large Array(OLA) is proposed to preserve the energy of nodes.

Cooperative WBAN protocol [9] extends the MAC layer to cross-layered gradient which supports multi-hop communication. In [10], several approaches for multi-hop cooperative are proposed to increase the lifetime of WBANs. Path loss parameters and time domain channel characteristics are obtained from the measured and simulated data. Sitting posture of humans is considered in [11] to study the on-body radio propagation in time-domain UWB channel. Reduction of bit error rate and improvement in network lifetime of WBANs is achieved in [12] using mobile device cooperative communication.

In [13], authors tried to improve the packet error rate probability by using multi-hop links instead of direct link using decode and forward protocol. They tried to address the problems in multi-hop mesh topology using time-varying fully connected network. Authors in [14] focused on improving the reliability of WBANs using Cooperative Network Coding in feed forward architecture. In this, packets are transmitted in spatially distinct paths which improved network throughput.

The authors in [15] GMFP (greedy minimum energy consumption forwarding protocol), considered distributed forwarding criteria for node selection that minimises transmitter and receiver energy consumption along with maximizing Euclidean distance. This protocol also extended maximising lifetime by considering the optimum forwarding node in LM-GMFP (Lifetime maximising GMFP) by combining distributed power control and interference aware forwarding technique in [16]. Similar work in [17] presents a meshed multipath routing based on selective forwarding hop by hop based on the conditions of downstream forwarding nodes.

Performance of cooperative relaying schemes improved the robustness of WBANs as reported in [18] . This is achieved by selecting a few sensors to provide redundant links for other nodes having worst channel conditions. In [19] authors focused on the problem of optimal power allocation with the constraint of targeted outage probability. In [20] a new protocol is used to determine the link performance of the sensor which records data and traffic lost for different transmitter locations around the human body.

Authors in [21] proposed a framework for the estimation of network lifetime of WBANs. Health Monitoring Network (HMN) is created and probabilistic analysis is used to determine the timing and distribution of time failure in the HMN. Virtual groups are formed between devices of patients, nurses and doctors to enable remote monitoring of WBAN data [22]. Quality of health is also introduced to provide feedback received by WBAN. A Zigbee based wireless patient monitoring system reported in [23] is based on reliable any cast routing protocol in which the mobile sensor nodes select the closet sink to forward their data. This reduces the number of control messages with fast rerouting and also latency by intermediate routers during route discovery process.

Scheduling problem of data transmission is analyzed in [24] to make use of sleep mode and opportunistic transmission for better energy efficiency. Authors introduced a MAC protocol for WBAN in [25] utilizing low cost wake-up radio module to prolong the network lifetime by reducing power consumption in idle state and increasing the sleep time of the sensor node.

"Anybody" [26] is a data gathering protocol based on self organization in which sensors attached to a person are grouped into clusters which reduces the number of direct transmissions to the remote base station. It uses LEACH routing protocol [27] that randomly selects a cluster head at regular time intervals. The cluster head aggregates all data and sends it to the base station. This protocol solves the problem by changing the cluster head selection and constructing a backbone network of the cluster heads. Energy efficiency is not thoroughly investigated and reliability is not considered. HIT (Hybrid Indirect Transmissions)[28] is an improvement over LEACH, that combines clustering by forming chains. This improved energy efficiency but reliability is not considered.

Many projects such as SMART [29], CareNet [30], AID-N [31], ALARM-NET [32] have been proposed to monitor patient data. All these have the mechanism to collect and send data to the base station. The major drawbacks with these projects are traffic congestion and database server or link failure which can cause delay in transmitting patient data. To address all these issues a new BAN network architecture and routing protocols for energy efficiency have been introduced. The ZKBAN [33] peering framework is designed to display in real-time BAN data which discover a dedicated BAN data display dynamically. These protocols use centralized and distributed schemes of communication.

2.2 Related work

Wireless Body Area Networks (WBANs) are expected to create a high impact in providing advanced healthcare. As per IEEE 802.15.6 working group notes, BAN communication is based on a hierarchical model with multiple tiers. The communication architecture consists of three tiers called BANC (Body Area Network Coordinator), MDC (Medical Display Coordinator) and NSC (Nursing Station Coordinator) as shown in Figure 2.1.

In tier 1, wearable or implanted sensors send data to the coordinator called BANC. In tier 2, the BANC data is sent to the peering MDC and in tier 3, all the central-

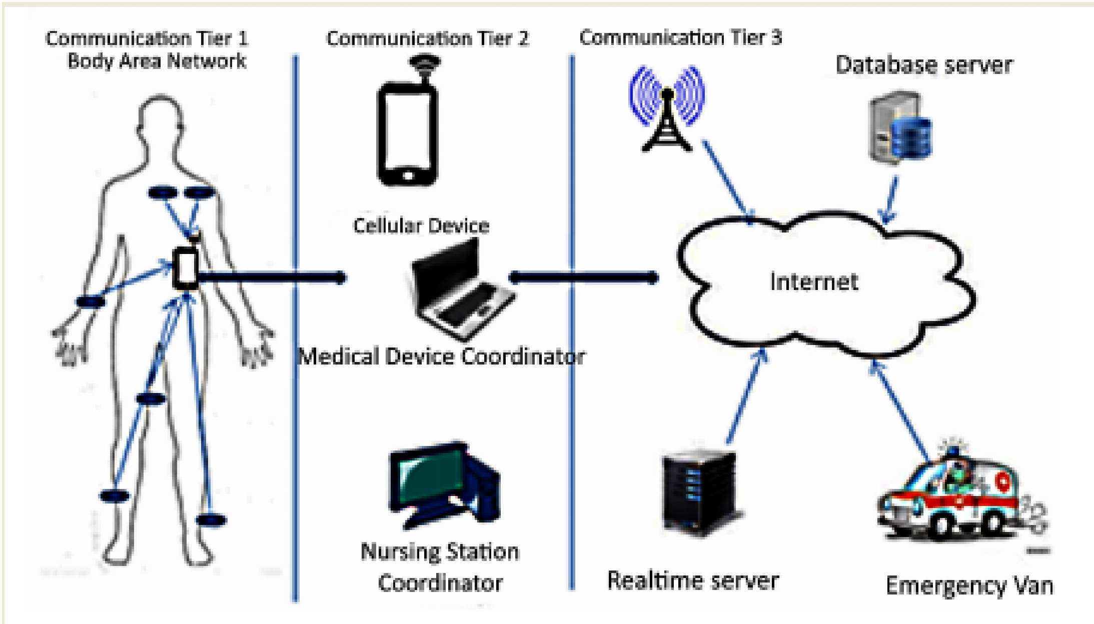


Figure 2.1: General Architecture of WBAN (IEEE 802.15.6)

ized data is stored at NSC. In an indoor hospital scenario, every patient's BAN needs a unique MDC for displaying patient's data and to send the same to the NSC which is the destination node. Communication of the data packets plays a vital role in WBAN since it consumes energy of the sensor nodes but which can be optimized by finding the best route. Finding best route also addresses other important issues such as latency, throughput, energy consumption and network lifetime. Work reported in [33] concerning indoor hospital environment uses centralized and distributed mode of communicating the BAN data packets that are sensitive and critical.

The challenges related to the management of patient's medical information and intelligent continuous monitoring of BAN data in hospital environment are discussed in [43]. Two communication tiers are used to send the data from body sensors to the base station [30, 43]. SMART [29] provides a description of monitoring system for indoor hospital environment but it covers only the emergency rooms. Recognition of body movement using sensors is discussed in [44, 45] while security based assistance during hospitalization is addressed in [46].

ALARM-NET [32] proposed a solution for living and residential monitoring of patients. The purpose of this work was to collect and analyze BAN data at central base station. However the availability of real-time BAN data in indoor hospital environment was not addressed. EPR (Energy-aware Peering Routing Protocol) [33] addressed energy consumption and QoS requirements for indoor hospital environment but not data routing when traffic congestion or link failure occurs which can cause delay or stop routing the data completely. Earlier work [29, 47, 48] used only centralized approach for monitoring the patient's data but failed to work for routing when there is no connectivity with central base station. Many researchers have proposed BAN network architecture by combining or splitting the BAN in inter-BAN communication but they did not address real-time routing of BAN data in indoor hospital environment [49, 43, 50].

2.3 Limitations of ZKBAN Peering Framework

In EPR(Energy Peering Routing) protocol is a part of ZKBAN peering framework discussed in [33]. In this protocol, a number of transmissions of Hello Packets is broadcast, which is maximum at every stage in order to discover its neighbor for the construction of routing table and neighbor table. The BAN devices are selected as next hops which are not capable of storing such large tables of information about their neighbor. It consumes more energy if BAN devices have chosen as next hops for data transmission. Thus resulting increase in overhead and hence performance of the overall network degrades. As a result, the workload of the intermediate nodes is not balanced due to which the lifetime of the network decreases. This leads to dead nodes in the network which results in reduction of effectiveness of BAN network. The drawbacks of the existing approaches are:

i) selecting a best neighbor node

ii) choosing an alternate path

2.4 Shortcomings in Energy Conservation of the network

In EPR Routing Protocol algorithm [33], energy is not conserved during construction of routing tables and neighbor tables. Optimizing the energy consumption of the sensor nodes as well as reduce number of nodes participation increases the overall network which is an important task when designing and routing of the sensitive and critical data of WBAN. Any changes in the topology don't help in updating the routing tables stored at each node in the network along the path. Routing discovery, route maintenance and route failure is not been addressed with respect to energy conservation in EPR algorithm [33] by using clustering process.

2.5 Routing data using Breadth First Search

The goal of WBAN has become prominent in health care field by deploying the sensors for given task to monitor a set of targets. Whenever the mode is in centralized mode of communication, it sends one message from one central node to all other nodes. Such an operation is called broadcasting which is used in scenarios like network discovery process, network configuration and routing processes. During this process, they consume more energy. Hence, in order to provide an efficient solution for the broadcast problem with consideration of energy consumption is an important issue in Wireless Body Area Network. As transfer rate of packets to the base station increases, starvation happens which results in failure of the nodes which may effect the network lifetime. Hence, Breadth-First Search (BFS) is a graph search algorithm used to explore the nodes in all directions from source to destination in all levels depending upon the transmission range.In [34] routing is through Ant Colony technique with BFS addressed to improve link failures but quality of ant's has not been addressed which is important for the routing of data.

Chapter 3

Data Routing in WBAN using Ant-Colony Algorithm

3.1 A Soft Computing Approach for Data Routing in WBAN

In this chapter, we propose a soft computing model for data routing in WBAN in an indoor hospital environment. Such an environment represents a situation where a large number of patients exist and the data traffic generated rapidly changes over time. The methodology we employ to find the shortest path is based on ant-colony algorithm described in the next section.

3.2 Ant-Colony Algorithm

Ant-colony algorithm is a meta-heuristic search algorithm for problem solving that takes inspiration from the behavior of real ants. The basic idea of this method lies in the fact that communication among the individuals in an ant colony happens based on the pheromone trails that are used for communicating with other ants. This approach has been applied successfully to a number of different combinatorial optimization problems [35] such as Vehicle Routing [36], Traveling Salesman [37] , and routing in communication networks such as AntNet [38] , Mobile Ants Based Routing (MABR) algorithm [39], ARA[40] , ARAMA[41] and AntHocNet[42].

Ant-colony based techniques take inspiration from the foraging behavior of ant species which deposit pheromone on ground in order to mark favorable paths that should be followed by other members of the colony. An individual ant is a simple insect with limited memory capable of performing simple tasks. An ant-colony expresses a complex collective behavior providing intelligent solutions to problems such as finding shortest routes from a nest to a food source, etc.

Ant-colony method exploits a similar mechanism like other techniques for solving the optimization problems.It builds a solution to the problem being solved by moving concurrently and asynchronously on a construction graph which represents any given domain. It differs in the way of solution construction, pheromone updating and possible interactions in the solution process [35].

In this work, an attempt has been made to apply the ant-colony algorithm to WBAN network in a hospital environment where continuous data is transferred to the destination and a number of nodes exist in the network while the traffic rapidly changes with time.

Conventional problem solving methods are difficult in such a scenario because when the traffic changes rapidly, the information obtained from an old search may not be helpful. In what follows, we explore how ant-colony based approach can help find a solution to such problems.

3.3 Motivation

As mentioned earlier, ZKBAN [33], used both centralized and distributed approaches in order to address the issues pertaining to traffic generated and energy consumed. This routing protocol was designed to display the real time monitoring of BAN data to a dedicated machine. These two communications were most effective in transferring the data wirelessly. If any data has to be sent from one node to another node, it must go through central computer called NSC. This device has the capability of storing the information of the nodes but the disadvantage is increased energy consumption and network traffic. Due to this reason, a dedicated device called Medical Device Coordinator (MDC) was assigned to each BAN to store its data timely instead of sending to NSC all the time. Every BANC has to find its nearby MDC to send its data continuously. This distributed approach helps the network to use minimum energy and traffic load is reduced because there is no need of sending the data directly to the NSC. The BAN gets its peering information from the NSC and then sends the data directly to the associated MDC unit.

ZKBAN uses two types of communication i.e. point-to point and point-to-multipoint. It is a hierarchical model with three communication tiers with sensors on the body either implanted or wearable that send data to the BAN Coordinator (BANC).

Table 3.1: Classification of Devices in a Hospital Environment

Class	Device name	Power Source	Channels	MAC Protocol	Mobility
1	NSC	Directly Connected	2	IEEE 802.15.4 IEEE 802.11	No
2	MDC	Replaceable batteries	2	IEEE 802.15.4 IEEE 802.11	Yes
3	BANC	Limited Energy	1	IEEE 802.15.6	Yes

The BANC forwards its information to MDC timely which is in tier 2 and finally as per demand to tier 3. Point-to-point (p-p) means the BAN information sends its packets to the next hop for a single destination i.e. only one MDC or NSC. Point-to-multipoint (p-mp) sends data packets to the next hop for multiple destinations. Table 3.1 refers to the classification of devices used in the hospital environment [33].

In what follows, we briefly describe the centralized and distributed modes of communication.

3.3.1 Centralized Method

In centralized method, there is a central entity which regulates the usage of time and frequency resources among the coexisting networks. In [51], authors proposed a mechanism in which a resource allocator server receives requests from Wireless Personal Area Network(WPAN) coordinators and allocates resources to them.

In this mode [33], the BANC connects to the NSC to obtain its dedicated machine MDC's information. Such information is provided to patient's BAN when he/she registers at the registration desk. The nurse provides the basic information to the BAN such as its BAN ID, device type and its peer's ID. The nurse decides as per the patients data whether it should be p-p or p-mp. If the nurse enters for a particular patient that communication type is p-mp for B_3, then its peers would be $MDC_3 - ID$ and $MDC_2 - ID$. All the information about BANs and MDCs is stored in the NSC table for further communication and data privacy. Thus the drawback with centralized method is that it leads to additional energy consumption of the nodes which are far away from the NSC.

3.3.2 Distributed Method Of Communication

In distributed mode [33], the BANCs find and send data to their respective peers like $BAN_1 - ID$ to $MDC_1 - ID$ and $BAN_2 - ID$ to $MDC_2 - ID$, etc. In the ZKBAN framework [33] , all the nodes in the indoor hospital are divided into three types, T1, T2, and T3. NSC belongs to Type 1 device which is connected directly to the power source. MDCs are Type 2 device which are battery replaceable with more memory and which act like nodes with higher energy that are capable of storing more data for transmission. BANs belong to Type 3 device with limited energy.

ZKBAN approach addressed the shortcomings of the DMQoS (Data-Centric multi objective QoS aware routing protocol) protocol [49]. The disadvantage of DMQoS [49] is that it sends Hello packets continuously causing increased network traffic and energy consumption. This is addressed by ZKBAN peering framework by considering different device types like NSC, MDC and BAN as next hops by controlling the broadcasts of the Hello Packets. It also proposed a peering mechanism of sending Hello Packets regarding whom and when to send which greatly reduced the number of Hello Packets. This method considers the neighbor with shorter distance, lower device type and higher residual energy in choosing the next hop node. These factors reduced the overall network traffic load and energy consumption within the network.

QoS-aware Peering Routing Protocol for Delay-sensitive data(QPRD) packets [52] has been considered and investigated by comparing with DMQoS Protocol in [49]. The disadvantage of this approach however is that only the delay information of the neighboring nodes is considered by the source node. The source node forwards the packet to a particular node which has lower node delay than the required delay. This causes an increase in the overall network traffic, and the required end-to-end latency may not be guaranteed. QPRD [52] addresses these shortcomings by selecting and choosing the next hop device based on the lowest end-to-end path delay from the source node to the destination. This approach calculates the node delays and path delays for all possible paths from the source node to the destination node, determines the best path and chooses the best next hop based on the delay requirements.

QPRR (QoS-aware Peering Routing Protocol for Reliability-Sensitive Data) [53] tries to improves on the reliable delivery of the critical BAN data at the destination. This method deploys and uses both centralized and distributed means of communication. In this technique however there are chances that the source node sends the packets to the neighboring node with highest reliability, but the neighboring node may not find the required reliability among its neighboring nodes resulting in dropped data packets. In this case the source gets acknowledgment from the neighboring node that the packets are successfully transmitted but in reality the packets are dropped by the upstream nodes instead of being forwarded to the destination. QPRR addresses these shortcomings by considering a low transmit power by choosing the next hop device based on the most reliable end-to-end paths from the source to the destination.

In the background of certain issues with the existing protocols in this work, we explore how a soft computing technique like Ant-Colony technique is deployed for data routing in WBANs.

3.4 Routing in WBAN Using Ant Colony Algorithm

The ant-colony algorithm is inspired by the ant food foraging intelligence where routing is done using exploration and updation locally and globally. Authors in [54] provide an extensive survey of application of this algorithm for routing in networks. When a source node has data for passing to the destination node it starts sending ant-like packets analogous to ant foragers which are used to find new paths locally. Artificial pheromone is laid on communication links between the adjacent nodes and route reply and data packets are inclined towards strong pheromone based on a probabilistic function.

3.4.1 General Procedure

The general procedure of the ant-colony algorithm as applied to WBAN being considered in this work is shown in Algorithm 1. The shortest path from the source to the destination includes all the BANs and MDCs. Ants start from the source node and the construction phase (a phase during which path discovery is made) gets terminated as they reach the destination. Solutions are constructed using the algorithm that restricts the set of accurate paths according to the pheromone and the heuristic information gathered by the algorithm.

3.4.2 Constructing a tour using the Ant-Colony algorithm

The route of the visiting BANs and MDCs is constructed and the paths between MDCs are planned by the algorithm. It terminates when it finds a solution within at-least a predefined optimal solution quality or a maximum number of algorithm iterations has been reached or shows a stagnation behavior.

Algorithm 1: General Procedure of Ant-Colony Algorithm in WBAN

```
Inputs: s, d, α, β, NC_max
Initialization: For every edge (i,j), τ_ij is constant for trail intensity
 △τ_ij ← 0 // Edges are initialized with some constant trial Initialize each
 ants visited nodes list 'VL' with 1 for source BAN 's'
 0 for other nodes(BAN'S , MDC'S) L =s;
// for each ant SL=s;
NC←1, Slen←0,l←0;
while NC < NC_max||stagnation not behavior observed do
    for  k=1 to m do
        // m is number of ants started from source BAN 's'
        while current node ≠' d'|| neighbor nodes of current node are 1 in
         list 'VL' do
            ant at current node 'i'(BAN or MDC) chooses next node 'j' (
             MDC) with probability p^k_ij ;
```

$$P_{ij} = \frac{(\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta}}{\sum\limits_{l \varepsilon U} (\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta}} \tag{3.1}$$

```
            add node 'j' to a list 'L';
            Update the list VL ;
        if current node == d then
            // required MDC or NSC is reached
             pheromoneLocalUpdate(k,L,l);
            updateShortestPath(SL,SLen,L,l);
pheromoneGlobalUpdate();
 NC ← NC + 1;
 Nullify the updates of list 'L' of each ant;
Nullify the updates of list 'VL' of each ant;
For every edge (i,j) set △τ_ij ← 0;
```

In this Algorithm 1, ‘i’ is the current node of a path and Visited List (VL) is a set of visited nodes by the ants. Ants start from the current node location of the network and construct a route to the destination, MDC or NSC. When the ant ‘k’ is at the node ‘j’ in constructing a route, next hop is selected based on the probabilities for all the neighboring nodes calculated using the Equation 3.2 given below:

$$P_{ij} = \frac{(\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta}}{\sum\limits_{l \varepsilon U} (\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta}} \tag{3.2}$$

Where

τ_{ij} is pheromone trail of combination (i,j)

η_{ij} is local heuristic of combination (i,j)

P_{ij} is transition probability of combination (i,j)

α is relative importance of pheromone trail

β is relative importance of local heuristic

In conventional methods, paths connecting each pair of sensor nodes are calculated while running the algorithm [52]. In the proposed method however we calculate the paths individually when they initiate for the first time. This approach helps in updating the candidate lists that include only the promising neighbors to participate, thus reducing the minimum number of nodes that participate. This leads to increasing the lifetime of the network.

3.4.3 Implementation of Ant-Colony Algorithm for Routing in WBAN

In this work, as mentioned earlier, the ant-colony algorithm is employed for BAN communication with MDCs in a hospital environment. The scenario in a hospital has already been described in Chapter 1 Figure 1.1. The main objective of the algorithm is to find a path between a BAN and an NSC taking into consideration the following two factors:

1. Shortest path
2. Minimal energy consumption

The procedure is as shown in Algorithm 1 mentioned earlier. To begin with, the network is initialized, with a constant pheromone trail τ_{ij}, on each connection between BANs and MDCs that are selected using a probabilistic function based on their pheromone and energy values at each node. Whichever node has the highest probabilistic value, that node is chosen as the next hop. Source BAN is designated as 's' and the destination MDC as 'd'. α, β are initialized with standard values whereas the heuristic values should be admissible to search problem. 'm' is the number of ants that started at source BAN. Each ant from the current BAN 'i' hops to the next MDC 'j' according to the probability function given by Equation the 3.2. 'L' is a list carried by each ant that contains the BAN IDs of devices in the path traversed by it while keeping track of the visited devices in list 'VL'. 'l' is the length of the path.

When all the ants have completed the tour, the shortest path is the best of all the paths taken by all ants after a few iterations. The list 'SL' is initialized with shortest path found based on the minimum cost function given by the Equation 3.3.

$$Cost \quad function(i,j) = min \sum_{i=0}^{N} VL(i,j) \tag{3.3}$$

The outer loop controlled by NC is iterated until it reaches a user defined parameter called maximum number of cycles, NCmax, or all ants make the same tour which is called the stagnation behavior. For every iteration, the shortest path is updated. Thus, the message from source BAN is communicated with NSC in shortest path given by the List 'SL'.

Further, '*pheromoneLocalUpdate*' procedure updates the pheromone trials on the connections of the devices given by the list 'L' for each ant. According to the Algorithm 2 given below, this operation makes the shortest path more probable for the next ant to choose. In the procedure '*pheromoneGlobalUpdate*', the evaporation of pheromone trail along the connections in the network is imposed according to Algorithm 4. Here ρ is the evaporation constant. In the procedure '*updateShortestPath*' given in Algorithm 3, for every shortest path found its length is compared with 'Slen', the length of the path formed by the list 'SL' nodes, and the 'SL' list is updated.

Algorithm 2: Pheromone Local Updation

```
pheromoneLocalUpdate(k,L,l);
l ← length of path formed by list 'L';
for every edge (i,j) path do
    △τ_ij^k = 1/l if (i,j) is in the path described by list 'L' = 0 otherwise
    △τ_ij = △τ_ij + △τ_ij^k
```

Algorithm 3: Update Shortest Path

```
updateShortestPath(SL,SLen,L,l)
input k %ant identifier
input i %counter for construction
SL ←0;
l ← 0
BAN ← ant[k].tour[i-1]
for j=1 to n do
    if ant[k].visited[nlist[c][j]] then
        if (pheromone value && Energy value ) > threshold values then
            ant[k].visited[nlist[c][j+1]];
            l=l+1;
            SL ←SL+1;
            Update in the routing table of the MDC node
            SLen=Costfunction(i,j);
if (pheromone value && Energy value) < threshold values then
    Update pheromone value ;
    Update Energy value;
    Repeat UpdateShortestPath(SL,Slen,L,l);
```

Algorithm 4: pheromone Global Updation

pheromoneGlobalUpdate();
for every edge (i,j) in the network;
$\tau_{ij} = \rho^{*}\tau_{ij} + \triangle\tau_{ij}$

Table 3.2: Ant Structure

ant-ID	ant-type	ant-nodes	ant-hopcount	ant-info

Table 3.3: Ant-information structure

Energy-residual	Queue-delay	Packet loss	ant-hopcount	ant-info

3.4.4 Ant's Structure

The data configuration of the ant's structure, referred to in Table 3.2 used in route discovery process is described below.

1. "ant-ID" is the ant's ID, while ant-type gives information about the type of ant in the route discovery process. This field can be "forward ant" or a "backward ant".
2. "ant-nodes" is the stack of the nodes visited that contains the IDs of the nodes by which the ant passes.
3. "ant-hopcount" is the field where it calculates the number of hops by which the ant passes from its source to the intermediate nodes till it reaches the destination.
4. "ant-info" field includes information about the route of the nodes given in Table 3.3.

3.4.5 Pheromone Table

An ant pheromone table is a structure that stores pheromone trail information for routing from node i to the destination via intermediate nodes j. The structure of pheromone table is as shown in Figure 3.1 .

Neighbor node	Energy Pheromone value(ij)	Delay Pheromone value(ij)	Packet loss pheromone value	Available memory pheromone	Device type	Time expire

Figure 3.1: Pheromone Table for Node i

Whenever the ant travel from node to node the pheromone table gets update with following structure.

1. "Neighbor node" is the node visited node during traversal.
2. "Energy Pheromone value(ij)" is the present pheromone energy of the node.
3. "Delay Pheromone value(ij)" time taken for updation of pheromone value.
4. "Packet loss pheromone value" is the value at which the packet lost during the updation process.
5. "Available memory pheromone" during the ants traversal evaporation of pheromones happen.
6. "Device type" represents whether it is BANC or MDC device.
7. "TIme expire" expiration of time of the ants during traversal.

3.5 Route Discovery

When a regular node BANC needs to send data to the destination, it checks its routing table to find an appropriate path for transmission. It checks out its pheromone table in order to find any non-expired node information. That information is considered expired if the value associated with the time expiration field is inferior to the node clock. If all the information in the pheromone table expires, a new route phase is generated and a number of forward ants are generated to be sent out for route checking. After the completion of route discovery process, data is sent to the destination immediately.

If a source node finds that there is no satisfactory and unexpired path to the destination in its routing table, it generates forward ants to search for paths leading to the destination. When an intermediate node receives the forward ants, it judges the existence of loops in the "ant-nodes" Table (3.1) field of the received forward ants. Those ants resulting in route loops are discarded, information field of the ant is updated and the ant's hop node stack is incremented.

3.6 Backward Ants

When a forward ant reaches the destination i.e. NSC, an evaluation of the route found is carried out. This information collected by the forward ants is compared with the parameter values set by the application for each metric, such as for instance, the demand routes with a packet loss value that is less than 1% and residual energy ratio greater than 85%, etc. The destination node evaluates this information and decides whether the route is adequate.

3.7 Load Balancing along the Route

While finding shortest path is important, it is also important to make sensor node network efficient by balancing the load among the sensor nodes. In the proposed algorithm, different factors help in calculating the weight of the node by using buffer load, pheromone value, energy consumption and hops at the base station as shown in Algorithm 5. To mitigate the occurrence of traffic congestion at the link or at the base station we calculate weight of the each node in order to improve the packet delivery ratio and reliability of the data sent. The load on a base station as a function of the processing load $'PL_{W_i}$' and communication load $'CL_{W_i}$' due to sensors in the network, is defined in Equation **??** [55].

Processing load on a base station arises out of processing the data from all the nodes (BANs and MDCs) in the network. Communication load, $'CL_{W_i}$' of the base station NSC is calculated as the summation cost of all nodes in the routing as in Equation 3.4 [55].

$$CL_{W_i} = \sum_{i=0}^{n} C_{i,j} \tag{3.4}$$

We set a threshold value to alternately select nodes with most ability to assist the traffic of the network. This way it leads to weight calculation at the neighboring node which can be obtained by Equation 3.5 [56].

$$W_i = \alpha CL_{W_i} + \beta B_i + \alpha P_{current} + H_i + \beta E_i \tag{3.5}$$

where, W_i is the weight of each node i

E_i denotes the energy consumption of ith node

B_i indicates the buffer space of node i

$P_{current}$ signifies the current pheromone value

H_i represents the number of hops to the base station from node i

α and β are control parameters with the values lying between 0 and 1.

The ant colony algorithm also tries to find the congestion of the traffic along a path since if congestion occurs, there is a possibility of the loss of the packets. Hence during the route discovery phase, whenever the source sends a packet to the network, it checks its buffer size, pheromone value, residual energy and hop count in the network.

Algorithm 5: Load balancing at the intermediate nodes

```
Input:routing table of node i
Input:forward packet structure
Output: update tables require to transmit data to the neighbor node
Output: Weight of each node, pheromone value, buffer space, Hop count
  and residual energy
packet p=buffer.next()
if an intermediate node is the neighbor node of source node then
    if p.bufferspace < thresholdvalue then
        forward ant is accepted from the source node and checks its weight
        at each node by equation 3.5
else
    find an alternate path
if ant creates a loop then
    discard it
```

3.7.1 Effective Initialization of Pheromone Trail

An effective solution for routing in WBAN requires early convergence for the reasons mentioned below:

1. It is necessary to calculate the shortest path between BAN and the NSC in practical situations since the distance between MDCs and NSC may change due to patient movement. Consequently, the order of visiting BANs and MDCs and the path between BANs to other nodes is estimated using probabilistic function.

2. When traffic congestion occurs at NSC and changes during traveling, the path should be re-evaluated.

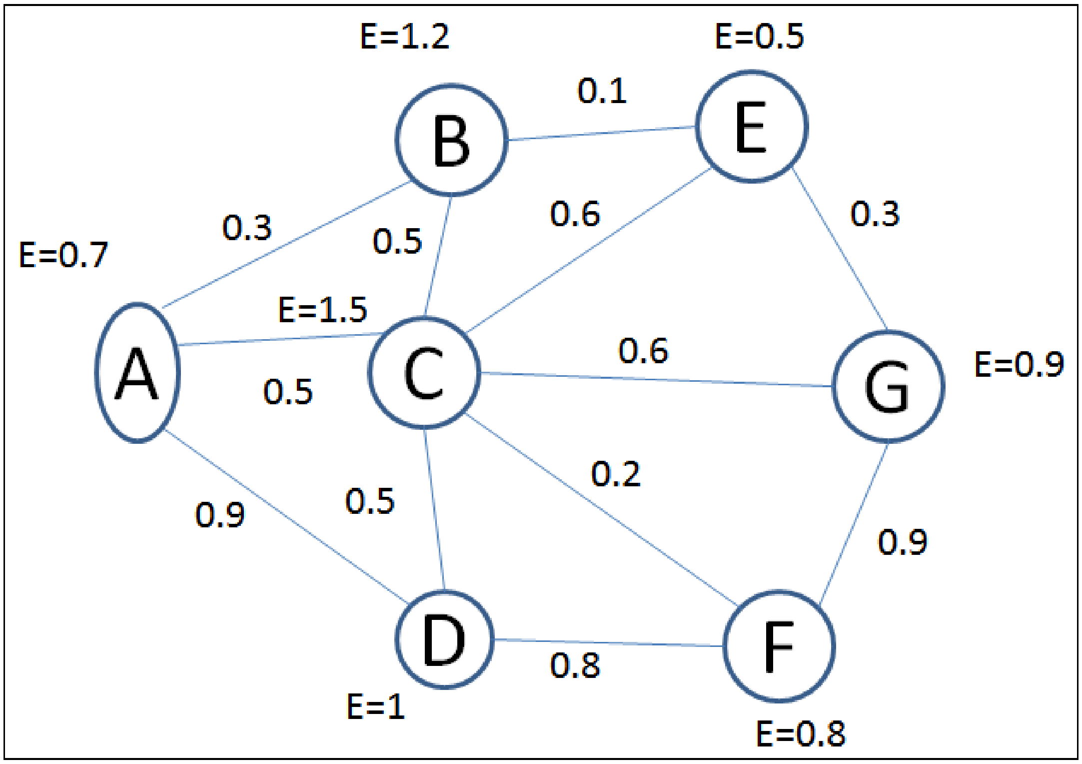


Figure 3.2: Ant Colony Example

3. This method helps to guide the search and reduce the number of BANs or MDCs visited in the network from the initial pheromone trials.

4. This reduction is achieved by using solutions built by the ant-colony algorithm. These help in the initial solutions which can include candidate partial solutions of the 'global' shortest solution.

3.8 Example to demonstrate ant-colony algorithm

As an example, Figure 3.2 shows a small network of nodes to demonstrate the ant colony algorithm. An ant from a node chooses next node to move based on pheromone value and energy value using Equation 3.2.

The experimental setting is the situation where the artificial ants have deposited the pheromone trials and an ant takes the shortest path based on ant-colony approach. An ant starting from source A reaches destination G. All other nodes B,C,D,E and F represents MDCs. The graph can be represented in the form of matrix 3.8. In Figure 3.2, E represents the energy of the node and value on an edge between any two nodes represents the pheromone value. The artificial ants traverse from node A to node G by selecting the appropriate MDCs using the ant-colony algorithm.

$$\begin{bmatrix} & A & B & C & D & E & F & G \\ A & 0 & 0.3 & 0.5 & 0.9 & \infty & \infty & \infty \\ B & \infty & 0 & 0.5 & \infty & 0.1 & \infty & \infty \\ C & \infty & 0.5 & 0 & 0.1 & 0.6 & 0.2 & 0.6 \\ D & \infty & \infty & 0.1 & 0 & \infty & 0.5 & \infty \\ E & \infty & 0.1 & 0.6 & \infty & 0 & \infty & 0.3 \\ F & \infty & \infty & 0.2 & 0.8 & \infty & 0 & 0.9 \\ G & \infty & \infty & 0.6 & \infty & 0.3 & 0.9 & 0 \end{bmatrix}$$

The two parameters α and β values are varied to see their impact on the performance. These values have a greater influence on whether an acceptable solution or an optimum solution is found. When α is reduced, the ant system's convergence time increases. This experiment is run with different combinations of α, β values keeping others constant to know the influence of these parameters on the algorithm. The values tested are $\alpha = \{0.5, 5, 10\}$ and $\beta = \{0.2, 1, 7\}$ and the experimental results are shown in Table 3.4.

It can be observed from the results of experiment that the path traversed has not

Table 3.4: Final Routing Tables

α	β	Costfunction	Path
5	1	2.1054917	A-D-F-G
0.5	1	1.1365	A-C-B-E-G
10	7	2.256	A-D-F-G
5	0.2	2.0998	A-D-F-G
0.5	1	2.5888	A-D-F-G

changed for most of the α, β sets. The cost function value of the paths however has changed.

The mean value was calculated by taking the average of the number of iterations for an optimal solution. The optimum result was achieved when α is 0.5 and β is 1 after 100 iterations and energy dissipated by these senors nodes which were tracked was more when compared to other values of α and β. Thus, the shortest path is A-C-B-E-G. Values greater than 1 have optimal solution with more than 130 iterations. As per the Table 3.4, all the values have been experimented with different energy values and for but one case from Table 3.4 where the cost function value is 2.5888, the energy is same for all nodes. But as the literature says [37], better the α, β values are in [0,1] will result in higher functional value.

3.9 Complexity

In this section, we analyze the time and space complexities of ant-colony algorithm as applied to routing in WBAN.

Theorem 3.9.1. *The time complexity of the WBAN routing using ant-colony based algorithm is $O(w * Iterations_{max} + (d^2 * w))$ per node.*

Proof.

$$T_1 = O(w * Iterations_{max}) = O(20 * 500) \tag{3.6}$$

Where w is the number of ants, and $Iterations_{max}$ is the maximum number of iterations for the algorithm to execute. In step 2, the time complexity of computing the Euclidean distance between the nodes is:

$$T_2 = (d^2 * w) = (d^2 * 20) \tag{3.7}$$

Thus, the total time complexity is

$$T_{total} = (w * Iterations_{max} + (d^2 * w)) = O(1) \tag{3.8}$$

□

Theorem 3.9.2. *The space complexity for WBAN routing algorithm using ant-colony based algorithm is $O(w * n)$ per node.*

Proof. Assume there are w ants and n number of nodes distributed in the network. The space complexity will then be:

$$T_{space} = O(w * n) = O(n) \tag{3.9}$$

□

3.10 Evaluation Metrics

3.10.1 Performance Metrics

The following performance metrics typical for routing algorithms, have been used for the purpose of comparison with the ZKBAN algorithm discussed earlier: 1) energy consumption, 2) end-to-end delay, 3) bandwidth, 4) throughput 5)jitter 6) Data Transmission and 7) network lifetime. . A brief description of the metrics used is given below:

3.10.2 Energy Consumption

Energy consumption is calculated during transmit and receive mode where switching time between these modes is assumed to be small. We have calculated energy consumption by counting the packets during these modes..

Transmit mode We have used 3 output power configurations [52] depending upon the supply voltage. Let K_i represent the current consumed during these configurations of i, where i is set at -15 dBm, -25 dBm and -35 dBm. The expression to compute for power consumption is given by Equation 3.10 [57].

$$Power_i = V * K_i \tag{3.10}$$

Where $Power_i$ is in Watts and V is the voltage in volts

The energy consumed by the transmissions is given below in Equation 3.11.

$$Energy_{tx} = Power_i * T_{tx} \tag{3.11}$$

Where $Energy_{tx}$ is in joules and T_{tx} is total time spent during the transmit mode expressed in seconds.

The total amount of time spent during transmit mode depends on the number of packets sent and the time taken to transmit each packet. By considering the acknowledgements and data packets, total time spent during the transmit mode is calculated by Equation 3.12 as,

$$T_{tx} = N_{txData} * \frac{P_{Data}}{R} + N_{txAck} * \frac{P_{Ack}}{R} \tag{3.12}$$

Where,

N_{txData} and N_{txAck} are the number of transmission packets and number of acknowledgements.

P_{Data} andP_{Ack} are the packet size of data packets and acknowledgements in bits respectively and

R is the data rate in bps (bits per second).

Receive Mode

Equation 3.13 [57] helps to calculate the energy consumption in receive mode.

$$Energy_{rx} = Power_i * T_{rx} \tag{3.13}$$

Where,

$Energy_{rx}$ is in joules and

T_{rx} is total time spent during the receive mode which is expressed in seconds

The total amount of time spent during receive mode depends on the number of packets sent and the time taken to receive each packet. By considering the acknowledgements and data packets, total time spent during the receive mode is calculated by Equation 3.14:

$$T_{rx} = N_{rxData} * \frac{P_{Data}}{R} + N_{rxAck} * \frac{P_{Ack}}{R} \tag{3.14}$$

Where

N_{rxData} and N_{rxAck} are the number of received packets and number of acknowledgements.

P_{Data} and P_{Ack} are the packet size of data packets and acknowledgements in bits respectively and

R is the data rate in bps.

3.10.3 End-to-End Delay

The delay between source and the destination is given by Equation 3.15 as

$$D_{end-end} = \frac{1}{delay(path_j(i,d))} \tag{3.15}$$

where delay($path_j(i,d)$) is the end-to-end delay from source i to destination d through the neighbor j. Its sum of transmission delay, propagation delay, processing delay and queuing delay w.r.t number of links.

3.10.4 Bandwidth

The available bandwidth of the path from i to d is calculated as minimum of available bandwidth of all links along that path [51].

$$B_{ijd} = min\left\{available - bandwidth(l)\right\} l\epsilon path_j(i,d) \tag{3.16}$$

where the available bandwidth of a link is calculated by Equation 3.17

$$available{-}bandwidth(link) = \frac{hello \quad packet \quad size}{hello \quad packet \quad start \quad time - hello \quad packet \quad receive \quad time} \tag{3.17}$$

3.10.5 Throughput

The network throughput is a measure of the amount of data transmitted from the source to the destination in a unit period of time(seconds). The throughput of a node is measured by counting the total number of data packets successfully received at the sink node, and thereby computing the number of bits received divided by the total simulation runtime given by Equation 3.18

$$Throughput = \frac{Total \quad data \quad bits \quad received}{simulation \quad runtime} \tag{3.18}$$

3.10.6 Jitter

Jitter is defined as variation in average delay. In ZKBAN algorithm, when a link breaks, possible route repair is done or otherwise new paths are explored. Thus, in case of path breaks, a time gap is introduced while data is transmitted causing increase in jitter. Ant-colony algorithm on the other hand builds various paths. When a path breaks, an alternate path is selected within less time leading to reduced jitter.

3.10.7 Data Transmission

The algorithm chooses one path to transmit data. According to 3.11, a modified load balancing function of path i [58] is given by

$$f_i = (E_{min}(i)) + \frac{1}{E(i)} + \frac{1}{Length_i} \tag{3.19}$$

Where $E_{min}(i)$ is the residual energy of the minimum energy node in path i, $E(i)$ is the sum of energy consumption in path i and $Length_i$ is the length of path i, which can be used to estimate the delay of a path [58].

$$P_i = \frac{f_i}{\sum_{j=1}^{N} f_j} \ (i = 1, 2, ..., N) \tag{3.20}$$

where N is the set of discovered paths.

$$\sum_{j=1}^{N} P_i = 1 \tag{3.21}$$

The nodes use Equations 3.19, 3.20 and 3.21 to calculate the probability and transmit data along the selected path. Since the path is chosen, load balancing among the paths is achieved.

3.10.8 Network Lifetime

Network lifetime is defined as the number of packets successfully delivered to the destination nodes before the network is declared to be dead.

3.11 Performance Evaluation using Simulator

Authors in [59] provide a detailed survey of WSN simulators. NS-2 is considered the most commonly used simulator for WSN; however OMNeT++ based Castalia simulator is found to be the best simulator for WSN, BAN, and generally networks of low-power embedded devices [60] . OMNeT++ provides more available models and protocols in addition to better GUI support when compared with NS-2.

The main features of Castalia are given below :

i. Specially designed for BAN and networks with low-power embedded devices

ii. Based on event driven OMNeT++ platform

iii. Uses realistic node behavior, wireless channel and radio models

iv. Mobility of the nodes is fully supported

v. Interference is handled as received signal strength

vi. Extended sensing modeling provides highly flexible physical process model

vii. Capable of Sensing device noise, bias and power consumption

viii. Availability of MAC and routing protocols

ix. Designed for adaptation and expansion

3.11.1 Simulator Overview

OMNeT++ is an object-oriented discrete event network simulator. The simulated components are defined using NED(Network Definition Language) as simple modules. C++ is also used to define the operational characteristics of each component. The components defined using NED in the simulated network are sink node, monitoring node, sensor node and connection manager. Components to be simulated are defined as modules in OMNeT++. An OMNeT++ model is based on the following three main parts:

i. NED language topology description (.nedfiles).

ii. Message definitions (.msgfiles)

iii. Simple module sources.

NED language stands for Network Description Language, with which the structure of the model, which is going to be simulated, is defined. NED is used to define simple modules and assemble them into compound modules. It is also used to define gates and channels for simple and compound modules through communication.

Simple modules are used as main structural components to build simulations in OMNeT++; their characteristics and functionalities are written in C++. They can also be congregated into compound modules while the number of hierarchy levels is unlimited. Table 3.5 refers to the parameters for simulation carried out using ant-colony algorithm. In our simulations, equal weight is given to the parameters α and β which as mentioned earlier, represent the importance of pheromone decay and delay respectively.

Table 3.5: Simulations Parameters

Deployment	Area	21m*21m
	Deployment type	scenario 1: Fixed packets scenario 2: Variable packets
	Number of nodes	7 and 49 nodes
	Initial node energy	18720 J (2 AA batteries)
	Buffer size	32 packets
	Transmit power	-35dBm, -15dBm, -25dBm
Task	Application type	Event-driven
	Max. packet size	80K packets
	Traffic type	CBR (Constant Bit Rate)
MAC	IEEE 802.15.4	Default values
Simulation	Time	1000 msec

3.11.2 Simulation Model

For the simulation model, we deployed seven nodes where, 3 BANs, 3 MDCs and 1 NSC as shown in Figure 3.3. Typically, MDCs are placed within 3 meters of the patient's bed [33]. The BANs (B_1,B_2 and B_3) are source nodes and MDCs and NSC are the destination nodes. B_1 send packets to MDC_1, B_2 send packets to MDC_2 and so on. In our model, the BANC B_2 and NSC are considered as source and destination nodes respectively and all the nodes are considered to be stationary. Node B_2 sends a total of 10k artificial packets. Further, to verify how the algorithm performance scales with netowrk size, we increased the number of nodes by deploying 49 nodes consisting of 24 BANs, 24 MDCs and 1 NSC as shown in Figure 3.4 placing NSC at the centre. These artificial packets return the tour and send real packets to the destination, that is, MDCs or NSC. On successful transmission of the packets to the final destination, the end-to-end path reliability is calculated by using the probabilistic function of the ant-colony

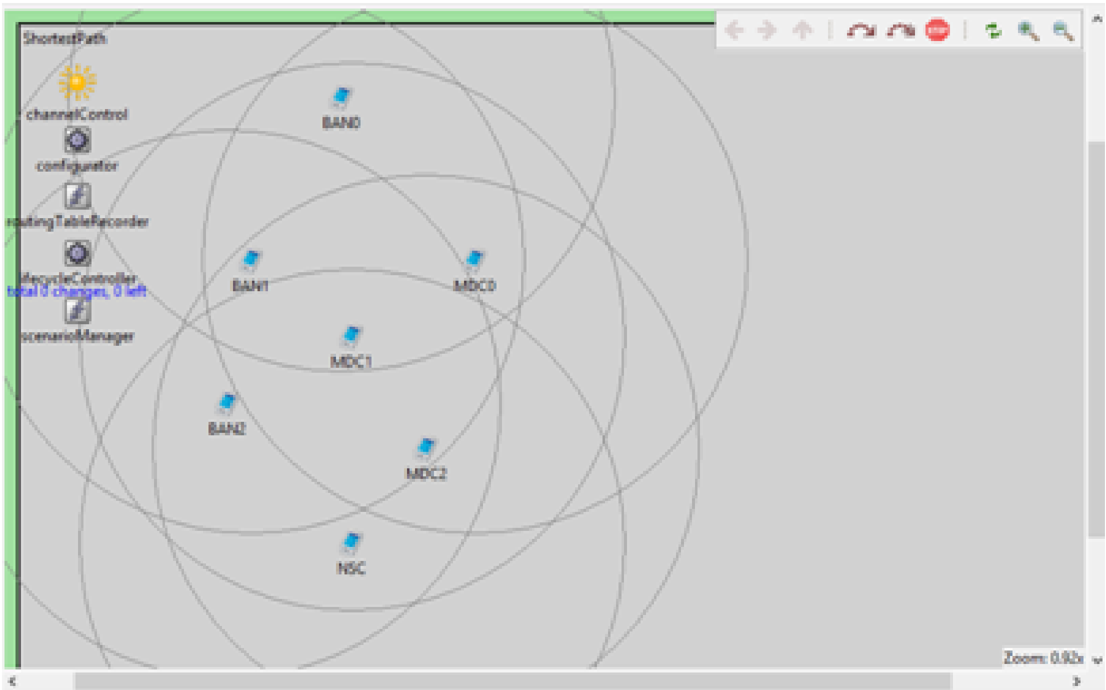


Figure 3.3: Deployment of Seven Nodes

algorithm. This overcomes the issues related to redundant paths to ensure that requested reliability is met. The path selection of the source depends upon the energy at each node at every interval of a few seconds and pheromone deposit between the nodes. Thus it ensures the link reliability between the nodes from source to the destination.

3.11.3 Simulation Scenarios

Two scenarios have been used for simulation in this work. In scenario 1, each BAN coordinator sends 1000 packets to the corresponding MDC or NSC. From all BANs Figure 3.3, B_2 is the closest BAN node to the NSC and MDCs. It results in more energy consumption for B_2 and increased congestion experienced by B_2. The proposed algorithm resolves these problems by choosing the most appropriate MDC as next hop on the lowest value of communication cost based on pheromone

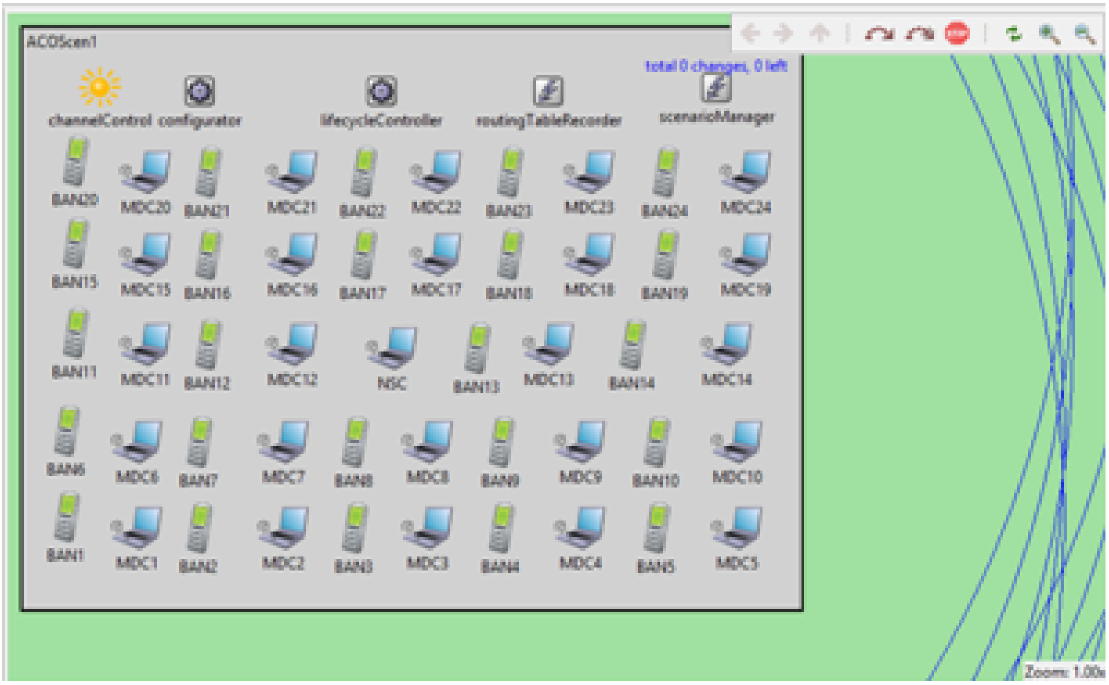


Figure 3.4: Deployment of 49 Nodes with NSC at the centre node

value and residual energy. In the proposed routing protocol, the BAN coordinator does not send data to another BANC due to its limited resources. In scenario 2, each BAN coordinator sends variable packets to the corresponding MDC or NSC.

The performance of the algorithm has been compared with ZKBAN [52]. A comparison with previous algorithms on the same subject has not been shown here since ZKBAN has demonstrated its superiority over the previous algorithms [52] of them. We used two cases for our experiments. For simulations, we used two scenarios of packets transmission. In scenario 1, fixed packets are sent from the source node while in scenario 2, a variable number of packets (of size 4k to 80k) are sent from BANs for observation and comparison. The transmit power used in our experiments is -35dBm, -15dBm and -25dBm for both the cases.

3.12 Results and Analysis

ZKBAN algorithm uses the mechanism of multi path routing but the packets will be more likely to send to the link which has more reliability. Proposed ant-colony algorithm uses a better multi-path mechanism where pheromone will adjust with current energy and load condition of the path in time and the data will be injected into each path of the network in a more balanced way. Thus, it leads to an automatic load balance in the network. As a result, the proposed algorithm outperforms those like ZKBAN when the routing problem arises.

3.12.1 Performance with Seven Nodes

In this section, we present the results of performance for networks with 7 nodes and the other one with 49 nodes. Two scenarios are used as mentioned earlier, fixed and variable packets. Results are compared with that of ZKBAN algorithm, analysed and discussed.

The sent byte counts of proposed and ZKBAN algorithms against node counts are shown in Figure 3.5 respectively. When node counts are increased linearly, the sent byte count values of the algorithms shows a linear increase but higher than ZKBAN algorithm for fixed number of packets. During variable packets from Figure 3.6 it is observed that more number of packets reach the destination and thus, ant-colony algorithm maintains its throughput higher than ZKBAN by transmitting more packets by 10%.

Figure 3.7 and 3.8 show the end-to-end delay. The multipath mechanism of ant-colony has completed more paths to the destination node than the ZKBAN. Pheromone in each link will adjust with current energy and load condition in time, resulting in load balancing. Further, ant-colony uses the mechanism of link failure recovery by consulting the routing table. Even when the routing problems arise, it can quickly resume routing using other paths and reduce the packet sending blindly and thus reduce the time delay correspondingly. For this simulation, maximal delay is set at 8ms. We notice that the end-to-end delays associated with our proposed packets are lower and better than those of ZKBAN. Since multiple paths were discovered, when a path to the destination breaks, packets could immediately continue to be forwarded using another paths without a new route discovery process.This results in ant-colony having lower packet delay when compared to ZKBAN.

Figures 3.9 and 3.10, represent the jitter where less time gap was taken to achieve better results. Whenever a route breaks it choose an alternative path from the routing table using ant-colony algorithm.

Figures 3.11 and 3.12 show, the energy consumption when the final destination node accepts the packet. Smaller the energy consumed, higher the energy efficiency of the network. Ant-colony shows a better performance compared to ZKBAN.

3.12.2 Performance Study with 49 Nodes

In this section, we present the results of performance of the ant-colony algorithm for networks of 49 nodes. In scenario 1, each BANC sends fixed packets to the corresponding MDCs to reach destination NSC and in scenario 2, a variable packets of size 4k to 80k is sent.

Ant colony algorithm out performs ZKBAN with a 10% increase in the throughput

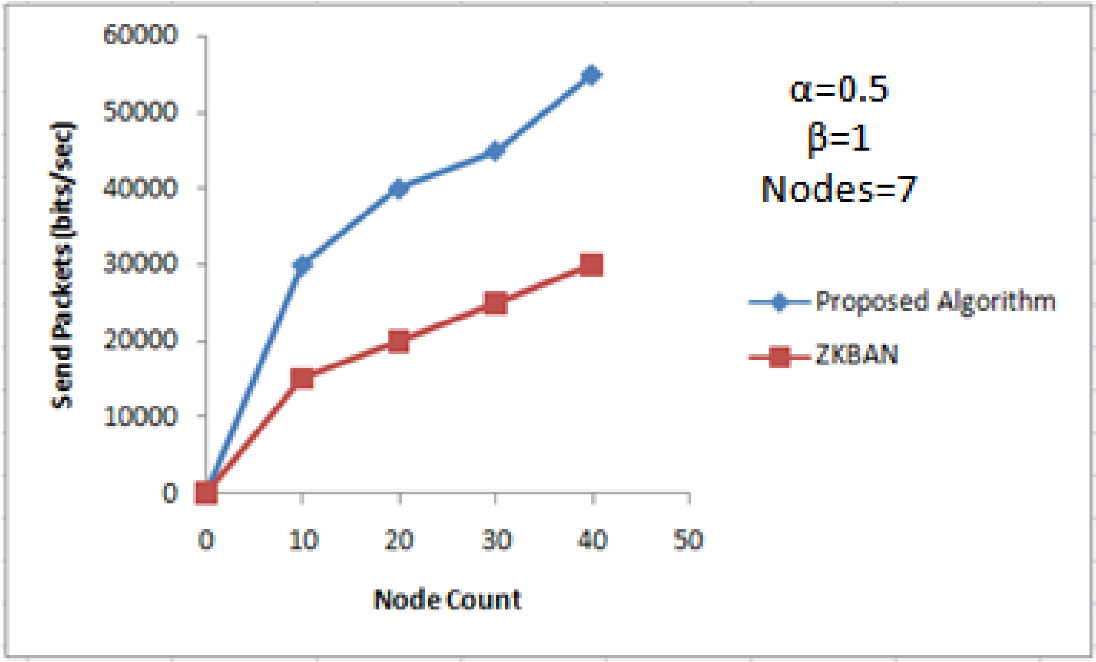


Figure 3.5: Throughput (scenario 1)

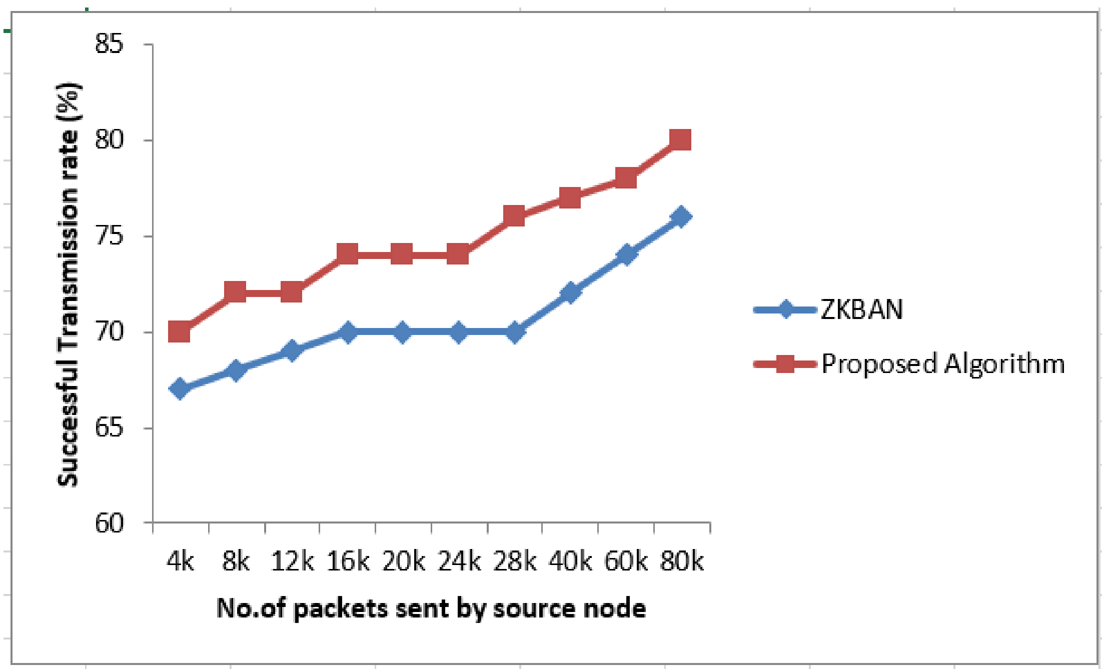


Figure 3.6: Throughput (scenario 2)

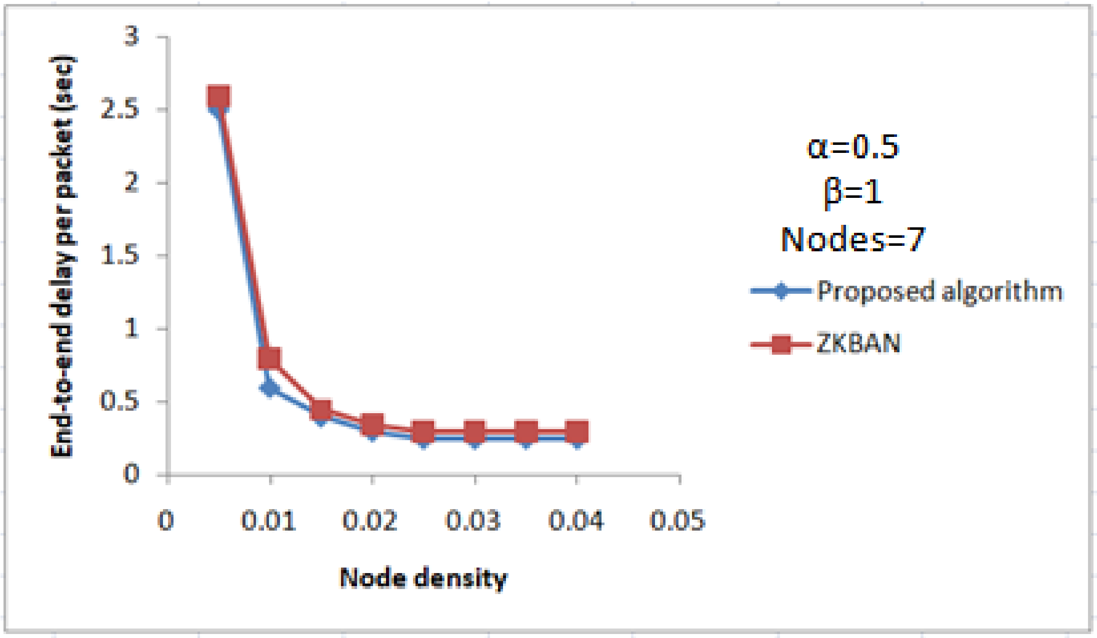


Figure 3.7: End-to-End delay (Scenario 1)

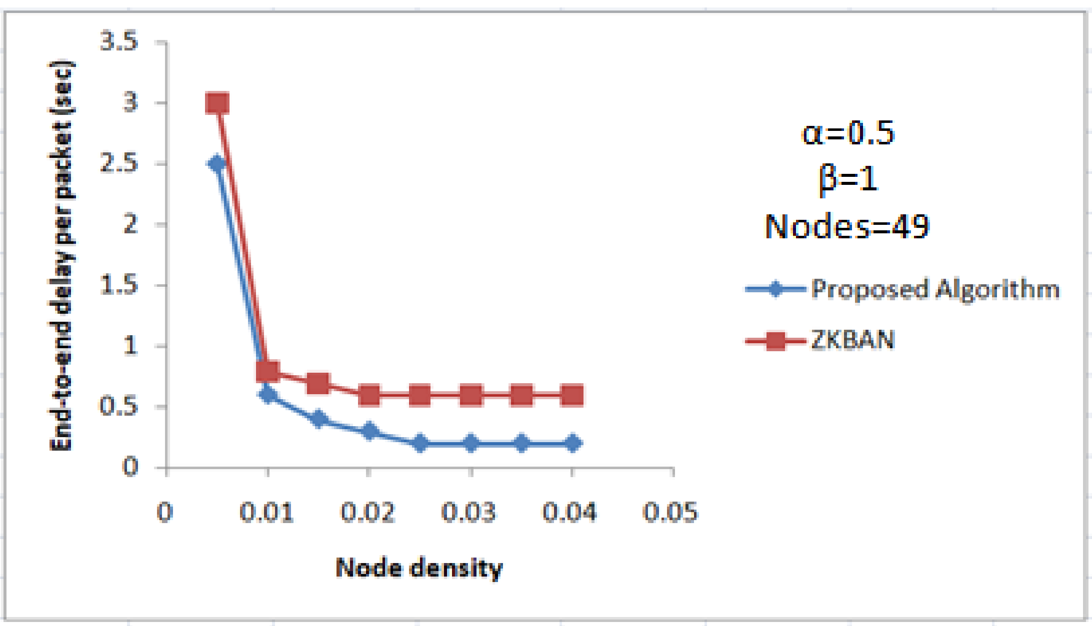


Figure 3.8: End-to-End delay (Scenario 2)

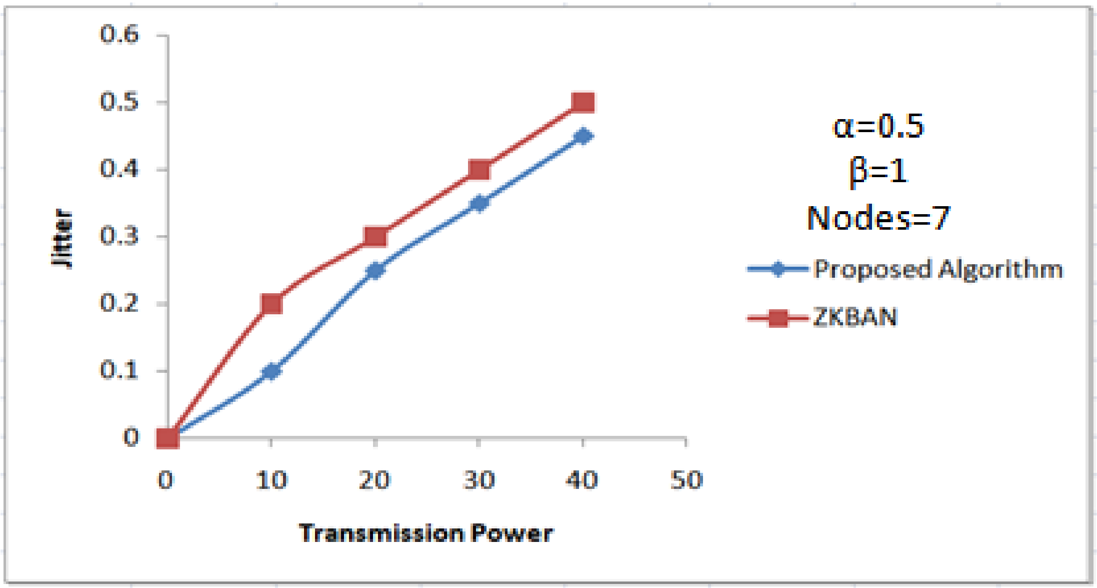


Figure 3.9: Jitter (Scenario 1)

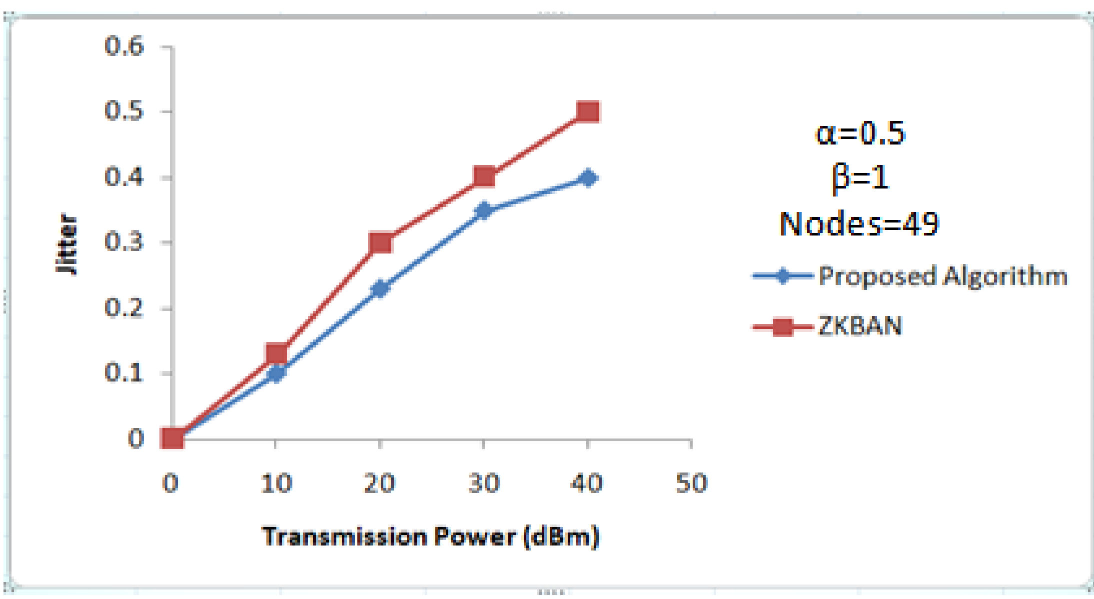


Figure 3.10: Jitter (scenario 2)

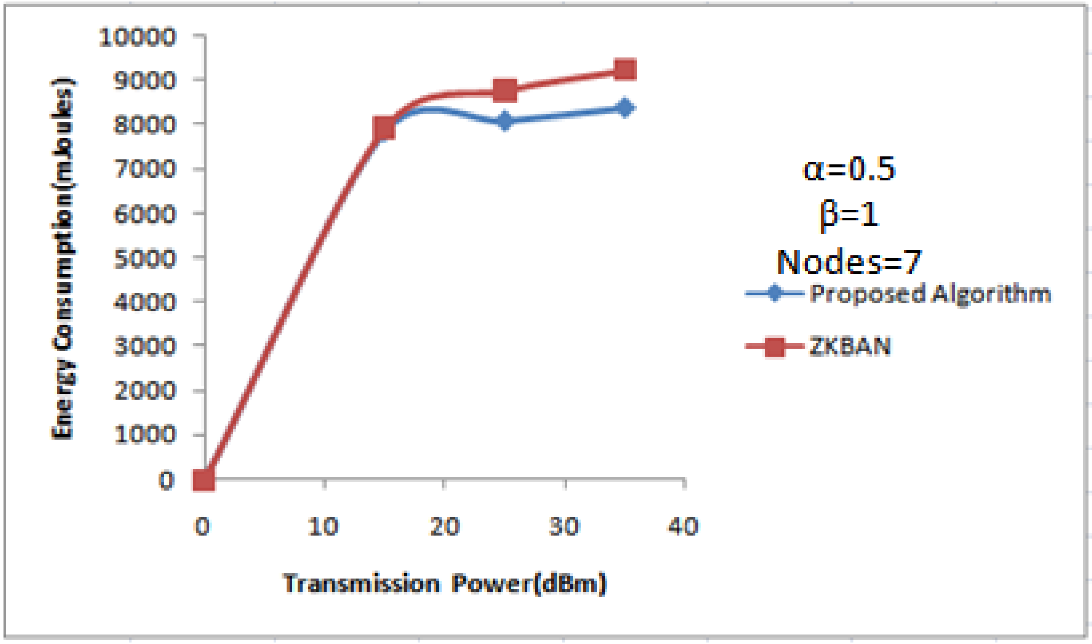


Figure 3.11: Energy consumption (Scenario 1)

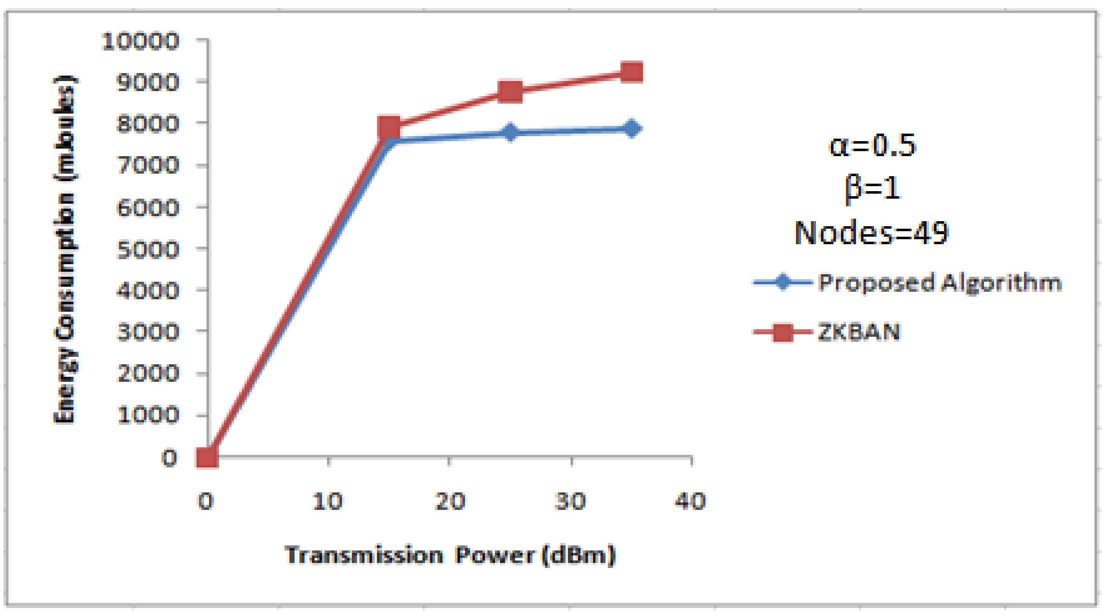


Figure 3.12: Energy consumption (Scenario 2)

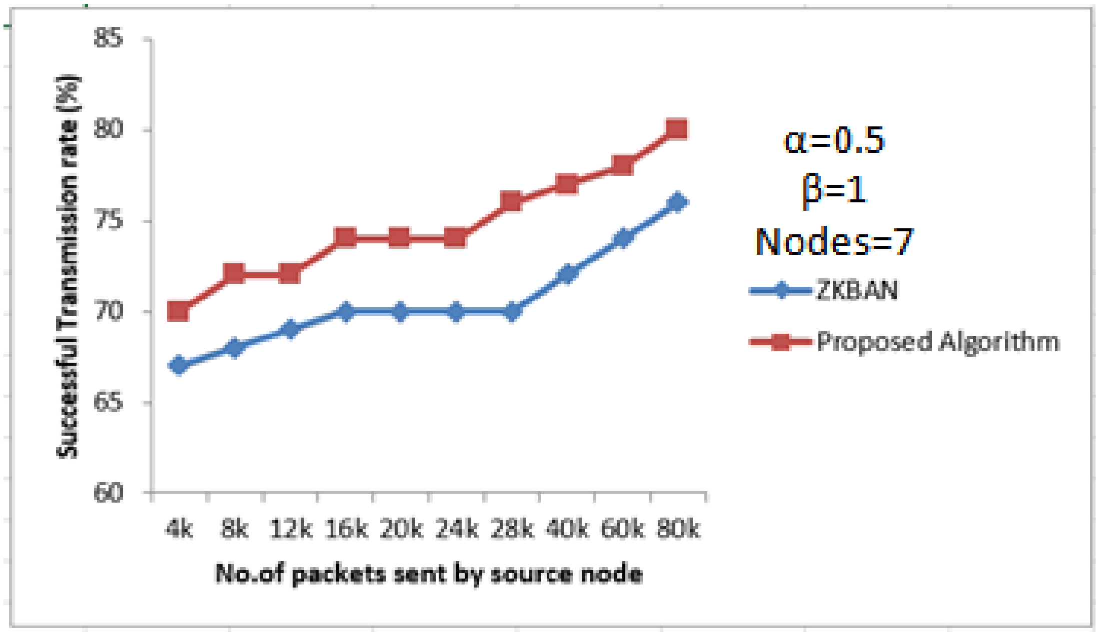


Figure 3.13: Throughput (scenario 1)

as can be observed from Figures 3.13 and 3.14. Since the number of nodes have increased so they choose few intermediate nodes for packet forwarding.

We also notice that the end-to-end delays in Figures 3.15, 3.16 associated with the packets are lower and better than those of ZKBAN.

Figure 3.17 and 3.18, represent the jitter where minimum time gap has been taken to achieve better results as compared to ZKBAN. Whenever a route breaks, it chooses an alternative path from the routing table using ant-colony algorithm.

The following results shown in Figures 3.19, 3.20 for energy consumption for fixed and variable packets also show improvement.

Figure 3.21 shows the number of packets forwarded by the intermediate nodes in the WBAN network. It is observed that data packets travel through the intermediate nodes i.e. MDCs before reaching the NSC when the transmit power is -25dBm. There are equal number of packets that travel through each node. Due

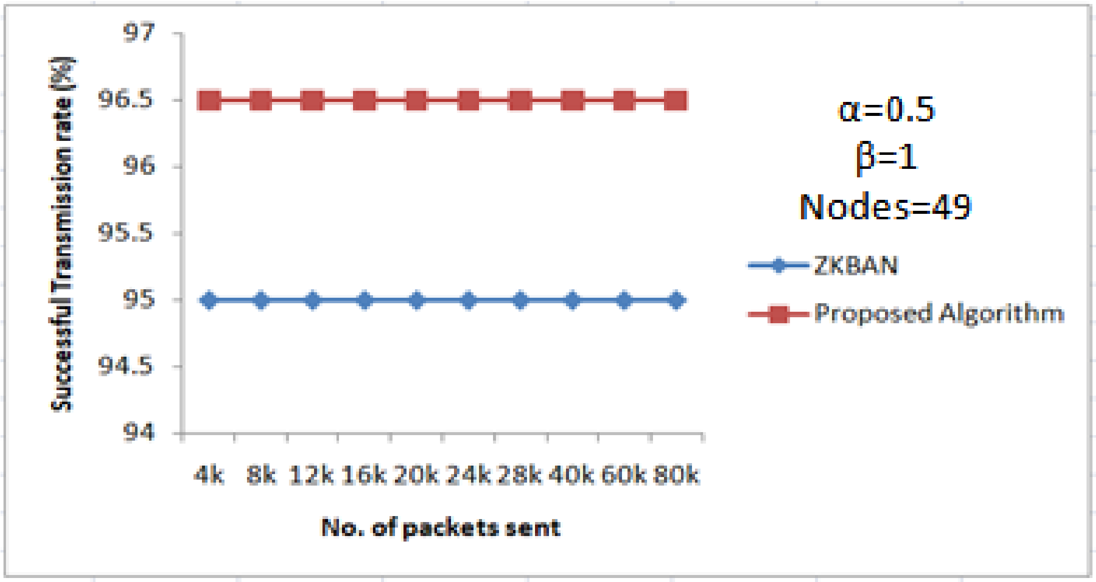


Figure 3.14: Throughput (scenario 2)

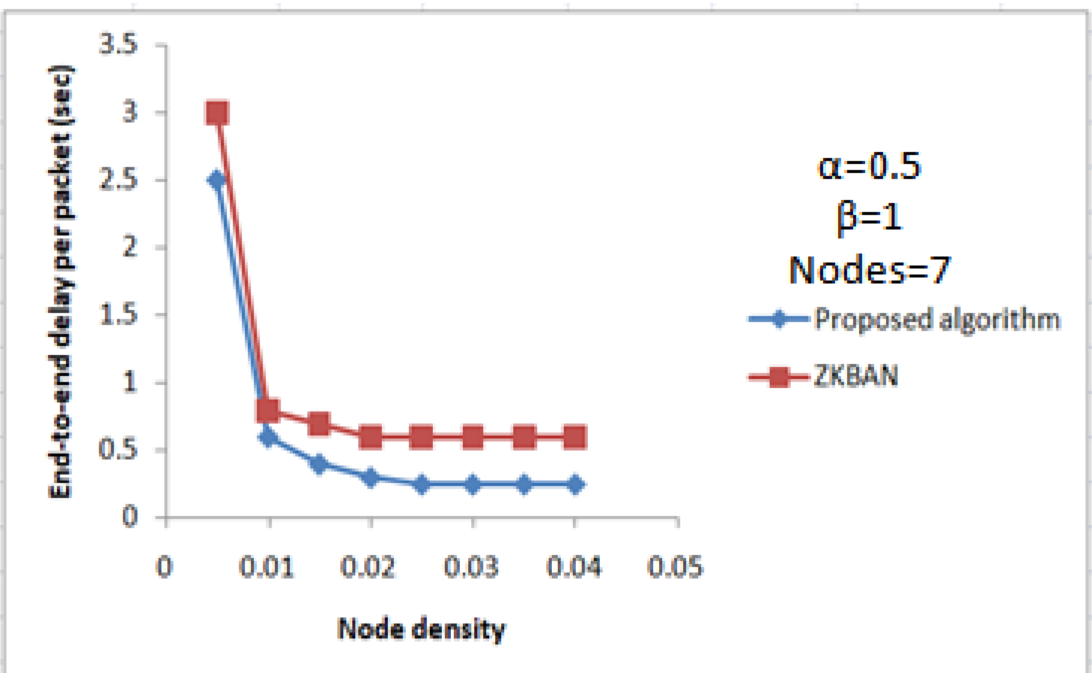


Figure 3.15: End-to-End delay (Scenario 1)

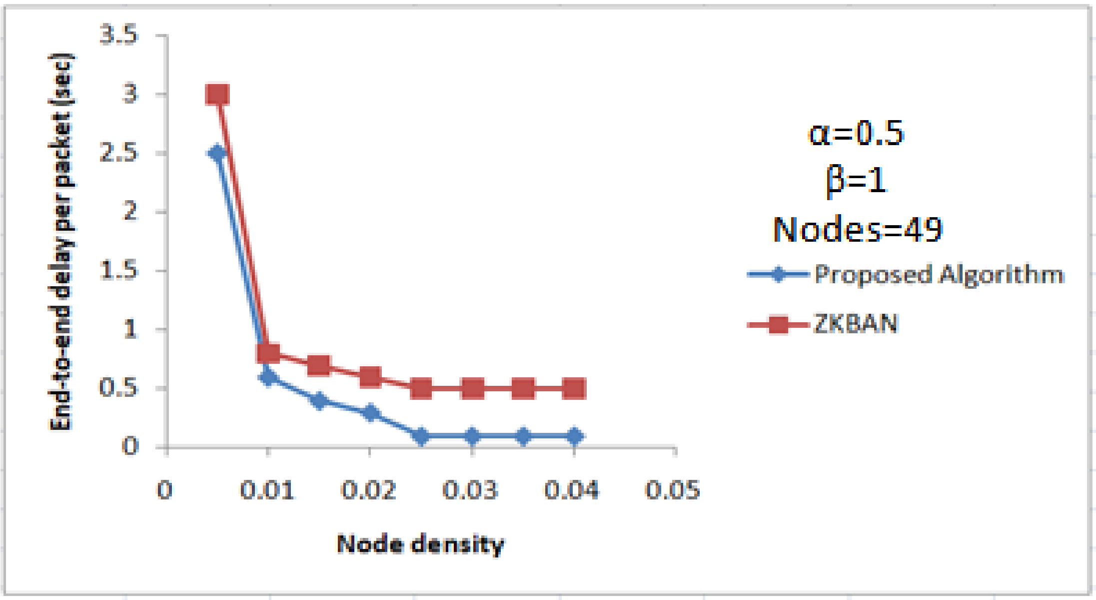


Figure 3.16: End-to-End delay (Scenario 2)

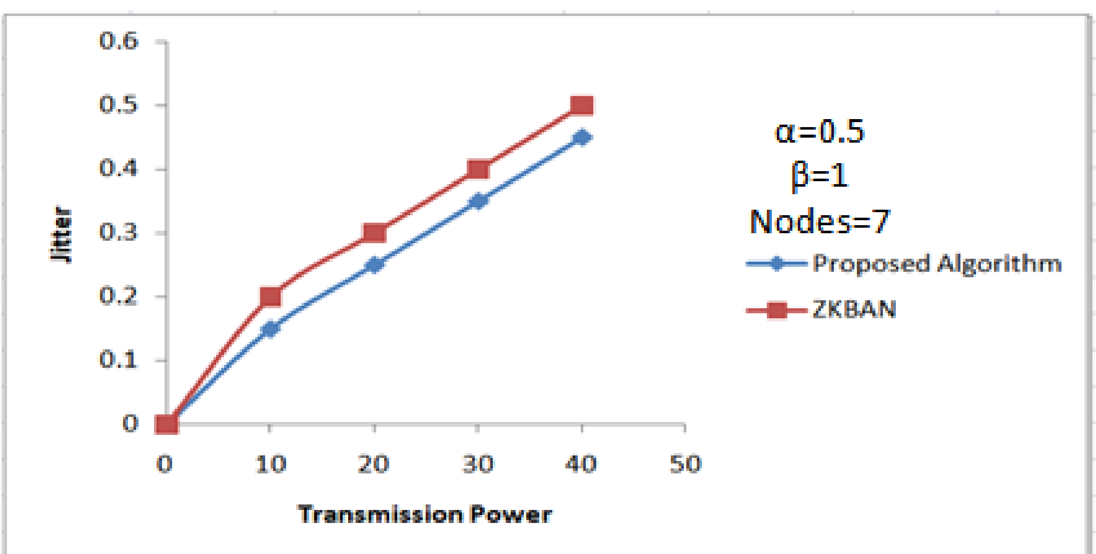


Figure 3.17: Jitter (Scenario 1)

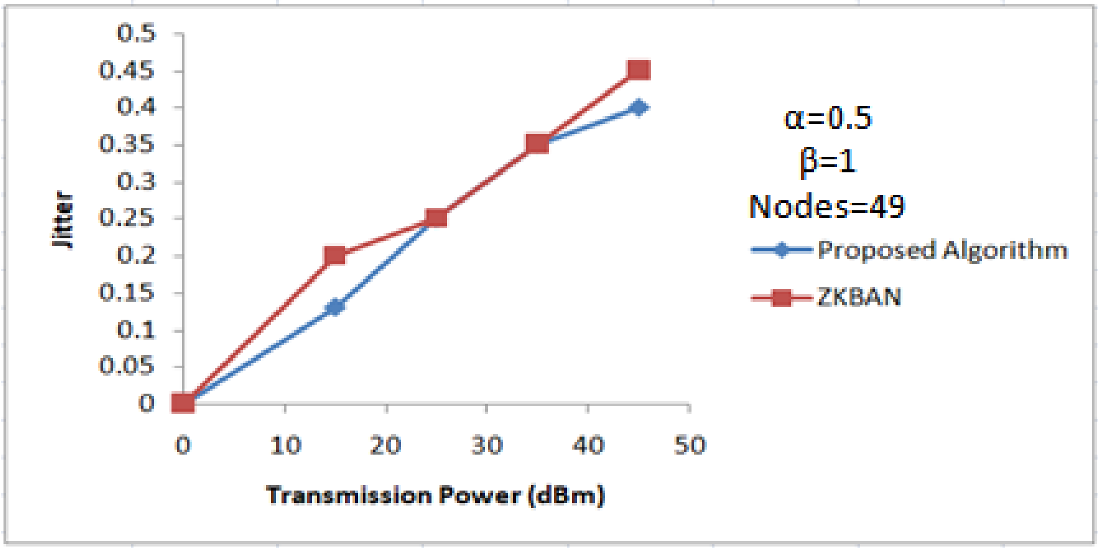


Figure 3.18: Jitter (Scenario 2)

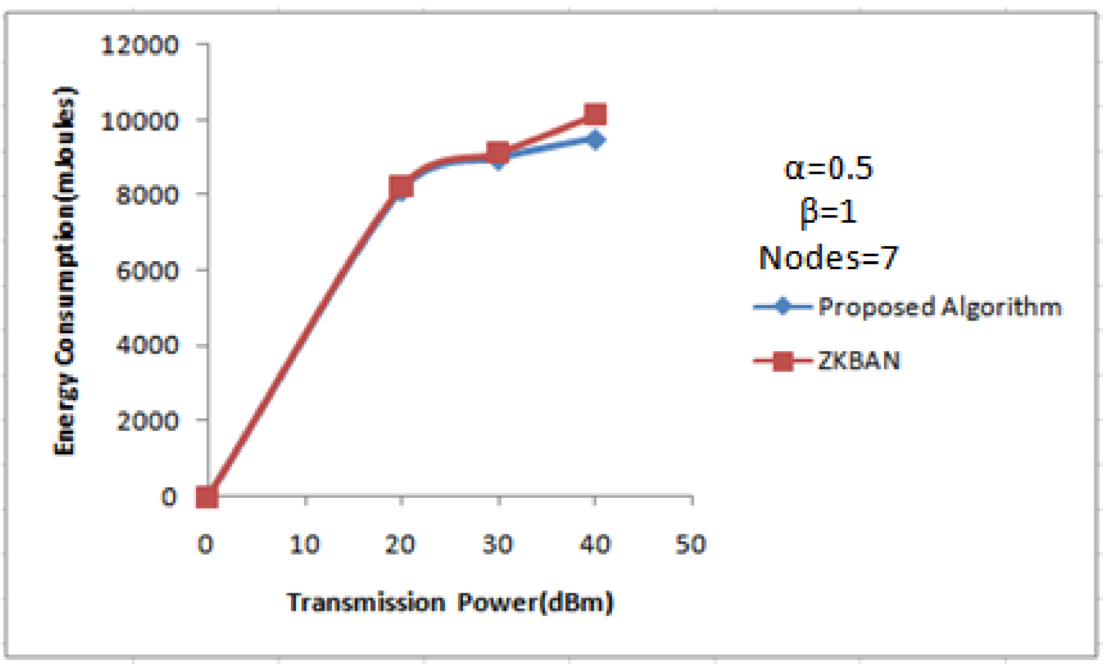


Figure 3.19: Energy consumption (Scenario 1)

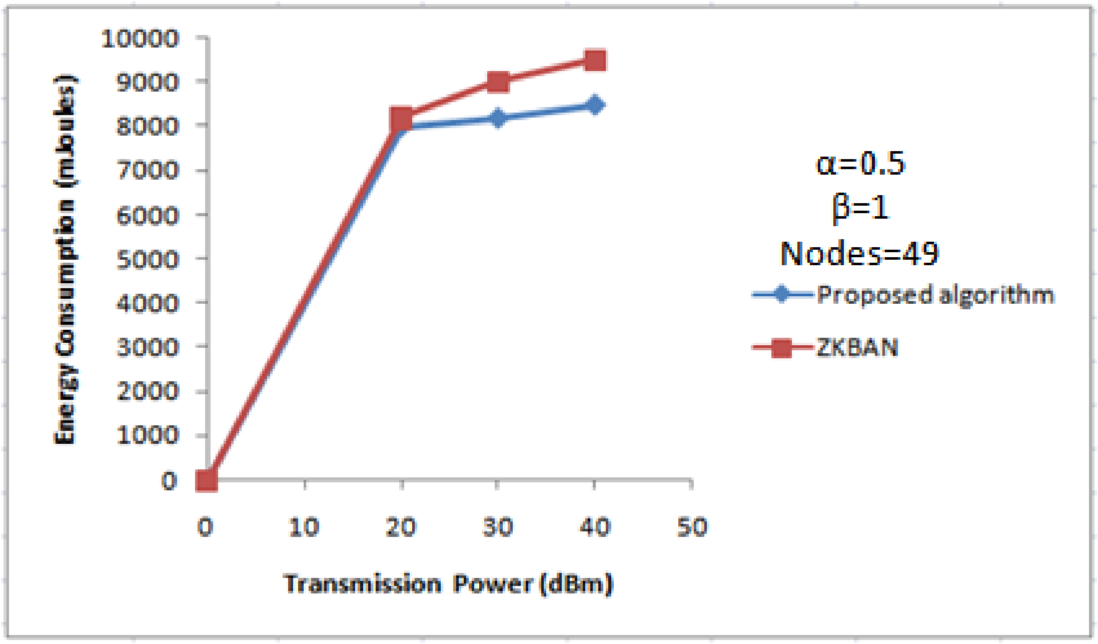


Figure 3.20: Energy consumption (Scenario 2)

to less computation overhead and reduced number of Hello Packets equal number of data packets are forwarded by the intermediate nodes thus resulting in reduced network traffic load and overall energy consumption as shown.

The figure also depicts the effects of the network load on intermediate nodes by increasing the number of source nodes sending the packets form 5 to 10. These results are shown from an average of 10 simulations of 500sec each.

Figure 3.22 shows a comparison of the network lifetime where it can be seen that ant-colony algorithm performs better than the ZKBAN.

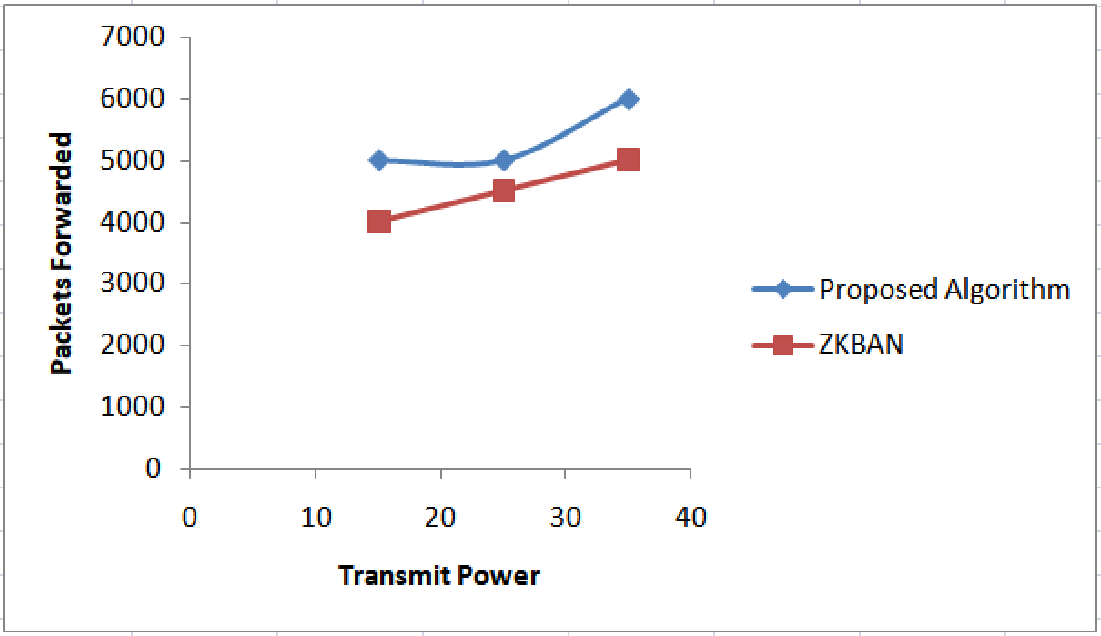


Figure 3.21: Packets forwarded by intermediate nodes

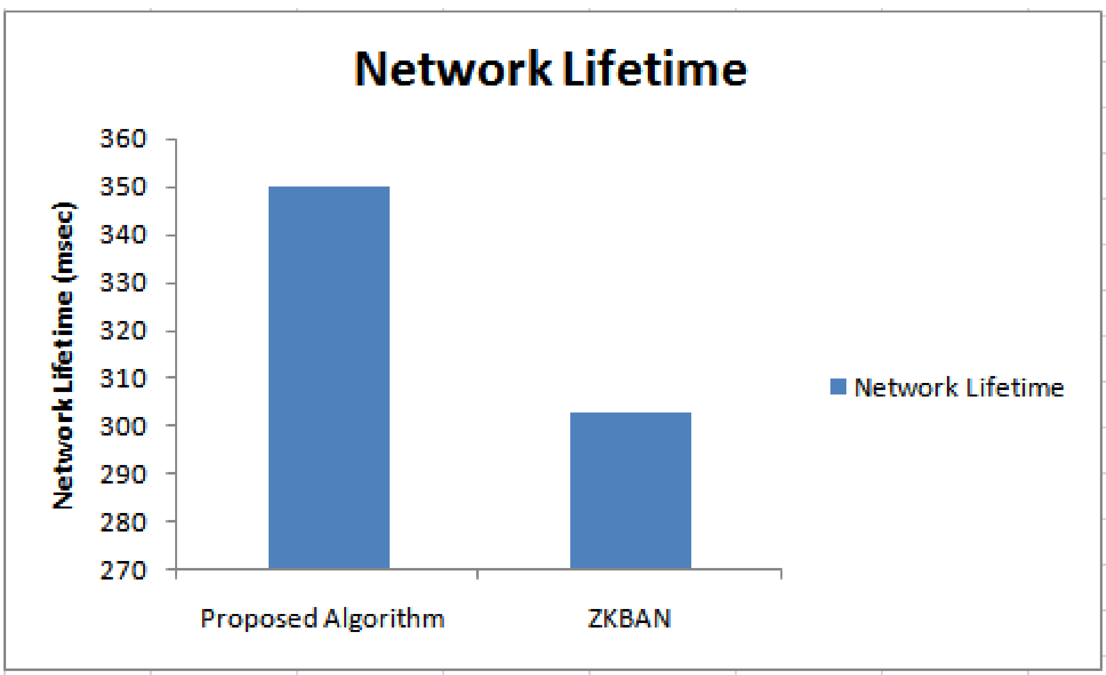


Figure 3.22: Network Lifetime

Table 3.6: WBAN without Ant-colony technique

No.of Nodes	Average Message Count	Network time (msec)
7	40	34
49	92	35

Table 3.7: WBAN with Ant-colony technique

No.of Nodes	Average Message Count	Network time (msec)
7	46	34
49	93	35

3.12.3 Analysis of WBAN with and without Ant-Colony Technique

Tables 3.6 and 3.7 show the message count received at destination node i.e. NSC and network lifetime. The system model is similar to that in [33]. These metrics have been analyzed for 7 and 49 number of nodes. It can be observed that both message count and the network lifetime have improved when ant colony technique is used in WBAN routing.

3.13 Conclusion

In this chapter, we proposed a novel routing protocol for WBAN using ant-colony algorithm. This approach tries to search for cost effective path from the source to destination. Pheromone and heuristic information accelerate the search process. Two types of pheromones have been used to find the coverage efficiently. The pheromone is deposited between every two devices to record the desirability for assigning them to the same terrain. Heavier pheromone indicates higher desirability of choosing the path. One pheromone called as local pheromone is updated after an ant has finished building its solution. The other pheromone called as global pheromone is updated at the end of iteration after all the ants in a colony have finished their tour. The performance results in terms of the metrics mentioned earlier prove to be better than the conventional methods. Our proposed algorithm out performs the ZKBAN (with which the current work has been compared) by 10% increase in throughput and 30% reduced network traffic while choosing the shortest path. In the next chapter we combine the existing cluster grouping techniques with ant colony algorithm to explore their effect on performance improvement.

Chapter 4

A Cluster Based Approach for Energy Efficient Data Routing in WBAN

4.1 Cluster based Routing Methodology

In this chapter we extend ant-colony algorithm to include cluster based routing for data aggregation. Cluster based routing protocols [61], [62] organize the sensor nodes into clusters where each cluster has a cluster head which is responsible for receiving and aggregating data from all other nodes in that cluster group. In order to have better operation, the cluster based routing protocol has to deal with cluster formation and cluster head selection to achieve efficient data transmission leading to high data throughput, reduced energy consumption and increased network life time. While many cluster based protocols exist in literature [63], one prominent and well-known one is LEACH [61] which is energy efficient when compared to other conventional protocols.

In most of the BANs, when the communication range is limited, a routing protocol is used to transmit data but it may require more than two intermediate nodes to transfer data from source to destination. A routing protocol is used for multi-hop communication and also for data aggregation within the network which is the best way for energy conservation. It reduces the communication burden on the network such as WBAN which has limited resources. Hence the routing protocol where selection and aggregation of nodes needs to be optimized in order to achieve high energy efficiency of data transfer. Energy consumption in the node is the main concern when designing the routing protocols of the WBANs to increase the network lifetime.

4.2 Motivation

Existing routing protocols [33, 52, 43, 45, 50] focus more on conventional techniques which may not give desired results. In this chapter ant-colony technique has been modified to include a cluster based approach by considering higher pheromones and energy residual by electing them level to level, to enhance the performance before its transmission to the destination. The proposed method uses a minimum cost function value from routing table to select the shortest path from source to sink for any kind of packets and shows better results in terms of reduced overhead, reduced number of packets forwarded by intermediate nodes and high rate of data transmission. For validating the performance of the proposed protocol, we have compared cluster based ant-colony BAN with traditional techniques like Anybody [26] that uses cluster based approach as well as ZKBAN which has been used for comparison earlier. In Anybody routing protocol [26], a group of sensors of WBAN is formed into clusters on the patients body as compared to our algorithm which uses devices MDCs as clusters.

4.3 Proposed Cluster based Routing Protocol using ant-colony based algorithm

The proposed algorithm introduces cluster formation within the network wherein each cluster of MDCs forms a cluster head within its terrain and forms a cluster called caves. The nodes in each cluster send their data to the cluster head. The cluster heads send their aggregated data to the next cluster head. In WBANs, reliable and sensitive data has to be transmitted to the destination to address the criticality of a patient at right time. Hence clusters are formed to forward only critical information to the destination rather than sending continuous data. Thus, critical data can be transmitted timely through cluster heads within the network. We propose a modified probabilistic function to choose next cluster head, level by level.

Link failure is a common occurrence in Wireless Body Area Networks due to its connectivity on the body in order to monitor the physical parameters of the patients in the hospital environment. This results in repetitive transmission of the data from BANs to MDCs or NSC due to a dead node in its path. Loss of the packets due to failure of the node results in high bandwidth and wastage of energy. This algorithm tries to improve on energy conservation of the nodes and load balancing within the network by using minimum node participation to forward critical data to the base station.

Table 4.1 provides definitions of terms used in our algorithm.

4.3.1 Clustering Technique

As mentioned earlier, proposed algorithm is a cluster based on ant-colony algorithm. It consists of two ant agents called forward ants and backward ants. Forward ants are basically used to find a path between a source i.e. BANs and to the base station MDCs or NSC. During the route discovery phase, a number of ants leaves the source node in search for food. Thus, the task of each ant is to find a route in communicating with the neighbour. They update the routing table of each sensor node while traveling with pheromone left on the trail and the residual energy of each node. During this procedure, the number of nodes grows which leads to overhead explosion. Cluster formation helps to improve the overall performance of the network by data aggregation, which subsequently balances the load on the network, limits the number of intermediate nodes and increases network lifetime. Only a cluster head will transmit the data to another cluster head. This helps in saving energy consumption by the nodes in the network and reducing the latency.

Many routing protocols have been proposed based on clustering such as LEACH [61], TEEN (Threshold Sensitive Energy Efficient Sensor Network Protocol) [62], HEED (Hybrid Energy Efficient Distributed Clustering) [64], PEGASIS (Power Efficient Gathering in Sensor Information Systems) [65] etc. LEACH routing protocol has been shown to be efficient in Wireless Sensor Networks since all the clusters are self-organized. Each cluster has one cluster head and other nodes transmit data to the cluster head. In setup phase, clusters are formed whereas in steady state phase transmission of data takes place.

Table 4.1: Notations used for the proposed algorithm

Field ID	Description
n	node identification in the current sensor network
p	percentage of selecting cluster heads
r	current round number
G	Set of nodes that havent elected as CH in the last rounds
$ph_{current}$	Current pheromone values of the nodes
$ph_{initial}$	Initial pheromone values of the nodes
$E_{current}$	Current energy of the node
E_0	Initial energy of the node
τ_{ij}	Pheromone trail of combination (i,j)
η_{ij}	Local heuristic of combination (i,j)
P_{ij}	Transition probability of combination (i,j)
α	Relative importance of pheromone trail
β	Relative importance of local heuristic
ρ	Trail persistence
q_0	Determines the relative importance of exploitation versus exploration
D_{ij}	distance between the nodes (i,j)
τ_i	type of the device
CostFunction (i,j)	Cost function from source node to destination i.e. (i,j)
Seqnum	Sequence number
Ant_visitednode	Ants visited nodes list
TTL	Time to Live
BAN ID_i	Source node BAN ID
Hops count	Hops count
Lastupdate time	Lastupdate time

In what follows, we describe how clustering approach is incorporated in ant-colony algorithm. During the set-up phase ants generate a random number between 0 and 1 and compare it with a threshold value $T(n)$. In LEACH algorithm, probability is computed and compared with a threshold value which is given by Equation4.1.

$$T(n) = \begin{cases} \frac{p}{1-p*\left(r \quad mod \quad \frac{1}{p}\right)} & if \quad n \quad \varepsilon \quad G \\ 0 & Otherwise \end{cases} \tag{4.1}$$

If the number is less than $T(n)$, the node is elected as cluster head, where the modified threshold $T(n)$ which is given by 4.2 [66]. In our work by using ant-colony algorithm, which is based on pheromone and energy values, probability is computed and compared with a modified threshold value which is given by Equation 4.2.

$$T(n) = \begin{cases} \frac{p}{1-p*\left(r \quad mod \quad \frac{1}{p}\right)} * \frac{ph_{current}}{ph_{initial}} * \frac{E_{current}}{E_{initial}} & if \quad n \quad \varepsilon \quad G \\ 0 & Otherwise \end{cases} \tag{4.2}$$

Once an MDC becomes a cluster head in that terrain, it sends a Hello Packet to all other nodes to join the cluster based on the received signal strength message. All other nodes in the network confirm by joining the cluster. Once confirmed, the cluster head allocates the TDMA information to all other nodes in the cluster when to transmit data. The non-cluster head sends data to the corresponding MDC. Further the cluster head chooses the next cluster head based on the modified probabilistic function until destination is reached. This way it selects the optimal among the cluster heads according to the cost function given Equation 4.3. It then checks the various routes the ants travel from source to destination through the clusters/caves. If the cost function is minimum from the routing table, then it is the optimum path from source to destination where in the Formula 4.3 N represents the set of all cluster Head nodes in the terrain. Routing table has information about the visited list of the nodes traversed. It removes the previous list data from the routing table.

$$Cost \quad function(i,j) = min(\sum_{i \varepsilon N} Modified \quad Probability \quad function) \quad (4.3)$$

4.3.2 Forward Ants

This ant helps in finding the best and shortest path by looking up the information stored in neighboring nodes from pheromone or routing tables. Initially it forwards `Hello_Packet` to the neighbour nodes as per Table 4.2. It maintains two distinct data points; first the distance between the BAN to its corresponding MDCs and the distance between MDCs of one cluster to all other cluster head MDCs from the NSC which is placed at centre of area. It is important for any ant to know the length between any other nodes as shown in Figure 4.1. In this table, BANs ID, MDCs ID, and NSC are the identification numbers. D_{ij} is the distance between BAN to any other node, either MDC or NSC. The pheromone value of each link increases every time its forward ant crosses through that particular link. The forward ant chooses its next hop based on the route discovery algorithm using ant-colony in order to reach its destination. The next hop cluster head is selected based on the modified probabilistic function given by Equation 4.4. Selection of cluster head with in each cluster is based on the Equation 4.5 [66].

Table 4.2: Hello Packet Structure

τ_i	$BANID_i$	$E_{current}$

$BAN\ ID_i$	$MDC\ ID_j$	NSC	D_{ij}	$Ph_{current}$	$E_{current}$	Seqnum	Ant_visitednode	TTL	CostFunction(i,j)

Figure 4.1: Packet Structure of forward Ant traversing

$$Modified \quad Probability \quad function = \frac{D_{ij} * \alpha + [P_{ij}(t)] * \beta * \tau_i}{\sum_{i=0}^{N} D_{ij} * \alpha + [P_{ij}(t)] * \beta * \tau_i} \tag{4.4}$$

$$P_{ij} = \frac{(\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta}}{\sum_{l \varepsilon U} (\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta}} \tag{4.5}$$

Cluster Head Probability P_{ij} gives the probability of each node to be next cluster head.

4.3.3 Backward Ants

After forward ants reach the destination, the NSC or MDCs extract and do the processing of the received packets.The backward ant add the information about the source node header, destination data header and stack value and send back to the source node in the same path which is trying to adapt to any changes in the network. During its transmission, if any link failure occurs, it is capable of searching for an alternate path by contacting the routing table. The packet structure is shown in Figure. 4.2.

Ant_visitednode	$Ph_{current}$	Hops Count	$E_{current}$	Last update time	D_{ij}

Figure 4.2: Packet Structure of Backward Ant

4.3.4 Route Discovery

Route discovery is the process of generating the shortest-minimal energy route between the source BAN and the destination MDCs or NSC. It uses two types of control packets called forward ant and backward ant as mentioned earlier. An ant starting from source moving in forward direction is called forward ant and the same ant returning from destination to the source BAN is called the backward ant. A forward ant establish shortest path from BAN to destination MDCs or NSC and the backward ant establishes a pheromone track from MDCs to source BAN, using the path formed by forward ant. A forward ant of a unique sequence number is broadcast from the source BAN device till it reaches the destination MDC or NSC through the intermediate cluster head devices of the network.

In Algorithm 6, forward ant carries a routing vector that contains intermediate MDC ID's of the route. A device receiving the forward ant, finds its neighboring nodes using the adjacency matrix of the network and computes probability function values of the connections to find its next cluster head level by level. Then the ant is forwarded to next device of highest probability value connection and adds current device ID to the routing table. When forward ant reaches the destination device, it resends the ant in the backward direction called the backward ant and that follows the routing vector ID's to reach the source. The backward ant deposits the pheromone trial and updates the pheromone value on the connections in the path. Thus a path is established from source BAN to destination MDCs or NSC and data can be sent along the path.

Working of the route discovery by the ants is as follows:

- Forward ants start from source device and broadcast to its neighbor devices

Algorithm 6: Tasks done by the other nodes

```
if an ant arrives at node i then
    if node i is not a CH then
        if there is a CH then
            pick a CH neighbor using Equation 4.4 send the ant to
            it;
        else
            store the ant;
            braodcast a message regarding the cluster head to all other
              nodes in the cluster;
    else
        if node i is a CH then
            decrement the value of TTL (maximum number of
              hops) of the ant;
            if (TTL > 0) then
                pick a next cluster head neighbor according to the
                  probability function using Equation 4.5 choose the
                  highest probability function and add current node
                  ID to the routing vector send the cluster ant to it
                  Forward the next hop ants;
            else
                destroy the ant;
```

using probability function of choosing cluster head based the pheromone and energy values at each node until destination is reached.

- Source BAN waits for the backward ant. If it has not received within the timeout period, it generates a new forward ant of a new sequence number and broadcasts it to its neighboring devices. If it has received within the timeout period, then a path is established and the process is repeated based on the formula 4.6 below to get a shortest path. The count of the iterations is calculated based on the Equation 4.6.

$$Iterations \quad count = 0.5 * \frac{current \quad iteration \quad number}{total \quad number \quad of \quad iterations} \tag{4.6}$$

4.3.5 Route Maintenance

Route maintenance phase is responsible for maintaining the path that has been generated and established in the route discovery phase. Whenever data packets are transferred between BANs and the destination nodes, either MDCs or NSC in the path discovered, the pheromone is incremented so that the shortest path obtained in the route discovery phase is sustained. An acknowledgment is sent by the destination to the source for the packets received. If a node doesn't receive the acknowledgment within a timeout period, then a route error message is transmitted to the previous node. This module works as per Algorithm 7.

Algorithm 7: Updates after time expires

if $ant\_position \neq target$ **then**
  moveTo($ant\_position + target$);
  leavepheromones ($terrain$);

UpdateType($terrain, caves, foodsources$);
nextMove($terrain, caves, foodsources$);

Route maintenance is also required when the network topology changes with time and also the route between the nodes has to be modified. Whenever there is a change in the network topology, the position of current BANs and MDCs is obtained from the NSC and the route discovery phase is restarted.

4.3.6 Route Failure Handling

This phase is responsible for handling route failure cases and generate alternative routes. Every packet is associated with an acknowledgment before the time expires. If a BAN does not receive an acknowledgement for a specific packet it has sent, it means that the connection has failed. Once the BANC detects the connection is failed it sends a route error message to the source BAN and terminates and gets removed from the routing table by marking this path, setting the pheromone value to zero. Now the previous BAN tries to find out an alternate path to reach the MDC. If an alternate path exists then the packet is sent to that path as per the Algorithm 8. Otherwise the BANC informs its neighboring MDCs to forward the packet back towards the source BAN. Once the packet reaches the source BAN, it calls for a new route discovery phase. Since multiple paths are generated, even if the optimal path fails, ant-colony algorithm chooses the next best path by considering the next highest pheromone value and maximum residual energy. Thus the proposed algorithm doesn't break down on failure of connections.

Algorithm 8: Route Failure Handling

if *node is dead* **then**
  An alternate path exists from the current node to MDC;
  Look at the routing table to send packets through other route;
if *packet not reached in time* **then**
  Pheromone ← 0;
  send route failure error message to BAN;

Table 4.3: Routing Table

α	β	cost function	path
5	1	2.41796809	A-D-F-G
0.5	1	1.991703487	A-D-C-G

4.4 Example to demonstrate cluster based ant-colony algorithm

The following example illustrates the operation of the proposed algorithm as per Figure 4.3 (7 nodes). In this figure, we consider each node to be the cluster head in that particular terrain for an instance of time. The next hop is selected based on the modified probability function given by Equation 4.4. For each cluster, E represents energy of the cluster head and value on the edge represents pheromone value of the cluster head.

Table 4.3 represents different values of α and β. The mathematical experiment using the cluster based ant-colony algorithm shows that the cost function is minimum for α and β for 0.5 and 1. Thus, the path is A-D-C-G.

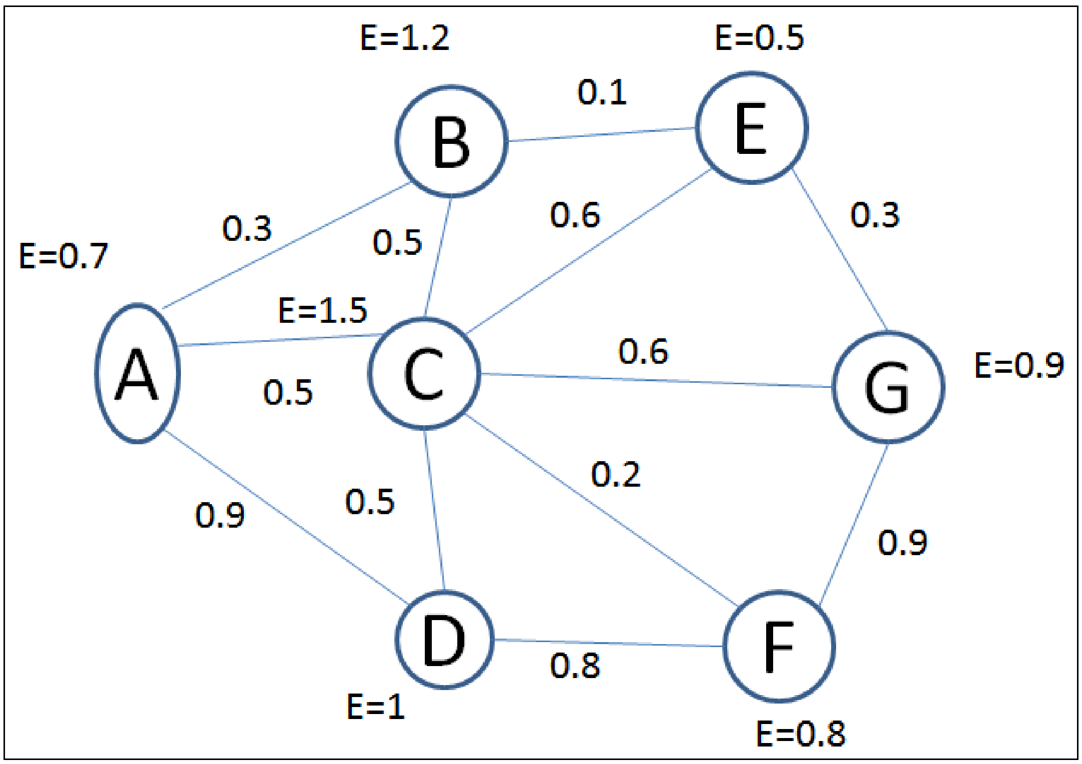


Figure 4.3: Cluster based with ant-colony example

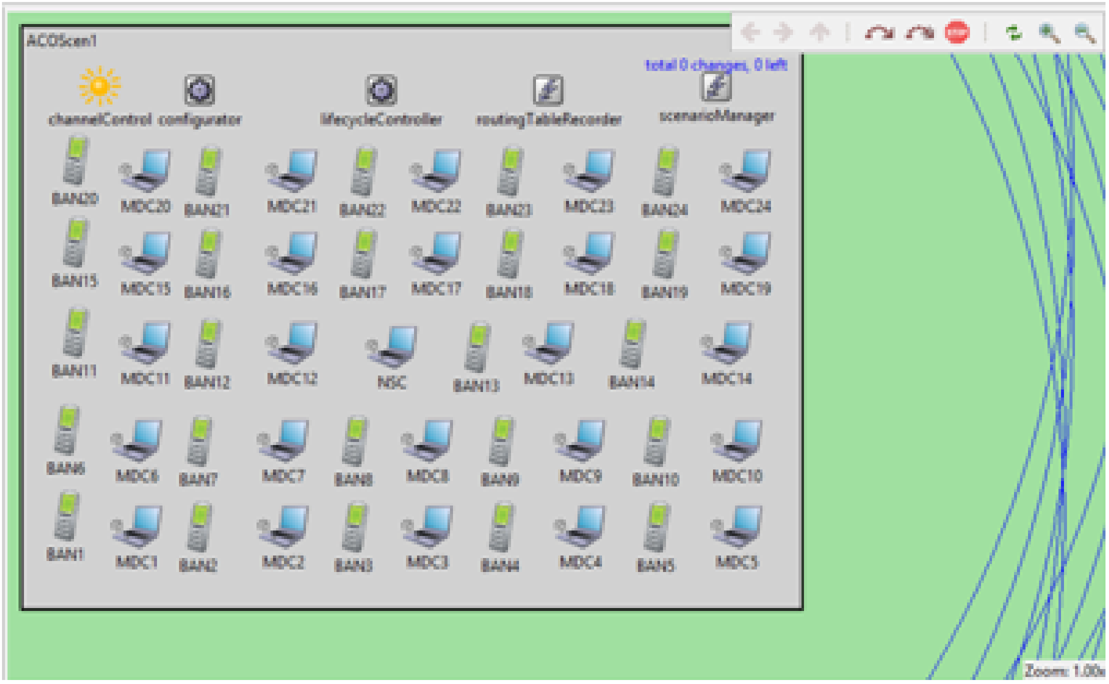


Figure 4.4: Deployment of 49 Nodes with NSC at the centre node

4.5 Simulation Model

In this section, we present the simulation of cluster based ant-colony algorithm for data routing in WBAN for 49 nodes as shown in Figure 4.4.

Extensive simulations in OMNeT++ have been performed in order to show the performance of the proposed extensions to the ant-colony based WBAN routing protocol to handle critical information for successful transmission without any link failure hence to increase the overall network lifetime. In this protocol, the system model is similar to ZKBAN [52] while the default values of α, β and pheromone values are set to 0.5, 1.0 and 1.0. Simulations have been carried out for 50 runs on an average to obtain the simulation results.

Table 4.4: Simulation Parameters

Deployment	Area	21m*21m
	Deployment type	Variable packets
	Number of nodes	49 nodes (24 BANs, 24 MDCs, 1 NSC)
	Initial node energy	18720 J (2 AA batteries)
	Buffer size	32 packets
	Transmit power	-25dBm, -15dBm, -35dBm
Task	Application type	Event-driven
	Max. packet size	80K packets
	Traffic type	CBR (Constant Bit Rate)
MAC	IEEE 802.15.4	Default values
Simulation	Time	1000 msec

4.6 Performance Evaluation and Results

The OMNeT++ based simulator is used to perform the experiments of proposed algorithm for WBAN using Table 4.4. We simulated the experiment by using 49 nodes with variable packets that simulate a real hospital environment. Successful transmission rate, overall energy consumption, traffic load are measured for all the nodes.

The results of the simulation are shown below, which shows the lifetime, throughput and energy of the different sets of cluster heads in the WBAN. Here nearly 5% cluster heads of total network nodes are more energy efficient and also throughput is good compared with Anybody and ZKBAN protocols.

Figure 4.5, shows the network lifetime for the cluster based technique. It is evident that the network lifetime of the proposed method is almost twice that of other algorithms. The reason is that clustering of devices dynamically chooses a given path to transmit data which can greatly contribute to reducing the energy

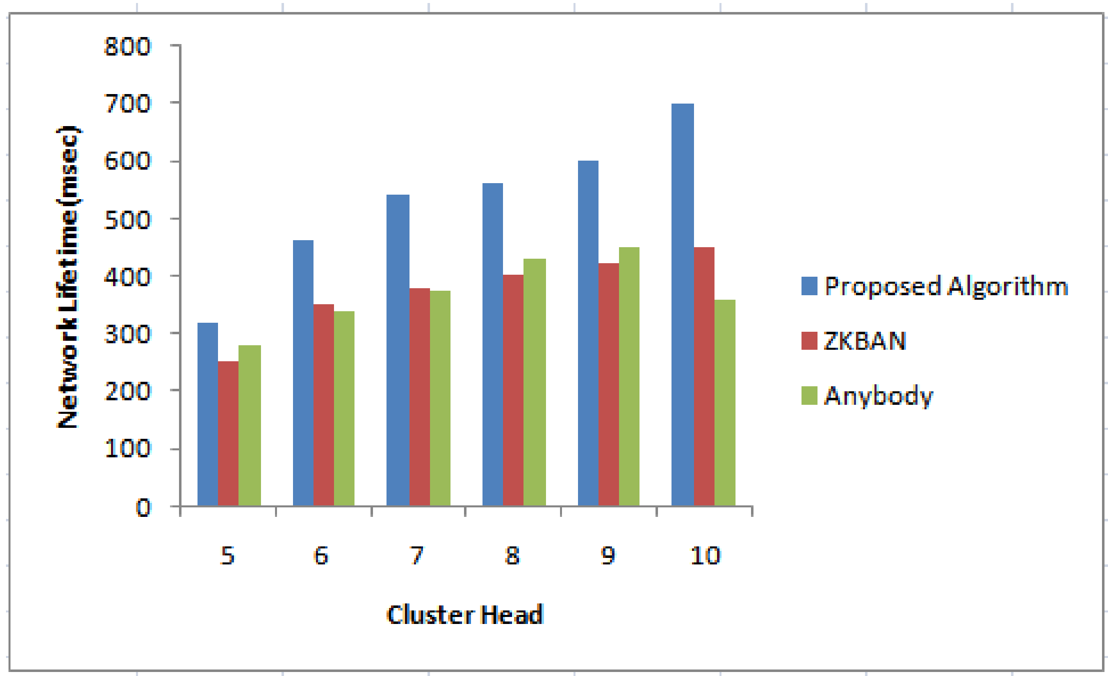


Figure 4.5: No.of clusters Vs Lifetime of the network

consumption and achieving load balancing among all the nodes.

Figure 4.6, illustrates the higher throughput with clustering. It proves to be better than the ZKBAN and Anybody algorithms. Figure 4.7, represents the energy consumption by varying the number of clusters in the network. The results prove that the energy consumption is less when compared to the ZKBAN and Anybody algorithms.

In Figure 4.8, the average energy of the proposed algorithm is higher than the other algorithm. This indicates that there exists more residual energy on the nodes in this algorithm, which implies the proposed algorithm needs less energy for transmitting data.

Figure 4.9 shows a linear increase in energy consumption as the network becomes denser that as is sensor nodes increase. This increases the traffic the network. However, the proposed algorithm out performs the existing algorithms.

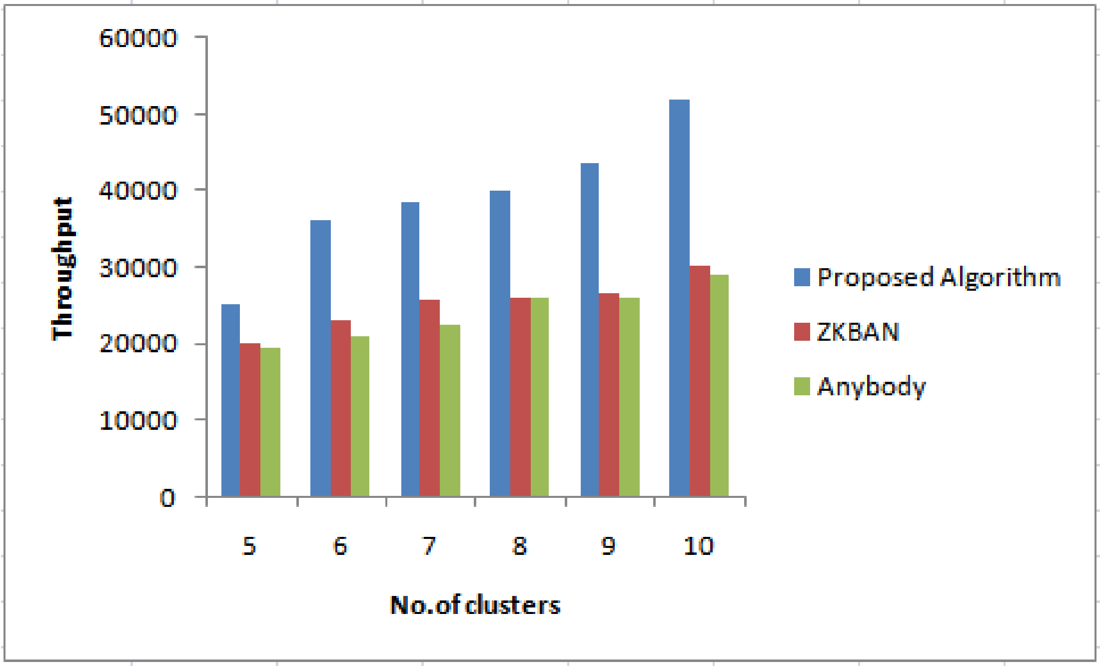


Figure 4.6: No.of clusters Vs Throughput

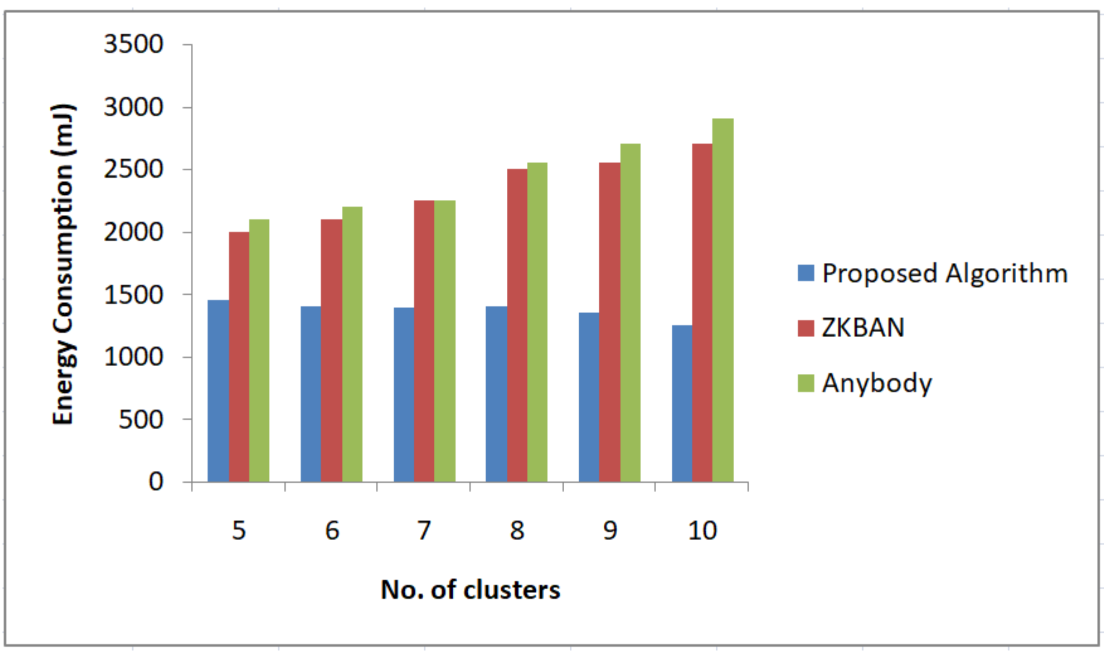


Figure 4.7: No.of clusters Vs Energy Consumption

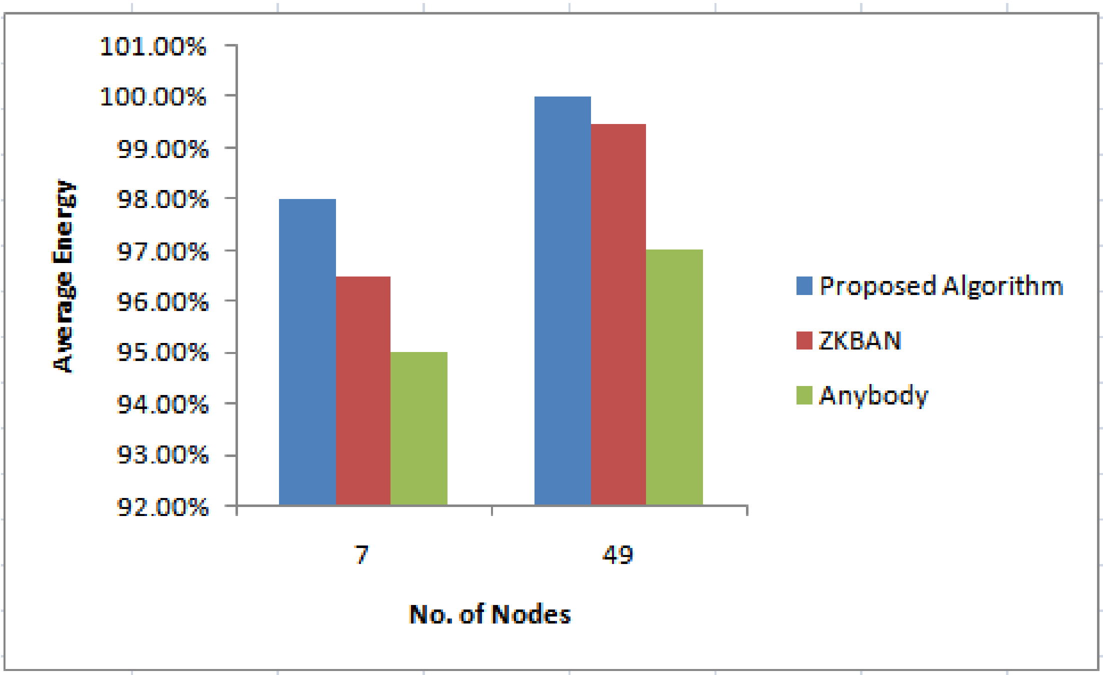


Figure 4.8: Average Energy

Table 4.5: Comparison of routing protocols without cluster using ant-colony algorithm

	Proposed algorithm	ZKBAN	Anybody
Network Lifetime (msec)	350	303.033	250
Energy Consumption (mJ)	295	350	310
Throughput (Packets/msec)	32279	25000	28000
Latency (msec)	0.4msec	1min	0.9msec

In Figure 4.10, when compared with other algorithm, we observe a significant reduction in standard deviation. This indicates it can efficiently balance the energy consumption on all nodes. Tables 4.5 and 4.6 represents the performance of routing protocols without and with cluster head techniques on average of 50 runs of the algorithm.

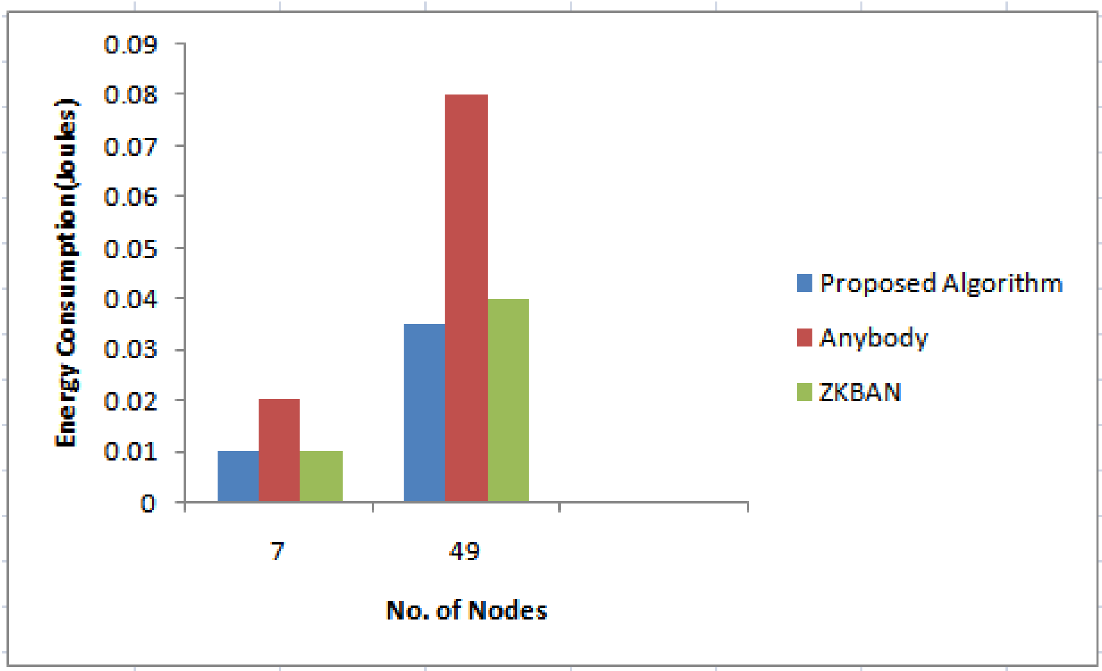


Figure 4.9: Energy Consumption

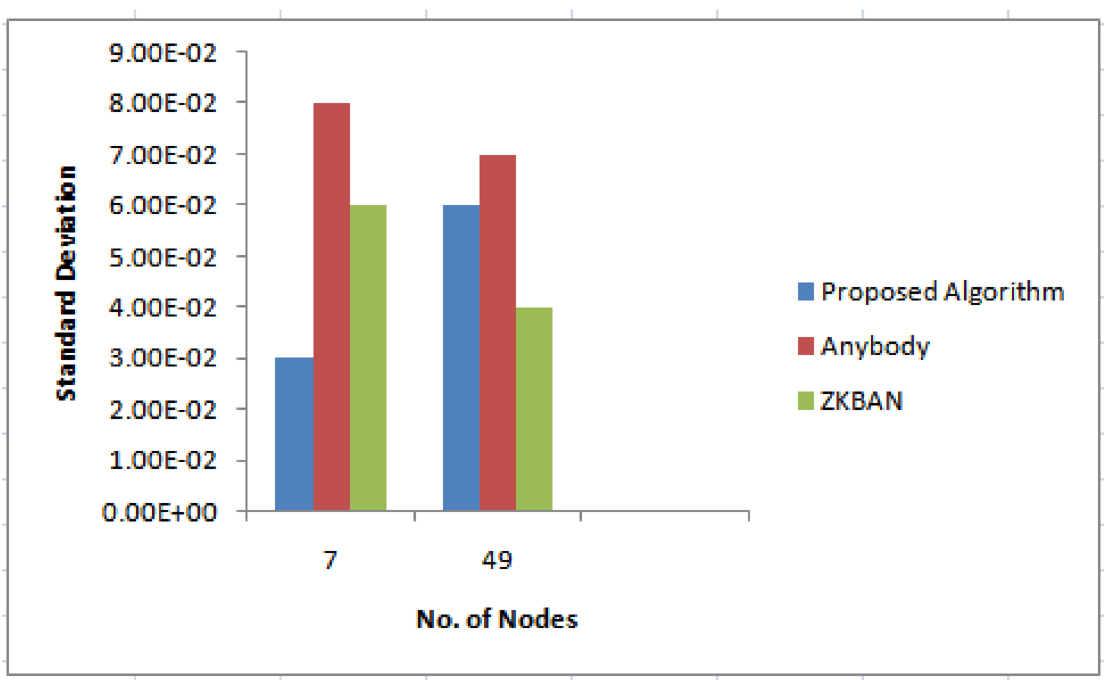


Figure 4.10: Standard Deviation

Table 4.6: Comparison of routing protocols with cluster using ant-colony algorithm

	Proposed algorithm	ZKBAN	Anybody
Network Lifetime (msec)	400	320	300
Energy Consumption (mJ)	180	450	300
Throughput (Packets/msec)	33000	24000	29000
Latency (msec)	0.7msec	3min	2min

4.6.1 Time Complexity

During the inter cluster formation, when ants travel from source to destination, the BAN's join and leave, only when the data needs to send to sink node. Due to these properties of inter cluster and intra cluster WBAN communication, its computation costs are relatively minimum.

In cluster based ant colony algorithm, the number of cluster rounds is equal to the network size. The total number of election of cluster head depends upon the network size and it is almost N. For network size N, the average number of cluster head node performs is 2S/N , where S is the sum of all probabilities and N is the network size.

So the computation complexity of the proposed work is $O(d^2/N)= O(n^2)$

In cluster ant colony algorithm, when establishing the network, each cluster head in the cluster must broadcast messages to his neighbors in order to inform them its election of cluster head in each round. Therefore, the complexity is $O(n^2)$.

where d is the degree of connectivity.

4.6.2 Discussion

In the previous chapter, ant-colony algorithm was compared with ZKBAN. It was found that the improvement obtained in various parameters was only marginal, that is only 10% improvement. However, it can be seen from Figures 4.5, 4.6,4.7, 4.8, 4.9, 4.10, that after clustering the nodes and using the technique described in this chapter, the parameter improvement has been significant with 45% higher throughput and 40% reduced network traffic while also choosing the shortest path.

4.7 Conclusion

In this chapter we proposed a cluster based ant-colony algorithm which is able to find an optimal way of choosing the next hop by clustering using a modified ant-colony probabilistic function based the pheromones and residual energy in each node. This approach monitors the patient data continuously and sends it to the base station through MDCs which act as cluster heads. The proposed technique has been simulated in OMNeT++ simulator and compared with ZKBAN and Anybody in terms of network lifetime, latency, energy and throughput. It has been observed that our algorithm has better performance than ZKBAN and Anybody.

Chapter 5

Ant-Colony with Breadth First Search Algorithm for Route Discovery in WBAN

5.1 Introduction

Since Wireless Body Area Networks (WBANs) are ad-hoc networks that consist of a few to hundreds of sensor nodes (including MDCs), coverage is an important issue in WBANs. It gives a measure of quality of surveillance WBAN provides over a field it is designed to monitor. When channel (edge) failures occur, the connectivity of the network is broken and ants cannot visit all the nodes in the network.

A WBAN can be modeled with a graph, $G = (V, E)$, where V is the set of nodes and E is the set of edges. Breadth First Search (BFS) [67] is a fundamental graph traversal algorithm which starts from the source node and search proceeds in breadth-first manner. Firstly the source node is visited; then all neighbor nodes of the sink node are visited. This operation continues, until there is no unvisited node in the graph. This search helps the ants to traverse the complete network and check whether they visited all nodes at least once. This helps in avoiding trapping or looping in the network. There are many BFS based approaches to construct a shortest path tree [68],[69]. .

Breadth First Search (BFS) is an important building block of many traversal algorithms and it is mostly used to test connectivity or compute single source shortest paths of the graphs. Starting from the source vertex, the entire terrain expands outwards during each step, visiting all of the vertices at the same depth before visiting any other at the next depth. During search, each vertex checks all of its neighbors to see if any of them are unvisited. Each previously unvisited neighbor is added to the list and marked as visited by the ants.

The majority of the computational work in BFS involves checking the edges of the terrain to see if the endpoint has been visited. This approach helps when the network is large in size and vast majority of the runtime exists. In such scenarios however, there is also a high consumption of energy. Failures occur when the neighbor has already been visited and these can be broken down which leads to drop of packets.

5.2 Related Work

Significant work has been done by others [58],[34] to evaluate the routing using ant-colony based algorithms for data transmission. They focused, for example, on multi-path routing [58] using three types of ants where they improved the reliability of data transmission and network lifetime but the algorithm had large overhead to find the best paths. Other algorithms [34] tried to address the link failure which is very common in WSNs, where more number of transmissions occurs due to back and forth nature of data which leads to failure of message at the destination and hence reduction in network bandwidth range and wastage of energy. They implemented using three ant agents in order to address the issue of link failure by using ant-colony algorithm with Breadth First Search (BFS) for effective data transmission. But they failed to address the issue on the quality of the ant trip during exploration i.e. data discovery phase.

In this chapter, we implement ant-colony based BFS to address the issue of link failure along with the quality of the ant's trip. The quality of ant's trip is very critical during data discovery phase to check whether it covered all nodes in the system to know the goodness of network conditions. It is very important to check the quality of the ants trip for the best path which makes the network stable and adaptive. Here it is done by keeping reinforcement value (r), whose values lies between 0 or less than or equal to 1[70], to be constant which in turn depends incrementing the pheromone values. The pheromones are updated based on the trip time of the forward ants which in turn is proportional to its length from the number of hops and the network load along the route. The same value of r is used by the backward ants to update the pheromone values.

This makes sure that, for any traffic load conditions at WBAN, a path receives one or more reinforcements which must be better than the explored paths. Using this procedure, quality paths can be computed by looking only at the frequency of ant arrivals.

5.3 Preliminaries

Given a distinguished "source vertex" S, BFS systematically explores the graph G to discover every vertex that is reachable from S. Let V and E refer to the vertex and edge sets of G, whose cardinalities are $n = |V|$ and $m = |E|$. We assume that the graph is unweighted; equivalently, each edge e ϵ E is assigned a weight of unity. A path from vertex s to t is defined as a sequence of edges $\langle u_i, u_{i+1} \rangle$ (edge directivity assumed to be $u_{i+1} \leftarrow u_i$ in case of directed graphs), $0 \leq i \leq l$, where $u_0 = s$ and $u_l = t$. The length of a path is the sum of the weights of edges. We use $d(s,t)$ to denote the distance between vertices s and t, or the length of the shortest path connecting s and t. BFS implies that all the vertices at a distance k (or "level" k)from vertex s should be first "visited" before vertices at a distance K+1. The distance from s to each reachable vertex is typically the final output[71].

5.4 Breadth First Search Technique

Traversing based algorithm for node proximity works by using Hierarchical control clustering algorithm. In this algorithm, two phases, tree discovery and cluster formation, are involved. In tree discovery phase, Breadth First Search is used in order to search whether each and every node is visited once or not.

This technique uses queue to store the nodes of each level of the graph as they are visited. These stored nodes are then treated one by one and their adjacent nodes are visited. It gets terminated when the queue is empty. The ants that travel along the network have three states with respect to the current node status. The field 'Node-Status' will keep an account of the states of the nodes.

A node that has not been visited yet and waiting to be processed will be in ready state. Initially all nodes will be in ready state. As soon as the node is added on to the queue, it will be in waiting state.The node that has been processed i.e. whose neighbors have been added on to queue will be in processed state. Nodes that have been processed once will not be considered again. Thus the field visit in a table will keep an account of it. In the beginning, all nodes will have zero in visit field but as soon as the node is visited the value gets updated to 1.

5.5 Implementation of Breadth First Search Technique

Wireless Body Area Networks (WBAN) consist of many nodes connected for regular monitoring of physical parameters that are sent to the base station continuously. Routing of the critical and sensitive data and data aggregation is very important in WBAN. During this process, searching the neighbors to know whether they have been visited or not at least once during the route discovery helps the ants to find the suitable and good path.

5.5.1 Forward Ants

The forward ant has the responsibility of finding the best and shortest path by looking up the routing table. Ant considers the distance between the current node to its neighbor nodes and the distance of all the nodes from the sink i.e. NSC which is placed at the center of the Figure 3.4, shown in Chapter 3 . It is important for an ant to know each and every length between the nodes and the

Table 5.1: Routing Table

BAN_i	MDC_i	$D_{(i,Dest)}$	$P_{current}$	$D_{(CH,dest)}$	$Ant_{visitednode}$	D_{ij}

Table 5.2: Packet Structure of Backward Ant

Ant_Visitednode	$ph_{current}$	Hops count	$E_{current}$	Last update time	D_{ij}

sink as shown in routing Table 5.1.

Where,

BAN_i, MDC_i are the identification numbers of the devices,

$D_{(i,Dest)}$ is the distance between current node and the base station,

$P_{current}$ is the current pheromone value of the node,

$D_{(CH,Dest)}$ is the distance between cluster head and the base station

$Ant_{visitednode}$ is the node that just visited and

D_{ij} is the distance between i and neighbor node.

The forward ant moves to next level by choosing the next cluster head based on the Equation 4.4 given in Chapter 4.

5.5.2 Backward Ants

After the forward ants reach the destination, the NSC or MDCs extract the packet and carry out the processing of the received packets. The destination nodes add the following information about the source node header, destination data header and stack value and send them back to the source node in the same path which is trying to adapt to changes in the network. During its transmission, if any link failure occurs, it will search for an alternate path by contacting the routing Table 5.2.

5.5.3 Route Discovery

If ants are placed at wrong position, it is harder for them to find and collect the food in the terrain. This mostly happens when some of the nodes die due to their energy consumption after the transmission which could be failure of a node that results in starvation. This leads to reduction in lifetime of the network. Thus keeping this problem in view, we implemented Breadth First Search in ant-colony algorithm to overcome the problem of trapping during route exploration. This process is used to explore the neighbour nodes i.e. MDCs from source node BANs to destination node level by level, as per Algorithms 9 and 10. This process continues until it finds a specific solution.

Algorithm 9: Breadth First Search

```
BFS Positionsource, Positiontarget
Given G(V, E) represented in terms of adjaceny lists
and source vertex sϵV, find d(υ)≡ d (s,υ) for all υ ϵ V.
Initialize: d(s) ← 0 ;
Queue ← {s};
d(υ) ← ∞ ;
push source node into currentQueue;
source Distance ← get distance between source and target;
while Queue ≠ ϕ do
    for node in the currentQueue do
        pop a vertex from the left end of Queue ;
        examine each vertex neighbours if
         BFS_next (position, target) < sourceDistance then
            increment the hopcount from source vertex ;
            returnposition;
    if (nextQueue == 0) then
        return position;
        currentqueue ← 0;
        currentqueue ← nextqueue; nextqueue ←; 0;
    return position;
```

Algorithm 10: BFS-NEXT

```
BFS_nextPosition next, Position target
scaned.push_back(next);
for i in moves do
    Position scanedPosition = next + possibleMoves[i];
    if scanedPosition.getX() < 0 || scanedPosition.getX() ≥ getWidth() ||
     scanedPosition.getY() < 0 || scanedPosition.getY() ≥ getHeight()
     then
        continue;
    if checkForWater(scanedPosition) then
        continue;
    if !isScaned(scanedPosition) then
        nextQueue.push_back(scanedPosition);
```

5.6 Illustration of Breadth First Search in WBAN

Figure 5.1 represents a network where ants travel from source to destination. During this procedure, they search whether ants visited all the nodes or not. Assume source node wants to send data to the destination node. During route traversal, ants use BFS for search process. Node A is the source node and G is the destination node.

shown below is the adjacency list for Figure 5.1.

A_A={B,C,D} A_B={A,C,E} A_D={A,C,G} A_C={A,B,E,F,G,D} A_E={B,C,F} A_F={E,C,G} A_G={F,C,D}

Table 5.3 presents the route traversal of the ant from source to destination using BFS to check whether all ants have covered or not.

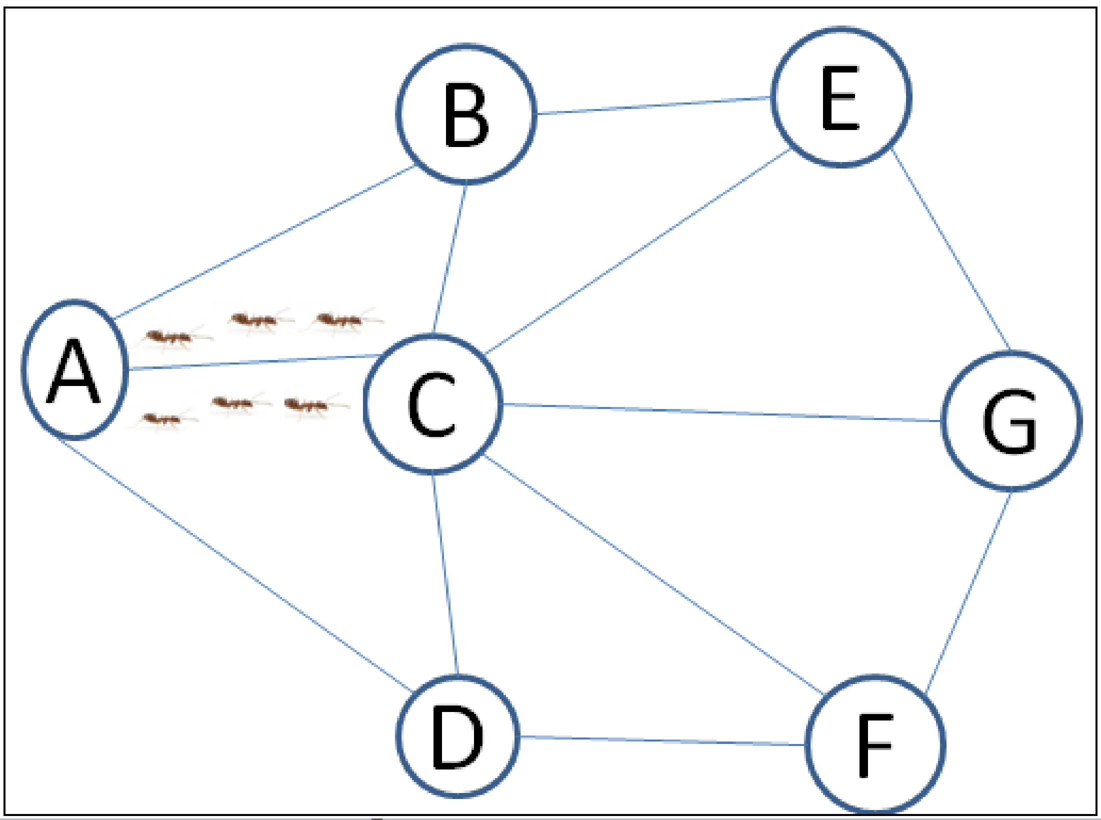


Figure 5.1: Breadth First Search ant-colony Example

Table 5.3: Breadth First Search - Example

υ	ω	Action	Queue
-	-	start	{A}
A	B	set d(B)=1	{B}
A	C	set d(C)=1	{B,C}
A	D	set d(D)=1	{B,C,D}
B	E	set d(E)=2	{C,D,E}
B	A	none,d(A)=0	{C,D,E}
B	C	none	{C,D,E}
C	A	none, d(A)=0	{D,E}
C	B	none	{D,E}
C	E	none	{D,E}
C	F	set d(F)=2	{D,E,F}
C	G	set d(G)=2	{D,E,F,G}
C	D	none	{D,E,F,G}
D	A	none, d(A)=0	{E,F,G}
D	C	none	{E,F,G}
D	G	none	{E,F,G}
E	B	none	{F,G}
E	C	none	{F,G}
E	F	none	{F,G}
F	E	none	{G}
F	C	none	{G}
F	G	none	{G}
G	F	none	{}
G	C	none	{}
G	D	none	{}

5.7 Complexity Analysis

In the following section, we state and prove the message, time, space and computational complexities of all ant-colony algorithms with BFS.

5.7.1 Message Complexity

Assuming, N is the node count, δ is the maximum degree of the graph and D is the graph diameter, following can be proved.

Theorem 5.7.1. *The complexity of the sent message count of the above algorithm is $O(N)$.*

Proof. In our approach, all nodes transmit one forward packet. Further, all nodes, except the base station, send one backward packet to the source node. Therefore, the total sent packet count is 2N-1. Thus, the sent message complexity is $O(N)$. □

Theorem 5.7.2. *The complexity of the received packet count is $O(\delta N)$.*

Proof. Due to the broadcast communication in the network, each ant may transmit a packet to its immediate neighbors after checking its pheromone and energy values. In the worst case, each node has a neighbor δ, except the base station. Thus, except the sink node all other nodes send backward messages, while its neighbor will receive $\delta - 1$ backward messages. Therefore, the received message complexity is $O(\delta N)$. □

5.7.2 Time and Space Complexities

Theorem 5.7.3. *The time complexity of the cluster based ant-colony algorithm using BFS algorithm is $O(D)$.*

Proof. In this algorithm ants start traversing from source node to the sink node. During this procedure, the forward messages are transmitted until they reach the intermediate nodes in the BFS tree. The maximum height of the BFS tree is D hence the time complexity of the cluster based ant-colony algorithm using BFS algorithm is $O(D)$. □

Theorem 5.7.4. *The space complexity of the cluster based ant-colony algorithm using BFS algorithm is $O(D)$ per node.*

Proof. Since each node must store its ancestor list in the worst case, a leaf node must hold a list with information of D-1 ancestors. This is because the maximum height of the BFS tree is D. Thus the space complexity of the algorithm is $O(D)$. □

Table 5.4 shows the time complexities of variations of the ant-colony based algorithm proposed in this work. The actual complexity was calculated as ($\neq$ of ants)$\star$($\neq$ max. of iterations)$\star$($\neq$ of total sensors)$\star$($\neq$ no. of nodes selected by ants). From the comparison of time complexities we observe that, the time complexity of cluster using ant-colony algorithm is least when compared to other techniques. Since the number of iterations is more for the ant-colony with clusters and BFS algorithm with cluster using ant-colony algorithm.

Table 5.4: Comparison of Time complexities of proposed algorithms for WBAN

Proposed Algorithms for WBAN	Time Complexities
ant-colony algorithm	$O(1)$
Cluster using ant-colony algorithm	$O(n^2)$
Cluster using ant-colony with BFS algorithm	$O(1)$

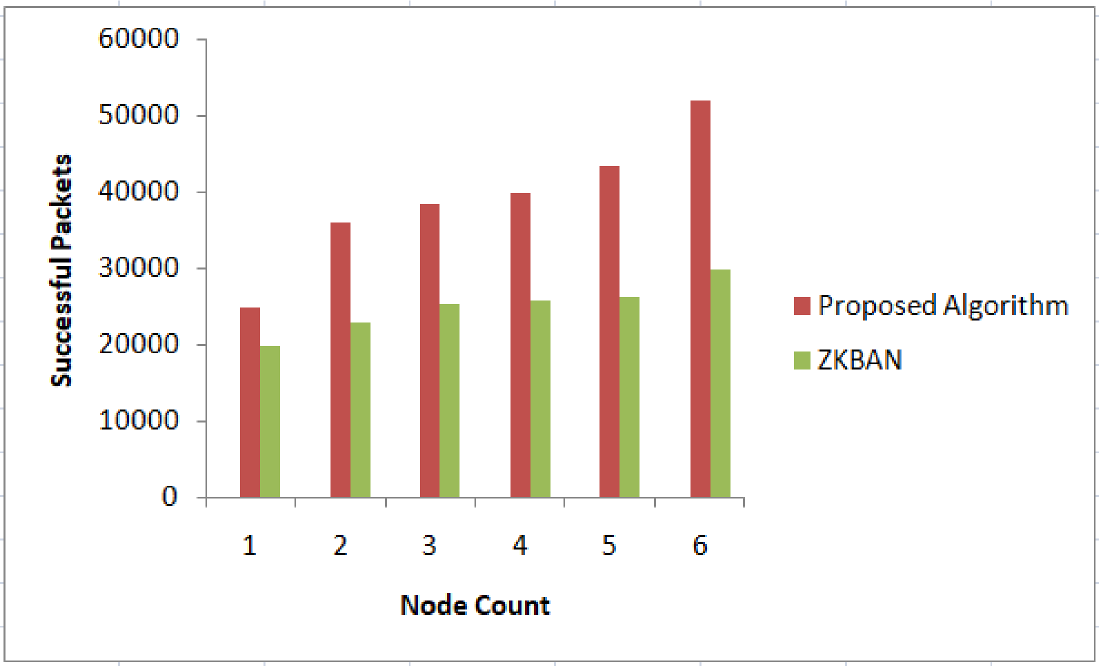


Figure 5.2: Throughput Comparison (Node count Vs Successful packets delivery)

5.8 Simulation Results

In this section, we present experimental results of cluster based ant-colony algorithm with Breadth First Search for route discovery in WBAN and compare with related work for 49 nodes. Simulations are carried out on OMNeT++. The radio range of the nodes in the network is 25m and the data rate equals 2Mbits/s.

Figure 5.2 shows the communication links between source node and the sink with high data rates. The nodes which transmit data through our proposed algorithm are allowed to send more packets than the other protocols. Thus the algorithm

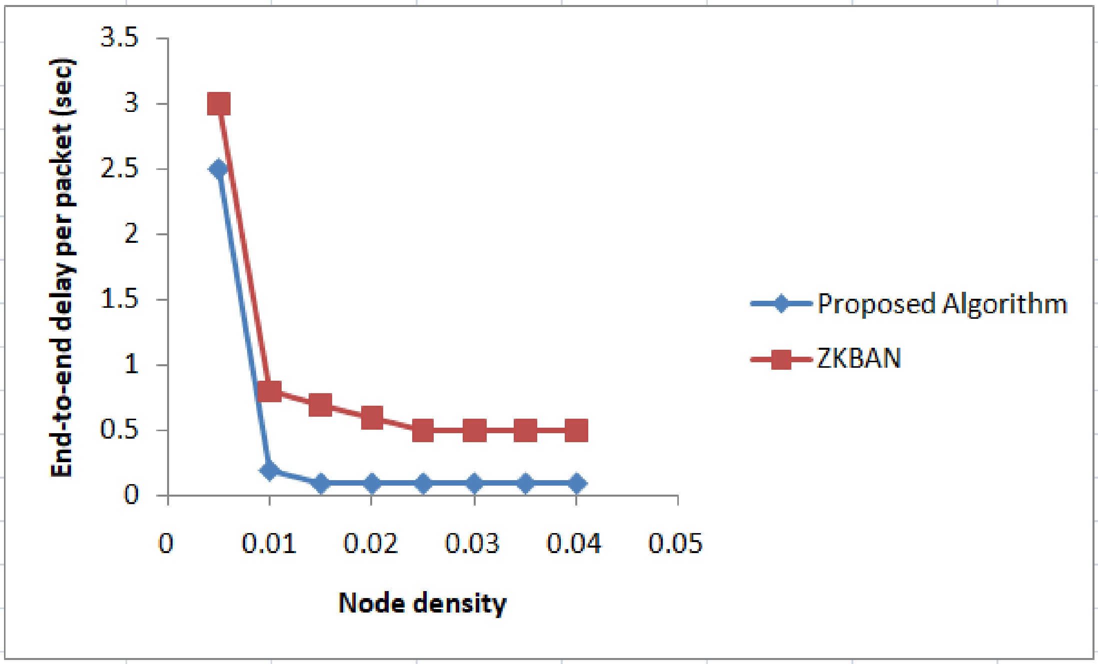


Figure 5.3: End-to-end delay analysis of WBAN using ant based and BFS (Node density (msec) Vs End-to-end delay Packets)

achieves higher throughput than the existing protocol.

Figure 5.3 presents the performance analysis of WBAN using ant based and BFS over time and residual energy. The results show the performance to be stable throughout the time. But whenever the loop occured or link failure occured, it reduces the path loss due to its multi hop transmission using BFS algorithm. Our algorithm shows an improvement in its performance on both by dropping the path-loss due to its route failure or dead nodes in the network.

Figure 5.4 compares the network lifetime computed with the proposed and existing algorithms [52]. Our algorithm shows considerably better performance since it focuses on the quality of the ant's traversal.

Figure 5.5 presents the energy consumption of WBAN using ant-colony based BFS. It consumes less energy when compared to ZKBAN.

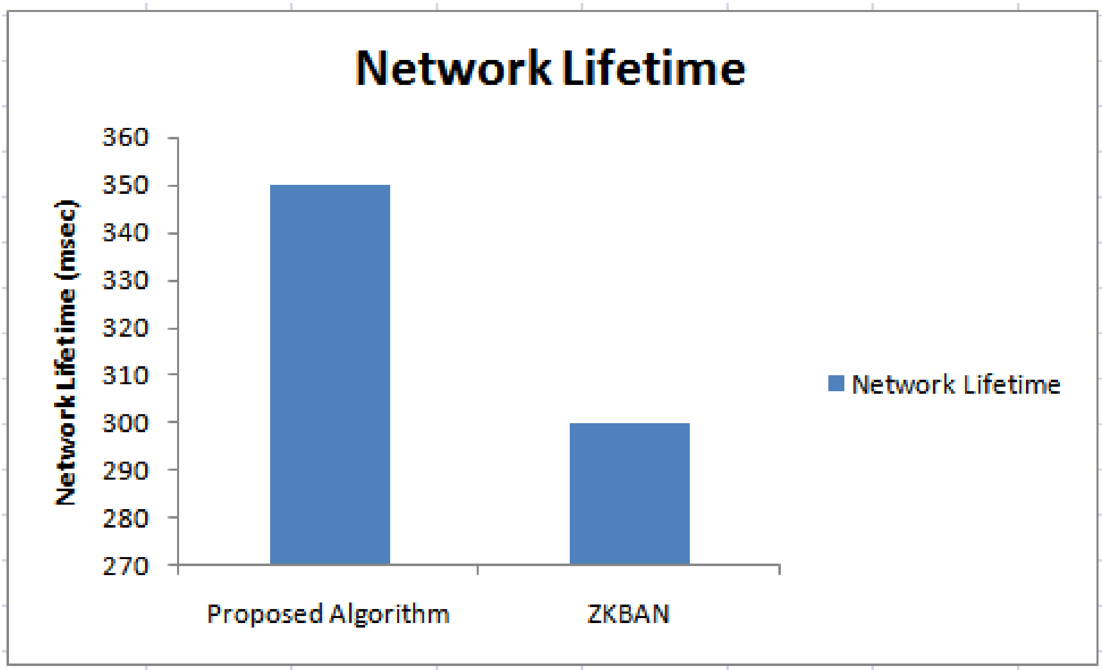


Figure 5.4: Network Lifetime

Figure 5.6 presents the comparison of proposed algorithm in terms of Network Lifetime and Energy Consumption. The results indicate that the proposed algorithm is superior than that of the existing algorithms in terms of network lifetime and energy consumption.

5.9 Conclusion

In this chapter, we proposed ant-colony based algorithm using Breadth First Search for route discovery in WBAN. During the process of route traversal, ants check whether they have visited all the nodes or not within its transmission range using quality of the ant's traversal which is based on reinforcement value. Simulation results prove the proposed algorithms to be better than the existing ones in terms of network life.

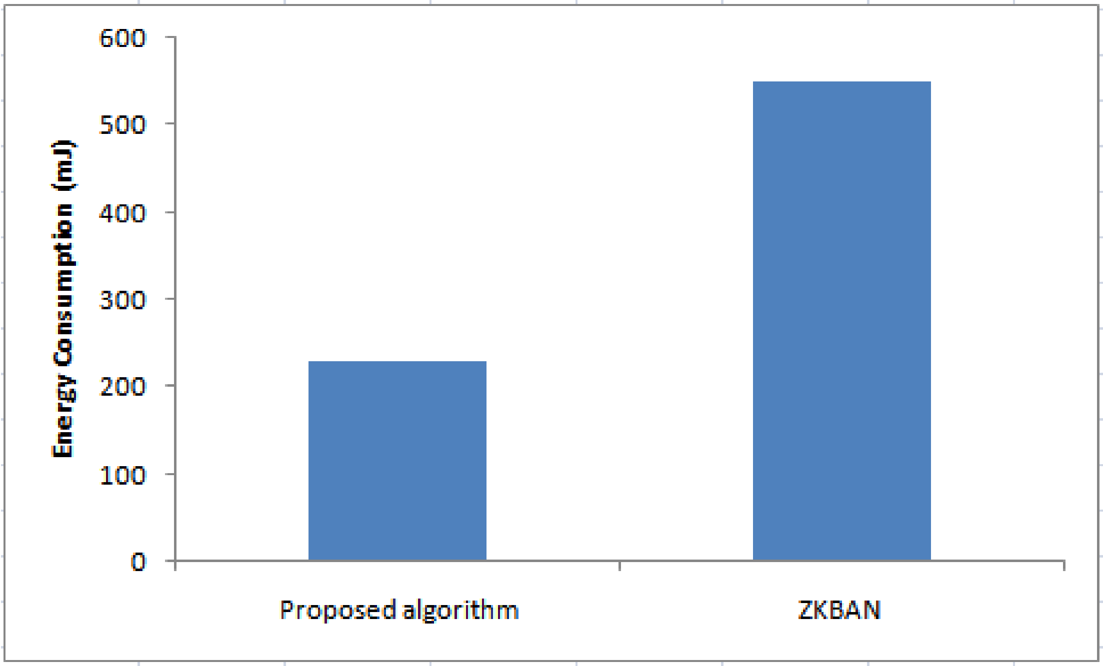


Figure 5.5: Energy Consumption

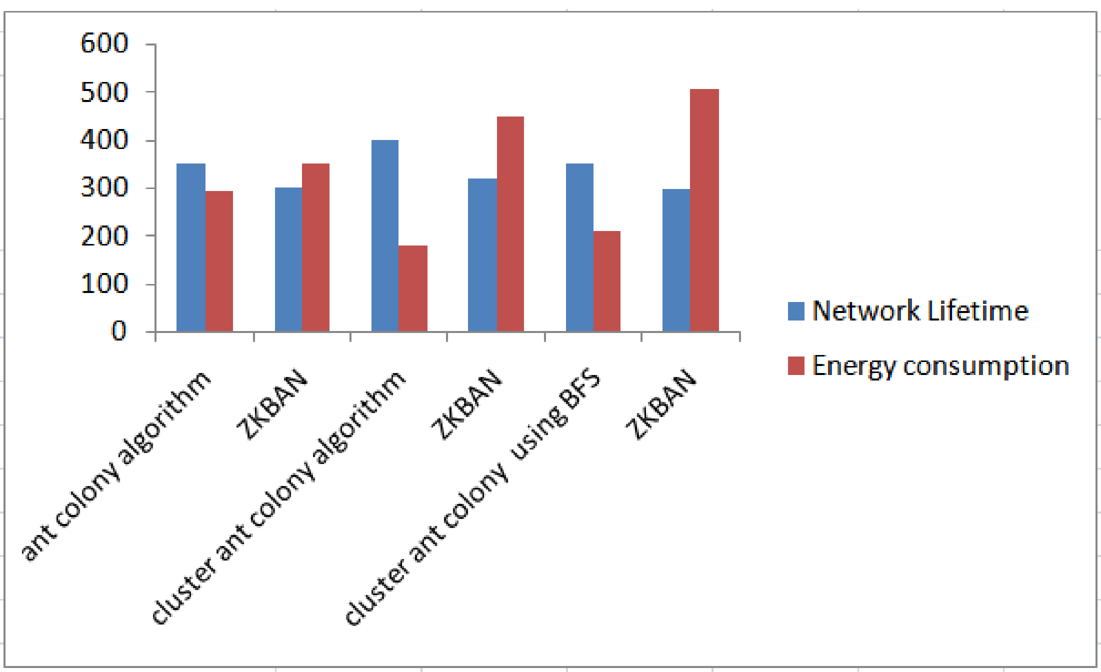


Figure 5.6: Comparison of all Proposed Algorithms with ZKBAN

Chapter 6

Conclusion and Future scope of work

6.1 Conclusions

In this chapter, major contributions of the thesis are summarized and some key directions for future work are suggested.

i. Wireless Body Area networks (WBANs) have significant potential to provide improved patient care in hospitals. Data routing in these networks is an important issue and has implications on metrics such as energy consumption, network life time, latency and data throughput, etc. In this thesis, an ant-colony based routing protocol has been developed and applied for data routing in WBAN. Results obtained indicate that this approach provides an improved performance of the BAN network in terms of all the parameters mentioned above, compared to the existing techniques. Route discovery coupled with balancing of workload for entire network results in a reduced number of transmissions which reduces overall network traffic among the intermediate nodes and thus the energy consumption. Simulation results show that the routing protocol based on ant-colony algorithm outperforms ZKBAN protocol with 10% higher throughput and 30% reduced network traffic while choosing the shortest path.

ii. Next a novel technique of cluster-based routing of data using ant-colony has been proposed so as to reduce the energy consumption during data traversal through the network. To achieve this, a modified cluster-based probabilistic function to choose next level of cluster head level by level, has been introduced. Within each cluster, nodes transmit data to their cluster head while the cluster head sends the aggregated data to the NSC.This results in higher residual energy leading to improved network lifetime. Extensive simulations in OMNeT++ based Castalia 3.2 simulator demonstrate better performance of this approach compared to 'Anybody' and 'ZKBAN', as discussed in Chapter 4. There is an improvement in data throughput of 45% due to the reduction of overall network traffic by 40% compared to these techniques.

iii. In data routing, it is important to know if all the nodes of the network have been visited at least once. A method of routing data using the well known search algorithm 'Breadth First Search' (BFS) has been proposed in this work. In this technique, we check if the forward ants traversed all the nodes during the route discovery which allows to identify any looping situations during the discovery phase. This will ensure safe path of the ants during their traversal across the network using queue. Thus, with this approach we found that the energy consumption was high when compared with the cluster based ant-colony algorithm. This is because the ants spend more time during traversal to check whether all the neighboring nodes have been covered or not.

6.2 Future Work

WBANs are predominantly used for patient care where data privacy and security are increasingly becoming important. Thus future work could focus on these issues. Also, with Internet of Things (IoT) going main stream, it would be interesting to explore their relevance to WBAN. An extension of the routing protocols could compare with other soft computing techniques with ant colony technique to know its performance in terms of network lifetime and energy consumption.

Appendices

Appendix A

A.1 Basic Simulation setup and screen shots

In this work, all sensor nodes are assumed to be stationary and with limited energy level in their batteries. We define the transmission range of each node is set to 3m. The input to the simulator is the location of nodes specified by their x and y coordinates. The energy of each sensor node is set to 2J of energy. In our experiments we assume all our devices to be stable. Sensor nodes are deployed as per the screen shots below and only one sink node is available in the network. The sink node is always assumed to have sufficient energy in its battery, which enables it to stay alive until the last node in the network dies. It is positioned in the middle where the sensor nodes are deployed.

A.2 sensor node and Network simulation

In these experiments, each simulation scenario ran for 900 seconds in an environment.

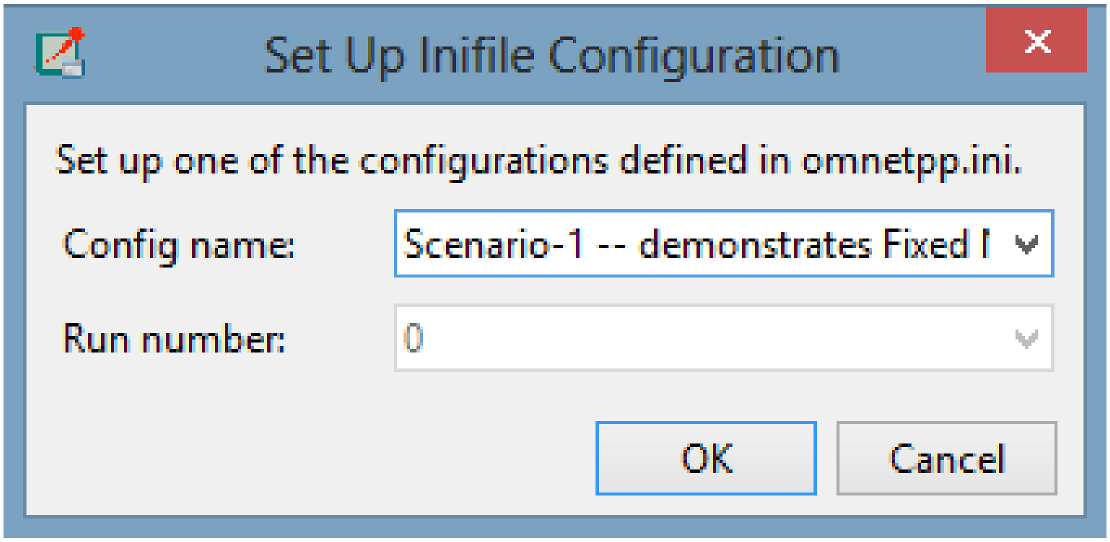


Figure A.1: screen shot of setup inifile for scenario 1- Fixed packets

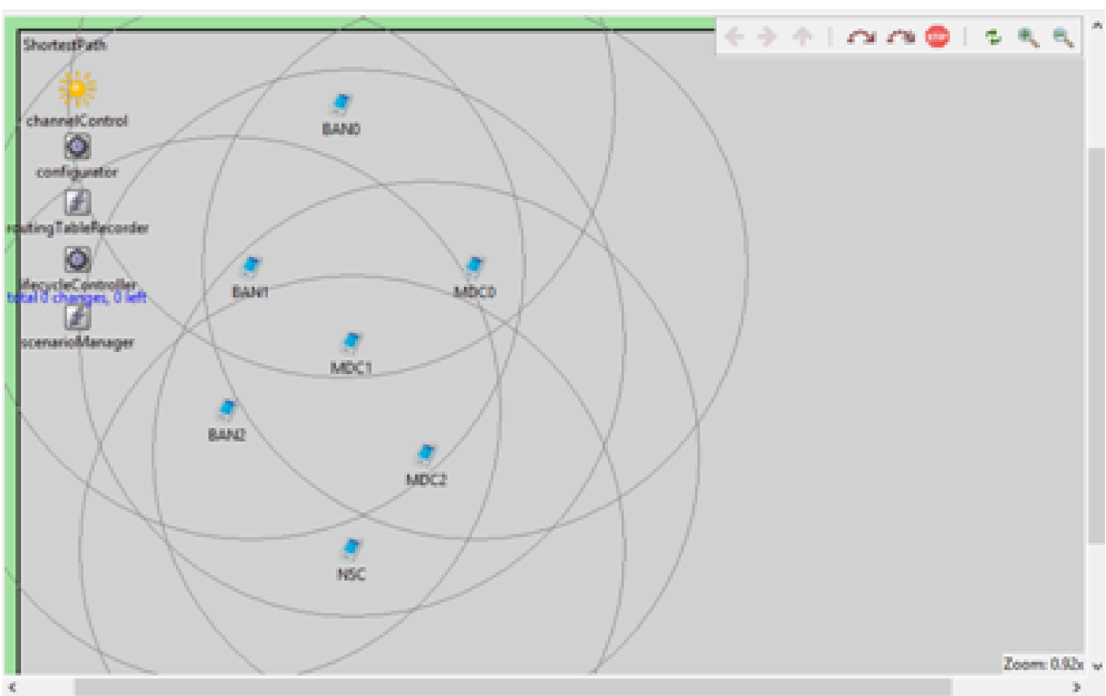


Figure A.2: screen shot of Deployment of seven nodes

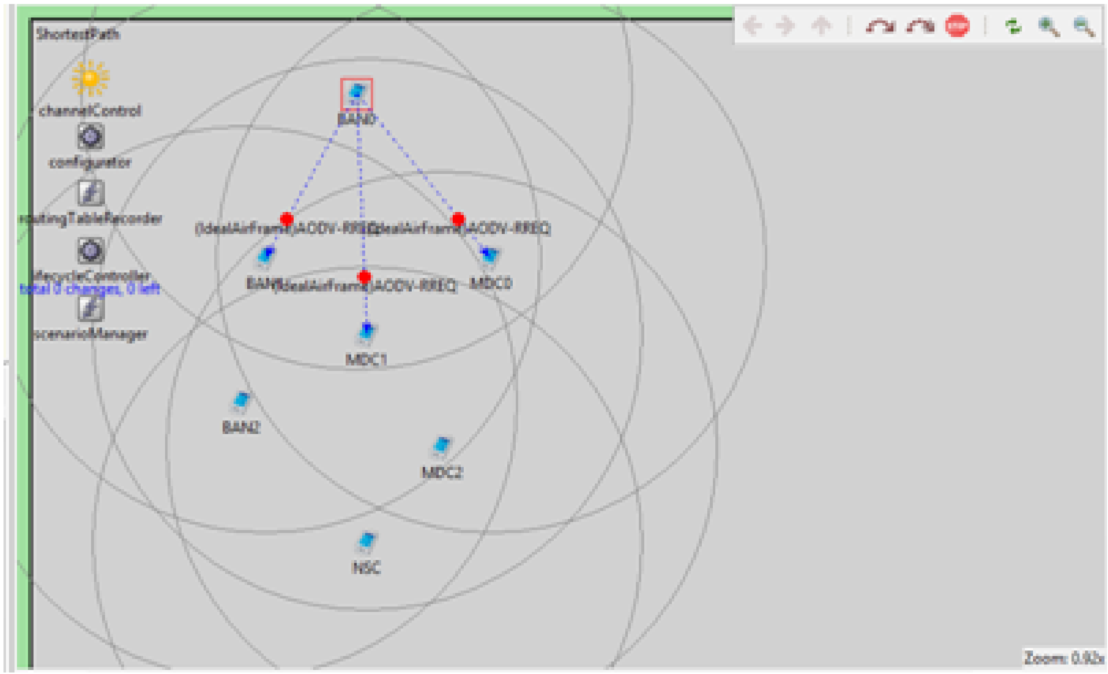


Figure A.3: screen shot of neighbor discovery

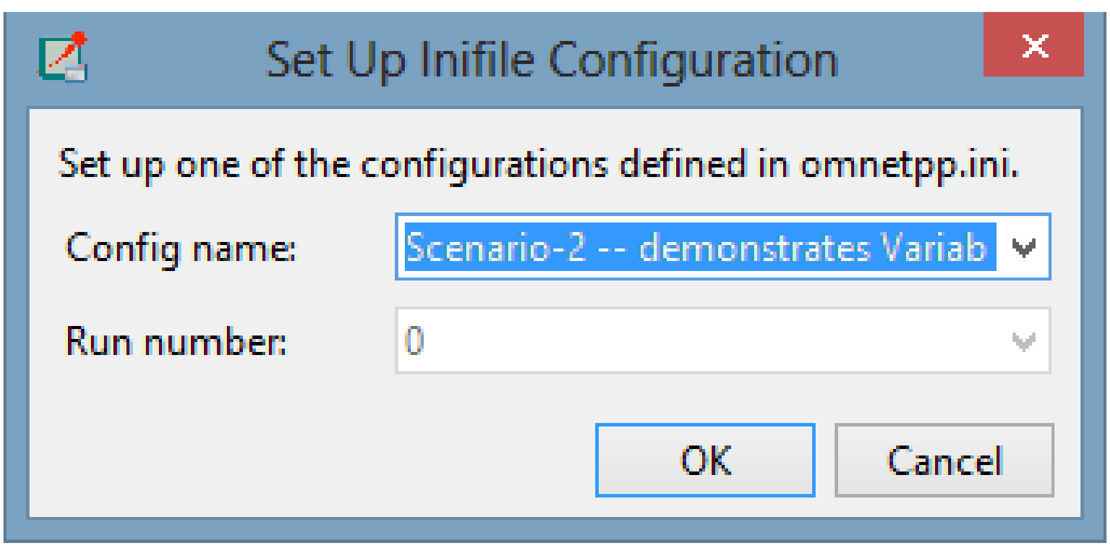


Figure A.4: screen shot of setup inifile for Variable Packets

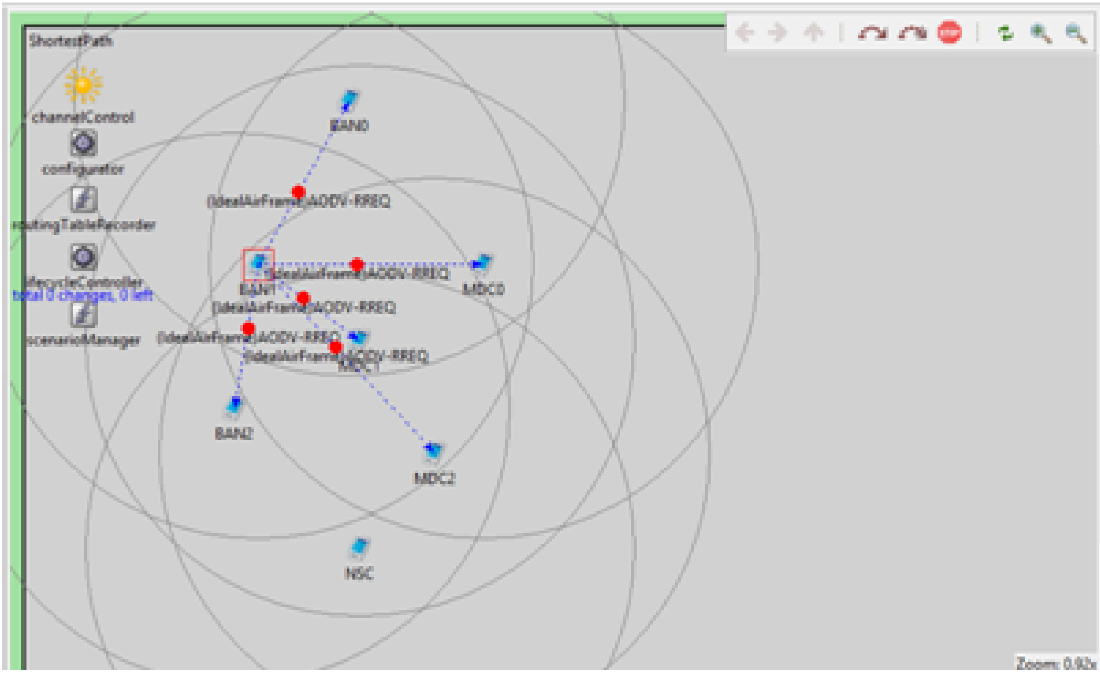


Figure A.5: screen shot of route maintenance using ACO technique

Figure A.6: screen shot of Forward ants packets

Figure A.7: screen shot of updating routing table at NSC

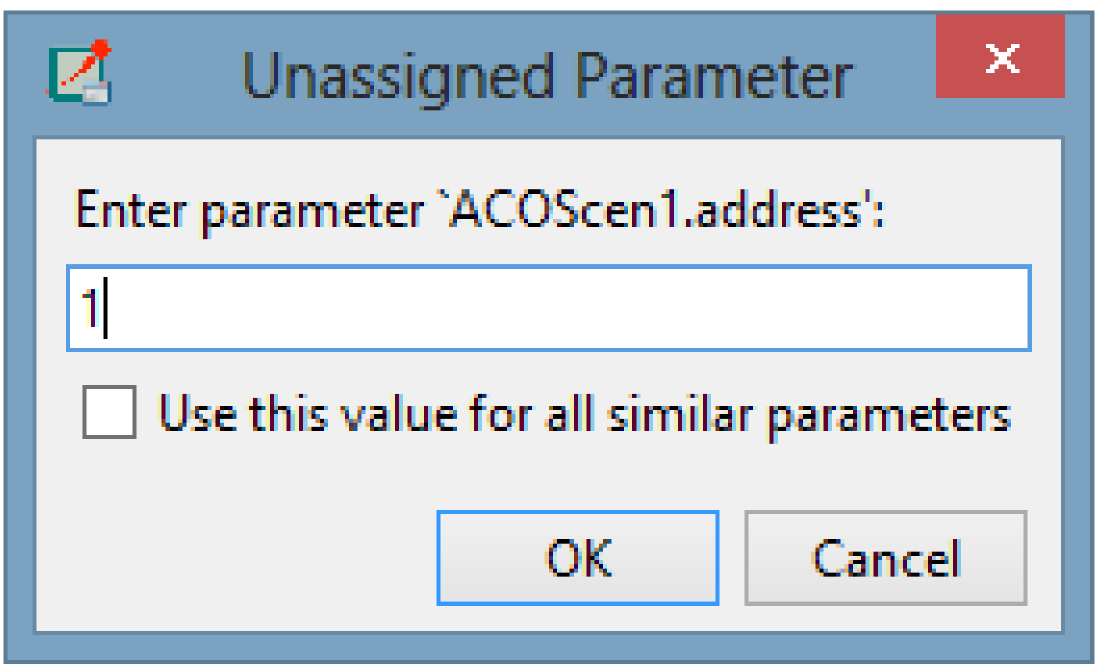


Figure A.8: screen shot of source address

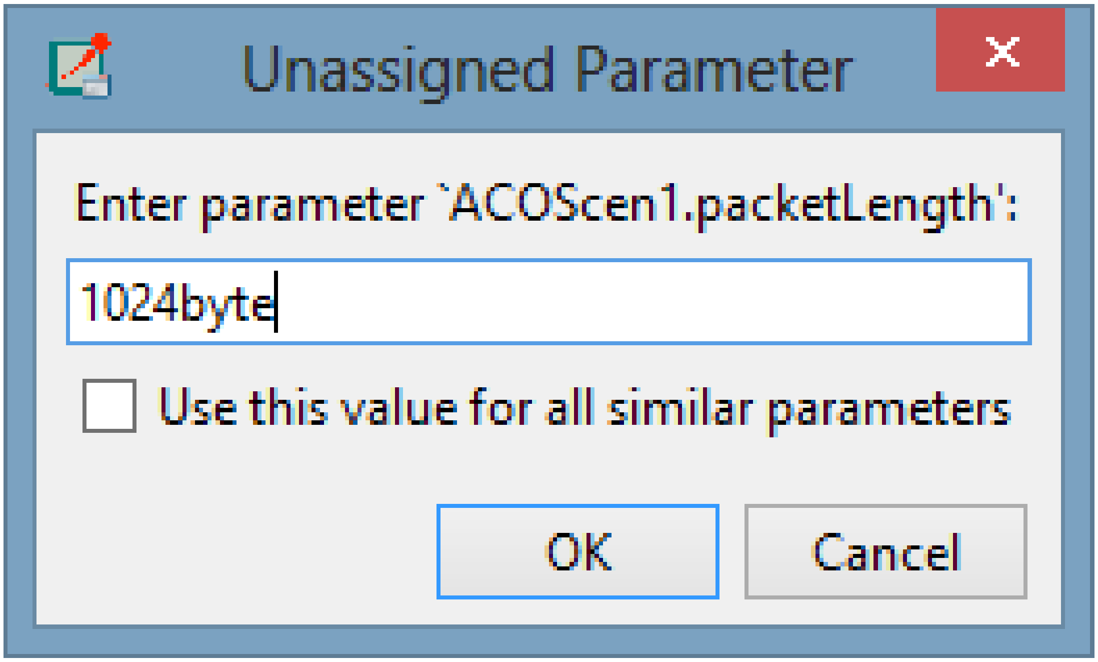


Figure A.9: screen shot of packet length

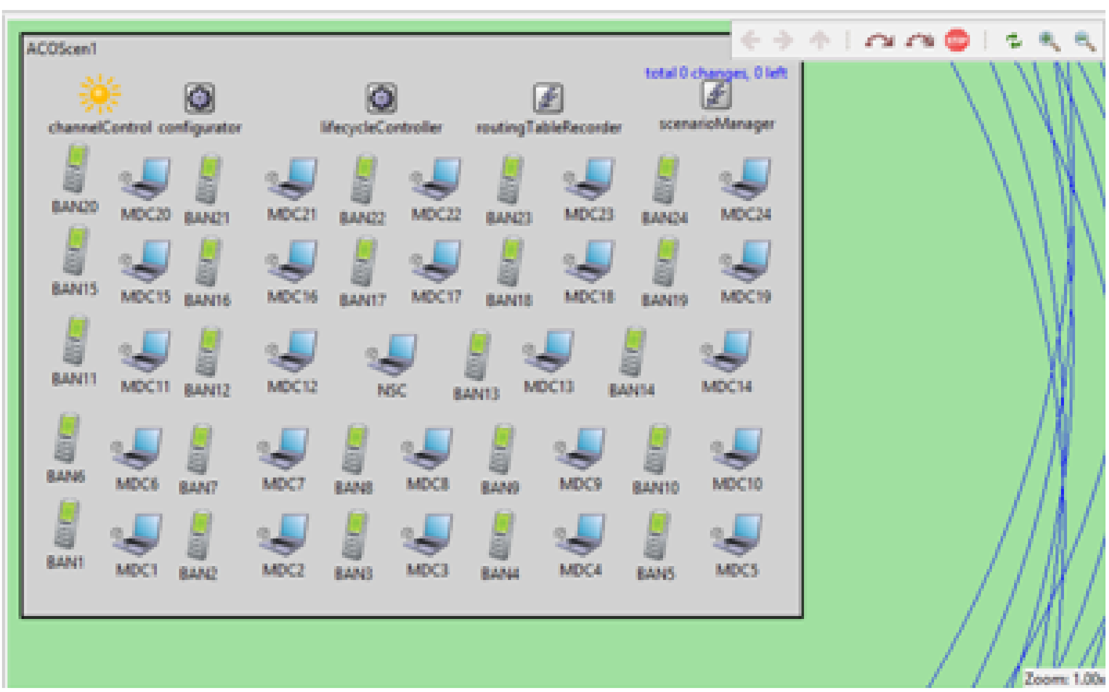


Figure A.10: screen shot of deployment of 49 nodes

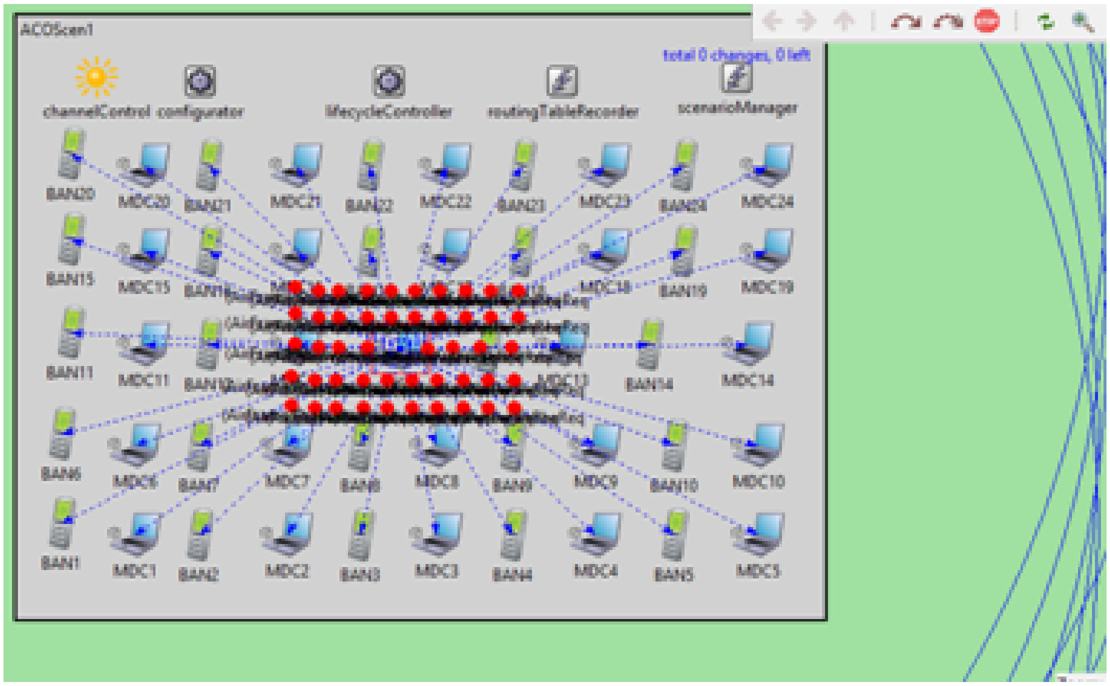
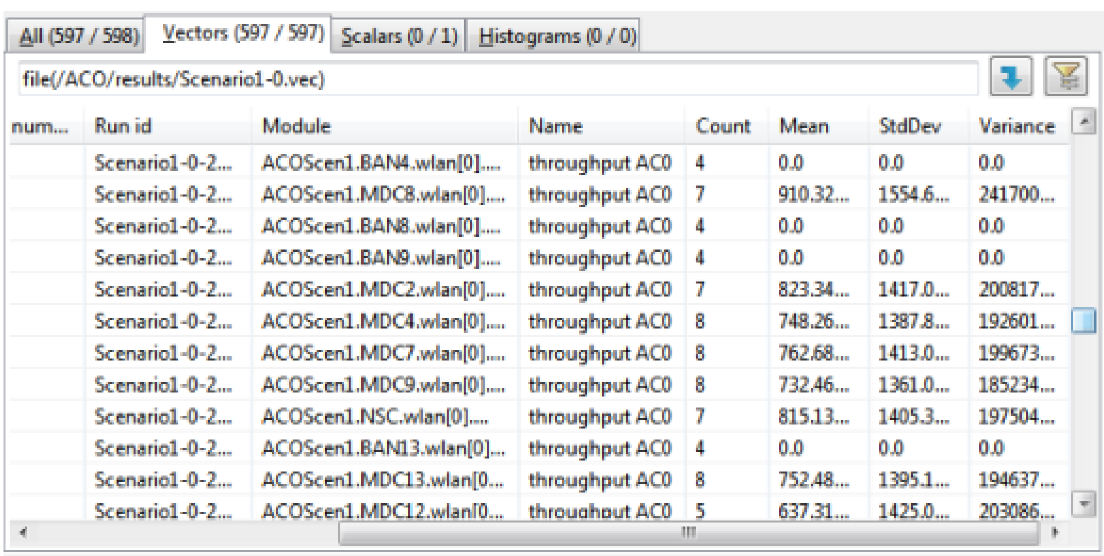


Figure A.11: screen shot of broadcasting message from NSC

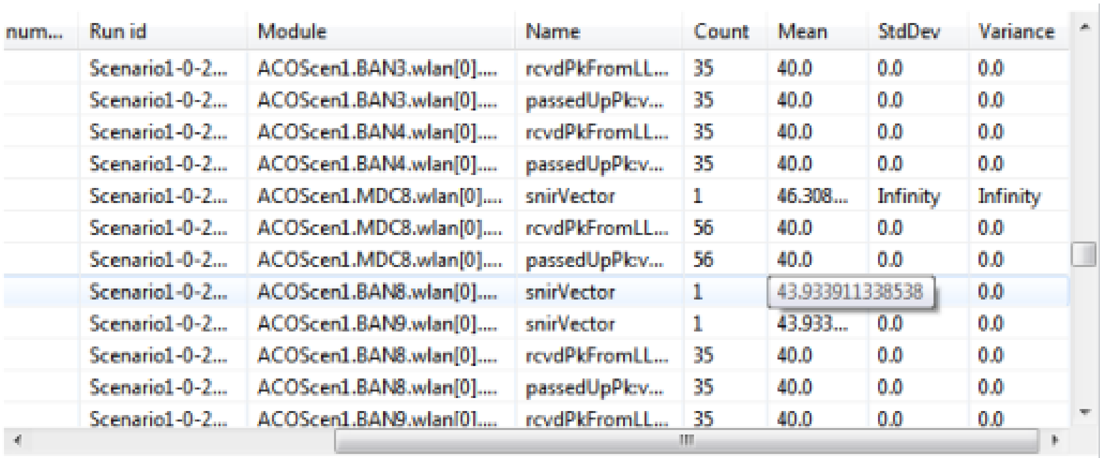


All (597 / 598) | Vectors (597 / 597) | Scalars (0 / 1) | Histograms (0 / 0)

file(/ACO/results/Scenario1-0.vec)

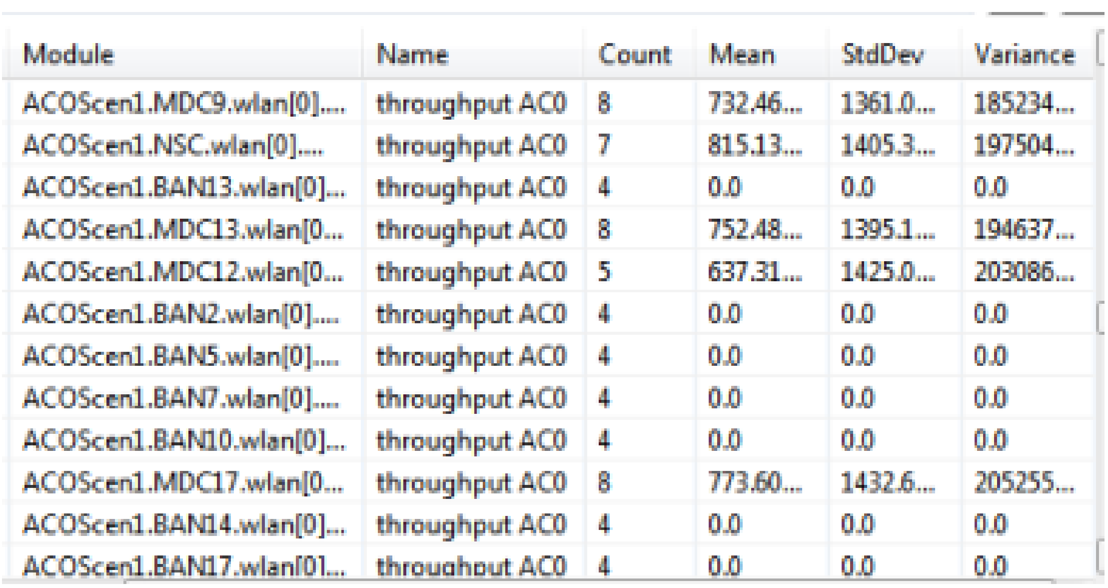
num...	Run id	Module	Name	Count	Mean	StdDev	Variance
	Scenario1-0-2...	ACOScen1.BAN4.wlan[0]....	throughput ACO	4	0.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.MDC8.wlan[0]....	throughput ACO	7	910.32...	1554.6...	241700...
	Scenario1-0-2...	ACOScen1.BAN8.wlan[0]....	throughput ACO	4	0.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.BAN9.wlan[0]....	throughput ACO	4	0.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.MDC2.wlan[0]....	throughput ACO	7	823.34...	1417.0...	200817...
	Scenario1-0-2...	ACOScen1.MDC4.wlan[0]....	throughput ACO	8	748.26...	1387.8...	192601...
	Scenario1-0-2...	ACOScen1.MDC7.wlan[0]....	throughput ACO	8	762.68...	1413.0...	199673...
	Scenario1-0-2...	ACOScen1.MDC9.wlan[0]....	throughput ACO	8	732.46...	1361.0...	185234...
	Scenario1-0-2...	ACOScen1.NSC.wlan[0]....	throughput ACO	7	815.13...	1405.3...	197504...
	Scenario1-0-2...	ACOScen1.BAN13.wlan[0]...	throughput ACO	4	0.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.MDC13.wlan[0...	throughput ACO	8	752.48...	1395.1...	194637...
	Scenario1-0-2...	ACOScen1.MDC12.wlan[0...	throughput ACO	5	637.31...	1425.0...	203086...

Figure A.12: screen shot consisting of throughput parameter for 7 nodes



num...	Run id	Module	Name	Count	Mean	StdDev	Variance
	Scenario1-0-2...	ACOScen1.BAN3.wlan[0]....	rcvdPkFromLL...	35	40.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.BAN3.wlan[0]....	passedUpPk:v...	35	40.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.BAN4.wlan[0]....	rcvdPkFromLL...	35	40.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.BAN4.wlan[0]....	passedUpPk:v...	35	40.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.MDC8.wlan[0]....	snirVector	1	46.308...	Infinity	Infinity
	Scenario1-0-2...	ACOScen1.MDC8.wlan[0]....	rcvdPkFromLL...	56	40.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.MDC8.wlan[0]....	passedUpPk:v...	56	40.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.BAN8.wlan[0]....	snirVector	1	43.933911338538		0.0
	Scenario1-0-2...	ACOScen1.BAN9.wlan[0]....	snirVector	1	43.933...	0.0	0.0
	Scenario1-0-2...	ACOScen1.BAN8.wlan[0]....	rcvdPkFromLL...	35	40.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.BAN8.wlan[0]....	passedUpPk:v...	35	40.0	0.0	0.0
	Scenario1-0-2...	ACOScen1.BAN9.wlan[0]....	rcvdPkFromLL...	35	40.0	0.0	0.0

Figure A.13: screen shot of packet delivery



Module	Name	Count	Mean	StdDev	Variance
ACOScen1.MDC9.wlan[0]....	throughput AC0	8	732.46...	1361.0...	185234...
ACOScen1.NSC.wlan[0]....	throughput AC0	7	815.13...	1405.3...	197504...
ACOScen1.BAN13.wlan[0]...	throughput AC0	4	0.0	0.0	0.0
ACOScen1.MDC13.wlan[0...	throughput AC0	8	752.48...	1395.1...	194637...
ACOScen1.MDC12.wlan[0...	throughput AC0	5	637.31...	1425.0...	203086...
ACOScen1.BAN2.wlan[0]....	throughput AC0	4	0.0	0.0	0.0
ACOScen1.BAN5.wlan[0]....	throughput AC0	4	0.0	0.0	0.0
ACOScen1.BAN7.wlan[0]....	throughput AC0	4	0.0	0.0	0.0
ACOScen1.BAN10.wlan[0]...	throughput AC0	4	0.0	0.0	0.0
ACOScen1.MDC17.wlan[0...	throughput AC0	8	773.60...	1432.6...	205255...
ACOScen1.BAN14.wlan[0]...	throughput AC0	4	0.0	0.0	0.0
ACOScen1.BAN17.wlan[0]...	throughput AC0	4	0.0	0.0	0.0

Figure A.14: screen shot consisting of throughput parameter for 49 nodes

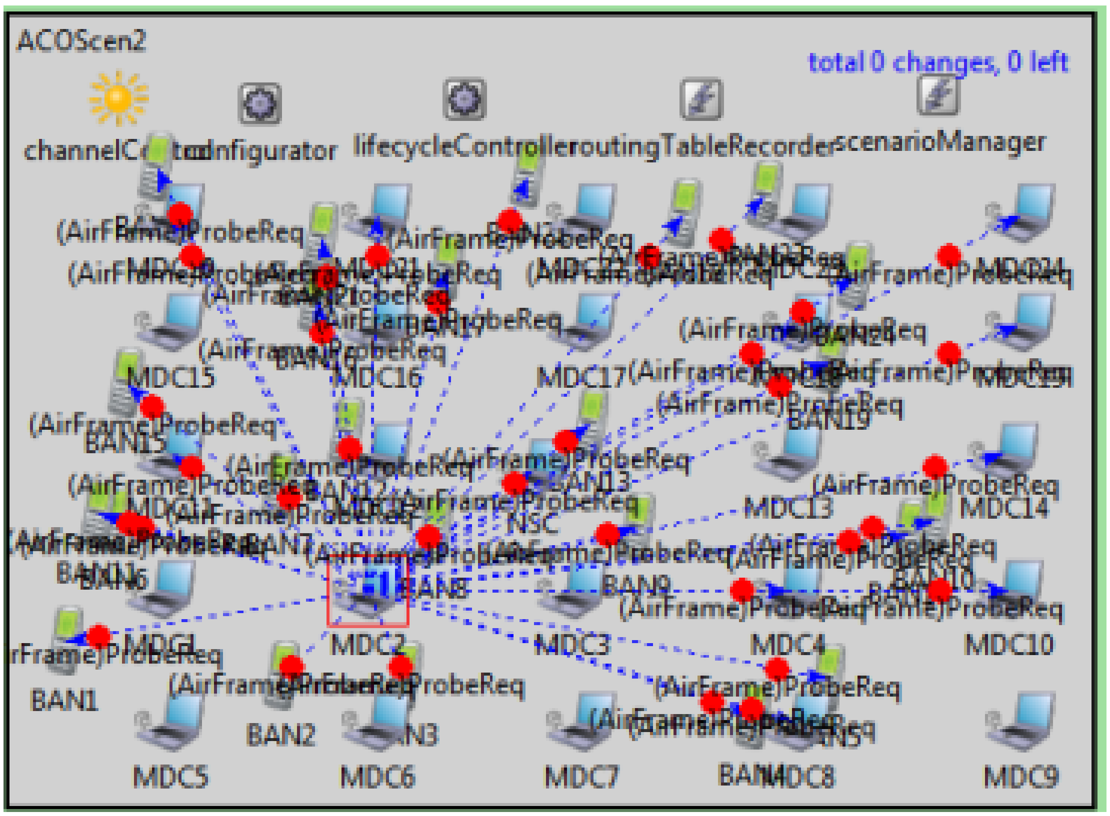


Figure A.15: screen shot consisting of clusters for 49 nodes

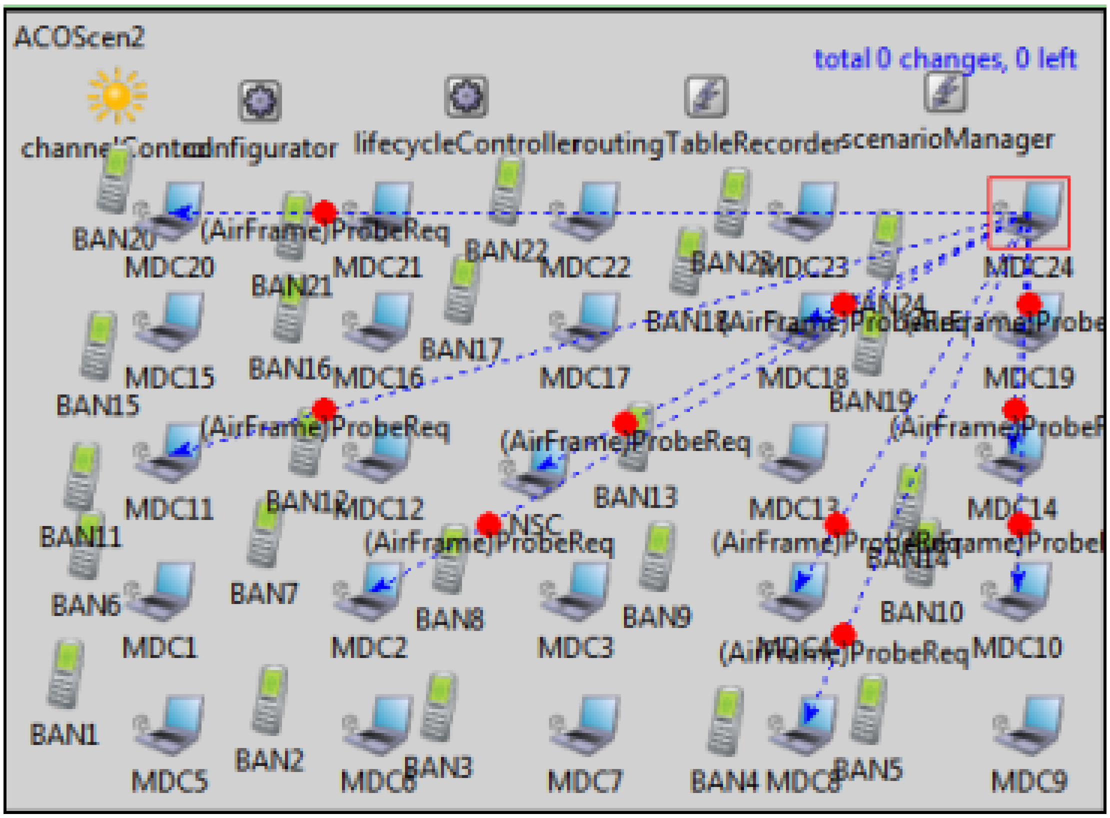


Figure A.16: screen shot finding shortest path

Appendix B

B.1 Mathematic Calculations for ant-colony algorithm

This section contains the brief information of mathematic calculations performed using ant-colony algorithm for few nodes.

Example 1:

Considered $\{\alpha, \beta, \rho\} = \{5, 1, 1\}$

Calculations:

Node A: $\sum = (0.3)^5(0.324) + (0.5)^5(0.405) + (0.9)^5(0.270) = 0.1723873$

: B(0.3, e = 1.2) $n_{ab} = 0.324$

$P_{ab} = (0.3)5(0.324)/0.1723873 = 0.00455$

: C(0.5, e = 1.5) $n_{ac} = 0.405$

$P_{ac} = (0.5)5(0.405)/0.1723873 = 0.07309$

: D(0.9, e = 1) $n_{ad} = 0.2702$

$P_{ad} = (0.9)5(0.270)/0.1723873 = 0.9223417$

Node B: F = $(0.5)^5(0.75) + (0.1)^5(0.25) = 0.234025$

: C(0.5, e = 1.5) $n_{bc} = 0.75$

$P_{bc} = (0.5)^5(0.75)/0.234025 = 0.99989$

: E(0.1, e = 0.5) $n_{be} = 0.25$

$P_{be} = (0.1)^5(0.25)/0.234025 = 0.0000107$

Node C: $\sum = (0.5)^5(0.2727) + (0.6)^5(0.1136) + (0.2)^5(0.2045) + (0.2)^5(0.1818)$ $+ (0.1)^5(0.2272) = 0.01695$

: B(0.5, e = 1.2) $n_{cb} = 0.2727$

$P_{cb} = (0.5)^5(0.2727)/0.01695 = 0.5027$

: E(0.6, e = 0.5) $n_{ce} = 0.1136$

$P_{ce} = (0.6)^5(0.1136)/0.01695 = 0.4896$

: G(0.2, e = 0.9) $n_{cg} = 0.2045$

$P_{cg} = (0.2)^5(0.2045)/0.01695 = 0.0038$

: F(0.2, e = 0.8) $n_{cf} = 0.1818$

$P_{cf} = (0.2)^5(0.1818)/0.01695 = 0.00343$

: D(0.1, e = 1) $n_{cd} = 0.2272$

$P_{cd} = (0.1)^5(0.2272)/0.01695 = 0.00013$

Node D: $\sum = (0.1)^5(0.6521) + (0.8)^5(0.3478) = 6.5210065$

: C(0.1, e = 1.5) $n_{dc} = 0.6521$

$P_{dc} = (0.1)^5(0.6521)/6.5210065 = 0.000001$

: F(0.8, e = 0.8) $n_{df} = 0.3478$

$P_{df} = (0.8)^5(0.3478)/6.5210065 = 0.99999$

Node E: $\sum = (0.1)^5(0.33) + (0.6)^5(0.4166) + (0.3)^5(0.25) = 0.032911$

: B(0.1, e = 1.2) $n_{eb} = 0.333$

$P_{eb} = (0.1)^5(0.33)/0.032911 = 0.0000100271$

: C(0.6, e = 1.5) $n_{ec} = 0.4166$

$P_{ec} = (0.6)^5(0.4166)/0.032911 = 0.98144$

: G(0.3, e = 0.9) $n_{eg} = 0.25$

$P_{eg} = (0.3)^5(0.25)/0.032911 = 0.0184$

Node F: $\sum = (0.8)^5(0.2941) + (0.2)^5(0.4411) + (0.9)^5(0.2647) = 0.8522$

: $D(0.1, e = 1)$ $n_{fd} = 0.2941$

$P_{fd} = (0.8)^5(0.2941)/0.8522 = 0.8166$

: $C(0.2, e = 1.5)$ $n_{fc} = 0.4411$

$P_{fc} = (0.2)^5(0.4411)/0.8522 = 0.00016$

: $G(0.9, e = 0.9)$ $n_{fg} == 0.2647$

$P_{fg} = (0.9)^5(0.2647)/0.8522 = 0.18316$

Every Ant carries a Bit vector [0, 0, 0...] which contains about visited and unvisited nodes. Ant at source 'A' chooses D, over B, C. Because path AD has probability value than AB, AD and It sets the node D Bit to 1. Then from D, ant hops to F, as DF path has higher probability value than DC and changes the Bit vector. From F, ant reaches the destination 'G' choosing the path FG and it can't choose path FD as D is already visited node as Bit of node D is 1. Thus the

Table B.1: Calculated Routing Table for $\{\alpha, \beta, \rho\} = \{5,\ 1,\ 1\}$

Unvisited	**Visited**	**Current**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**Bit Vector**
A,B,C,D,E,F,G	-	-	∞	∞	∞	∞	∞	∞	∞	[0,0,0,0,0,0,0]
B,C,D,E,F,G	A	A	-	0.00455	0.07309	0.9223	∞	∞	∞	[1,0,0,0,0,0,0]
B,C,E,F,G	A,D	D	-	∞	0.00001	-	∞	0.999999	∞	[1,0,0,1,0,0,0]
B,C,E,G	A,D,F	F	-	∞	0.00016	-	∞	∞	0.18316	[1,0,0,1,0,1,0]
B,C,E	A,D,F,G	G	-	-	-	-	-	-	-	[1,0,0,1,0,1,1]

ant from A reached G through the path A-D-F-G.

Routing Path: Let the number of nodes be $n \leq 2^n - 1$, the number of bits needed to represent the nodes in the network is m and numbering of nodes starts from binary equivalent of 1. Initially the routing vector of $n * m$ bits is set to 0. An ant when it reaches a unvisited node, it sets the next 'm' bits from J_w^k Bit in the routing vector. When it reaches the destination, the set of consecutive 'm' bits corresponds to the node it traversed until it reaches the value of 0.

For $\{\alpha, \beta, \rho\} = \{5, 1, 1\}$. Number of nodes: 7 (m = 3)
Nodes : $\{A(001), B(010), C(011), D(100), E(101), F(110), G(111)\}$ Routing Vector: [000000000000000000000] (7*3 = 21 bits) When ant starts from source 'A' (node 1), the routing vector sets to [001000000000000000000], J_w^k is set to 0 and it hops to the node 'D'(4), J_w^k is incremented ,in the routing vector from $((1 * 3) + 1) = 4^{th}$ bit , next 3 bits are set to 100, thus the vector sets to [001100000000000000000] and then ant hops to node 'F'(6), from 7^{th} bit of the vector , next 3 bits are set to 110 , the vector sets to [001100110000000000000] and finally the ant hops to destination node 'G'(7) and sets routing vector to [001100110111000000000].

Table B.2: Calculated Routing Table

Unvisited	**Visited**	**Current**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**Bit Vector**
A,B,C,D,E,F,G	-	-	∞	∞	∞	∞	∞	∞	∞	[0,0,0,0,0,0,0]
B,C,D,E,F,G	A	A	-	0.2464	0.3976	0.3558	∞	∞	∞	[1,0,0,0,0,0,0]
B,C,E,F,G	A,C	C	-	0.367	-	0.1367	0.1673	0.1547	0.174	[1,0,1,0,0,0,0]
E,D,F,G	A,C,B	B	-	-	-	∞	0.1296	∞	∞	[1,1,1,0,0,0,0]
D,F,G	A,C,B,E	E	-	-	-	∞	-	∞	0.2423	[1,1,1,0,1,0,0]
D,F	A,C,B,E,G	G	-	-	-	-	-	-	-	[1,1,1,0,1,0,1]

Analysis of routing vector at destination: As the number of nodes is 7, three bits are used to represent the node. From the vector, consecutive 3 bits are taken to find the routing path. First 3 bits are non-zero of 001-A, next 3 bits 100-D, next 3 bits 110-F and next 3 bits 111-G and next 3 bits are 000, So our path is terminated. Thus the path is A-D-F-G.

Experiment 2: Consider $\{\alpha, \beta, \rho\} = \{0.5, 1, 1\}$.

As explained previously, the ant starts from source node A and chooses node C as its next node over B, D because of the higher probability value of the path AC over AB and AD. Now the ant chooses the node B over D, E, F, G owing to the higher probability value of path CD, CE, CF, CG. Next the ant chooses the node E. Finally from E it goes to G (Target) again based on the higher probability value of that path taking care of the condition that it can't go to a visited node even in case of a higher probability value. The Bit Vector changes accordingly.

Routing Path: As explained previously, every ant carries a routing vector. And the vector at destination 'G' is [001011010101111000000]. Number of bits to represent node is 3. So , first 3 bits of vector are 001-A, next 3 bits are 011–C,

Table B.3: Calculated Routing Table $\{\alpha, \beta, \rho\} = \{0.5, 1, 1\}$

Unvisited	**Visited**	**Current**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**Bit Vector**
A,B,C,D,E,F,G	-	-	∞	∞	∞	∞	∞	∞	∞	[0,0,0,0,0,0,0]
B,C,D,E,F,G	A	A	0	0.0233	0.044	0.932	∞	∞	∞	[1,0,0,0,0,0,0]
B,C,E,F,G	A,D	D	-	-	0.000000008152	-	∞	1	∞	[1,0,0,1,0,0,0]
B,C,E,G	A,D,F	F	-	-	-	-	-	-	0.324	[1,0,0,1,0,1,0]
B,C,E	A,D,F,G	G	-	-	-	-	-	-	-	[1,0,0,1,0,1,1]

next 3 bits are 010-B , next 3 bits are 101–E , next 3 bits are 111–G and next 3 bits are 000, so we terminate the path. Thus the path traversed is A-C-B-E-G.

Experiment 3: Consider $\{\alpha, \beta, \rho\} = \{10, 7, 1\}$.

Similarly, when the α and β values are taken to be 10 and 7 respectively, the first ant starting from A takes the path AD of the possibilities AC, AD and AB taking the higher value of the function into consideration. From D, the path chosen has to be DC or DF and based on the functional value it is found to be F. From F the possible nodes are C and G and because of higher value for the path FG, the next node it travels to is G which is the destination node. Hence, with the chosen values of the parameters, the path obtained is A-D-F-G.

Routing Path: As explained previously, every ant carries a routing vector. And the vector at destination ‘G’ is [001100110111000000000]. Number of bits to represent node is 3. So First 3 bits are non-zero of 001-A, next 3 bits 100-D, next 3 bits 110-F and next 3 bits 111-G and next 3 bits are 000, So our path is terminated. Thus the path is A-D-F-G.

Experiment 4: Case where all the nodes have the same energy 0.5.

Table B.4: Calculated Routing Table

Unvisited	**Visited**	**Current**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**Bit Vector**
A,B,C,D,E,F,G	-	-	∞	∞	∞	∞	∞	∞	∞	[0,0,0,0,0,0,0]
B,C,D,E,F,G	A	A	0	0.003894	0.05007	0.946	∞	∞	∞	[1,0,0,0,0,0,0]
B,C,E,F,G	A,D	D	-	-	0.00003051	-	∞	0.9999	∞	[1,0,0,1,0,0,0]
B,C,E,G	A,D,F	F	-	-	0.000348	-	∞	∞	0.6429	[1,0,0,1,0,1,0]
B,C,E	A,D,F,G	G	-	-	-	-	-	-	-	[1,0,0,1,0,1,1]

Every Ant carries a Bit vector [0, 0, 0...] which contains about visited and unvisited nodes. Ant at source 'A' chooses D, over B, C. Because path AD has higher functional value than AB, AD and It sets the node D Bit to 1. Then from D, ant hops to F, as DF path has higher functional value than DC and changes the Bit vector. From F, ant reaches the destination 'G' choosing the path FG and it can't choose path FD as D is already visited node as Bit of node D is 1. Thus the ant from A reached G through the path A-D-F-G.

Routing Path: As explained previously, every ant carries a routing vector. And the vector at destination 'G' is [001100110111000000000]. Number of bits to represent node is 3. So First 3 bits are non-zero of 001-A, next 3 bits 100-D, next 3 bits 110-F and next 3 bits 111-G and next 3 bits are 000, So our path is terminated. Thus the path is A-D-F-G.

From the experiment results we found that the minimum cost function was for α is 0.5 and β is 1. Thus, the shortest path is A-C-B-E-G.

B.2 Mathematical Calculations cluster based using ant-colony algorithm

This section represents the mathematical calculations of the network, where the nodes represents the cluster head in each cluster. The example shows how the each cluster head selects another cluster based on the probability function.

Calculations for $\alpha, \beta = \{5, 1\}$ and $\alpha, \beta = \{0.5, 1\}$

Node A: $\eta_i = 1/(Ie - e); Ie = 2J$

$B : (\tau = 0.3, e = 1.2)$

$\eta_i = 1.25$

$\alpha = 5 => P_{ab} = 0.176726510017172$

$\alpha = 0.5 => P_{ab} = 0.245842590129558$

$C : (\tau = 0.5, e = 1.5)$

$\eta_i = 2$

$\alpha = 5 => P_{ac} = 0.294181627504293$

$\alpha = 0.5 => P_{ac} = 0.311460064753239$

$D : (\tau = 0.9, e = 1)$

$\eta_i = 1$

$\alpha = 5 => P_{ad} = 0.529091862478535$

$\alpha = 0.5 => P_{ad} = 0.442696762338052$

Node B: $\eta_i = 1/(Ie - e); Ie = 2J$

$C : (\tau = 0.5, e = 1.5)$

$\eta_i = 2$

$\alpha = 5 => P_{bc} = 0.700008532787235$

$\alpha = 0.5 => P_{bc} = 0.549006727124306$

$E : (\tau = 0.1, e = 0.5)$

$\eta_i = 0.667$

$\alpha = 5 => P_{be} = 0.299991467212765$

$\alpha = 0.5 => P_{be} = 0.450993272875694$

Node C: $\eta_i = 1/(Ie - e); Ie = 2J$

$B : (\tau = 0.5, e = 1.2)$

$\eta_i = 1.25$

$\alpha = 5 => P_{cb} = 0.2446165$

$\alpha = 0.5 => P_{cb} = 0.219363993998849$

$E : (\tau = 0.6, e = 0.5)$

$\eta_i = 0.666666666666667$

$\alpha = 5 => P_{ce} = 0.28923312720101$

$\alpha = 0.5 => P_{ce} = 0.238727987997697$

$G : (\tau = 0.6, e = 0.9)$

$\eta_i = 0.909090909090909$

$\alpha = 5 => P_{cg} = 0.28923312720101$

$\alpha = 0.5 => P_{cg} = 0.238727987997697$

$F : (\tau = 0.2, e = 0.8)$

$\eta_i = 0.833333333333333$

$\alpha = 5 => P_{cf} = 0.11076687279899$

$\alpha = 0.5 => P_{cf} = 0.161272012002303$

$D : (\tau = 0.1, e = 1)$

$\eta_i = 1$

$\alpha = 5 => P_{cd} = 0.0661503091984853$

$\alpha = 0.5 => P_{cd} = 0.141908018003454$

Node D: $\eta_i = 1/(Ie - e); Ie = 2J$

$C : (\tau = 0.1, e = 1.5)$

$\eta_i = 2$

$\alpha = 5 => P_{dc} = 0.111123768915506$

$\alpha = 0.5 => P_{dc} = 0.372081458476355$

$F : (\tau = 0.8, e = 0.8)$

$\eta_i = 0.833333333333333$

$\alpha = 5 => P_{df} = 0.888876231084494$

$\alpha = 0.5 => P_{df} = 0.627918541523645$

Node E: $\eta_i = 1/(Ie - e); Ie = 2J$

$G : (\tau = 0.3, e = 0.9)$

$\eta_i = 0.909090909090909$

$\alpha = 5 => P_{eg} = 1$

$\alpha = 0.5 => P_{eg} = 1$

Node F: $\eta_i = 1/(Ie - e); Ie = 2J$

$G : (\tau = 0.9, e = 0.9)$

$\eta_i = 0.909090909090909$

$\alpha = 5 => P_{fg} = 1$

$\alpha = 0.5 => P_{fg} = 1$

The above calculations shows for various values of α and β by using the modified Equation 4.5by showing the steps in choosing the next level of cluster head based

Alpha = 5 , Beta = 1

Table B.5: Routing Table for Alpha=5 and Beta=1

Unvisited	Visited	Current	A	B	C	D	E	F	G	Bit Vector
A,B,C,D,E,F,G	-	-	∞	∞	∞	∞	∞	∞	∞	[0,0,0,0,0,0,0]
B,C,D,E,F,G	A	A	-	0.17672651	0.294181628	0.52909186	∞	∞	∞	[1,0,0,0,0,0,0]
B,C,E,F,G	A,D	D	-	∞	0.111123769	-	∞	0.88887623	∞	[1,0,0,1,0,0,0]
B,C,E,G	A,D,F	F	-	∞	∞	-	∞	∞	1	[1,0,0,1,0,1,0]
B,C,E	A,D,F,G	G	-	-	-	-	-	-	-	[1,0,0,1,0,1,1]

Alpha=0.5 , Beta=1

Table B.6: Routing Table for Alpha=0.5 and Beta=1

Unvisited	Visited	Current	A	B	C	D	E	F	G	Bit Vector
A,B,C,D,E,F,G	-	-	∞	∞	∞	∞	∞	∞	∞	[0,0,0,0,0,0,0]
B,C,D,E,F,G	A	A	-	0.24584259	0.311460648	0.44269676	∞	∞	∞	[1,0,0,0,0,0,0]
B,C,E,F,G	A,D	D	-	∞	0.549006727	-	∞	0.45099327	∞	[1,0,0,1,0,0,0]
B,E,F,G	A,D,C	C	-	∞	∞	-	∞	∞	1	[1,0,0,1,0,1,0]
B,E,F	A,D,C,G	G	-	-	-	-	-	-	-	[1,0,0,1,0,1,1]

upon pheromone value and energy value. This way a shortest path is obtained by considering these parameters.

The mathematical experiment by using the cluster based ant-colony algorithm shows that the cost function is minimum for α and β for 0.5 and 1. Thus, the path is A-D-C-G.

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List of Publications

The following list of peer-reviewed publications have come out during the course of this project:

Peer-reviewed journals

i. **Rakhee**, M. B. Srinivas," Cluster based energy efficient routing protocol using ANT colony optimization and Breadth first search", Elsevier procedia, computer science, August 2016, Vol.89, pp.124-133.

   http://dx.doi.org/10.1016/j.procs.2016.06.019

ii. **Rakhee**, M.B. Srinivas, A Soft Computing Approach For Data Routing In Hospital Area Networks (HAN)", International Journal of Business Data Communications and Networking (IJBDCN), Journal Vol.12(2), pp.16-27.

   DOI: 10.4018/IJBDCN.2016070102

iii. **Rakhee**, Sai Phaneendra P, M.B. Srinivas, " Evaluation of WSN Protocols on a Novel PSoC-Based Sensor Network", Springer CCIS. ISBN: 978-3-642-32111-5 (Print) 978-3-642-32112-2 (Online) **BEST PAPER AWARD NOMINATION**.

Peer-reviewed International / National Conferences:

1. **Rakhee**, M. B. Srinivas, "Energy Efficiency Load Balancing Of Nodes Using Soft Computing approach In WBAN", 4th International Conference on Harmony Search and Soft Computing (ICHSA 2018), Springer, February 2018. BML Munjal University, Haryana. (Presented).

2. **Rakhee**, M.B. Srinivas, " Load Balancing of the nodes for energy efficiency in Wireless Body Area Networks", SEEDS-2017, Department of Electronics and Instrumentation Technology, University of Kashmir, March24-25th, 2017.

3. **Rakhee** Mohiddin, ManojKumar, ShashiKumar Palakurty, SurabhiBothra, Sai Phaneendra P, M.B. Srinivas, NarayanaPidugu, Karthikeyan Mahalingam, Patrick Kane, " Building a Sensor Network with PSoC", International Conference on Sensing Technology, ICST 2011, November 28 - December 1, 2011, New Zealand.

4. **Rakhee**, M.B. Srinivas:" Sensor Network Test-bed for Flood Monitoring", National Conference on Sustainable Water Resource Management (SWRM), March 5-6, 2010, BITS-Pilani, Hyderabad Campus, Hyderabad.

Biographies

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