THERMAL AWARE ROUTING IN IMPLANTED SENSOR NETWORKS

by

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ABSTRACT

Medical biosensors are a special class of wireless sensor networks that are used in-vivo for medical applications like prosthesis, monitoring etc. There has been lot of prior research done in routing in wireless sensor networks but to the best of our knowledge none of them are designed to be used in medical biosensor networks. This thesis addresses the issues of the heat induced by the biosensor communication. The proposed routing protocol uses the heat residue information at the location of the forwarding node to do the routing towards the packet destination. Since the medical biosensors are often used in mission-critical applications, the routing should not only be hazard free but also be able to help meet the packet deadlines.

In the proposed protocol, since it distributes the temperature across the network by routing the data towards lesser temperature areas, this thesis argue that it prevents the potential congestion areas in the network, as the rise of temperature in an area can be directly attributed to the rise in data traffic in that area. Matrix Laboratory is used to simulate the temperature distribution across the network when data is routed using the proposed protocol. We also simulate the shortest hop-forwarding approach and analyze the performance of both these protocols. We also use tinyos and mica2 motes to implement the proposed protocol in different scenarios and traffic levels and compare the transmission times with the shortest hop forwarding approach. Simulation results show that the proposed protocol is more effective at reducing the heat residing in tissue caused by communication. Implementation results show that proposed protocol may have a higher delay compared to shortest hop routing during lower traffic,however the performance of our protocol increases with increase in traffic across the network.

To my mom Ramesh Kumari, dad Nageswara babu.

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CHAPTER 1

INTRODUCTION

The advances in the micro-electronics industry and wireless technology have led to the development of sensors which can be used for accurate monitoring of inaccessible environment. A sensor is a device, that can be controlled and queried by an external device to detect, record, and transmit information regarding a physiological change or the presence of various chemical or biological materials in the environment. A collection of such sensors form a network that can be used for efficient monitoring of health, environment, military etc. These sensors use the wireless medium to communicate amongst themselves and with a central node capable of controlling this network. We call such networks wireless sensor networks.

A class of such sensors which are used specifically for Biomedical purposes are called as Medical Biosensors. These Biosensors are implanted in human body and communicate wirelessly for obvious reasons. Biosensors are finding use in increasingly broader ranges of application - retinal prosthesis, organ monitoring, glucose monitoring, cancer detector just to name a few.

Sensor networks are application specific. The communication model, routing protocol, MAC protocol, data aggregation and various other features of the network are adopted based on the specific requirements of the application. However, in this work we propose a general purpose routing protocol for Biomedical sensor network considering all the possible requirements in biomedical applications.

The communication in the Biomedical sensor network is done in wireless medium. Since the sensors are implanted in human body, it is not possible to periodically change their batteries. These sensor nodes need a renewable source of power supply. There are various possible sources of power supply that can be used for the sensor node. One approach uses the motion of the person and generate the required power for the sensor implants. Solar and mechanical energy harvesting techniques were also investigated as an alternative approach for powering the implants. However, all these approaches seems to be infeasible or still under study in the research labs. There are two standard approaches that can be used to provide power to the sensor implants: Infra red and Radio frequency. Infra red communication requires a line of sight between the communicating points which might not be practical inside human body which has uneven surfaces. Radio Frequency (RF) seems to be the only feasible approach for recharging the sensor implants.

The sensors implants communicate with RF waves. During the communication, the RF waves propogated by the antenna of the source induces into the tissue surrounding the antenna. This area of tissue is called the ’Near-Field’. The travelling RF waves when induced into a tissue generates heat in the tissue thereby damaging the tissue when excessively heated.

Routing in wireless sensor networks has been a well studied problem. Most of the routing protocols in wireless sensor networks are designed to be energy efficient. Since they are not designed for Medical Biosensors, they do not consider the possibility of restricting the communication of the sensor nodes due to the excessive generation of communicating waves. So all these routing protocols that are designed for wireless sensor networks are not feasible for medical biosensor network. Also, these medical biosensors are used in critical applications such as organ monitoring and prosthesis, the communication should not only be hazard free but also be in real time.

Providing Quality of service(QOS) for the data traffic is another important aspect of routing in Medical Biosensor network. The QoS characteristics for an application depends on the application requirements and includes timeliness, bandwidth and reliability. The networking applications have diverse application requirements and most of the real time protocols have been proposed to capture these diverse requirements. So far there has been lot of research done in providing QOS for time critical applications. Most of such real time protocols are proposed at Media Access Control(MAC) and architecture layers, but it is also important to route the data efficiently so that it will traverse to its destination away from the areas of congestion (also known as hotspots) [8]. There have been a few routing protocols proposed which are aimed at providing real time services but most of them use a lot of control messages to propogate the location of hotspots through out the network. Such a high use of control messages which are basically the the communicating waves causes heat in the tissue, so they cannot be used in Medical Biosensor networks.

1.1. Applications of Medical Biosensor Network

In this section we describe some of the proposed applications that can be developed using the medical biosensor networks. These applications give an idea of the potential impact that medical biosensor networks will have on the health of the patients.

- Artificial Retina The goal of this application [1] is to build a chronically implanted artificial retina with sufficient visual functionality to allow a person to see at an acceptable level. Currently a smart sensor system, each with 100 microsensors, have been built for an ex-vivo testing system of a retina. These smart sensors are small and light enough to be placed upon a retina with relatively less support. These sensors produce electrical signals which are converted by the underlying tissue into a chemical response, imitating the normal operating behavior of the retina from light simulation.

- Cancer Detectors Usage of Wireless medical biosensors for the detection of cancer has been investigated and studies show that the cancer cells exude nitric oxide, which affects the blood flow in the area surrounding a tumor. Sensors can be placed in the suspected places or the places that are more prone to cancer and have them transmit the nitric oxide level to the external base station. Some of the alternative approaches in cancer detection include, placing sensors on a needle enabling the physicians to diagnose tumors without doing biopsy.

- Health Monitors Wireless Medical Biosensors have been proposed for use in implanted or ingested health monitors. various research institutes are currently working on several different biotelemetry and bioinstrumentation sensor systems. Each of these biosensors which are very small in size are designed to be swallowed by a person and the sensor communicate wirelessly about the intestinal acidity,pressure, contractions etc. and help the physicians to better diagnose the medical problem in a non-invasive manner. Some of the other health monitoring applications include organ monitor,glucose level monitor etc. Glucose level monitor is currently well-researched and highly regarded as a very effective way to treat diabetes by providing a more consistent, accurate and less invasive method for monitoring glucose levels.

- Other Applications Some of the other interesting applications of medical biosensor networks that are currently under research are neural recording or pattern tracking devices, post surgery monitoring devices. These devices are RF-powered intelligent sensor that are designed to record the brain activity. post surgery monitoring devices are used to monitor the patient’s health situation after the surgery. Typically an accelerometer, a microcontroller and a transmitter that are powered by an inductive link are used.

1.2. Challenges

The main challenges for wider use of medical biosensor networks are:

- Size and weight of the available sensor devices.
- Low Power.
- Regulation by government and Food and Drug Administration.
- Limited Computation.
- Robustness and Fault Tolerance.
- Security and Inteference.
- Radiation from communication

CHAPTER 2

MOTIVATION

Routing in wireless sensor networks is a well studied problem. Due to the application specific nature of sensor networks, there has been various routing protocols proposed with respect to a specific application or a domain of applications. The various routing protocols proposed so far can be classified into four major groups. 1) Data Centric protocols 2) Hierarchial protocols 3) Location based protocols 4) Qos-aware protocols

The goal of these protocols is to prevent the redundancy of the transmitted data. Typically, data is transmitted from every sensor node within the deployment region with significant redundancy. Since this is very inefficient in terms of energy consumption and latency, these data-centric protocols select a set of sensor data and utilize data aggregation during the relay of data. In these protocols, the sink sends queries to a certian portions of the network and wait for the data from the sensors.

Hierarchial protocols aim to efficiently maintain the energy consumption of sensor nodes by either forming them into clusters or performing data aggregation techniques in order to decrease the number of transmissions. Most of these protocols are based on the idea that energy consumption decreases exponentially as the distance transmitted decreases.Most of these protocols are designed to increase the preserve the energy reserve of the sensor nodes.

Location based protocols route the data based on the location information of the other sensor nodes. Since there is no IP-like addressing scheme, sensor networks use the location information to efficiently route data to the destination. Typically it is proven that location based routing also conserves energy as most of the unnecessary data transmissions can be minimized as these protocols know the location towards which the data needs to be transmitted.

QOS protocols consider end-to-end delay requirements while setting up the paths in the sensor network. Typically these protocols are used to satisfy real-time demands by routing the packets based on the packet deadline. These protocols use queuing and scheduling mechanisms for providing quality of service to the applications.

Though all these protocols may work well in their respective applications, most of these protocols are not specifically designed to work in Medical biosensor networks. Medical biosensor networks are in-vivo sensor implants in biological bodies for various applications like organ monitoring, Cancer detection, prosthesis etc. Design of network protocols in biosensor environment should consider communication properties of sensors nodes. Most of the sensor nodes use radio frequency communication, so when these RF waves are induced into the tissue of biological bodies, heat is generated. Not only these protocols aim to minimize the radiation effects on human body, they should also provide Quality of service for the data transmitted as these protocols are normally used in mission critical applications. The goal of this thesis is to develop a real time routing protocol suitable for biological environment.

CHAPTER 3

PROBLEM STATEMENT

Wireless sensor network is a collection of sensor nodes (hereafter called nodes) that operate wirelessly without any fixed infrastructure. The nodes communicate between themselves without the intervention of centralized base station, inorder to provide connectivity and services.Each node in such a network act as both a host and a forwarding node.

Sensor nodes have limited transmission capabilities. So data is relayed to destination through multihops. Routing is an important aspect of developing sensor network applications. Due to the application-specific nature of sensor networks, it is difficult to design a single routing protocol that can be optimal for every application. Since these sensor networks are low energy and most often battery operated devices, a few routing protocols are designed with energy consumption as the goal. For usage of these sensor nodes in mission-critical applications such as in medicine, military etc., routing protocols are designed with latency/real-time/QOS as the goal.

Recent development of microsensors in environmental monitoring and novel sensing applications has stimulated great interest in the development of sensors for usage in medicine. Such sensors are called as Medical biosensors. Some of applications in which these medical biosensor networks can be used are: organ monitoring, prosthesis, cancer detection etc. . Medical biosensors pose great challenges in bio-compatability, fault tolerance, energy efficiency.

Current routing protocols that are designed for non medical sensor networks are not applicable for medical biosensor network applications as they focus only on the data communication and only on data communication. The environment in which the Medical biosensor networks are operated is sensitive to radiation caused by the sensor nodes due to radio communication. Most of the routing protocols do not consider the effects of radiation due to communication. So a routing protocol that is specifically designed for in-vivo environment is needed for communication in medical biosensor network.

This thesis is the development of a routing protocol which considers the temperature residue at the tissue of the forwarding node. Our protocol could potentially lead to less amount of heat residing in the environment in which it is operated. Our protocol desires not only thermal awareness among the forwarding nodes but also meeting packet deadlines for mission critical applications that these sensor nodes will be operated in. Incorporating thermal awareness and deadline awareness in the design of a routing protocol for medical biosensor network keeps the protocol's operation in in-vivo environment hazard free and avoids the risk of heating in bodies.

Given a biosensor network BSN which has k number of nodes, let E be the set of links in the network and V be the set of nodes. we denote r_i as the number of data units of input data at node i that has to be routed to the gateway.

$BSN = < V, E > .|V| = k.$

let i_n be the neighbor node of i such that $i_n \in N_i$, the neighbor set of node i.

Let t be the temperature rise caused by the radiation from communicating 1 data unit.

Let C be the capacity of channel which is assumed to be same for all links

let x_j^i is the data units forwarded to node j from node i where j $\in$ N.

let $temp_{i-j}$ be the residue temperature along link i-j.

let T_{cutoff} be the temperature value beyond which it may be hazardous to the tissue.

let h_f be the number of hops the node f is away from destination.

The data is routed to the next hop using temperature residue and hop count(to destination) information. So we use a cost metric function $fn(i-j)$.

$fn(i-j)$, the cost function = $x^i_j t$ + $temp_{ij}$, h_j.

With reference to cost function in selecting the forwarding node for the data, the problem can be written as ∀ i-j ∈ E, minimize the maximum fn(i-j)

subject to

$$\sum_{i_n \in N_i} x^i_{i_n} = r_i,$$
$$x^i_{i_n} * t < T_{cutoff}$$

CHAPTER 4

DESIGN GOALS

In our design of a routing protocol for wireless medical biosensor network, we observed that unlike the wireless sensor networks, the routing in wireless medical biosensor networks should be ’radiation-aware’. Wireless medical Biosensor networks are often used in mission critical applications so they should be operating in real-time. In view of this, the key design goal of the proposed protocol is to support a real-time communication with limited radiation effecting the tissue surrounding the medical biosensor. Our protocol is designed considering the following design objectives:

- Thermal Aware: Sensors communicate with radio frequency waves. These RF waves when induced in human body generate heat which when exceeds a safety limit might be harmful to the tissue or any biological substance surrounding the medical biosensor. Our protocol considers the heat residue in the tissue towards which it is forwarding the packet.

- Real Time: Medical biosensors are used in various time-critical applications like organ monitoring etc. Each forwarding node makes a localized decision based on the packet deadlines and thus the packet is always kept on pace to meet its deadline. Our protocol also takes into consideration various factors causing packet delay like congestion, packet loss etc.

- Fault Tolerant: Due to its usage in critical applications, biosensor nodes should be adaptable to other nodes failures or temporary shutdowns. Some nodes may be inaccesible due to the high amount of residual heat surrouding it or some failure, our protocol is designed to route the data around such inoperable nodes as those nodes cannot be attended often due to their placement in body.

- Lesser Control Messages: Control messages are a form of communication between the sensor nodes using RF waves. Every control message used in the protocol adds to the heat residue in the surrounding tissue. Our protocol is designed to minimize the usage of control messages.
- Continuous Monitoring: Most of the applications that use the biosensor nodes needs to continuously sense the environment. This differs from most other Adhoc sensor applications where sensors acquire data based on specific conditions like occorance of an event etc. Our Protocol doesn't assume that nodes turn off their antenna some times.

CHAPTER 5

SYSTEM MODEL

The system consists of a number of Biomedical sensors (also called nodes) in a network. The position of the placement of these sensor nodes is predetermined. Each sensor has an omnidirectional antenna. The communication medium is homogeneous in nature. Each sensor nodes has an equal transmission range and no sensor node is disconnected from the network. The sensors sense the data continuously and transmit them over to the nodes at the edge of the network, which in turn transmit them over to the base station. Sensors are recharged through an external radio frequency source. The communication between the sensor nodes also takes place through radio frequency. The sensor nodes are operated in-vivo. The heat variations in the tissue caused due to communication doesn't have any effect on the speed of operation of the sensor processor as the crystal oscillator that is responsible for the processor speed employs a ”heat oven” technique which shields it from the outside environmental effects with the help of a thermistor.

The network consists of a group of medical biosensor nodes whose placement is predetermined.A sample scenario explaining the system model is shown in figure 5. In our system model, a node sense some value like glucose content, heart rate etc. and reports the value when it changes. So a node will send a packet only in the following conditions

- When the value that a node is sensing changes.

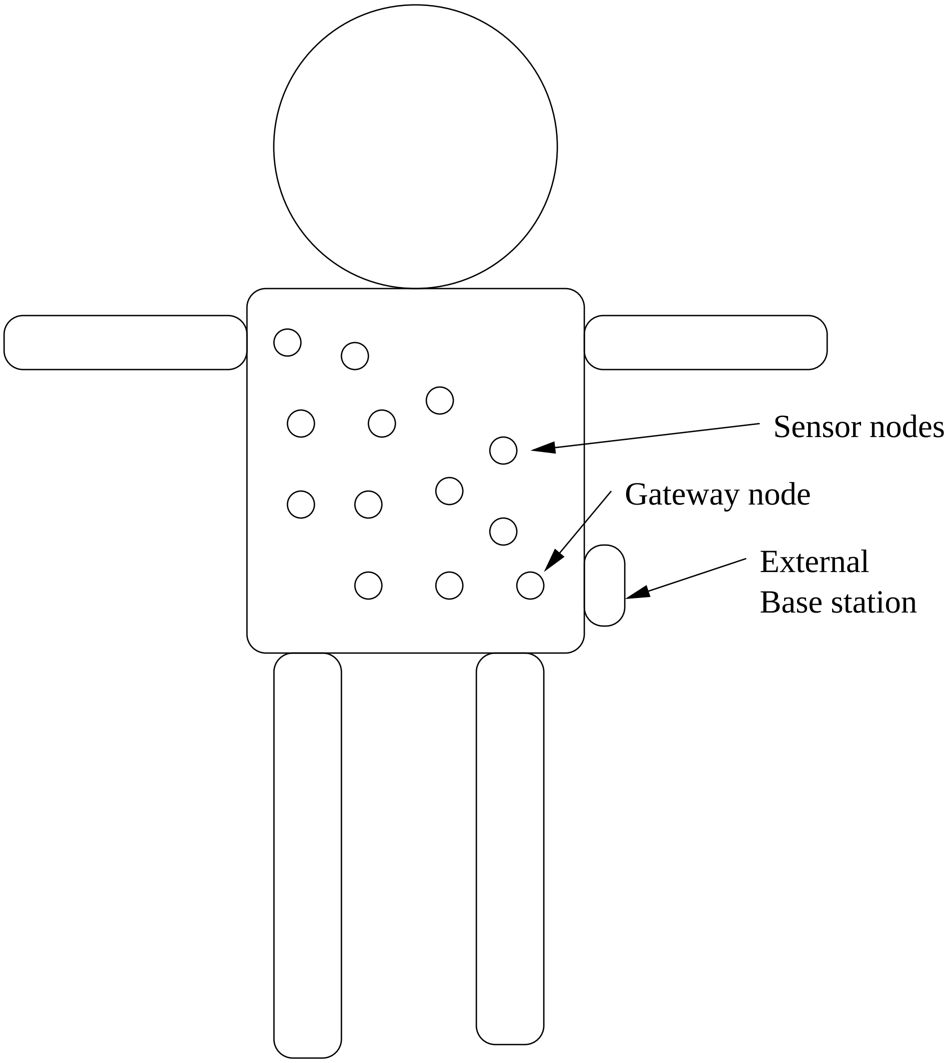

Figure 1: Sample system model

- When a base station requests for the value at a specific node.

Each node transmits the sensed data to a common gateway node that is normally positioned at the edge of the network. The gateway node forwards the data to the base station through various forwarding mechanisms.

CHAPTER 6

ASSUMPTIONS

We make the following assumptions in the design of our protocol.

- Once the node registers its neighbors during the setup phase, the neighbor set is assumed to be constant.
- The protocol is operated in homogeneous tissue environment.
- Nodes are aware of their location. During the setup phase the neighbor nodes transmit the location information along with their node id with the beacon messages.
- Nodes sense the data and transmit it over to a common gateway node which further transmits it to the base station.
- The protocol assumes that sensors can be placed at any specific location of the network. So the protocol doesn't consider the special cases where the placement of sensors is restricted by bones or any sensitive areas of body, so that data has to be necessarily routed across a particular sensor without alternative routes.
- Each node has a forwarding path to the destination.

CHAPTER 7

RELATED WORK

Although sensor networks have been around for a long time, recent technological revolutions like low cost, small size etc. have greatly enhanced their applications in medicine. There has been considerable amount of research done in the wireless adhoc communication protocols, a very few of them have been proposed with reference to medical biosensor networks. To the best of our knowledge , we have not come across any routing protocol, which is specifically designed for medical biosensor network. Some of the research in routing protocols, real time communication and medical implants which helped us in our work are examined here.

Hirata, Ushio and Shiozawa [2] have calculate the specific absorption rate (SAR) in an interaction between human eye with electromagnetic waves in industrial, scientific and medical frequency bands. In doing so, they evaluated the possible health hazards especially to human eye with varous electromagnetic waves through our body like microwave induced cataract formation. They calculate the maximum permissible exposure (MPE) limit in a controllable environment and found it to be far below MPE for cataract formation. In RF powering of mm sized implants paper [12], Heetderks discussed the RF powering of millimeter and submillimeter sized neural prosthetic implants.

Bernardi *et al.* [18] evaluated the temperature rise of the human eye due to the radiation of Wireless LAN. Riu and Foster conducted a numerical study on SAR produced by microwave radiation from a half-wavelength dipole near tissue models. Either of them only considered one of the two radiation sources, namely, RF powering or wireless communication. Researchers at North Carolina State University [3] and John Hopkins University have developed a model to estimate the temperature rise of the tissues resulting from RF powering and power dissipation of implanted retinal stimulator. In our work, we further consider the rotation of the sensor leader to minimize temperature rise and the potential hazard that may result from continuously operation and recharging.

Karp *et al.* [7] proposed a Greedy Perimeter Stateless Routing (GPSR), is a routing protocol designed for wireless adhoc networks. GPSR uses greedy forwarding to forward the packets to nodes that are always progressively closer to the destination. However, GPSR has higher packet latency when there is no greedy path to the destination. In [4], Hari proposed a protocol called Low Energy Adaptive Clustering hierarchy (LEACH) which is designed for the sensor networks where the external base station collects the data from the sensor network. PEGASIS [5] is a chain based binary scheme for power efficient data aggregation. The algorithm starts by constructing a chain of all nodes in the network. Data collection is done in cycles. Most of these approaches are application dependent and did not consider the issues with medical biosensors in designing the approaches for them.

Sullivan *et al.* [17] uses a finite differential time domain method for calculating EM Absorption in Man Models. Shankar ,Gupta [6] proposed an enhanced version of LEACH protocol which can be adopted for medical biosensor networks. They use a multi-level multiple access approach and TDMA along with cluster based routing as used in LEACH. This protocol is proposed with reference to retinal prosthesis application in cluster-based medical biosensor networks but doesn’t consider the thermal effects of the RF radiation on the tissue during communication. This work is the primary motivation for this thesis.

SPEED [8]is a real time routing protocol which improves the packet deadlines ratios from most other real time routing protocols. Though it has high packet deadline ratio, it uses a large number of control messages which may lead to excess communication waves which might not be feasible for medical biosensor networks.

A real time communication architecture [9]for large scale wireless sensor networks is proposed by Lu. A complete architecture for handling real time traffic in large scale microsensor networks is presented. It uses a novel packet scheduling policy called velocity monotonic scheduling that inherently accounts for both time and distance constraints. The architecture also present the techniques to reduce the end-to-end packet deadline miss ratio.

CHAPTER 8

TEMPERATURE RISE IN BIOLOGICAL BODIES

Radio Frequency (RF) is the most commonly used communication in wireless sensor networks due to their cheap infrastructure setup and accessibility. Some of the other communication systems are not feasible for wireless sensor nodes. Infra red communication need a line of sight between communicating nodes. Wired communication is not feasible because the sensor nodes are implanted in-vivo and it is difficult to draw wires across the body. In our system, the sensor nodes use RF communication. Though RF have the above mentioned advantages over other forms of communication, they might be hazardous to biological bodies when overly exposed.

When nodes communicate using RF in a biosensor network, the RF waves are induced into the tissue that is exposed to the radiation. When these RF waves are induced into the tissue, it sparks the motion of atomic particles thereby causing heat. RF radiation is not the only source causing heat in biosensor networks, some of the other sources causing heat are summarised below.

8.1. Radiation from the Sensor Node's Antenna

Sensor nodes use wireless communication for data transfer. Radiation from wireless antenna is another heating factor that needs to be carefully examined. To analyze the effect of radiation on the tissue, we assume the tissue to be homogeneous with no sharp edges and rough surfaces. The space around the antenna is divided into near field and far field. The region of space immediately surrounding the antenna is known as the near field. The extent of the near field is given by $d_0 = \frac{\lambda}{2\pi}$, and λ is the wavelength of RF used by wireless communication.

SAR in the near field is given by: [10]:

$$SAR_{NF} = \frac{\sigma}{\rho}\frac{\mu\omega}{\sqrt{\sigma^2+\epsilon^2\omega^2}}\left(\frac{Idl\sin\theta}{4\pi}e^{-\alpha R}\left(\frac{1}{R^2}+\frac{|\gamma|}{R}\right)\right)^2 \ (W/kg); \qquad (8.1)$$

and in the far-field is given by: [11]:

$$SAR_{FF} = \frac{\sigma}{\rho}\left(\frac{\alpha^2+\beta^2}{\sqrt{\sigma^2+\omega^2\epsilon^2}}\frac{Idl}{4\pi}\right)^2\frac{\sin^2\theta e^{-2\alpha R}}{R^2} \ (W/kg). \qquad (8.2)$$

Assuming R is the distance from the source to the observation point, the angle between the observation point and the x-y plane is θ, and γ is the propagation constant

8.2. Power dissipation by sensor node circuitry

When a sensor node processes the data, there will be power consumed by its circuitry for data aggregation, encryption, operation of processor and various other house keeping chores. Due to the power consumption, heat will be released by the circuitry. The amount of power consumed is completely dependent on the architecture of the sensor. We denote Power dissipation, $P_{Circuitry}$ as the power consumed by the sensor circuitry divided by the volume of sensor. In our analysis, we have considered the typical power consumption for a regular sensor circuitry operation.

8.3. Heating caused by RF powering

The sensor nodes are recharged by an external RF powering source. The frequency of RF power supply is normally between 2 MHz to 20 MHz. [12] [13]. An RF source can recharge a group of sensors simultaneously. The power absorbed by the tissue surrounding the sensor is one of the factors for heating the tissue. The SAR caused due to the radiation from RF powering by external source is [14].

$$SAR_{RF} = \frac{\sigma \left|E\right|^2_{RF}}{\rho} = \frac{2\sigma W_d}{\rho \, \mathrm{Re}\left\{\frac{1}{\eta}\right\}} \; (W/kg). \tag{8.3}$$

CHAPTER 9

THERMAL AWARE ROUTING ALGORITHM

Thermal Aware Routing Algorithm (TARA) is presented in this section. This algorithm is a greedy approach based on the temperature at the forwarding node. The forwarding is done based on the localized information of the sensor nodes. The algorithm starts with an initial setup phase during which there will be a transmission of beacon messages by all the nodes in the network. During this transmission all the nodes identify their neighbors and update their neighbors list. After the initial setup phase, all the nodes transmit the sensed data to the destination. Each nodes selects the forwarding node for a packet based on the temperature information. The algorithm can be used for multi-hop routing in Medical biosensor networks. We now introduce a few definitions that we will be using in the description of our protocol

9.1. Definitions

1. **Beacon:** A Beacon is a characteristic radio signal which indicates the location of the emitting node. A Beacon signal is used by a node to identify the its neighbors and their location.
2. **Neighbor List:** It is list of nodes that are within the radio propogation range of the node. Entry to this list is added based on the beacon message obtained during the initialsetup phase.

3. **Forwarding Node:** It is a node that act as a router for the transmission of packets through multiple hops to the destination.
4. **Hot spot:** The region of the network which has a hazardous level of temperature that is normally generated by the radiation from communication.
5. **Gateway Node:** A gateway node is the destination for the packets in the biosensor network. Typically they are positioned at the edge of the network. Gateway node communicate with the external base station through different mechanisms. A gateway node can be treated as a network sink.

9.2. Description

Each node uses this algorithm for routing the packets to their destination. The algorithm maintains a ”neighbor list”. Each node has the location of its position and also the location of its neighbors. Each node can also calculate the distance from another node, provided it knows its location. When a node receives a packet, the packet contains the origin of the packet and its location, destination of the packet and its location, and the previous hop, p of the packet where
$\forall$ i, such that p $\in Neighborlist_i$

The algorithm has two phases of operation.

9.2.1. Setup Phase. After the nodes are predeployed in the network, the set up phase of the algorithm is run. During this phase, each node transmits a beacon messages with the node id and location. The nodes which receive the beacon message will add the node id present in the beacon packet to their neighbor set. Setup Phase is used by nodes to identify their neighbors. Once the neighbor setup is done, then the neighbor set of each node is assumed to be constant.

9.2.2. Operation Phase. Data transmission is done within the network(N) in this phase. Each node sends a data to the gateway node in either of these two circumstances: when there is a change in the sensed reading or when a base station sends a signal to the node asking for the data.

It is assumed that each node knows the location of the gateway(d). When either of the above mentioned events occur, the node, i dynamically creates a forwarding set(F_i) from its neighbor set(N_i) that is created during setup phase such that

∀i, i∈N, $\{F_i \in N_i\}$

∀f, f∈ F_i $\{$ distance(d,i)≥distance(d,F_i)$\}$

When a node receives a packet that is destined to the gateway, it selects the next node based on the temperature residue at the location of next node. The temperature at the location of the next node is calculated by using the Finite Differential Time Domain (FDTD) method that is described in next section. Once the temperature is calculated at the location of all the nodes in the forwarding set, the current node selects the node with least temperature as the forwarding node. Each forwarding node executes the same steps of protocol to identify the next hop (or next node) for the packet towards the destination. In certain circumstances, a node might receive a packet where it doesn't have any next hop to forward to or all the nodes in the forwarding set are in the hotspot. Our protocol prepares the nodes for such adverse effects through a technique, we call ”cordoning”.

9.2.2.1. *Cordoning.* Cordoning is the key to avoid the dead ends in the routing of data to the destination. It is an effective approach that helps keep the route alive between the origin and destination. When a packet reaches a dead end where it cannot proceed further, either due to the absence of next hop beyond the current node or due to the presence of hotspot in the location of the forwarding set. During such a situation, the node ”back routes” towards the origin until it finds an alternative route to the destination. During this back routing phase, each node that receives the back routed packet will update itself with the hotspot information like the location of hotspot and

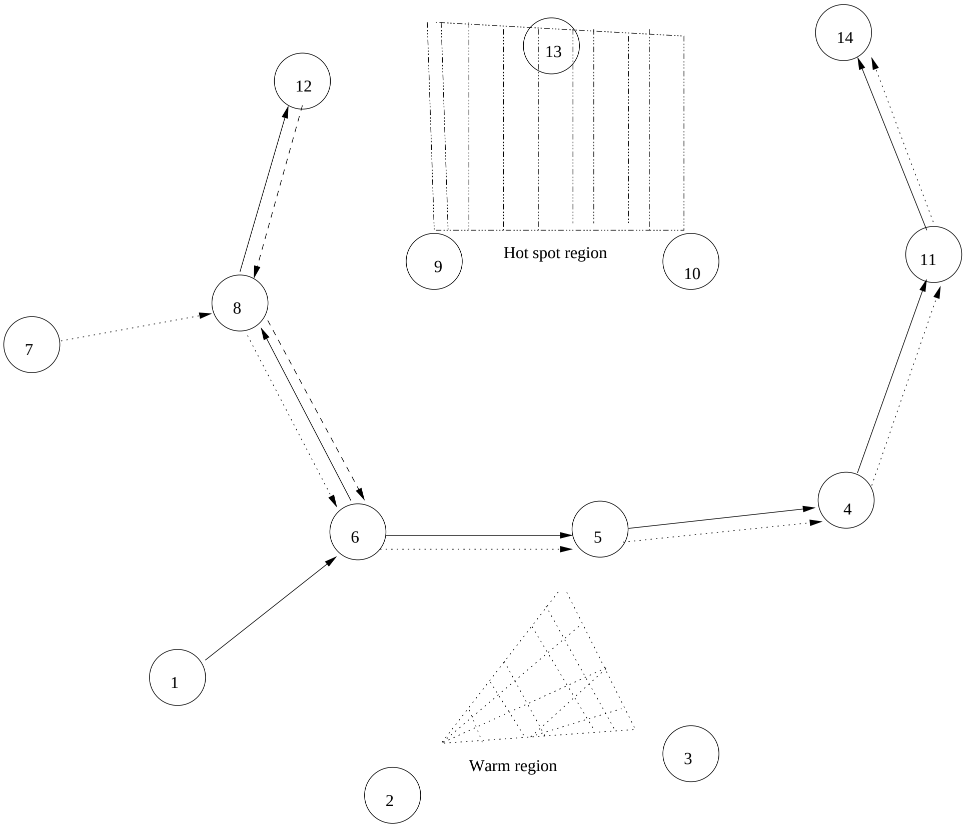

Figure 2: Example Scenario explaining Cordoning

the temperature at it. This information can be looked up when the node receives a packet that is to be forwarded to another node. If the destination of the packet happens to falls within the hotspot, then the packet is back routed.

To better explain the cordoning technique, we consider an example as shown in figure 2. In the scenario we will discussing, node 1 is the origin of the packet and node 14 is the destination. The area enclosed within nodes 9, 13 and 10 is the hotspot which means that the temperature residue in the tissue in this area is too high to be exposed to any further radiation. The area of the tissue enclosed within nodes 2,3 and 5 is called the warm region which means that the temperature is higher than normal temperature but not as critical as hotspots. When node 1 tries to find the next hop for the packet that is destined for node 14, since both the neighbors have the same hop count, it estimates the temperature at all the nodes of the neighbor set which are $\{2, 6\}$. Since the temperature at 6 is less than temperature at 2, node 6 is selected as the next hop. Similarly the protocol runs at every node that receives the packet and when the packet reaches node 12 through the path $1- >6- >8- >12$, computation of temperature at neighbor nodes of 12 $\{13, 9\}$ reveal that the temperature is too high to further route across the nodes. Since there is no safe next hop, node 12 does a back routing towards the packet origin i.e. 1 until it finds a safe node to forward data. During this back routing phase the packet direction is set to be negative. Any node that receives a packet that has a negative direction knows that it is a back routed packet and updates within itself the hotspot information contained in the packet i.e. the highest temperature at node 9 and 12 and the farthest location among nodes 9 and 13.

Now if the node 7 has to transmit to node 14, it sends the packet to next hop i.e. node 8. Node 8 upon receiving a packet first selects node 12 as the next hop as it has low hop count then rest of its neighbors, but also realises that routing through node 12 leads to a hotspot along the route from the back routing information of the previous packet from 6. So it chooses node 6 as the next hop.

9.3. Temperature Estimate at Neighbor nodes

We use a finite differential time domain method for calculating the temperature at various locations of the network. The flow of heat in a biological material is expressed by Pennes bio heat equation as follows.

$C\rho\frac{dT}{dt} = K \bigtriangledown^2 T + A_o - B(T - T_b).$

ρ is the density,

C specific heat,

K Thermal conductivity,

T is the temperature as a function of time and space,

T_b is the temperature of the blood flow which is assumed to be of body temperature.

A_o is the basal metabolism, B is the cooling effect of the blood perfusion.

When the effects of radiation caused by the communication of the sensor nodes the bio heat equation becomes.

$C\rho\frac{dT}{dt} = K \bigtriangledown^2 T + A_o - B(T - T_b) + SAR_{source} + Power_{source}$

We discretize the bio heat equation over time and space in order to formulate it to be implemented by a computer. We develop the Finite difference approximations for the first derivative over time, $\frac{dT}{dt}$ and second derivative over space, $\frac{d^2T}{dx^2}$.

The equations for the first derivate over time and space will be

$\frac{dT}{dt} = \frac{T^{n+1}_{(i,j)} - T^{n}_{(i,j)}}{dt}$

$\frac{dT}{dx} = \frac{T^{n}_{(i+1,j)} - T^{n}_{(i,j)}}{dx}$

where $T^n_{(i,j)}$ is the temperature at the location (i, j), dt is the discretized time step and dx is the discretized space step in x direction. Similar equations can be developed in y direction as follows

$\frac{dT}{dy} = \frac{T^{n}_{(i,j+1)} - T^{n}_{(i,j)}}{dy}$ The equations for the second derivative over space will be

$\bigtriangledown^2 T = \frac{d^2T}{dx^2} + \frac{d^2T}{dy^2} + \frac{d^2T}{dz^2}$

$\frac{d^2T}{dx^2} = \frac{\frac{T^{n+1}_{(i,j)} - T^{n}_{(i,j)}}{dt} - \frac{T^{n}_{(i+1,j)} - T^{n}_{(i+1,j)}}{dx}}{dx}$i

Using the above discretized equations, the bioheat equation can be rewritten as

$$T^{m+1}_{(i,j)} = \left[1 - \frac{\delta_t b}{\rho C_p} - \frac{4\delta_t K}{\rho C_p \delta^2}\right] T^m(i,j) + \frac{\delta_t}{C_p} SAR + \frac{\delta_t b}{\rho C_p} T_b + \frac{\delta_t K}{\rho C_p \delta^2} \begin{bmatrix} T^m(i+1,j) + T^m(i,j+1) + \\ T^m(i-1,j) + T^m(i,j-1) \end{bmatrix} + \frac{\delta}{\rho C_p} Power_{source} \tag{9.1}$$

From Eq. 9.1, we can find the temperature at the location (i, j) at time $m + 1$, which is a function of the temperature at location (i, j) at time m, as well as a function of the temperature of surrounding grid points (such as $(i+1, j)$, $(i, j+1)$, $(i-1, j)$, and $(i, j-1)$) at time m.

The node estimates the temperature of its surroundings using the above described method. As shown in the figure, if the node at (i, j) is the current node that receives the packet to forward and the nodes at $(i+1, j)$, $(i-1, j-1)$ and $(i+1, j+1)$ are the forwarding nodes then node at (i, j) compares the temperature estimate, $T_{(i+1,j)}$, $T_{(i-1,j-1)}$ and $T_{(i+1,j+1)}$ and forwards the packet to the node with least T.

```
Algorithm: TARA()
begin
    Neighborlist = ∅

    while (setup phase)
        Network wide flooding
        find hop count
        transmit a beacon
        if (beacon message received)
            Neighborlist.insert(beacon− >source)
        end if
    end while
    while (operation phase)
        if (packet received)
            if (payload− >next ! = currentnode)
                drop the packet
            else
                if (payload− >destination == currentnode)
                    extract packet information
                    exit
                end if
                        if (packet− >direction< 0)
                            extract the location of hotspot from packet
                            extract temperature at hotspot from packet
                            add the node from which the packet is received to critical set
                        end if
                        if (payload− >next == currentnode)
                            for (each n ∈ Neighborlist)
                            while (m ∈ Neighborlist)
                            m = lowest hop count neighbor with minimum temperature residue
                            end while
                            end for
                        end if      end if
        end if
    end while
end
```

Figure 3: Routing Algorithm.

CHAPTER 10

OVERVIEW OF SHORTEST HOP ROUTING

In this chapter we explain how shortest path routing is done. We also simulate the and implement the shortest hop routing and compare the performance of it with our protocol. It is shortest path routing for mobile, wireless networks. Shortest hop routing exploits the correspondence between geographic position and connectivity in a wireless network, by using the number of hops of the node to the destination to make packet forwarding decisions. Shortest hop uses greedy forwarding to forward packets to nodes that are always progressively closer to the destination.

Shortest hop uses the hop count of routers to the destination and a packet's destination to make packet forwarding decisions. The algorithm makes greedy forwarding decisions using only information about a the current node's immediate neighbors in the network topology. When a packet reaches a region where greedy forwarding is impossible, the algorithm recovers by routing around the perimeter of the region. By keeping state only about the local topology, shortest hop scales better in per-router state than other ad hoc routing protocols as the number of network destinations increases. Under mobility's frequent topology changes, shortest hop can use local topology information to find correct new routes quickly. Shortest hop is scalabile on densely deployed wireless networks.

Shortest hop is considered to be more efficient than GPSR [7] in applications where the nodes are static and data is routed to a common gateway node.

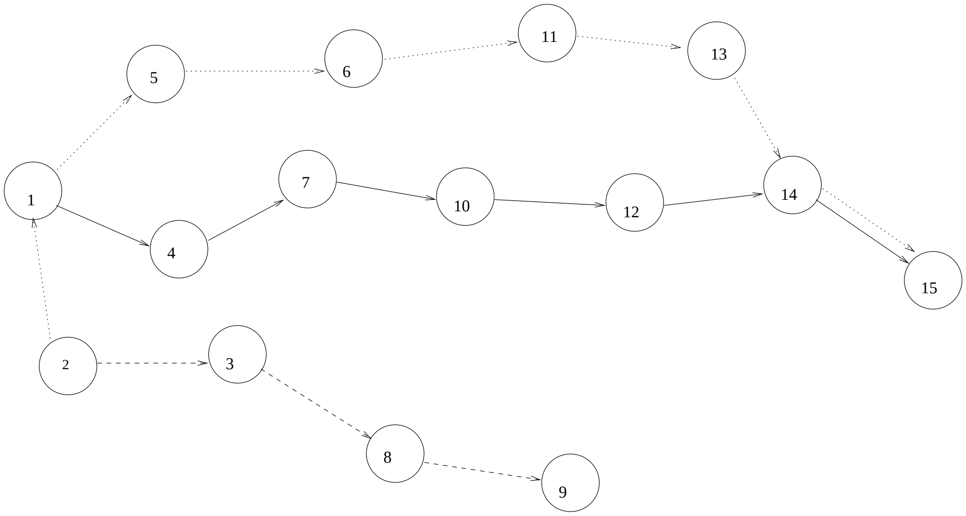

Figure 4: Example Scenario demonstrating Shortest-hop

As shown in the figure 4, GPSR each node forwards the packet to one of the neighbor node which is closest to the destination. If the source node is 1 and destination node is 15 then the packet is forwarded along $1 - > 4 - > 7 - > 10 - > 12 - > 14 - > 15$. In an alternative scenario, if the source node is 2 and destination node is 15 then using greedy approach the packet is forwarded along $2 - > 3 - > 8 - > 9$. In this situation node 9 has no where to send the packet to, so it drops the packet. Now source node routes the packet through the perimeter of the network towards the destination as shown in dotted lines in the figure. When the shortest hop routing is run for the above scenario, each node knows the hop count to route data to the destination i.e. node 15. If node 1 wants to transmit a data to the gateway i.e. node 15, it knows that node 4 and node 5 has equal number of hop length to the destination, so it forwards the packet to either nodes, thereby reducing the routing overhead involved in alternative routes.

CHAPTER 11

SIMULATION MODEL

To analyze the performance of TARA, we simulate TARA and Greedy routing algorithm in Matrix Laborotary (MATLAB) software. Matlab is an interactive software system for numerical computations and graphics. As the name suggests, Matlab is especially designed for matrix computations: solving systems of linear equations, computing eigenvalues and eigenvectors, factoring matrices, and so forth. In addition, it has a variety of graphical capabilities, and can be extended through programs written in its own programming language.

Our main aim of this simulation is to bring out the effects of routing data without considering the thermal effects of communication in a wireless sensor network. In our simulations we modelled a 100 X 100 area with 36 nodes predeployed before the start of simulation. We used various scenarios with different node locations and different routes and took the average to plot the graphs.

The nodes are static and and their location is predetermined. Each node is omni directional and have equal computational and transmission capabilities. We measure the performance of different protocols based on the following metrics.

Highest temperature raise: Since the sensor nodes may be placed in sensitive areas like human eye, drastic rise in temperature may be hazardous to the organ. This metric shows the effectiveness of the protocol in handling extreme raise in temperature during communication.

Average temperature raise: The maximum permissible temperature rise in a tissue is dependent on the location where the tissue is placed and the sensitivity of the organ nearer to the tissue. For example: A human eye tissue is more sensitive than hand tissue. Average rise of temperature conveys the effectiveness of routing protocol to minimize the radiation effects of communication throughout the period ofcommunication all across the tissue.

CHAPTER 12

SIMULATION RESULTS

In this section, we compare our protocol TARA with a shortest hop forwarding algorithm that was explained in chapter 10. Based on our simulations, we analyze the performance of TARA in varying conditions and with respect to shortest hop algorithm. The system specific values of the parameters used in the simulations are detailed in Table.

- Maximum Temperature Rise: Maximum Rise in temperature captures the effectiveness of a routing protocol to direct the data away from the hotspots. So a protocol well suited for medical biosensor network will have a low rise in the temperature at any point in the network. As shown in figure 5, the low rise in temperature for TARA can be attributed to its property of selecting the next node that has the least temperature residue.

- Average Temperature Rise: Average Rise in temperature is to estimate the total amount of heat induced into the tissue area of the entire network. This value can be used to evaluate the over all performance of the network. It can also be used to make changes to the network. For example, if the physician feels the need to add more medical biosensors to the existing network, then he can make a decision based on the value of the average temperature rise in the network. The rate of increase in temperature is proportional to the amount of heat and the duration of heat provided, in this case heat is caused by radiation. So the average temperature

Table 1: Parameters and their values used in Simulation

Parameter	Property	value
P_0	Power Density of incident plane wave	10 $\left[\frac{W}{m^2}\right]$
ε_r	Relative permittivity at 2MHz or 2.45GHz	47 or 850
σ	Conductivity at 2MHz or 2.45GHz	1 or 2.21 $\left[\frac{S}{m}\right]$
C_p	specific heat	3140 $\left[\frac{J}{kg^\circ C}\right]$
K	Thermal conductivity	0.502 $\left[\frac{J}{m s^\circ C}\right]$
b	Blood perfusion constant	0 or 1647 $\left[\frac{J}{m^3 s^\circ C}\right]$
T_b	Fixed blood temperature	37 $^\circ C$
P_{Node}	Power consumption of sensor node	1 mW
δ	Control area	100X100 mm
δ_t	time step of FDTD	10 S
I_0	Current provided to sensor node antenna	0.1 A
ρ	Mass density	1070 $\frac{kg}{m^3}$

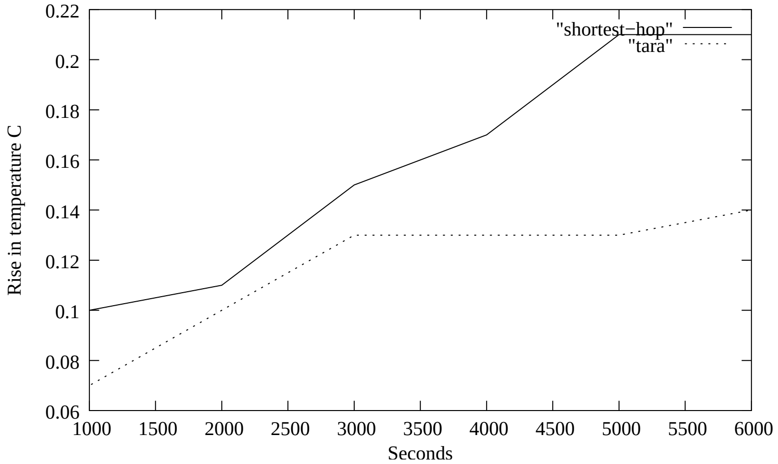

Figure 5: Maximum Rise in Temperature

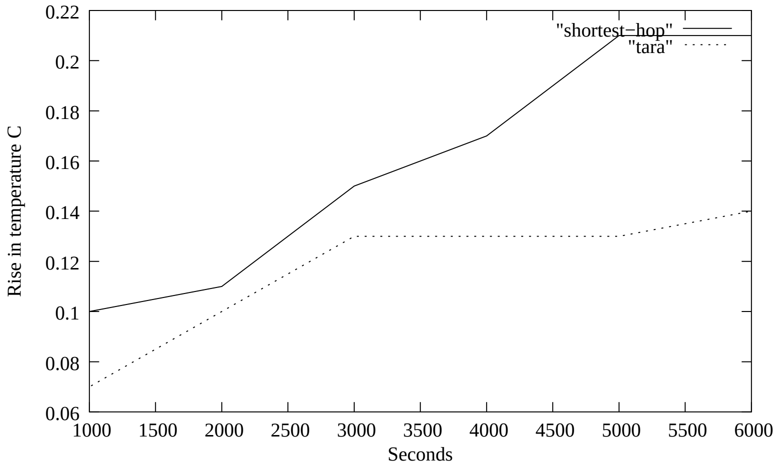

Figure 6: Average Rise of Temperature in the Network

is higher if the same area of the tissue is exposed to the radiation for longer periods. From the figure 6, TARA has a lower average temperature than greedy. This might be due to continuing usage of the same path to route data between the source and destination. Since the same path is used, the same area of the tissue is being heated continuously which results in higher rate of rise in temperature thereby resulting in higher average temperature.

To demonstrate the impact of the operation of both the protocols on the tissue over the entire network, we performed a simple experiment in which we send the data from one edge of the network to the opposite edge, which is the gateway to document the distribution of temperature caused by radiation due to communication. Data transmission is done at the rate of 20 packets/sec for 3000 seconds. We projected a 3D view of the temperature residue across the entire network after the operation of both the protocols as shown in figures 7 8 .

- Network wide temperature distribution of TARA: Figure explains the network wide temperature residue in the tissue after the routing is performed through the routing algorithm TARA. Though the temperature rise is across the network, the maximum rise in temperature at any point of the network is low.

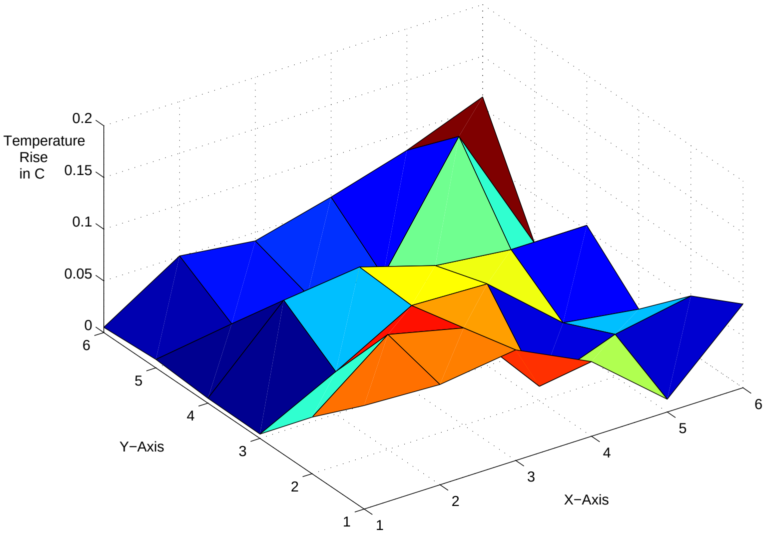

Figure 7: Temperature Distribution Across the Network for TARA

- Network wide temperature distribution of Greedy: Figure explains the network wide temperature residue in the tissue after the routing is performed through the routing algorithm TARA. While there is an extreme rise in temperature along the greedy path from source to destination, all the other areas of network has a minimal rise in temperature. This could lead to extreme rise in temperature in one area of the network which might be hazardous to the tissue in that area.

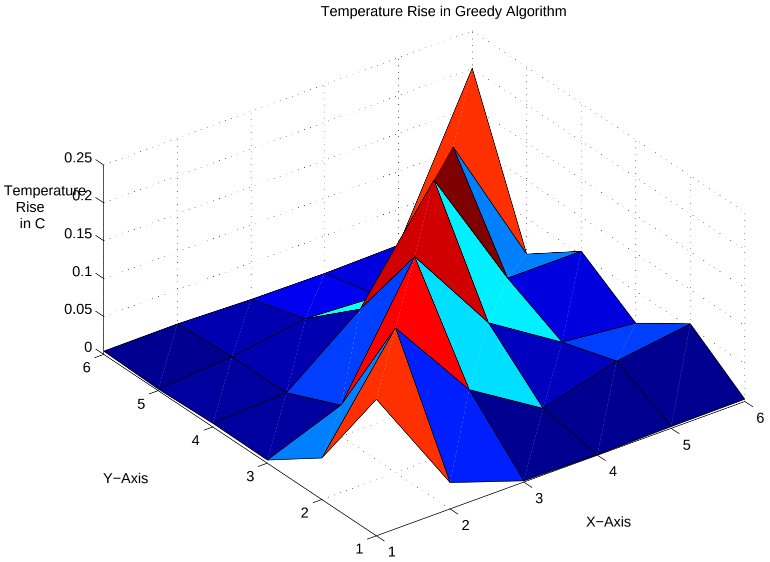

Figure 8: Temperature Distribution Across the Network for shortest hop

CHAPTER 13

IMPLEMENATION MODEL

Tinyos is the component based runtime environment developed by university of California, Berkeley. TinyOS system, libraries and application are written in nesC , language for programming structured component based applications. It has C like syntax, support TinyOS concurrency model, structuring, naming and linking software components together into robust network embedded systems. For any application we need to define a component with well defined bidirectional interface and an implementation module which defines tasks, uses hardware event interrupts, standard commands and events they generate to drive hardware units called motes.

13.1. Mica2 Motes Hardware Overview

A standard mote usually called as mica motes (mica2) are second generation mote modules used for research and development of low power, wireless, and sensor networks. Motes are equipped with ATmega 128L is a low power microcontroller which runs TOS from its internal flash memory. It uses a CC1000 ISM band radio transceiver module for wireless communication. It has 128kb onboard flash memory, operates at 4MHz speed, and has UART serial communication with 10bit ADC. The CC1000 radio operates at 916 MHz radio frequency and is capable of 100feet radio range. It has data rate of 40Kbits/sec, has 51 pin external connector and draws 0.75mW when fully operational. It provides user interface through onboard 3 LEDs and can be drove through 3V external power supply or 2 AA batteries.

Sensor boards connects onto mica motes through surface mounted 51 pin connector which supports Analog Inputs, I2C, SPI, UART, and a multiplexed Address/Data bus. These sensor boards have Photo diode, Thermistor, Microphone, Sounder, Magnetic and Acceleration Sensor.

These mica motes are programmed via mica interface board, which has a parallel port from programming motes and a serial port to read data from motes. These interface boards are powered by 3V external power supply or by the 2AA batteries of the mote when they are plugged on top of the interface boards. The sensor boards can be plugged in to expansion connector on other side of the interface board.

Tinyos provides concurrency model, there are tasks and hardware event handlers running in parallel figure8. Tasks are like function which should be extremely light because once entered wouldn't exit till it executes the task. The hardware event handlers are executed in response to hardware interrupts and are run to completion. Commands and events that are part of hardware event handlers are to be declared with Async. There are atomic statements to perform small operations and norace keyword to avoid race condition.

13.2. Protocol Model

The protocol implementation has several sensor motes which act as Adhoc sensor nodes in a Biosensor network. Typically these motes have a propogation range of about 50 feet. Inorder to facilitate in-lab testing, we set up the motes to receive the data within a desired propogation range. Each mote is assigned an ID during the compilation and upload of program into the flash memory. Each packet is of the type TOS_MsgPtr. Each packet contains the following fields: source address, destination address, current address, next address, type. Most of the above packet fields are self explanatory. Type is used to indicate if the received packet is a control packet or data packet.

When a node sends a packet, tinyos places the send command in the node scheduler. Each node has one scheduler. At the earliest possible time, the packet is removed from the scheduler queue and aired out. As RF communication is used for transmission, the hop delay will be in the order of micro seconds and can be safely ignored. Moreover the nodes have the capability to only measure a time of minimum 1 milli second.

In order to calculate the time taken by the packet to reach the destination, we start a timer(timer 1) which repeats itself every milli second and stop it when the send command is removed from the scheduler. To calculate the time taken by the forwarding node to forward the packet to the next hop, we start a timer(timer 2) which is fired every milli second immediately after the packet is received from previous node and stop it after the packet is removed from the scheduler. The sum of timer 1 at the source node and timer 2 at all the forwarding nodes give the packet delay at the destination.

During the initial setup phase, each node identifies its neighbors based on packet signal strength information. During this phase, nodes also share their location information with their neighbors. So each node knows the location co-ordinates of the neighbor nodes.

Greedy: During the operation of greedy algorithm, nodes start sending packets to the destination. When a node receives a packet, it checks to see the next field of the packet. If the next field is not the local address of the node then the packet is dropped. if the next field is the same as the node’s local address, then the current field of the packet is set to the node’s local value and the neighbor that is closer to the destination is chosen as forwarding node and the packet’s next field is set to the address of that node. When a node receives the packet whose destination address is the same as the node’s local address, then the packet is processed or send to the base station. In our implementation, when the packet reaches its destination, it forwards the packet information to the computer through the programming board.

Tarra: Data transmission is done to the destination during the operation phase. In our protocol, each node initially set a predetermined destination to the packet and forwards it. When a node receives a packet, it first checks the next field of the packet. If the next field is not the local address of the node then the packet is dropped. If the next field is the local address of the node then the node creates a list of forwarding set from its neighboring set. Forwarding set is the set of neighboring nodes whose distance to destination node is smaller than the current nodes distance to the destination node. From the forwarding set node picks up the a node whose temperature at its location is the least among all the nodes in the neighbor list and set it as the forwarding node. When a node receives a packet whose destination address is the local address of the nodes, then the packet is processed and the values are send to the base station, which is the computer in our implementation.

In our implementation, By the time Timer1 and Timer2 find the time taken for the packet to be send or forwarded, the packet will already be transmitted. So we store those values and at the end of simulation, we send a control message which traverses through the network and collects the timer values and send them to the computer.

When a node transmits, the neighboring nodes receives the packet and by checking the current value of the packet, the neighbors can determine the source of transmission. By using this information, the node can calculate the temperature at the node using the FDTD method.

CHAPTER 14

IMPLEMENTATION RESULTS

In this section, we explain the results of our protocol implementation in sensor motes. The results shown in this section were taken in varying topologies and the protocol's performance is analyzed with respect to the greedy algorithm.

The aim of our implementation is to demonstrate the tradeoff made by our protocol in delay to route the data away from the hotspot. We use the average delay and percentage of packets meeting the deadline as the metrics to demonstrate the performance of protocols. Sensor networks are very application specific so the packet deadline is set based on the requirements of the application. In our graphs, we document the percentage of packets that would have met the deadline for various deadlines.

First we find the percentage of packets meeting the deadline for the scenario as shown in figure 10. We introduce a constant flow of traffic from an edge of the network and direct it to the gateway which is at the opposite edge of the network. As shown in figure 9, the line between the node represents the link between the nodes and node S is the source and node G is the gateway. The figure 10 shows the different deadlines and the percentage of packets that meet the deadlines.

we find the delay of the packets to reach the gateway in low traffic environment. For this, we introduce a low amount of traffic i.e. about 100 bytes/second in various nodes of the network and document how long the packets take to reach the gateway. Figure shows the percentage of

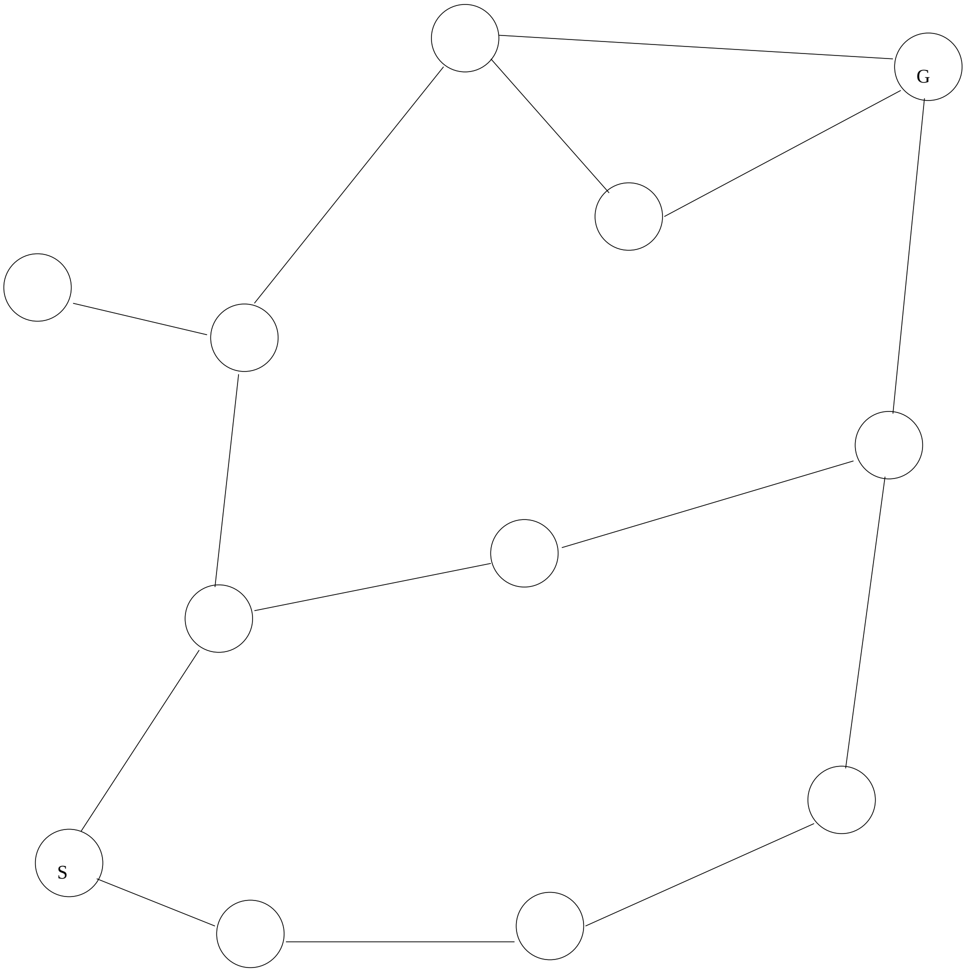

Figure 9: Sample scenario for demonstrating the average packet delay

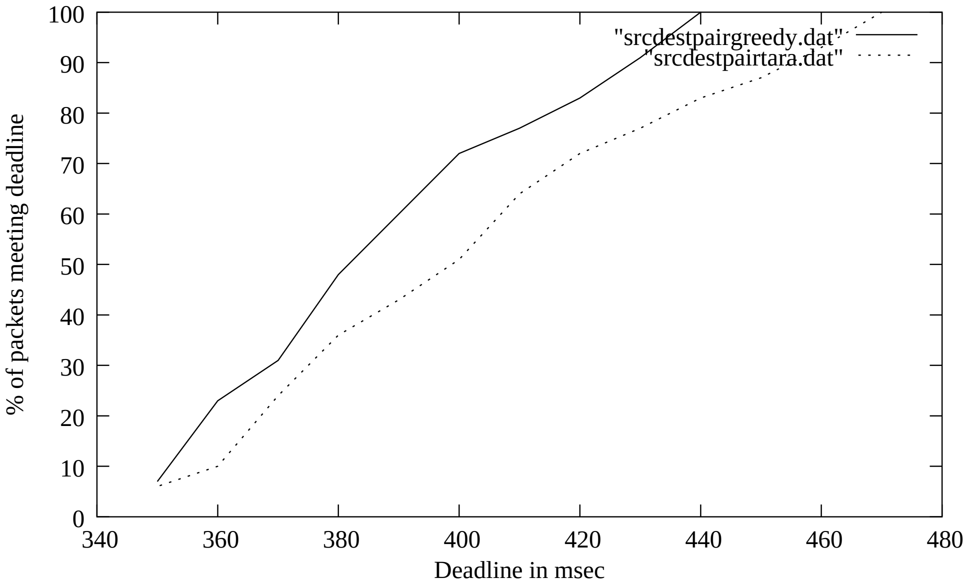

Figure 10: Performance of TARA and Shortest-hop for the scenario in figure

packets that would have met the corresponding deadline (in msec). In the figure 11, TARA has higher percentage of packets meeting the deadline than the greedy. Though the greedy algorithm takes the shorter path to the gateway, its percentage of packets meeting the deadline is almost the same or a little lesser than TARA. This might be attributed to the loss of packets caused by routing all of them along the same path.

Figure shows the percentage of packets meeting the deadlines for higher traffic i.e. about 250 bytes/second. TARA clearly has a better percentage of packets meeting the deadline than greedy routing. The difference in the performance of both the protocols have increased from the figure 12, which led us to believe that TARA is a better performer than greedy as the traffic increases.

From the figures 11 12, we get the perception that shortest hop algorithm has longer delays. But in reality, the less percentage of packets meeting the deadline is due to the fact that packet miss the deadline due to collision and not due to the delay in transmission. So all the packets other than the ones that met their deadline do not reach the destination at all. To demonstrate this, we give the average packet delay at each node to meet its deadline in figure 13. Figure shows that the average

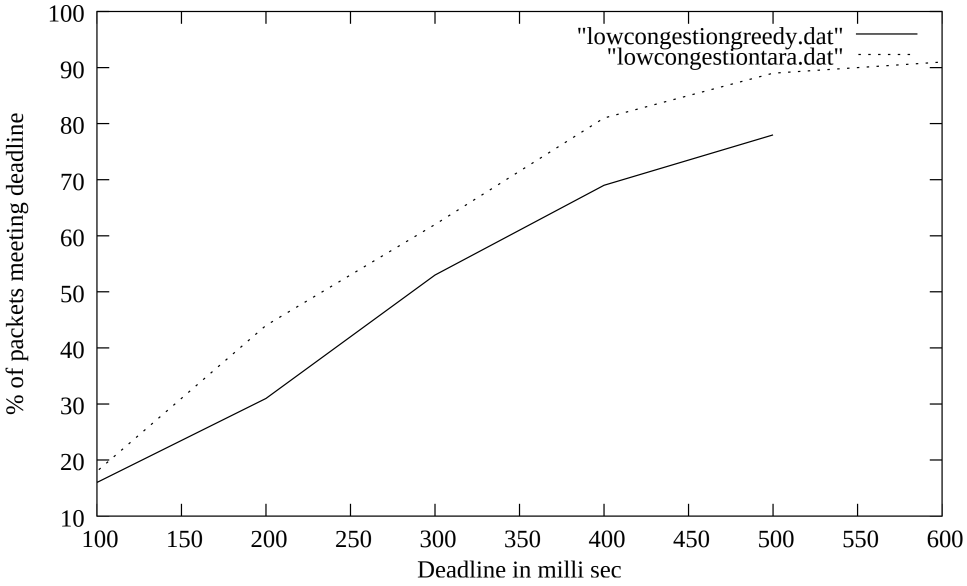

Figure 11: Performance of TARA and shortest hop routing for low traffic

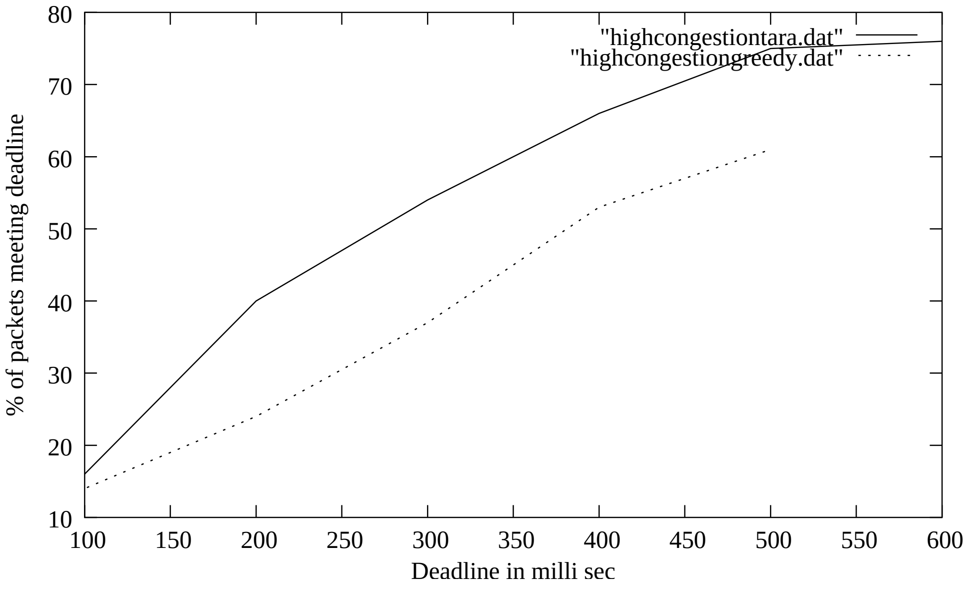

Figure 12: Performance of TARA and shortest hop routing for low traffic

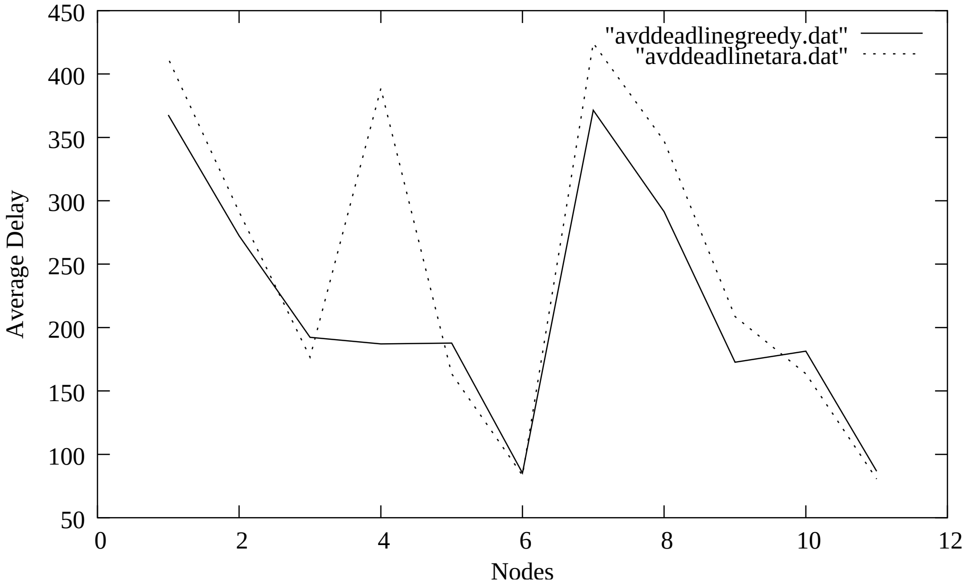

Figure 13: Average packet delay of packet send by each Node

packet delay for each node is generally higher for TARA when compared with shortest hop routing.

CHAPTER 15

CONCLUSION

This thesis proposes an algorithm called TARA for routing data in medical biosensor networks. We surveyed a few routing protocols that are proposed for wireless sensor networks and found that they are not feasible for use in medical biosensor networks. We also identify the characteristics of a protocol that can be used in in-vivo environment.

TARA routes data in medical biosensor networks by taking into consideration the thermal residue in the tissue at the forwarding node. As the biosensors are most often used in some mission critical applications, this protocol also helps the packets to meet their deadlines by routing them not only with thermal awareness, but also with deadline awareness at each forwarding node.

We simulated our approach in MATLAB to find the rise in temperature at the tissue due to radiation caused by communication. We compared our simulation with a shortest hop forwarding algorithm. The simulation results show a definite need for considering the radiation effects in the design of a routing algorithm for biosensor networks.

We also implemented our approach using mica2 sensor motes. We found the time delay of the packets and the percentage of packets meeting various deadlines. We compared our implementation results with the implementation of a shortest hop forwarding algorithm. The results showed that our approach is more effective when there is a higher traffic in the network. We also infer that since our approach aims at distributing the heat across the network, it also automatically distributes the packet flow across the network with due consideration to the packet deadline.

CHAPTER 16

RELATED ISSUES AND FUTURE WORK

In this section we give some of the issues related to routing in medical biosensor networks that are not within the scope of this thesis and can possibly be studied in future.

- **Placement of sensors:** Due to the invasive nature of medical biosensor network, placement of sensor nodes is predetermined and cannot be changed often. The sensor nodes should be strategically placed such that there would be less interference in communication and no single area of the nodes is overly exposed to the radiation due to communication. A protocol for such strategic predeployment of sensor nodes needs to be proposed.
- **Gateway node:** In earlier sections, we describe a gateway node as a bridge between the biosensor network and the external base station. Since all the nodes need to send their data to the gateway node, an alternative approach for deployment of multiple gateway nodes or using data aggregation techniques for reducing the communication near the gateway region needs to be investigated.
- **Choosing the threshold** The permissible rise in temperature caused by radiation depends on the location of the body where the communication happens. So the threshold to be chosen for limiting the temperature should be selected based on the application in which the protocol is operated.

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