AN ENERGY EFFICIENT ADDRESSING SCHEME FOR

A STATIC WIRELESS SENSOR NETWORK

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ENERGY EFFICIENT ADDRESSSING SCHEME FOR

WIRELESS SENSOR NETWORKS

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ABSTRACT

In this thesis, we propose architecture for a static wireless sensor network where sensors are arranged into a zones with the nodes at each zone interconnected with nodes in sub zones. We also provide an energy efficient routing algorithm in the network. In our proposed architecture, every sensor obtains a unique node identifier addressed in a binary addressing fashion. We show that our algorithm can handle addition or deletion of nodes, admits simple and distributed routing**,** and is easily extensible. We also present simulation results showing the energy required per packet transmission and overhead analysis in our approach is less as compared to other work.

This thesis starts with an introduction to Wireless Sensor Networks and the Directional Source Aware Protocol (DSAP). Then a hierarchical structure and Spatial IP address assignment architecture is studied. We then propose our zone architecture which implements energy efficient addressing scheme.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Computing and Engineering have examined a thesis titled "An Energy Efficient Addressing Scheme for a Static Wireless Sensor Network," presented by Sawal Nilesh C., candidate for the Master of Science degree, and certify that in their opinion it is worthy of acceptance.

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CHAPTER 1

INTRODUCTION

1.1 Wireless Sensor Network

A wireless sensor network (WSN) is composed of spatially distributed sensors. These sensor nodes cooperatively monitor surrounding conditions. Every node in a sensor network usually contains radio transceiver, a small microcontroller, one or more sensors and an energy source, a battery. The sensing electronics keeps track of surrounding conditions related to the situation neighboring the sensor and alter them into an electric signal.

A Wireless Sensor Network (WSN) contains such multiple sensor nodes which can intercommunicate or communicate directly to an external base-station (BS). All nodes coordinate among themselves to generate high-quality data about the ambient conditions. A base-station is a fixed or mobile node with much more computational and energy resource having the capability of linking the sensor network to an existing communications infrastructure or to the Internet where a user can have access to the collected data.

1.2 Applications

The applications of Wireless Sensor Networks involve monitoring, tracking or controlling. In all the following applications a WSN is implemented to collect data through its sensor nodes.

- Area Monitoring

- Search and Rescue
- Building Safety
- Military Applications
- Ocean and Wildlife Monitoring
- Monitoring of Fires
- Greenhouse Monitoring
- Earthquake Monitoring
- Medical Monitoring and Research
- Waste/Wastewater Monitoring

1.3 Challenges for Routing in a Wireless Sensor Network [4]

This section discusses several challenges that must be overcome.

Energy Consumption

Sensor nodes have a limited supply of energy. This energy is used for three purposes, sensing data, manipulating data and data communication. Sensor nodes are deployed mostly in uninhabited areas where there is no power supply; hence the energy lifetime of sensor nodes strongly depends on battery lifetime. Energy conservation protocols are essential in this matter.

Sensor Deployment

Node deployment depends upon the application, thus it can either be deterministic or random. In case of deterministic deployment pre-defined paths are used to route data. However in case of random deployment there is no definite topology, which generates the need of self-organization for sensor nodes. It is mostly possible that routes will consist of multiple hops.

Transmission Capability

In a WSN, nodes are connected by wireless channels. Fading and high error rates are problems associated with the wireless channel. It is costlier to use MAC protocols like CSMA for sensor networks. Moreover a sensor's view of the environment is limited in range as well as accuracy.

Global Addressing Scheme

As sensor nodes are very large in number, it is not possible to have a global addressing scheme for deployment of sensor nodes. It also increases the overhead cost of maintaining a unique ID for every node. Hence traditional IP based protocols cannot be implemented for a WSN.

Localization

The process of determining the exact locality of sensor nodes is termed as Localization. GPS cannot be used in a WSN as it will prove expensive; moreover GPS won't work in indoor areas. Hence there is need to develop means of establishing co-ordinate system without relying on an existing infrastructure. Currently this problem is solved using Trilateration and Multilateration techniques, but they pose problems like accuracy and attenuation of RSSI.

Fault Tolerance

It is highly possible that sensor nodes may fail due to lack of power supply, environmental interference or physical damage. This condition necessitates that the implemented protocol should have the capability to form new links and interconnect the network to route data up to a base station. Having multiple levels of redundancy is good approach towards making a fault tolerant sensor network.

Scalability

Depending upon the application, number of sensor nodes can vary in order of hundreds. Implemented routing scheme must be able to handle any given number of sensor nodes at any time.

Dynamic Topology

Most WSN architectures are stationary, but it possible that some nodes or a base station are mobile. It is more challenging to route messages in a mobile environment as network also needs to maintain stability along with other constraints like bandwidth and energy consumption.

1.4 Classification of Routing protocols

Flat Network Routing

In case of flat networks, all the sensor nodes are at same level with same resources which coordinates with each other to perform the sensing task. Routing is data centric, where a base station sends queries and waits for a response. Attribute based naming is used in order to specify the properties of data.

Hierarchical Network Routing

In the hierarchical networks, nodes work in layers. Nodes which possess higher energy are used to process and send the information and those with lower energy are used to perform the sensing task. This leads to formation of clusters, with cluster heads and members.

Location Based Routing

In Location based routing, location of the sensor is used as means of addressing for sensor nodes. The distance between neighboring nodes is determined by judging the incoming signal strength. Information is exchanged among the neighbors so that they can manipulate their relative coordinates. It is also possible to obtain the location of nodes by directly communicating with a satellite or using GPS, provided the nodes are equipped with a GPS receiver.

1.5 Motivation

A sensor network is normally a wireless ad-hoc network, which implies that each sensor node supports a multi-hop routing algorithm. Sensor nodes are constrained by parameters like size and cost. This condition further results in parallel constraints on resources like energy, computational speed and bandwidth and memory. Hence, there is need of innovative techniques which can eliminate energy inefficiencies and thus increase the network lifetime. All such constraints in combination with a typical deployment of a large number of sensor nodes put forth many challenges to the design, stability and management of WSNs which further necessitate awareness and balance of energy in the network.

1.6 Problem Statement

In case of wired network more importance is given to optimizing the available routing paths as the nodes are mostly stationary and physically connected. However in case of a Wireless Sensor Networks, the sensor nodes are co related with their physical neighborhood. That is why it is more essential for study on defining a topology which will give the optimal number of neighbors for a particular node which it can handle to transmit messages to and receive messages from its neighbors. It is obvious why numerous topologies suggested for wired networks cannot be used in case of wireless networks

Some of the applications mentioned above demand random deployment, but for certain specific applications like in the medical area and research or building safety we can control the placement of these sensors. In such applications location of the sensors are fixed relative to each other. The essential thing is to determine the best topology for network of wireless sensors. As placement of the sensing nodes can be controlled and we do not even require mobility of the sensors relative to each other, placement of fixed nodes can be done more efficiently. We do not need to consider self-organization of the sensor nodes into a network. Location of base station can be pre-determined and hence communication with a base station won’t be as much of a problem. What is finally needed is to accomplish efficient communication among the network nodes.

In this thesis we propose an architecture in which sensor nodes are given a unique ID, in a binary fashion like IP addresses. This reduces the overhead of node address and MAC address while it communicates and also routes the data in an easy and simple manner.

CHAPTER 2

BACKGROUND WORK

The work in this thesis is motivated by several previous works, which are described here.

2.1 Directional Source Aware Protocol (DSAP)[1]

In DSAP each node is identified with a unique ID referred to as Directional Value depending upon its position in the network. This unique ID is set of coordinates in which each coordinate tells total number of nodes between that node and edge of the network in all possible directions.

For example, consider the four-neighbor case of Figure 1, Node 24 would have an identifier of (4, 2, 1, 3). This means that there are 4 nodes to the left edge in direction 0, 2 nodes to the top edge in direction 1, 1 node to the right edge in direction 2 (right), and 3 nodes to bottom edge in direction 3 (down). This information is hard coded during initial setup of the network.

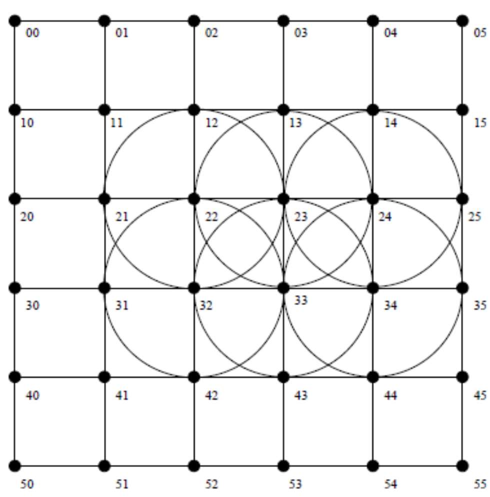

Figure 1: 2D Topology with Each Node Having 4 Neighbors

Directional Value offers the following advantages:

• Every node in the network is identified by a unique ID.

• DV indicates relative distance of the node from the network perimeter in each direction.

• It is possible for every node to compute the relative direction to another node from its ID.

2.1.1 Operation of DSAP

In DSAP Routing follows these simple steps

- Step1: The destination node identifier is subtracted from source node identifier
- Step2: It gives at most two positive numbers, out of which negative numbers are discarded.
- Step 3: Direction to move in is decided by Directional Value(DV) of next eligible node
- Step 4: Consider each of eligible neighbor's identifier and subtract it from destination node's identifier to compute their corresponding DV's
- Step 5: Add Mod value of the four numbers together and choose one with the smaller value. If both nodes have same value, then choose randomly.
- Step 6: Consider new node as next source node and repeat the Steps 1-5 until the destination node is reached

2.1.2 Example

In the given network consider 30 as source and 12 as destination

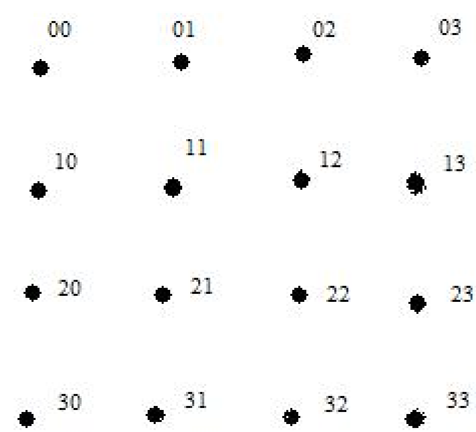

Figure 2: Sample 4X4 Network to Illustrate DSAP Operation

DV of source and destination would be as follows

S – DV(30) = (0,3,3,0)

D – DV(12) = (2,1,1,2)

Subtracting D-DV from S-DV gives

S – D = (-2, 2, 2, -2)

Discard negative and zero values; it gives at most 2 positive values

Nodes in the top and right direction have positive values

Consider node 20 and node 31 as eligible next hops

S20–DV(20) = (0,2,3,1)

S31–DV(31) = (1,3,2,0)

Subtracting D – DV(12) gives

S20 – D = (0,2,3,1) – (2,1,1,2)

= (-2,1,2,-1)

S31 – D = (1,3,2,0) – (2,1,1,2)

= (-1,2,1,-2)

Adding all four numbers (Mod value) together gives DV as

S20 – D = 2 + 1 + 2 + 1 = 6 and

S31 – D = 1 + 2 + 1 + 2 = 6

As both the values are equal, S30 will randomly select one from S20 and S31 as next hop; if they are not different, then the one with the maximum value is selected and the message is transmitted to it.

The algorithm continues, considering the selected node as the new source and the whole process is repeated until the message reaches the destination.

2.1.3 Problem in DSAP

Using directional value as a deciding metric poses a problem for DSAP mechanism that most of the time it will select the neighbor node which has the smallest Directional value and shortest path. Energy in the nodes of particular chosen path will deplete much faster as compared to rest of the network. It would finally result in unbalanced power dissipation in the network. Moreover, by following the current approach, some of the nodes in the network will stay untouched, instead of choosing them as a path to prolong the network life time and also increase the number of message deliveries.

2.2 Hierarchical architecture [7]

This paper proposes a novel hierarchical architecture for a large wireless sensor network in which sensor nodes are arranged into a multi-layer architecture. Peculiarity of the architecture is that the nodes at each layer are interconnected as a de Bruijn graph. This structure provides a hierarchical routing algorithm in the network, by use of this approach, every sensor node in the network obtains a unique node identifier which is addressed in a binary addressing fashion.

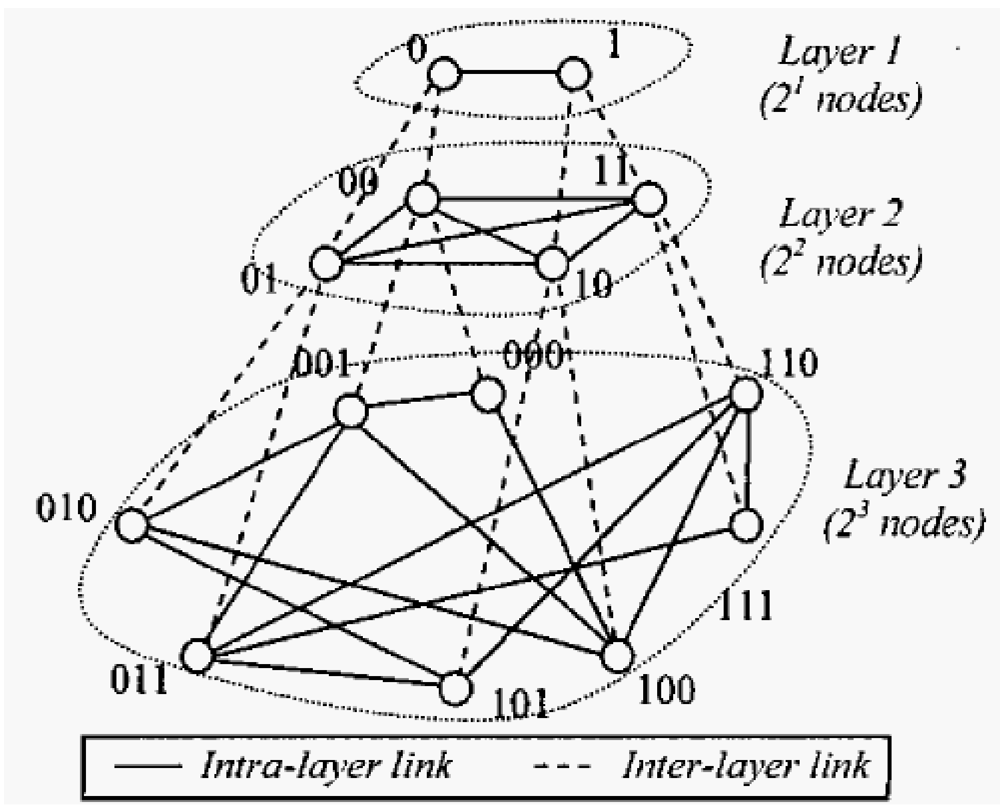

Figure 3: A 3 Layer Hierarchical Architecture

2.2.1 Packet Format

The Packet format contains the destination node addresses, a counter (c), and a routing flag (RF).

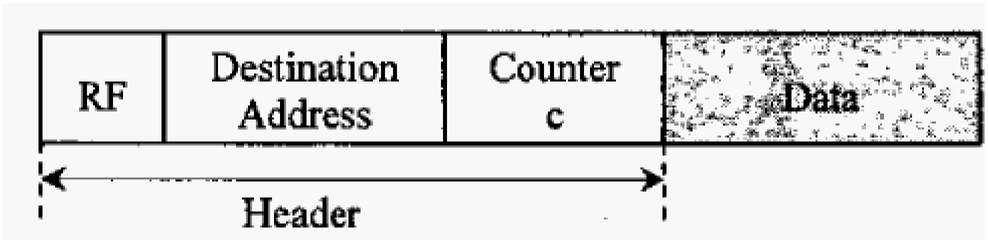

Figure 4: Packet Format for Hierarchical Architecture

The RF is a 2-bit binary number set to

- 00: First bit as 0 indicates that the Source node as well as Destination node is in the same layer. Second bit as 0 indicates that the source node uses Path 1 to route a packet to the destination. It is a default choice.
- 01: First bit as 0 indicates that the Source node as well as Destination node is in the same layer. Second bit as 1 indicates that the source node uses Path 2 to route a packet to the destination.
- 10: First bit as 1 indicates that the Source node and Destination node are in different layers. Second bit as 0 indicates that the source node is at a higher layer than the destination.

- 11: First bit as 1 indicates that the Source node and Destination node are in different layers. Second bit as 1 indicates that the source node is at a lower layer than the destination.

Counter C:

- It is used to record the number of packet hops from the source node to the current node.
- To generate the address of the next node in the path.

2.2.2 Advantages

- The algorithm has reasonable fault-tolerance.
- Admits simple and decentralized routing.
- Addition of new nodes is easier

2.2.3 Limitations

- Physical implementation is difficult.

2.3 Spatial IP Address Assignment [5]

In this paper, the author proposes a spatial IP address assignment mechanism to solve the problem of address assignment. Using this assignment scheme; each sensor node constructs an IP address with the aid of its spatial location. It is assumed that nodes are aware of their spatial location.

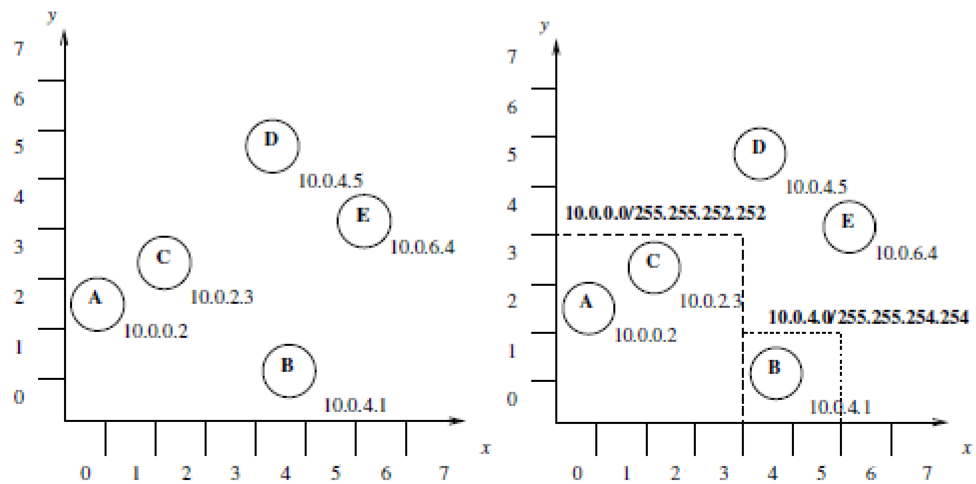

Figure 5 : Example Spatial IP Address Assignment and Two Regional Subnets

Figure 5 shows a network with spatially assigned IP addresses. A Sensor constructs its IP address by taking its (x, y) coordinates as the two least significant octets in the IP address. As location information is encoded in the IP address, a regional subset can be defined as a set of sensor nodes that share a prefix.

2.3.1 Advantages

- A regional broadcast mechanism can be implemented because of regional subnets.
- Address assignment neither needs a central server nor intra communication among the sensor nodes.
- No need of special mapping between physical and logical location.

2.3.2 Limitations

- The spatially assigned IP addresses are not guaranteed to be unique.

CHAPTER 3

ENERGY EFFICIENT ARCHITECTURE

3.1 Assumptions

In case of Wireless Sensor Networks the network topology can be viewed from a different outlook, from a neighborhood point of view. In such cases the number of neighboring nodes regulates the number of receivers. Hence it would result in more overall power usage for reception as the sensor node broadcasts, even though the number of transmissions decreases. In this paper, the effects of communication with a base station are not considered. We assume that the base station can be placed at any required location according to the application since the topology is fixed and known. It implies that, the power requirement for communicating with the base station is independent of the topology. This aids us to concentrate on the effects of the topology on the communication among the sensor nodes in the network only.

3.2 Architecture

A network is made up of multiple nodes. These nodes are geographically as well as logically divided into zones which forms the base of our architecture. The addressing scheme used is similar to IP addressing notations like 00.00.00.00. except the numbers are either 0 or 1.

Consider a network categorized into 4 zones. They are uniquely identified with addresses 00, 01, 10 and 11. This address space can be further divided as nodes get added to a particular zone.

For an instance, if zone 00 is sub zoned then addresses for nodes in zone 00 would be 00.00, 00.01, 00.10, and 00.11 (fig8). Further division in any of the sub zones would distribute the address space as 00.00.00, 00.00.01, 00.00.10, 00.00.11. A particular zone can be sub zoned at most 3 times, which could support 256 nodes with unique IDs

Procedure to allocate addresses to nodes

If a zone is divided vertically then the 2nd bit differs

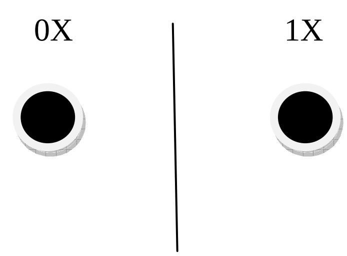

Figure 6: Vertical Division

If a zone is divided horizontally then the 1st bit differs

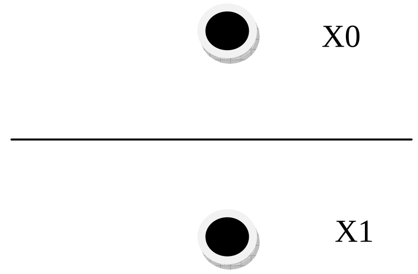

Figure 7: Horizontal Division

Example

Consider a network of 4 nodes, 00.XX, 10.XX, 01.XX and 11.XX.

Addition of a node on the right side of 00

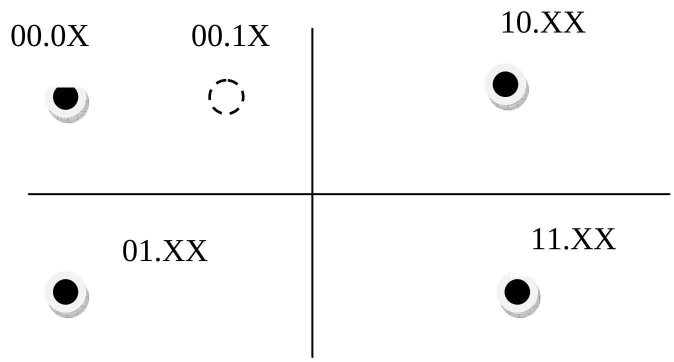

Figure 8: Addition of Node on Right Side of 00

Addition of another node below 00

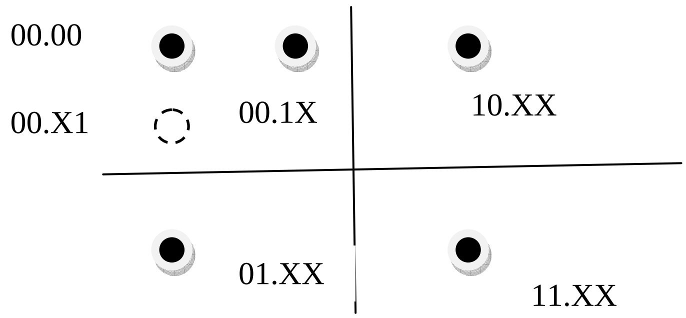

Figure 9: Addition of Node at Bottom

Addition of a fourth node in zone 00

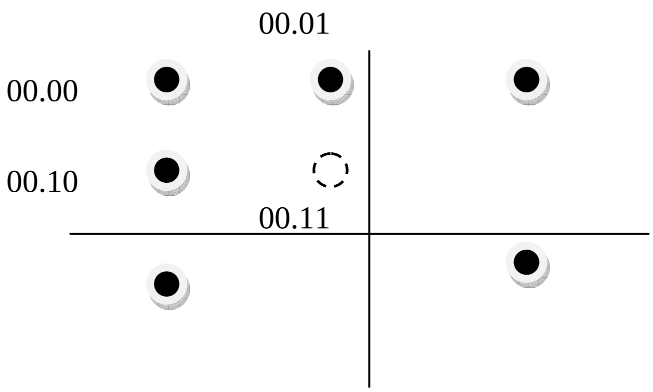

Figure 10: Addition of Fourth Node to Zone

A final network for 16 nodes gives the following topology and addresses.

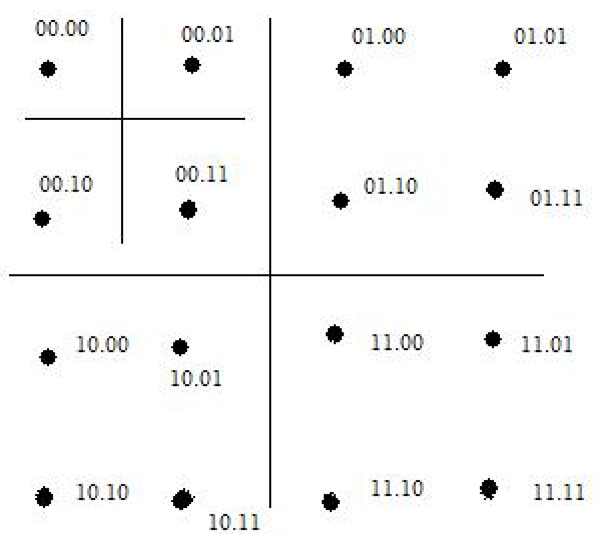

Figure 11: Sub Zones in 16 Node Network

3.3 Routing Algorithm

- Every node keeps information about all the neighbors in the sensing range

Step 1: for index = 0 to addr_Len

If 2 bits from index match in dest_addr and node_addr then

index = index + 2

Step 2: if index = addr_Len then

Current node is destination

Step 3: ptr = index

Step 4: for each node in range

If 2 bits from index in node[i] matches with ptr in dest_addr then

forward directly to node[i]

Else

if 1 bit from index match then

forwarding_node[i] = node[i]

Step 5: If Level1_Array is not empty then

Forwarding node = Max_Energy(forwarding_node[])

Else

Index = index +2 , goto step 4

Example

Consider 00.11 (zone 00) as source and 10.11 (zone 10) as destination which is in a different zone. All nodes in sensing range of 00.11 are considered as its neighbors (00.01, 00.10, 01.10, 11.00, 10.00 and 10.01)

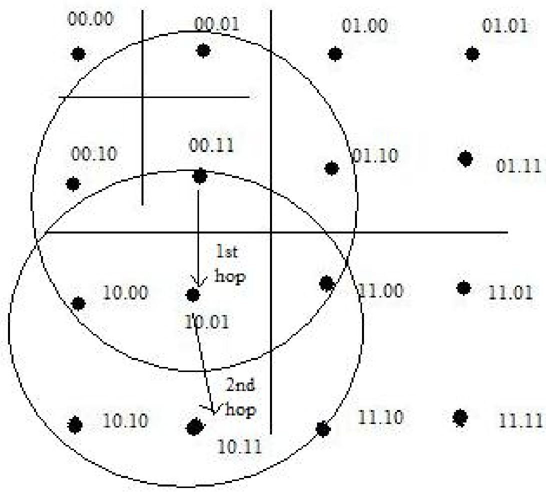

Figure 12: Routing Mechanism

The First two bits for the destination node are 10

Match with first two bits of all available neighbors; the only eligible neighbors are 10.00 and 10.01

Among qualified two neighbors 10.00 and 10.01, select one with the maximum power and forward the message to it.

Let’s consider 10.01 had more power as compared to 10.00 and it was selected.

Now 10.01 will match the first two bits with its available neighbors (00.11, 11.00, 11.10, 10.11, 10.10 and 10.00)

The eligible neighbors are 10.11, 10.10 and 10.00 and the destination node is within range; hence it would directly transmit the message to 10.11

3.4 Packet Format

Packet format is very simple, consisting of Source ID, Destination ID and Payload. There is no need for RF and Counter fields as in Figure 4 for the hierarchical architecture.

Source ID	Destination ID	Payload

Figure 13: Packet Format for Zone Architecture

CHAPTER 4

ANALYSIS

4.1 First Order Radio Model [13]

We use the following simplified view of the radio communication of a sensor

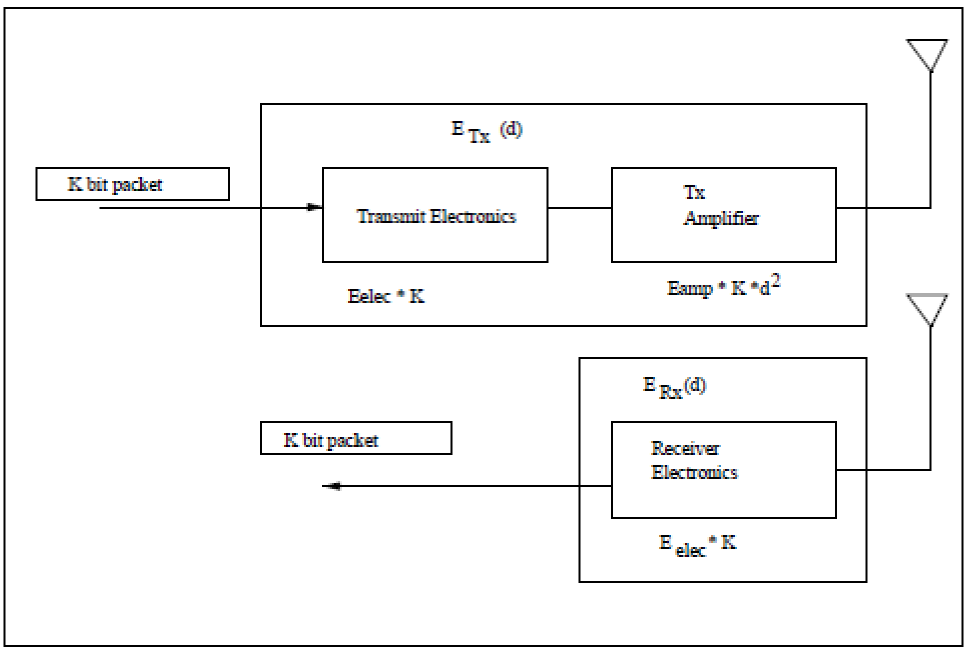

Figure 14: First Order Radio Model

The following parameters are used as typical values

Operation	Energy Dissipated
Transmitter Electronics ($E_{Tx-elec}$) Receiver Electronics ($E_{Rx-elec}$) ($E_{Tx-elec} = E_{Rx-elec} = E_{elec}$)	$50\ nJ/bit$
Transmit Amplifier (E_{amp})	$100\ pJ/bit/m^2$

Table 1: Radio Characteristics

Transmission Cost:
$E_{Tx}(k,d) = E_{elec} * k + E_{amp} * k * d^2$

Reception Cost:
$E_{Rx}(k,d) = E_{elec} * k$

Consider 3 nodes N1, N2 and N3 (N2 and N3 both are in sensing range of N1)

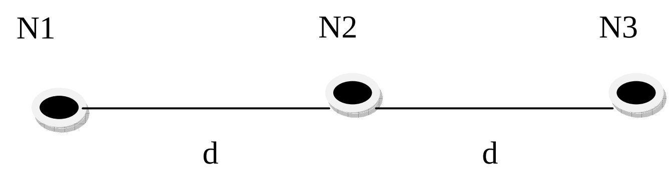

Figure 15: Energy Comparison between Direct Transmission and Using Intermediate Nodes

We now conduct a comparison of energy required to transmit a message from N1 to N3 using N2 as an intermediate node and without using N2, i.e., direct transmission.

k = Packet length = 512 bits

d = distance between nodes = 10m

Using N2 as intermediate node (N1- N2- N3)

Total Energy $= E_{Tx}(N1) + E_{Rx}(N2) + E_{Tx}(N2) + E_{Rx}(N3)$

$= 2(E_{Tx} + E_{Rx})$

$= 2[(E_{elec} * k) + (E_{amp} * k * d^2) + (E_{elec} * k)]$

$= 4(E_{elec} * k) + 2(E_{amp} * k * d^2)$

$= 11.26 * 10^{-5}$ J

Direct Transmission from N1 to N3 (Distance is doubled)

$= E_{Tx}(N1) + E_{Rx}(N3)$

$= [(E_{elec} * k) + (E_{amp} * k * 4d^2)] + [E_{elec} * k]$

$= 2(E_{elec} * k) + 4 (E_{amp} * k * d^2)$

$= 7.168 * 10^{-5}$ J

It can be observed that direct transmission is better, given the typical energy values where E_{elec} is much larger than E_{amp}

4.2 Address Space Comparison

		Address Space	
Network Size	No. of nodes (n)	DSAP	Zone Architecture
2 x 2	4	4	2
4 x 4	16	8	4
8 x 8	64	12	6
16 x 16	256	16	8

Table 2: Address Space Comparison

The Address Space in terms of bits needed to uniquely identify nodes in DSAP is $2\log_2(n)$, whereas in our zone architecture it is $\log_2(n)$.

4.3 Node failure

If a node fails, neighbor nodes would be informed as they won't receive heartbeat messages. Neighbors would update their routing tables accordingly.

The unique ID for all the nodes still remains the same, as compared to DSAP where DV is dependent on the number of nodes between the perimeter and itself. In case of DSAP, all the nodes in the horizontal and vertical axis would need to be updated.

4.4 Node Addition

Previous work done in the DSAP protocol does not consider addition of nodes, same as in case of node failure. When a node is added then all the nodes in its horizontal or vertical axis would need to update their IDs. Using the addressing scheme as discussed in the previous chapter makes addition of a node easier. The added node needs to identify in which zone it is placed, and it can get its ID from the nodes already present in that zone or from its neighbors. The added node would need to load its routing table with the neighbor's node id and similarly its neighbor needs to update its routing table to incorporate the new ID.

In case of a hierarchical architecture, the addition of nodes would need to add an extra layer, further increasing the complexity. Consider addition of a node at the 4th layer. All the nodes in the 4th layer cannot be interconnected; hence a message needs to be sent from one node to another node in the 4th layer or even the 3rd layer needs the message to be routed via its upper layer nodes. This would result in upper layer nodes getting used up at a faster rate as compared to other nodes, thus decreasing lifetime of the network.

4.5 Advantages

Here is a summary of the advantages of our zone routing protocol

- Every node has a unique ID.
- Node addition is easier.
- Even if node fails; other nodes ID does not change as in the DSAP Protocol
- Physical implementation is easy as compared to the Hierarchical Architecture.
- Address space required is half as that compared to the DSAP Protocol.
- A unique MAC address is not needed for every node or group of nodes as a unique node id itself helps in routing from one node to another node either in the same or different zone.
- Packet format is very simple, consisting of Source ID, Destination ID and Payload. There is no need for RF and Counter field as in Fig 5 for the hierarchical architecture.

CHAPTER 5

SIMULATION

In this chapter we provide details for simulation setup and then evaluate the performance for routing using our proposed zone architecture and DSAP protocol. For evaluating the system performance we use a simple Java program. Evaluation is done for a network consisting of 16, 64 and 256 sensor nodes. Various parameters evaluated are Energy required per Packet Transmission and Overhead Analysis.

The simulation model used a simple radio model [5] from chapter 4. The radio model was also used in [4] for simulation of DSAP protocol. In this radio model, the radio dissipates E_{elec}=50nJ/bit to run the transmitter or receiver circuitry and E_{amp}= 100pJ/bit/m^2 for the transmit amplifier to achieve an acceptable signal to noise ratio. The packet size in this simulation is k= 512 bits for all packets. $E_{Tx(k,d)}$ is the amount of energy that a node needs to spend to transmit a k bit message to a distance d meters. Whereas, $E_{Rx(k)}$ is the amount of energy needed by the receiving nodes. The distance between each node in this network is d=10 meters. And sensing range of each node is 15m. Initially, all nodes were set to 0.l J as the initial energy.

There are some assumptions made for the simulation model which are as listed below

- Communication with a base station is not considered. The packets are routed internally between a source node and a destination node.
- Processing energy is ignored for the purpose of evaluation.

5.1 Energy required per packet transmission

- Energy needed for 4 nodes is the same compared to DSAP in figure 16 as there could be only maximum 2 hops for both the cases
- From 16 to 256 nodes energy required increases exponentially as the Zone architecture uses direct transmission which involves less number of nodes and the DSAP Protocol uses hop-by-hop transmission

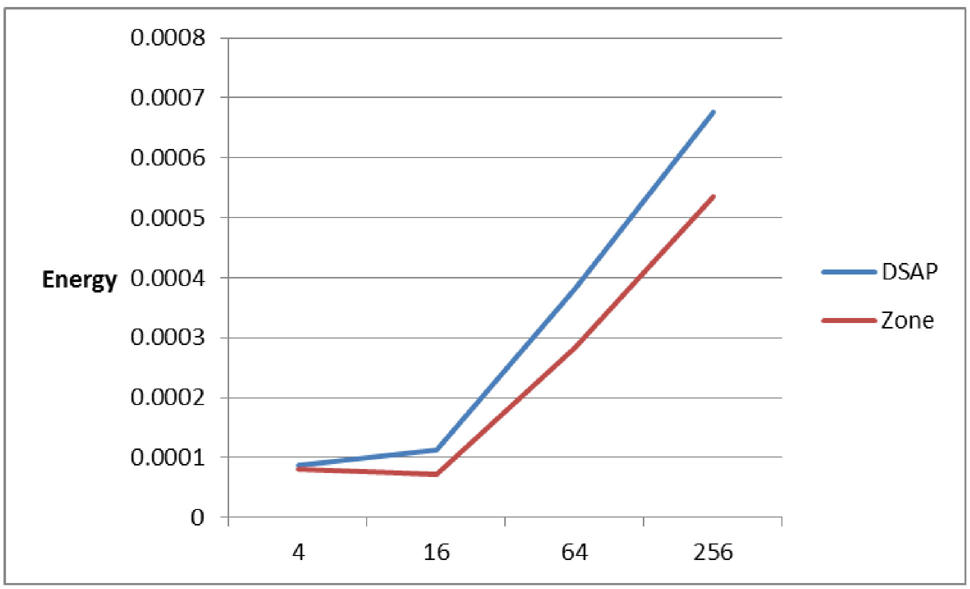

Figure 16: Energy Required Per Packet Transmission

5.2 Overhead Analysis

- Address space required is half as that compared to the DSAP protocol
- The Address Space needed to uniquely identify nodes in DSAP is $2\log_2(n)$, whereas in our zone architecture it is $\log_2(n)$.

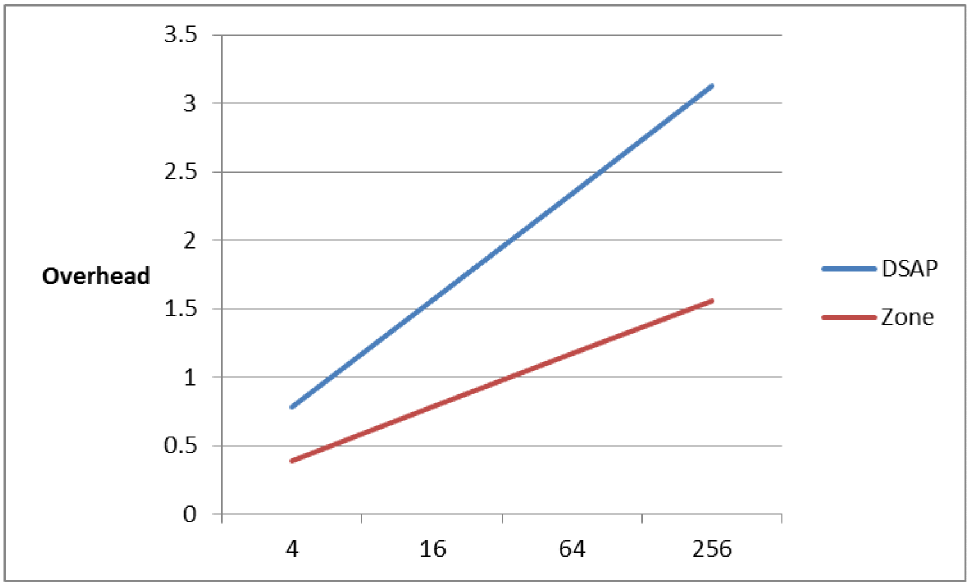

Figure 17: Overhead Analysis

CHAPTER 6

CONCLUSION

This paper describes the architecture for static WSNs wherein sensor nodes are distributed into zones. Our proposed Zone Architecture easily improves fault tolerance, and addition and deletion of nodes. A simple routing algorithm between any two nodes in the network is also provided.

As a conclusion, it can be said that the network lifetime for a WSN can be increased by using the proposed architecture. As mentioned earlier, prolonging the lifetime of a Wireless Sensor Network is more important in order for the network to be able to collect more data.

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VITA

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