PERFORMANCE EVALUATION OF ROUTING ALGORITHMS IN WIRELESS SENSOR NETWORKS

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MASTER OF TECHNOLOGY
IN
COMPUTER SCIENCE AND TECHNOLOGY

BY
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This is to certify that the dissertation entitled "**PERFORMANCE EVALUATION OF ROUTING ALGORITHMS IN WIRELESS SENSOR NETWORKS**" being submitted by **Mr. Rakesh Kumar** to the **School of Computer and Systems Sciences, Jawaharlal Nehru University, New Delhi**, in partial fulfillment of the requirements for the award of the degree of **Master of Technology in Computer Science and Technology**, is a record of bonafide work carried out by him under the supervision of **Mr. Sushil Kumar, Assistant Professor**.

This work has not been submitted in part or full to any university or institution for the award of any degree or diploma.

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DECLARATION

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The matter embodied in the dissertation has not been submitted for the award of any other degree or diploma in any university or institute.

July 2007
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Dedicated to

My Parents, Yash and, No

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ABSTRACT

In the world of fast and dynamic communication, we need information to be retrieved in efficient manner. Especially when we have limited resources then managing them is our critical need. In communication network, we have to deal very carefully with all the related issues, while designing and implementing network. Here we are describing routing problem in wireless sensor networks. Since in wireless sensor network, battery power, bandwidth etc. is very limited, we have developed our solution to the problem of routing, mentioning these resources.

The fibo-data gathering algorithm is especially designed when we have retrieve information in very less delay (as in binary chain scheme) and with optimized energy consumption (as in PEGASIS). It has delay about Log (N), like binary chain scheme, where N is number of nodes in the interested region. And when on another metrics (energy * delay) it is evaluated, its performance is nearly same as PEGASIS.

The algorithm uses Fibonacci sequence concept while grouping of nodes in fibocells. The fibocells contain nodes, which are close together location wise. Each fibocell has its fibohead that transmit the fused data of its fibocell's nodes. Also if some nodes die then it need only to reorganize the affected fibocells.

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Chapter 1

INTRODUCTION

1.1 Introduction to Network

A network is formed because we need things to be formed as collective or collaborative way so that all parts of the network share the workload in distributive way. So the main stress will be in reference to the communication field. The communication area in turn can be categorized into analog, digital or, more frequently hybrid type of data. In this work the main focus area will be "Digital data communication". The network model we will use is ***wireless network type*** in which the communication devices communicate with each other via any wireless media (generally radio frequency). Also wired networks will coexist along with the wireless type since connection to any wired network will still be required from where the required data has to be sent or where the data has to arrive, e.g. the last mile connectivity issue [24].

Wireless network communication area has been in limelight in recent years and will continue to be the center of attraction because of its obvious advantages. Definitely the coming era will be the engulfed by the wireless jargon. But on the flipside of the advantages there are many limitations, which invite some serious research, work in this field. For example, one cannot use the traditional MAC layer protocol in this, because of its bandwidth limitations. Similarly we cannot use traditional network layer protocols in wireless network because of the different requirements and challenges in wireless network. We also have different situation specific applications. So we need wireless version protocols to implement the specific needs [25].

A very fine and successful example of wireless network communication is Cellular technology. In cellular communication the cellular devices connect with each other via radio frequencies. They generally stay in a cell (area which has some allocated frequency that will be used to communication by devices).

Before we delve into intricacies of the work performed lets have a quick snapshot on wireless network concepts. In wireless communication, electromagnetic waves are broadcasted and received. Similar to the other waves, electromagnetic waves are also characterized by their frequency and wavelength. The speed of waves generally varies from one medium to another medium.

When considering the network communication, one can't resist the obvious comparison between wireless and wired network communication. Or one can say that there are many issues that are to be dealt with in the case of wireless communication, which has nearly perfect solutions in wired communication. For example, in wired network the addressing scheme refer the geographical location of the terminals/nodes/station. But in case of wireless network the addressing would not refer the exact geographical location of nodes. This problem becomes obvious as soon as we consider the mobility concept of the nodes.

The wireless communication networks also have very dynamic topology. Another very serious issue in wireless communication is the connectivity, where availability of a terminal at any instance of time is the issue. For example, a terminal may be in a reach at any instance but at another instance its availability cannot be guaranteed [25].

Also the boundary associated with a node can not be well defined because it changes randomly as it depends upon many constraints like noise level and environmental factors. One major problem is that the medium in which we are going to transmit the information is open air and hence, more prone to error. For example in wireless communication the bit error rates are of order 10^{-4} but in wired communication it is 10^{-9} (in fiber optic cables) [25]

1.2 Major Constraints in Wireless Networks [25]-

While using wireless network some constraints are-

- It should be simple in use like wired network communication.
- It should be generic i.e., it should be compatible with other related technologies.
- The security threats must be focused.
- The efficiency in power usage must be there.
- The quality of service (QoS) must be guaranteed.

1.3 Cell, Cluster and Channel-

In wireless network communication a particular region is selected which is further divided into **cells**. In each cell there is a base station at the center. The mobile terminals (MTs) can communicate to base station (BS) referred as **uplink channel** communication and **downlink channel** is for BS to MTs. Suppose a particular radio spectrum is used in the communication. Then the groups of cells which uses entirely the radio spectrum are cover a logical area called **cluster** [24].

The wireless radio channel places fundamental limitations on the performance of wireless communication systems. There are three basic propagation mechanisms which impact propagation in a wireless communication system, are reflection, diffraction and, scattering.

In wired communication the transmitted signal power and the received signal power are not same due to attenuation. The same situation arises in the wireless network communication. Here also there is loss of signal strength due to some factors which we are as follows:

1.4 Path Loss -

It includes propagation losses caused by the natural expansion of the radio waves front in free space, absorption to electromagnetic waves, diffraction losses etc. Path loss leads reduction in power density of electromagnetic waves. It is one of the critical components while the wireless communication is analyzed and designed [25].

1.5 Fading-

The received signal doesn't have the same signal strength as the transmitted one. Some changes occur due to fluctuation in the signal. The fading term can be more specifically defined by the two concepts; slow fading and fast fading [25].

1.6 Interference-

This is a very common complexity issue associated with wireless communication. Technically it occurs due to following two factors

1.6.1 Adjacent Channel Interference-

When the two adjacent cells frequencies are comparable then this kind of interference occurs. This can be avoided by using appropriate gap between the adjacent channel frequencies called **guard band**.

1.6.2 Co-Channel Interference-

This occurs in a region when the two cells use the same frequency. Since channel reuse concept (or frequency reuse concept) is very necessary and in practical use in wireless communication, the co-channel interferences cannot avoid totally. But it can be further suppressed by using directional antennas and dynamic channel allocation schemes [25].

1.7 Objective-

The goal of this dissertation is to study the related issues in routing (especially data gathering) in wireless sensor networks. We will also study two important performance evaluation metrics while comparing the fibo-data gathering algorithm with the other two famous data gathering algorithms (PEGASIS and binary chain based scheme).

Chapter 2

SENSOR NETWORK

2.1 Introduction to Sensor Networks

Now the next focus is on sensor networks. The term **sensor network** constitute of different sensors in any particular area where the network is established. Generally, a sensor network is highly distributed in nature. In this network very large number of sensors is deployed. A **sensor** is a **micro-electro-mechanical device**. These are fabricated on the silicon substrates in a similar fashion like integrated chips. The sensors are small in size, low cost and low powered device. A sensor may have **computational, sensing** and, **communicational** capability. It means a sensor have three separate units called processing unit, sensing unit and, communication unit respectively [25].

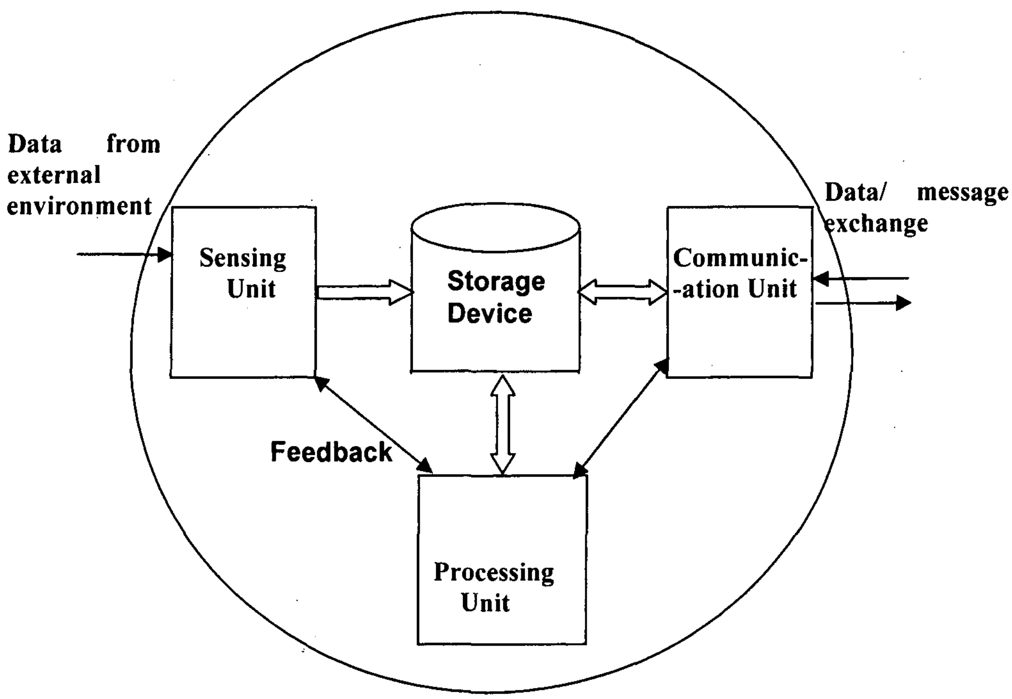


Fig. 2.1 Simple demonstration of a sensor node

Processing unit may consist of the components that can perform the required processing on given data to the sensors. In this unit there may be the requirement of operation such as sorting of data, searching of a particular data, applying any aggregation functions on data, changing the format of data into any other format etc.

Sensing unit should contain the components which can sense data as at least in hard real time constraint, from the area of interest. Generally a sensing unit takes data as input and transfers it to the storage device or to the processing unit. This unit may act as secondary unit or as autonomous unit. This means it can sense data initiating itself taking command from the processing unit or without so. In the later case the node has to be active all the time and sense data proactively. But in the earlier case it has to sense data only when it would get command to do so from the processing unit. We will use the nodes as slave behavior of the sensing unit for the reason of energy efficiency. A **feedback** path may also be there which will tell the sensing unit whether more data can be sensed or not. Through this link only the processing unit will command the sensing unit.

Communication unit is mainly responsible for the data exchange with other nodes. There are paths between this unit with processing unit as well as with storage unit. Whenever a request will come for any particular data/ message then the processing unit will perform the required computation and then inform the communication unit to transfer it further. When a node will receive any data/message then also it will inform the processing unit and store it accordingly instructed by the processing unit.

Since all nodes are wireless and need to send or receive data to/from a fixed wired station called **base station**. A base station may or may not present in a wireless sensor topology. If only one base station is deployed in the whole topology then it is the central fixed structure and all sensor nodes will communicate with this base station also. But more than one base station can also be deployed. In every cluster there is a node, which behaves like the primary node called **cluster head**. Any node within the cluster can be assumed as a cluster head with consensus of all remaining nodes. Every cluster head deals with many sensor nodes within a cluster. A cluster can be partitioned on the basis of many criterions like, number of nodes or communication range of the base station. Actually a cluster covers an area, which entirely connects sensors present in that region. A base station has no dearth of energy but sensor nodes have the problem of low power battery. A base station has also large enough communication range, powerful processing capability. Now we are going to explain some characteristics of the wireless sensor network.

2.2 Characteristics of Sensor Networks [25]

- The sensor nodes are small in size.
- The nodes are tough enough to be put in harsh climate condition (excessive pressure and temperature).
- The nodes have very limited in resources such as memory, computational power, communication range and most importantly battery power.
- The sensor networks are self-organizing and self-induced because there is rarely any human intervention. All nodes have to behave like in proactive manner.
- The deployment of sensor nodes is totally distributive in nature. The node density is thus varying at different places. Due to this reason one can find dense as well as sparse region in the same topology.
- Like other networks there is no scope of the hierarchical addressing or flat addressing in case of sensor networks. And due to this reason there is lack of any IP address or a single global identifier for a single node.
- The data, which is to be communicated in the sensor network, is very redundant because of large number of nodes to sense the same data.
- In order to maintain the connectivity nodes must be active even if they need not to be active for sensing data.
- Generally the sensor networks are data centric which lead the nodes to be addressed when they satisfy some specific data condition.

2.3 Quality of Service (QoS) Issues:

Generally the protocols on WSN are energy aware only. By using these protocols the optimal path can be assured but what about the bandwidth (or delay) issue. So we required energy efficient QoS protocols in WSN that will ensure the guaranteed bandwidth (or delay) while communication over the optimal energy efficient path. By the use of QoS protocols we will also consider the other issues as well like latency, throughput and delay jitter. The needs of all the issues are mandatory when our application is for the audio, video stream. We are going to discuss the performance matrices which one should consider in order to develop a QoS aware protocol for a WSN [16].

- **Bandwidth:** the traffic nature in WSN can be burst (may be real time data or non real time data).it may be possible that sometime it is needed that bandwidth is divided into multiple traffics simultaneously which cause the collisions also. Also it is not accepted that the allocation of the maximum part of the bandwidth for QoS only.
- **Redundant data:** data generated in WSN is highly redundant because many nodes sense and generate the same data. For this reason data aggregation function are used. But these functions have overhead also. Suppose our data is non real time data then the use of such functions is not a big problem and complex. But when we have real time data, video stream, graphics data the comparison on the traffic is very much complex. For example the comparison between two images would require large amount of energy as well as large number of computational steps. Another factor is the amount of the traffic at any given time. Some time on the channel the traffic load can vary from a lowest point to highest point.
- **Energy and delay tradeoff:** in WSN if a packet is directly transmitted to the base station from a node then it is obvious that it will produce small

delay at the same time energy requirement will go high exponentially or even higher. The same case is applied from base station to a node transmission also. Thus number of hops is increased in the path. But here we have to think so that the balance between energy use and the time delay is considerable.

- **Buffer size:** in case of WSN we required frequently multihope routing that requires data storage at intermediate nodes. Also the data aggregation and data fusion involves storing all the redundant data at nodes. For long sessions communication we need the buffering capacity more at nodes. Also if we need scheduling of packets, retransmission of packets, variable delay, varying transfer rate then enough buffers will be required.
- **Different types of traffic:** the diverse nature of sensed data in WSN leads to develop the hybrid type of nodes which can sense different type of events like, temperature, pressure, humidity etc. there may be need in which dynamic events are to be sensed. Thus the data may be of real time data, non real time. The QoS aware scheme must support all type of data.

Above mentioned factors are the prime constraints that should be carefully solved while protocol formulation. In the table given below some important architectural design issues are mentioned.

DESIGN ISSUES	PRIMARY FACTORS
Network dynamics	Mobility of nodes, target, and sink
Node deployment	Deterministic or ad hoc
Node communication	Single hop or multi hop
Node capability	Multi or single function, homogeneous or heterogeneous capability
Data delivery model	Continuous, event driven, query driven, or hybrid
Data aggregation/fusion	In network or out of network

Table 2.1 Architectural design issues [16]

2.4 Different Approaches of Network Model [14]

2.4.1 Node Centric

In this type of network model all nodes have a unique name, which can be mapped into a unique identifier. All data delivery operation can be performed in this model using nodes identifiers. The hierarchical addressing structure can applied in this model easily. The layered architectural concept is also easily corporate according to this model. But there are some reasons, which avoid this model being used in sensor network. First, the gather cast operation (many to one communication) could not perform simply in this model. Second, any point-to-point or end-to-end communication could not be recognized in node centric model via nodes identifiers, as there are no unique names in sensor network. In the figure given below one can think that every node has a unique identifier, by which a node will be addressed and communicated. There may or may not be provision of clustering in node centric approach. Thus given any particular identifier a unique node will be selected.

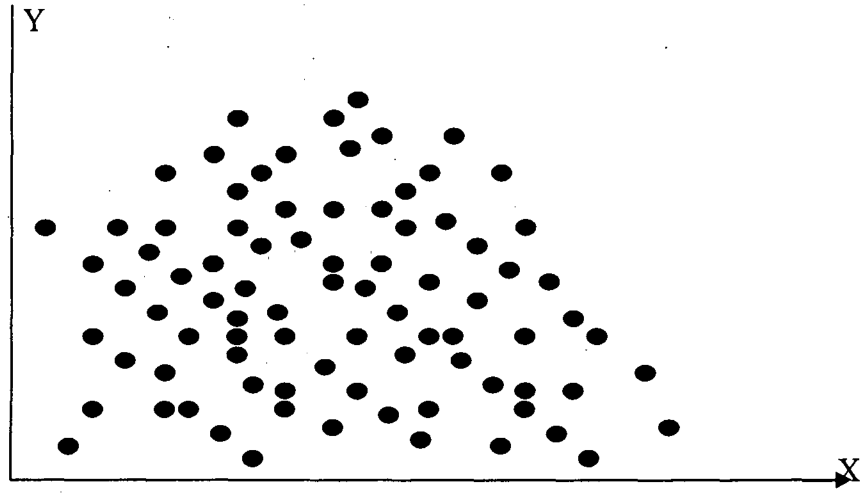


Fig 2.2 randomly nodes are deployed in any area

2.4.2 Data Centric

In this model there is no concept of address of the nodes in terms of identifiers. In data centric approach all the data delivery operations are performed in terms of data itself because here data is more important than the nodes, which produced the data. It means the data is generated distributed manner and same data can be found from many places. For example if some one is interested that how many nodes have sensed the temperature between 30 to 40°C. Here the response will have many nodes sensed values. One can also generate address corresponding to the noses but that has no significance as here our main attention is the data. In this model the number of transmission depends upon the number of queries, and the density of nodes. Sensor network fits well in this model. In accordance with model, given some condition a group of nodes will be selected and they will transmit the conditioned data. Suppose the following nodes are satisfying a condition then they will exchange sensed data so that the data aggregation will take place. This could be seen in fig-5. All the blue nodes have satisfied the given condition.

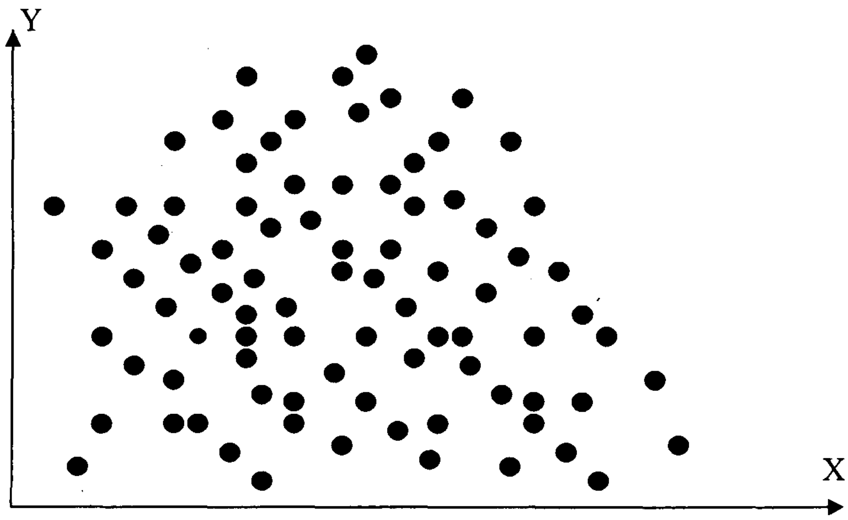


Fig. 2.3 data centric approach

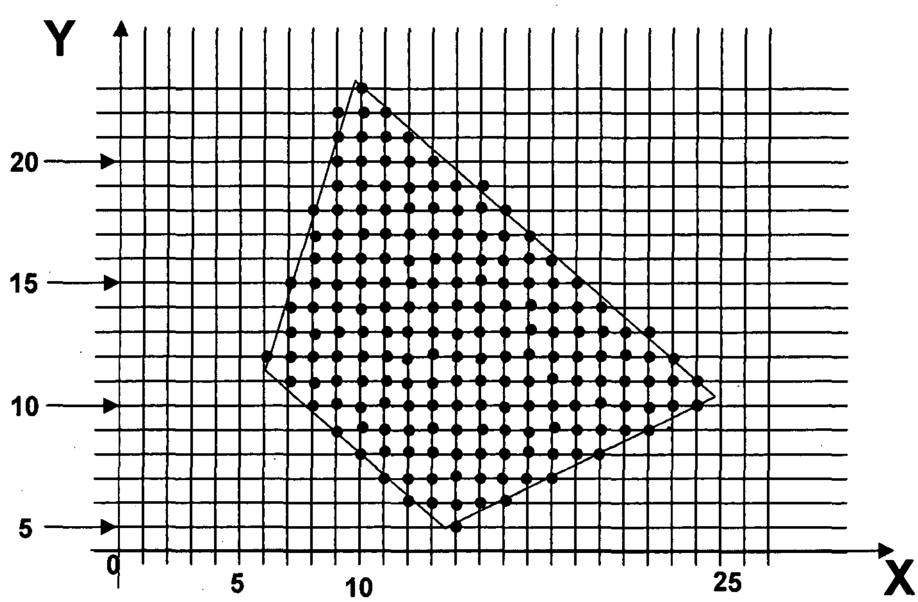


Fig. 2.4 position centric approach

2.4.3 Position Centric

In this model the nodes deliver data according to their location values. This means the location values of the nodes are used in different data delivery operations in sensor network. Ultimately all nodes have to do sense data at some physical location. In this model that physical location are mapped into the nodes address. By this scheme one understand that there is no need of any routing table, as all nodes have just to follow the location. Also route discovery and maintenance are not any overhead. All these positive aspects are there at the cost of knowledge of position of destination to the source.

2.5 History of Sensor Networks

Since networked micro sensors lead the concept of broad spectrum of systems in the field of military operation. It further leads the new opportunities in reconnaissance and surveillance and, tactical activities. The sensor network fits well in military operation as the nodes can deployed in air, in water, in vehicles, in buildings, and any other suspected area. Then the nodes can sense activities for which they were deployed in the specific area. One more special thing is that nodes can sense event related with chemical activities, physical activities or biological activities. The nodes have capability to operate in acoustic, seismic, infrared, and magnetic modes.

One can think of usage of the network in military sensing, physical security, air traffic control traffic surveillance, video surveillance, industrial and manufacturing automation, distributed robotics, environment monitoring, building and structure monitoring. But the use of sensor network started in late seventy's. To detect the location and some other important information during cold war, sensors were deployed in the ocean bottom against Soviet Union submarines by USA. It was the type of Sound Surveillance System (**SOSUS**), in which hydrophones were used to detect the events. Nowadays SOSUS are used to detect activities in the oceans, especially for seismic activities.

At the same time of cold war, in the region of USA and Canada, network of air defense was deployed. Later this air defense network evolved as aerostats as sensors and airborne warning and control system (**AWACS**). In 1980, Distributed Sensor Network (DSN) program was started in which integration of internet with sensor network was the main issue. This project was initiated a basic advance research in distributed nature if sensor networks. Apart from the distributed nature, signal processing, tracking and, test beds were also the main areas where researchers put their attention. In 1978, in a workshop sponsored by Defense advances research projects agency (DAPRA) the components of a sensor node were specified which defines: - Acoustic as sensor, different process in an application of resource sharing network as communication, different algorithms and processing capability and, other things apart from DARPA, Carnegie Mellon University (CMU), develop a network operating system especially for DSN, called **Accent** run on the mach operating system. It was so successful in commercial field also. Protocols for the support of dynamic rebinding were also developed at CMU.

At Massachusetts Institute of technology (MIT) using signal abstractions and different matching techniques, distributed array of acoustic microphones are realized for knowledge based signal processing. At the same time Signal Processing Language and Interactive Computing Environment (SPLICE) and Pitch Director's Assistant (for interactive estimation of fundamental frequencies) were developed in MIT. In Mountain View, CA, multiple hypotheses tracking scheme was developed. This was the standard later in the field of multiple hypothesis tracking.

The first demonstration was given by MIT, with the help of a low flying aircraft, in which a PDP 11/34 computer and a array processor processed the data, having 256 kb memory, and 512 kb shared memory. Vehicle monitoring system based on DSN was developed at University of Massachusetts, Amherst. After this trend there was evolution of network centric approach, in which the sensor do not necessarily established on the platform. Sensor could operate independently and cooperate with the related vehicle, weapon, or platform. One such example was Cooperative Engagement Capability (CEC) having several radars for air object detection. Fixed Distributed System (FDS), Advanced Deployable System (ADS), Remote Battlefield Sensor System (REMBASS) and, Tactical Remote Sensor

System (TRSS) are some more network centric warfare's. Latest technological growths lead the development of Sensor Information Technology (SensIT). It can be assumed as the highest capable among recent sensor technology. Nowadays more researches are going on to solve some core issues related with energy problem in sensors, efficient data gathering and diffusion, route discovering etc.

	Past	**Present**	**Future**
Manufacturer	Custom Contractors	Ember corp., Crossbow technology, Sensoria Corp.	Dust Inc.
Size	Large shoe box and up	Pack of cards to small shoe box	Up to Dust particles
Weight	Kilograms	Grams	Negligible
Architecture	Separate Sensing, Processing and communication	Integrated sensing, processing and, communication	Highly integrated sensing, processing and, communication
Topology	Point to point, star	Client server, peer to peer	Peer to peer
Power	Large batteries	AA batteries	Solar
Deployment	Vehicle-placed or air drop single sensor	Hand emplaced	Embedded, Sprinkle left behind

Table 2.2 Three Generation of Sensor Network [11]

Chapter 3

RELATED WORK

3. Related Works

Several studies have already done in the field of routing in wireless sensor networks. The main applications of these networks are very wide. Some important issues related with their use for habitat monitoring are discussed in [1]. Environmental sensing application and vehicle tracking system are discussed in [2] and, [3]. The different architectural facts have discussed in [2], [4], [5], and [6]. In these papers, the total expenses and the power in terms of performance have been also drafted. The different networking possibilities and other concepts related with routing and data transmission protocols are mentioned in [9] and [10].

Having wide area of application, sensor networks are considered one of the 21 most important technologies for the 21st century, by "Business week-September 1999". History of sensors research started actually in late 60s. But during cold war sensor networks were in their developing phase [11]. It also discussed different challenges against the wireless sensor network.

One can develop a better, efficient network layer protocol when unit disk graph model is replaced with a physical layer model (assuming nodes cannot communicate exactly as they do in unit disk graph model, which allows two nodes to communicate if they are in the transmission range) [12]. It is also indicated that packet transmission, reception cannot be exactly described in terms of function of only distance between two nodes. Hence the route discovery cannot be defined in single retransmission by each node. Also due to ignorance of random variation in received signal strength the unit disk graph model is not realistic in designing of robust protocol, as non-deterministic radio fluctuations cannot be ignored. One very concrete finding provided by [12] is that, "hello" packet should not always be used as trivial protocol for neighbor nodes information. Rather a localized position based routing protocol is advised.

The different characteristics impose separate design as well as implementation issues in sensor networks [15]. For example there is varying node density in wireless sensor network, that can cause node connectivity problem and at every time topological information is changed. Different system architecture and design issues on terms of QoS are focused in [16].Jamil and Imad [15] also discussed the routing protocols in terms of hop count model. After that the design criteria for a routing protocol in wireless sensor network have been discussed. One can evaluate a protocol by going through their approach given in [15].

Generally the transmission range of sensor nodes is fixed in temporal and spatial context. But it is shown that varying the transmission range the longer network lifetime can be achieved [13].a efficient clustering technique (Dynamic Transmission Range Adjustment Protocol , DTRAP) is also established having two phases, shrinking phase and growing phase. DTRAP is based on a basic assumption that at any time each node, even in distributed situation also, has nearly a fixed number of neighbor nodes. On the basis of remaining battery power the cluster head is elected n the second phase (in Cluster Head Election Protocol CHEP). Hierarchical clustering concept is also used to demonstrate the layered approach.

Due to very application specific nature of sensor networks use, different communication paradigms have been discussed in [14]. In case of node centric, data centric and, position centric approaches different routing, discovering and, querying strategies are focused. The nodes have one more interesting behavior- on off behavior. Due to this they have to operate in reduced duty cycle in order to maintain connectivity and relay capacity. Finally it is shown in the paper that data centric and position centric approaches are more scalable, better adaptable in application and conceptually more appropriate in many cases. But node centric approach is still most famous and understandable approach.

In [17] and [18] the performance of the network is investigated, considered the two states of nodes, based on the energy constraint. A node may be in either of any two states, named active and sleep. In the sleep phase, a node corresponds to the lowest power consumption, as it would not take part in network connectivity. But in active state a node can perform different operational activities. All these are based when node considered as static [17]. This paper also attempts to derive several performance metrics like data delivery delay and network capacity etc. In [18] the analysis is done while sensor networks are location based. Finally [24] and [25] collects all related information in descriptive manner. In [26] an application layer multicast protocol, based on Fibonacci series, is described. Our work is also based on the same concept, taking from [23].

Chapter 4

FIBO-DATA GATHERING ALGORITHM

4. Fibo-data Gathering Algorithm

The algorithm described in this section is motivated from the concept used in [23]. But the algorithm used in [23] is for application layer and for multicasting. In this work, the nodes are collectively taken in a group based on Fibonacci sequence. Then recursively grouping is done and finally a single node collects fused data, which further transmit that data to the base station.

4.1 Basic Assumptions-

- All the nodes have CDMA capability.
- All sensor nodes are homogeneous.
- All nodes are location aware and have knowledge about others location.

4.2 Algorithm Description-

This data-gathering algorithm is distributed in nature. In this we are going to define a new term called fibocell. Whenever we grouped some nodes together then that grouping is called **fibocell**. Generally a fibocell will have number of nodes, which belong to the Fibonacci sequence. But some fibocell may not have this property. For example, if we have 17 nodes then grouping these in two fibocell which have 13 and 4 nodes. Here the second fibocell doesn't have the above property. The grouping will be done as following way:-

Case: 1 when N belongs to the Fibonacci sequence- In this case we can find a g_n such that,

$N= g_n$, for n greater than equal to 1.

For example if we are going to run our algorithm with 13 nodes then, here we have N= $g_{n,}$ because 13 belong to the Fibonacci sequence (1, 1, 2, 3, 5, 8, 13, 21, 34...). Here n= 7.

Case: 2 when N does not belong to the Fibonacci sequence- Our taken example fits to this case, which have 15 nodes. In this case we can find the maximum n such that g_n belongs to Fibonacci sequence and

$$\boxed{N = g_n + K}$$

Where, K is a positive integer. Here the value of K may or may not be possible that K belongs to the Fibonacci sequence.

(a) When K belongs to the Fibonacci sequence. The example which being present has the same case here. It has total 15 nodes. Thus the value of K= 15-$g_{n,}$ for appropriate value of n and thus we can find that n = 7.

So we have K=2, which belongs to the sequence. If K has belongingness then the fibocell that contains all the K number of nodes follows the same procedure as happened in case 1.

(b) If K has some value that cannot satisfy the case 2(a) then the process is repeated again according to case 2. This is applied recursively until we achieve all the fibocells.

We are going to demonstrate our data-gathering scheme in a cluster with the help of 15 nodes. It is assumed that nodes are randomly distributed on a straight line with equal spacing such that distance between any pair of nodes is same. Also the numbering of nodes is taken just for simplicity. A special **token,** marked by small triangular shape over the nodes (represented by circles) will make the node as fibohead. Also initially any node is chosen randomly as fibohead and marked, so that in next round of data gathering another node behaves as the fibohead.

Here we marked the node 1(in fig-4 (a)) as the default fibohead to start our scheme; hence node 1 is marked with the token (triangular symbol). Node 1 will be the overall cluster head as well for the first round of gathering. When data from all nodes are aggregated and diffused at one node and transferred to the base station, this is referred as one round. For next round any other node except node 1 will be the default fibohead. By doing so we are trying to distribute the energy load.

Since the number of nodes, which is deployed in the area, is known, so we have knowledge about N. On the basis of the value of N and g_n can be decided.

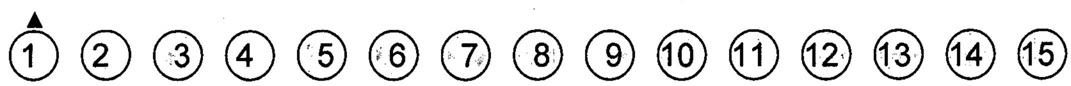
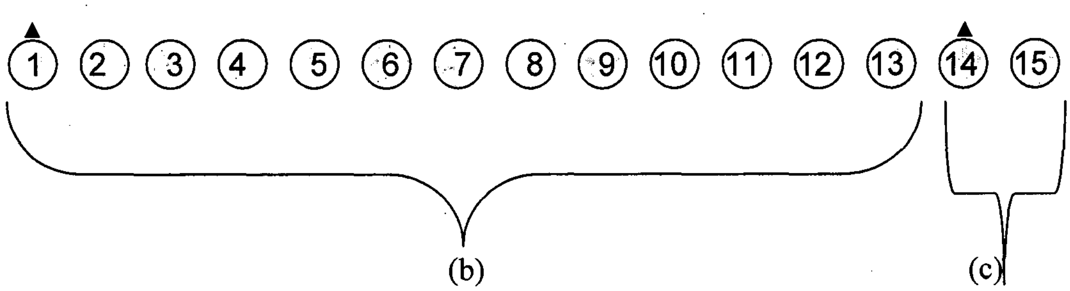
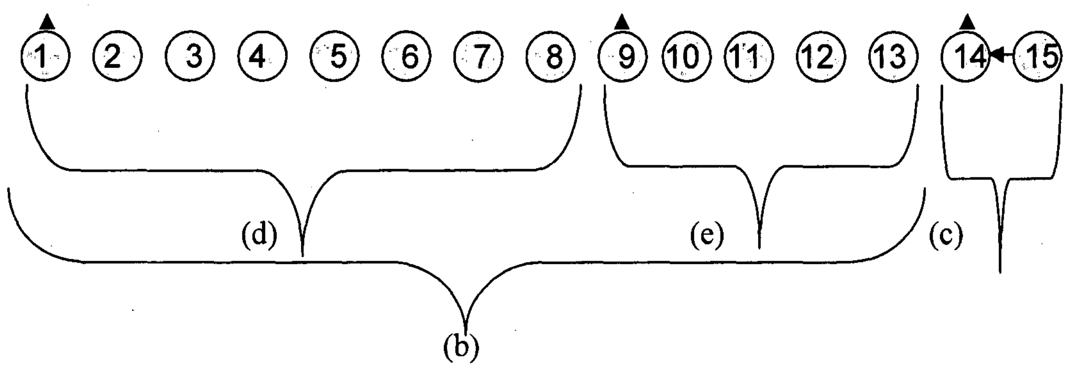


Fig: 4 (a)

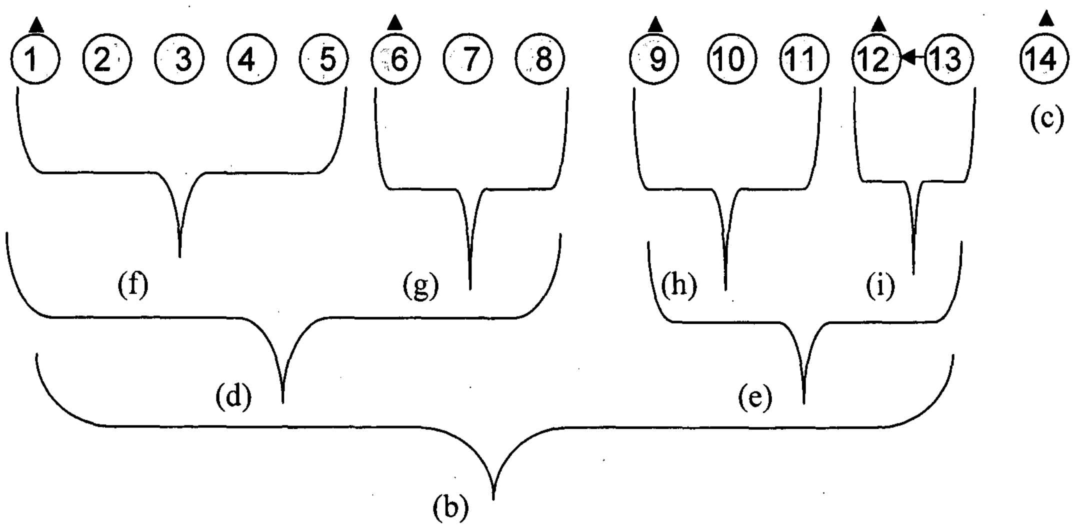
Then the next step is to create next fibocell and its fibohead. Due to this, the fibocell (in fig- 4 (c)) contains node 14 and 15 and, node 14 is the fibohead. The number of nodes in this fibocell is 2, which will be treated under case 1. In (c) node 15 will send its sensed data to its fibohead, node-14. At node 14 data fusion will take place and fused data will further transmitted to any other fibohead according to the algorithm.



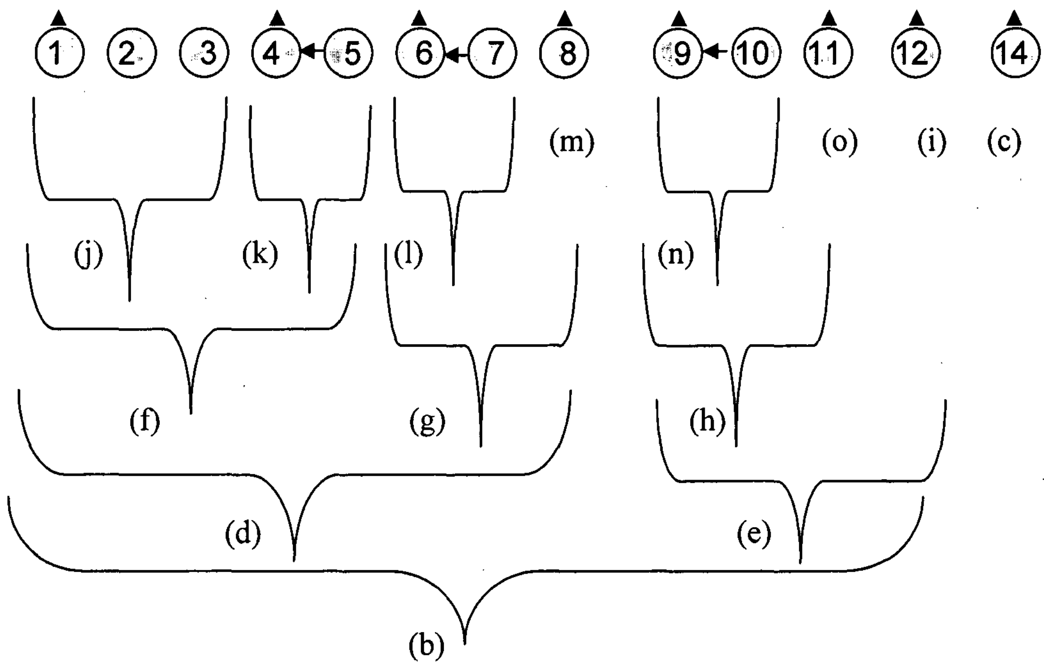
Now the fibocell (b) have 13 nodes which belong to the Fibonacci sequence for n=7 as g_7=13. Thus it is broken and two fibocells (fibocell (d) and (e)) will be created, having 8 and 5 nodes with their respective fiboheads. Or one can say that fibocell (e) is separated from fibocell (b). The new fibohead of fibocell (e) is node 9.



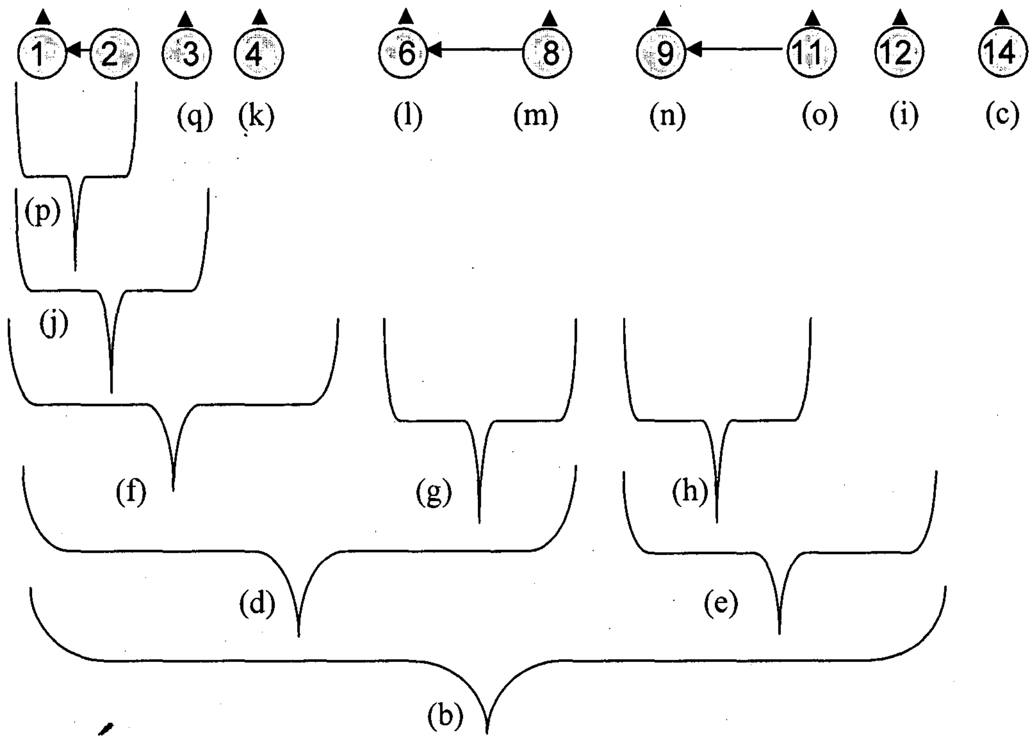
We delete all the nodes from figure, when a node sends data to a fibohead for data fusion. Hence node 15 is deleted and the fibocell is represented by only node 14. Further fibocell (d) and (e) are created four new fibocells (f, g, h and, i) with their fibohead as node 1, node 6, node 9 and node 12 respectively.



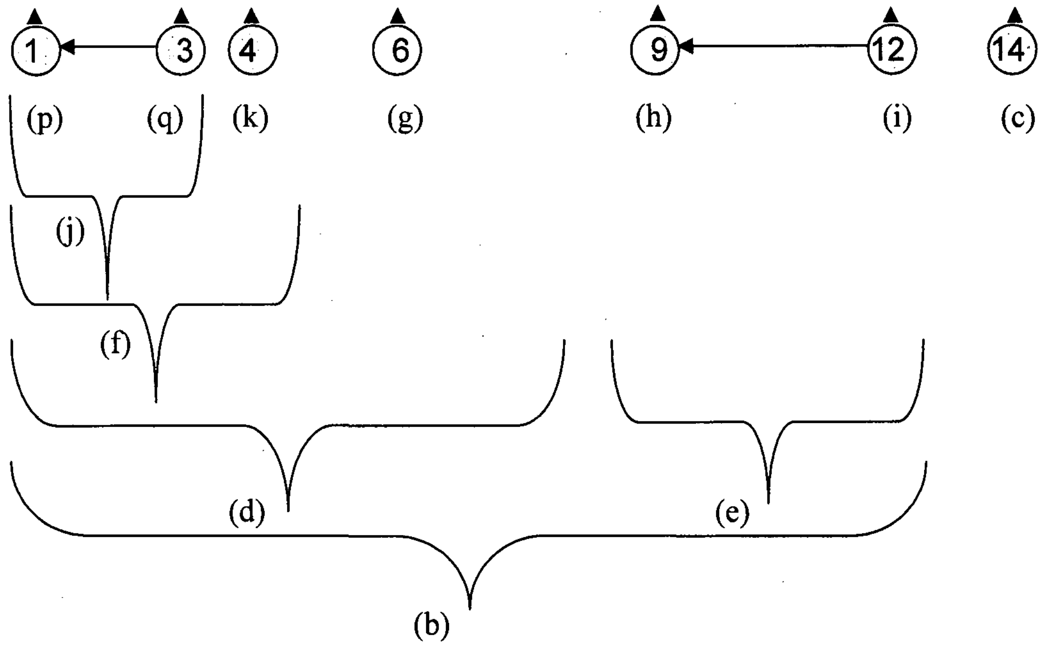
In fibohead (i) node 13 send its data to node-12 for data fusion. After fusion node-12 will have to wait to send its data to its corresponding fibohead. The fibocells (f, (g), and (h) will further break and new fiboheads are generated. The newly generated fibocells are (j) and (k) from (f), (l) and (m) from (g), (n) and (o) from (h) and (i) has remaining only node-12 as fibohead.

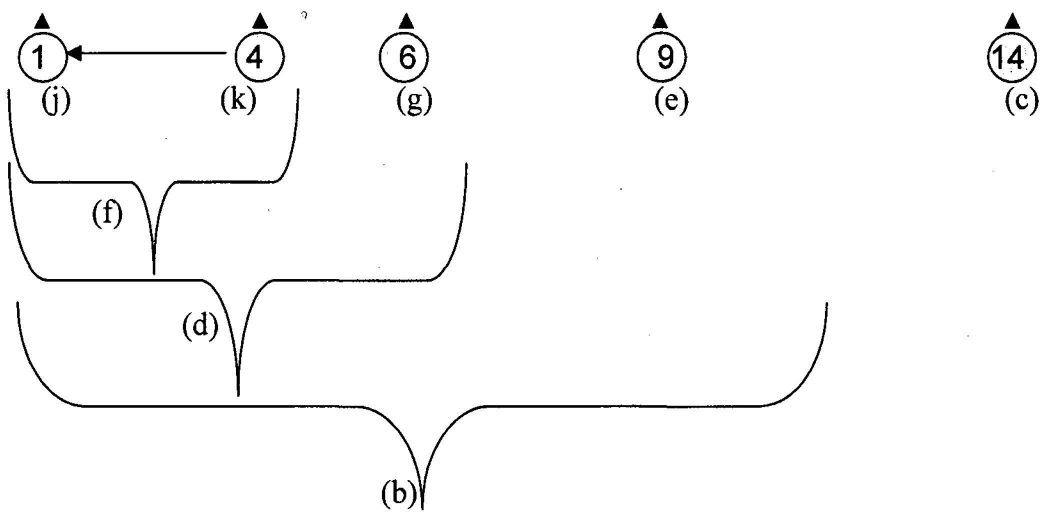


One can see that there are three data fusions taking place in fibocells (k), (l), and (n). In fibocell only node 11 is there and this is the fibohead as well. When data fusion is over at node 6 (with node 7) and node 9 (with node 10), then node 8 and node 11 will send their data to node 6 and node 9 for data fusion respectively. Thus fibocells (i) and (m) will get their new fibohead as node 6 within the fibocell (g). Similarly fibocells (n) and (o) will get merged after data fusion within fibocell (h) with node 9 as fibohead. Also from the fibocell (j), two new fibocells (p) and (q) are created. Node 3 is single in (q) and it is fibohead of the fibocell (q) also. In fibocell (p) data fusion will take place between node 1 and node 2 at node 1. Node 1 will be the fibohead of fibocell (p).

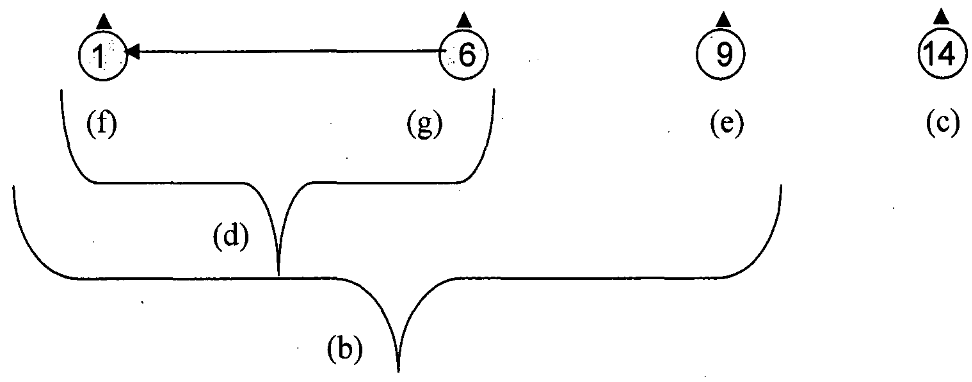


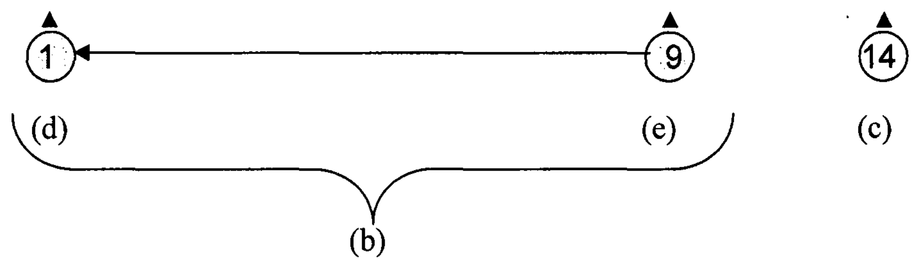
When fibocells (p) and (q) have merged then data fusion will take place between node 1 and node 3 at node 1 in fibocell (j). Since the fibocells (j) and (k) were part of (f) originally, hence they will create a single fibohead after merging their data at node 1 in fibocell (f). At the same time fibocells (i) and (m) will also create a single fibohead in (g) with fibohead as node 6. Similarly in fibocell (h) node 9 will be the fibohead after data fusion of node 9 and node 11.



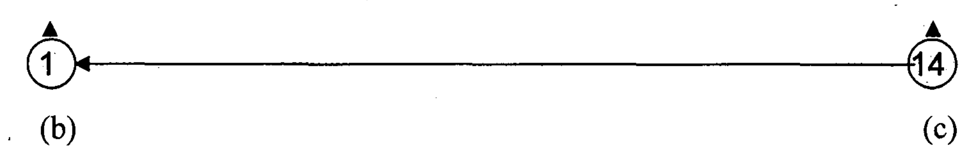


After the fusion of node 1 and node 4, node 6 will be fused at node 1 within fibocell (d). Then the fibohead node 1 will collect data of node 9 from fibocell (e) and fuse it. The new fibocell (b) will have its fibohead as node 1.





Finally fibocells (d) and (e) will be fused their data of node 1 and node 9 at fibocell (b). Then overall the node 1 will be fibohead and hence node 1 can be treated as cluster head also.



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Chapter 5

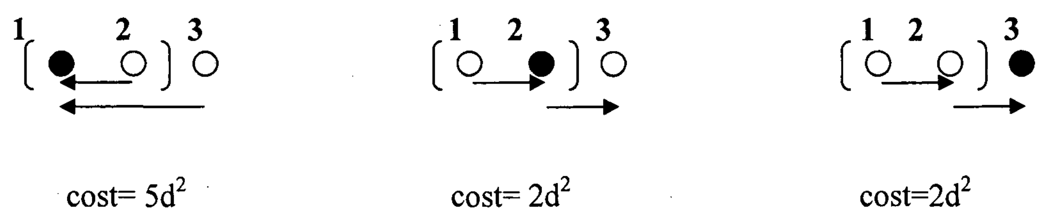
OPTIMIZATION IN FIBO-DATA ALGORITHM

5. Optimization in Fibo-Data Gathering Algorithm-

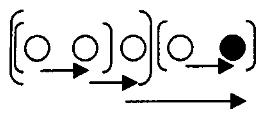
5.1 Fibohead Selection-

The cost of processing in the algorithm can be further reduced if some changes occur in the position of fibohead. Whenever we have number of nodes in such a way that N belongs to the Fibonacci sequence, then we can take final fibohead in middle (or nearer to middle) of the line. But when we have some extra nodes then it will be better to fix fibohead in lower fibocell. This can be understood by the following example.

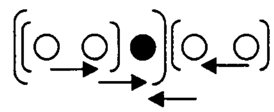
Suppose N=3, node 1, node 2, and node 3 are in single straight line. Let node 1 and node 2 are in fibocell (a) and node 3 is in fibocell (b). If node 1 is chosen final fibohead then the energy cost will be $5d^2$ (d + 4d). But if node 2 or node 3 is final head then the cost is only $2d^2$. This can be seen from the figure given below. Black circular shape represents final fibohead. The smaller line is for single unit of distance and larger one is for double unit of distance.



The same approach can also applied when N=5.



Cost= $7d^2$



cost= $4d^2$

5.2 Energy Distribution-

In PEGASIS there is only one node (the last node of chain), which does not perform data fusion. In the fibo-data gathering algorithm, there are many such nodes, which do not perform data fusion. These are the nodes, which transmit their data to their corresponding fiboheads. In the example, which we described earlier, there are nine nodes out of fifteen nodes, which are not performing data fusion. These nodes can be marked for next rounds. In next round any of these nodes can be treated as fibohead. With this effect, the overall energy distribution will be uniform (approximately).

Chapter 6

ALGORITHM ANALYSIS AND EVALUATION

6.1 Cost (Energy and Delay) Based Analysis-

In data gathering the main objective is to get filtered data from the interested nodes at base station. It can be done easily if all the nodes send data directly to the base station. But the problem in this is the high energy consumption. Due to more depletion of energy at nodes, the nodes will die very soon and the network is no longer for appropriate use. Also in each round the more energy will use. The transmission of the sensed, fused data from nodes to the base station is called one round. So another algorithm was proposed in [22], called LEACH. In LEACH in every round some nodes are reserved for the transmission to the base station. These nodes collect the sensed data from other nodes, fuse the data and transmit to the base station. But in this scheme several transmissions to the base station leads the waste of energy. Instead there can be a possibility that only one node will transmit the overall fused data to base station in each round [19]. In next round of transmission another node will be the head that will transmit to the base station. In this manner the energy load is balanced [20]. Also the cost of formation of cluster which was used in LEACH, is very costly and can be reduced [20], [21], and [22]. So there are many new algorithms creating cluster in the beginning of data transmission and use the same information for several next transmissions, until any substantial changes do not occurred.

In fact our algorithm is also based on the same concept that in nearly static topology, the information that once computed can be used for further communication. Because of this property [20] performs better than [21] and [22]. [20] Also use temporal characteristics of nodes in greedy approach and hence gain some improvements. A simple chain is formed and a single leader transmits the fused data to the base station. The leadership role is changed in each round. The chain is so formed that each node has to transmit its data to relatively closer node. If a node transmits relatively in close distance then it will save energy. Here we discover from our analysis that in many cases some problems are there in PEGASIS [20]. The problems are mentioned as -

1. Each node collects data only from its predecessor node in the chain.

2. If the distances between the sequential nodes are not so close then also it will take more energy.

3. The number of nodes, which do not perform data fusion.

The first problem leads the dependency between nodes transmission. The algorithm proposed by us does not have this type of dependency as it uses simultaneous transmission between pairs of nodes. This can be shown in fig-4 (in fibocells k, l, n, and etc.) in the pairs of nodes 4 and 5, 6 and 7, and 9 and 10.these three pairs of nodes simultaneously communicate for data fusion at node-4, node-6 and, node-9 respectively. Here we gain some improvement in delay metrics.

In second problem, PEGASIS always goes through the chain. If some nodes are at same distant from the base station then also they will be added in chain one by one. But our algorithm may go under two possible cases. First all the nodes may go under the same fibocells or they may go under different fibocells. And here the Fibo-Data Gathering algorithm differs. Using this approach obviously we energy as well as delay taken will be less (as the node will come in relatively close proximities).

In third problem, PEGASIS perform data fusion at every node except the end node in the chain. Hence more nodes are involved in data fusion processes, which lead more energy consumption at every node but the last one. But in our algorithm there are many nodes that do not perform the fusion process. At least one node in the smallest fibocell is of such type i.e. that will not perform data fusion and only send data to its corresponding fibohead. In the example, which we took earlier, out of 15 nodes 9 nodes are not performing data fusions. We can mark these nodes, and use them as fibohead in next rounds, as the fibohead has more requirement of energy.

Our algorithm will do create fibocells at the beginning, and then data transmission can be carried out for several rounds. If any node will die then at that time only some affected fibocells need to adjust. In the table given below the **delay** and **energy×delay** metrics are compared for PEGASIS, Chain Based Binary Scheme and, Fibo-data Gathering scheme.

A= No. of nodes

B= PEGASIS

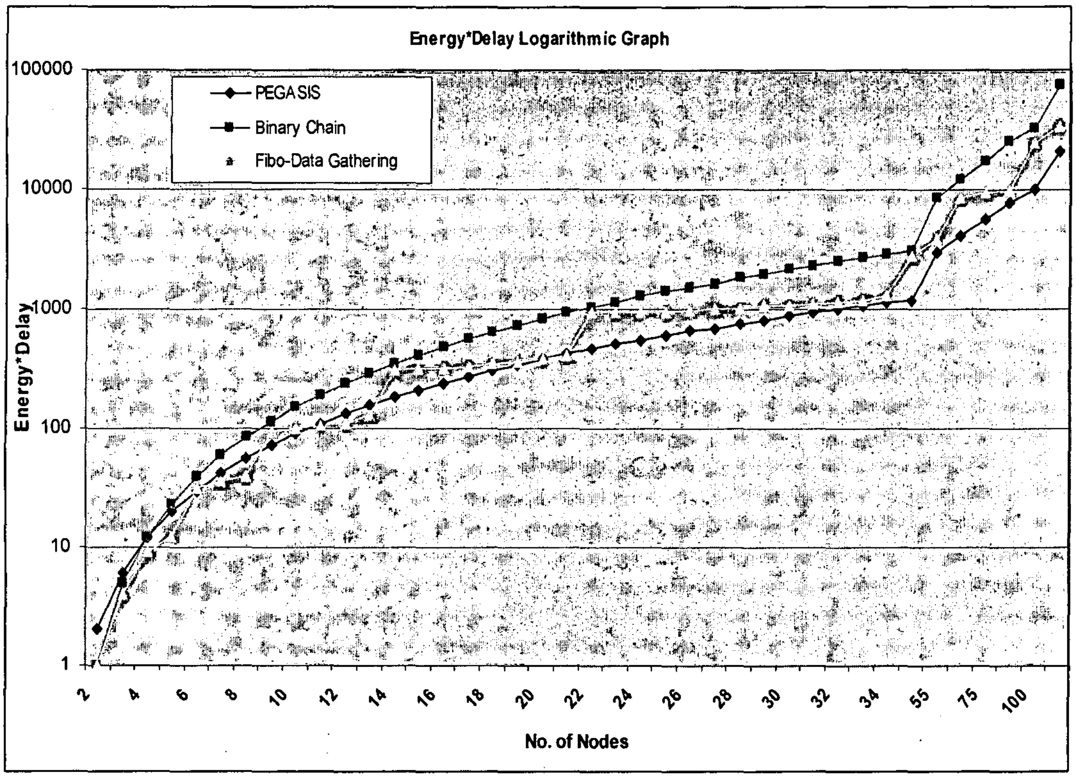
C= Chain Based Binary Scheme

D= Fibo-data Gathering Scheme

From the table- 6, it is clear that fibo-data gathering scheme has the advantages of chain based binary scheme in terms of delay and of PEGASIS in terms of energy×delay. It is easily visualized that for some values of nodes in fibo-data gathering scheme; the energy×delay values are lesser than PEGSIS and vice versa (when N is large). But one thing is very clear that the delay values of fibo-data gathering scheme and chain based binary scheme are approximately same.

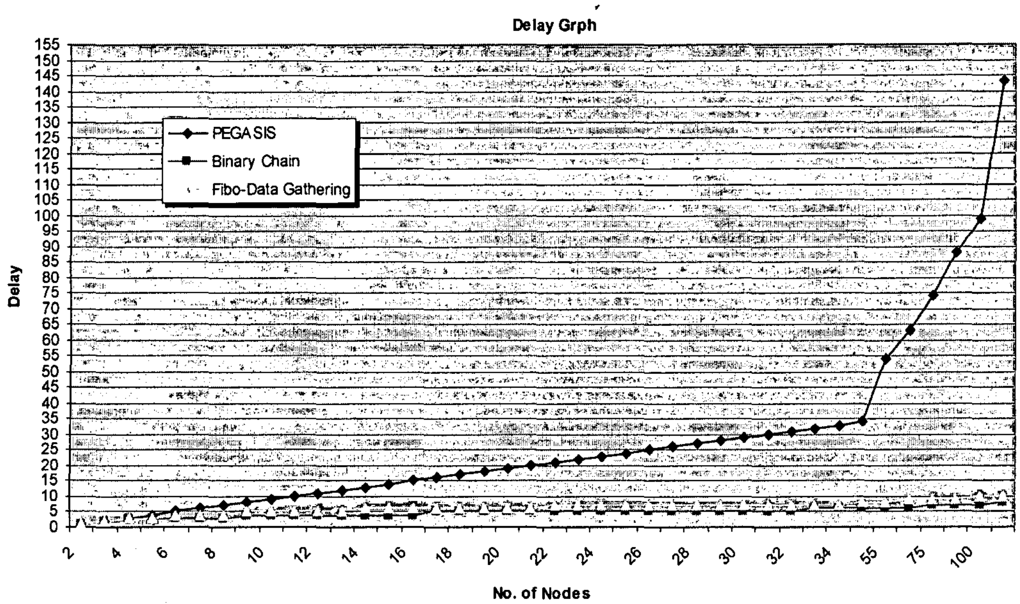
	Delay			Energy×Delay		
A	B	C	D	B	C	D
2	1	1	1	2	1	1
3	2	2	2	6	5	4
4	3	3	3	12	12	9
5	4	3	3	20	23	12
6	5	3	4	30	40	32
7	6	3	4	42	59	36
8	7	3	4	56	84	40
9	8	4	5	72	115	95
10	9	4	5	90	150	100
11	10	4	5	110	191	105
12	11	4	5	132	238	110
13	12	4	5	156	290	130
14	13	4	6	182	348	306
15	14	4	6	210	412	312
16	15	4	6	240	483	318
17	16	5	6	272	559	324
18	17	5	6	306	641	348
19	18	5	6	342	730	354
20	19	5	6	380	826	378
21	20	5	6	420	927	414
22	21	5	7	462	1036	931
23	22	5	7	506	1151	938
24	23	5	7	552	1272	945
25	24	5	7	600	1401	952
26	25	5	7	650	1536	980
27	26	5	7	676	1616	987
28	27	5	7	756	1827	1015
29	28	5	7	812	1983	1057
30	29	5	7	870	2146	1064
31	30	5	7	930	2316	1085
32	31	5	7	992	2493	1127
33	32	6	7	1056	2678	1183
34	33	6	7	1122	2870	1281
35	34	6	8	1190	3069	2816
55	54	6	8	2970	8632	3872
64	63	6	9	4032	12162	8496
75	74	7	9	5550	17379	9495
89	88	7	9	7832	25497	9693
100	99	7	10	9900	33066	24680
144	143	8	10	20592	74223	33560

Table-6



Graph- 6.1

From graph 6.1, one can easily watch out that for some range of no. of nodes (e.g. From 21 to 34), fibo-data algorithm is consuming nearly constant energy*delay value. But the same for PEGASIS is not constant but linear. At some points there are sudden increase in the energy*delay in fibo-data algorithm, which are the points where new fibocells are created.



Graph- 6.2

In graph 6.2, it can be taken out that, fibo-data algorithm is well suited where binary chain based algorithm can be used. Especially, when delay metric is important issue in the application. PEGASIS may have overall good performance but have high delay.

Conclusion and Future Work

7. Conclusion and Future Work-

In the field of networking, wireless networking is at its zenith nowadays. Wireless sensor networks are very application specific networks. And so the routing in sensor networks is very critical issue. Data gathering is a part of routing. In this work a new concept is described based on Fibonacci sequence. The data from all the nodes will be sending to a single node, through many intermediate nodes, and finally the node will send fused data to the base station. In many situations our need is very real time, and hence we must have minimum delay as possible. Apart from the delay, the energy constraint play very important role in sensor network. As the nodes have dearth of energy so the routing and other processing's energy need should be minimum.

In this work the algorithm for data gathering is developed. The algorithm has appropriate balance between the energy and delay. It has nearly same delay as the binary chain based algorithm. And it has nearly same energy consumption as in PEGASIS (though for some number of nodes it could vary). But overall performance of Fibo-data gathering algorithm is balanced.

In this work there are some issues that still not mentioned. The network can be integrated with IP network. There are security related issues that still not mentioned in many research publications. Synchronization between the nodes is also very burning issue when the application is to be integrated with other incompatible applications.

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