COMPARATIVE ANALYSIS OF TIME SYNCHRONIZATION METHODS FOR WIRELESS SENSOR NETWORKS

Dissertation Submitted in partial fulfillment of the requirement for the degree of

MASTER OF TECHNOLOGY
IN
ELECTRONICS AND COMMUNICATION ENGINEERING

By

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DECLARATION

I hereby declare that the work reported in the M. Tech thesis entitled **“Comparative Analysis of Time Synchronization Methods for Wireless Sensor Networks”** submitted by “Mr. DHIREN KASHYAP” at Jaypee University of Information technology, Waknaghat, Solan, India is an authentic record of my work carried out under the supervision of “Mr. TAPAN JAIN”. I have not submitted this work elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work titled **“Comparative Analysis of Time Synchronization Methods for Wireless Sensor Networks”** submitted by “**Dhiren Kashyap**” in partial fulfillment for the award of degree of M. Tech at Jaypee University of Information Technology, Waknaghat has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

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ABSTRACT

Wireless sensor network usually consists of very large number of nodes having limited resources in terms of memory, power and processing capabilities. It is therefore necessary to use the available resources in an efficient manner to prolong the lifetime of the network. A typical wireless sensor network faces many challenges during its design, due to scarcity of energy supply in sensor networks. So, unlike other wireless networks protocols which are aimed to maximize capacity, lower bit error rate etc. the protocol design here in wireless sensor networks need to focus on efficient use of available energy within the network. One of the major concerns in wireless sensor networks design is time synchronization. As the sensor nodes have limited energy resources and once deployed may remain unattended for a long period of time, so for the entire network to work in coordination it is important to maintain synchronization between all the nodes in the network. In this dissertation we compare two existing time synchronization schemes namely Reference Broadcast Synchronization and Adaptive Clock Synchronization for different network environments and present an algorithm which provides network wide synchronization while assuring the minimal energy dissipation. In a sensor network every time a synchronizing node in a region dies, all the receiver nodes under its vicinity are dropped which affects the network coverage and connectivity of that region in an adverse manner. Thus re-synchronization of the entire network is necessary, which is an inefficient procedure for large networks as it consumes a lot of energy. The proposed algorithm instead of re-synchronizing the entire network again only synchronizes the particular region which is associated with the depleted synchronizing node.

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LIST OF ABBREVIATIONS

WSN	**Wireless Sensor Network**
NTP	**Network Time Protocol**
GPS	**Global Positioning System**
MAC	**Medium Access Control**
TDMA	**Time Division Multiple Access**
CSMA	**Carrier Sense Multiple Access**
ADC	**Analog to Digital Converters**
TPSN	**Timing-Sync Protocol for Sensor Networks**
RBS	**Reference-Broadcast Synchronization**
ACS	**Adaptive Clock Synchronization**
TDP	**Time Diffusion Synchronization Protocol**
RDP	**Rate-Based Diffusion Protocol**
BS	**Base Station**

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Chapter 1 INTRODUCTION

The ubiquity of wireless links in our surroundings is increasing day by day. The rapidly growing field of Wireless Sensor Network (WSN) is one of its examples. Wireless sensor network consists of a large number of tiny sensors called sensor nodes which are connected to each other wirelessly to monitor a large physical area. Each sensor node has the capability of sensing, processing, transmitting and receiving the desired information. There is a wide range of applications for sensor networks, some of the application areas are household health, military, and security. Based on the sensing task Wireless sensor networks may consist of many different types of sensors which are able to monitor temperature, humidity, pressure, speed, direction, movement, light, soil makeup, noise levels, the presence or absence of certain kinds of objects, and mechanical stress levels on attached objects [1, 2]. So, typically a “WSN is a type of network in which a large number of sensor nodes are deployed randomly either inside or very close to a particular event to be monitored.” Along with the variety of scopes in this field, it also presents many challenges. Unlike other wireless networks nodes in wireless sensor networks are power constrained [3]. Due to their small size they can carry batteries of very low capacity and furthermore due to high density of sensor nodes it is not feasible to recharge or replace those batteries, also sometimes sensor nodes are deployed in the areas where human cannot be reached e.g. inside a volcano. Another difficult aspect of wireless sensing is time synchronization. The nodes in the network are usually static and are energy constrained and works in a collaborative manner to collect data and then transmit it to the central processing system usually called a base station or a sink, where it is processed further [4]. For efficient communication between the nodes in the network, synchronization between their clocks is necessary. GPS [5] provides good synchronization accuracy, but requires a very large amount of power for its operation. As the sensor nodes are energy-constrained, this synchronization is not suitable for WSN. Synchronization protocols designed for traditional computer networks will not scale well for wireless sensor networks. So some new synchronization methods have to be developed specifically for sensor networks.

1.1 Motivation

The advancement in the field of wireless communication has led to the design of sensor nodes which are energy efficient, have low cost and can perform various sensing tasks. Unlike other wireless networks sensor networks are power constrained so there exists the need to design the new protocols for wireless sensor networks to use the available resources in an efficient manner. Also the other traditional protocols which produces ideal for other wireless networks may produce disastrous results when applied to wireless sensor networks. A typical wireless sensor network consists of thousands of low-cost nodes deployed over a field or an area which is to be monitored. As the end user is interested in the collaborative information from the nodes in the network, it is therefore necessary to maintain synchronization between the sensor nodes. The existing synchronization methods like Global Positioning System (GPS) are not suitable for sensor networks as embedding a GPS unit to every sensor node will increase the total cost of the network, which is not desired. So it becomes important to design synchronization protocols for wireless sensor networks which can provide network wide synchronization while maintaining the cost and efficiency of the entire network.

1.2 Objective

The major issue in Wireless sensor networks is power, so it is desirable to use it in an efficient manner so that the network lifetime is increased. The sensor nodes once deployed may remain unattended for a long period of time, so for the entire network to work in a desirable manner it is necessary for every node to work in co-ordination with each other for which the nodes clocks must be synchronized to reference value. The Time synchronization protocols used for synchronizing the network must be used in such a manner so that the energy consumption required in synchronizing the whole network gets minimized. In this project we propose a synchronizing algorithm which provides network wide synchronization while assuring minimum energy dissipation. When the energy of the sensor nodes starts depleting, a depleted synchronizing node will drop all of its receiver nodes and if a the node which gets energy deficient has large number of receivers under its vicinity the network connectivity and coverage gets severely affected. In order to maintain network coverage and connectivity resynchronization of the network is necessary every time a synchronizing node dies.

1.3 Organization

The complete dissertation is divided into eight chapters.

The **Chapter 1** gives the problem statement, motivation and brief introduction to the project.

In **Chapter 2** research already done in the field of time synchronization is discussed.

A detailed knowledge about WSN, challenges to be faced during its design, typical sensor node architecture and the protocol stack used for sensor network communication is given in **Chapter 3.**

The detailed operation of time synchronization protocols for WSN is given in **Chapter 4 and Chapter 5.**

The **Chapter 6** discusses the details of the proposed work. Assumptions taken are also described in this chapter.

The implementations related to the proposed algorithm are given in **Chapter 7.**

The **Chapter 8** contains conclusion and future work.

Chapter 2 RELATED WORK

The main area of research in wireless sensor networks involves routing and assuring the QoS required for the various applications. Various protocols have been developed in these areas to meet the desired requirements and hence in turn to increase the lifetime of the entire network. In a WSN, each sensor node carries its own local clock for internal operations. Each particular event that is related to operation of the sensor node including sensing, processing, and communication requires timing information controlled through their local clock. Since we are interested in the collaborative information from multiple sensor nodes, timing information associated with the data at each sensor node must be in sync with each other. Also, the WSN should be capable of ordering the events sensed by different sensor nodes in the network based on their occurrence to correctly model the geographical area which is to be monitored. This work aims at minimizing the energy consumption required for the synchronization of entire network. A lot of synchronizing algorithms have been proposed for synchronizing the WSN. Some of these are discussed in the upcoming sections [6].

2.1 Network Time Protocol (NTP)

Network Time protocol (NTP) is one of the traditional time synchronization protocols which is used to provide synchronization in computer networks [7]. In NTP the entire network is divided into levels. At the top there is a root node which is synchronized to UTP, as we move down the network each level synchronizes itself with sub-network to which it is connected. NTP works on the two way handshake mechanism to estimate the clock offset and delay between their clocks. Consider a scenario in which server ‘p’ is synchronizing peer ‘q’ as shown in Fig. 2.1. The server ‘p’ issues a SYNC message to node ‘q’ at time t_1^p according to its local clock. This message is time stamped at node ‘q’ at t_2^q according to node q’s local clock. Then after time stamping node ‘q’ issues a REPLY message at time t_3^q , which is time stamped at server ‘p’ at time t_4^p.

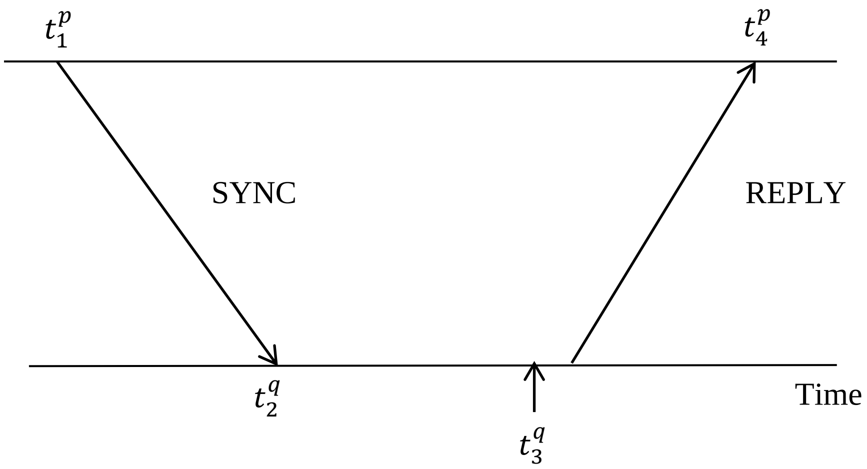


Fig. 2.1 NTP two-way handshake mechanism

The clock offset and round trip delay time of the above scenario can be calculated as

$$\varDelta_{pq} = \left(t_2^q - t_1^p\right) - \left(t_3^q - t_4^p\right) \tag{2.1}$$

$$\varTheta_{pq} = \frac{\left(t_2^q - t_1^p\right) + \left(t_3^q - t_4^p\right)}{2} \tag{2.2}$$

Where, $\varDelta_{pq}$ = round trip delay between two nodes

$\varTheta_{pq}$ = relative clock offset between two nodes

NTP provides time synchronization in the order of milliseconds for computer networks. However, this time synchronization protocol may not scale well for wireless sensor networks as its characteristics are not similar to those of the traditional computer networks. NTP takes into account an assumption that transmission delay between the two nodes to be synchronized is same in both directions which is not true for wireless sensor networks as the transmission delay in WSNs need not to be same for both paths as it depends heavily on the environmental conditions. Furthermore the sensor nodes are prone to failure so it is not possible to connect all the nodes to the server in a multi-hop environment. NTP requires large memory to store its data which is further used for synchronization, which is not feasible for WSN as sensor nodes are limited in memory.

In [8] authors describe Timing-Sync Protocol for Sensor Networks (TPSN) which is designed in particular for WSNs and is quite similar to NTP. Like NTP, TPSN also assigns a root node to synchronize the entire network to a single reference value. There are two main phases in the working of TPSN

1) Level discovery phase: In this phase the entire network is flooded with the level discovery packets building a hierarchical structure starting from the root node.
2) Synchronization phase: In this phase pairwise synchronization is carried out in the entire network

In TPSN every node is synchronized to a single node and due to the protocol operation it automatically gets synchronized with every other node present in the network.

2.2 Global Positioning System (GPS)

GPS is a space-based positioning, navigation, and timing system. It emerged in the early 1970s and is developed by the U.S. Department of Defense (DoD). The basic system of GPS consists of more than 24 satellites located in space around the world. GPS operation is based on triangulation of signals coming from the satellites. By using the technique of time difference of arrival GPS receiver calculates its position based on the signals coming from each GPS satellite.

In a WSN the number of nodes deployed over a given area may be very large in number so it is not feasible to get every sensor node equipped with GPS to provide network wide synchronization as GPS units are costly and also have large size as compared to sensor nodes. The signal attenuation due to scattering and diffraction increases with the increase in frequency and as GPS receivers works around the frequency range of 1.5 GHz so for the sensors deployed in harsh environment conditions the GPS signals are beyond reach and thus cannot synchronize the network [9].

2.3 MEDIUM ACCESS CONTROL (MAC) EFFECTS

The broadcast nature of a wireless channel is one of the key features of wireless communication. In WSN various protocols have been designed to ensure that the communication between the sensor nodes within the network runs flawlessly and also the entire network connectivity is maintained. The protocols defined in this layer also takes care that how the nodes in the network should share the channel so that the collisions within the network gets reduced to zero, typically a collision occurs when two neighboring nodes initiate transmission at the same time. Whenever a collision occurs in the network the packets lost in the collision needs to be transmitted again, which is highly energy inefficient in WSNs if the packet size is large.

One of the ways to avoid packet collision is to use Time Division Multiple Access (TDMA) based protocols for proper channel allocation. Low Energy Adaptive Clustering Hierarchy (LEACH) is one of the protocol which uses TDMA approach for channel allocation. LEACH divides the entire network into group of clusters with a cluster assigned for each cluster [10]. One of the tasks of the cluster head is to assign time slots to each and every node within the cluster for collision free communication. The TDMA based protocols may not perform well in multi-hop scenarios or in the scenarios having high node density, as the network is divided into cluster so nodes having same time slot within different clusters may collide during inter-cluster communication. So, for the efficient working of TDMA based algorithms it is strictly necessary to maintain synchronization between the clocks of the nodes in the network.

Some MAC layer protocols do not require accurate time synchronization between the nodes clock such protocols are known as contention based protocols. In [11, 12] authors describe a protocol sensor- MAC (S-MAC) which is based on the scheme of Carrier Sense Multiple Access (CSMA) but is improved in terms of energy efficiency, as unlike CSMA continuous sensing of the channel is eliminated in S-MAC. In [13] Berkeley-MAC (B-MAC) is proposed which is an improvement over S-MAC in terms of channel efficiency. In Timeout-MAC (T-MAC) [14] adaptive duty cycle operation is used to minimize the energy consumption when data traffic is low.

Chapter 3 LITERATURE REVIEW

Due to the development in micro electro-mechanical systems (MEMS) technology, wireless communications and digital electronics, it becomes easier to design and produce low-cost, low-power multifunctional sensor nodes of small size and can communicate within short distances. It is due to these increasing capabilities of the tiny sensor nodes which make possible the realization of wireless sensor networks (WSNs). WSNs have a variety of applications from house hold to harsh environments. In fact WSNs are becoming an integral part of our lives. These technological advancements make it easier to implement and deploy sensor networks in accordance with the particular application. Depending on the requirements of a particular application WSNs requires highly efficient protocols to be designed for that application. A protocol designed specifically for one application can produce drastic results if applied to another application. In WSNs sensor nodes are densely deployed either inside or close to an event to be monitored. For the sensor nodes, in order to model the environment correctly in which they are deployed it is important for the sensor nodes to work in co-ordination with each other. Moreover, before sending the raw data to the BS or sink, sensor nodes usually process the recorded data to some extent to make it easier to transmit it over a wireless link. It is due to these properties that it is necessary to design efficient protocols for WSNs. Sensor nodes internal architecture pose additional challenges in the design of these protocols. The small size of sensor nodes imposes a limit on the power source which it can carry therefore it becomes essential to use the power of the sensor node in an efficient manner to increase the lifetime of the network. The protocols designed for other wireless networks may not scale well for a WSN as unlike sensor networks those networks are not power constrained, so increased power efficiency should be the main aim of any WSN protocol.

The random deployment of sensor nodes in a WSN is another factor which must be accounted for the design of WSN protocols. Due to high density and random deployment of sensor nodes there may be some sensors which lies close to each other and thus are sensing the same data which in turn produces copies of similar data at the BS or sink. In order to remove this data redundancy at the sink it becomes necessary to turn off the nodes which lie in the proximity of other sensor node, doing this network lifetime can be increased up to a certain extent [15].

The sensor nodes in a particular region can also be deployed in an organized manner. Deploying the sensor nodes in an organized manner improves coverage, connectivity and power dissipation of the entire network but it is not possible to deploy the sensor nodes in an organized manner every time e.g. inside a volcano or any other environment where human cannot be reached. So in such environments the sensor nodes are deployed in random fashion and thus the protocols for these types of networks must be self-organizing in nature.

3.1 Sensor Node Architecture

As shown in Fig. 3.1 typical sensor node is mainly equipped with the following components

- Sensing Unit
- Processing Unit
- Transceiver Unit
- Power Unit

and some additional application specification components are

- Location finding system
- Power Generator
- Mobilizer

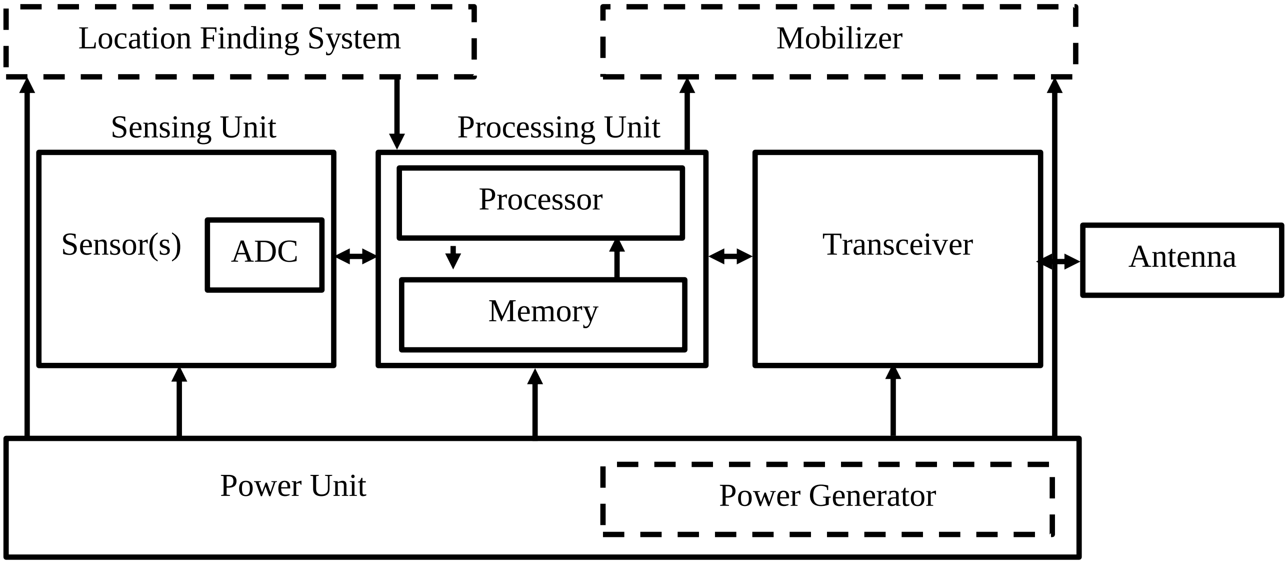


Fig. 3.1 General hardware architecture of a sensor node

3.1.1 Sensing Unit

The sensor unit is the basic component of a wireless sensor node. It mainly consists of two subunits

- Sensors
- Analog to Digital Converters (ADC)

Each sensor unit may contain many sensors embedded in it, each designed to sense a particular physical phenomenon. The analog signals recorded by different sensors are converted into digital using an analog to digital converter (ADC). The output of an ADC is then fed to processing unit for further processing.

3.1.2 Processing Unit

The processing unit controls all the important operations carried out within the sensor node. It is divided into two sub parts

- Processor
- Memory

The signal received from the ADC is further processed using the processor unit. All the signal processing tasks are run by this unit. It also takes care of algorithms and communication protocols associated with the particular application. Each sensor node requires memory to store the information regarding to a particular task, such as process values, data or packets. The processor unit works in co-ordination with the memory unit to achieve the desired response.

3.1.3 Transceiver Unit

This unit helps the sensor nodes to communicate with each other or with the BS. The communication can be established in any range of frequencies i.e. either in infrared or optical or in radio frequency (RF) range. In case of RF transmission the bit stream is converted into a RF waves and is then transmitted, which are then recovered back at the other end.

3.1.4 Power Unit

Power unit is one of the most important components of the sensor node. It supplies the power required to run every component in the sensor node, usually a battery is used as a power source. As the power is limited, so it is required to use it in an efficient manner to enhance the lifetime of a node. An ideal power source must have features like high capacity, low cost, small size, light weight etc.

3.1.5 Location Finding System

This is one of the additional units mounted on the sensor node depending on the requirement of the application or task. As some applications or tasks require the knowledge of physical location of a sensor in order to route data or to sense a particular event in a region, so sensor nodes requires a location finding system to find its position in the physical environment. GPS can be used in location finding system, but it may increase the size and cost associated with the sensor node. However, location finding algorithms can also be used to find the location of a particular sensor in a network.

3.1.6 Power Generator

As the whole operation of the sensor node is carried out using a battery, so it becomes necessary to use it in an efficient manner to prolong the network lifetime. Sometimes the sensor nodes which are deployed in external environments can use solar cells to generate power for the functioning of their components.

3.1.7 Mobilizer

The sensor nodes in a network are usually static in nature, but sometimes movement of sensor nodes is necessary in order to fulfill the tasks associated with the particular application. So, a mobilizer is required to move the sensor nodes within the network.

3.2 Factors influencing sensor network design

In order to design a wireless sensor network one requires a great knowledge in the fields of software, digital signal processing, embedded systems, networking and wireless communication. There are many factors which influence the design of any typical wireless sensor network e.g. scalability, hardware constraints, fault tolerance, production cost, sensor network topology, transmission media and power consumption [1]

3.2.1 Scalability

The sensor nodes deployed over a particular task can be large in number. In order to monitor a physical phenomenon the node density may vary from few hundreds to thousands [16, 17]. The new protocols designed should be able to deal with such high density of nodes in an efficient manner. In particular, node density depends on the task or event which had to be monitored by sensor nodes. e.g. for machine diagnosis application, the node density is typically around 300 nodes in a 5 x 5 m^2 region, and the node density for the vehicle tracking application is around 10 sensor nodes per region 18. Generally the node density can be as high as 20 nodes/m^3 [18, 19, 20].

3.2.2 Hardware Constraints

A typical sensor node constitutes of four basic units viz. sensing unit, processing unit, transceiver and power unit. All these units must be of small size so that they can be fitted inside a module not larger than a size of a matchbox. Along with that it must consume very low power for its operation, should have low production cost, must be able to operate in harsh environments or if left unattended for a long period of time [21, 22, 23].

3.2.3 Fault Tolerance

The sensor nodes in a network may die due to lack of power or can get damaged during their deployment in harsh environments. The failure of sensor nodes within the network should not affect the coverage and connectivity of the entire network. The protocols and algorithms should be designed in accordance with the application or with the environment in which they are deployed. Some applications such as household can work fine with low fault tolerance protocols but for the applications such as military the fault tolerance of the protocols designed should be high as the sensor nodes are more prone to failures as they can get damaged due to the hostile actions.

3.2.4 Production Cost

As the wireless sensor network consists of high density nodes, so the cost of one node should be kept low in order to minimize the cost of entire network. Typically a sensor node consists of different subunits and also requires some additional units depending on the application, so it is a tedious task to keep the cost of a sensor node less than a dollar [24].

3.2.5 Sensor Network Topology

As the sensor nodes are prone to failures so topology maintenance is a challenging in a wireless sensor network. The topology maintenance mainly works in three phases.

- Pre-deployment phase
- Post-deployment phase
- Re-deployment of additional nodes phase

In pre-deployment phase sensor nodes can either be deployed randomly or in an organized manner. In post-deployment phase the issues like position of sensor nodes, its remaining energy, task details, reachability etc. are taken into account. Lastly if there is a need to replace the malfunctioning sensors with the working ones, additional sensors are deployed again in re-deployment phase [21, 25].

3.2.6 Transmission Media

The sensor nodes within the network are connected using wireless links with each other or with the BS. The choice of the wireless link to be used depends upon the application for which the network is being designed. For the network to operate globally the transmission medium selected for the transceiver unit must be available worldwide.

3.2.7 Power Consumption

As the sensor nodes can carry limited amount of power so it is important to use it in an efficient manner to increase the network lifetime. Sensing operation involves three main tasks sensing, processing and communication. Communication process includes both transmission and reception of data and consumes the maximum amount of energy among the all three, so to design an ultra-low power transceiver is necessary requirement for any wireless sensor network [26].

3.3 WSN Protocol Stack

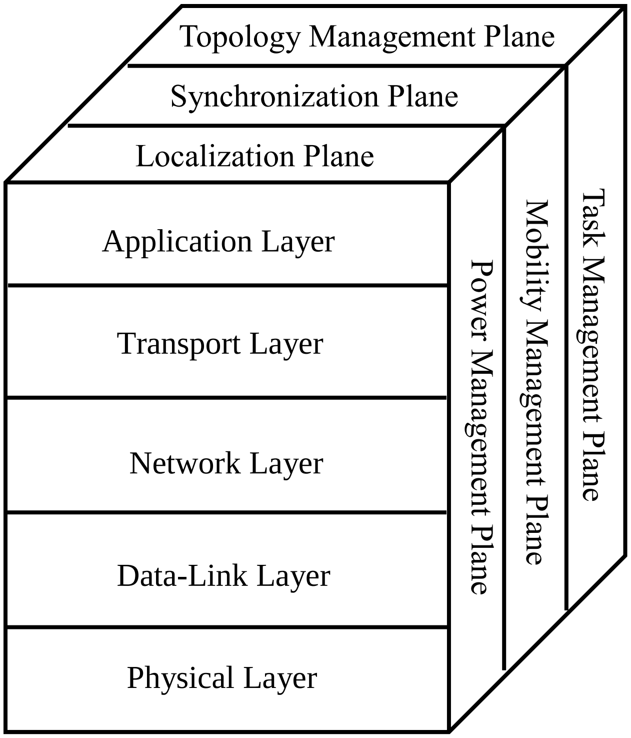


Fig. 3.2 The Sensor Network Protocol Stack

The protocol stack of a wireless sensor network helps the nodes to work in co-ordination and also enables power efficient working of the entire network. Fig. 3.2 shows the sensor network protocol stack, it mainly consists of five layers physical layer, data link layer, network layer, transport layer, application layer, and six management planes synchronization plane, localization plane, topology management plane, power management plane, mobility management plane, and task management plane.

3.3.1 Physical Layer

The first layer of the five layered protocol stack is physical layer. It is responsible for the conversion of digital bit stream into signals so that they can be further transmitted over a wireless channel. All the schemes such as modulation, carrier frequency generation, data encryption and decryption, signal detection are carried out by this layer.

3.3.2 Data Link Layer

This layer deals mainly with the two issues viz. medium access control and error control. The other issues which data link layer takes into account are data frame detection, multiplexing and de-multiplexing of data streams and reliability.

Medium Access Control

The main aim of this layer is to form the basic network infrastructure required for single-hop or multi-hop communication and also to share all the available resources for communication in an efficient manner. In order to achieve the above goals several MAC layer protocols have been developed. Energy efficiency must be the main aim of any MAC layer protocol. The most efficient way of power saving is to turn off the transceiver circuitry, but turning off the transceiver circuit should not affect the network coverage and connectivity in an adverse manner as once the transceiver of any sensor node is off it is not able to take part in any kind of communication anymore. Moreover, turning off the transceiver circuitry blindly may lead to more energy dissipation than if it has been left on.

Error Control

Error control is another important task to be done by data link layer. The two traditional error control techniques are forward error correction (FEC) and automatic repeat request (ARQ). Due to the limitation of power in wireless sensor network these techniques may not perform efficiently, as FEC have high coding and decoding complexity and in WSN retransmissions are allowed only up to a certain extent as it may increase retransmission cost and overheads. So it becomes necessary to develop simple error correcting codes with low encoding and decoding complexity.

3.3.3 Network Layer

As the sensor nodes in a wireless sensor network are deployed randomly and have high density, also the short transmission range of the sensor nodes makes it impossible for the sensor nodes to communicate directly with the sink so to establish a routing path between the sensor nodes and the BS or sink is the major concern of the network layer. The traditional routing protocols may produce drastic results if applied directly to a wireless sensor network, as power here is a main issue which is not so in most of the wireless networks. Due to the high density of nodes it is sometimes not possible to assign unique IDs to every node, so in wireless sensor network nodes need to be identified based on their data or their location, so instead of using the traditional protocols new protocols based on data centric approach needs to be designed.

3.3.4 Transport Layer

The need of transport layer arises when the sensor network has to be accessed through internet or any other external network. The protocols used by the traditional networks like TCP cannot be used for wireless sensor network as the sensor nodes are based on data centric addressing rather than unique global addressing. Due to limited power and memory of the sensor node designing of transport layer protocols is a difficult task. Inside a wireless sensor network the function of transport layer includes congestion control and reliability. As sensor networks have limited energy sources so instead of assuring end-to-end reliability it is efficient to apply local reliability schemes.

3.3.5 Application Layer

The main aim of application layer is to provide interface between the user and the wireless sensor network. It holds the unique application code associated with each application and also takes care of functionalities associated to query processing and network management.

The management planes in the wireless sensor network protocol stack are needed so that the entire network can work in a collaborative manner, in the absence of these management planes maintaining co-ordination between the nodes in the network would be impossible. However, to increase the lifetime the lifetime of a wireless sensor network it is necessary for the entire network to work in a collaborative manner. The power management plane controls the power usage of a sensor node, it tells the sensor node when to turn on its transceiver on or off and it also ensures that if a sensor node is capable of routing the messages within the network or not, if not then the sensor node is used only for the purpose of sensing. In any sensor network it is necessary that a route back path to the end user is always maintained, if the sensor nodes in the network are mobile then it becomes a challenging task to do so. With the help of mobility management plane every sensor node can keep track on the movement of other sensor nodes in their neighborhood and thus can maintain connectivity of the entire network. As the sensor nodes in the network are densely deployed so there may exist some sensors which are sensing the same event at the same time so it is the duty of the task management plane to schedule the sensing task in a particular region.

Each sensor node in the wireless sensor network carries its own local clock, this clock is used to control the basic operations carried out in a sensor node. As the nodes have to work in a collaborative manner so timing information associated with data at each sensor nodes needs to be accurate. So in order to satisfy these timing requirements time synchronization protocols for wireless sensor networks need to be developed. Location management plane deals with the design of localization protocols in order to provide a correct view of the field or area under observance. Finally the topology management plane provides protocols and algorithms which assure full coverage and connectivity of the entire network, issues like network deployment and activity duration of sensor nodes are also covered under this plane.

Chapter 4 TIME SYNCHRONIZATION IN WSN

In Wireless Sensor Networks each sensor node carries its own local clock for internal operations. Every event related to operation of the sensor node e.g. sensing, processing, and communication is associated with timing information which is controlled through the local clock of the sensor node. As the end users are interested in the collaborative information from multiple sensor nodes, timing information associated with data at each sensor node needs to be accurate to some extent. Also, the WSN should be able to order the events in a manner they have happened in time i.e. one after the other to correctly model the physical environment. GPS is one of the techniques which can provide network wide synchronization, but due to its large size of GPS units and their high cost it is not feasible for wireless sensor networks [15, 27]. It is due to these requirements that make time synchronization protocols an integral part of communication for wireless sensor networks.

Time synchronization helps the user to solve the issues like

Temporal event ordering

In a multi-hop wireless sensor environment the arrival time of data packets at the base station may not correctly show the actual order of their happening as the delay between the sensor nodes and the sink is related to distance between them, the farther the node the larger the delay and vice-versa. So, if the network is synchronized it becomes easier to order the events at the base station.

Synchronization to global time

If a wireless sensor network is synchronized it will be an easier task to synchronize it with the global time. As the network is now synchronized with the global time it becomes possible to access many wireless sensor networks through internet.

Synchronized network protocols

Time synchronization of the sensor network also provides many advantages in terms of protocol development. Exempli gratia some MAC layer protocols like time division multiple access (TDMA) requires synchronization of entire network so that they can follow a common time frame for the sharing of available resources in time. Hence synchronization protocols and MAC protocols works side by side to provide a common frame of reference in protocol operation.

4.1 Challenges for Time Synchronization

The time synchronization is one of the important requirements for most of the applications in wireless sensor networks. There are many important factors which must be taken into account while designing of synchronization protocols for wireless sensor networks.

1) Low-Cost Clocks

In order to reduce the cost of the sensor node the components used within each sensor node must be of low-cost. The crystals used in local clocks of the sensor nodes are not of superior quality which gives arise to sudden clock jitter and clock drifts for as long as the node is not dead. The synchronization protocols mainly aim at correcting the relative time difference between the clocks of the nodes. This can be achieved by sharing of messages between the nodes which are to be synchronized. Furthermore, synchronizing the network once is not sufficient in case of wireless sensor networks, as the clocks once synchronized may get desynchronized with passage of time. So it has to be synchronized from time to time in order to maintain network wide synchronization.

2) Wireless Communication

The channel for communication in sensor networks is wireless which adds extra challenges for the design of synchronization protocols. The synchronization packets may get corrupted due to erroneous nature of wireless channel, which may result in synchronization of clocks in a given region to a wrong reference value. Hence rather than synchronization of entire network to a same reference value different regions within the network gets in sync with different reference values which is not desired. The protocols exchanges messages between the pair of nodes to be synchronized and the round trip time which is approximately equal to twice the delay in one direction, is considered for calculation, but due to the nature of wireless channels the delay may be different in each direction. Also the delay introduced by MAC layer must be taken care of as the time at which synchronization protocol sends a packet and the time at which it is actually sent may be different.

3) Resource Constraints

The synchronization methods designed for other wireless networks may not scale well for sensor networks as wireless sensor networks have limited energy supply and low memory. The sending and receiving of multiple messages for synchronization are limited in sensor networks to minimize energy consumption of the entire network as transceiver unit is the major source of energy consumption.

4) High Density

Due to the dense deployment of sensor nodes in a wireless sensor network it is not efficient to use protocols which use pair wise synchronization techniques as communication costs related to energy consumption gets increased. However, broadcast nature of wireless channels can be used in order to lower the energy consumption.

5) Node Failures

The sensor network is prone to node failures mainly due to power loss. Some protocols uses single node to synchronize the entire network but if the master node in a region dies all nodes which are synchronized to that nodes are dropped and thus the network becomes unsynchronized.

4.2 Time synchronization protocols in WSNs

In order to design the synchronization protocols for sensor networks it is important to study the nature of the wireless channel, the random nature of communication delay between the pair of nodes is a crucial factor which needs to be considered. Considering the synchronization scheme as shown in Fig. 4.1 the delay between a pair of nodes mainly consists of four factors viz. send time, access time, propagation time, and receive time. These factors that contribute to delay are known as critical path.

- **Send time (t_{send}):** It is the time required by the transmitter to construct the message and transfer it to the MAC layer for transmission. This delay constitutes of transceiver, operating system and kernel delays and also is random in nature as interactions between the software and hardware components are complex in nature.
- **Access Time (t_{acc}):** Time required for getting the access of the transmit channel, after the message has been constructed is known as access time or delay. MAC layer protocols such as TDMA, CSMA etc. can introduce a significant amount of delay based on their operation. Access delay is also non-deterministic in nature.
- **Propagation Time (t_{prop}):** Propagation time is the time required by the message to propagate completely from transmitter to receiver over the transmission medium, if the medium used is air the delay is negligible and is proportional to distance between the communicating nodes.
- **Receive Time (t_{recv}):** Time required by the receiver to extract the desired information from the message once it is received completely. Transmission delay (t_{tx}) is an important part of receive time. It mainly depends on the data rate and length of the packet to be sent.

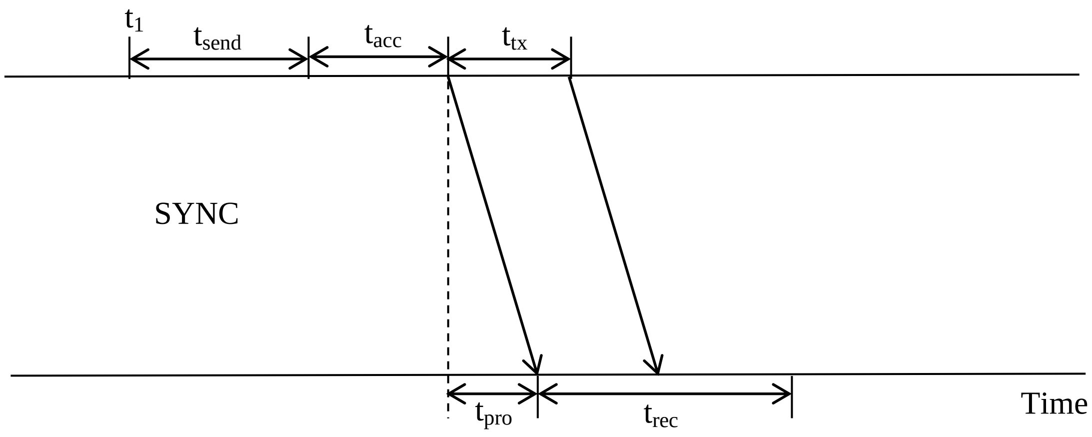


Fig. 4.1 Synchronization delay between pair of nodes

4.2.1 Timing-Sync Protocol for Sensor Networks (TPSN)

Timing-Sync Protocol for Sensor Networks [8] implements a hierarchical structure to synchronize the whole wireless sensor network to a single reference value. It is based on sender-receiver synchronization model. TPSN assigns a root node which is used to partially or fully synchronize the nodes in the sensor network. It mainly consists of two phases

- The level discovery phase
- The synchronization phase

In the level discovery phase, the root node is assigned to level 0, and the nodes in the network hierarchy are assigned levels according to their distance from the root node as shown in Fig 4.2. The root node constructs the hierarchy by broadcasting a level discovery packet. The first level of the hierarchy where the root node resides is level 0. The nodes that receive the level discovery packet from the root node are assigned with level 1, then the nodes in level 1 broadcast their level discovery packet and the nodes receiving the level discovery packet for the first time are labeled as level 2 nodes. This process is carried out until all the nodes in the sensor network have a level number.

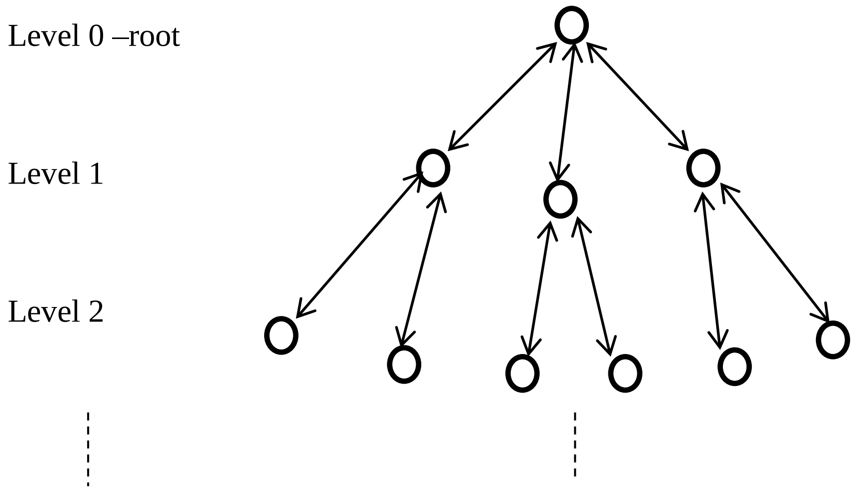


Fig. 4.2 Hierarchical synchronization architecture of TPSN

In Synchronization phase the root node sends a time sync packet to begin the time synchronization process. Then, the nodes in level 1 start synchronization with the root node by sending a synchronization pulse to level 0. In order to prevent collisions, each node in level 1 waits for a random amount of time before transmitting the synchronization pulse. The root node sends an acknowledgment back to the node in order to complete synchronization. As a result, level 1 nodes are synchronized to the root node. The synchronization pulse from level 1 also serves as a time sync packet to the nodes in level 2. Upon hearing this packet from a node in level 1, the nodes wait for a random amount of time then they initialize the synchronization process by transmitting a synchronization pulse. The level 1 node then sends an acknowledgment as shown in Fig. 4.3. In this way entire network gets synchronized to a single time frame.

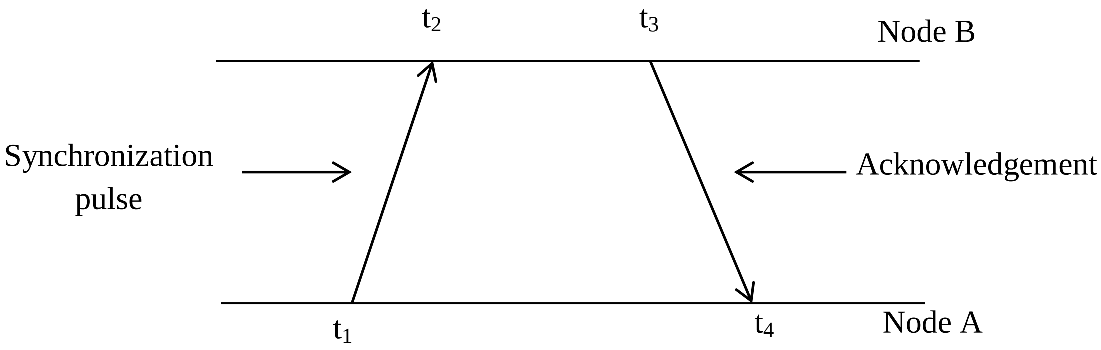


Fig. 4.3 Two-way message handshake

4.2.2 Reference-Broadcast Synchronization (RBS)

Reference Broadcast Synchronization scheme unlike other traditional synchronization schemes it uses receiver-receiver synchronization method i.e. it establishes synchronization between the pairs of receivers which are within the vicinity of the single transmitter, rather than synchronizing transmitter with each receiver individually. RBS reduces the critical path by exploiting the broadcast nature of the wireless channel [29].

In RBS the transmitter broadcasts the synchronization packets to all the nodes within the vicinity of that transmitter, each of the receiver then records the value of time of arrival of synchronization packets and then they share the information with each other in order to synchronize their clocks To lower the value of clock offset for each receiver multiple exchanges of observations between receivers take place to provide synchronization in single-hop environments. This approach is illustrated in Fig. 4.4

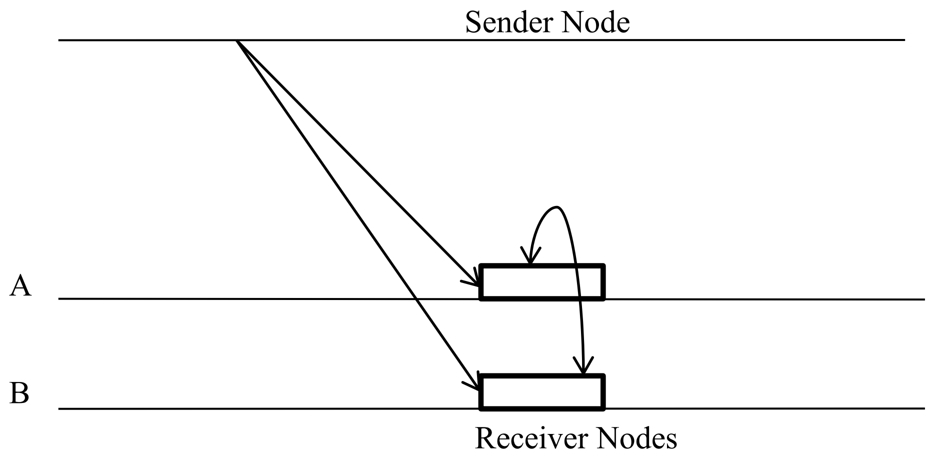


Fig. 4.4 Reference Broadcast Synchronization Scheme

4.2.3 Adaptive Clock Synchronization (ACS)

Adaptive clock synchronization algorithm [30] uses both receiver-receiver and sender-receiver handshake mechanism for synchronizing the network. The synchronization procedure of this approach is shown Fig. 4.5. Major advantage of ACS is that it limits the number of transmissions required to synchronize a network as compared to RBS. The process of synchronization is initiated by the sender node by broadcasting synchronization packets to all its neighboring nodes, on receiving the information from the sender each receiver calculates the relative clock drift by using linear regression and the information is transmitted back to the sender after a random amount of time in order to avoid collisions from other receiver nodes. The receiver then calculates clock skew related to each of its neighboring nodes and the information is again broadcasted within the network.in order to provide network wide synchronization in single-hop environment.

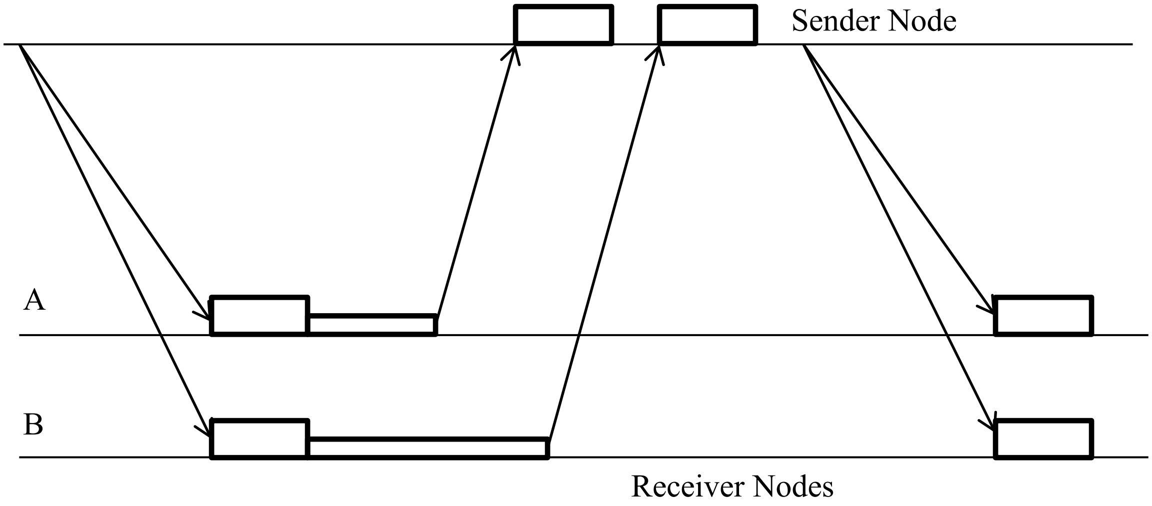


Fig. 4.5 Adaptive Clock Synchronization Scheme

4.2.4 Time Diffusion Synchronization Protocol (TDP)

Time Diffusion Synchronization Protocol unlike RBS and TPSN, which provides multi-hop synchronization extending from single-hop aims mainly to provide a common time throughout the network which is to be synchronized. The network time can also be translated into the global time at the base station using a time translation algorithm [31]. To provide multi-hop synchronization TDP assigns the following three different tasks to nodes in the network.

- **Master Nodes:** The task of the master nodes is to begin the synchronization procedure by sending synchronization messages. In order to decrease the number of hops and convergence time of protocol many master nodes can be assigned within the network
- **Diffused Leaders:** Diffused leaders are the nodes whose task is to propagate the synchronization messages to those nodes which are out of the broadcast range of master nodes.

- **Regular Nodes:** The nodes which are neither master nodes nor diffused leaders are assigned as regular nodes. Their task is only to take part in synchronization process in order to provide network wide synchronization.

TDP mainly works in two phases, viz. active phase and passive phase as shown in Fig. 4.6. All the synchronization tasks are done during active phase. The active phase of TDP is divided into cycles of length τ. At each cycle master nodes are reelected and the synchronization operation is performed. Each cycle of length τ is further divided into rounds of length δ, where the synchronization messages are repeatedly broadcasted by the master nodes. In passive phase there is no further updating of timing information. As the duration of the passive phase increases, the network deviates from the reference value of time, which necessitates resynchronization of the network.

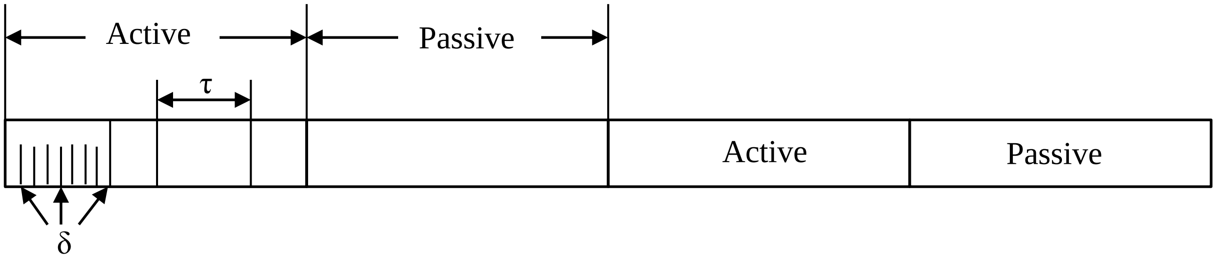


Fig. 4.6 Frame structure of TDP

4.2.5 Rate-Based Diffusion Protocol (RDP)

In TDP the timing information of the master node is diffused within the network using several diffused leaders. Thus, the network gets synchronized to the local clock of the master node. Using the similar procedure, RDP synchronizes the nodes in the network to the average value of the clocks in the network [32, 33]. In RDP, instead of sharing the timing information, the difference between the clocks of the sensor nodes and their relative information is diffused within the network. This version of RDP is called as synchronous RDP, in asynchronous RDP each node calculates the local average value from the average values calculated by its neighbors and then again broadcasts the information to its neighbors.

4.2.6 Tiny-Sync and Mini-Sync Protocols

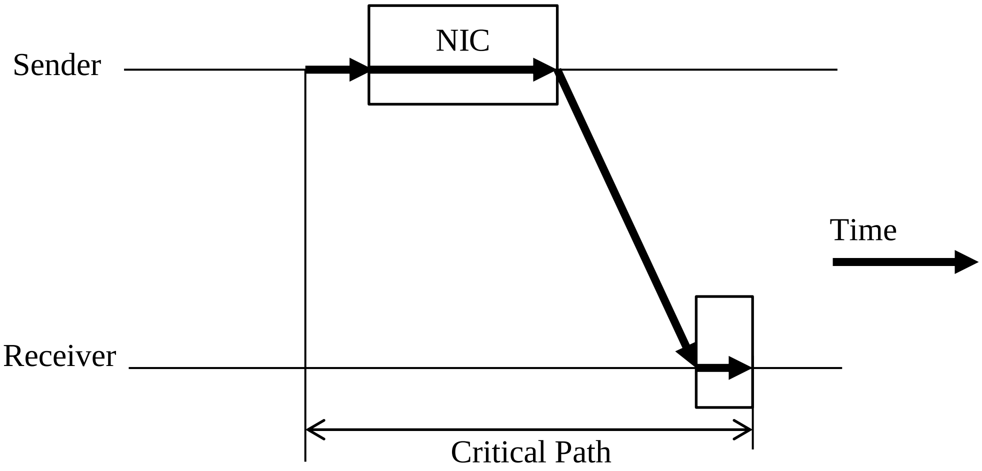
As the sensor nodes have limited computational power so it is important to design protocols having low computational complexities, tiny-sync and mini-sync are two such protocols which are designed to provide simple and accurate time synchronization [34]. Both protocols use the hierarchical structure to provide network wide synchronization. Each protocol stores data points in order to estimate clock drift and offset with respect to parent node clock. As sensor nodes have limited memory onboard so minimum number of data points must be stored. Tiny-sync protocol stores only four data points where as data points in case of mini-sync protocol can be greater than that of tiny-sync protocol.

Chapter 5 RBS AND ACS SYNCHRONIZATION ALGORITHMS

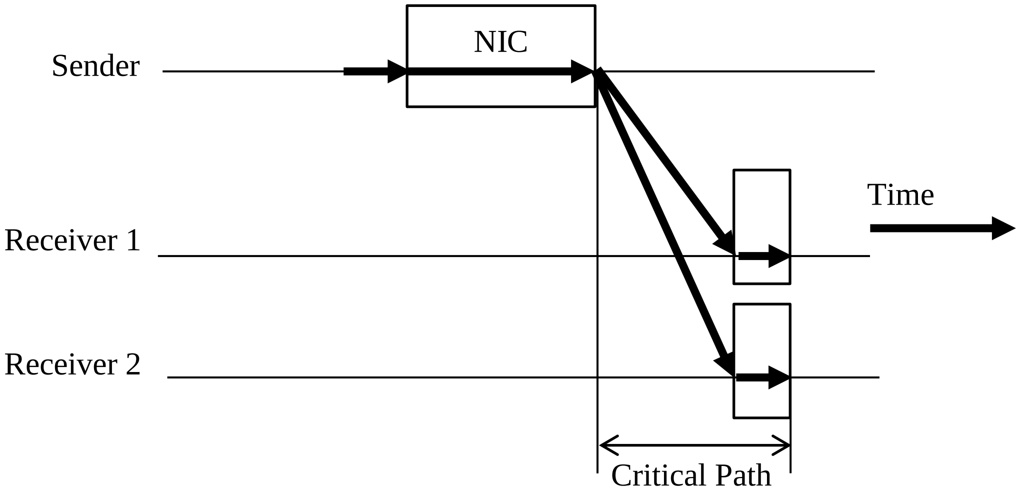
Due to random deployment of sensors over an area there may exist some regions where node density may be high as compared to other regions in that area. RBS and ACS both reduce the critical path by taking the advantage of broadcast nature of a wireless channel. Both of these algorithms have their own pros and cons in different WSN scenarios, in terms of energy required for synchronization of entire network

5.1 Reference Broadcast Synchronization (RBS)

RBS algorithm is mainly based on receiver-receiver synchronization method. By exploiting the broadcast nature of the wireless channels RBS algorithm reduces the length of the critical path [29] as shown in Fig. 5.1 and thus removing the clock uncertainty caused by Send Time and Access Time at the transmitter end which helps in reducing the sources of errors in synchronization.



(a) Critical path for pair-wise synchronization



(b) Critical path for RBS

Fig. 5.1 Critical path for different synchronization procedures

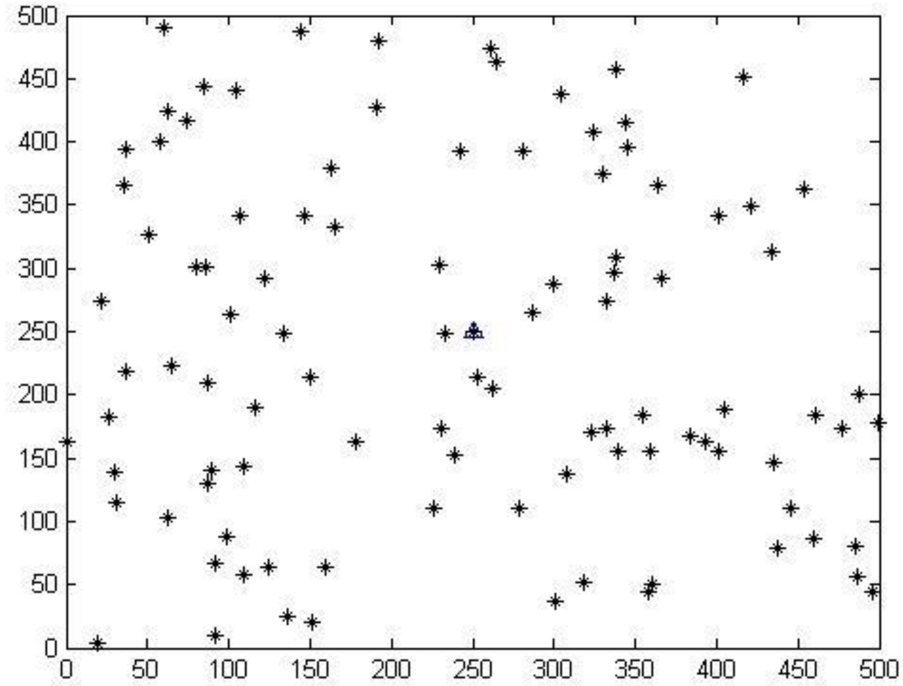
5.1.1 Protocol Scheme

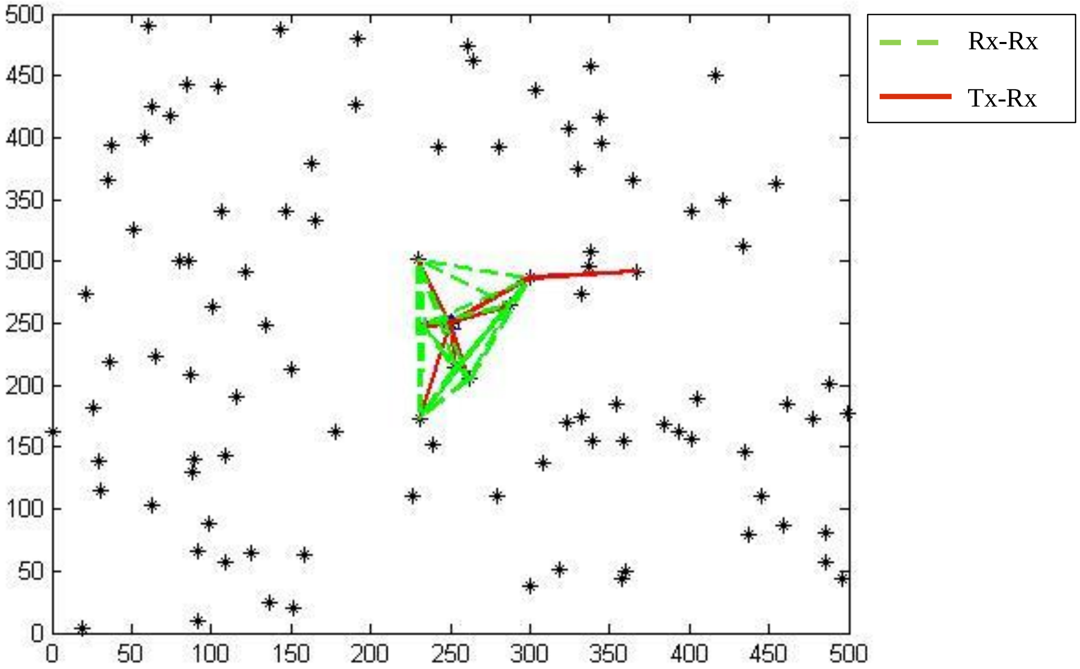
RBS algorithm works mainly in three main phases:

- Transmitter initializes the synchronization process by broadcasting synchronization packets.
- When the packet is received, each receiver within the vicinity of the transmitter records the time according to its local clock.
- Lastly, exchange of observations between receivers takes place.

In order to provide synchronization in multi-hop environments RBS selects those nodes which lie in the vicinity of more than one transmitter such nodes are called as translation nodes and are used to synchronize the nodes which lies in different broadcast region.

Fig. 5.2 shows how a typical sensor network is synchronized using RBS synchronization. Here, 100 nodes are deployed randomly over an area of 500 x 500 m^2 with the BS is located at the center of the field. The red lines denote the transmitter-receiver communication whereas receiver-receiver communication are denoted by green dotted lines.

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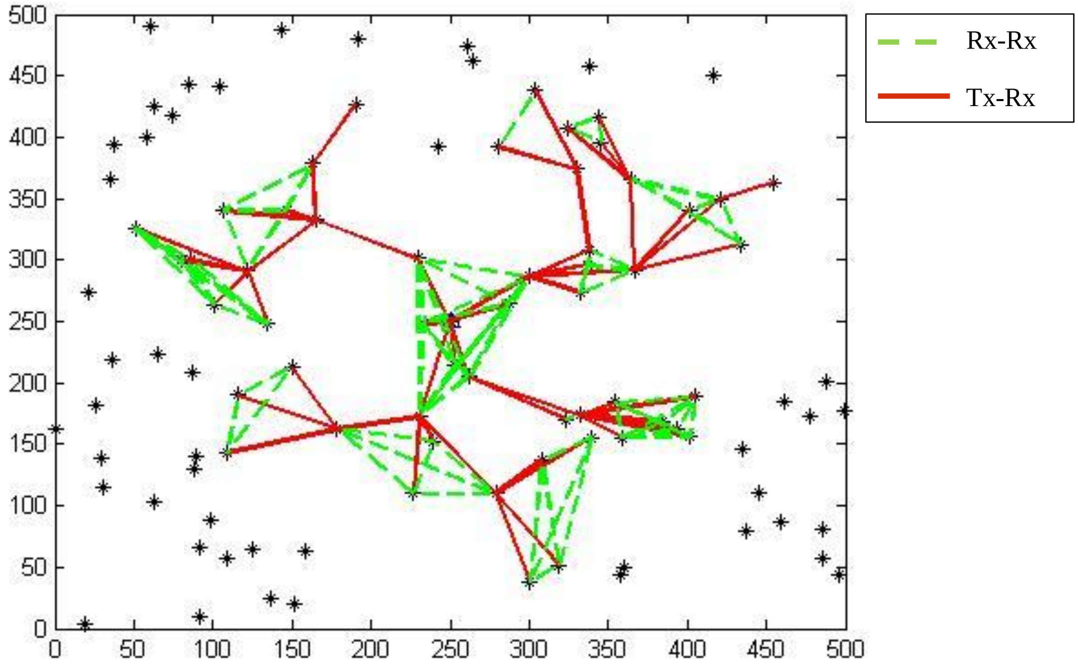
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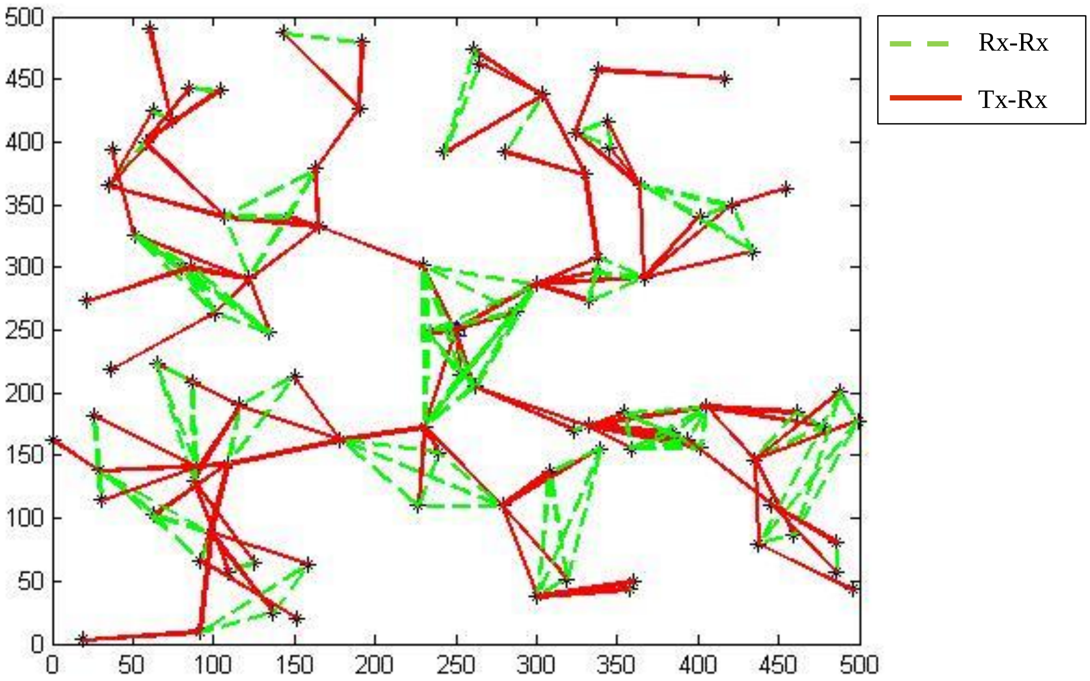


Fig. 5.2 RBS Synchronization Scheme

5.1.2 RBS Limitations

RBS scales better for sparse networks but as the network density increases its performance deteriorates [28]. For a given transmitter having 'n' nodes within its vicinity the number of transmissions (Tx_{RBS}) and receptions (Rx_{RBS}) are given as

$$Tx_{RBS} = n \tag{5.1}$$

$$Rx_{RBS} = n + \sum_{k=1}^{n-1} k \tag{5.2}$$

$$Rx_{RBS} = \frac{n^2 + n}{2} \tag{5.3}$$

It can be seen that the number of transmissions vary with O(n) whereas receptions vary with O(n^2). Also RBS does not account for coverage and connectivity as the nodes energy starts depleting. So if the synchronizing node dies it drops all the receivers connected to it and the network becomes unsynchronized.

5.2 Adaptive Clock Synchronization (ACS)

Adaptive clock synchronization approach uses both receiver-receiver and sender-receiver handshake scheme for synchronization [30]. Like RBS algorithm this approach also reduces the length of critical path for communication in sensor network.

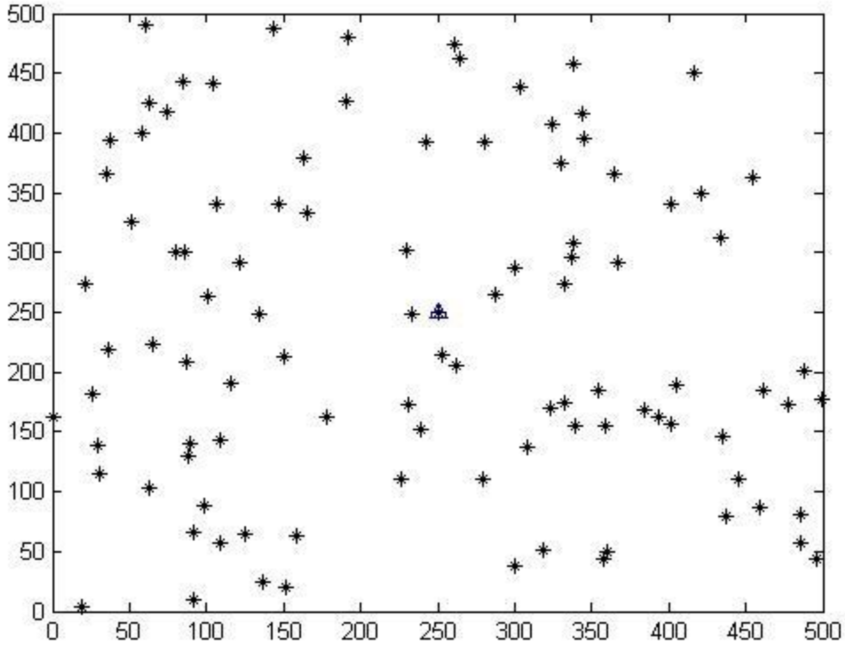
5.2.1 Protocol Scheme

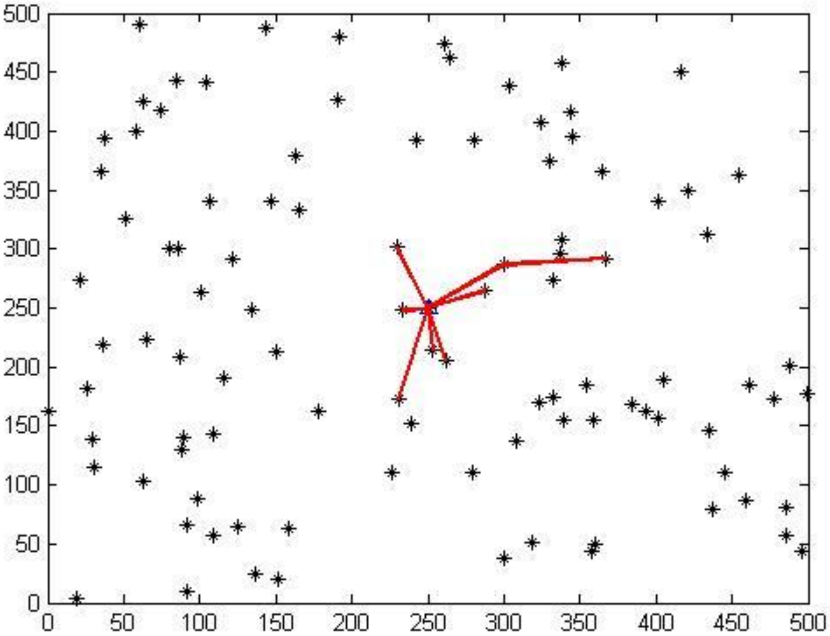
The five main phases of ACS algorithm are:

- Transmitter broadcast reference messages to all its receivers
- When the packet is received, each receiver within the vicinity of the transmitter records the time according to its local clock.
- After receiving the synchronization message each receiver perform some calculations regarding clock drift and that information is transmitted back to the transmitter.
- On receiving reply from all the receivers the transmitter again broadcast reference messages containing information about clock skew.
- Each receiver within the vicinity of the transmitter now on receiving the broadcast message can calculate clock offset and clock skew with reference to transmitter.

In multi-hop scenario ACS selects a transmitter node and is assigned level 0, the receiver nodes at the one hop distance from that transmitter are assigned one level greater than the transmitter node i.e. level 1. After being assigned a level each receiver node can act as a synchronizing node for the nodes which are two hops away from level 0, this procedure is now repeated until each node in the network has been assigned a level and hence the whole network gets synchronized.

Fig. 5.3 shows how a typical sensor network of 100 nodes deployed randomly over an area of 500 x 500 m^2 with BS located at the center, is synchronized using ACS synchronization.

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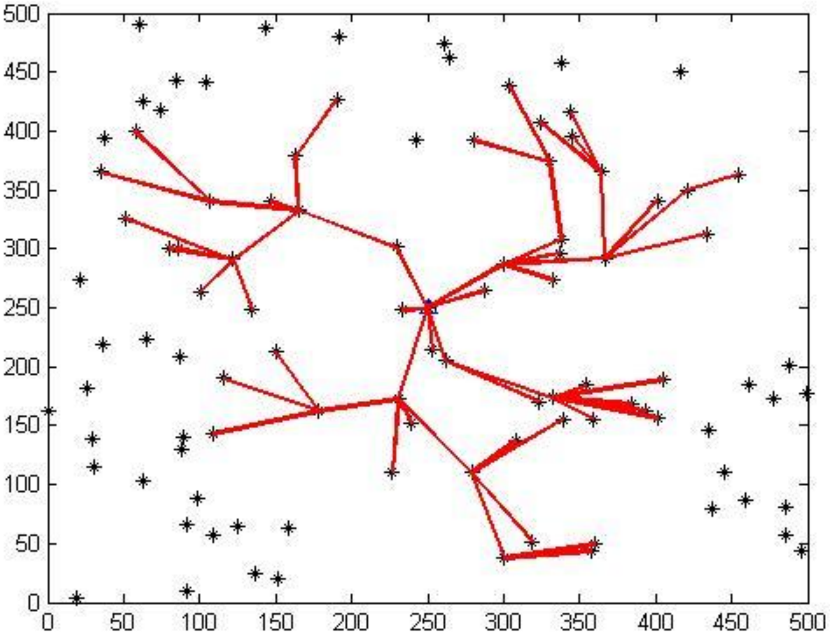
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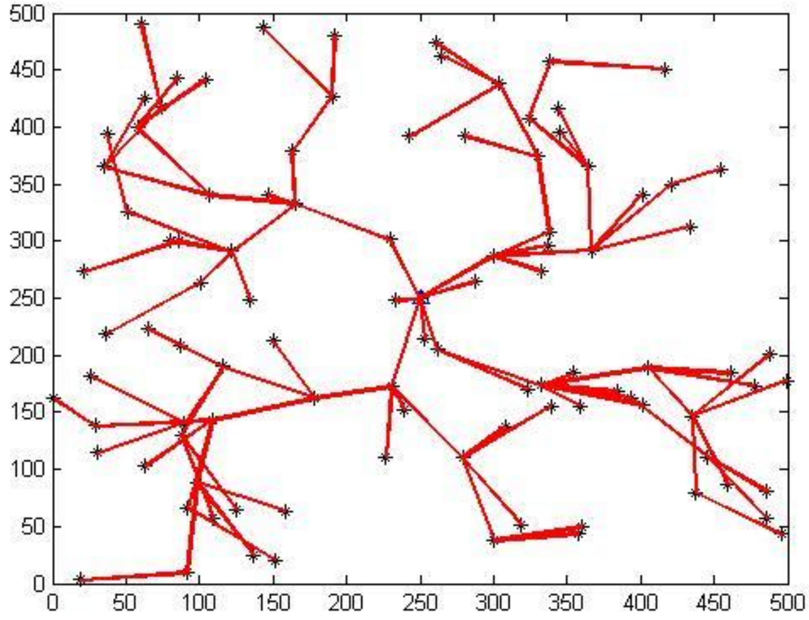


Fig. 5.3 ACS Synchronization Scheme

5.1.2 ACS Limitations

ACS is a better option than RBS for high density networks but as the network density decreases ACS becomes less efficient than RBS in terms of energy used in synchronization. e.g. for a synchronizing node S having two receiver nodes under its vicinity viz. R1 and R2, synchronization with RBS requires 2 transmissions and 3 receptions while ACS requires 4 transmissions and 6 receptions and hence here the energy consumption of ACS is more than that of RBS. For a given transmitter having 'n' nodes within its vicinity the number of transmissions (Tx_{ACS}) and receptions (Rx_{ACS}) for ACS are given as

$$Tx_{ACS} = n + 2 \tag{5.4}$$

$$Rx_{ACS} = 3n \tag{5.5}$$

ACS faces the same difficulties as there in RBS for coverage and connectivity issues.

Chapter 6 PROPOSED WORK

This project mainly focus on increasing the lifetime of the network by minimizing the energy consumption required for synchronizing the entire network. Two synchronization protocols viz. reference broadcast synchronization and adaptive clock synchronization are used in this project. The project aims to exploit the advantages of these synchronization protocols for different network scenarios of WSN, characterized here by node density.

6.1 The First Order Radio Model

The first order radio model [10] as shown in Fig 6.1 is used here for communication between any two nodes in the network.

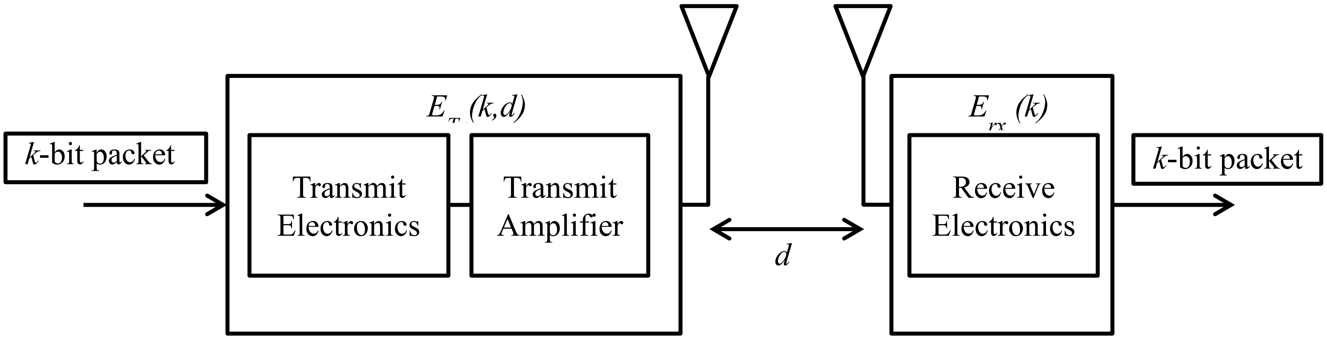


Fig. 6.1 The First Order Radio Model

6.2 Mathematical Modeling

For a transmitter to send a *k*-bit message through distance *d*, the energy utilization is given by [14]

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \tag{6.1}$$

$$E_{Tx}(k,d) = k * E_{elec} + k * \xi_{mp} * d^4 \tag{6.2}$$

For a receiver to receive a k-bit message energy utilized is given by

$$E_{Rx}(k) = E_{Rx-elec}(k) \tag{6.3}$$

$$E_{Rx}(k) = k * E_{elec} \tag{6.4}$$

Where,

k = number of bits in a packet

d = distance between two communicating nodes.

E_{elec} = energy required to run the transmitter or receiver circuitry in nJ/bit.

ξ_{mp} = energy required by the transmitter amplifier, for d^4 power loss in pJ/bit/m^4

ACS behaves better i.e. saves more energy in dense WSN's while for sparse networks RBS is a better option. Consider a network with 'n' receivers and one transmitter, also the energy required for transmission is greater than that required for reception so we define a constant 'λ' which is equal to transmitter to reception energy ratio.

Now we have to find the value of 'n' i.e. number of receivers for a single transmitter for which RBS and ACS consumes approximately same amount of energy. i.e.

$$Tx_{RBS} + Rx_{RBS} / \lambda = Tx_{ACS} + Rx_{ACS} / \lambda \tag{6.5}$$

Using equations 5.1, 5.3, 5.4 and 5.5, we get

$$n + \left(\frac{n^2 + n}{2}\right) * \frac{1}{\lambda} = (n + 2) + \frac{3n}{\lambda} \tag{6.6}$$

$$n - (n + 2) = -\frac{1}{\lambda}\left(\frac{n^2 + n}{2} - 3n\right) \tag{6.7}$$

$$-2 = -\frac{1}{\lambda}\left(\frac{n^2 + n - 6n}{2}\right) \tag{6.8}$$

$$-2 = -\frac{1}{\lambda}\left(\frac{n^2 - 5n}{2}\right) \quad (6.9)$$

$$4\,\lambda = n^2 - 5n \quad (6.10)$$

$$n^2 - 5n - 4\,\lambda = 0 \quad (6.11)$$

Now if λ = 2 i.e. energy required for transmission is twice of which is required for reception then the equation 6.11 becomes

$$n^2 - 5n - 8 = 0 \quad (6.12)$$

$$n = \frac{-(-5) \pm \sqrt{(-5)^2 - 4(1)(-8)}}{2(1)} \quad (6.13)$$

$$n = \frac{5 \pm \sqrt{57}}{2} \quad (6.14)$$

$$n = \frac{5 \pm 7.549}{2} \quad (6.15)$$

$$n = 6.274\,, -1.274 \quad (6.16)$$

As value of ‘n’ can’t be negative so for ‘n’ equal to 6.274 and λ equal to 2 both RBS and ACS consumes same amount of energy for synchronization.

6.3 Energy Efficient Time Synchronization Protocol

The value of ‘n’ given by the equation 6.12 is the value of receiver threshold i.e. if the number of receivers under one transmitter is greater than ‘n’ ACS algorithm is used for time synchronization otherwise RBS algorithm is used.

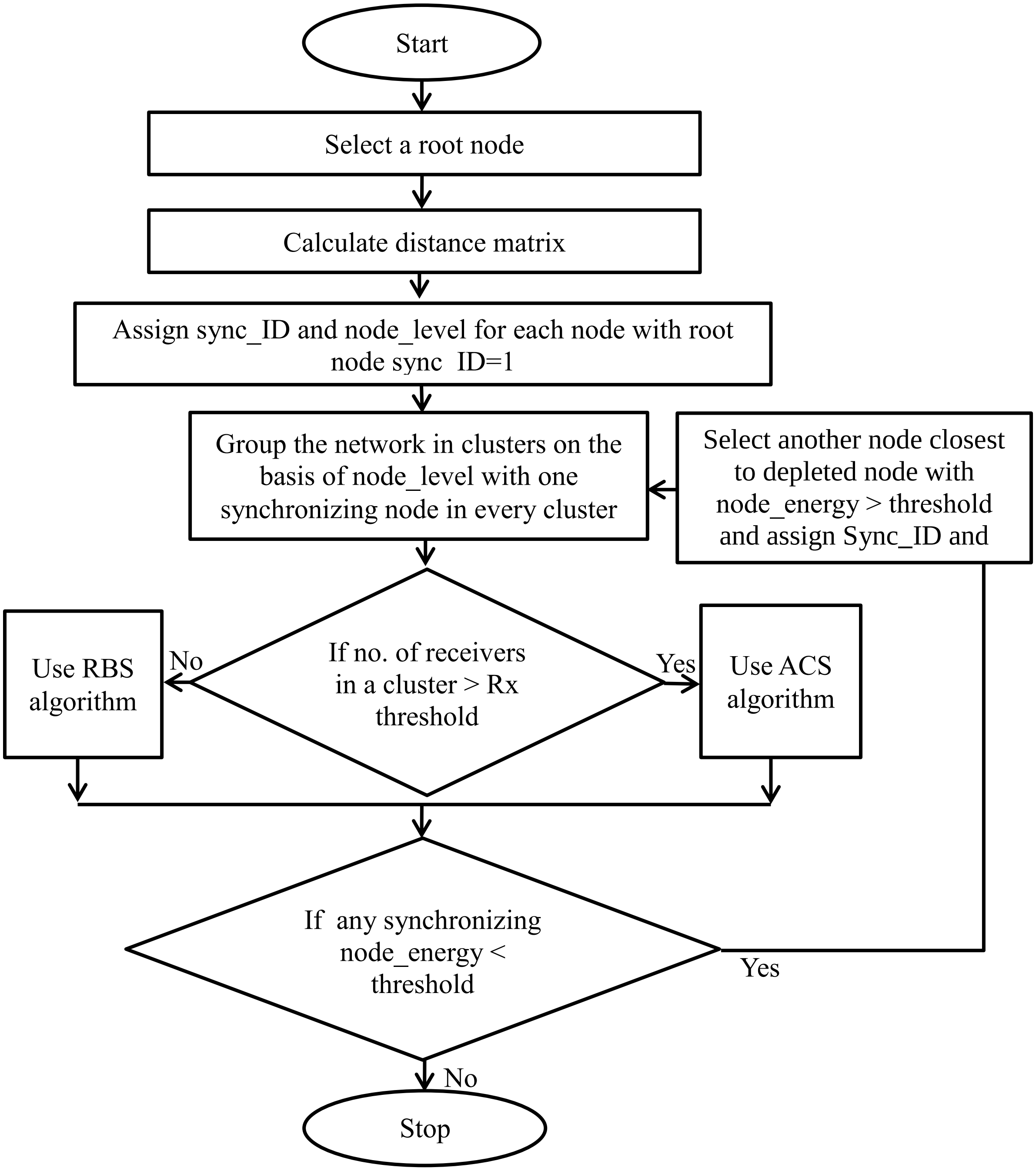
The protocol has the following assumptions

a) The nodes are deployed randomly over an area of 500 x 500 m^2.
b) The base station is located at the center of the field.

c) The nodes are provided with the initial energy of 2J

d) The energy consumption of processing circuitry of transmitting and receiving nodes is equal.

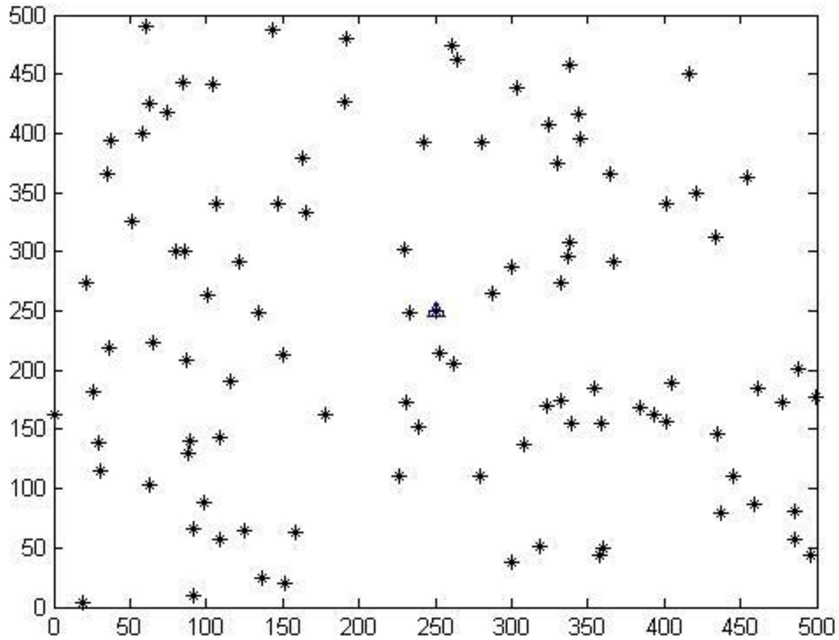
6.3.1 The Energy Efficient Time Synchronization Protocol Flowchart

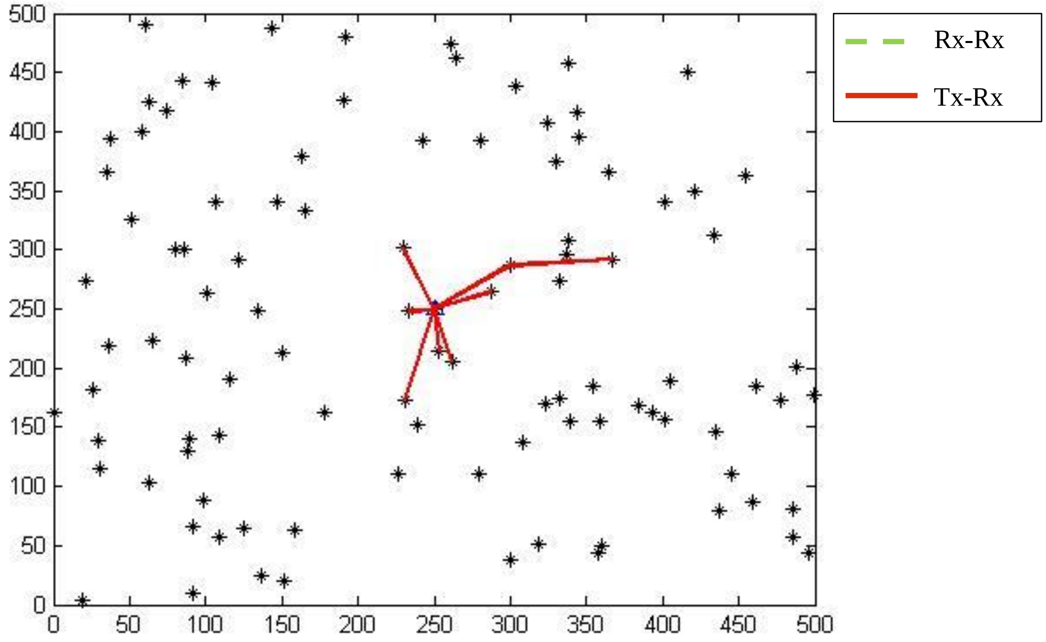


Depending upon the value of ‘λ’, i.e. transmission to reception energy ratio, we can find the optimal value of ‘*n*’ from which we can decide when to switch from RBS to ACS or vice-versa. The proposed algorithm also takes care of the issue of coverage and connectivity of the entire network by flooding only the area whose synchronizing node dies or whose energy is below a certain threshold and thus reducing the energy consumption for large area networks.

6.3.2 Synchronization using Energy Efficient Time Synchronization Protocol

The Fig. 6.2 shows how the network of about 100 sensors deployed over a field of 500 x 500 m^2 with BS located at the center is being synchronized using the proposed scheme.

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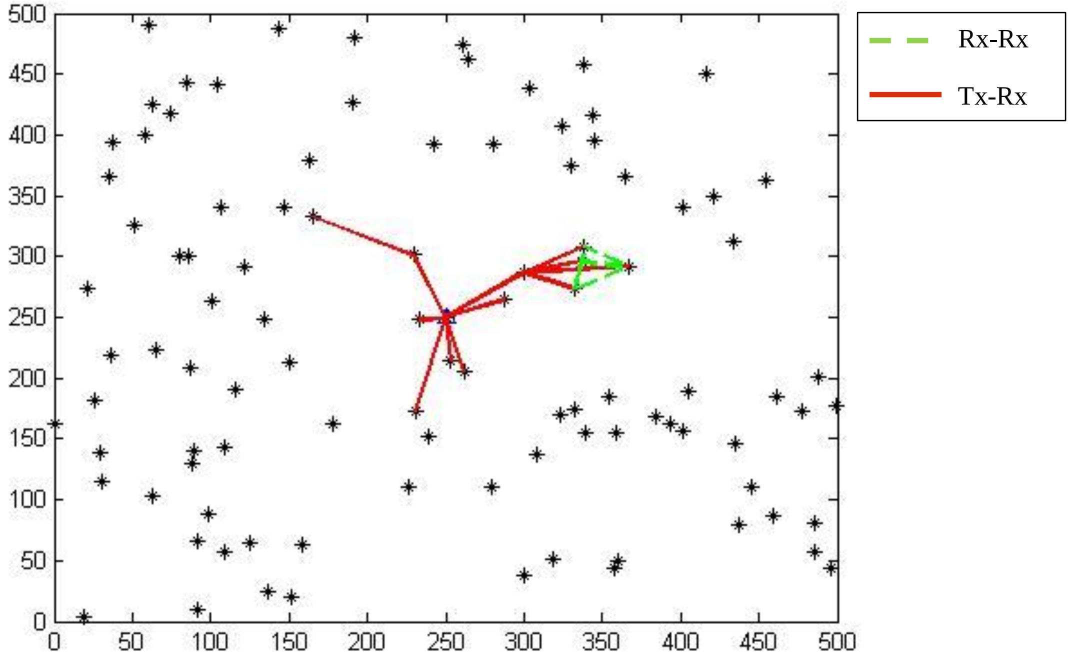
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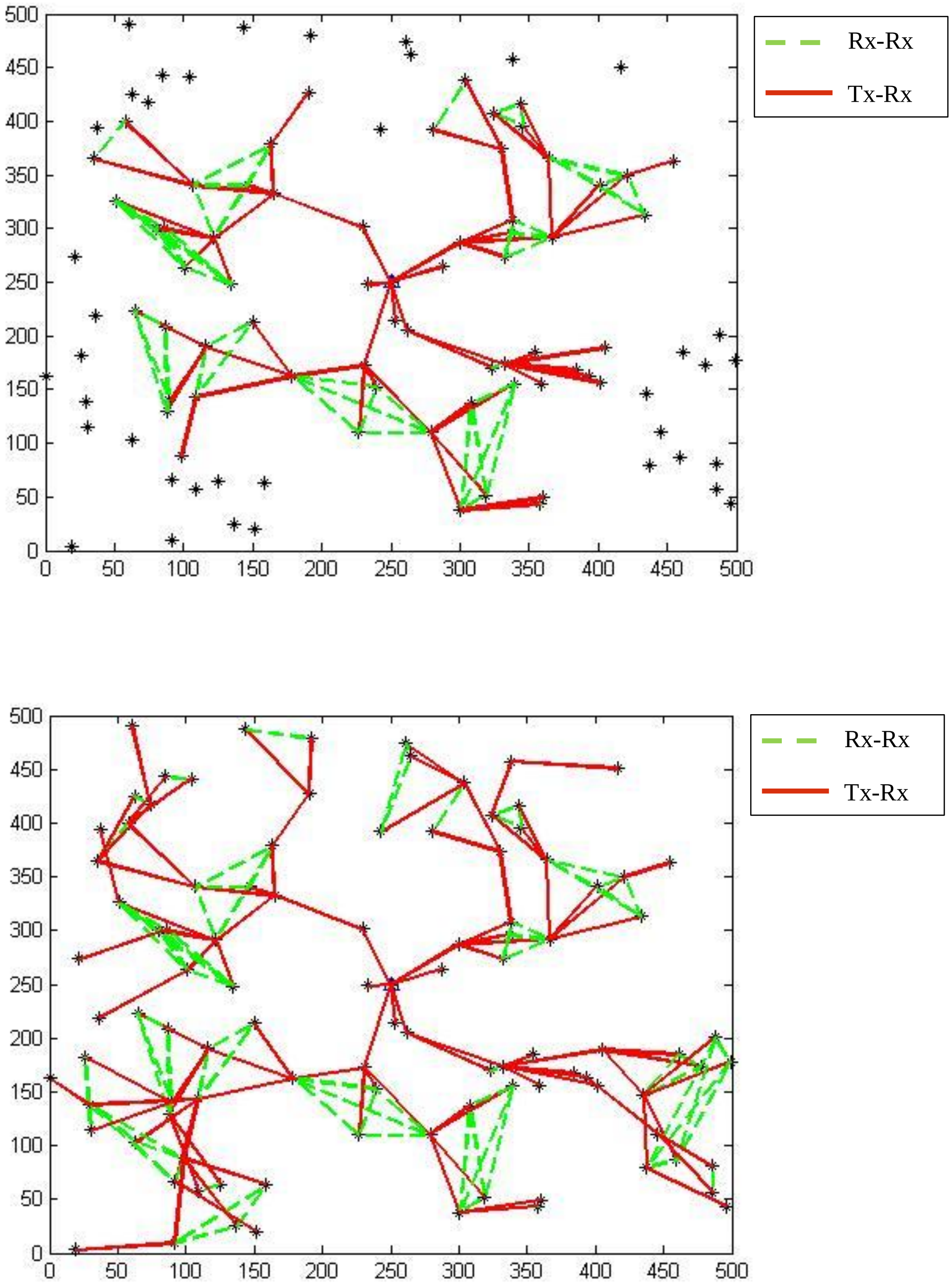

Fig. 6.2 Energy Efficient Time Synchronization Protocol Synchronization Scheme

Chapter 7 IMPLEMENTATION

All the simulations are done in MATLAB using the system parameters as given in the Table 7.1

Table 7.1 System Parameters

Parameter	**Value**
Network Size	500 x 500 m^2
Number of nodes	250 – 1500
Initial energy for each node	2J
Transmitter electronics, E_{elec}	50nJ/bit
Receiver electronics, E_{elec}	50nJ/bit
ξ_{mp}	0.0013pJ/bit/m^4
K	2000 bits
Path loss exponent	4
d	50 – 70 m

The value 'λ' transmitter to reception energy ratio can be calculated as

$$\lambda = \frac{E_{Tx}(k,d)}{E_{Rx}(k)} \tag{7.1}$$

$$\lambda = \frac{k * E_{elec} + k * \xi_{mp} * d^4}{k * E_{elec}} \tag{7.2}$$

Using the values of parameters from the Table 6.1, we get the value of λ as

$$\lambda = \frac{2000 \; * \; 50 * 10^{-9} \; + \; 2000 \; * \; 0.0013 * 10^{-12} \; * \; 70^{4}}{2000 \; * \; 50 * 10^{-9}} \tag{7.3}$$

$$\lambda = 1.6243 \tag{7.4}$$

Now, using the value of λ in equation 6.11 we get

$$n^{2} - 5n - 6.497 = 0 \tag{7.5}$$

$$n = \frac{-(-5) \pm \sqrt{(-5)^{2} - 4(1)(-6.497)}}{2(1)} \tag{7.6}$$

$$n = \frac{5 \pm \sqrt{50.9882}}{2} \tag{7.7}$$

$$n = \frac{5 \pm 7.1406}{2} \tag{7.8}$$

$$n = 6.0703\,, -1.0703 \tag{7.9}$$

So the value of receiver threshold is, n = 6.0703 as ‘n’ cannot be negative i.e. the transmitters having 6 or less receivers under their vicinity should use RBS algorithm for synchronization and the transmitters having more than 6 receivers in their vicinity should use ACS algorithm.

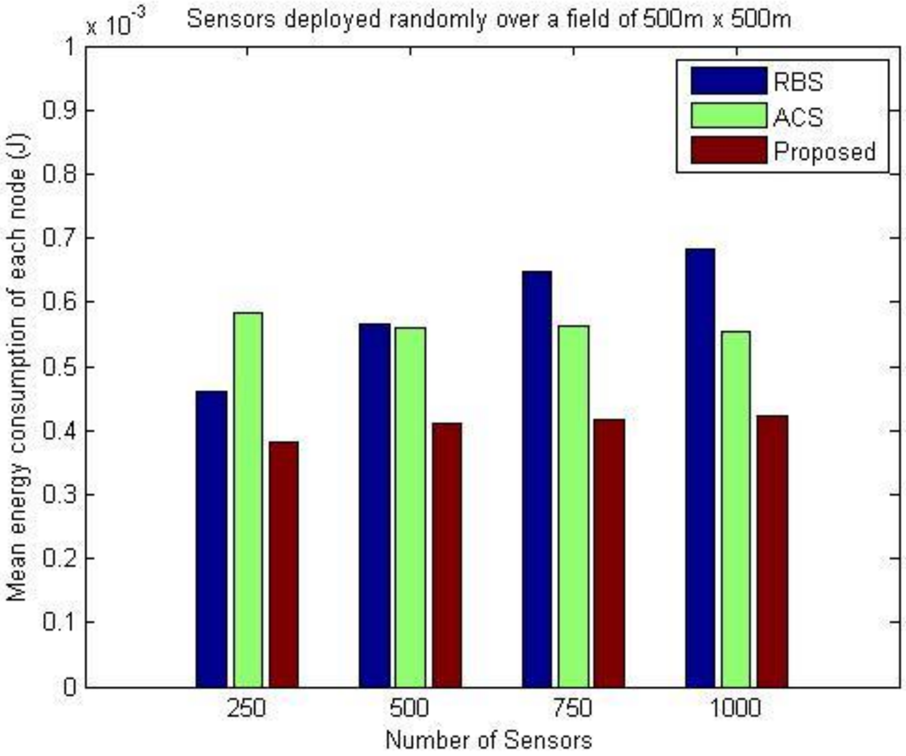

Fig. 7.1 Mean energy consumption of each node

Fig. 7.1 gives mean energy consumption of each node while using RBS, ACS and proposed algorithm for synchronization of entire network having different number of sensors deployed over the same area. It can be clearly seen from the figure that the mean energy consumption for each node is highest for ACS when the network is sparsely populated, but as we increase the number of nodes for the same area it can be seen that RBS becomes least efficient in terms of energy consumption. However the mean energy consumption for each node in case of proposed algorithm is less than the other two schemes.

Table 7.2 Number of Transmissions

Number of Nodes	250	500	750	1000	1250	1500
RBS	250	500	750	1000	1250	1500
ACS	440	808	1212	1574	1914	2242
Proposed	262	536	814	1088	1364	1642
Savings over RBS	-4.80 %	-7.20 %	-8.53 %	-8.80 %	-9.12 %	-9.47 %
Savings over ACS	40.45 %	33.66 %	32.83 %	30.88 %	28.74 %	26.76 %

It can be seen from Table 7.2 that the number of transmissions are least in the case of RBS while ACS has maximum number of transmissions among the three schemes. In case of number of transmissions the performance of proposed scheme over RBS degrades up to 9.47 % while there are 40.45 % more savings over ACS.

Table 7.3 Number of Receptions

Number of Nodes	250	500	750	1000	1250	1500
RBS	749	2019	3656	5223	8185	12106
ACS	750	1500	2250	3000	3750	4500
Proposed	532	1190	1813	2451	3099	3791
Savings over RBS	28.97 %	41.06 %	50.41 %	53.07 %	62.14 %	68.68 %
Savings over ACS	29.07 %	20.67 %	19.42 %	18.30 %	17.36 %	15.76 %

The table 7.3 shows that as the network size increases the number of receptions also increases in a linear manner, whereas it is not so in the case of RBS. The savings over RBS is 28.97 % for sparse networks but it increases up to 68.68 % for dense networks, while savings over ACS is 29.07 % in case of sparse networks and decreases to 15.76 % as the network density increases.

Table 7.4 Energy used for the synchronization (in Joules)

Number of Nodes	250	500	750	1000	1250	1500
RBS	0.1150	0.2825	0.4868	0.6840	1.0207	1.4533
ACS	0.1459	0.2807	0.4213	0.5551	0.6853	0.8136
Proposed	0.0954	0.2056	0.3131	0.4214	0.5310	0.6454
Savings over RBS	17.04 %	27.22 %	35.68 %	38.39 %	47.98 %	55.59 %
Savings over ACS	34.61 %	26.75 %	25.68 %	24.08 %	21.52 %	20.67 %

Table 7.4 gives us the energy required for the synchronization of the entire network using RBS, ACS and proposed algorithm. The maximum savings over RBS is up to 55.59 % when the network is densely populated with sensor nodes. However, in case of ACS the energy savings achieved by propose algorithm are more when network is sparsely populated and the savings over ACS decreases as the density of the nodes in the network increases.

Chapter 8 CONCLUSIONS

8.1 Conclusion

After the deployment of sensor nodes what poses main challenge is the shelf life of a sensor node. So, in order to increase the lifetime of the entire network we have to use the available resources in an efficient manner. For the sensor nodes to detect a particular event correctly i.e. in the order in which they have happened in actual time, is possible if all the nodes within the network works in co-ordination with each other. So, to maintain co-ordination between them synchronization between their clocks is necessary. The degree of synchronization between their clocks however depends upon the type of application for which the nodes are being deployed. As the nodes are deployed in a random fashion, so the nodes density varies from region to region within the network. The project aims to minimize the energy consumption required for synchronization of the entire network based on the node density of a particular region to be synchronized. To achieve our goal we make use of two existing time synchronization protocols viz. Reference Broadcast Synchronization (RBS) and Adaptive Clock Synchronization (ACS).

It is clear from the simulations that RBS consumes less energy than ACS for synchronization when the network is sparsely populated but consumes more amount of energy for high density networks. The proposed algorithm however switches between both RBS and ACS based on the number of nodes under one synchronizing node and thus providing about 55.59 % energy savings over RBS and a maximum of about 34.61 % energy savings over ACS. The energy consumption of the energy model used depends upon the factors like packet size, distance between two communicating nodes, power profile of hardware used etc., another important factor upon which energy consumption depends is that for how much time the transceiver circuitry of the node stays on.

8.2 Future Work

The future work includes considering an energy model which takes into account the on time of transceiver circuitry. The on time can be reduced by reducing the packet size i.e. instead of sending data bit-by-bit multiple bits can be coded into one symbol by using higher order modulation schemes. Decreasing the packet size helps in reducing the time required to send the desired data and thus the on time of the transceiver circuit also gets reduced. The value of path loss exponent used here is also assumed to be constant, further this work can also be modeled for different values of path loss exponents in different environments.

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RESUME

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COMPUTER SKILLS

Languages **:** C, C++, VHDL
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ACADEMIC PROJECTS

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Duration **:** 1 Year

B.Tech Project

Project Title **:** Microcontroller based 3D globe with RF & keyboard interfacing
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