Time Synchronization in Wireless Sensor Network

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Final Approval

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Declaration

I hereby declare that this thesis, neither as a whole nor as a part thereof has been copied out from any source. It is further declared that No portion of the work presented in this report has been submitted in support of any application for any other degree or qualification of this or any other university or institute of learning.

Zahid Mehmood

Acknowledgements

This project and all my efforts are fruitful only due to Allah Almighty, the Most Merciful and Beneficent Who gave me strength to complete this task to the best of abilities and knowledge.

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Zahid Mehmood

Every researcher needs to address "What", "Why" and "How" for every research problem.

Abstract

Sensor network, due to its important properties like low cost, small size and low power consumption, got significant attention in modern communication systems. Power efficiency is the key issue in wireless sensor network. The proposed architecture will be based on the fact that all the sensors should be in sleep (in low power) mode until there is some activity to be monitored. When there is some task to perform or some event to be monitored the sensor network should wake its sensors up. It is also essential that all the nodes are able to wake up at the same time to be able to exchange information. Further to avoid the synchronization overhead the synchronization will be location based, A sensor node will be able to synchronize its neighbours only, which can be identified by an adjacency matrix which will be calculated by base station, the synchronization will be performed using breadth first search.

From the research gaps found future directions are identified. To verify the research results some studies are analyzed mathematically and by simulation. The fundamental study performs reduce message passing. We have simulated the existing results and determined the effects for different parameters like Noise, Delay etc. We presented a method to reduce message passing in the presence of channel coefficient for energy efficient transmission.

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Chapter 1

Introduction

1.0. Introduction

Communication is typically achieved by sending data from source to destination with intermediated nodes. In early 1950s computer and terminal started communication over long distances. Various factors have contributed to this dramatic increase in the data transmission rates. Radio transmission for telex over a long distance was used in World War II. A lot of work has been done on enhancement of reliable and efficient communication.

The new envision in the telecom has introduced a new way of development. The compact size of equipment gave us way to reduce the energy. The rapid development in sensor technology provides us a raising area to deploy Wireless Sensor Network (WSN). Synchronization method can be adopted exchanging message between sensor nodes. Energy efficiency is the main issue in wireless sensor network. In the literature review many techniques and protocols are purpose for the synchronization in wireless sensor network but they are not as much fast and efficient for synchronization process.

1.1. Wireless Sensor Network

Wireless sensor networks (WSNs) can be only a few to thousands of sensors wirelessly connected to each other and base station, capable of performed computation, communication, sense and respond. Sensor nodes cooperate in order to merge individual sensor readings into a high-level sensing result, such as integrating a time series of position measurements into a velocity estimate. The common technologies are radio, infrared light, laser etc. The most common of them is the radio communication technology which does not required line of sight over medium range. Infrared and laser can be used even low power consumption where line of sight is possible. The size of single sensor be varies from shoebox down to millimeter. These devices are very limited amount of energy they can store. Replacing batteries and maintenance of sensor over a large area is almost impossible to perform.

Various applications of wireless sensor network are monitoring, tracking or controlling. Some of these particular applications involve object tracking, habitat monitoring, nuclear reactor control, object tracking, fire detection and traffic monitoring. Data is collected through sensor node spread in the targeted region in wireless sensor network.

1.2. Applications of Wireless Sensor Network

Sensors are manufacture and installed in a large number due to low cost and small in size to cover remote locations. The resources of sensor network like memory, computational speed, energy and bandwidth are strictly critical. Different kinds of sensors like accelerometer, thermal, pressure, camera, microphone, humidity, vehicular movement, lighting condition, soil makeup, the availability of certain kind of objects and the mechanical stress level on the attached objects, the current characteristics/properties of such as direction, speed and object size. They sense the target object, perform necessary processing and communication of information to other sensors in the network are the components of sensor nodes.

Sensors are used in different fields such as Military, Environment, Wireless sensor network plays vital role in monitoring military command and control, intelligence tasks, computing, communication, surveillance of sensitive areas and activity, inspection of mission critical and locating a targeted system. Tasks like monitoring military commands are critical and need consistent and efficiency in communication like battlefield.

Sensors are very important and extensively deployed in the agriculture research work, traffic signal control and smoke and fire detection. The delay and disruption of a sensors network are not tolerated in military and traffic signaling control.

A collection of sensor combined for the monitoring humidity, moisture level, direction and speed of wind, with collectively satellite image determining the forecasting for the targeting area and other important information regarding the environment. Such type of network helps authorities to set immediate arrangement at disaster area for relief activities.

1.3. Time Synchronization

Time Synchronization in wireless networks is not only important for basic communication, it also provides the ability to detect movement, location, and propinquity. The synchronization problem consists of four parts: send time, access time, propagation time, and receive time. Three current synchronization protocols are Reference Broadcast Synchronization, Timing-sync Protocol for Sensor Networks, and Flooding Time Synchronization. In the referred protocols are presented and how they attempt solve the synchronization problem is also discussed. Security concerns as well as an industry case are also presented.

1.4. Breadth First Search

The Breath First Search (BFS) is one of the standard graph traversal methods. Each node is visited once only. The method proceeds by visiting all intermediate neighbours (vertices and one edge away), then visiting neighbours 's neighbours (Vertices two edges away), and so forth, until all reachable vertices have been vertices have been visited.

If a graph has any sub-graph (which is not reachable from the initial vertex) the procedure may be re-started by choosing a vertex from the unvisited sub-graph.

A queue is used to implement the BFS procedure. It keeps track of vertices to be visited next. A vertex pushed to the queued to the queue is said to be in ***ready*** state.

An en-queued ***vertex*** is said be in Wait state. The de-queued vertex is referred to as ***processed***.

The queue is initialized with the address of a starting vertex.

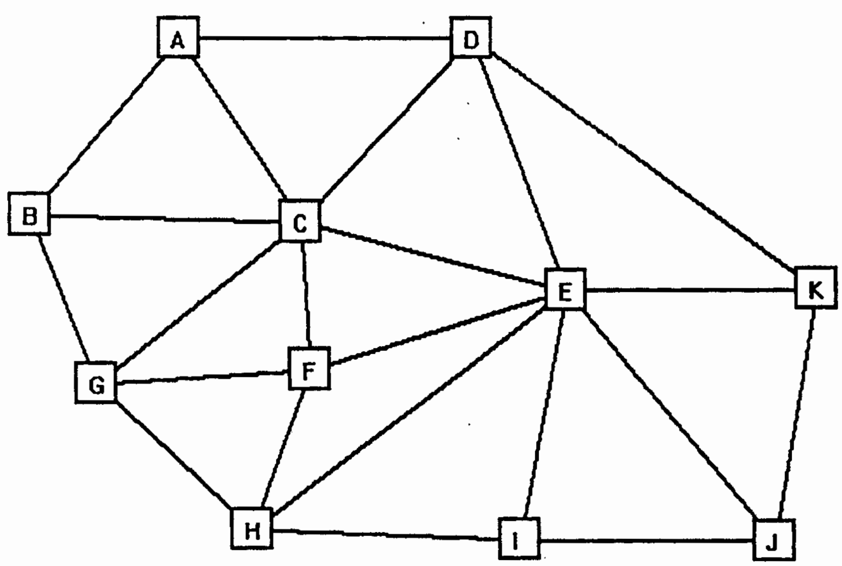


Fig 1.1 An undirected graph

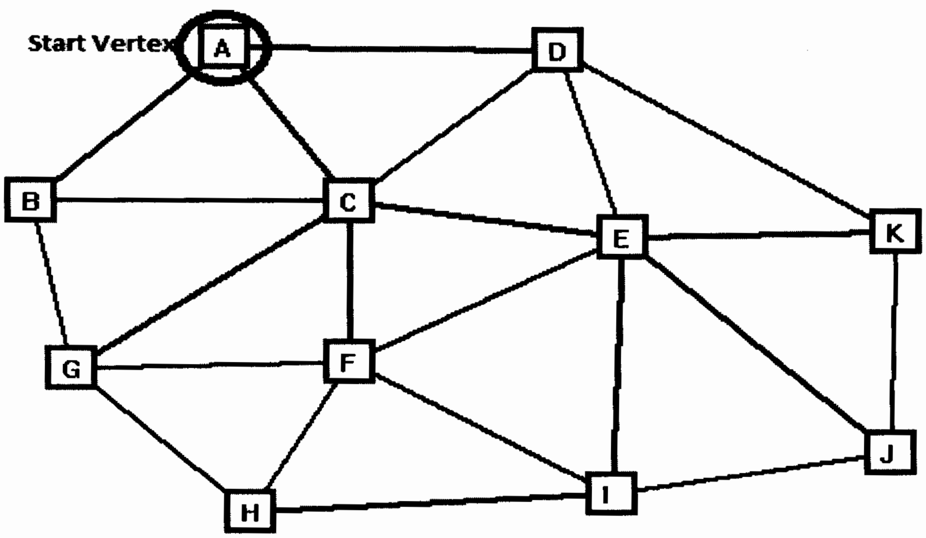


Fig 1.2 BFS spanning tree of above figure taking vertex A as start vertex

The spanning tree is ABCDEHFGKIJL.

1.5. Aims and Objectives:

The reason of this research is to review and acknowledge the work that has been contributed by previous researchers in the area of wireless sensor networks. Opportunistically it gives a chance to discuss certain areas which relate to the time synchronization of the wireless sensor networks. The most significant aspect of conducting this research is that it allows focusing and exploring the pros and con of mechanism of time synchronization in WSN. Furthermore, in order to support the idea of the subject an in-depth analysis will be made which will ultimately be helpful to provide better understanding of the time synchronization factor, however, “depth first search algorithm” will remain the focal area of the research.

1.6. Research Methodology:

An enormous study and literature review has been accomplished before writing about the subject in detail. The topic demands high degree of exploration in latest journals, articles, white papers and technical writings. To make better understanding of the topic relevant books and electronic resources such as digital library, e-journals and websites of industrial partners have been accessed. In order to support the topic tests are conducted in Visual C++ which are discussed in next chapters.

1.7. Thesis Organization:

The rest of the thesis consists of these chapters. Chapter arrangement and description are mentioned below.

Chapter 2 Provides a detailed study of the subject technology.

Chapter 3 Proposed solutions Design

Chapter 4 Simulation and statistical analysis

Chapter 5 Conclusion and Future works

Chapter 2

Literature Review

2.0. Literature Review Process

*"Indeed, one of my major complaints about the research field is that whereas Newton could say , **If I have seen a little farther than others, it is because I have stood on the shoulders of giants,** I am forced to say, Today we stand on each other's feet. Perhaps the central problem we face in all of research field is how we are to get to the situation where we build on top of the work of others rather than redoing so much of it in a trivially different way. Science is supposed to be cumulative, not almost endless duplication of the same kind of things".*

Richard Hamming 1968 Turning Award Lecture

2.1. Motivation and Benefits

The aim of this research is an essential feature of the academic project and to pay gratitude to the researchers that have contributed much in the field of wireless sensor networks. This research provides the chance of working in wireless sensor network. Main emphasis of this research is to discuss Time Synchronization in wireless sensor networks. During the research different aspects of the Time Synchronization are discussed and analyzed the Positive and negative aspects of the time synchronization in wireless sensor networks. A detailed analysis is required to completely understand the time synchronization. Breath First Search algorithm is used in time synchronization and BFS is the central area of interest.

Objectives of literature review are as follows

- ✓ Formulation of search string to find relevant literature
- ✓ Formulation of the research questions
- ✓ Evidence gathering for existing research
- ✓ Identification of research gaps
- ✓ Identification of future directions

Identifying the valid research questions is an important component of any literature review. For the formulation of the research questions in this literature review we have used the following terms.

Table 1: Terms

Area of interest	Synchronization in wireless sensor network
Technique	Collaborative Communication
Goal	Energy efficient communication, High signal to noise ratio (SNR)
Environment	Wireless communication in distributed Sensor network

The question identification process was iterative. Below are the research questions that we finalized and investigated.

2.1.1. Research Question 1

What are types of synchronization that affect the energy of sensors?

2.1.2. Research Question 2

What are different characteristics of time synchronization for distributed wireless sensor networks?

2.1.3. Research Question 3

What is the priority of each characteristics of time synchronization in sensor network that affects the energy requirements of sensors?

2.2. Selected Studies

After careful investigation, the study selection process short listed the following studies that satisfied the inclusion criteria.

- **P1** → Jeremy Elson and Deborah Estrin, "Time synchronization for Wireless Sensor Networks," In 2001 International Parallel and Distributed Processing Symposium (IPDPS), Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Comp, San Francisco, USA, April 2001.

- **P2** → L. Liu, M. Lei and J. Zhang, "Effect of Channel Errors on Time Synchronization in Wireless Sensor Networks" GLOBAL TELECOMMNICATIONS CONFRENCE 2007 GLOBECOM '07. pp. 1248-1252 2007.

- **P3 →** Y. Zhao, Y. Wang, J. Huang, X. Shi, "A Stable Clock Synchronization based on Clock Drift Rate," Proceedings of the 2008 IFIP International Conference on Network and Parallel Computing ,Pages: 204-209,Year of Publication: 2008

- **P4 →** R. Solis, V. S. Borkar , and P. R. Kumar, "A New Distributed TS Protocol for Multihop Wireless Network," Decision and Control, 2006 45th IEEE Conference on Issue Date: 13-15 Dec. 2006 , page(s): 2734 - 2739 .

- **P5 →** D. R. Bheemidi, and Nigamanth Sridhar "A Wrapper based Time Synchronization in Wireless Sensor Network," Computer Communications and Networks, 2008. ICCCN '08. Proceedings of 17th International Conference on Digital Object Identifier: 10.1109/ICCCN.2008.ECP.55 Publication Year: 2008, Page(s): 1 – 6.

- **P6 →**Murtuza Jadliwala, Qi Duan ,Shambhu Upadhyaya,Jinhui Xu "Secure Time Synchronization in Sensor Networks," Proceedings of the second ACM conference on Wireless network security Zurich, Switzerland ,Pages: 201-212 ,Year of Publication: 2009.

2.3. Detailed Summary of Selected Studies

- **P1 →** Jeremy Elson, Deborah Estrin, "Time Synchronization for Wireless Sensor Networks," ipdps, vol. 3, pp.30186b, 15th International Parallel and Distributed Processing Symposium (IPDPS'01) Workshops, 2001

The Requirements for time synchronization in distributed WSN is different as compared to ordinary distributed systems. The unique requirements are scope and availability, life time, efficiency, cost and form factor and precision of synchronization achieved. Post-facto synchronization can be achieved using low power. Post-facto synchronization is a multimodal scheme in which each node consists of two processors one is pre processor used for synchronization and the other one is general purpose used for communication between the sensors. Post-facto synchronization keeps the nodes in low power (sleep nodes), when pre processor detects a potentiality feasible signal it *powers on* the general purpose processor. Typically nodes clocks are unsynchronized. A Processor sends sync message acting as beacon, nodes receiving the sync message normalize their clocks with reference sync signal.

Study Goals are:

1. Characterization of synchronization requirements.
2. Maximize the battery time by keeping the sensors sleep while not communicating.
3. Trading of precision for energy, or scope for convergence time

Assumptions considered as follows:

1. Each node accurately measures the interval elapsed between their detection of events and arrival of synchronization.
2. All nodes detect the synchronization signal at same time.
3. Synchronization pulse is an absolute time reference at the instant of its arrival.
4. There are no transmission impairments and channel is known to every node.

The results of this study are shown in Figure 1

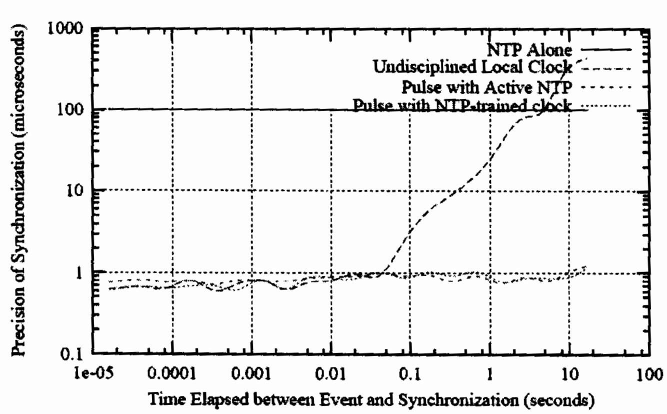


Figure2.1: Empirical results of post-facto synchronization

Claims of P1

Study claims given below

1. The most affecting Metric for time synchronization consists of
   - Precision
   - Life Time
   - Scope & Availability
   - Time and Energy Efficiency
   - Cost & Form Factor
2. Traditional synchronization schemes do not cope with energy requirements of sensors
3. Communication power is much high than computation power.
4. A Multimodal Post Facto Synchronization can reduce the energy requirements of sensors.

Mention Future Work in Discussed P1

1. Implementation of post-facto synchronization in hardware

- P2 → L. Liu, M. Lei and J. Zhang, "Effect of Channel Errors on Time Synchronization in Wireless Sensor Networks" GLOBAL TELECOMMNICATIONS CONFRENCE 2007 GLOBECOM '07. pp. 1248-1252 2007.

Time synchronization (TS) is one of the most challenging and desired element in WSN. The outcome of the TS can be obtained by using an algorithm or a protocol. If the protocol is applied in the right way then the results obtained are meaningful. Many researchers are working on time synchronization and Wireless Sensor Network but the impact of channel errors in Time Synchronization has been a neglected area.

This paper is based significantly on the study of effect of channel errors and evaluation of the outcomes from simulations. This document highlights the impact of channel error on time synchronization of WSN. The study reflects that exponential increase is directly proportional to channel error rate i.e. the channel error increases with the increase in offset._The battery life time and improving computing capabilities of sensors is the main goal of this research. Without Time synchronization it becomes difficult to monitor the behavior of the analyzing data and chances are likely to obtain the incomplete and inaccurate results.

It is very difficult to measure that was used for the time synchronization between the sensors nodes. Message passing is a feasible way to achieve the time synchronization. In this paper a protocol is proposed to calculate the impact of channel error on time synchronization.

Goals

1. Increase the battery lifetime.
2. To prove that channel error is the main cause of time synchronization process failure.
3. To find the reason how channel error impact on cock drift.
4. Evaluate the performance and result via simulation.

Assumptions

1. Purposed protocol uses the static routing.
2. The route of the node is fixed and cannot be changed if not necessary.
3. The proposed protocol works in three steps.
   i. Route Search
   ii. Packet Forwarding
   iii. Synchronization

Solution

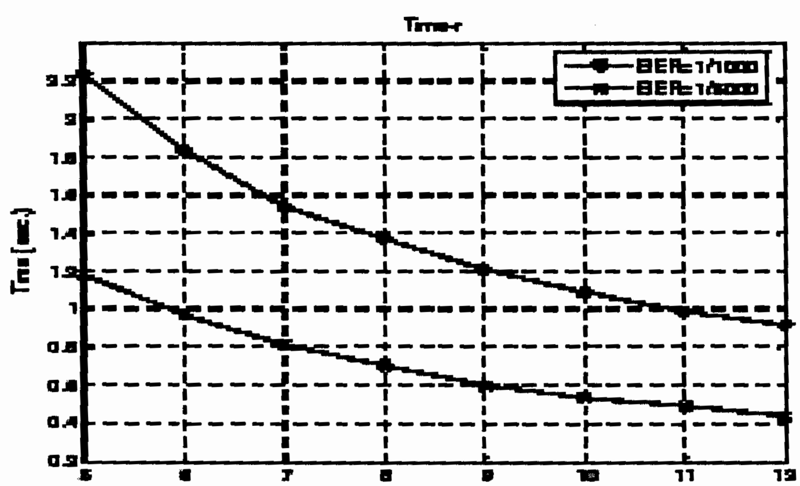


Figure 2.2 Total Synchronization time with different node ranges

Conclusion

In this paper simulation and some configuration is used to evaluate the impact of channel error on time synchronization in WSN. The results of the paper are very important that show how the channel errors disturb the time synchronization process.

- **P3 → →** Y. Zhao, Y. Wang, J. Huang, X. Shi, "A Stable Clock Synchronization based on Clock Drift Rate," Proceedings of the 2008 IFIP International Conference on Network and Parallel Computing ,Pages: 204-209,Year of Publication: 2008

The paper described and used a method of linear fitting for adjustment of time and stability which is based on clock drift rate. Every slave node having its own local clock and receives the time stamp from the server, A trend equation was developed to retrieve the drift rate of slave nodes, a strategy is proposed for adjusting time stamp using offsets. The paper used least mean square (LMS) for calculating the clock drifts.

Study Goals are:

1. Achieve the stable clock synchronization by offset fitting to adjust time.
2. Creation of a linear fitting model for calculating clock drift rate
3. Proposing some mechanism for reducing network delay

Assumptions considered as follows:

1. LMS is based on continuous communication model so the proposed model also does.
2. Clock drift is fixed for each slave node with respect to reference server.
3. NTP(Network Time Protocol) is used for time stamp transmission

The results of this study are shown in Figure 2.2

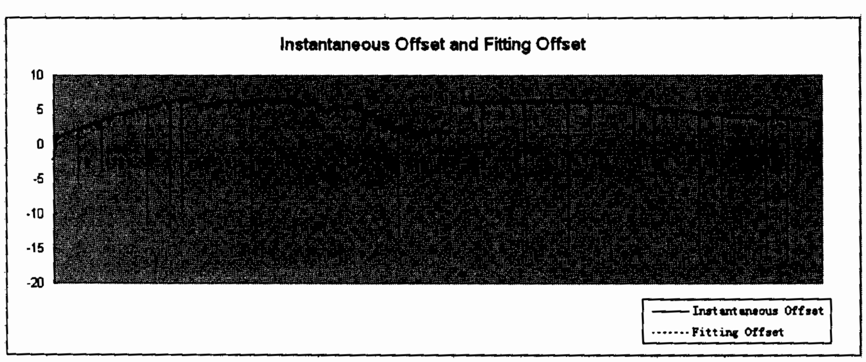


Figure 2.2: Time tuning comparison between instantaneous offset and fitting offset

Claims of P3

Study claims given below

1. Stability in clock synchronization is an important issue for research.
2. Running of a clock securely can be ensured by self adaptive and stable models even in failures of server or connections.

- **P4 →** R. Solis, V. S. Borkar , and P. R. Kumar, "**A New Distributed TS Protocol for Multihop Wireless Network,**" Decision and Control, 2006 45th IEEE Conference on Issue Date: 13-15 Dec. 2006 , page(s): 2734 - 2739 .

Authors proposed a clock sync protocol for wireless sensor network and adhoc network .They exploited the broadcast domain wireless medium basic idea was sync the neighbors only (pair wise sync), For the above mentioned purpose an incidence matrix was created. Using this incidence matrix an offset between neighboring nodes was estimated. In pair wise sync three motes a sender, a receiver and a gateway node connected at serial port of a PC for data collection are involved. The purpose of gateway mode is to continuously sense the medium and act as interface for communication of data being transmitted to the PC.

Study Goals are:

1. To design an algorithm to achieve a high performance Clock Synchronization in multi-hop wireless sensor network.
2. To improve the accuracy of clock synchronization by using global network wide constraints employing on the local broad cost.

Assumptions considered as follows:

1. An Incidence matrix is pre calculated and each node having access to this matrix.
2. Author assumed that all the nodes are running at the same speed having different offsets.

Claims of P4

Study claims given below

1. Changing the clock reference required just a single message.
2. Nodes will no need to know the reference of other node and topology of the network.
3. The manner of changing from one reference to another is also easy by using incidence matrix

- **P5** → D. R. Bheemidi, and Nigamanth Sridhar "A Wrapper based Time Synchronization in Wireless Sensor Network," Computer Communications and Networks, 2008. ICCCN '08. Proceedings of 17th International Conference on Digital Object Identifier: 10.1109/ICCCN.2008.ECP.55 Publication Year: 2008, Page(s): 1 – 6.

The main emphasis of authors in the paper is on high message exchange between sensor nodes in wireless sensor networks they states that nodes are synchronized with each other through periodically message exchange using local time stamping. The energy cost of message is very high. A large number of small nodes is deployed to get the meaningful information from nodes. It is stated that most of the algorithms are not yet so much equipped to achieve the constant level of accuracy over specific period of time. Message exchange can be processed as low power that only the quality of message needs to be synchronized otherwise message exchange is not affected. The author used time synchronization protocol (BSTP) wrapper for increasing the performance of time synchronization protocol while maintaining the accuracy and efficiency. The average clock drifts using clock wise handshaking as

$$D_{avg} = \frac{D_2 - D_1}{T_{training}}$$

Study Goals are:

1. Reducing the number of message exchange on average and consequently the energy consumed significantly

Assumptions considered as follows:

1. Hand shaking does not take much of energy

Claims of P5

Study claims given below

1. Improved the energy efficiency by reducing number of message exchanges
2. Fixed the Synchronization time as constant
3. Clock drift calculated accurately

Mention Future Work in Discussed P5

Design of Broadcast Synchronization protocol for protocols like FTSP

- **P6** →Murtuza Jadliwala, Qi Duan ,Shambhu Upadhyaya,Jinhui Xu "Secure Time Synchronization in Sensor Networks," Proceedings of the second ACM conference on Wireless network security Zurich, Switzerland ,Pages: 201-212 ,Year of Publication: 2009.

Time synchronization is very critical in design of senor network; its benefits are multifold including accurate localization, beam-forming and similar signal processing tasks, These advantages also make time synchronization a target of prime interest to malicious activities. So there is a need for some secure mechanism for time synchronization, the author proposed a mechanism for secure time synchronization. The author claimed to perform security analysis of sender and receiver synchronization process; he also explained the need of secure synchronization in case of time as process can be compromised by exploiting its weaknesses, the attacker can be able to calculate the clock offsets between a pair of nodes. Author proposed a pair wise synchronization in sensor networks and he claimed that the mechanism is able to restrict the attacker even in a malicious environment. The idea of pair wise synchronization was extended to group synchronization, secure group synchronization can be useful in applications like fire monitoring, intruder detection, beam-forming, vehicle tracking etc, in addition to these it can also detect inconsistencies caused due to compromised nodes or corruptive processes or some hardware failure. The pair wise synchronization was performed using following algorithm

A($T1$)→($T2$)B: A, B, *sync*

B($T3$)→($T4$)A: B, A, $T2$, $T3$, *ack*

A calculates offset $\delta = (T2-T1)-(T4-T3)$

The author considered omni present attack which is pulse delay attack and use following algorithm to detect pulse delay attack

A(T1)→ (T2)B: A, B, NA, sync

B(T3)→ (T4)A: B, A, NA, T2, T3,ack, MACKAB[B, A, NA, T2, T3, ack]

A calculates delay d = (T2−T1)+(T4−T3)

If $d \leq d_{\Gamma}$ then $\delta = (T2-T1)-(T4-T3)$ else abort

Secure group synchronization was performed using following algorithm

$$\begin{aligned}
&G_i(T_i) \rightarrow (T_{ij})* : G_i, N_i, sync \\
&G_i(T'_i) : m = T_{ji}, N_j, G_j^{j=1,\dots,N;j\neq i} \\
&\quad : M = MAC_{K_{ij}}[G_i, T'_i, ack, T_{ji}, N_j, G_j]^{j=1,\dots,N;j\neq i} \\
&G_i(T'_i) \rightarrow (T'_{ij})* : G_i, T'_i, ack, m, M \\
&G_i : \text{compute } d_{ij} = \tfrac{1}{2}((T_{ij} - T_i) + (T'_{ji} - T'_j)) \\
&\quad if\ d_{ij} \leq d^* \text{ then } \delta_{ij} = \tfrac{1}{2}((T_{ij} - T_i) - (T'_{ji} - T'_j))\ else \text{ abort} \\
&\quad O_i = O_i \cup \delta_{ij} \\
&G_i : M = MAC_{K_{ij}}[G_i, O_i]^{j=1,\dots,N;j\neq i} \\
&G_i \rightarrow * : G_i, O_i, M \\
&G_i : \text{Run the SOM}(\lfloor (N-1)/3 \rfloor) \text{ algorithm to compute } C_{ij} \\
&G_i : \text{Compute } C^i_n = median(C_i, [C_{ji}]^{j=1,\dots,N;j\neq i})
\end{aligned}$$

Time complexity of SGS algorithm is $T(n) = O(n^{\lfloor (n-1)/3 \rfloor})$

MAC and shared key was used for authenticity and integrity, the algorithms were evaluated using time complexity and synchronization precision.

Study Goals are:

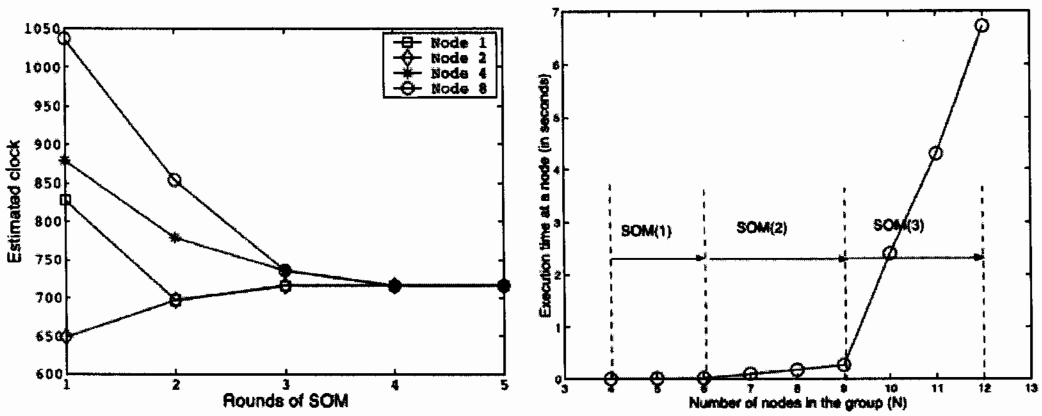
1. Reducing the number of message exchange on average and consequently the energy consumed significantly

Assumptions considered as follows:

1. Clock offset and skew errors do not take into consideration.

2. Nodes to be synchronized are with in communication range of each other.

Paper Results are shown in figure 2.3



(a) Performance of SOM in simulations. (b) Time complexity of SGS on motes.

Figure 2.3: Performance and Time complexity of SGS and SOM

Claims of P6

Study claims given below

1. Achieved secured time synchronization under pulse-delay attack,
2. Synchronization is performed with in 40 μs even under attack.
3. The algorithm can converge for maximum 1/3 nodes are compromised.

Mention Future Work in Discussed P6

4. The synchronization process can be extended by establishing multiple relationships between disjoint paths.

Chapter 3

Proposed Solution

3.0. Proposed Solution

Modified master slave architecture is being proposed in our solution, It consists of a number of sensor nodes, a base station and some arbitrary event generator, The nodes are deployed randomly but are able to locate each other Further sensor nodes and base station can locate each other. After deployment, the base station will calculate and propagate the adjacency list of each sensor node. Proposed solution is uses the *post-facto* synchronization [1], in each that sensor node consists of a pre-processor and a processor, all the sensor nodes are in sleep mode (i.e. low energy mode having processor off and pre-processor on) till the happening of some arbitrary random event. When an event is occurs, the sensor node which first receives the event information will turn its processor on, and will act as master node. The master node will be the initiator for time synchronization all other nodes, Termed as receptors. Initiator will broadcast the synchronization message to all its neighbor, the neighbors will propagate synchronization message to their neighbors and so on until the node which is closest to base station will receive synchronization information, it will also act as bridge to communicate between base station and sensor nodes. After synchronization all the nodes will start monitoring the event and the information will be sent aggregately to the base station through the bridge node.

3.1. Network Structure

Sensor nodes can be deployed in two distinct ways Fixed array antenna and distributed wireless sensor networks. In fixed array antenna the distances between the base station and all the sensors are known well in advance and are equivalent to each other, So in case of fixed array antenna the synchronization process is of very low worth, because of equal distance the phase frequency offsets can be calculated easily also the noise can be estimated easily. But it is not a real time scenario, the sensor are always deployed randomly (thrown by some airplane etc.), so the available real time sensor network termed, As distributed sensor network has distinct distances between base station and different sensor nodes.

The fixed size array and distributed sensor network are shown in Figure 3.1 (a) and 3.1 (b).

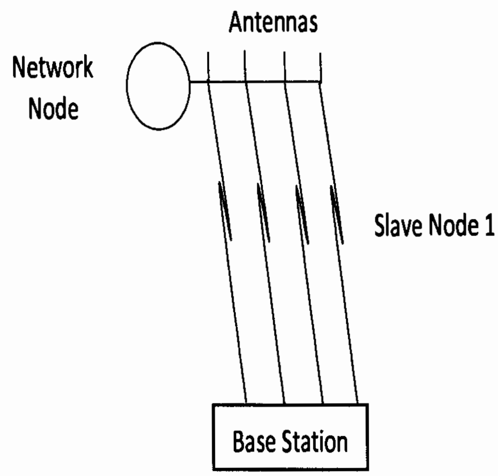


Figure 3.1 (a): Fixed Antenna Array

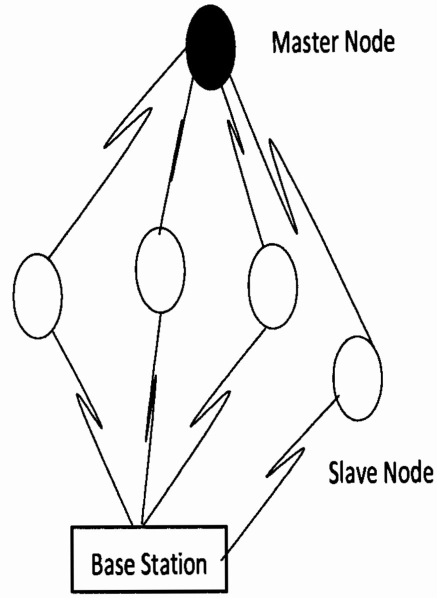


Figure 3.1 (b): Distributed Sensor Network

Figure 3.2 is our proposed distributed modified master slave architecture having an event generator a master node, the slave nodes, a base station, some communication media/ internet and an information receiver and processor.

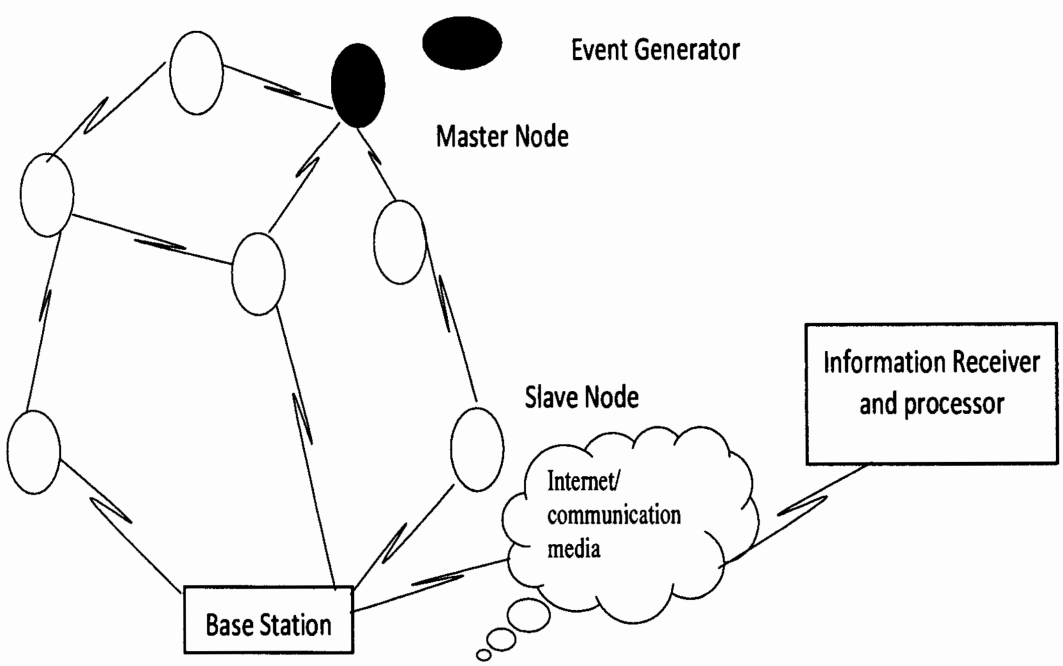


Figure 3.2 : Proposed Distributed Sensor Network

The sensor nodes can work as master or slave according to the requirements. A sensor node will become master if it receives event information directly from event generator. When event is generated the master node starts synchronizing. The slave nodes by transmitting the sync signal to the slave nodes in its forward and backward Adjacency list. On reception of event information each node's pre-processor wakes up its processor on then the event is monitored by that node and information is transmitted to all the nodes in its adjacency list for synchronization, In the same fashion all nodes are synchronized, channel coefficient are also estimated by each node and base station during synchronization to reduce error rates.

After synchronization the data is sent by master node to all adjacent slave nodes, the data received by each node is then retransmitted to all the nodes in the adjacency list of each slave node who received information by master node.

3.1.1 Goals

Main goals of proposed solutions are as follows:

1. Energy efficient monitoring of events by sensor nodes.
2. Reducing synchronization overhead
3. Adjustment of channel coefficients for errorless communication

3.1.2 Assumptions

We considered following assumptions in our proposed solution:

1. Distinct distances between sensor nodes and base station are known prior to communication.
2. Nodes and base station can adjust their Channel coefficients h_{i1}, h_{i2}, h_{i1}^H and h_{i2}^H which are zero mean and statistically identical and independent random variables.
3. Forward and backward adjacency List is premeditated by base station and is propagated to each node.
4. Phase and frequency are pre-synchronized.

3.2 Communication Model

Communication system model of the proposed solution consists of seven steps

In first step Channel coefficients $h_{i\,i\text{-}1}$ between nodes i-1 and i are estimated at node i, node i-1 adjusts its coefficients according to the estimation. In second step The channel coefficients $h_{i\,i\text{-}1}$ estimated by node i are propagated to node i-1 after receiving the channel coefficients the node i-1 adjust its coefficients In third step The channel coefficients $h_{b\,n}$ between slave node N and base station are estimated by base station. In fourth step The channel coefficients $h_{b\,n}$ estimated by base station are propagated to slave node N and slave node N updates its channel coefficients $h_{b\,n}$.

In fifth step the data in amplitude modulated form is sent by master node to all its adjacent nodes, the slave nodes send the data to their adjacent nodes and so on until the N^{th} slave node receive the data. In Sixth step the received modulated data by N^{th} slave node is transmitted to base station,

Base station is connected to some information receiver and processor through internet, Just after receiving the information, The base station sends the information to information receiver and processor for processing/ interpretation of received data (step seven).

The transmitted signal by master node to its adjacent slave nodes is given by following equation

$$\Phi(t) = [A + s(t)]\cos(2\pi f_0 t) \qquad (1)$$

Where f_0 is the carrier frequency and s(t) is the known sequence. Slave node demodulates the data received from master node and estimates the channel coefficients $h_{i\,i\text{-}1}$.

The signal is further transmitted by all the slave nodes who received (1) by master node to their adjacent nodes so all the channel coefficient between nodes and between last node and base station are estimated in the same fashion. As shown in figure 3.3

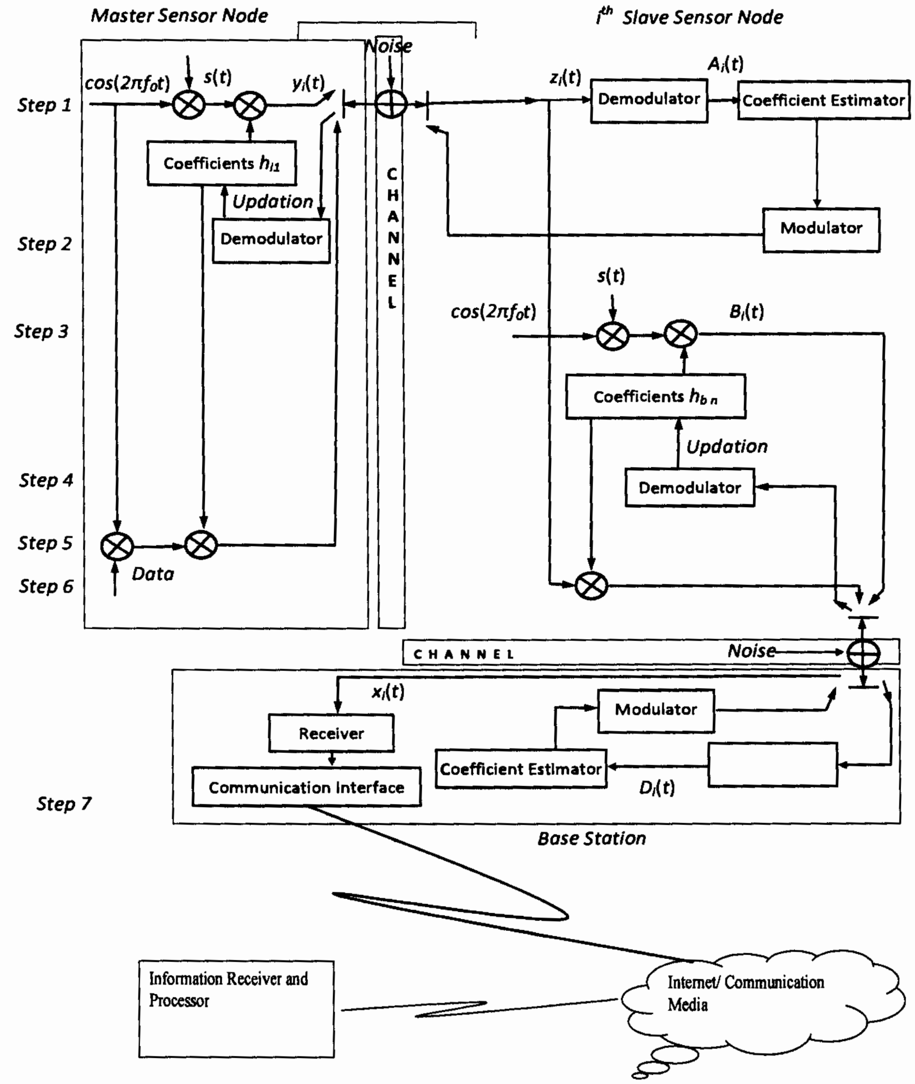


Figure 3.3: Communication systems Model

3.3. Block Diagram Sender and Receiver

Sender and receiver block diagrams are shown below

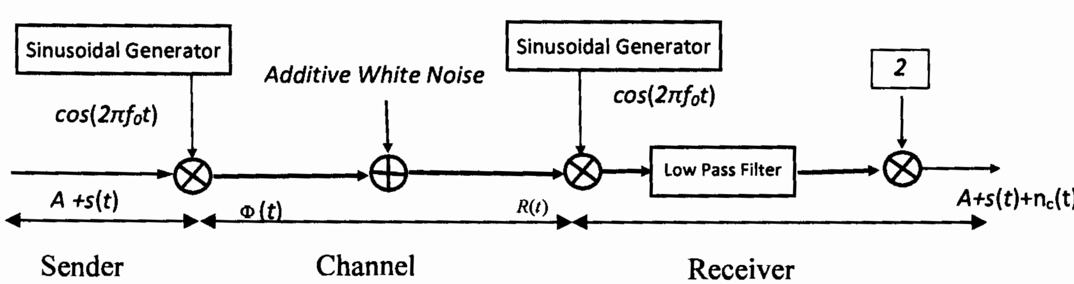


Figure 3.4: Block Diagrams for receiver channel and sender

3.4. Mathematical Model

Master node will transfer the event data s(t) and a dc component A to all its neighboring slave nodes, The neighboring slave nodes will forward the information to their neighboring nodes and so on until the nodes whose neighboring list contains the base station, now the last slave node near to base station will transfer information to base station. The information received R(t) by base station will contain s(t)+A along with additive white noise.

$$R(t) = [A + s(t)]\cos(2\pi f_0 t) + n(t) \tag{2}$$

Power Spectral density of additive white noise in the received signal is given in (3)

$$n(t) = n_c(t)\cos(2\pi f_0 t) + n_s(t)\sin(2\pi f_0 t) \tag{3}$$

$$R(t) = [A + s(t) + n_c(t)]\cos(2\pi f_0 t) + n_s(t)\sin(2\pi f_0 t) \tag{4}$$

The receiver will multiply R(t) with sinusoidal of frequency f_0, The resultant signal will be

$$Z(t) = [A + s(t) + n_c(t)]\cos^2(2\pi f_0 t) + n_s(t)\sin(2\pi f_0 t)\cos(2\pi f_0 t) \tag{5}$$

Using trigonometric rules

$$Z(t) = [A + s(t) + n_c(t)]\cos(4\pi f_0 t) + n_s(t)\sin(2\pi f_0 t)\cos(2\pi f_0 t) + [A + s(t) + n_c t] \tag{6}$$

After passing through low pass filter and multiplying (6) with 2 we will get the original signal

$$B(t)=A + s(t) + n_c(t) \tag{7}$$

For small noise power we have

$[A + s(t)] >> n_c(t)$

The signal to noise ratio

$$\frac{S_0}{N_0} = \frac{\overline{S^2}}{A^2 + \overline{S^2}}\gamma \tag{8}$$

If noise power is small the signal to noise ratio will high and the envelop detector can easily detect the signal and bit error rate will also be decreased.

3.5 Synchronization process

Time synchronization will start after happening of some event, Breadth First Search method will be used for time synchronization, where the neighbours of the initiator node are synchronized first, then the neighbours of the neighbours are synchronized and so on till the remotest neighbour is synchronized. The algorithm works as follows

BFS(G,s)

```
for each node u ∈ V[G]-{s}
        do state[u] ← READY
state[s] ← WAIT
S ← φ
ENQUEUE(S,s)
While S ≠ φ
        do u ← DEQUEUE(S)
                for each v ∈ Adj[u]
                        do if state[v] ← READY
                                then state[v] ← WAIT
                                        ENQUEUE(S,v)
state[u] ← PROCESSED
```

The BFS algorithm is used for creating a spanning tree which will be used as forward and backward adjacency list for time synchronization, An event is generated near node ***A*** , it will act as master node and will start propagating the event information to all nodes using time synchronization, The time synchronization will be performed in a sequence ***A C B D E F G H I J K L M*** It is a spanning tree and does not contain any cycles.

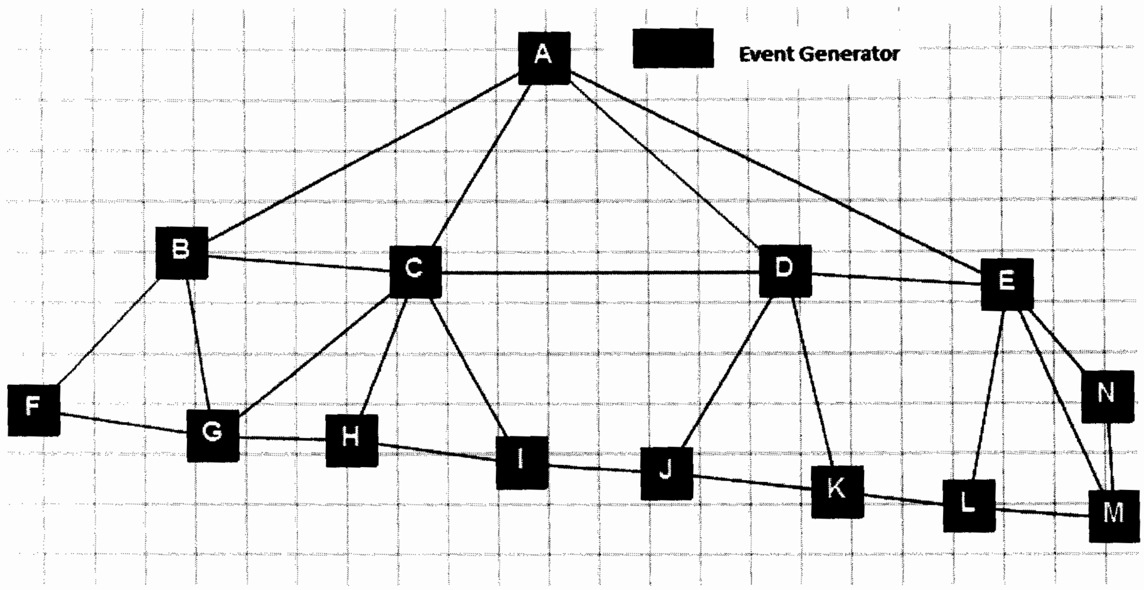


Figure: 3.5 A sample graph of sensor nodes

BFS spanning tree for the example given above is shown below

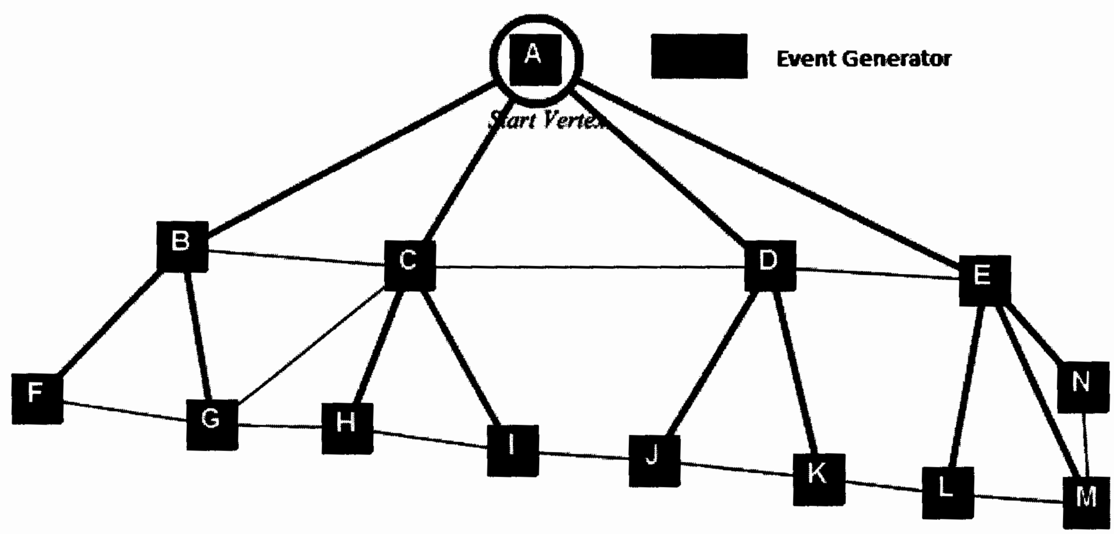


Figure 3.6: BFS spanning tree for master node *A*

The worst running time for BFS Time synchronization is

$$T_{BFS} = O(|V| + |E|)$$

Here V is number of sensor nodes and E is V × V, as all nodes are having edges with each other so, In our case the worst running time for BFS is

$$T_{BFS} = O(|V^2|)$$

In our proposed architecture each node contains a processor in addition to a pre-processor the idea is based on the fact that 90 % of time there is no need for time synchronization.
The pre-processor remain ON while the processor will remain OFF (i.e. sleep mode) until a significant power event has been generated. After event generation the pre-processor of initiator will switch its processor ON.

Two matrices a forward incidence matrix and backward incidence matrix will be calculated by each node just after their deployment. The purpose of adjacency matrix is to find their adjacent nodes toward and opposite to the base station. When a node receives information from some other node first of all the node will check the residence of sending node in both adjacency matrix. If send by nodes reside in forward adjacency matrix. The receiving node will act as initiator and send the event information to all the nodes in backward adjacency matrix (which are present in backward adjacency matrix) and vice versa. Furthermore all the receiving nodes which received information from current node will transmit this information to all the nodes in their backward adjacency matrix. Similarly the whole network will be synchronized and will receive information.

Chapter 4

Simulation and Analysis

4.0. Simulation and Analysis

Wireless sensor networks got importance in the current era due to minimal resources utilization; sensors are deployed in remote areas to monitor activities like enemy movement in the battlefields, identifying the targeted objects, weather forecasting etc. Transmission of data from remote sensor to the base station or to other sensor is critical due to the limited sensor power. Sensors are deployed once and cannot be renovated like replacing batteries and others components. Power is a critical factor of the sensor networks. Sensor should be able to respond till the project or monitoring of the whether or other deployed mission is not completed. Communication between these sensor networks utilizes as low energy as longer the life of the sensor. To prolong the life of the sensor we should reduce the energy consumption as for as possible.

Extensive communication between the sensors is the other factor that consumes the energy, To save the energy we have to reduce the number of messages between the sensor nodes.

We have devised a mechanism that helps us to reduce the number of message passing between the sensor network nodes, Minimizing of message passing helps us to prolong the life of the sensor nodes.

If we have reduces the hops in the sensor networks nodes, we can optimize the message passing. We have adopted the Breadth First Search (BFS) algorithm to analyze the graph of nodes and compute the minimal distance between all the nodes. BFS can be used to calculate the spanning tree of directed and undirected graph. Wireless sensor network are undirected graph, we have used BSF to compute the spanning tree of WSN. Each node is sensing the event that can happen in that access point and when a sensor senses some task, activity or transmission of data, it will pass that information to the minimum number of sensors nodes calculated by spanning tree and that node pass the same information to the next node and so on. The information reached the base station.

We have simulated the above mechanism to conclude that BFS helps to reduce the message passing. We have seven sensors and one base station. Base station is represented in the Black colour and event occurring near a sensor is represented in the red color. Spanning tree of the sensor node is already calculated, event occurred near sensor A. B, C, D, E, F, G, H and I are the neighbors of the node A and similar to the other nodes.

4.1. Simulation Model

Event occurs near the sensor A in the network.

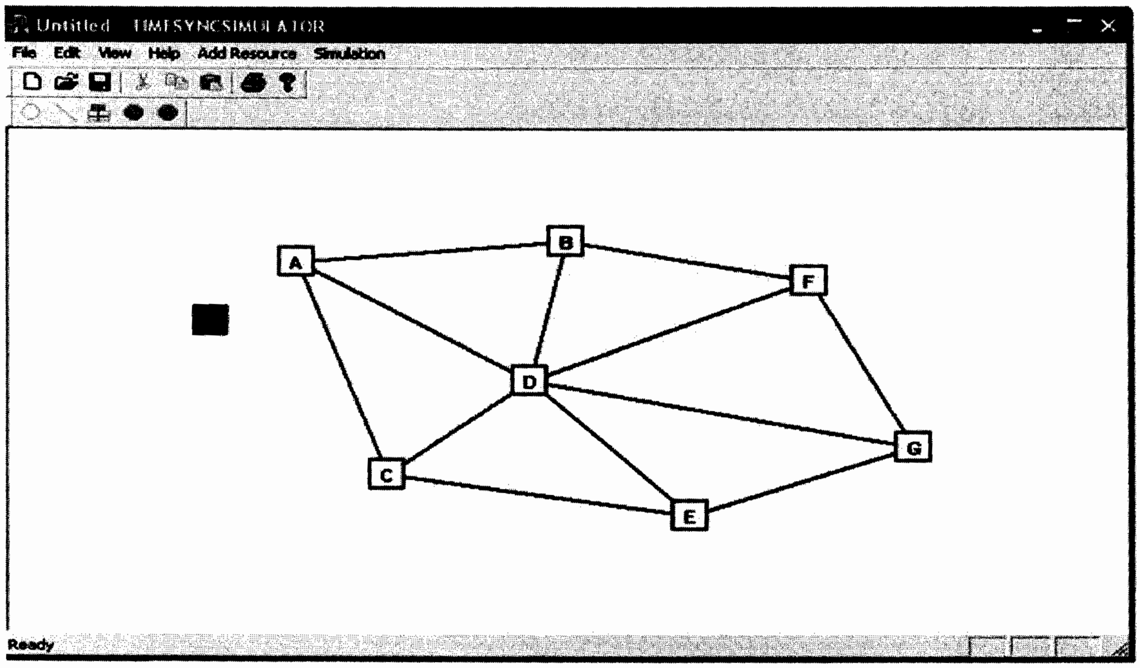


Figure 4.1: Event generator

The node nearest to the event will sense the event and act as a master node of this event and pass the message to the next node. In above example A is the master node.

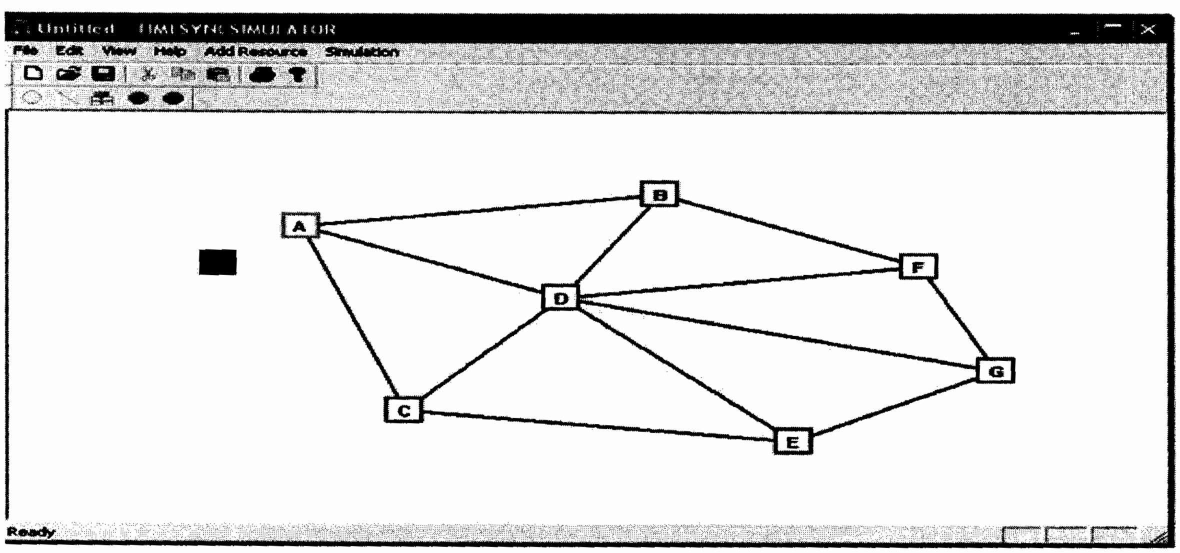


Figure 4.2: Master Node A

Node that has sense the event and is acting as a master node will send a sync message to all the neighboring nodes of it. In this case A will send message in the following patterns i.e.

A → B   A → C   A → D

A, B, C and D are now synchronized.

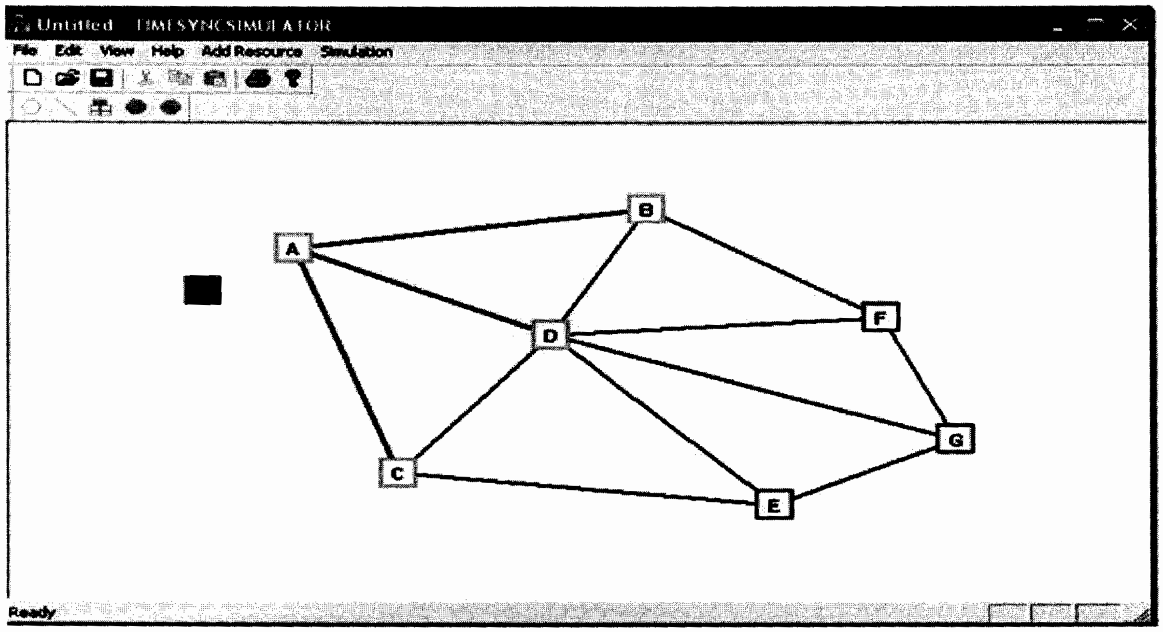


Figure 4.3: A sends sync messages to all its neighbors B, D and C.

When A completes the message sending to all neighboring nodes, any of the neighbor's node of A will send the sync message to its neighboring nodes. In this above case D will send message to F, G and E. In this process D will not sent any message to the nodes that have already received the message like B, C, D. Message sending pattern of the node D will be

D → F   D → G   D → E

F, G and E are now synchronized.

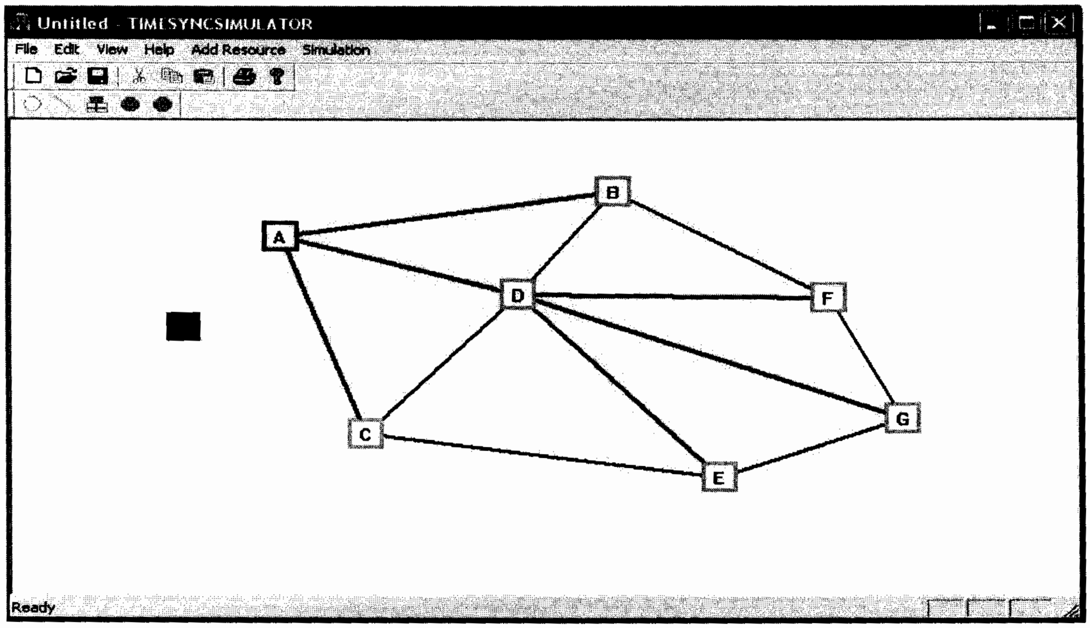


Figure 4.4: D sends sync messages to all its neighbors F, G and E

Synchronization of nodes A, B, C, D, E, F and G have bee accomplished

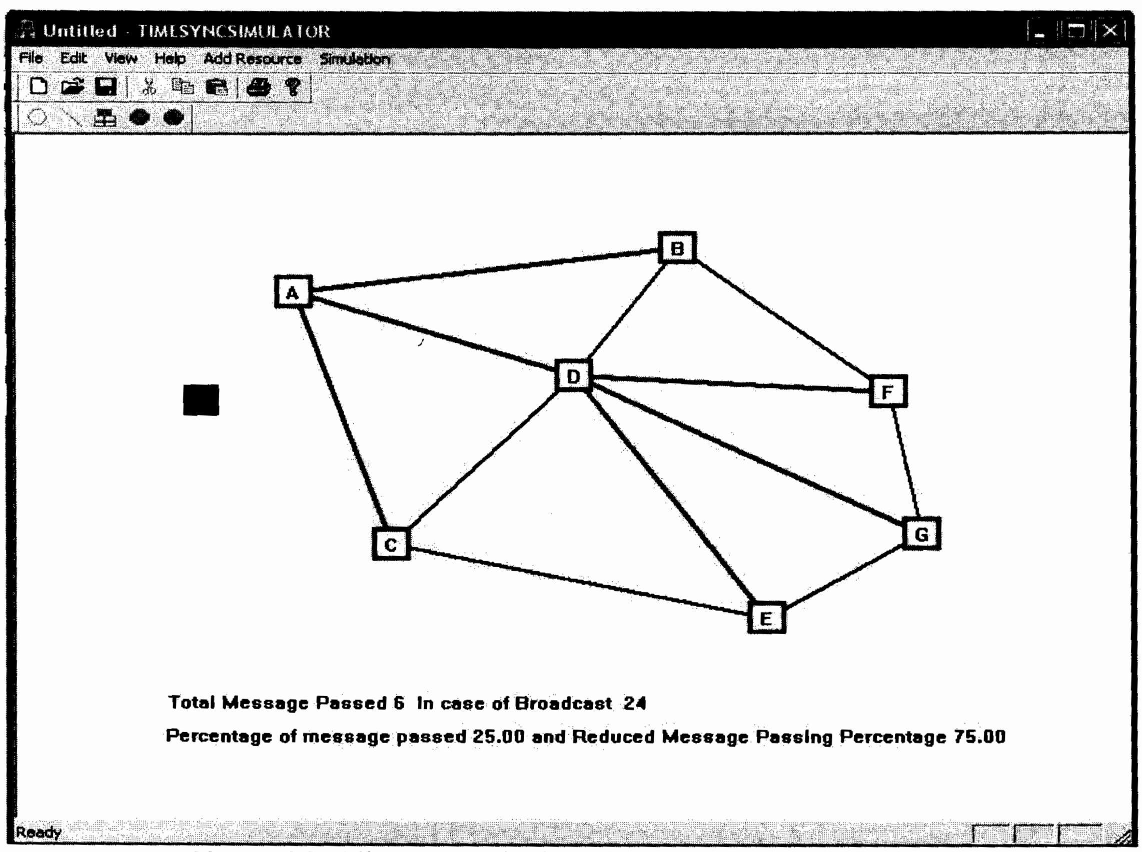


Figure 4.5: All sensor nodes have been synchronized

In our simulated scenario, 24 messages have to be sent if we broadcast message to synchronize the nodes in WSN. We have sent 6 messages to synchronize all the nodes using BFS spanning tree. We have reduced the no of the message passing from 24 to 6. No of messages saved in this communication is 18 that is equal to the 75 % reduction and only one fourth effort is used to achieve the desired results. We have summarized these results in the below table.

Scenario	Messages Passed	Message Passing Rate
In Normal Case (Broadcast)	24	100%
In Our Case (BFS)	6	25%

Table 4.1

Messages passing reduced up to 75%.

4.2. Ring Network

Event occurs near the sensor A in the network.

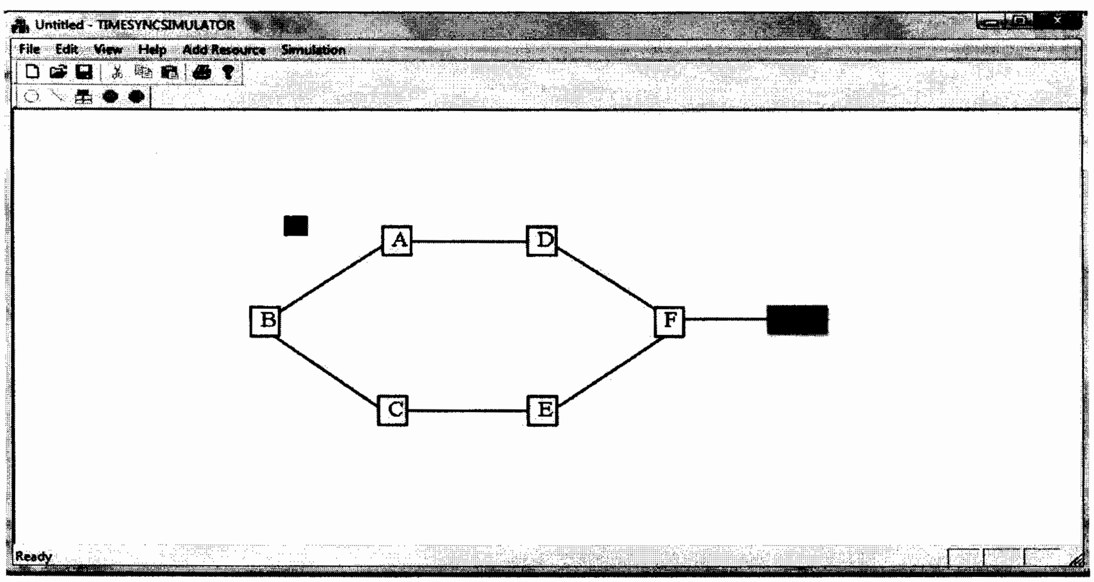


Figure 4.6: Event generator

The node nearest to the event will sense the event and act as a master node of this event and pass the message to the next node. In above example A is the master node.

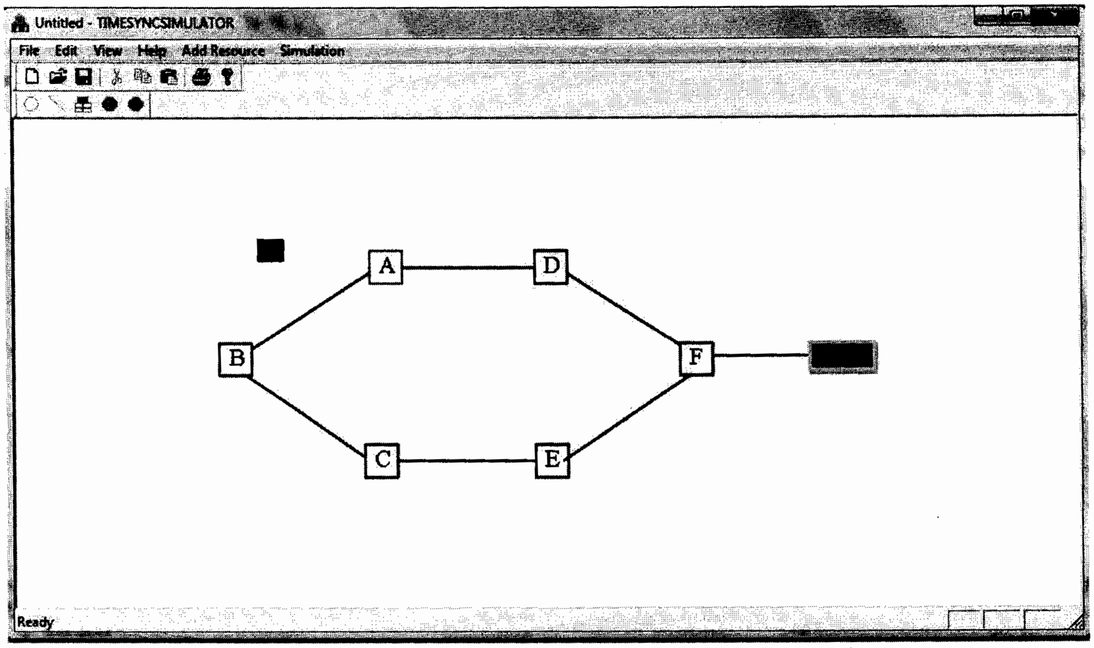


Figure 4.7: A Node designated as master node.

Node that has sensed the event acts as a master node, will send a sync message to all the neighboring nodes of it. Like A will send message in the following patterns i.e.

A → B A → D

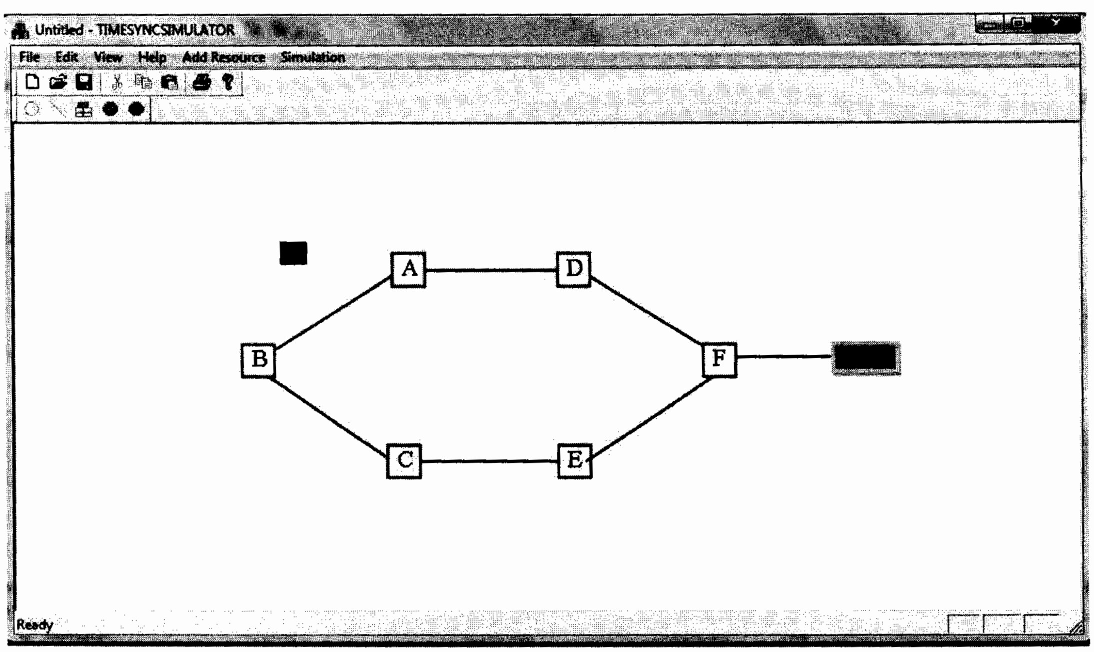


Figure 4.8: A sends sync messages to all its neighbors B, D.

When A will complete the message sending to all neighboring nodes, any of the neighbor node of A will send the sync message to its neighboring nodes. In this case A will send message to B and D. In this process D will not send any message to the nodes that have already received the message like A. Message sending pattern of the node D will be

A → B and A → D

A, B and D are now synchronized.

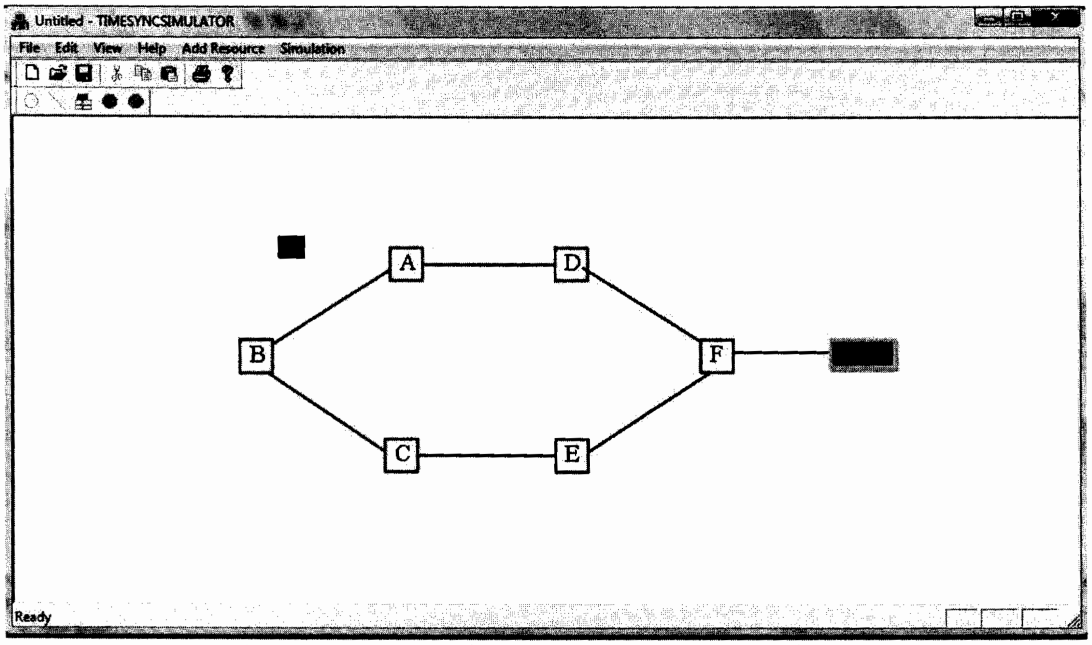


Figure 4.9: B sends sync messages to its neighbors C.

In this case D will not send any synchronization message to its neighbour because B has already sent a synchronization request to C.

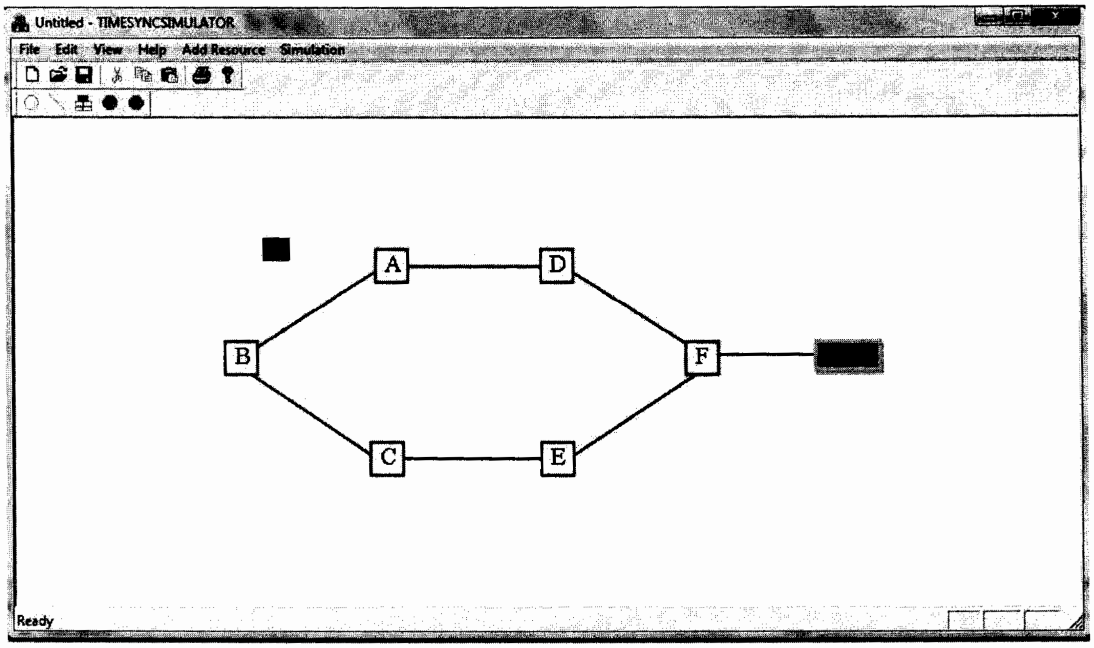


Figure 4.10: D sends sync messages to F.

When B will complete the message sending to its neighboring node, D will send message to F. In this process C will not send any message to the nodes that have already received the message nearly E. Message sending pattern of the node D will be

C →E

A,B ,D ,C and F are now synchronized.

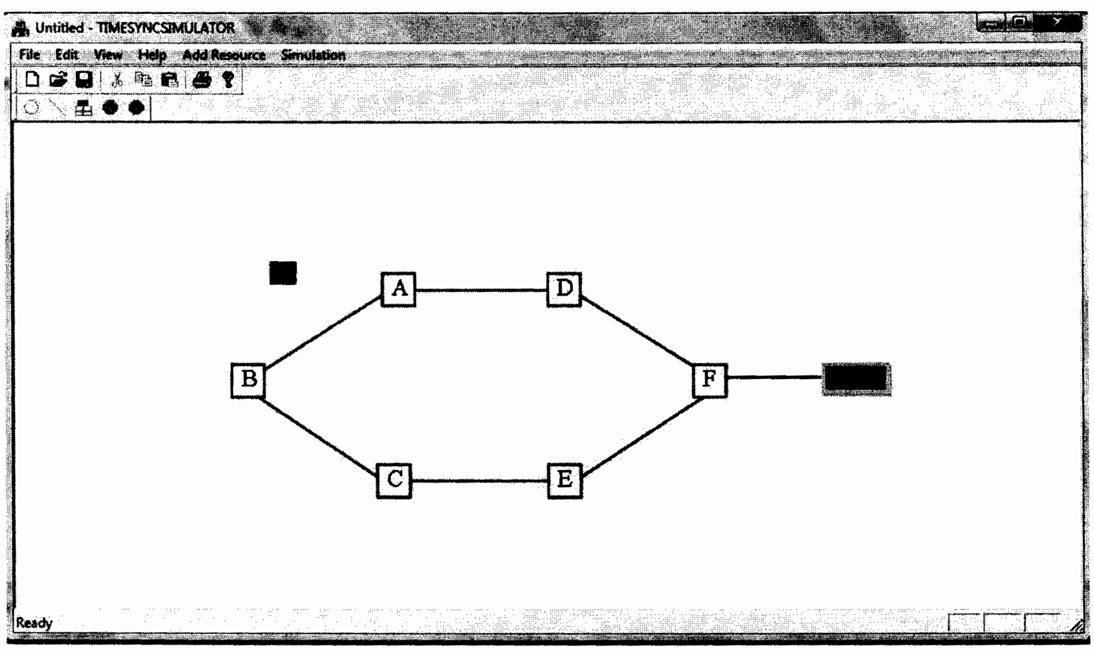


Figure 4.11: C sends sync messages to E.

Now C will send a message to D node and C and D synchronized.

Now A, B, D, C and F are synchronized.

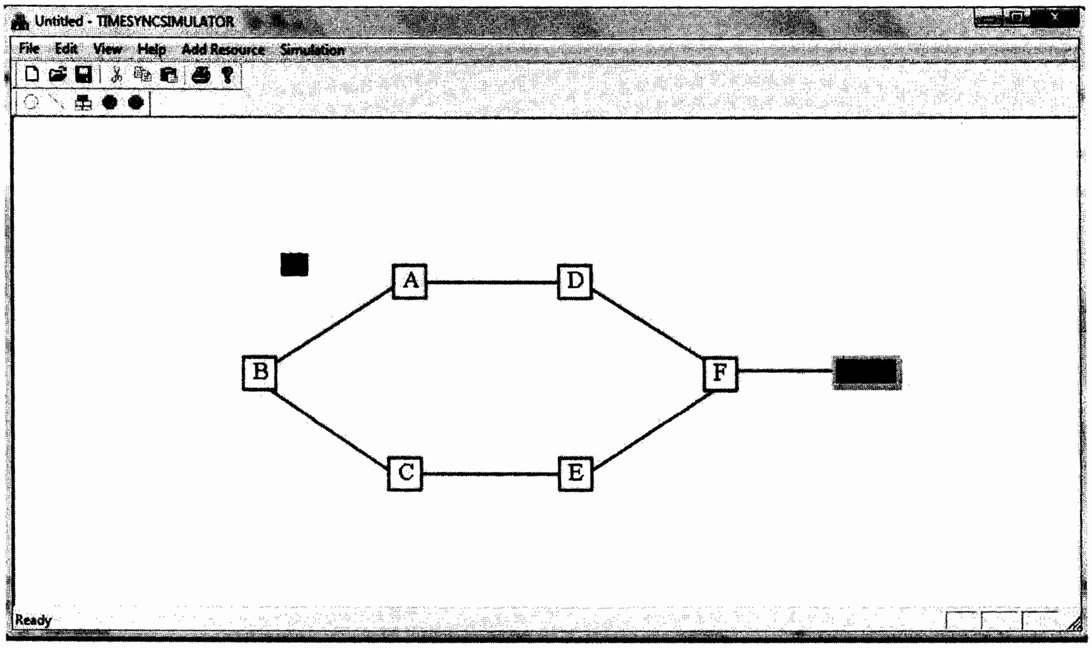


Figure 4.12: F sends sync messages to Based station.

Total message passed 6 in case of Broadcast 13.

Finally F sends message to the based station.
Now are the nodes are synchronized with each other as well as with based station.
A,B,D,C,F and E will be synchronized .

In our simulated scenario, 13 messages have to be sent if we broadcast message to synchronize the nodes in WSN. We have sent 6 messages to synchronize all the nodes using BFS spanning tree. We have reduced the number of the message passing from 13 to 6. No of message saved in this communication is 7 that is equal to the 54 % reduction, Only one fourth effort is used to achieve the desired results. We have summarized these results in the table below.

Scenario	Messages Passed	Rate of Message Passing
In Normal Case(Broad Cast)	13	100%
In Our Case (BFS)	6	46%

Table 4.2

Messages passing reduced up to 54%.

4.3. Mesh Network

Event occurs near the sensor A in the network.

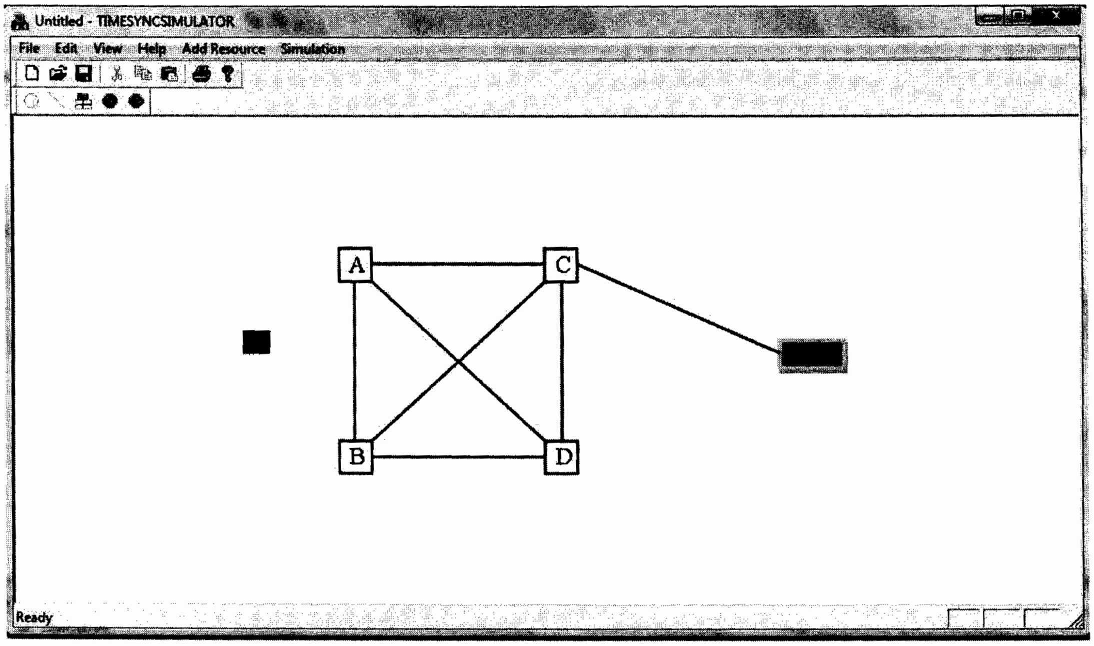


Figure 4.13: Event generator

Now node a designated as Master node.

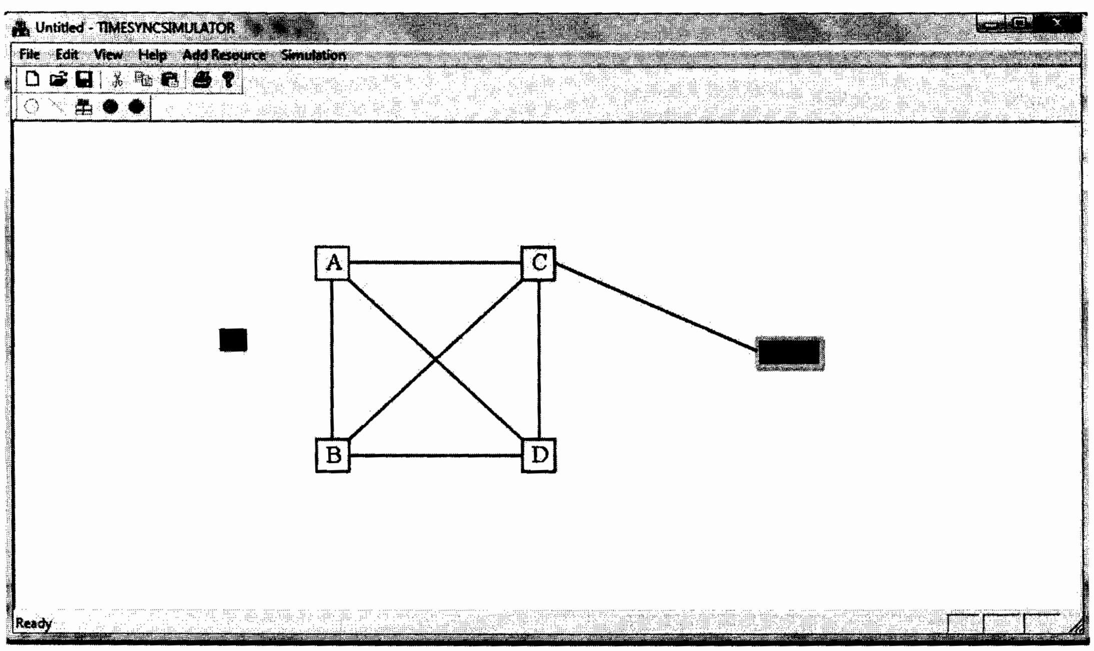


Figure 4.14: A Node designated as master node.

A will send the messages to its neighboring node B,C and D.

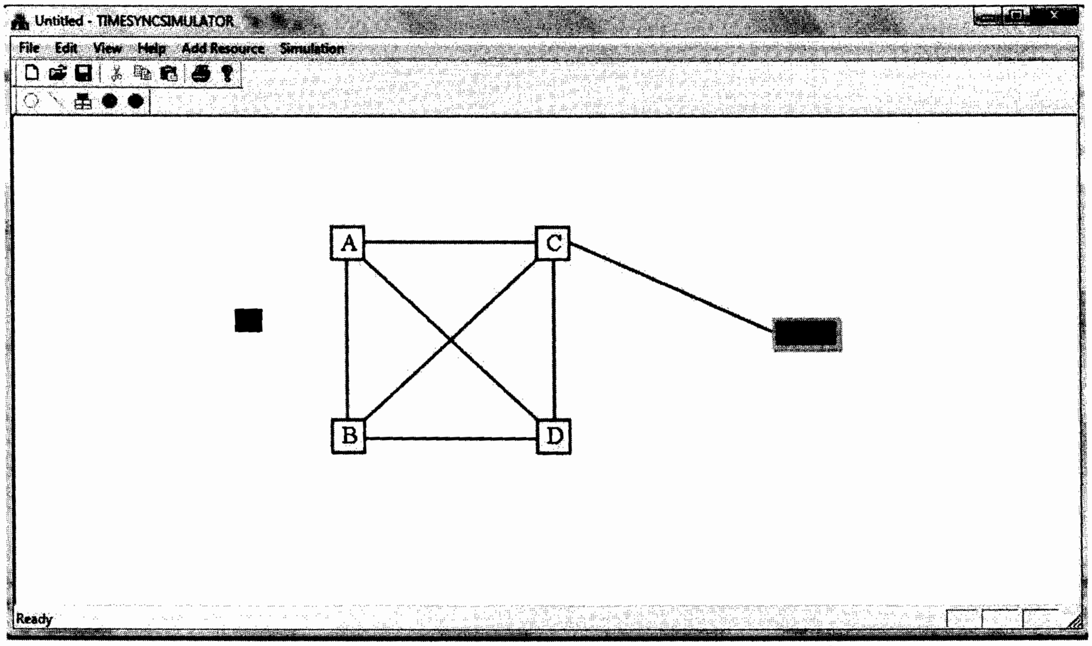


Figure 4.15: A sends sync messages to all its neighbors B

Now A is synchronized with node B and B will not send a message to other nodes, because A already has sent the message for synchronization to C and D.

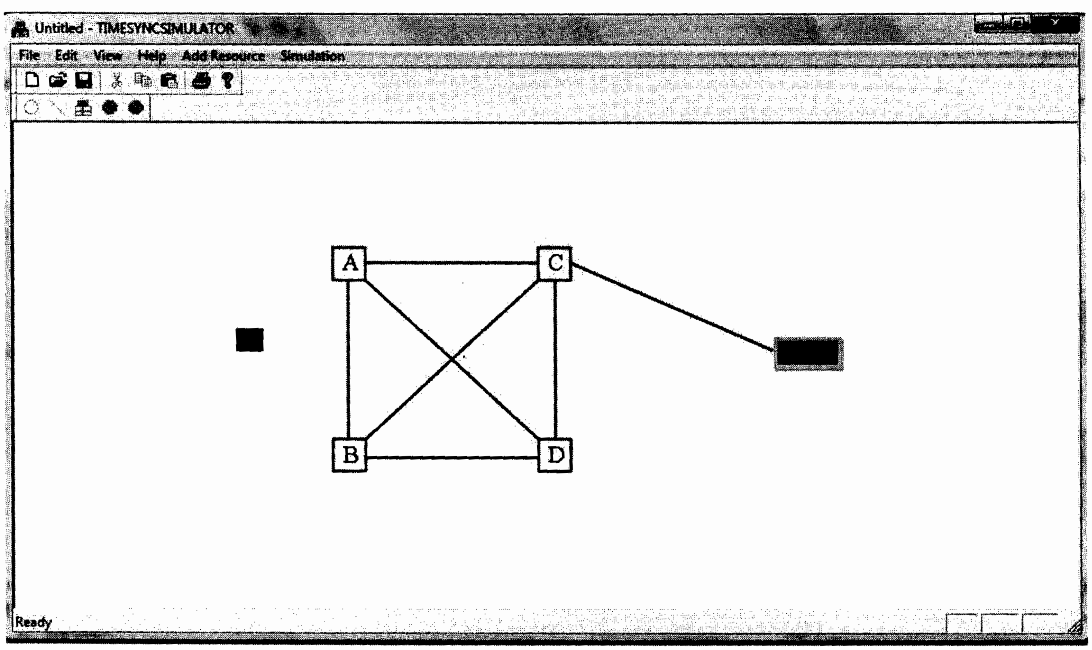


Figure 4.16: A sends sync messages to its neighbors C

Now C will be synchronization with the A.

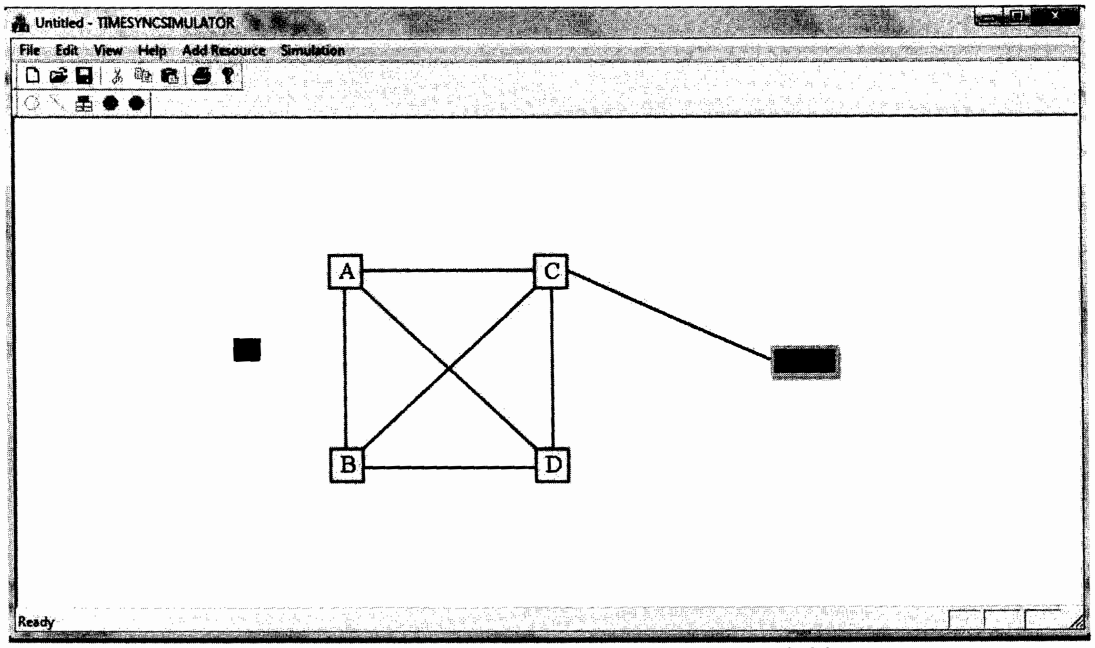


Figure 4.17: A sends sync messages to its neighbors D

Now D synchronized with the A

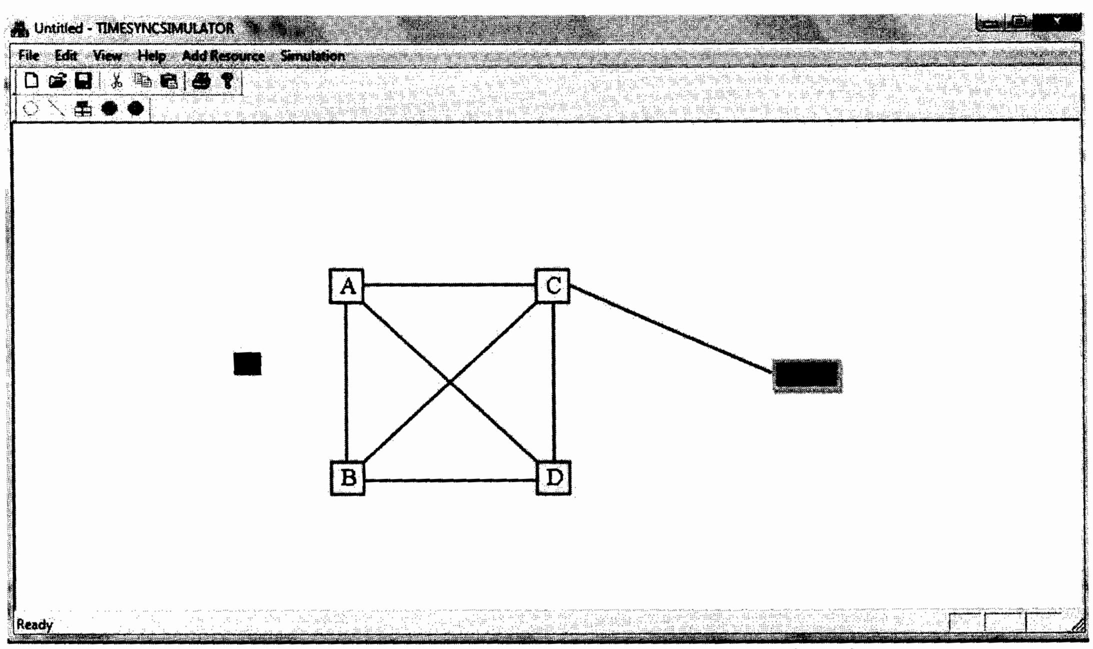


Figure 4.18: C sends sync messages to Based station.

Total message passed 4 in case of Broadcast 13.

In our simulated scenario, 13 messages have to be sent if we broadcast message to synchronize the nodes in WSN. We have sent 4 messages to synchronize all the nodes using BFS spanning tree. We have reduced the no of the message passing from 13 to 4. No of message saved in this communication is 9 that is equal to the 70 % reduction and only one fourth effort is used to achieve the desired results. We have summarize these results in the below table.

Scenario	Messages Passed	Rate of Message Passing
In Normal Case	13	100%
In Our Case	4	30%

Table 4.3

Messages passing reduced up to 70%.

4.4. Sparse Network

Event occurs near the sensor A in the network.

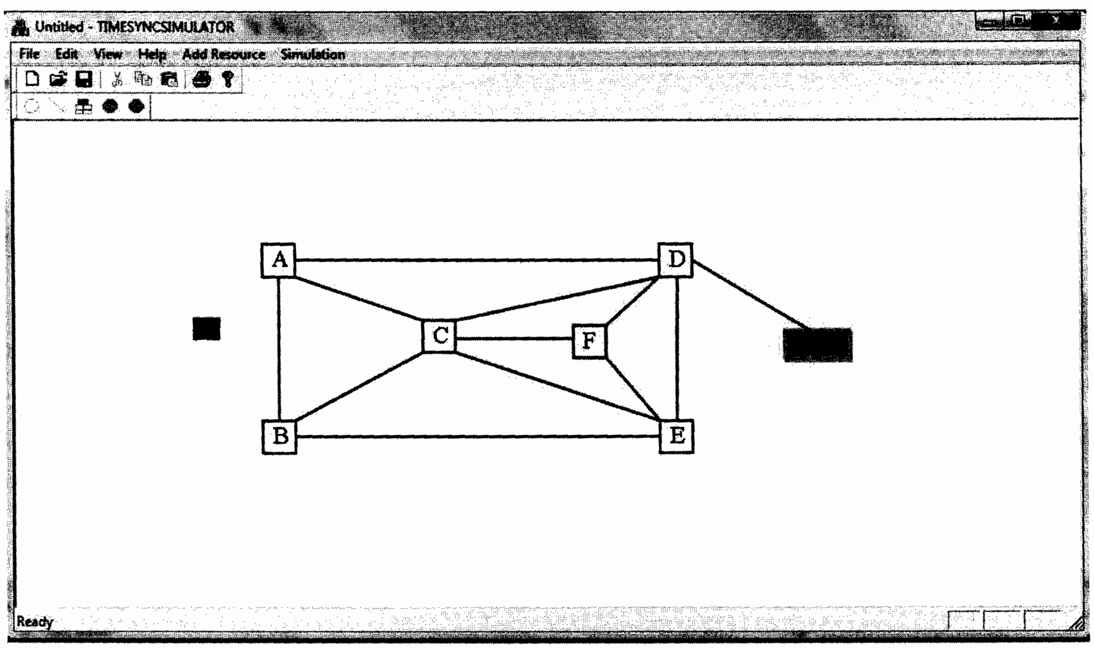


Figure 4.19: An event generated in a sparse network.

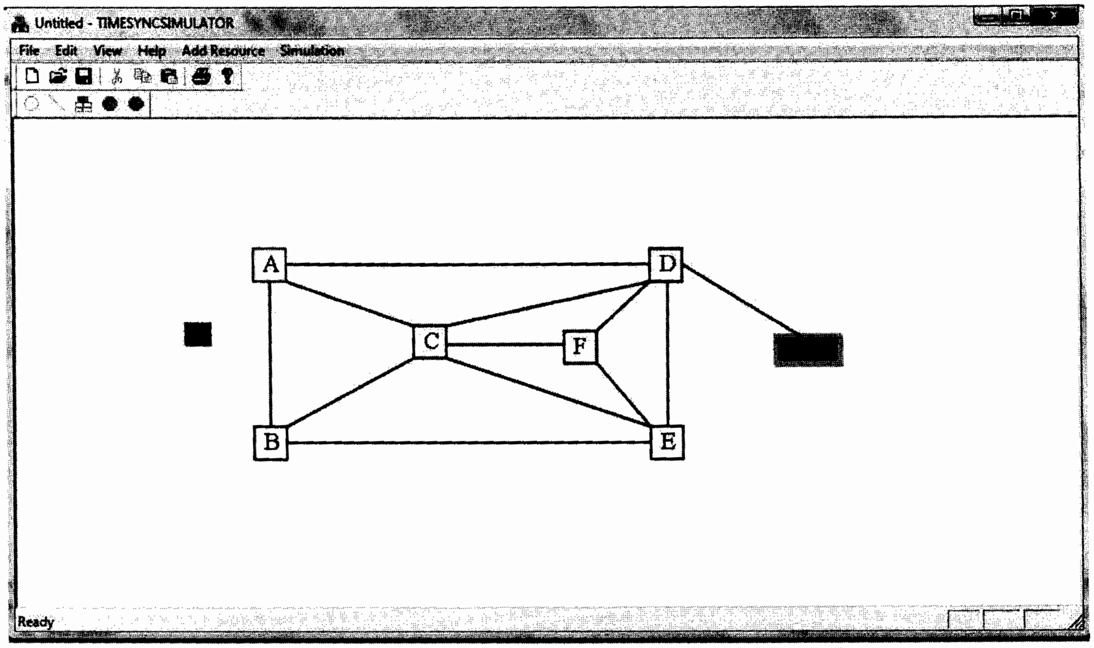


Figure 4.20: A Node designated as master node.

The node nearest to the event will sense the event and act as a master node of this event and pass the message to the next node. In above example A is the master node.

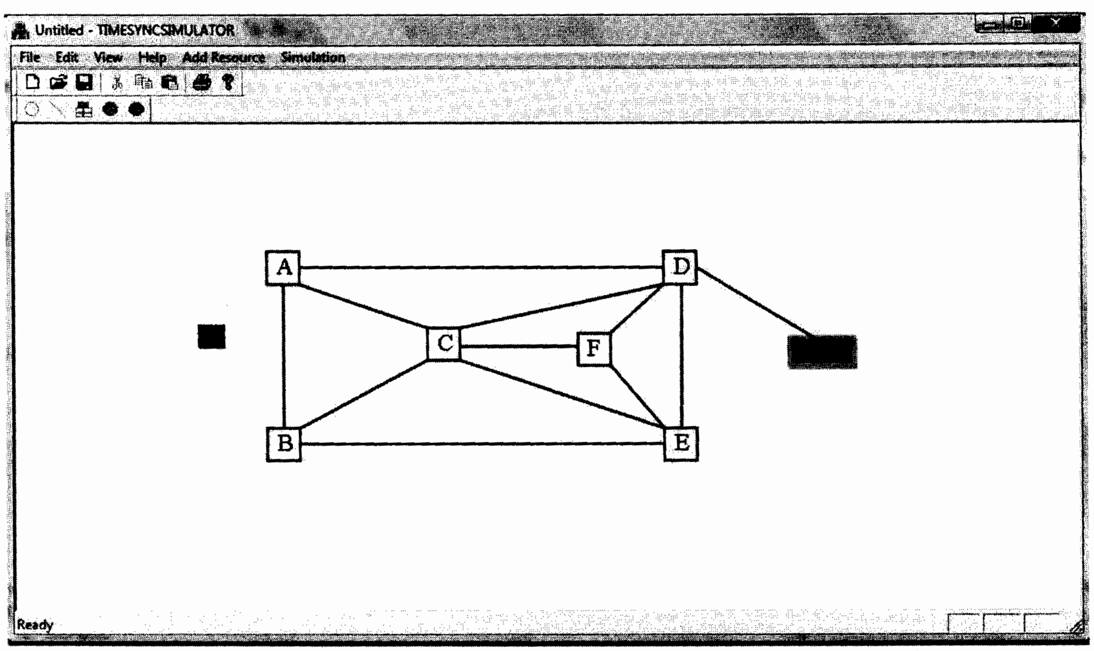


Figure 4.21: A Node sends message to the B as master node.

Node that has sensed the event and is acting as a master node will send a sync message to all the neighboring nodes of it. A will send message to the node B.

A → B

A and B are now synchronized.

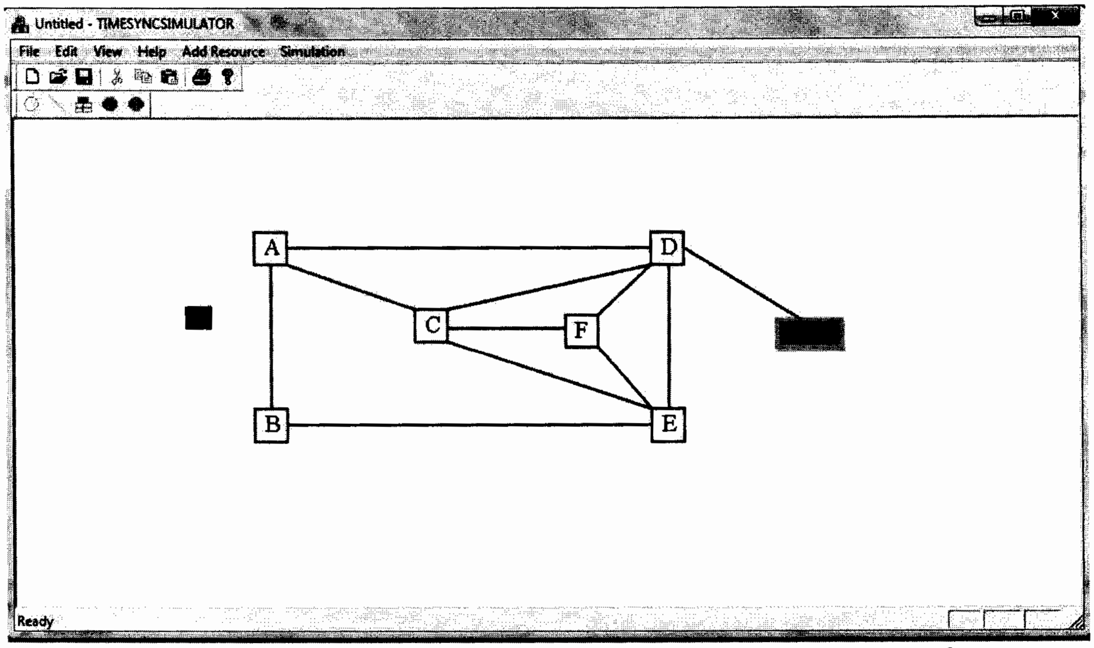


Figure 4.22: A also sends a sync message to the C as master node.

After completion of first transition node A will send message to its other neighbor C.

A → C

A, B and C are now synchronized.

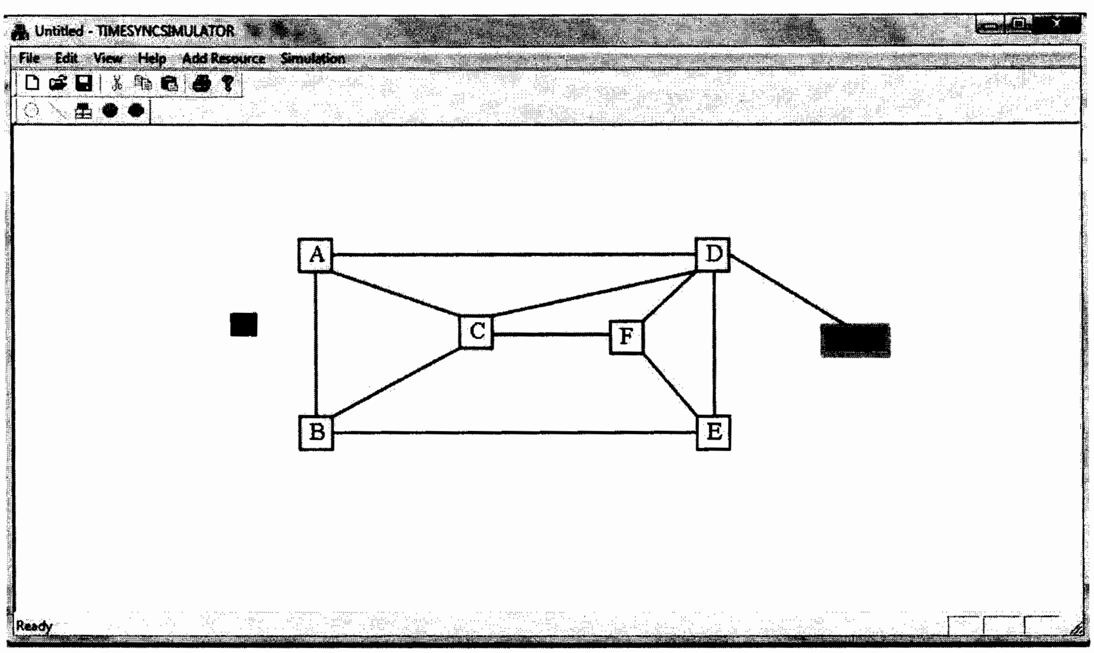


Figure 4.23: Now A sends a sync message to the D as master node.

After completion of second transition node A will send message to its other neighbor D in similar manner.

A → D

A, B , C and D are now synchronized.

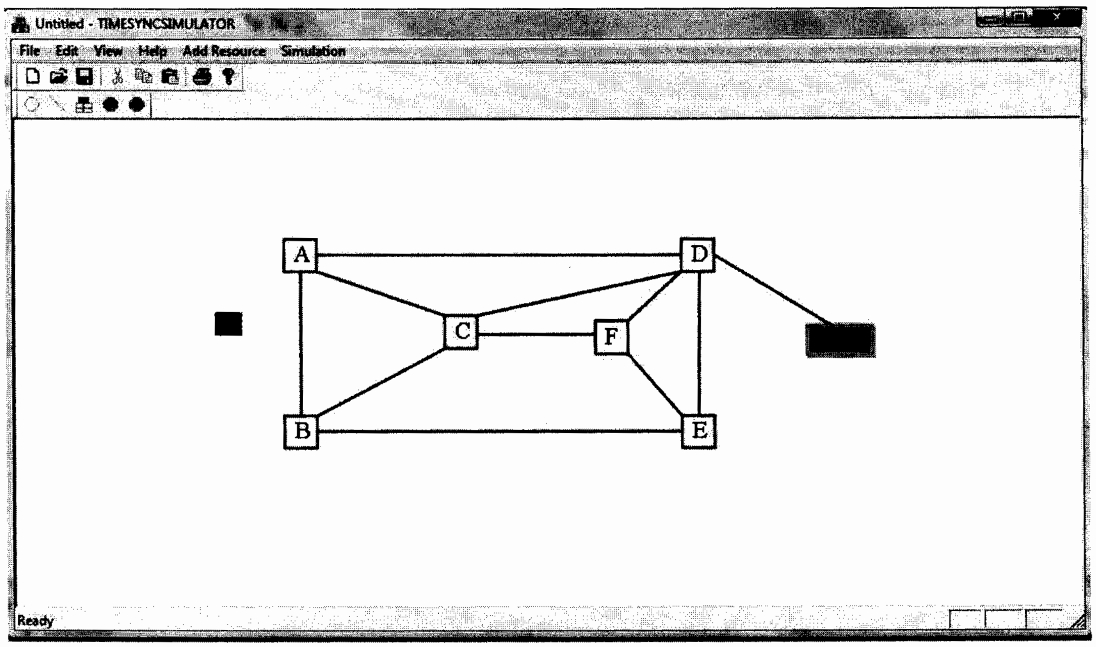


Figure 4.24: B sends a sync message to the E.

When A will complete the message sending to all neighboring nodes, any of the neighbor nodes of A will send the sync message to its neighboring nodes. In this case B will send message to E. In this process B will not send any message to the nodes that have already received the message like A, C. Message sending pattern of the node B will be

B → E

A, B and D are now synchronized.

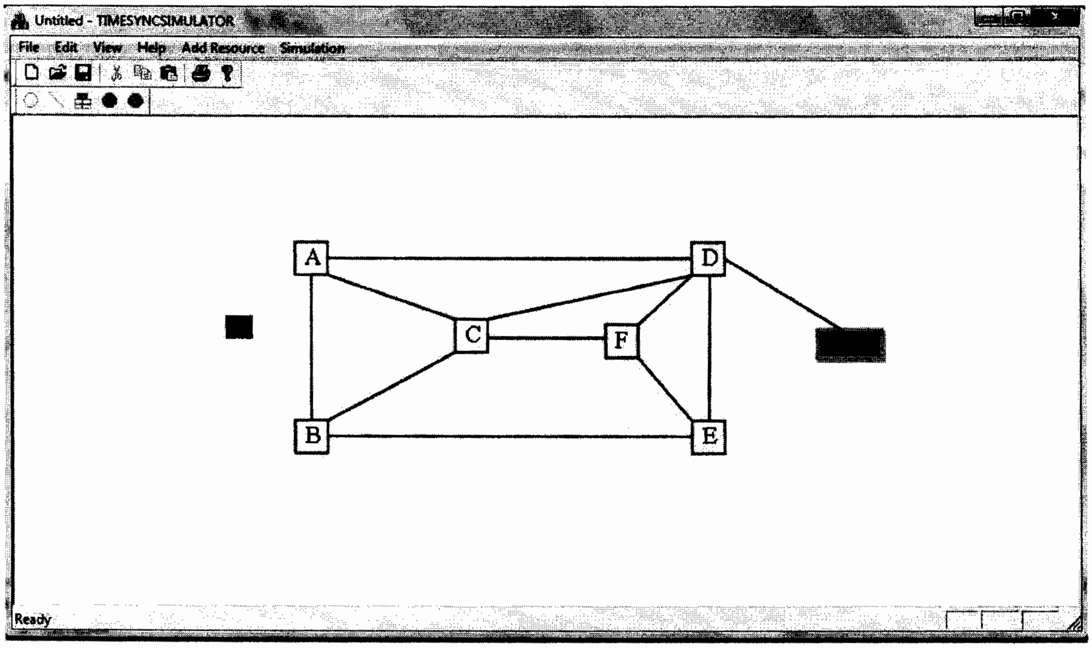


Figure 4.25: C sends a sync message to the F.

When B will complete the message sending to all neighboring nodes, now any of the neighbor node of neighboring B has been synchronized. In this above case C will send message to F. In this process E will not send any message to his neighboring nodes that have already received the message like F, D. Message sending pattern of the node B will be

C → F

C and F are now synchronized.

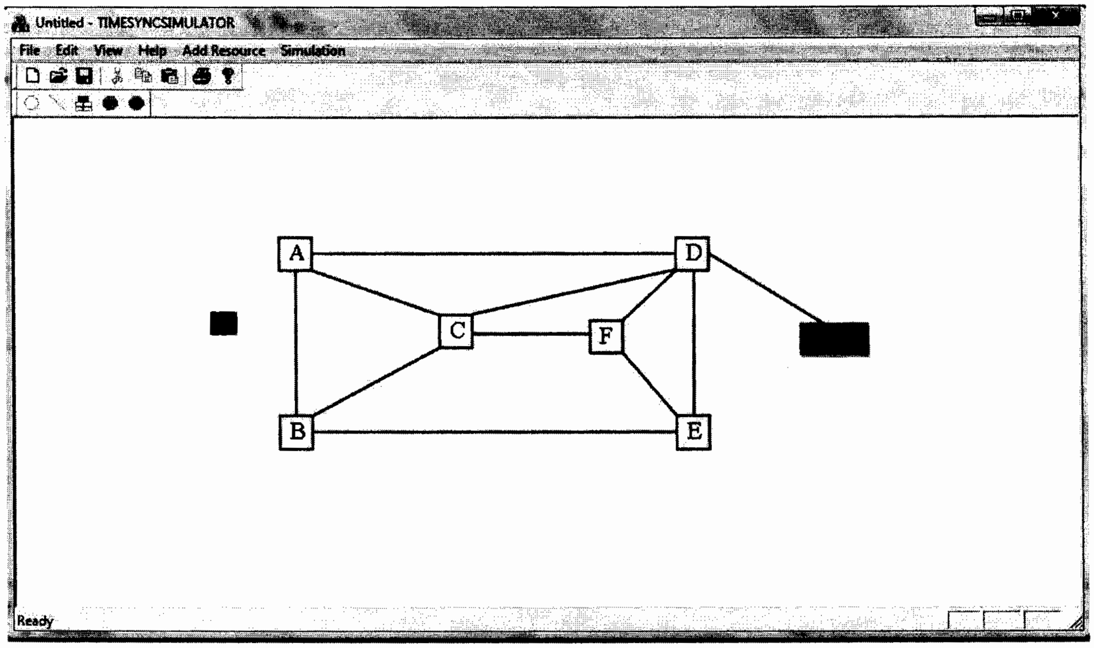


Figure 4.26: D sends a sync message to the Base station.

Total message passed 6 in case of Broadcast 23.

Synchronization of nodes A, B, C, D, E and F have been accomplished

In our simulated scenario, 23 messages have to be sent if we broadcast message to synchronize the nodes in WSN. We have sent 6 messages to synchronize all the nodes using BFS spanning tree. We have reduced the no of the message passing from 23 to 6. No of message saved in this communication is 17 that is equal to the 74 % reduction and only one fourth effort is used to achieve the desired results. We have summarized these results in the below table.

Scenario	Messages Passed	Rate of Message Passing
In Normal Case	23	100%
In Our Case	6	26%

Table 4.4

Messages passing reduced up to 74%.

4.5. Simulation Environment & Results

Simulation was performed on WeC 99 "Smart Rock" Berkely mote of type AT mega163, because of its low power consumption, sharp wake up time, small size, long life and low cost.

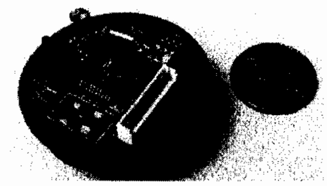


Figure 4.5 WeC 99 "Smart Rock" Berkely mote

Table below describes different characteristics of WeC 99 "Smart Rock" Berkely mote

Sr #	**Type**	**AT mega163**
1	Program Memory (KB)	16
2	RAM (KB)	1
3	Active Power (mW)	15
4	Sleep Power (μW)	45
5	Wakeup Timer (μW)	36
6	Radio Communication Channel	TR1000 (916.30~916.70 MHz)
7	Data Rate ($kbps$)	10
8	Modulation type	On-Off Keying
9	Receive Power (mW)	9
10	Transmit Power (mW)	36
11	Power Consumption Minimum Operation	2.7
12	Power Consumption Total Active power (mW)	24
13	Communication	IEEE 1284 & RS232

Table 4.5: Characteristics table WeC 99 "Smart Rock" Berkely mote

Depending on the application type the motes can be configured to synchronize in different ways as described follows.

4.5.1. Periodic

The most common method is periodic synchronization, which is performed for applications like habitat monitoring, weather forecasting, periodic data collection (temporal resolution), network maintenance etc. Figure 4.7 shows typical periodic synchronization process of wireless sensor networks using normalized power and time

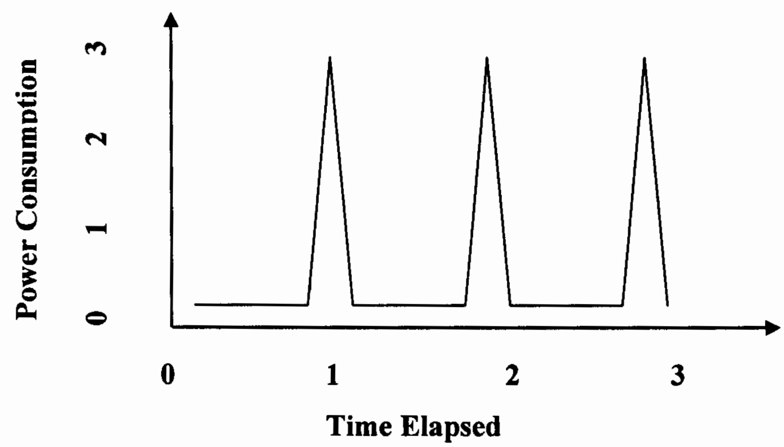


Figure 4.7: Typical Periodic Synchronization

4.5.2. Triggering of an Event

In some cases there is no need of periodic synchronization, the synchronization occurs unevenly and infrequently, here the synchronization is subject to triggering of some event to be monitored, typically in cases where sensors detect something or where sensors needs to notify some information. These cases should be reported reliably and quickly.

The mote WeC 99 "Smart Rock" we selected for simulation is based on its low power consumption during sleep times and randomly the motes will be in sleep mode about 99% of the time during sleep times, The mote isolates and shuts down its individual circuits and use of low power hardware, It runs typically $32\,khz$ oscillators, performs ADC conversions as well as DMA transfers and bus operations keeping the $\mu controller$ in off state. There is some overhead of switching from sleep to active mode. (i.e 36 $\mu \sec$)

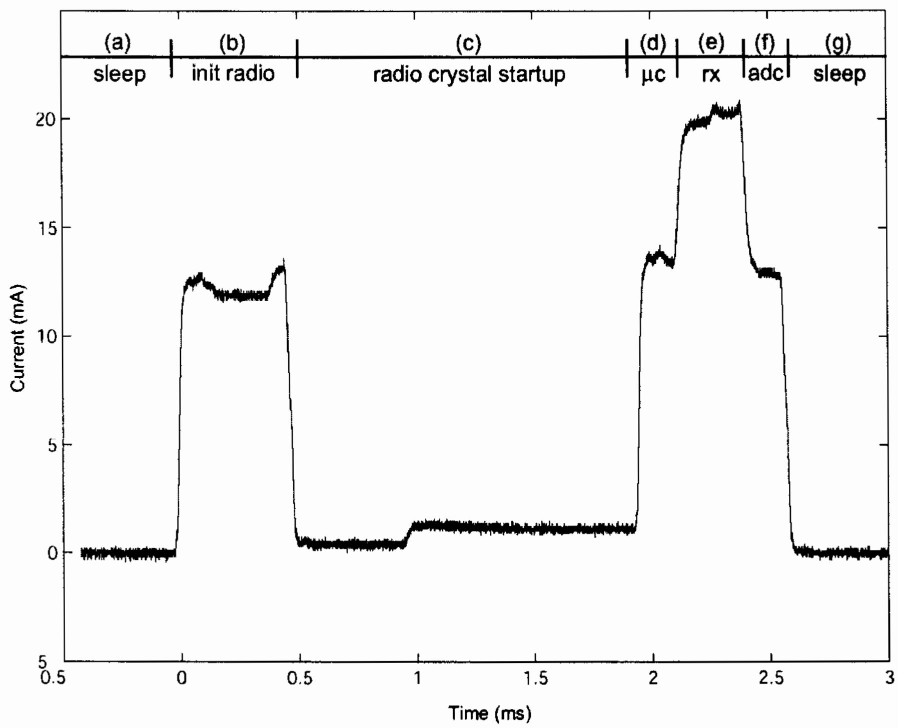


Figure 4.27: Typical wakeup time of mote [7]

In Active mode the mote performs fast processing and uses low power, producing high data rate $10kbps$. The mote takes $36mW$ of energy for transmission and $9mW$ of received power, In our proposed solution each sensor network will synchronize on triggering of an event, a short pulse typically of $1-10m\sec$ duration is sent for synchronization of the whole network. So each sensor will remain awake for $10m\sec$ during the synchronization process. We assume a random time of 10 minutes before each wakeup call, so for a typical day (24 hours) total power consumption of a sensor can be computed as

Time in a day is $24\times 60\times 60 = 8.64\times 10^4 \sec$

Active time of a node is ($10m\sec$ after each $10\min$) = 8.64×10^2

Sleep time of the node is $8.64\times 10^4 \sec$ - $8.64\times 10^2 = 8.5536\times 10^4$

Energy consumption active mode is $8.64\times 10^2 \times 15\times 10^{-3} = 12.96W$

Energy consumption in sleep mode is $8.5536\times 10^4 \times 45\times 10^{-6} = 3.85W$

Total energy consumption in a day (i.e. 24 hour) is $12.96W + 3.85W = 16.81W$

In General scenario sensor nodes are active all the time and can't go in sleep mode so they use energy all the time.

Total energy consumption in a day (i.e. 24 hours) is $8.64 \times 10^{4} \times 15 \times 10^{-3} = 1296W$
Amount of Energy saved in a day =1296-16.8= $1279.2W$

The amount of energy saved using proposed solution under the simulation environment can be calculated as

$$P_{\%saved} = \frac{P_{saveinproposedsolution}}{P_{generalscenario}} = \frac{1279.2}{1296} = 98.7\%$$

4.6. Message Passing Analysis of Different Network

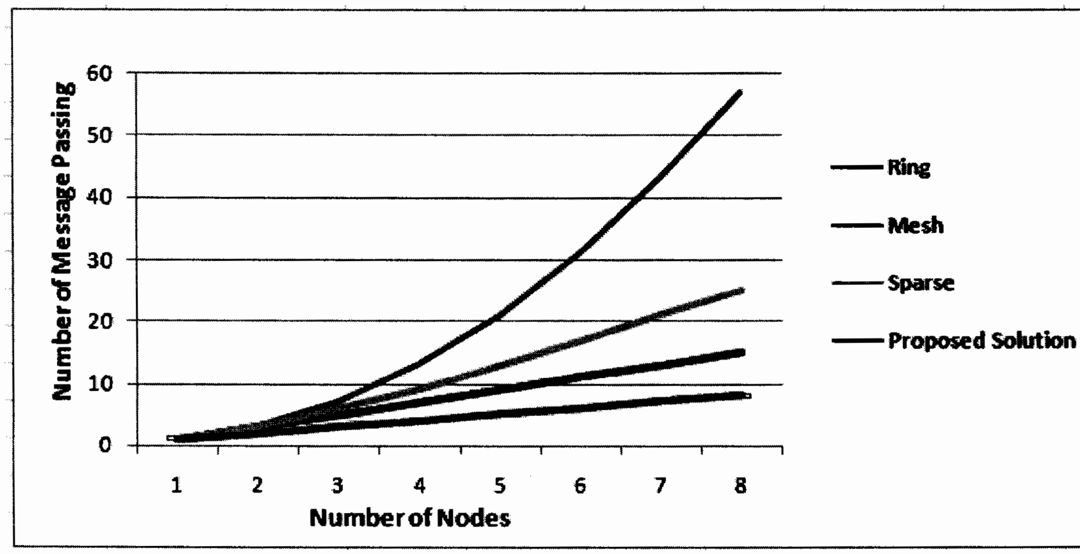


Figure 4.28 : Nodes Vs Message passing

In mesh network the rate of messaging passing is much higher than our propose solution.
In Sparse message passing is less the Mesh but higher than the ring and proposed solution.
The message passing rate of all the network are higher than the proposed solution.

4.7. Hop Count Analysis of Different Network

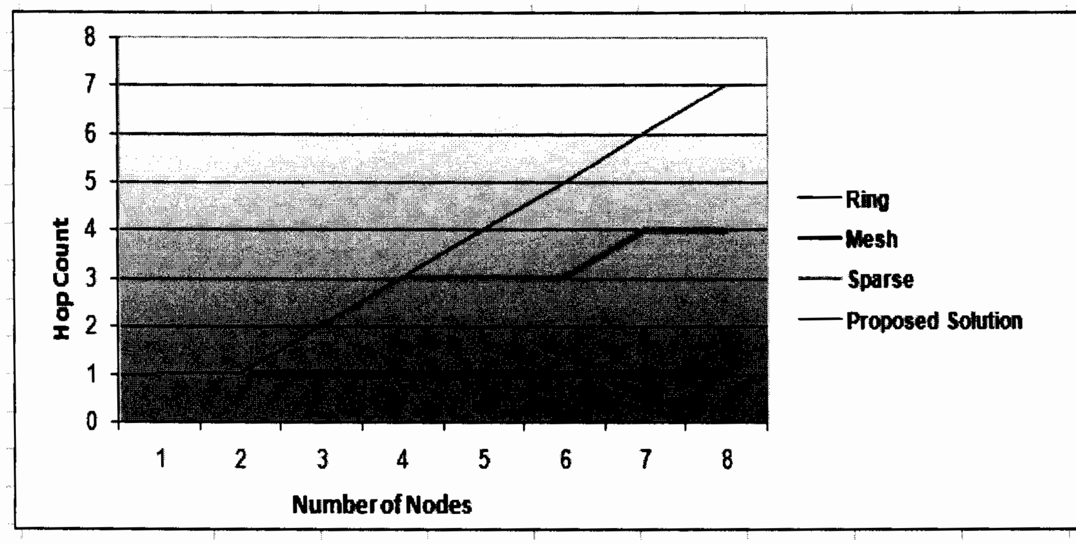


Figure 4.29: Hop Count Complexity

In hop count analysis the number of hops of ring network is greater than our proposed solution and sparse network and our proposed solution are the same in this scenario.

The mesh network is best of all because it is directly connected to all nodes but due to heavy rate of message passing it becomes impractical in large networks.

4.8. Comparison of Hop Count and Message Passing Analysis

Scenario	Messages Passed	Hop Count
Sparse Network	nlg(n)	lg(n)
Mesh Network	n(n-1)	1
Ring Network	2(n-1)	n
Arbitrary Network	4n	lg(n)
Proposed Solution	n	lg(n)

Table 4.6

In the comparison table we have listed down the message pass and hope count function for different network. The rate of messaging of our proposed solution is less than the other networks. In hope count the mesh network is best all of them but the message passing rate is very high.

Chapter 5
Conclusion and Results

5. Conclusion and Future Work

Wireless sensor network contribute a valuable part in the field of communication. Wireless sensor network are often used for military and civil applications.

Sensor networks are very advantageous but have some limiting factors like low memory and low power/energy, which makes them harder to use for real time applications, The main research field in wireless sensor networks focuses on reducing the power consumption for different operations of the sensors and using low memory.

The focus of our research is to reduce power consumption during time synchronization of sensor nodes, which is accomplished by reducing number of message passing during the synchronization process.

We have studied more than 50 papers and on the basis of relevancy we have selected 6 of them. We have proposed a modified master slave architecture model in which a node is designated as a master which firstly received a signal. All nodes are synchronized with each other using BFS algorithm. Nodes are synchronized according to their position in the queue. Using BFS in the time synchronization we have saved up to 97% of energy as compare to broadcast. In our propose solution the message passing rate is directly proportional to the number of sensor nodes. But in other cases the message passing is directly proportional to number of edges between sensor nodes in wireless sensor network.

We also compare our proposed solution with different types of sensor networks and it is found that message passing in the proposed solution falls below compared to all other networks. In hop count analysis only mesh is better than the proposed solution, but mesh network becomes impractical in large network and having very high message passing.

The research can be enhanced by using greedy algorithms for synchronization which generates minimum spanning tree, In this case the synchronization will be performed according to minimum spanning tree, and the idea is to send message to the neighbor which is close in terms of distance, This will definitely reduce the power consumption, as the sensor will require less power to transmit a message to its nearest sensor as compared to a sensor who is at large distance.

Appendix-A

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