Node Heterogeneity for Energy Efficient Synchronization for Wireless Sensor Network

Dnyaneshwar, Mantri; Prasad, Neeli R.; Prasad, Ramjee

Published in:
Procedia Computer Science

DOI (link to publication from Publisher):
10.1016/j.procs.2016.03.102

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 79 (2016) 885 – 892

Procedia Computer Science

7th International Conference on Communication, Computing and Virtualization 2016

Node Heterogeneity for Energy Efficient Synchronization in Wireless Sensor Network

Dnyaneshwar s Mantri[a]*, Neeli Rashmi Prasad[b], Ramjee Prasad[c]

[a,b,c]*Center for TeleInFrastruktur, Aalborg University, Denmark*
{dsm,prasad}@es.aau.dk, neeli.prasad@ieee.org

Abstract

The energy of the node in the Wireless Sensor Networks (WSNs) is scare and causes the variation in the lifetime of the network. Also, the throughput and delay of the network depend on how long the network sustains i.e. energy consumption. One way to increase the sustainability of network is the introduction of heterogeneous nodes regarding energy, and the other is to synchronize the local clock of the node with the global clock of the network. In this context, the paper proposes Node Heterogeneity aware Energy Efficient Synchronization Algorithm (NHES). It works on the formation of cluster-based spanning tree (SPT). In the initial stage of the algorithm, the nodes are grouped into the cluster and form the tree. The nodes in the cluster and cluster heads in the network are synchronized with the notion of the global time scale of the network. Also, clock skews may cause the errors and be one of the sources of delay and energy consumption. To minimize the energy consumptions and delay, NHES synchronizes the time slots using TDMA based MAC protocol. The results show that level by level synchronization used in NHES is energy efficient and has less delay as compared to the state-of-the-art solutions.

Peer-review under responsibility of the Organizing Committee of ICCCV 2016

Keywords: Delay; Energy; Synchronization; WSN.

1. Introduction

Time and clock synchronization are an important services for the collaborative and coordinated operations in WSNs. Time synchronization in the WSN is mainly affected by low-cost clocks, frequent topological changes, error

* Corresponding author. Tel.: +919922431612
E-mail address: dsm@es.aau.dk

Peer-review under responsibility of the Organizing Committee of ICCCV 2016
doi:10.1016/j.procs.2016.03.102

sources during communication, node failures and the resource constraint nature of the nodes. For instance, network protocols such as time division multiple access (TDMA) strictly demands synchronization among sensor nodes. The unsynchronized clocks in the network take more time to send the packet to sink and hence consumes more energy. The nodes used in the formation of the network are scare of energy, and cannot sustain for a long time. Also, some part of node energy is utilized in the synchronization of activities of the nodes. To increase the lifetime and solve the problem, some percentage of the nodes with varying energy are added to the network. The energy consumption of the synchronization algorithm is minimized by matching the global clock of the sink and the local clock of the node[1,2].

The activities of the node are scheduled according to the time frame, and all the slots are synchronized with the global clock of the network. The unusable network conditions and scare resources of WSN make it essential to develop a time and clock synchronized protocol that can sustain the network long time with reduces energy consumption. The spanning tree mechanism used operates level by level reducing the multi-hop communication restricting the requirement of large network bandwidth. The improper scheduling and synchronization of the packets generated from the lower layer of the network to the upper layer cause more energy consumption. Also, retransmission delay is caused due to the variation in the clock skews and improper slot allocation to transfer the aggregated packets.The efficient way to reduce the retransmission delay is scheduling MAC protocol to manage the time slots of nodes and cluster head (CH) with global time scale. The data propagation from node to sink may be in one–hop or multi-hop, it depends on the depth of the spanning tree formed in intra and inter-cluster communication. The packet scheduling activities of the nodes are dependent on the availability of the channel, at least, equal to the synchronization time [2]. The neighboring node will synchronize their schedules periodically to prevent long term clock drift. Timing-Sync Protocol for Sensor Networks (TPSN) [3], considers the traditional approach of two-way message exchange between sender-receiver synchronization with an increase in sync errors and energy consumption. The traditional protocols are not energy efficient and difficult to implement for WSN. Due to the constraints of energy supply and processing ability, the current time synchronization mechanisms like RBS, NTP and GPS could no longer serve WSNs well, and need to be modified or redesigned.

The paper focuses on the addition of controlled node heterogeneity to minimize the energy consumption with reduced delay. The nodes used are heterogeneous regarding energy that helps to increase the network lifetime. The clustered architecture forms the spanning tree with non-ideal clocks. The frequency of each clock is assumed to fixed.The level by level synchronization used in SPT improves the network performance than a structured algorithm.

The paper has different sections as; Section 2 focuses on the present work related to synchronization algorithms. Section 3 presents the required assumptions and network model. Section 4 briefs about the NHES, Section 5 discuss simulation setup and results, and section 6 conclusion along with the future scope.

2. Related works

This section provides the idea how one can improve the QoS of the network by use of synchronizing the clocks of the node and sink. In [2] Synchronized Data Aggregation (SDA) algorithm considers the spanning tree mechanism to improve the energy consumption as compared with TPSN. It shows the reduced sync errors and energy consumption. [4] Defines a time synchronization protocol based on spanning tree. A spanning tree formed by the nodes is divided into multiple sub-trees. The sub-tree synchronization process helps to minimize the synchronization errors by adjusting the clock time within the level. In [5] Clustered Time Synchronization algorithm and energy model is presented, that conserves the energy beside accuracy while synchronizing the WSNs. Reference Broadcast Synchronization Protocol (RBS) [6] uses the synchronization between two receivers by the intermediate node within the listening range of the sender and receiver. The intermediate node sends the message for recording the time hence saves the energy in clock updates. The major disadvantage of the protocol is that the energy is wasted in synchronizing the reference sender. [7] Proposes the distributed clustering data aggregation algorithm with consideration of mobile and heterogeneous nodes into the clusters. The mobility of node frequently changes the structures and accordingly consumes more energy. In [8] Author considers the network with heterogeneous nodes regarding energy with a mobile sink. It shows improvement in throughput and network lifetime. Due to the mobility of sink control overheads are increased and consumes some part of node energy. [9] Consider hybrid synchronization scheme for WSN used to analyze the vibrations with minimum sync errors. Authors used the partial offset time synchronization of TPSN and clock adjustment for reduced energy consumption of K nodes. [10] Proposes the hybrid scheme to ensure the sync accuracy with minimum energy. It considers partial scheme to calculate the time offset of few child nodes. In [11] time synchronization of node and network is done at the time of cluster tree formation. It reduces the energy consumption and relative time drifts used in data collection from the tree. [12] Proposes the cycle-based sync scheduling in the delay-sensitive applications to achieve low packet delay and high throughput in the communication of packets from intra to inter-cluster communication. It rearranges the transmission order by optimizing the cycle length. It has a limitation of overhead with increased network size and synchronization error. [13] Proposes TDMA based slot allocation for transferring the aggregated packets from CH to sink with reduced energy consumption even though the mobility of node restructures the cluster and increases the energy consumption. The TDMA scheduling demands the proper synchronization for reduced packet collisions. [14] Proposes the bandwidth efficient hybrid synchronization algorithm [BESDA] which uses the combination of scheduling and synchronization algorithm to improve the throughput. 15] Mobility–aware Hybrid synchronization (MHS)consider the random mobility of node to improve the throughput and delay, but the mobility of nodes causes the energy consumption in collecting the packets from nodes to CH and CH to sink. In [16] clock skew is minimized by synchronizing the local clock of the node concerning the global clock of the network.

The time and clock synchronization is the important issue of WSN for improving the network parameters. The clock drifts and unbalancing of the global clock of the network with the logical clock of the node results in sync errors during synchronization. Also, slot allocation for collision-free data transmission plays an important role. This paper proposes the technique of adding the heterogeneous nodes with energy in the network so that it can sustain for a long time and minimizes the energy loss and error. The spanning tree mechanism is used to transfer the packets to sink level by level with collision-free slot allocation.

3. Proposed Network Model

The paper proposes the cluster- based Time Synchronization for WSN. It uses the spanning tree mechanism for synchronizing the slots as well as clocks of the heterogeneous nodes with the global clock of the network (Sink). The clusters in the network are used to form the spanning tree with 'V' set of CH connected with 'E' wireless links T (V, E) as shown in Fig.1.

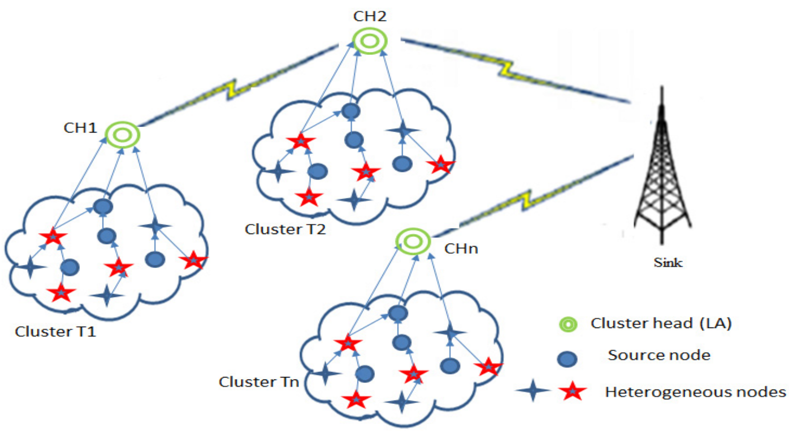

Fig. 1. Network Model.

The network T (V, E) is divided into many sub-trees of clusters T1, T2, T3,…, Tn. The sink is located at the root of the tree. The network has sub-tree of clusters (inter-cluster) with one CH and a number of nodes within the cluster. Also, a spanning tree of all nodes in the cluster is created and then divides into sub-levels (inta-cluster). Each sub-tree is a set of nodes including CH and several child nodes. The frequency of each clock is approximately fixed and maintains the time stamp which is synchronized with the global clock of the network during synchronization.

4. Proposed Mechanism

The main objective of proposed node heterogeneity-aware approach is to minimize the energy consumption and delay. The formation of algorithm progress as: 1. Form the cluster tree and perform level by level aggregation. 2 Synchronize the activities of the node to reduce energy consumption, 3. Schedule the activities of the nodes according to free slots. 4. Reduce the errors due to clock skew hence the energy consumption and delay.

4.1. Spanning Tree Formation

The main goal of synchronizing the local clock of all nodes within the cluster with CH and then with sink is to reduce the sync errors and energy consumption. In the initial stage, all the randomly distributed nodes are grouped into a number of clusters based on the clustering algorithm [7,8] at time interval ‘t’. The re-election of CH is not considered to minimize the energy consumption in broadcasting the messages. The CH is assumed to have level 0 and broadcast the message, nodes receiving broadcast messages at one hop are connected and represents as set of forest. The Kruskal algorithm is used to form the minimum spanning tree of nodes with the edge forming the loop are discarded as shown in Fig.2.

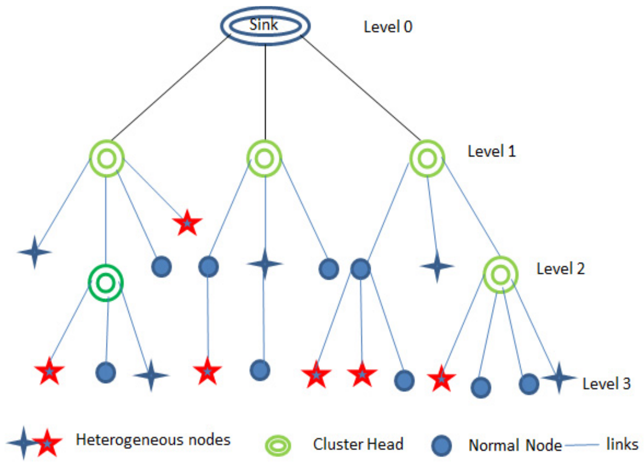

Fig. 2. Proposed spanning tree mechanism

In the second level (inter-cluster), the spanning tree of CH is formed with different level and sink at root with 0 level. The CH directly connected to sink are at level 1 and the remaining CH and nodes will maintain the higher order according to the depth of spanning tree. All the CHs at level 1 are synchronized with level 0, level2 with level1 and so on. The process of synchronization continues in the same manner inside the cluster till all nodes in the network have been synchronized with sink. The sink node maintains the global notion of time to synchronize the clocks of all nodes in the formation of spanning tree and communication of packets. The errors due to clock skew between local and global clock will occur during the synchronization process. The level by level synchronization of child and parent node reduces the clock drifts and overheads required to maintain equal time scale among all nodes at one time.

4.2. Energy and delay analysis

The main objective of adding the heterogeneous nodes in the network is to sustain the network for a long time with minimum energy consumption and delay. NHES considers the energy model used in [8], with introduction of controlled node heterogeneity the total initial energy of cluster is

$$E_i = n\,(\alpha E_n + \beta E_a + \gamma E_s) \qquad (1)$$

α = % of normal nodes with energy E_n = 20 J, β = % of advanced node with energy E_a = 30J, γ = % of super nodes with energy E_s = 40J, with equal number of nodes in the network $\alpha= \beta= \gamma=1/3$, n= number of nodes in cluster.

In WSN, the energy consumption depends on the time required for communication of aggregated packets, depth of spanning tree and clock skews causing errors. According to the depth of SPT i.e. from node to CH, CH to sink, and the number of packets transmitted by the nodes in the lower level to CH, and to 0 levels by CH., the energy consumption is

$$e(di)= k(et\ di\mu +e_0)\ t_{slots} \quad (2)$$

Where μ- path loss and depends on the distance of a node to CH and sink, k- the number of packets, e_t- transmitter energy, e_0- initial energy.

The energy consumption according to radio states as transmitter (E_{tx}), receiver (E_{rcv}), listen (E_{lst}) and sleep (E_{slp}) and clock skew 'e_s' is considered according to [15] is

$$Energy\ consumption= (E_{tx} +E_{rcv} +n * E_{ls}t)\ L * t_{slot} *e_s \quad (3)$$

Where synchronization period 'T' is composed of consecutive time slots L as shown in Fig 3. The total time is logically divided into slots as t_{slot}, and these time slots are synchronized among nodes to avoid collision of packets and clock skews. Also, the time required to schedule the 'k' packets at CH is calculated according to the number of forwarding's as

$$T_{ch}= ((N/k)-1)\ t_{slot} \quad (4)$$

The total time required to send the aggregated packets to sink: $T_{sink} = k.\ t_{slot}$ (5)

Hence, total time required for packets to reach to sink is: $T = [((N/K)-1) +K]\ t_{slot}$ (6)

All the activities of each node are scheduled and synchronized in the time slot $1\leq t_{slot} \leq T$

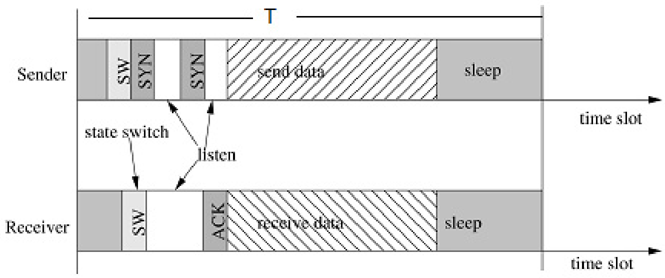

Fig. 3. Synchronization frame.

5. Results and Discussions

The parameters considered for simulation of randomly placed heterogeneous nodes are summarized in Table I. The cluster based spanning tree used operates level by level in the intra and inter-cluster aggregation and communication of packets towards the sink. The performance of energy efficient synchronization algorithm (NHES) is compared with SDA [2], BESDA [14], MHS [15] and time synchronization (TPSN) [3] a network-wide time sync algorithm.

Table 1. Simulation Details

Particulars	Value
Number of nodes	25,50,75 and 100
Number of sources	24, 49, 74 and 99
Number of Sinks	1
Placement of source and sink	Random and sink at corner
Initial energy	100J
Idle power	14.4mW
Receive power	14.4mW
Transmit power	36.0mW
Runs of each simulation	20
Energy of heterogeneous nodes	20 J, 30J and 40 J

5.1. Synchronization error

Fig. 4 shows the result of synchronization errors with TPSN and spanning tree synchronization mechanisms. It is seen that the performance in case of SPT mechanism is better than TPSN. The major reason for better performance is level-by-level synchronization performed by the proposed mechanism. CH next to sink will receive the clock from the sink while nodes at a lower level will receive it from respective CH. In TPSN mechanism, the global timescale is applied across the network at one time, and every node has to synchronize with global time, it introduces the clock drifts at different levels and performance decreases.

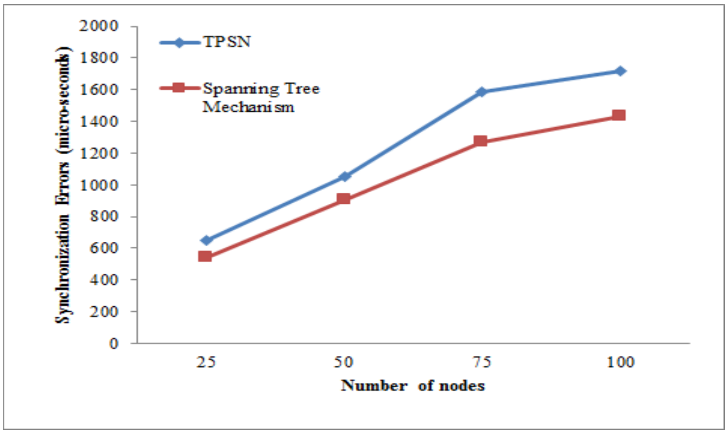

Fig. 4. Synchronization error

5.2. Average Energy Consumption

Fig 5 shows the average energy consumption of NHES is less as compared to TPSN, BESDA and MHS (30.66%, 18.01%, and 34.44% respectively) but more than SDA. The average energy consumption by TPSN is more than that of NHES because TPSN tries to apply global timescale across the network at one time while NHES uses the spanning tree based synchronization mechanism which works on a level by level. The clustered tree architecture does not require to transmit the message for long distance hence saves energy.

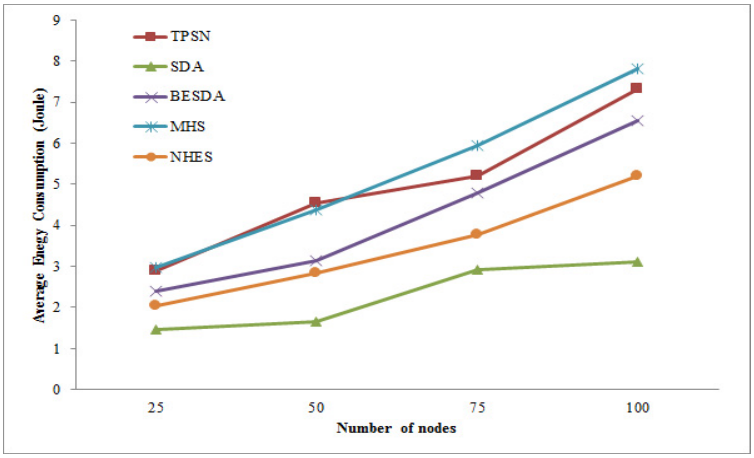

Fig.5. Comparison of Average energy consumption.

Also, BESDA and MHS uses the fixed and random mobility of the nodes, which requires more energy in message exchange for the formation of tree, since the mobility of nodes frequently changes the network structure and consumes energy. In the NHES the nodes added with controlled heterogeneity and re-election of CH is avoided this saves the energy and sustains the network for a long time.

5.3. Throughput

Fig 6 shows a comparison of average throughput measured at the sink. The average throughput of SDA, BESDA and MHS is greater (1.76%, 4.59%, and 2.92%) than the NHES. The reason is that the mobility of nodes in the network increases the probabilities of one hop neighbours to transmit the aggregated packet. By adding controlled heterogeneity, the network remains operative even though some nodes die early. It shows improvement in throughput of NHES as compared to TPSN. This improvement in the result is due synchronizing the clocks of parent and child node level by level.

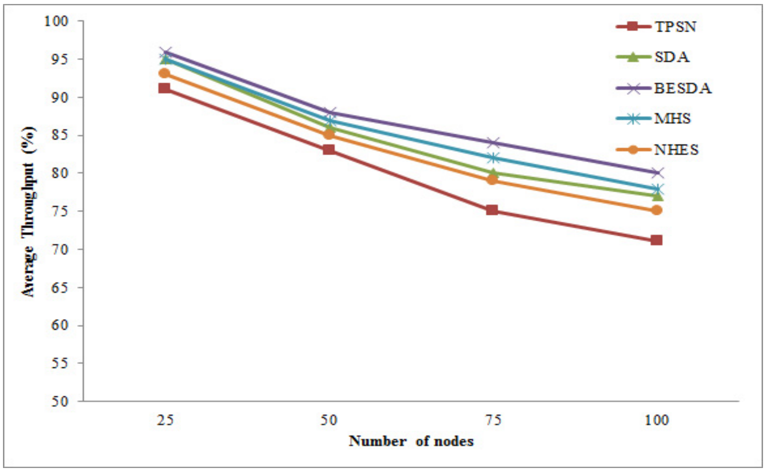

Fig.6. Comparison of Average Throughput.

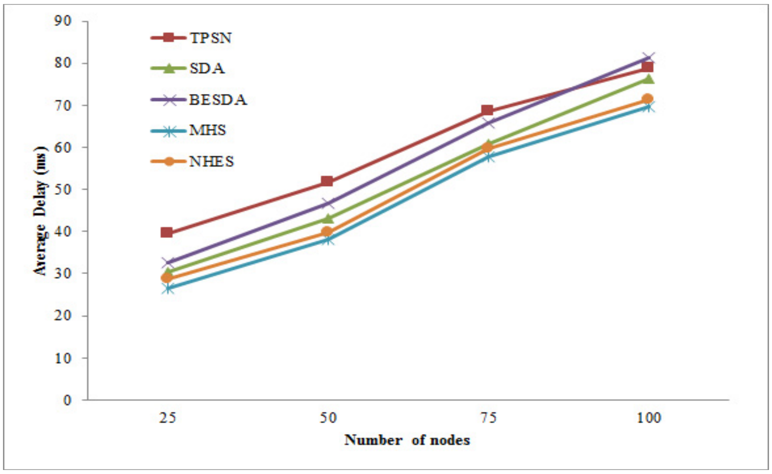

Fig.7. Comparison of Average Delay.

5.4. Delay

Fig 7 shows the delay that causes in the transmission of packets from nodes to CH, and CH to sink. With the introduction of controlled heterogeneity of nodes, an avg delay in matching the local and global clock is reduced by 16.40%, 5.35 % and 11.94% with SPT as compared to TPSN, SDA, and BESDA since network sustains for a long time. The larger time drifts introduced in TPSN takes a large time to make a decision on schedule as compared to NHES. Also, the retransmission delay is caused due to the clock skews occurred due to mismatch of clocks. The overheads in the network are increased, which leads to increased delay and reduced throughput in case of TPSN

6. Conclusions and future works

The proposed synchronization algorithm with spanning tree mechanism shows improvement in energy consumption and delay as compared with TPSN, BESDA, and MHS. The addition of heterogeneous nodes in the network along with the synchronization of local and global clock helps to sustain the network for a long time. The clock synchronization reduces the clock drifts and hence errors which result in an increase of the throughput, and reduces the delay. With the introduction of controlled node heterogeneity, the performance of the synchronized algorithm is improved by 2%. Also, the pairwise synchronization reduces the possibility of retransmission of packets and reduces the delay. Form the results and discussion the paper concludes that BESDA and MHS are bandwidth efficient while NHES is energy efficient. The work can be extended by considering sink mobility in the network.

References

1. Bharath Sundararaman, Ugo Buy, and Ajay D. Kshemkalyani, “Clock synchronization for wireless sensor networks: a survey,” Elsevier Ad Hoc Networks 3 (2005) 281–323.
2. Dnyaneshwar S. Mantri, Neeli Rashmi Prasad, and Ramjee Prasad, “Synchronized Data Aggregation for Wireless Sensor Network,” 1st IEEE Global Conference on wireless computing and networking, pp 263-267, December 22-24, 2014, SIT, Lonavala, India.
3. Saurabh Ganeriwal, Ram Kumar, and Mani B. Srivastava, “Timing-sync Protocol for Sensor Networks,” SenSys’03, November 5-7, 2003, Los Angeles, California, USA.
4. LI-Ming He, “Time Synchronization Based on Spanning Tree for Wireless Sensor Network,” IEEE Wireless 4th International Conference on Communication, Networking and Mobile Computing, WiCOM’08.
5. Gopal Chand Gautam, T. P. Sharma, Vivek Katiyar and Anil Kumar, “Time Synchronization Protocol for Wireless SensorNetworks using Clustering,” 2011 ICRTIT, pp417-422 June 2011, India.
6. J. Elson, L. Girod, and D. Estrin, “Fine-grained network time synchronization using reference broadcasts,” Proceedings of Fifth Symposium on Operating Systems Design and Implementation (OSDI 2002), Vol. 36, pp. 147–163, 2002.
7. Dnyaneshwar Mantri, Neeli Rashmi Prasad, & Ramjee Prasad, “Mobility and Heterogeneity aware Cluster-Based Data Aggregation for Wireless Sensor Network”, Springer Journal-Wireless Personal Communication, vol.86, Issue 2, pp975-993, Jan 2016, DOI 10.1007/s11277-015-2965-2
8. Dnyaneshwar Mantri, Neeli R Prasad, Ramjee Prasad, “Bandwidth Efficient Heterogeneity aware Cluster based Data Aggregation for Wireless Sensor Network,” Elsevier Journal of Computer and Electrical Engineering, vol 41, Pages 256–264, January 2015. DOI : 10.1016/j.compeleceng.2014.08.008 [ISSN:0045-7906, IMF:0.992
9. Yixuan Gong, Harutoshi Ogai, WanyuLI, “A Partial TPSN Time Offset Synchronization Scheme in Wireless Sensor Network applied for bridge health,” 20 II International Conference on Computer Science and Network Technology, PP 254-258, Dec 24-26, 2011.
10. L. Schenato and F. Fiorentin, “Average time synch: a consensus-based protocol for time synchronization in wireless sensor networks,” Automatica, 47(9), pp. 1878–1886, 2011.
11. Huang Hai-ping, Wang Ru-chuan, Liu Li, Sun Li-juan, Li Wen-feng, “Time synchronization algorithm of wireless sensor networks based on data aggregation tree,” vol 17, pp. 24–29, July 2010.
12. Xi Deng, and Yuanyuan Yang “Communication Synchronization in Cluster-Based Sensor Networks for Cyber-Physical Systems,” IEEE Transaction on Emerging Topics in Computing, 1(1), pp 98-110,.June 2013.
13. Dnyaneshwar S. Mantri, Pranav Pawar, Neeli Rashmi Prasad, and Ramjee Prasad, “An Efficient Schedule based Data Aggregation using Node Mobility for Wireless Sensor Network,” Wireless Vitae2013, pp1-5, May11-14, 2014, Aalborg, Denmark.
14. Dnyaneshwar S. Mantri, Neeli Rashmi Prasad, and Ramjee Prasad,“Bandwidth Efficient Hybrid Synchronization for Wireless Sensor Network,” 4th International Conference on Advances in Computing, Communications and Informatics (ICACCI2014), pp 2108-2013, August 12, 2014. Kochi, India
15. Dnyaneshwar S. Mantri, Neeli Rashmi Prasad, and Ramjee Prasad, “Mobility-aware Hybrid Synchronization for Wireless Sensor Network,” WPMC 2015, 14 dec 2015 Hyderabad, India (Presented)
16. Yildirim K.S. and A ylin Kantarci, “External Gradient Time Synchronization in Wireless Sensor Networks,” IEEE Transactions on Parallel and Distributed Systems, 25(3), page: 633–641, march 2014.