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Energy Efficient Clustering Algorithm for Throughput Maximization using Mobile Sink for Wireless Sensor Networks

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Abstract: Wireless Sensor Networks (WSNs) using mobile sink along a fixed trajectory is proved to be efficient in terms of data collection. Most of the existing algorithms using mobile sink have not considered the lifetime of sensor nodes near the mobile sink's trajectory that participate in data relay on behalf of other nodes. This results in fast depletion of battery power of these nodes which ends up in network partitioning, thereby result in network instability. To overcome this situation, a novel clustering algorithm is proposed which segregates the nodes into zones along the trajectory of the mobile sink and schedules the sleep-wake period of the nodes such that the life of the nodes close to the trajectory is increased 48.3% compared to the standard algorithm. An Adaptive Time Synchronization (ATS) algorithm is also developed for effective data transfer among clusters. The proposed techniques are validated through simulation and real time experiments using TinyOS environment.

Key words: Data collection, dual cluster head, mobile sink, time synchronization, TinyOS, wireless sensor network

INTRODUCTION

Wireless Sensor Networks (WSNs), composed of densely deployed, low-cost, low-power, multifunctional sensors have emerged as a new information gathering paradigm for taking spatial and temporal measurements of a given set of parameters such as temperature of a field. In such applications, sensors are randomly deployed over a field without a preconfigured infrastructure. Each sensor has the capabilities of monitoring the environment, collecting data and routing data back to a data sink. Typically, most energy of a sensor is consumed on two major tasks: sensing the field and uploading data to the data sink. Energy consumption on sensing is relatively stable since it only depends on the sampling rate. On the other hand, the energy consumption on data uploading is non-uniform among sensors. It strongly depends on the network topology and the location of the destined data sink. As a result, the energy of the sensors near the sink is depleted much sooner than others since these sensors need to relay much more packets from the sensors far away from the sink. Therefore, how to efficiently aggregate the information from scattered sensors, generally referred to as data gathering is an important and challenging issue in WSNs as it largely determines network lifetime.

In WSN data gathering can be broadly classified into two categories: efficient relay routing with static or mobile sinks and hierarchical infrastructure. In the first category data packets are forwarded by multi hop based routing to the base station (Shah *et al*., 2003). Factors such as load balance, schedule pattern and data redundancy are also jointly considered with the routing scheme. In the second category, a WSN was organized into a hierarchical infrastructure for better scalability in which sensors are grouped into clusters (Dechene *et al*., 2008; Fang *et al*., 2012). Each cluster is maintained by single or multiple cluster heads (Hu and Wang, 2011; Li *et al*., 2011). However, in such hierarchical networks, cluster heads selection (Lee and Jeong, 2011; Selvakennedy and Sinnappan, 2006) and operation inevitably consume more energy than other sensors (Enam *et al*., 2012). To avoid hot spots, sensors can become Cluster Heads (CH) rotationally as done in LEACH. Since, every sensor may possibly become a cluster head, each of them has to be powerful enough to handle incoming and outgoing traffic which increases the overall cost of the network. Furthermore, it may incur high overhead due to frequent network information exchange among sensors.

To address these problems in static hierarchical networks, mobile data gathering schemes have been proposed. In such schemes, a special type of mobile nodes (usually called mobile sink) is introduced for facilitating connectivity among static sensors. It has recently been observed that sink mobility can still improve network lifetime (Konstantopoulos *et al*., 2012; Vupputuri *et al*., 2010; Rakhshan and Rafsanjani, 2012; Marta and Cardei, 2008; Jain *et al*., 2006). The reason is

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that the typical many to one traffic pattern in WSNs imposes a heavy forwarding load on the nodes close to sinks. While no energy conserving protocol alleviates such a load, moving the sink can distribute over time the role of bottleneck nodes and thus even out the load.

The mobile sink (Luo and Hubaux, 2005) takes the responsibility of collecting the data from various clusters distributed around the observation area and loads the collected data to the base station. Based on the trajectory of the mobile sink, sink mobility can be classified into two categories: random path, fixed path. In sensor networks where the path is random (Heidari *et al*., 2103), it is difficult to bound the data transfer latency and the data delivery ratio. On the other hand, fixed (predictable) sink mobility is exploited to improve energy efficiency of sensor networks (Gao *et al*., 2011; Somasundara *et al*., 2006).

A routing protocol, MobiRoute is discussed for WSNs with a path predictable mobile sink to prolong the network lifetime and improve the packet delivery ratio where the sink sojourns at some anchor points and the pause time is much longer than the movement time (Luo *et al*., 2006). Accordingly, the mobile sink has enough time to collect data which is different from the scenario. Moreover, in MobiRoute all sensor nodes need to know the topological changes caused by the sink mobility. While in the proposed approach, only the nodes that directly communicates with the mobile sink, i.e., the cluster head need to know the change of the sink location and the members just send their data to their respective cluster head chosen in advance.

In a WSN with predictable sink mobility, the nodes that are present close to the trajectory of the mobile sink tend to drain their energy faster thereby leading to the creation of hot spots as shown in the Fig. 1. From the study of various hierarchical cluster based networks the Cluster Heads (CHs) take up the various functions such as collecting data from the cluster members, aggregate the data and transmit the data to the mobile sink.

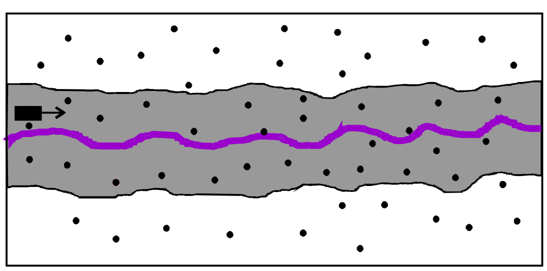

Fig. 1: The shaded region shows the hot spot created by dead nodes

These tasks make the CH to be functionally overloaded and make its energy resources to drain out very fast resulting in node death. This situation forces the nodes in the cluster for a re-election which imposes overhead in terms of energy utilization and creates additional traffic due to the transfer of control packets in the network. In other standard protocols like LEACH (Renugadevi and Sumithra, 2013), the cluster heads are selected in a periodical manner by conducting election. Frequent cluster head election also creates the above discussed drawbacks. This sudy contributes following points to overcome the problem:

- A Zone based Dual Cluster Head selection (Z-DCH) technique is designed and analytically analyzed for energy efficient cluster formation for enhancing network lifetime
- A data collection algorithm is developed to implement the Z-DCH technique for maximizing the throughput of the network
- Proposed protocol is validated through simulation and real time experiments

PROPOSED SOLUTION

The proposed solution is mainly designed for mobile sink with predictable fixed trajectory. The mobile sink transmits beacon signals while traversing the predefined path. The nodes calculate the distance from the trajectory based on the received beacon signal. The nodes then segregate into zones (Z1-Z3) based on the hop count to the trajectory of the mobile sink as shown in the Fig. 2. The nodes which are in one hop distance from the trajectory are grouped as zone Z1, the nodes with two hop distance from the trajectory are categorized as zone Z2 and the nodes with more than two hop distance are categorized as zone Z3. The first zone Z1 closer to the mobile sink's trajectory comprises of the nodes that directly communicate with the mobile sink (i.e., they are in

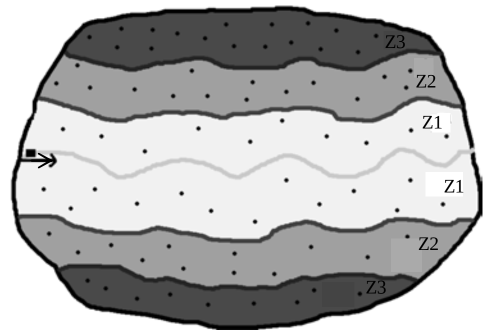

Fig. 2: Network partitioned into zones

the single hop distance with the mobile sink). As the nodes are hierarchically distributed, the network is designed such that the energy level of the nodes in zone Z1 are comparatively higher than the nodes of the successive zones. These nodes have the eligibility to act as cluster head to perform the function of data collection, data aggregation from the nodes of lower zones and finally data transfer to the mobile sink. Based on the CH selection algorithm two nodes Master Cluster Head (MCH) and Vice Cluster Head (VCH) are elected as Cluster Heads.

The protocol is executed in two phases. In the first phase: Setup phase and Mapping phase. The Setup phase involves the network partitioning into zones along the trajectory of MS based on the hop count and cluster formation (selecting dual CHs MCH and VCH) based on the cost of the node. In the Mapping phase, the Master Cluster Head (MCH) of each cluster will act as the CH for a fixed time slot T1. For the first round of data collection by the mobile sink the MCH will get mapped to the mobile sink for transferring data. Meanwhile the Vice Cluster Head (VCH) takes over the assignments of CH for that cluster. The MCH after data transfer enters into sleep mode till the next data transfer time slot of the cluster. For the second round of data collection, the VCH which is currently acting as CH gets mapped with the mobile sink for data transfer, at that time the MCH takes over the control of CH in the cluster. The VCH after data transfer enters into sleep mode.

For each successive round the role of CHs switches between MCH and VCH. By putting the CH to sleep state, the CH life increases and the cluster is not forced for a re-election within a short span of time. In a cluster by alternating the assignment of CH between rounds, the lifetime of the nodes in zone Z1 are proved to have an extension twice when compared to the system of having the one CH. The proposed technique aims to reduce the frequent cluster head selection procedure by the cluster members.

ENERGY MODEL

The effective part of data transfer from the cluster head to the mobile sink does not mainly depend on setup phase of the individual clusters, therefore the energy utilization in these phases are considered as an overhead energy as discussed by Enam *et al.* (2012). Therefore, the overhead energy caused by the setup and contention phase could be avoided to the maximum by postponing of CH election. The following Eq. 1-3 are the energy spent by a node during transmitting, receiving and listening:

$$E_{Tx}(k,d) = E_{elec}\times k+E_{tr}\times k\times d^2 \quad (1)$$

$$E_{Rx}(k) = E_{elec}\times k \quad (2)$$

$$E_{Lx}(k) = \beta\times(E_{elec}\times k) \quad (3)$$

Where:

- E_{Tx} = Energy consumed in transmission of data
- E_{Rx} = Energy consumed in reception of data
- E_{Lx} = Energy consumed in idle listening state
- E_{elec} = Energy consumed by the electronics for transmitting or receiving a1-bit of data measured in (J/b)
- k = Number of bits
- β = Ratio of reception and idle listening energy and
- d = Distance between transmitter and receiver

The energy consumed by a node to broadcast advertisement for cluster head election:

$$E_{BCHAd}(k, d) = K_c\times(E_{elec}+E_{amp}\times d_{max}^{2}) \quad (4)$$

Energy spent by associated node is given by:

$$E_{BNAd}(k, d) = (p\times n)\times k_c E_{elec} \quad (5)$$

Where:

- p = Maximum percentage of CH per round
- n = The total number of nodes in the network

The energy consumed by cluster head during contention phase:

$$E_{CHCP}(k, d) = N\times k_c\times E_{elec}+k_t\times(E_{elec}+E_{amp}\times d_{max}^{2}) \quad (6)$$

where, N is the number of associated nodes in this cluster. The energy consumed by associated node during contention phase is given by:

$$E_{NCP}(k, d) = \left(\frac{k_c}{\alpha}\right)\times(E_{elec}+E_{amp}\times d_{toCH}^{2})+\left(\frac{(N-1)}{\alpha}\right)\times (k_c\times\beta\times E_{elec})+k_t\times E_{elec} \quad (7)$$

where, α is the throughput of non-persistent CSMA. When the ratio of propagation delay and transmission delay is 0.001, the value of α comes out to be 0.814. Energy consumed by CH for transmitting m frames in each cluster and the aggregated data to the sink is given by:

$$E_{CHT}(k, d) = m\times\big((N_i\times k_d\times E_{elec})+(N-N_i)\big)\times (\beta\times k_d\times E_{elec})+k_d\times(E_{elec}+E_{amp}\times d_{tosink}^{2})) \quad (8)$$

where, N_i is the number of those associated nodes who have to send the data in this round. Energy consumed by associated node for transmitting m frames to CH is given by:

$$E_{NT}(k, d) = m \times E_{elec} \times (E_{elec} + E_{amp} \times d_{toch}^{2}) \quad (9)$$

Where:

N = Number of nodes/cluster

m = Number of data frames per round in each cluster which is taken as 10

Except Eq. 1-3 all the energy calculated is considered as overhead energy (i.e., from (Eq. 4-8). Let E_{oh} be the total over head energy, E_{eff} be the efficient energy and E_{ro} as the total network consumed in R rounds then from the above equations:

$$E_{oh} = \sum_{q=1}^{R} (E_{qCHAdv} + E_{qCHCont} + E_{qNAdv} + E_{qNCont} \quad (10)$$

$$E_{eff} = \sum_{q=1}^{R} (E_{qCHtrans} + E_{qNtrans}) \quad (11)$$

$$E_{ro} = E_{eff} + E_{oh} \quad (12)$$

The effect of the overhead energy on network lifetime is calculated in the above equation. It could be clearly understood that if a network goes for frequent cluster head selection process, the overhead energy E_{oh} would create unwanted wastage of essential energy by the network. By adopting the proposed method of employing dual cluster heads will reduce the energy spent due to overhead by half for a time period 'T'. The Eq. 10 changes as follows:

$$E_{OH} = \frac{\sum_{q=1}^{R} (E_{BCHAd} + E_{qCHCP})}{2} \quad (13)$$

$$E_T = E_{OH} + E_{eff} \quad (14)$$

Where:

E_{OH} = The overhead energy spent by the network

E_T = The total energy spent by the network

ZONE BASED DUAL CLUSTER HEADS (Z-DCH) SELECTION TECHNIQUE

According to the above energy analysis, it is observed that the energy consumption for a node to handle control and maintenance information of a cluster is considered as overhead. By applying the proposed technique to a network two cluster heads are selected and operated simultaneously in a cluster. This technique avoids frequent cluster head selection process, thereby preserving the energy spent by the nodes for such overheads.

After deployment of nodes, during the setup phase the Mobile Sink (MS) sends beacon signal as it moves along its predefined trajectory. The nodes which are present in zone Z1 receives the beacon signal with good RSSI, the eligible node volunteers announces itself as cluster head and starts to broadcast the CH advertisement message to the nodes in the lower zones in the radio range. As discussed in Algorithm1, the eligibility of the node to be a cluster head is based on the residual energy and the average energy of the neighboring nodes and the hop count of the node to the cluster head trajectory (i.e., fixed as one).

Algorithm 1 (Z-DCH based cluster formation):

```
MSD = Minimum Separation Distance
    dc = Number of desired custer heads = 2;
    energy (n) = Remaining energy for node n
    Hop_count = RSSI value; m-node in the radio range;
    avg = ∑Energy (n) / Number of alive nodes
   while true do
    T←Ø
    While Q≠Ø do
    (u,v)←Q. removeMinElement()
    If P. find (u)≠P. find (u) then
    add edge (u, v) to T P. union (u, v)
    return T
   eligible = {n|energy(n)≥avg }
        While(|CH|<dc)
                if (n:n € eligible(m-CH, MSD(m, n))
        ≥MSD&& Hop_count==1)
    add (n, CH)
             remove (n, eligible)
        end if
      endwhile
   endif
    endwhile
```

The algorithm selects two eligible nodes from the cluster as MCH and VCH. A Minimum Spanning Tree (MST) is constructed having MCH as the root. The nodes in zone Z2 gets updated with the information of MCH and VCH of the corresponding cluster.

Once the cluster is formed, during the second phase (i.e., mapping phase) the leaf nodes in Z3 send their sensed data to the acting CH through the intermediate zone Z2. The nodes in Z2 are scheduled to communicate with CH (either MCH or VCH) based on the time slot. At odd number of time slots the nodes are mapped to MCH and at even slots the nodes are mapped to VCH. The data collection of MS is done as in algorithm 2.

The mapping period of the mobile sink with the CH depends on the fairness of the RSSI value between the nodes (i.e., mobile sink and CH). The mapping period determines the duration of data transfer from the CH to MS. Based on the speed of the MS the length of the timeframe is fixed.

Algorithm 2 (Data collection using Z-DCH algorithm):

```
Initialize the routing table;
LocalZone = 2; MinHop = 2;
if receive Broad Msg {t1, Src, RE, pid, hop}
   if routing table is empty
       LocalZone = ZID; MinHop = hop +1
       Update Routing Table {Dest = Src,
        metric = MinHop, zone = zid}
   endif
Broadcast Broad Msg {Src, residual time t2,
                         energy, 2};
send RREQ {zid, pid};
else if LocalZone = ZID
Lookup the routing table with zone = ZID and dest = Src;
    if no match in route entry
    Add a new entry to the routing table:
    {dest = Src; metric = hop+1; zone = ZID};
    Broadcast Broad Msg {Src, re, pid, 1};
    if new RREQ{zid, pid}
    Check all route entries in the routing table
   if zone = zid
          Update the routing table
   else
      Add a new entry to the routing table:
   {dest = Src; metric = Hop+1; zone = ZID};
   end if
   end if
   end if
```

The CH senses the presence of the MS in its radio range by the transmission of periodic beacon signals sent by the MS. There is a possibility of more than one CH trying to communicate in the radio range of MS. This situation creates data loss due collision of packets during simultaneous data transfer from various CHs. To avoid such data loss a synchronization techniques (Elson *et al*., 2002; Rhee *etal*., 2010; Mock *et al*., 2000; Coca and Popa, 2012) is adopted among CHs.

ADAPTIVE TIME SYNCHRONIZATION

As the nodes are densely placed, the possibility of more than one CH from zone Z1 transmitting to MS at the same time slot is more. This results in collision of packets and loss of data. An Adaptive Time Synchronization (ATS) Method is developed based to support the proposed protocol. ATS is designed as two level synchronization, Receiver Based Synchronization (RBS) for inter-cluster and Master Slave Synchronization (MSS) for intra-cluster synchronization.

As discussed by Elson *et al*. (2002), in RBS a receiver with receiver synchronization is used, instead of sender with receiver synchronization. Nodes broadcast beacons and other nodes use the arrival time of those beacons as a reference to find the time offsets between them. The communication scenario is that one node sends a beacon to its neighbors and receivers exchange their receive time of this beacon to find their relative time offsets and hence synchronize with each others as shown in Fig. 3. Precision of this scheme increases with the increase number of beacons used to synchronize. Precision of few μsec can be reached using this technique. On Berkeley mote, a precision of 11 μsec was achieved.

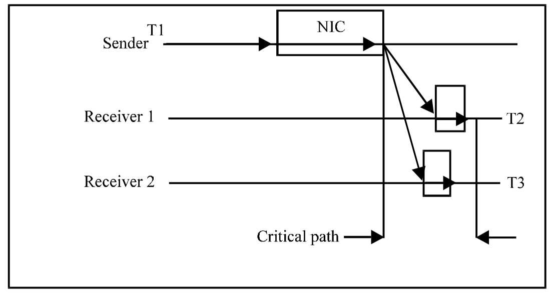

Fig. 3: Critical path analysis based on RBS

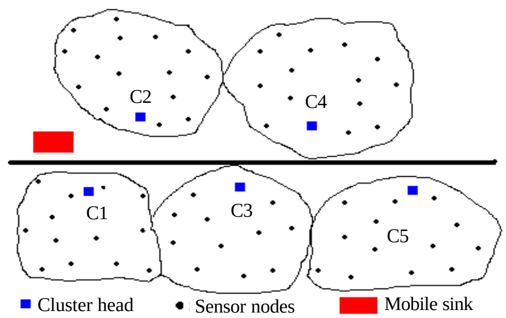

Fig. 4: Synchronization between clusters

During the traversal of the mobile sink along the trajectory, it sends the beacon signals. The first CH node which receives the signal applies the RBS synchronization technique and synchronizes with the neighboring CHs which falls in its radio range, i.e., C1 synchronizes with C2; C2 synchronizes with C3 and so on as shown in Fig. 4. This will avoid more than one CH communicating with MS simultaneously.

The CHs synchronizes with its cluster members by using the MSS Method. The slave nodes regard the local clock reading of the master node as the reference time and try to synchronize w ith the master. Here, the master is the CH and slaves are the cluster members. The synchronization happens during the transfer of data and control packets.

PERFORMANCE EVALUATION

This study evaluates the performance of the proposed data collection scheme implemented using TOSSIM (Levis *et al*., 2003). In this study, the performance of the proposed protocol is compared with the standard protocol like mobile LEACH. The simulation is done with a set of 300 sensor nodes deployed in a

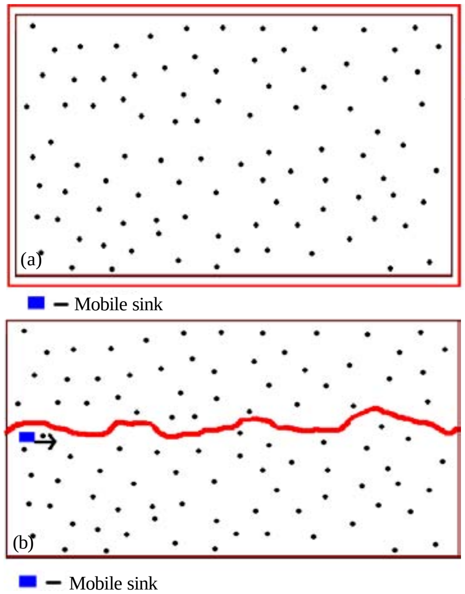

Fig. 5: Trajectory of mobile sink; a) across the observation area; b) along the edge of the observation area

Table 1: Simulation parameters

Parameter names	Parameter values
Initial energy	30 J
Packet size	100 bytes
Packet interval	15 msec
Simulation time	2000 sec
Number of nodes	300
Radio model	Two ray ground
Grid size	400×400 m
MAC protocol	MAC/802_15_4
Data traffic	CBR

random manner over a square region of 400×400. Except the sink node all other nodes in the network are static. The sink node travels at a speed of 20 m sec^{-1}. The mobile sink is assumed to have more storage area compared to the other nodes. The data rate of the sensor nodes is 250 kbp. The initial energy of the entire sensor node is set to 20 J. The size of the generated packet is 100 bytes and the packet interval is 15 msec. The other simulation parameters are as discussed in the following simulation Table 1.

The experiment is carried out in two scenarios. In the first scenario the mobile sink is made to traverse in the mid path across the observation area (PATH 1) as shown in Fig. 5a. In the second scenario the mobile sink travels along the edges of the observation area (PATH 2) as shown in Fig. 5b. Researchers observe the following metrics to evaluate the performance of the scheme:

- Throughput shows the total amount of data collected by the mobile sink during various simulation time (kbp)

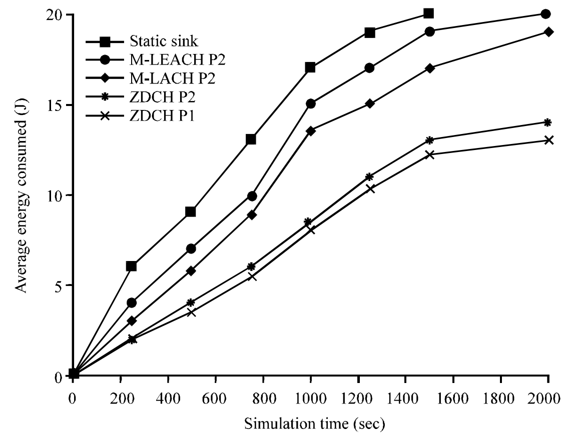

Fig. 6: Average energy consumed

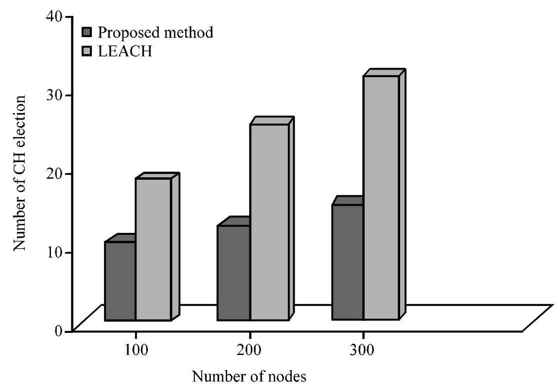

Fig. 7: Number of CH elections

- Network lifetime is defined as the time the mobile sink enters the observation area to the time all the nodes in zone 1 are dead (sec)
- Average energy consumed is the average energy consumed by all the nodes in the network during the simulation time

Figure 6 shows the comparison of the average energy consumed by the network against the simulation time (sec). The proposed protocol shows more energy conservation compared to Mobile-LEACH and static sink. The gradient curve in the graph infers that the proposed protocol shows more network stability as time increases by avoiding hotspot problem and reducing unnecessary control traffic. This is achieved by postponing the CH election, thereby eliminating congestion due to control traffics and network updates.

From Fig. 7, it is shown for a simulation time of 1500 sec the proposed protocol goes for 50% less times of CH election compared to the standard CH election protocol like LEACH. The experiment is conducted by varying the number of nodes in the network for the same simulation time.

Figure 8 shows the throughput of the proposed protocol in two trajectories (PATH 1 and 2) compared with Mobile LEACH and static sink. It has been clearly observed that the network with proposed protocol in PATH 1 is able to collect more data compared to PATH 2. In PATH 2 scenario the MS is passing through one cluster at a time, on the other hand in PATH 1 scenario the MS communicates with multiple clusters. The throughput of the other methods is observed to be very less on analysis for various levels of simulation time.

In Fig. 9 the lifetime of the network is calculated based on the time from the start of the MS traversal to the death of all the nodes in zone Z1, at this point the network is partitioned. From the graph it is shown that the proposed protocol shows an increase in the lifetime of nodes by efficiently utilizing the sleep/wake cycle of a node. The nodes in Z1 communicate to the MS by single hop, so the energy spent by the nodes are to maintain the cluster only during alternate cycles. Compared to the other methods the proposed protocol shows 48.3% increase in the number of alive node when using Mobile LEACH and 74% increase when using static sink.

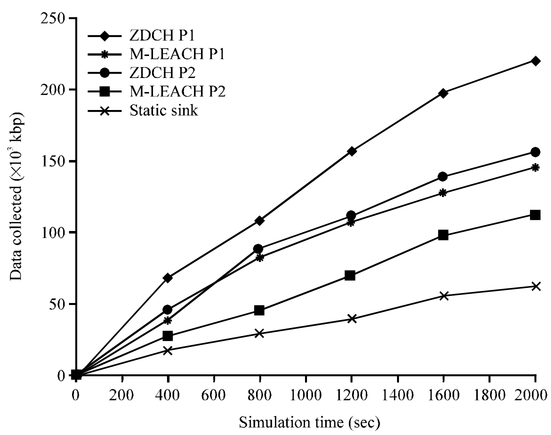

Fig. 8: Throughput of the network

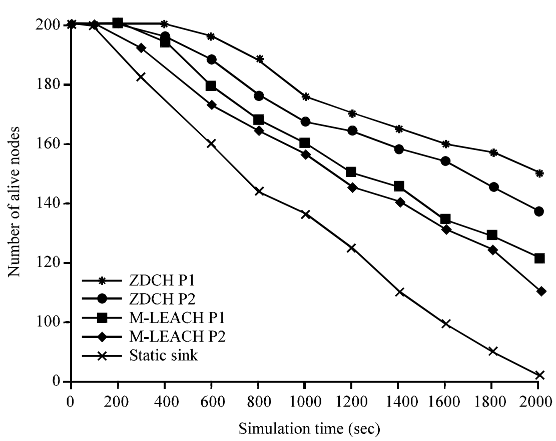

Fig. 9: Network lifetime

EXPERIMENTS

To validate the proposed scheme in real wireless communication environment, the proposed research was implemented on 24 IRIS motes. A prior test about the communication range of IRIS nodes has been made. The test results show that the transmission range of IRIS nodes is dynamic and heterogeneous and transmission between two IRIS nodes will strictly fail at the distance 1.3 μm in any direction when putting them on the ground and setting the transmission power of nodes to be 30 μm. The real time Testbed run for a simulation time of 2000 sec, the sum of energy consumed the nodes in the cluster is observed.

It is inferred from Fig. 12 that the sum of energy consumed by the cluster for the proposed protocol is less compared to LEACH.

Fig. 10: Crossbow IRIS motes

Fig. 11: Deployment of 24 IRIS nodes (circled in red) and mobile sink (circled in blue)

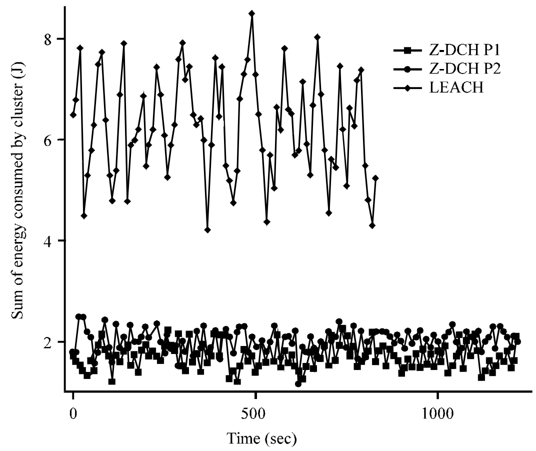

Fig. 12: Sum of energy consumed by cluster

CONCLUSION

An energy efficient clustering algorithm was designed using Zone-based Dual Cluster Head (Z-DCH) method to maximize data collection using mobile sink for wireless sensor network. In this technique, the mapping between sensor nodes and CHs (master and slave cluster head) is scheduled to balance the energy consumption of the nodes close to the trajectory and to maximize the lifetime of the node. In addition, a routing protocol is designed such that it supports the proposed clustering algorithm. The hybrid time synchronization method minimizes collision during data transfer and helps to improve the throughput of the network. The proposed schemes are validated on various trajectories of mobile sinks (i.e., through PATH 1 and PATH 2) and compared with the standard clustering protocol. It is proved from simulation and real time experiments that the proposed protocol and algorithm outperforms the existing techniques in terms of throughput and energy utilization.

REFERENCES

Coca, E. and V. Popa, 2012. A practical solution for time synchronization in wireless sensor networks. Adv. Electr. Comput. Eng., 12: 57-62.

Dechene, D.J., A. El Jardali, M. Luccini and A. Sauer, 2008. A survey of clustering algorithms for wireless sensor networks. Proceedings of the 4th International Conference on Information and Automation for Sustainability, December 12-14, 2008, Colombo, Sri Lanka, pp: 295-300.

Elson, J., L. Girod and D. Estrin, 2002. Fine-grained network time synchronization using reference broadcasts. Proceedings of the 5th Symposium on Operating Systems Design and Implementation, Volume 36, Dececember 9-11, 2002, New York, USA., pp: 147-163.

Enam, R.N., M. Imam and R.I. Qureshi, 2012. Energy consumption in random cluster head selection phase of WSN. IPCSIT, 30: 38-44.

Fang, W., S. Li, X. Liang and Z. Li, 2012. Cluster-based data gathering in long-strip wireless sensor networks. Adv. Electr. Comput. Eng., 12: 3-8.

Gao, S., H. Zhang and S.K. Das, 2011. Efficient data collection in wireless sensor networks with path-constrained mobile sinks. IEEE Trans. Mobile Comput., 10: 592-602.

Heidari, M., A. NooriEmamzade and H.R. Naji, 2013. Effect of using mobile sink and clustering on energy consumption in wireless sensor networks. Turk. J. Electr. Eng. Comput. Sci.

Hu, Y. and X. Wang, 2011. PSO-based energy-balanced double cluster-heads clustering routing for wireless sensor networks. Procedia Eng., 15: 3073-3077.

Jain, S., R.C. Shah, W. Brunette, G. Borriello and S. Roy, 2006. Exploiting mobility for energy efficient data collection in sensor networks. Mobile Networks Appli., 11: 327-339.

Konstantopoulos, C., G. Pantziou, D. Gavalas, A. Mpitziopoulos and B. Mamalis, 2012. A rendezvous-based approach enabling energy-efficient sensory data collection with mobile sinks. IEEE Trans. Parallel Distrib. Syst., 23: 809-817.

Lee, C. and T. Jeong, 2011. FRCA: A fuzzy relevance-based cluster head selection algorithm for wireless mobile Ad-Hoc sensor networks. Sensors, 11: 5383-5401.

Levis, P., N. Lee, M. Welsh and D. Culler, 2003. TOSSIM: Accurate and scalable simulation of entire TinyOS applications. Proceedings of the 1st International Conference on Embedded Networked Sensor Systems, November 5-7, 2003, Los Angeles, CA., USA., pp: 126-137.

Li, F., X. Wang and T. Xu, 2011. Energy aware data gathering and routing protocol based on double cluster-head. Communi. Inform. Sci. Manage. Eng., 1: 24-29.

Luo, J. and J.P. Hubaux, 2005. Joint mobility and routing for lifetime elongation in wireless sensor networks. Proceedings of the IEEE 24th Annual Joint Conference of the IEEE Computer and Communications Societies, Volume 3, March 3-17, 2005, IEEE Computer Society, USA., pp: 1735-1746.

Luo, J., J. Panchard, M. Piorkowski, M. Grossglauser and J.P. Hubaux, 2006. MobiRoute: Routing towards a mobile sink for improving lifetime in sensor networks. Proceedings of the 2nd IEEE International Conference, Distributed Computing in Sensor Systems, Volume 4026, June 18-20, 2006, San Francisco, CA, USA., pp: 480-497.

Marta, M. and M. Cardei, 2008. Using sink mobility to increase wireless sensor networks lifetime. Proceedings of the 9th IEEE International Symposium on World of Wireless, Mobile and Multimedia Networks, June 23-26, 2008, Newport Beach, CA., pp: 1-10.

Mock, M., R. Frings, E. Nett and S. Trikaliotis, 2000. Continuous clock synchronization in wireless real-time applications. Proceedings of 19th IEEE Symposium on Reliable Distributed Systems, October 2000, Nurnberg, pp: 125-132.

Rakhshan, N. and M.K. Rafsanjani, 2012. Improving network lifetime using a mobile sink with a new energy efficiency and minimum delay movement strategy for WSNs. J. Basic Applied Scientific Res., 2: 4275-4281.

Renugadevi, G. and M.G. Sumithra, 2013. An analysis on LEACH-mobile protocol for mobile wireless sensor networks. Int. J. Comput. Appli., 65: 38-42.

Rhee, I.K., J. Lee, J. Kim, E. Serpedin and Y.C. Wu, 2010. Clock synchronization in wireless sensor networks: An overview. Sensors, 9: 56-85.

Selvakennedy, S. and S. Sinnappan, 2006. An energy-efficient clustering algorithm for multihop data gathering in wireless sensor networks. J. Comput., 1: 100-110.

Shah, R.C., S. Roy, S. Jain and W. Brunette, 2003. Data MULEs: Modeling three-tier architecture for sparse sensor networks. Proceedings of the 1st IEEE International Workshop on Sensor Network Protocols and Applications, May 11, 2003, IEEE Communicatlons Society, USA., pp: 30-41.

Somasundara, A.A., A. Kansal, D.D. Jea, D. Estrin and M.B. Srivastava, 2006. Controllably mobile infrastructure for low energy embedded networks. IEEE Trans. Mobile Comput., 5: 958-973.

Vupputuri, S., K.K. Rachuri and C.S.R. Murthy, 2010. Using mobile data collectors to improve network lifetime of wireless sensor networks with reliability constraints. J. Parallel Distrib. Comput., 70: 767-778.