Target tracking solution for multi-sensor data fusion in wireless sensor networks

Duong Viet Huy, Nguyen Dinh Viet[*]

University of Engineering and Technology, VNU Hanoi, Vietnam

Abstract

Wireless sensor networks are often composed of many sensor nodes, they are powered by batteries with limited capacity. The sensor nodes are randomly scattered within in the ranger monitoring and send – receiver data using radio waves. Many research projects had demonstrated the consumption of battery power by the data transceiver occupy large compared to the calculation on the sensor node. In this paper, we propose energy saving solutions of nodes in a cluster by only choosing some nodes in the cluster to track the target and transmit this data to cluster head nodes. We based on the location of the sensor nodes in the cluster compare with the location of target and cluster head nodes to perform this selection. The effectiveness of the proposed solutions will be evaluated based on the number of sensor nodes are selected considering the number of nodes in the cluster, this is the base for the effectiveness of energy saving as well as the cluster nodes.

Keywords: Target tracking; multi-sensor data fusion, WSNs, ETR-DF.

1. Introduction

Currently, the monitoring system with sensor networks are developed in size (number of sensor nodes, range monitoring) and quality (parameter monitoring, the fineness of the measurement, etc..). There are different types wireless sensor networks (WSN) architecture to be studied as [1]: flat network, cluster-based network, tree-based network, grid-based network, structure free. WSNs with cluster-based network is choosen by many authors to study solutions to save energy. Clustering solutions, typically is algorithms LEACH (Low Energy Adaptive Clustering Hierarchy) at work [2] with the objective of sensor network split into grassroots networks called clusters, communication in clusters in style singlehop or multihop. Each cluster has one cluster head (CH) responsible for data fusion from all of number of sensor node in cluster, while participating in the routing to sent the results of data fusion to the base station (BS). Without loss of generality, we view that a cluster of sensor is a miniature sensor network. And, the content of the article will be directed to the sensor node cluster. With synthesizing data from multiple sensors is "data fusion" or "data aggregation", we will use the term "data fusion".

When WSNs operates in round, the sensor nodes in the cluster tracking target then sends the data to CH, CH data fusion and send this result to the BS. After each round, the network devide into the new clusters and elect new CH to continue operating. Thus, in each round, all nodes in a cluster must be monitored for 01 target and send the results to CH for data fusion, this has the following challenges: *first,*

measurement data can be the same, if all these sensor nodes send this the same data on CH will cause redundant data at the CH; *secondly,* the sending and receiving this redundant data on the network is causes wasting of stored energy of sensor nodes; *thirdly*, it will cause the risk of network congestion. According to [3], studies [4, 5, 6], energy consumption for the transceiver radio signals many times greater than the energy consumed to process other operations, including the calculation on the sensor node. We will back this content in the following section.

To resolve these challenges, we propose solutions ETR-DF (**E**fficiency in **TR**acking to target in multi-sensor **D**ata **F**usion in WSNs). The goal of this solution is energy saving of sensor node of the cluster by the optimizing in selecting sensor nodes in the cluster to track the target. The selection was based on the relative distance between the sensor node and the target should be monitored. Effective energy savings expressed in reducing the number of packets must send-receive between sensor nodes in clusters with CH and reduce the amount of data that must be proccess in the CH when CH fusion data. Beside the introduction and conclusion, the content of this article includes 3 main parts: Analysis of the strategic monitoring target of sensor nodes by radio waves; propose solutions ETR-DF; analyse effectiveness of solutions proposed by software simulation.

2. Strategy Of Tracking target

A. Target tracking methods

For wireless sensor network, there are two target tracking methods [7]: target oriented and track oriented. Target oriented is often used when the target is known in advance. The results of target tracking sensor nodes are used to synthesize and make decisions about targets. With track oriented, independent measurements

of each node will be determined based on the history of sensor nodes measure that during the period from start to finish with the measured values in a specified threshold before. This paper uses multi-sensor nodes to monitor a target, there are 3 models tracking Fig.1 [7]:

1) Complementary type

This tracking type in Fig. 1a, the sensor nodes are not directly dependent each other, each sensor node monitoring part of the target, measuring results can be different but they are measurement events of the target. Thus, the measured value of the sensor nodes can be complemented to each other. Inputs to data fusion from the sensor nodes can be better.
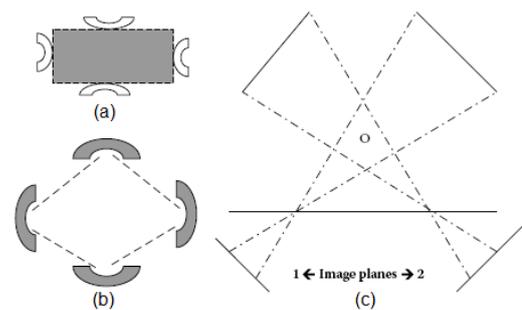

Figure 1 – Models tracking [7].

2) Competitive type

This tracking types in Fig. 1b, each sensor node independently measure all properties of the entire target. Fusion data from multiple measurement results of sensor nodes on the same set of attributes of the target, the measurement results can be different depending on the time sensitivity of the sensor nodes to the target at the same measuring time or at different time points measured. This tracking type, the CH can tolerance better because CH can compare measurement results of sensor nodes in the data fusion process.

3) Cooperative type

Examples of this type of tracking in Fig. 1c of 2 sensor nodes measuring by image of the

target. A sensor node can not measure all the target, CH uses additional measurement results (the intersection) of an other sensor nodes.

B. Sending - receiving data by radio wave

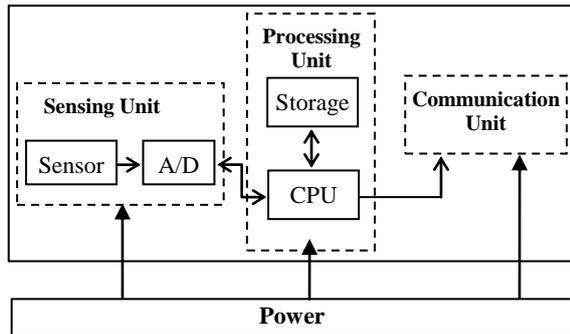Energy consumed on each sensor node in Fig. 2, there are 03 Units of energy consumption [8]:

Figure 2 – Diagram of power supply for sensor node [8].

Processing unit (PU): Consumption of energy to control and process entire operation of the sensor node. PU includes data storage and CPU processing.

Sensing unit (SU): Consumption of energy to provide sensing and transmission of information about the event of the target to PU. SU includes sensor, adapter A/D (analog/digital) signal conversion Digital to Analog (from PU to SU) and signal conversion Analog to Digital (from SU to PU).
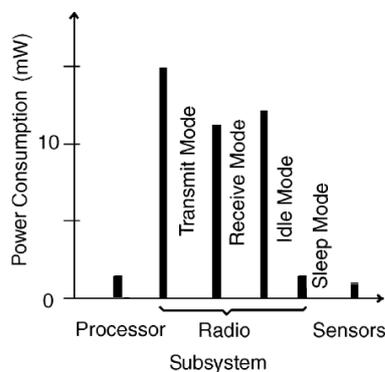

Figure 3 – Rate of energy consumption during sensor operation [5]

Communication unit: Power consumption to communicate signal as sending data or receiving data by electromagnetic waves from the sensor node to another node or BS.

According to the statistics [2], the energy consumed by transceiver radio signals many times greater than the energy consumed to process task other of sensor node, including the calculation on the sensor node. Chart comparing the rate of energy consumption during sensor operation in Fig. 3. The relationship between energy consumption E_{TX} when sending *k bit* with distance *d* and E_{RX} when receiving *k bits* have been proven in [1]: $E_{TX} = E_{elec}*k+E_{amp}*d^2$ *and* $E_{RX}=E_{elec}*k$, where E_{elec} is energy consumption of sensor node to send or receiving *1 bit*, E_{amp} is energy consumption of sensor node to sending *1 bit/m²* by radio signals.

Thus, the energy of the electromagnetic waves transmitted from the sensor node data. They will decrease exponentially compared to the distance between sender node and receiver node, to ensure the packet to its destination. The sensor node must to manually adjust (amplifier) power transmitters with the square of the distance [1]. For this reason, research groups oriented to reduce the amount of data sent from sensor node.

3. ETR-DF solution

A. Input data to fusion

As discussed in Part II, A, target measurement data from the sensor nodes can be same completely or partially. If all the same data are sent to CH by sensor nodes (for synthesis). It will also cause of excess data at CH and the risk of traffic congestion. More importantly, useless energy wasted when sending the same data to CH.

Therefore, this paper aims to select sensor nodes based on the relative position between

the sensor nodes with CH with target. The target of tracking and resolving partially drawback above is solution named ETR-DF.

B. Selecting the sensor node

Suppose there is *a cluster of* sensor nodes (S) consists of *n* nodes are scattered randomly on a plane. It's known that the location of the *01* target (Tag) and *01* node cluster heads (CH). Initially, the stored energy of sensor nodes are the same. In the process of using the energy of the decline button and the inventory levels can not be equal. ETR-DF solution selects buttons located on the road shortest between CH and Tag. Without loss of generality, in this paper, we use the distance calculation in plane geometry.

1) Selected sensor node area

a) Distance

It can be considered sensor nodes, Tag, CH are the points in the plane, then the coordinates of the points are Node (x_{node}, y_{node}), Tag (x_{tag}, y_{tag}), CH (x_{CH}, y_{CH}). Call $d_{node-CH}$, $d_{node-tag}$, d_{CH-tag} are respectively distances between sensor nodes and CH, between sensor nodes and Tag, between CH and Tag and they are calculated as follows:

$$d_{node-CH} = \sqrt{\left(x_{node} - x_{CH}\right)^2 - \left(y_{node} - y_{CH}\right)^2}$$

$$d_{node-tag} = \sqrt{\left(x_{node} - x_{tag}\right)^2 - \left(y_{node} - y_{tag}\right)^2}$$

$$d_{CH-tag} = \sqrt{\left(x_{CH} - x_{tag}\right)^2 - \left(y_{CH} - y_{tag}\right)^2}$$

Between CH and Tag always exist one line d_0, straight lines d_1 and d_2 perpendicular to go through CH and Tag. They divided space to sections as Fig. 4. An example, the position of

the sensor node S_0 to S_7 with CH and Tag are corresponding with 8 probable cases:
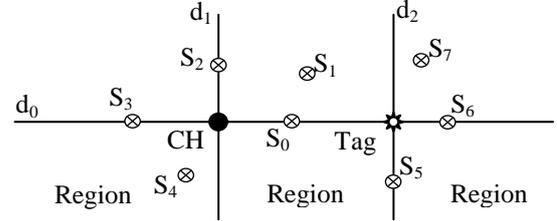

Figure 4 – Position of the sensor node with CH, Tag

We found that if at the time of review, the stored energy of nodes are the same, and measure Tag and send to CH with the same data unit. The nodes located on the straight line connecting CH with Tag (eg node S_0 in Fig. 4) may consume less energy because the distance d = $d_{node-CH}$ + $d_{node-tag}$ = d_{CH-tag} = d_{min}. Call $Ed_{node-tag}$ and $Ed_{node-CH}$ are respectively energy consumption of sensor nodes when measuring target and sending data to CH. Then: $Ed_{node-CH} > Ed_{node-tag}$ according to [6] and the case for $d_{node-CH} = d_{node-tag}$. So in this case, the node S_0 near CH may be more efficient in energy saving.

b) Deviation of distance

We propose to use the number $\delta \geq 0$ to determine the limit of the distance incorrect position of the sensor compared to the boundary determined priority areas, priority levels. δ is used only in blocked areas by d_1 and d_2. This means that if a horizontal axis *(Ox)* contains d_0, the origin O is the midpoint of CH and Tag. We only consider the sensor nodes coordinate axis *Ox* on blocked area (or close area) *[-(d_{CH-Tag}/2, (d_{CH-Tag}/2]* Where $\delta = 0$, the sensor nodes are on the boundary. Since $\delta \geq 0$ and there are 3 priority levels, so a sensor node can belong to many different priority levels. The location of sensor nodes are in the intersection area of priority levels.

c) Priority area

Based on the analysis of the distance between sensor nodes, CH and Tag, ETR-DF solution focuses on analyzing region 2 - area bounded by d_1, d_2 and including d_1, d_2 in Fig. 4. Region 2 is divided into priority areas and priority levels in Fig. 5. The priority level from high to low is used by CH in case of selection results-measurement of target to data fusion. This means that, in the same period of cluster activity, the CH can select any node in the cluster sensor of priority areas that have higher priority, using measure results to data fusion. In these priority areas, criteria of selecting sensor nodes of CH, except for the priority levels, there also have other criteria such as energy sensor node reserves, the packet must be forwarded to the CH to complete measurement data target, rate $d_{node\text{-}CH}/d_{node\text{-}tag}$, etc.

If the location of sensor nodes from high to low priority are following: *Level 1* is a straight line CH-Tag; *Level 2* limited by the diameter circle CH-Tag; *Level 3* the area bounded by d_1 and d_2 with Ellipse have 2 special points CH, Tag and focal (or focal distance) $d_{CH\text{-}tag}$.
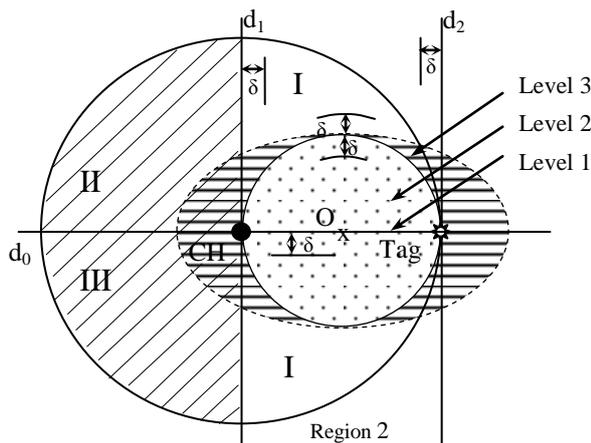

Figure 5 – Priority area, priority levels

- The first priority area *(A-Prio1)* is rectangular *($d_{CH\text{-}Tag}$ * 2δ)*, coordinates 4 points

$(-(x_{CH} + x_{tag})/2, -\delta)$, $((x_{CH} + x_{tag})/2, -\delta)$, $((x_{CH} + x_{tag})/2, \delta)$, $(-(x_{CH} + x_{tag})/2, \delta)$;

- The 2nd priority area is annular that limited by *2* circles (center O), radius $(d_{CH\text{-}Tag}/2) - \delta$ (limited to inner circle) and the center O, radius $(d_{CH\text{-}Tag}/2)+\delta$ (limit outside the circle). Priority Area for level 2, *A-Prio2 = π * [(($d_{CH\text{-}Tag}$ / 2) + $\delta)^2$-(($d_{CH\text{-}Tag}$/2) - $\delta)^2$]* and blocked by d_1, d_2.

- The 3rd Priority area *(A-Prio3)* is the area bounded by d_1, d_2 and the ellipse not communicate with priority 1 and priority 2. The Ellipse has CH, Tag, called semi-major axis, small axis, haft focal, eccentricity of Ellipse are $a_{ellipse}$ $b_{ellipse}$, $c_{ellipse}$, $e_{ellipse}$. *Set $c_{ellipse} = b_{ellipse} = d_{CH\text{-}Tag}/2$* and

$$a_{elip} = \sqrt{b_{elip}^2 + c_{elip}^2} = \frac{\sqrt{2}}{2}d_{CH-Tag} \quad \text{and} \quad e_{elip1} = \frac{\sqrt{2}}{2}. \text{ We}$$

set the hypothesis, there exists at least one sensor node of at least 1 in 3 priority areas.

2) ETR-DF algorithm

1. Set n = num_cluster_nodes; δ;
2. Define CH,Tag
   and set CH(x_{CH}, y_{CH}),Tag(x_{tag}, y_{tag});
3. The CH-Tag line in horizontal axis (Ox), $y_{CH} = y_{tag} = 0$;
4. Origin is midpoint CH-Tag line, O((x_{CH} + x_{tag})/2, 0);
5. Define d(node,CH), d(node,Tag), d(CH,Tag);
6. Identify priority areas: A-Prio1, A-Prio2, A-Prio3;
7. Select sensor node in cluster, add nodes to priority areas;
8. For {set i 1} {$i <= $n } {incr i};
9. If not any S_i belong to A-Prio$_J$ (j=1, 2, 3) then add CH to node_prio$_J$
10. Eles S_i belong to A-Prio$_J$ (j=1, 2, 3) then add S_i to node_prio$_J$;
11. Sent data to CH
12. Set m = num_nodes_ prio$_J$;
13. For {set j 1} {$i <= $3 } {incr j};
14. For {set k 1} {$i <= $m } {incr k};
15. Sent S_k.data_measure to CH;
16. End.

Right after clusters have been established, there have nodes in the cluster and CH, ETR-DF algorithm is started. *Line 1*, set number of node in cluster and deviation of distance δ. *Line 2*, Define CH, Tag and determine the coordinates of CH, target (Tag). *Line 3, 4,* CH-Tag line on the horizontal axis *(Ox)*, O point is a centre of circle and midpoint of CH-Tag line. *Line 5*, determine distance between sensor node and CH, sensor node and target, CH and target. *Line 6*, identify priority areas with deviation of distance δ. *Line 7 to 10*, in priority areas, select sensor node in cluster and belong to priority areas *(line 9)*, add nodes to priority areas (line 10) for selecting sensor node next step. *Line 11 to 15*, select sensor node in $node\_prio_1$ set with *k* sensor node, *k* may variable depend on node priority set, then this sensor node send data measure about target to CH. *Line 16,* the end of round.

C. Simulation and analysis

1) Parameters simulation

Table 1: The main parameters

Parameter	Value
Number of sensor nodes	*100*
Coordinates node in the (100m x 100m)	*Random*
The min and max number of clusters	*1 $\rightarrow$ 10*
The number of clusters desired	*5*
Initial stored energy of sensor nodes	*2 J*
Energy to receive 1 bit	*5 nJ*
Energy consumption to send 1 bit	*50 nJ*
Amplification factor radio transmissions	*10pJ/bit/m²*
Capacity of node while Idle or Sleep	*0 W*
Speed of radio transmissions	*1 Mbps*
Header size (hdr_size)	*25 Byte*
Sensing data size (sig_size)	*500 Byte*
Time per round/ data fusion (T)	*20 s (option)*
Number of sensor nodes in cluster (n)	*Random*
Deviation of distance (δ)	*1 m*

2)   Analysis and evaluation efficiency

We use NS2 simulation software, version 2.34 installed on Ubuntu 12.04 operating system and source code from MIT *(Massachusetts Institute of Technology)* [2, 9, 10]. The parameters ETR-DF simulation are in Table 1.

Simulations with *01* Target *(70, 70), 100* sensor nodes (stored energy *2J/node*) are randomly distributed in *Fig. 6*, network automated clustering with LEACH algorithm [2].

Time per round $T = 20s$, can change *T*. At the beginning of each cycle, sensor network including *100* sensor nodes is divided into clusters, the number of sensor nodes in each cluster may be different in *Table 2*.

Table 2. Number of cluster, sensor

Time (secth)	Total live node	CLUSTER							
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
20	*100*	14	10	9	5	26	26	10	
40	*100*	26	16	23	10	25			
60	*100*	18	11	44	27				
80	*100*	48	25	11	16				
100	*100*	11	15	18	37	19			
120	*100*	17	10	10	17	17	14	15	
140	*100*	28	52	20					
160	*100*	17	8	10	7	11	19	14	14
180	*99*	17	24	16	31	11			
200	*99*	27	10	18	25	19			
220	*99*	26	29	5	39				
240	*98*	16	39	14	29				
260	*98*	14	31	30	23				
280	*97*	28	53	11	5				
300	*94*	9	13	27	12	14	19		
320	*94*	22	20	21	31				
340	*92*	48	4	26	14				
360	*89*	17	19	5	4	20	24		
380	*73*	22	30	21					
400	*68*	6	13	8	5	16	5	8	7
420	*50*	5	9	15	17	4			

In each round, we will examine the cluster has the most sensor nodes, apply ETR-DF algorithm to ensure repeatability and representation of the sampling size. During the survey, after cycle $T = 20s$, network clustered again, the number cluster and numbers in each cluster node sensor in Table 2. In each cycle, we use ETR-DF algorithms for sensor node cluster. For example in second 80th, sensor network is divided into 4 clusters in Fig. 7, the nodes in the CH following Leach algorithm, distributed nodes position as follows: Cluster 1: 48 nodes (Fig. 7a), Cluster 2: 25 nodes (Fig. 7b), Cluster 3: 11 nodes (Fig. 7c), Cluster 4: 16 nodes (Fig. 7d). Applying ETR-DF solution to choice measurement results from the sensor nodes in the cluster, an example for Cluster 1 and Cluster 4 in Fig. 8.
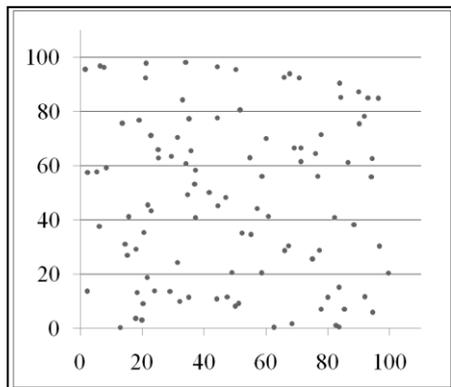

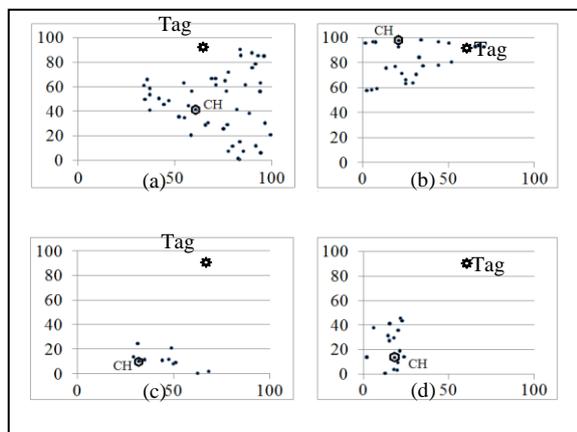Figure 6. The position of the sensor nodes in the survey plane

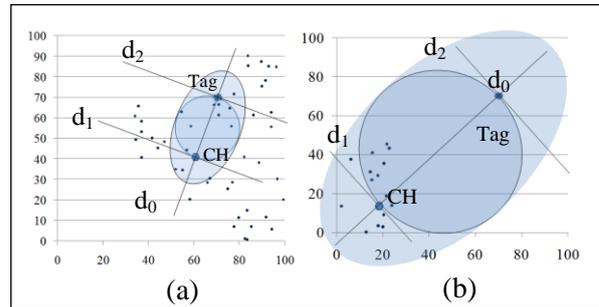Figure 7. Cluster and number of node in cluster.

Figure 8. Apply ETR-DF to select sensor node, Cluster 1 with 48-nodes in figure 8a and Cluster 4 with 16-nodes in figure 8b.
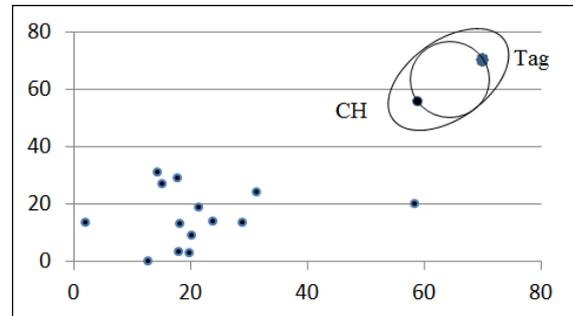

Figure 9. Apply ETR-DF to select sensor node Cluster 7 in the 120th second.

Cluster 1 with 48 sensor nodes (including the CH 1): after applying the algorithm ETR-DF, 13 of the 47 sensor nodes are selected for CH button to retrieve data. Thus, there are 34 sensor nodes without energy loss due to send data to CH. With simulation profile in Table 1 and the simulation results, we calculate the size of sensing data (sig_size) savings from 34 button is 681, equivalent to 681 * 340 500 bytes 500byte =. Since energy consumption is to send 1 bit 50nJ, so energy savings of 34 340 500 bytes * button 8bit / byte * 50nJ / bit = 17,025,000 NJ = 17.025μJ = 0.017025J. In this case, the energy saving efficiency reaches 76.5%.

With Cluster 4, when applying ETR-DF, all nodes participate in send and receive data processes, energy-saving efficiency is 0%.

Table 3. The average effective fusion of cyclic clusters in simulation
between ETR-DF and LEACH

Time (s[th])	20	40	60	80	100	120	140	160	180	200	220
ETR-DF	553	730	1175	833	928	1587	1236	377	1228	870	589
LEACH	1328	2638	2125	1725	1709	2074	1893	1286	3076	2308	2116
Efficent (%)	41.64	27.67	55.29	48.29	54.30	76.52	65.29	29.32	39.92	37.69	27.84

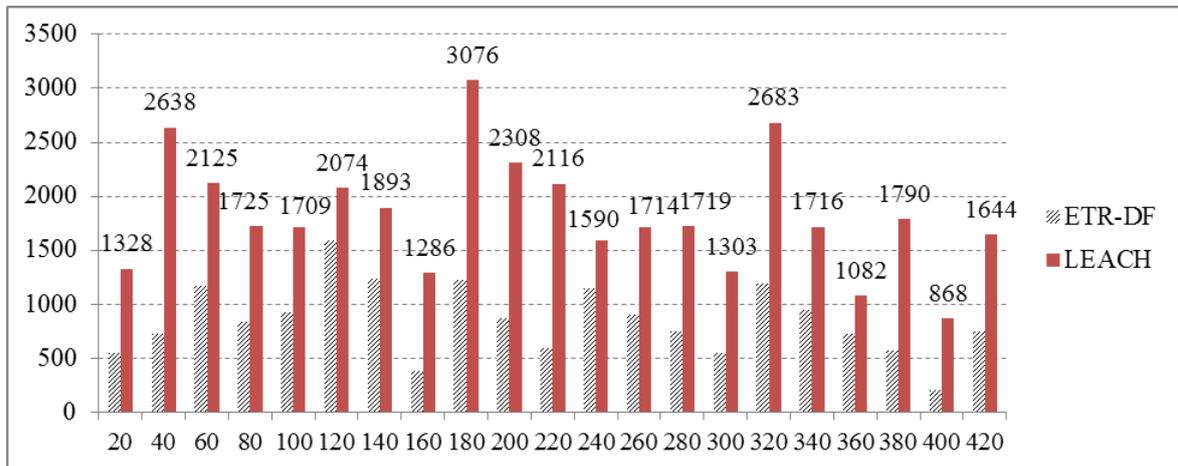| Time (s[th])	240	260	280	300	320	340	360	380	400	420
ETR-DF	1152	902	752	547	1193	950	722	569	204	747
LEACH	1590	1714	1719	1303	2683	1716	1082	1790	868	1644
Efficent (%)	72.45	52.63	43.75	41.98	44.47	55.36	66.73	31.79	23.50	45.44

Figure 10. comparing the number of packets to transmit by ETR-DF and LEACH

However, there are some cases that energy-saving efficiency reaches 100%. For example, network is divided into seven clusters at 120 seconds, each cluster node numbers in Table 2. According to the simulation results the position of the nodes of the cluster 7 versus CH and Tag in Fig 9.

This is a special case when applying ETR-DF because CH plays two roles as a sensor node and a CH node. Effect of energy savings of clusters reaches 100%. However, in this case, conditions are CH node must be dependable and using measure results from a sensor node

does not affect to the measure efficiency. We expect to continue to research this problem in the future.

By analyzing data for all clusters in each cycle T = 20s and comparing with LEACH algorithm in the simulation time to the 420th second, we can realize that nodes rate selected with total nodes in clusters with about great oscillations, from 0% to 100% in each cluster. However, if calculating in each cycle the T the effection is between 23.5% and 76.52%. The average effective fusion of cyclic clusters in simulation time of cycle T between ETR-DF

and LEACH in Table 3. Effective energy saving by limiting the data sent by radio waves in Fig.10.

Conclusion

We have proposed the solution of cluster target tracking sensor nodes based on the distance between the sensor nodes with CH and target in this paper. This solution has effect to reduce the amount of data to synthesize CH input data by reducing the number of packets to be transmitted from the sensor nodes in the cluster send to CH, so it saves enegry of sensor nodes simultaneously, limit the risk of causing congestion.

ETR-DF algorithm efficiency will be better if the stored energy of sensor nodes is relatively uniform, then the distance is the main criterion for choosing the sensor node. In addition, the measurement reliability of the sensor node is being considered because in some cases, measurement data from a sensor node may be better than the aggregated results from multiple sensor nodes. This is very natural for data fusion from multiple sensor in wireless sensor networks.

In the future, we will research the optimal solution in choosing the sensor nodes based on remain energy of sensor nodes and location of the sensor node to the position of CH and targer. We will also research special case when applying ETR-DF with cases exist only CH in the priority region.

References

[1] Vaibhav Pandey, Amarjeet Kaur and Narottam Chand, "A review on data aggregation techniques in wireless sensor network", Journal of Electronic and Electrical Engineering, Vol. 1, Issue 2, 2010, pp.01-08.

[2] W. Heinzelman, A.P. Chandrakasan and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks", IEEE Proceedings of the Hawaii International Conference on System Sciences, January 4-7, 2000, Maui, Hawaii.

[3] Kazem Sohraby, Daniel Minoli, Taieb Znati, *"Wireless Microsensor Networks Technology, Protocols, and Applications",* Published by John Wiley & Sons, Inc., Hoboken, New Jersey, 2007, pp. 307-319

[4] W. Heinzelman, A. Chandrakasan, H. Balakrishnan, ''An Application-Specific Protocol Architecture for Wireless Microsensor Networks,'' IEEE Transactions on Wireless Communications, Vol. 1, No. 4, Oct. 2002, pp. 660–670.

[5] A. A. Ahmed, H. Shi, Y. Shang, ''A Survey on Network Protocols for Wireless Sensor Networks,'' Proceedings of Information Technology Research and Education (ITRE), 2003.

[6] C. Schurgers, V. Tsiatsis, S. Ganerival, M. Srivastava, ''Optimizing Sensor Networks in Energy–Latency–Density Design Space,'' IEEE Transactions on Mobile Computing, January 2002, pp. 70–80.

[7] Jitendra R. Raol, "Multi-Sensor Data Fusion with Matlab", CRC Press, by Taylor and Francis Group, 2010, pp 97-206.

[8] Bing Liang, Qun Liu, "A Data Fusion Approach for Power Saving in Wireless Sensor Networks", Proceedings of the First International Multi-Symposiums on Computer and Computational Sciences (IMSCCS'06 - 2006), Vol 2, pp. 582 – 586.

[9] NetworkSimulator: http://www.isi.edu/nsnam/ns/

[10] Neha Singh, Prof. Rajeshwar Lal Dua, Vinita Mathur, "Network Simulator NS2-2.35", International Journal of Advanced Research in Computer Science and Software Engineering, Volume 2, Issue 5, May 2012.