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A Novel Data Dissemination Algorithm for Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) are usually deployed in a remote or inaccessible area to be monitored and their duty is to sense raw data and then disseminate them to some remote base stations. It is desired that data transmission is energy efficient and energy consumption is balanced among all nodes so that lifetime of WSNs can be prolonged. In this paper, we propose a novel routing algorithm named energy cost and residual energy oriented (ECREO) for WSNs based on geographical and energy aware routing (GEAR). The ECREO mechanism can not only be used as a flat protocol in small-scale network but also can be integrated in many hierarchical routing protocols. ECREO algorithm takes advantage of the sufficient energy of BS and makes a good tradeoff between energy cost and residual energy. It adopts improved Dijkstra algorithm to find the best scheme. Simulation results show that ECREO algorithm can well balance energy efficiency of each node and avoid hot spot phenomenon. The network lifetime can be prolonged twice based on our ECREO algorithm than other routing algorithms.

Keywords: *wireless sensor networks, data dissemination, clustering, routing*

1. Introduction

Wireless sensor networks (WSNs) are composed of a large number of wireless sensor nodes that are densely deployed either inside the phenomenon or very close to it. WSNs can be used in many application areas such as military application, environment monitoring, health-care, smart home, structure status monitoring and so on [1].

The tiny and low cost sensor nodes are usually energy limited and have no energy supply. Thus, energy efficient routing protocols for WSNs are very important [2, 3]. It is desired that all nodes can have a synchronous speed of energy consumption so that there always are some living nodes in the area we deployed sensors in and network lifetime can be as long as possible [4]. There are two challenges in prolonging network lifetime. The first challenge is utilizing energy efficiently. That means abating energy cost and avoiding the unwanted energy dissipation. The second one is how to balance energy consumption among all nodes of network to avoid hotspot phenomenon. That means avoiding the scenario that nodes suffer high load and die very early and others in leisure die very lately.

Most of existing routing protocols aim at solving these two issues, and they can be divided into two classes, namely flat and hierarchical. Flat protocols include Minimum Transmission Energy (MTE), energy aware routing using sub-optimal path [5], *etc*. Famous hierarchical protocols include Low-Energy Adaptive Clustering Hierarchy (LEACH) [6], a Hybrid Energy-Efficient Distributed clustering approach (HEED) [7], GAF [8], *etc*.

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Clustering technique helps to reduce the communication traffic between network and base station. Generally speaking, clustering protocols can outperform flat protocols in balancing energy consumption and network lifetime prolongation by using technology of data fusion [9] [10]. Cluster heads (CHs) gather data from nodes in their cluster and execute data aggregation operation locally. Most of existing clustering protocols have a common point: nodes can only get the topology around them; therefore the generated route is local optimum. In other words, this kind of schemes can only balance energy consumption in local cluster rather than in global network. Nowadays many sensors assemble global positioning system (GPS) and many position location techniques like triangulation location [11, 12] are proposed, and then it is no longer hard to get sensor's geography position. By this way, it is also no longer hard for base station to know the topology of whole network.

In this paper, we propose an energy cost and residual energy oriented (ECREO) algorithm which can balance the energy consumption in global network. In our model, node only needs to transmit data to the next node with specified ID. Each node maintains an integer locally which refers to the next hop node's ID. And this ID renews when node receives new ID-updating orders from the base station. ECREO algorithm can not only be used as a flat protocol in small-scale network but also can be used to optimize many hierarchical protocols by balancing energy consumption among CHs.

2. Related Work

In [8], authors proposed a GAF protocol which divides one network into several fixed sub-network by their geographic location, and then rotate cluster head role among nodes in a cluster round by round. GAF protocol is easy to implement and outperforms flat protocols, but it doesn't consider about optimization of the data transmission between CHs and base station. In [6, 7], LEACH and HEED are proposed. In both of them, cluster head nodes are elected randomly and clusters distribution changes in every round. These two protocols use direct transmission approach to implement communication between CHs and BS. In each round, when the clusters set-up phase is done, the sub-network consists of CHs suffers the problem same to GAF.

Authors in [13] proposed a self-organized clustering protocol named topology discovery algorithm (TopDisc) for WSNs. It is distributed and use only local information to construct the approximate topology of the network. TopDisc algorithm forms a tree of cluster (TreC) rooted from a specified node. When clustering process is completed, efficient data dissemination and aggregation can be achieved. However TopDisc algorithm is sensitive to the topology change and iterant processes of cluster construction cost too much. In addition, TopDisc algorithm does not consider the residual energy of nodes which could cause the hotspots phenomenon.

In [14], an advanced inter-cluster routing protocol (ICRP) based on HEED is proposed. Its main idea is optimizing transmission between CHs and BS by using multi-hop scheme. The router it found is based on local area's information but not global. And it requires further data fusion of packets from adjacent clusters, or it would lose its superiority. At transmission phase, center CHs also transmits packets to base station by direct transmission. Compare to ICRP, our proposed ECREO algorithm is easier to implement and asks for less requirements.

3. Our Proposed ECREO Algorithm

3.1 Assumptions

Some assumptions we made in our work are listed as follows.

- The base station is fixed and out of sensor fields.
- Each node has its own fixed ID.

- This wireless sensor network is based on query.
- Each sensor node's geographic location can be known.

3.2. Main Idea of ECREO.

The key algorithm of ECREO is an improved Dijkstra's algorithm. Original Dijkstra's algorithm is a graph search algorithm that solves the single-source shortest path problem for a graph with nonnegative edge path costs [15]. It uses distance as its weight-evaluation function. In ECREO algorithm, we use weight-evaluation function shown in below equation (1). See equation (1), "EnergyCost" stands for the total energy consumption of node i in transmission and "RestEnergy" stands for the rest energy of node i. Before using them, we need to normalize them to reduce the error caused by their 0different value ranges.

$$Weight\ (i) = \frac{Normalized\ \ EnergyCost}{Normalized\ \ \mathrm{Re}\ stEnergy} \qquad (1)$$

3.3. Details of ECREO Mechanism

3.3.1. System Model

(1) Radio model

In our work, we use the radio model proposed by literature [6]. In this model, there are three steps in the procedure that node A sends a 1-bit packet to node B. Suppose the distance between A and B is 1 meter.

Step 1. Node A runs the transmitter electric circuitry to get ready for transmission. The energy consumption of node A is E_{t-elec} .

Step 2. Node A runs the transmit amplifier to transmit the 1-bit signal. It costs node A ε_{amp} energy units to transmit 1-bit signal to node B 1 meter away.

Step 3. Node B runs the receiver electric circuitry to receive the 1-bit signal. It costs node B E_{t-elec} energy units to receive 1-bit signal.

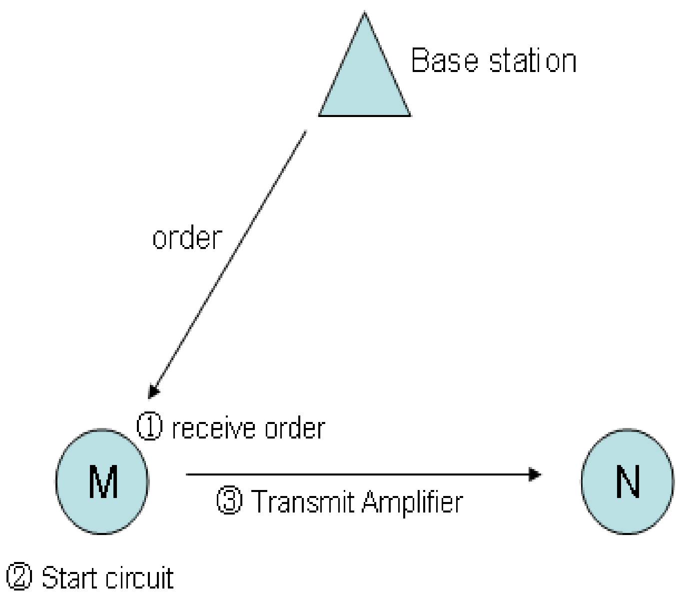


Figure 1. Three Phases of Transmission

(2) Energy dissipation model

To each node in wireless sensor networks using ECREO algorithm, there are three phases it has to dissipate energy when it (its ID is M) transmits k-bits data to next node with specified ID of N (see Figure 1).

Corresponding to Figure 1, detailed process and energy cost is listed as follows:

1. Initially, node M doesn't know which node it should transmit data to. And this situation is persisting until it receives the order from the base station. The order contains several fields (see Figure 2-a). By getting the next hop node's ID from the order, node M knows which node it will forward packet to. We assume the length of order is L-bits. Energy dissipation in first phase is computed by equation (2).

$$E_1 = L * E_{r-elec} \qquad (2)$$

2. We suppose the length of the result data is k-bits and the length of additional information of node's rest energy is R-bits (see Figure 2-b). Energy dissipation in second phase is computed by equation (3).

$$E_2 = (k + R) * E_{t-elec} \qquad (3)$$

3. Another field in order is the distance between M and N (denoted by d). According to the distance, the transmit amplifier adjusts its signal intensity to make sure that node N can receive signals from it. Energy dissipation in third phase is computed by equation (4).

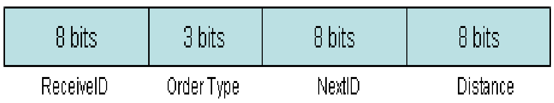
$$E_3 = (k + R) * d^2 * \varepsilon_{amp} \qquad (4)$$

Because E_{t-elec} equals to E_{r-elec}, the total energy cost in these three phases is computed by equation (5).

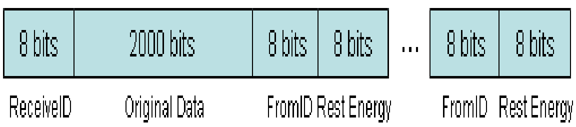
$$\begin{aligned} E_{total} &= E_1 + E_2 + E_3 \\ &= (L + k + R) * E_{r-elec} + (k + R) * d^2 * \varepsilon_{amp} \qquad (5) \end{aligned}$$

(3) Data structures

Two important structures related to network communication are "Order" and "Data Packet". Fields of them are shown in Figure 2 in which "FromID" refers to ID of the source node and "ReceiveID" refers to ID of the destination node. In Figure 2 (b), fields of "FromID" and "RestEnergy" can repeat N times, N equals to forwarded times of this packet. By receiving a data packet, the base station can know energy information of each node involved in this query.



(a) Order Structure



(b) Data Packet Structure

Figure 2. Structure of Order and Data Packet

3.3.2. Network Communication Principle

In the network using ECREO algorithm, base station plays a centric role. It maintains the global information of network and controls every communication among nodes. Nodes in this network doesn't care about how to choose the best path, they just need to forward packets to the next hop node. In other words, they are blind to the procedure of generating the best scheme. There are three phases for base station to receive data from all nodes in each round. They are scheme generating, order Broadcast and data transmission.

(1) Scheme generating phase

In this phase, base station considers the current state of the whole sensor network and generates the best scheme. We assume there are (n+1) nodes in the sensor network and the (n+1)th node is the base station. Some relevant variables are shown in Table 1.

Table 1. Relevant Variables

Variables	Subject to	Illustration
$Flag\ (i)$	$1 \le i \le n$	If Flag(i)=1, it stands for this node has found its best path.
$SCost\ (i, j)$	$1 \le i \le n$ $1 \le j \le n$	Normalized total energy cost (include receiving and transferring) for node j to transmit 2000 bits data to node i.
$SBC\ (i)$	$1 \le i \le n$	Normalized total energy cost for once transmission via the best path.
$SRE\ (i)$	$1 \le i \le n$	Normalized rest energy of node i.
$A(i)$	$1 \le i \le n$	It can be computed by equation 1. Initially, it stands for the evaluation value of node i in direct transmission. Initially, $A(i) = \frac{SBC\ (i)}{SRE\ (i)}$
$AN\ (i, j)$	$1 \le i \le n$ $1 \le j \le n$	The evaluation value for node j to transmit data to the next node i. $AN\ (i, j) = \frac{SCost\ (i, j)}{SRE\ (j)}$
$Next\ (i)$	$1 \le i \le n$	Next node's ID which node i forward packets to in the best path.

(2) Order broadcast phase

When the base station generates the best scheme for every node in the network, it is ready to begin a query. For example, if the base station wants to get data from node A, and the best path is A-B-C-BS. First, the base station broadcasts three orders in which one is for node A, one is for node B and the other one is for node C. Second, each node receives just 8 bits from the data signal and compares it with its own ID, if they are same, then goes on receiving the rest signals, or stops receiving. Otherwise, order sent to A is different from the orders sent to B and C. These three orders' types are: "query", "set-next" and "set-next".

The Following is some pseudo codes of the scheme generating algorithm:

```
Step 1. Find k subject to:
            A(k) = Min {A(i) | Flag (i) = 0}
        Then set Flag(k)=1;
        If k can't be found, go to Step 4. (Each node finds its best path)
Step 2. Update A(j) while Flag(j)=0
        For i=1 to n, step by 1
          If Flag(i)=0
               If A(k)+AN(k,i) < A(i)
                    A(i)= A(k)+AN(k,i);
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```
                Next(i)=k;
            End If
        End If
      End For
Step 3. Go to Step 1;
Step 4. End of algorithm.
```

(3) Data transmission phase

For instance, the base station asks for result data from node A, and the best path is A-B-C-BS. There are four steps in this procedure.

Step 1. Node A receives the order, then collects the result data and sets its Next-ID by “B”; Node B receives the order and sets its Next-ID by “C”; Node C receives the order and sets its Next-ID by “BS”;

Step 2. Node A forms the packet which consists of rest-energy information and the original data, and then transmits it to node B.

Step 3. Node B receives packet from node A, then adds its own rest-energy information to the tail of the packet to form a new packet and transmits it to node C;

Step 4. Node C receives packet from node B, then adds its own rest-energy information to the tail of the packet to form a new packet and transmits it to the base station (BS).

4. Performance Evaluation

4.1. Simulation Background

To execute our simulations, we use the random 100-node network shown in Figure 3, nodes are randomly distributing in the square which the x-axis and y-axis both range from 50~150. And the base station locates at point (x=10, y=10). In addition, we assume each node has 2000-bits data packet to transmit and each node initially given 0.5 J of energy. Some radio characteristics used in our simulations are shown in Table 2.

Table 2. Radio characteristics

Operation	Name	Energy Dissipated
Transmitter Electronics	E_{t-elec}	50 nJ/bit
Receiver Electronics	E_{r-elec}	50 nJ/bit
Transmit Amplifier	ε_{amp}	0.1 nJ/bit/m^2

4.2. Flat structure network

It is clear that in direct transmission routing, nodes far from base station suffer more energy dissipation than those close to base station. And in MTE routing, the nodes closest to the base station will die first, thus new closest nodes will die more quickly due to longer distance from the base station. That is a vicious circle. Disadvantages of these two protocols are:

- In both of them, nodes die sharply. In our simulation, there is a big difference between the first round (the round nodes begin to die) and the last round (the round nodes die out) both in Direct Transmission and MTE (See table 3).
- In both of them, nodes die regionally one by one. In Direct Transmission, nodes in the area far from the base station die first, and then this area can’t be monitored any more. In MTE, it is inverse.

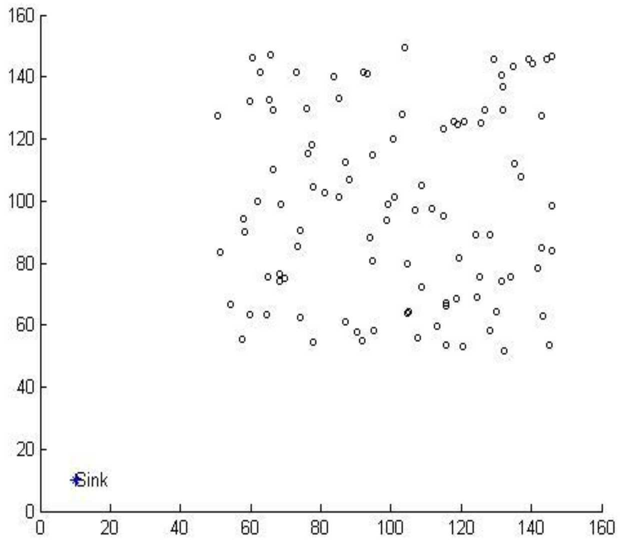

Figure 3. 100-node Random Network

As shown in Table 3. Flat network using ECREO algorithm (FECREO) can excellently achieve the balance of energy dissipation among all nodes. Its effect is obvious and dramatic.

Table 3. Lifetime of DT, MTE and FECREO

Protocol	First Round	Last Round
DT	68	506
MTE	9	400
FECREO	182	185

Figure 4 shows us the detailed number of alive nodes in each round using DT, MTE and FECREO. Though FECREO algorithm's total rounds are less than the other two protocols, but it excellently balances lifetime among all nodes. In WSNs using FECREO, entire area can almost be monitored during whole networks' lifetime.

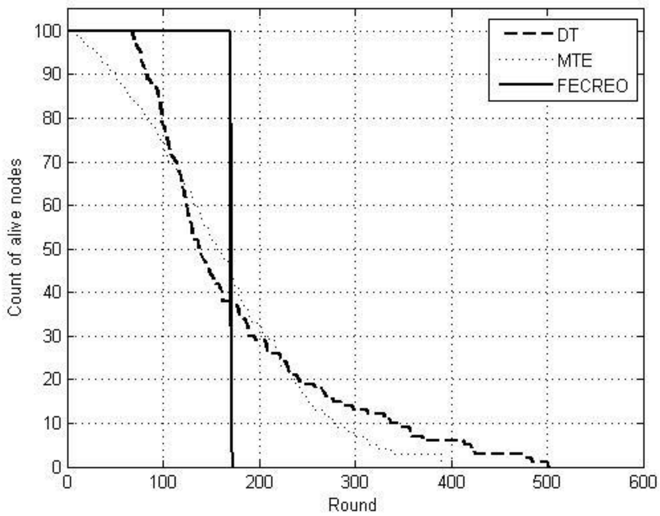

Figure 4. Count Number of Alive Nodes in Each Round

4.3. Clustering Structure Network

ECREO algorithm can not only be used directly in flat network but also can be used to enhance many clustering protocols. Before using ECREO mechanism to optimize other clustering protocols, it needs to transfer these original protocols to similar protocols which can work in query-based WSNs.

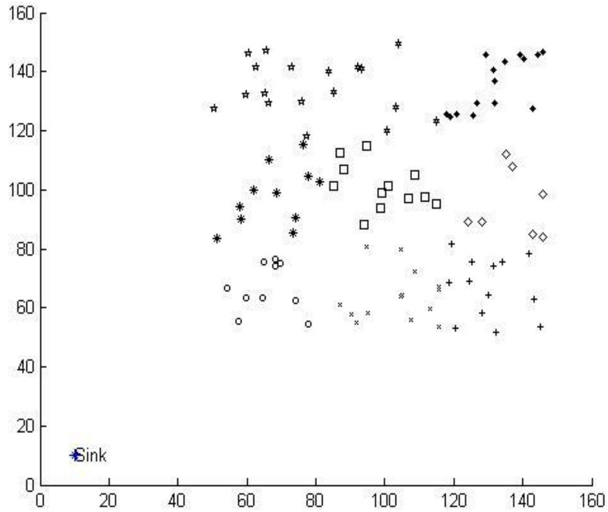

Figure 5. Clusters Division based on GAF

In this part, we firstly simulate one of the most famous traditional clustering protocols: GAF. And then use ECREO mechanism to optimize it, and we called the new protocol ECREO-improved GAF (ECREO-GAF). We assume the sensor's communication radius $R = \sqrt{5} * r$ and r=33.3 meters. Because the map is 100*100, the network can be divided into 9 clusters. The partition result is shown in Figure 5 (nodes of different shapes stand for different clusters).

In traditional GAF, the cluster head transmits packets to the base station using direct transmission (DT-GAF). If we regard the cluster as a unit, it is obvious that communication between CHs and BS using DT is same as the situation we discussed in flat structure network.

Table 4 shows us the ECREO-GAF protocol can effectively monitor the whole area till 1120 rounds. The detailed numbers of living nodes in each round for DT-GAF and ECREO-GAF are shown in Figure 6.

Table 4. Lifetime of DT-GAF and ECREO-GAF

Protocol	First Round	Last Round
DT-GAF	542	1389
ECREO-GAF	1082	1142

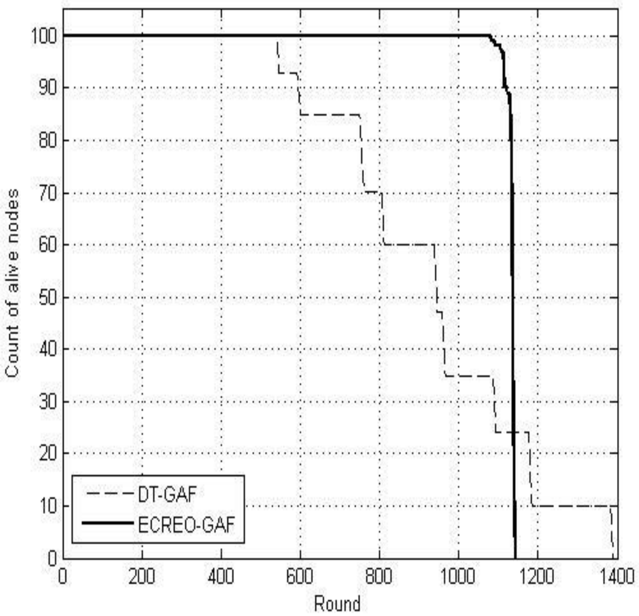

Figure 6. Count of Alive Nodes in Each Round Using DT-GAF and ECREO-GAF

5. Conclusions and Future Work

In this paper, we propose a global best path routing algorithm for WSNs based on GEAR. Its main idea is using the global topology and energy information to find the best scheme for every node transmitting data to base station. The key algorithm of ECREO is Dijkstra's algorithm and the core of ECREO algorithm is the weight-evaluation function which aims at reducing total energy cost of one node while considering its rest energy in transmission. In flat structure network, ECREO algorithm balances energy consumption and lifetime among all nodes of the entire network. In hierarchical structure network, ECREO algorithm can also be used to optimize the sub-network consists of CHs. Because the base station needs to know the entire topology of network, this mechanism can only be used in GEAR-based WSNs. In hierarchical structure network, we optimize the communication between CHs and BS and neglect the optimization of inner-cluster communication routing.

In the future, we will use ECREO algorithm to optimize inner-cluster communication and try to use ECREO algorithm in some applications to improve and perfect it.

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References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "A survey on sensor networks", IEEE Communications Magazine, vol. 40, no. 8, (**2002**).
[2] J. Kim, J. Lee and K. Rim, "Energy Efficient Key Management Protocol in Wireless Sensor Networks", International Journal of Security and Its Applications, vol. 4, no. 2, (**2010**).

[3] H. Y. Lin, D. J. Pan, X. X. Zhao and Z. R. Qiu, "A Rapid and Efficient Pre-deployment Key Scheme for Secure Data Transmissions in Sensor Networks Using Lagrange Interpolation Polynomial", International Conference on Information Security and Assurance, (**2008**) April 24-26.
[4] D. Wang, B. Xie and D. P. Agrawal, "Coverage and Lifetime Optimization of Wireless Sensor Networks with Gaussian Distribution", IEEE Transactions on Mobile Computing, vol. 7, no. 2, (**2008**).
[5] R. C. Shah and J. M. Rabaey, "Energy aware routing for low energy ad hoc sensor networks", IEEE Wireless Communications and Networking Conference, (**2002**) March 17-21.
[6] W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks", IEEE Hawaii International Conference on System Sciences, (**2000**) January 4-7, Maui, Hawaii.
[7] O. Younis and S. Fahmy, "HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks", IEEE Transactions on Mobile Computing, vol. 3, no. 4, (**2004**).
[8] S. Roychowdhury and C. Patra, "Geographic Adaptive Fidelity and Geographic Energy Aware Routing in Ad Hoc Routing", International Conference on Advances in Computer, Communication Technology and Applications, (**2010**) August 3-5.
[9] J. Haupt, W. U. Bajwa, M. Rabbat and R. Nowak, "Compressed Sensing for Networked Data", IEEE Signal Processing Magazine, vol. 25, no. 2, (**2008**).
[10] D. R. Kisku, P. Gupta and J. K. Sing, "Multibiometrics Feature Level Fusion by Graph Clustering", International Journal of Security and Its Applications, vol. 5, no. 2, (**2011**).
[11] J. L. Poirot and G. Arbid, "Position Location: Triangulation versus Circulation", IEEE Transactions on Aerospace and Electronic Systems, AES-14, vol. 1, (**1978**).
[12] J. Beutel, "Geolocation in a picoradio environment", M.S. thesis, ETH Zurich, Electron. Lab., Zurich, (**1999**), Switzerland.
[13] B. Deb, S. Bhatnagar and B. Nath, "A topology discovery algorithm for sensor networks with applications to network management", DCS Technical Report (DCS-TR-441), Rutgers University, (**2001**) May.
[14] X. Zhang, H. Zhang and C. Song, "Research on inter-cluster routing protocol based on HEED", Computer Engineering and Applications, vol. 45, no. 18, (**2009**).
[15] E. W. Dijkstra, "A note on two problems in connexion with graphs", Numerische Mathematlk, vol. 1, no. 1, (**1959**).

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