An Adaptive and Robust Routing Approach in Wireless Sensor Networks

Yanjiao Zhang, Liansheng Tan, and Yan Wang

***Abstract*—In wireless sensor networks (WSNs), realizing the network life cycle maximization is still a huge challenge due to the problems of energy constraint. In this paper, we propose Modified Multi-source Opportunistic Shortcut Routing Algorithm (MMOSRA), which is on the basis of the shortest remaining hops MOSRA algorithm, we add the new parameter ERH_i according to the weight value of energy-hop for achieving the purpose of balancing sensor nodes energy consumption. When one flow changes its routing path for some emergency, we can find a optimized routing path with the MMOSRA algorithm and avoid that a slid change in one link causing a huge oscillation of all the network link. Next we use the measured parameters that condition number $K(A)$ of routing matrix to evaluate the impact on the entire network link and select data transmission routing path finally. Compared with the MOSRA algorithm, the MMOSRA rationally utilize residual energy of each node to prolong the network life cycle. Example and simulation demonstrate that our proposed scheme has significantly increased the network lifetime and balanced energy utilization efficiency of all nodes.**

***Index Terms*—Condition number, ill-conditioned, life cycle maximization, routing matrix, wireless sensor network.**

I. Introduction

Wireless sensor networks (WSNs) [1] have great potentialthat are exploited for many applications in real world scenarios. However, it has been concluded that the problems ofenergy constraint and data redundancy emerge inevitably inthe course of designing an application of WSNs, especiallyfor high-density large scale network.

Now, wireless sensor network has been well-suited for a variety of applications including environmental monitoring, biological detection, smart spaces, and battlefield surveillance [1]-[3]. These applications can be divided into two broad categories in terms of the way of data collection based on theobserver interest: event-based detection and continuous data sampling.

In event-based detection, the sensors report the data expect- ed to collect information to the sink only when an interesting event occurs. It means that the significant characteristic of the event-based detection in WSNs is delay intolerant and error sensitive. In other words, the data delivered to the sink need to be reliable once an emergency occurred within the sensing range of sensors in real time. So the detection success rate of interested events is crucial to the efficiency of the application.

In the continuous data sampling applications, the local measures in the sensing area of sensor nodes are regularly sampled and reported, such as the ambient temperature and humidity. After receiving all samples, the sink generates a data snapshot of the area at one point in time. Some applications may be more tolerant to discrepancies in the sensed values, not demanding the receiving data without any error. In a general case, the observers are more focused on the evolving process or spatial structure evolution of certain physical phenomenon in the monitored area. Such frequent sampling behavior ex- pends more energy than the event detection. Thus reducing energy waste is even more important to the continuous data sampling applications [4]-[6].

To realize the network utility maximization in the wireless sensor network, developers have made a lot of works, Consid- ering mainly the following two aspects: maximize the network life cycle and maximize application performance [6].

- Generally the network life cycle refers to the time that from the network initialization to the first sensor node energy run out. The life cycle of sensor nodes usually is inversely proportional to the sum of transmission information and the rate of generating information. so when considering the network life cycle, we need to consider the above two aspects in detail.
- Application performance has a closed relationship with the generated data quantity of each node to the gathering node in WSNs. For example, for video sensors, more data mean that more high quality effect of pictures, the application of high accuracy is the basic performance requirements in the thermal sensors.

In WSNs, a higher data rate means that consume more energy, and it will directly cause the network life cycle shorten. So the network life cycle maximization and the application of utility maximization are the two most basic but conflicting design goal, which are interrelated and can not maximize at the same time. In this paper, We mainly considered how to maximize the network life cycle of cluster nodes in WSNs.

II. Related Works

A. Network Topology

The concept of clusters is introduced into hierarchical routing protocol [1], a number of adjacent nodes form a cluster on the basis of some kind of clustering algorithm, each cluster select a cluster head based on some kind of cluster head selection algorithm, the information collected by the

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sensor nodes will be transmitted to the cluster head, The connection between cluster heads form the topmost network, all communications are sent via the upper network between clusters. The advantage of the network topology is that it can effectively reduce network traffic, and reduces the energy consumption of the whole network.

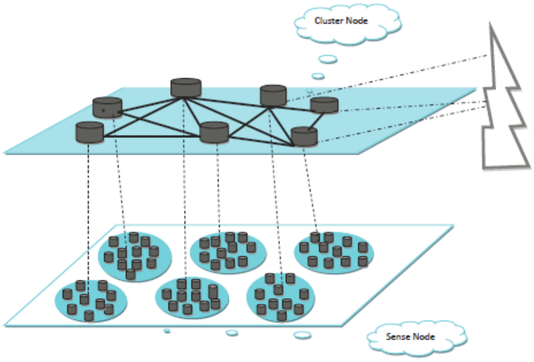


Fig. 1. Network topology of wireless sensor network.

In wireless sensor network, the data flow tends to be more-to-one pattern, all sensor nodes collect data and then sent to the sink node [7]. In the minimal hop algorithm, the sensor nodes which close to the sink nodes are bound to assume a variety of data forwarding tasks, making its energy run out quickly, resulted in the destruction of network connectivity. In addition, the WSNs environment often occurs the failure of node or link, the minimal hop algorithm maintains only a single routing mechanism, leading to its poor robustness.

Assume that the wireless sensor network is a hierarchical structure, this structure can effectively eliminate the redundant information between adjacent nodes and won't cause the re- dundant communication between sensors. There are two types of sensor nodes in a network: the sense node (SNs) and the cluster node (CNs). The sense nodes are specific sensor node, such as temperature sensor nodes (TSNs), pressure sensor nodes (PSNs), and video sensor nodes (VSNs), these SNs constitute the bottom of network. The function of SNs is very simple: once the event is triggered, they begin to collect real- time information of target events, and then the informations are transmitted to the cluster nodes through the way of one or more than one hop. The CNs are aggregational nodes which aggregating dates from the SNs in the same cluster, and they have a finite life cycle and energy. Once one CNs runs out of its energy, collected datas from SNs in the area of this cluster may be unavailable even if other SNs may also have enough energy. Each CNs sends the collected data to a base station directly or over a multi-hop path [7]. The primary goal of base station is to gather sensed data from CNs in WSNs, visualize and analyze the data. Any link breakage or change in network topology is handled in timely manner by adaptive and robust routing approach.

B. Routing Matrix

In order to sum up the traffic fact of within the domain or domains in the view of overall network, research introduces the concept of "Traffic Matrix", which reflects the demand of traffic between all the pair of origin and destination (OD)in the network. Link traffic Y was obtained traffic data through the general method SNMP (simple network manage- ment protocol). Routing matrix A was obtained by the router configuration information or by collecting link weights to get.

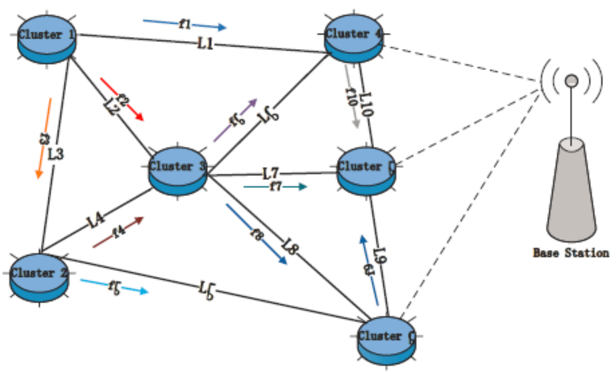


Fig. 2. The transmission model of cluster nodes in wireless sensor network.

$$AX = Y \tag{1}$$

where

$$A = \begin{bmatrix} f_1 l_1 & f_2 l_1 & \cdots & \cdots & f_n l_1 \\ f_1 l_2 & f_2 l_2 & \cdots & \cdots & f_n l_2 \\ f_1 l_3 & f_2 l_3 & \cdots & \cdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ f_1 l_m & f_2 l_m & \cdots & \cdots & f_n l_m \end{bmatrix}$$

$$X = \begin{bmatrix} X_1 & X_2 & \cdots & \cdots & X_n \end{bmatrix}^T,$$

$$Y = \begin{bmatrix} Y_1 & Y_2 & \cdots & \cdots & Y_m \end{bmatrix}^T,$$

The specific description of above parameters are described in Table I.

TABLE I: Parameter Description

Metric	Specific description
Y	$Y = (Y_1, Y_2, ...Y_m)^T$ Y_i indicates the traffic of link i, m indicates the sum of all the link in the network, Set Y express the link traffic of all the link in the network.
A	$A = [f_i l_j]_{m \times n}$ $0-1$ routing matrix indicates the state of the link, if OD_{ij} flows through the link j, then $f_i l_j = 1$, else $f_i l_j = 0$, the column vector$(f_i l_1, f_i l_2, ..., f_i l_n)^T$ of the matrix A show that one flow traffic demand at all the links in the network.
X	$X = (X_1, X_2, ...X_n)^T$, the traffic demand of all the OD nodes, the transmission data volume from node i to node j, X_i indicates the elements of the matrix.

C. ILL-Conditioned Systems

The solutions of some linear systems are more sensitive to round-off error than others. For some linear systems a small change in one of the values of the coefficient matrix or the right-hand side vector causes a large change in the solution vector. When the solution is highly sensitive to the values of the coefficient matrix A or the righthand side constant vector b, the equations are called to be Ill-conditioned [8].

Ill-conditioned systems pose particular problems where the coefficients or constants are estimated from experimental results or from a mathematical model. Therefore, we cannot rely on the solutions coming out of an Ill-conditioned system. The problem is that how do we know when a system of linear equations is Ill-conditioned.

1) Vector and Matrix Norms: A norm of a vector is a measure of its length or magnitude.

$$\|x\|_\infty = \max_{1\le i\le n} |x_i| \tag{2}$$

The notation max{} denotes the maximum element of the set. The formulation shown by Eq. (2) is also called the infinity norm of the vector x: and satisfied the following properties of infinity norm.

(1) positive def initeness : $\|x\| \geqslant 0$; and $\|x\| = 0$;

(2) homogeneity : $\|kx\| = |k| \cdot \|x\|$; $k \in F$;

(3) the triangle inequality : $\|x + y\| \geqslant \|x\| + \|y\|$:

Now we need to consider the notion of a matrix norm. A matrix norm can be defined in terms of a vector norm in the following manner.

$$\|A\|_\infty = \max_{1\le i\le m} \sum_{j=1}^{n} |a_{ij}|, \tag{3}$$

Note that the expression for *A* involves summing the absolute values of elements in the rows of *A*: The matrix norm satisfies all the properties of a vector norm and, in addition, a matrix norm has the following important property.

$$\|Ax\| \le \|A\| \cdot \|x\| \tag{4}$$

From the perspective of the network traffic evaluation, in order to implement maximization of the network life cycle, we introduce the conception of condition number. When routing matrix changes slightly, whether the tiny change of the routing path will cause a great shock in network link, we can judge it with the condition number. Here we introduce the conception of condition number.

2) Condition number: Let us investigate first, how a small change in the vector b changes the solution vector x. x is the solution of the original system and $x + \triangle x$ is the solution when *b* changes from *b* to $b + \triangle b$:

Then we can write

$$A(x + \triangle x) = b + \triangle b$$

Because $Ax = b$; it follows that

$$A \triangle x = \triangle b.$$

$$\triangle x = A^{-1|} \triangle b$$

By using the relationship shown in Eq. (4) we can write that

$$\|A^{-1} \triangle b\| \le \|A^{-1}\| \cdot \| \triangle b\|$$

$$\| \triangle x\| \le \|A^{-1}\| \cdot \| \triangle b\| \tag{5}$$

Again using Eq. (4) to the original system $Ax = b$ we can write that

$$\|b\| \le \|A\| \cdot \|x\| \tag{6}$$

Divide Eq. (5) by Eq. (6)

$$\frac{\| \triangle x\|}{\|A\| \cdot \|x\|} \le \frac{\|A^{-1}\| \cdot \| \triangle b\|}{\|b\|}$$

$$\frac{\| \triangle x\|}{\|x\|} \le \|A\| \cdot \|A^{-1}\| \cdot \frac{\| \triangle b\|}{\|b\|} \tag{7}$$

$$\frac{\| \triangle x\|}{\|x\|} \le K(A) \cdot \frac{\| \triangle b\|}{\|b\|}$$

Now, let us investigate what happens if a small change is made in the coefficient matrix *A*: Consider *A* is changed to $(A + \triangle A)$ and the solution changes from *x* to $(x + \triangle x)$: $(A + \triangle A)(x + \triangle x) = b$: It can be shown that the changes in the solution can be expressed in the following manner.

$$\frac{\| \triangle x\|}{\|x\|} \le K(A) \cdot \frac{\| \triangle A\|}{\|A\|} \tag{8}$$

where *K*(*A*) is called the condition number of the matrix *A* and is defined as

$$K(A) = \|A\| \cdot \|A^{-1}\| \tag{9}$$

provided *A* is nonsingular.

K(*A*) is a measure of the relative sensitivity of the solution to changes in the right-hand side vector *b*: Eq. (9) gives the upper bound of the relative change. When the condition number *K*(*A*) becomes large, the system is regarded as being ill-conditioned. Matrices with condition numbers near 1 are said to be Well-conditioned.

III. The System Model and Algorithm

A. *Energy Consumption Model*

Energy consumption usually due to a data communication that is sending and receiving information, the consumption of the two way occupy an important position in total energy consumption of sensor nodes.

Assume that one cluster contains n sensor nodes and n_i ($i \leqslant n$) represents node *i*; each node has the same initial energy denoted as $E_{initial}$ in wireless sensor networks, forwarding the same size packets consumes the same energy between any two nodes and the energy consumption of forwarding packets with size *m* denoted as $Packet_m$, $dis(n_i; n_j)$ express that the sum of hops from node *i* to node *j*, $\sum_{k \ne i} f_{ki}$ calculate the sum of sensor nodes which transmit dates to node *i*:

$$Etrans(i) = Packet_m \times dis(n_i; n_j) \tag{10}$$

$$E_{recs}(i) = Packet_m \times \sum_{k\ne i} f_{ki} \tag{11}$$

Energy consumption includes two parts: receive energy consumption and transfer energy consumption. For the SN s; energy consumption is mainly forwarding collected data to the *CNs*; but for the *CNs*; energy consumption contains the two parts: receiving dates from *SNs* and selecting routing path to forward them to base station through single hop or multiple hops. So the basic energy consumption mode of the sensor nodes in wireless communication are bellow:

$$Cons(i) = \begin{cases} Packet_m \times dis(n_i, n_j) \\ Packet_m \times (dis(n_i, n_j) + \sum_{k \neq i} f_{ki}) \end{cases} \quad (12)$$

Assuming that the initial energy of each cluster nodes express as $E_{initial}$, the cluster nodes will update the current energy after receiving or sending packets denoted as E_{left}:

$$E_{left} = E_{initial} - \sum_{i=1}^{k} Cons(i) \quad (13)$$

$$T_i = \frac{E_{left}(i)}{max_{RH}(i)} \sim T_i = \frac{E_{left}(i)}{min_{RH}(i)} \quad (14)$$

Then the *CNs* can select a optimized routing path for forwarding collected data on the basis of the parameters E_{left} and T_i.

B. Model Assumptions

1) Within a cluster, any sensor node only has one gathered node and belongs to one cluster head.

2) The defined model of energy consumption ignores the energy consumption of transfering feedback information. 3) Each cluster node store information that the Remaining Hops (RH) destined to the base station.

4) Each sensor nodes can measure their remaining battery power and the energy of transmitting consumption.

5) The cluster nodes will update the current energy E_{left} after receiving or sending packets.

6) Calculate the max and min hops of the cluster nodes directed to base station.

C. Multi-Source Opportunistic Shortcut Routing Algorithm

To apply the OR mechanism [9]-[11] in Multi-source Opportunity Shortcut Routing Algorithm (*MOSRA*), a source or an intermediate node forwards a packet by broadcasting, and all the receiver nodes have an opportunity to forward the packet. Moreover, the receiver nodes are provided the priority according to *RH* (the remaining hops to the destination)in order to suppress a number of duplicate packets from forwarder candidates. The detail algorithm of *MOSRA* is detailed described in Algorithm 1.

Note that identifiers, source (*i*), receiver (*j*), and destination (*k*) are the network addresses in wireless sensor network and indicate a source node, a receiver node, and a destination node respectively. If receiver (*j*) receives a packet for the first time, it investigates whether receiver (*j*) is an intermediate node or a destination node. If receiver (j) is an intermediate node, next it compares the remaining hops (*RH*) to the destination from itself with that from the previous sender source (*i*). Then the intermediate node that can reduce the remaining hops becomes the future forwarder candidate.

In other words, it sets broadcast timer *t* proportionally to the size of the remaining hops, allowing the nodes with the smaller remaining hops and more remaining energy to have higher priority to forward a packet. Thus, the packet transmission is canceled if it overhears the same packet before the timer expires.

This retransmission procedure is stopped by the rebroadcasting from the forwarding node with the smaller remaining hops than receiver (*j*), since the rebroadcasting packet can be considered as an acknowledgement. Even though a packet is directed to destination (*k*), for the same reason, destination (*k*) need to rebroadcasts packet to forward node as an acknowledgment.

Algorithm 1 Multi-source Opportunistic Shortcut Routing Algorithm

Input:
Graph $G(V, E)$, $V = 1, 2, \ldots, n$;
Weighting function $\omega : E \rightarrow R$;
Output:
n-dimensional vector A shows the shortest routing path from node S to node D.

if (j receives a packet p_0 destined for d from sender s)
  if (p_0 is received for the first time)
    if ($RH(j, d) == 0$)
      rebroadcast packet p_0
      else if ($RH(j, d) < RH(s, d)$)
        store p_0 to the buffer, set timer t
    end if
  else
  if (timer t is activated and $RH(j, d) > RH(s, d)$)
    remove p_0 from the buffer
    cancel the timer t
  end if
  if (timer t expires)
    rebroadcast packet p_0
end if

D. Example of MOSRA Algorithm

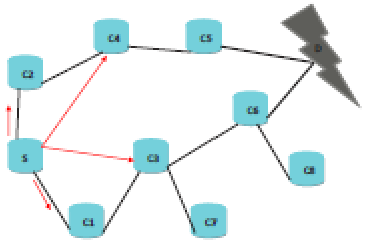
Fig. 3 shows an example of an end-to-end routing transmission path with Multi-source Opportunistic Shortcut Routing Algorithm.

1) the red line expresses that broadcasting packets to the next-hop node and packet is received successfully.

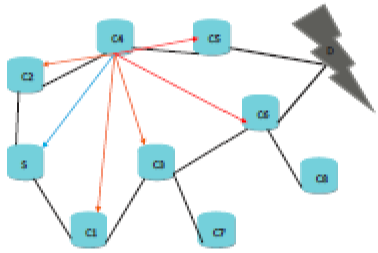
2) the yellow line expresses that sending packets for suppressing other node to forward.

3) the blue line expresses that sending acknowledgement to its parent's node.

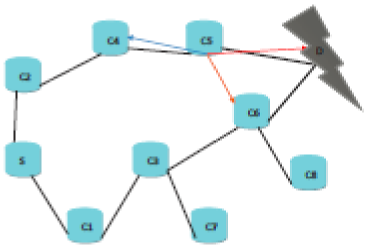
Assuming that source (*S*) transmits a packet to the destination (*D*). Suppose that nodes C_1; C_2; C_3 and C_4 as receiver nodes in Fig. 3 receive a broadcasting packet sent by source(*S*). While node C_1; C_2 and C_3 set random delay within RH ∗t: As shown in Fig. 3. a, node C_4 firstly rebroadcasts the packet with the priority of the smallest remaining hops, and then the node C_1, C_2 and C_3 cancel the timer for forwarding the packet when they receive inhibition of packets from node C_4. At the same time, source (*S*) also stops the timer set for retransmission, since the packet from C_4 is regarded as an acknowledgement. Again, node C_5; C_6 set random timer to forward the received packet, and C_5 forwards the packet earlier than others, because it has the smallest remaining hops to the destination (*D*). As shown in Fig. 3. c, the packet is reached to the destination, and it suppresses C_6 to forward. Note that the destination (*D*) rebroadcasts the packet in Fig. 3. d in order to notify C_5 that it received packet well. The interesting characteristic of the *MOSRA* is that there are many forwarder candidates on a path, enhancing the packet delivery ratio against failures of particular nodes on a path. The detail discussion about the number of forwarder candidates and the packet delivery ratio is proved.



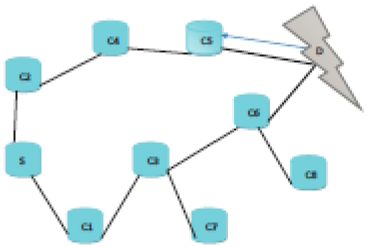
(a) Source S broadcasting packets



(b) Intermediate node C forwarding packets



(c) Next hop intermediate node H forwarding packets



(d) the destination D rebroadcasts acknowledged packet

Fig. 3. Multi-source opportunistic shortcut routing algorithm.

E. *Modified Multi-Source Opportunistic Shortcut Routing Algorithm*

In order to find a better route transmission path to lengthen the life cycle of the wireless sensor network, in this section we use the Multi-source Opportunistic Shortcut Routing Algorithm to find optimal routing path [9]. Instead of the *RH*, the priority of forwarder node can be expressed with ERH_i:

$$ERH_i = \frac{E_{left}(i)}{RH} \tag{15}$$

We add the new parameter ERH_i to modify the MOSRA algorithm, which can help us search a rational utilization of each node energy and prolong the network life cycle routing algorithm. when we want to select an optimized routing path for transmitting data packet, not only we need considering that after the minimum hops to the base station, the transmission capacity and residual energy of each node is also fully consid- ered. In the algorithm 2, we describe the Modified MMOSRA algorithm.

Algorithm 2 Modified Multi-source Opportunistic Shortcut Routing Algorithm

Input:
Graph $G(V,E)$, $V = 1,2,\ldots,n$;
Weighting function $\omega : E \rightarrow R$;
Output:
n-dimensional vector A shows the optimized routing path from node S to node D.
1:if (j receives a packet p_0 destined for Base Station d from sender s)
2: if (p_0 is received for the first time)
3: if ($RH(j,d) == 0$)
4: rebroadcast packet p_0 as acknowledgement signal
5: else if
5: ($RH(j,d) < RH(s,d)$ *and* $ERH(j) > ERH(i)$
5: i receive packet at the same time with j)
6: store p_0 to the buffer, set timer t
7: end if
8: else
9: if (timer t is activated and $RH(u,d) > RH(s,d)$)
10: remove p_0 from the buffer
11: cancel the timer t
12: end if
13: if (timer t expires)
14: select other receive node rebroadcast packet p_0
14: jump to step 3 to judge
15: end if

IV. Example and Performance Analysis

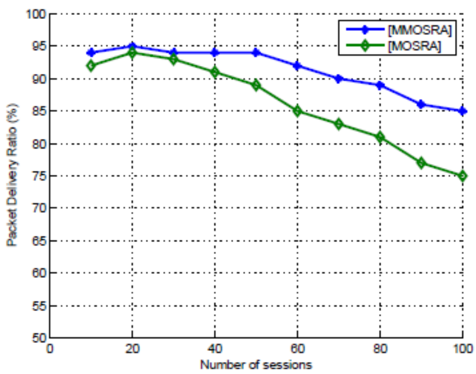


Fig. 4. Packet delivery ratio.

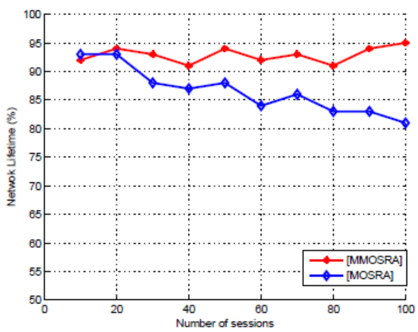


Fig. 5. Network lifetime.

We evaluate MMOSRA in diverse metrics on the routing performance and overhead by comparing with MOSRA algo- rithm. Especially, we focus on the packet delivery ratio and network lifetime by change the number of traffic sessions in order to investigate the reliability of the proposed algorithms in high congestion condition. The general parameter settings are summarized in Table II, we fixed the number of nodes to 150 except the evaluation on network density. The packet delivery ratio tends to decrease as the number of traffic sessions increases as shown in Fig. 4, and it is natural in that contention and collision of packets increase for the higher number of packets. Both of MMOSRA and MOSRA show 75% and 85% packet delivery ratio even in 100 traffic sessions. In addition, MMOSRA always shows better performance than OSTR. We evaluate the network lifetime by calculate the earliest time of dead nodes. Regard to the life cycle of network nodes, we can see that MMOSRA is much better than MOSRA, MMOSRA remains unchanged as the number of traffic sessions increases as shown in Fig. 5, while MOSRA tends to decrease obviously.

TABLE II: SIMULATION PARAMETER

Simulation Parameters	Value
Network size	150×150
Number of nodes	150
Number of iteration	30
Network Protocol	MOSRA / MMOSRA
Packet type	CBR
Packet interval	1 packet/sec
Number of session	$10, 20, 30, \cdots, 100$
Number of fault	$10, 20, 30, \cdots, 100$

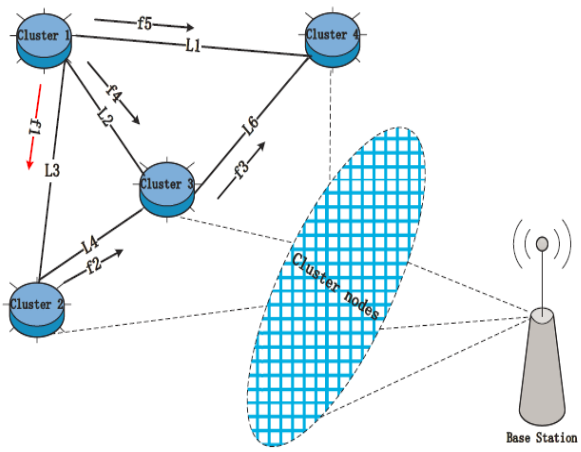


Fig. 6. The example cluster topology in wireless sensor network.

For example shown in Fig. 6, when flow 1 change its routing path for some emergency, we can find all possible routing paths by traversal search, we also can find a optimized routing path through the modified MMOSRA algorithm, as we all known, we do not want a slid change in one link causing a huge oscillation in all the network link. Next we will use the measured parameters of condition number $K(A)$ to evaluate and verify these routing path.

$$\begin{bmatrix} f_1l_1 & f_2l_1 & f_3l_1 & f_4l_1 & f_5l_1 \\ f_1l_2 & f_2l_2 & f_3l_2 & f_4l_2 & f_5l_2 \\ f_1l_3 & f_2l_3 & f_3l_3 & f_4l_3 & f_5l_3 \\ f_1l_4 & f_2l_4 & f_3l_4 & f_4l_4 & f_5l_4 \\ f_1l_5 & f_2l_5 & f_3l_5 & f_4l_5 & f_5l_5 \end{bmatrix} \bullet \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{bmatrix} = \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ Y_4 \\ Y_5 \end{bmatrix}$$

$$A_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 \end{bmatrix} A_2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 \end{bmatrix} A_4 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 \end{bmatrix}$$

$$A_5 = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 \end{bmatrix} A_6 = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 \end{bmatrix}$$

$$A_7 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 \end{bmatrix} A_8 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 \end{bmatrix}$$

$$A_9 = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 \end{bmatrix}$$

$K(A)$ is a measure of the relative sensitivity of the solution , when the condition number $K(A)$ becomes large, the system is regarded as being ill-conditioned. Matrices with condition numbers near 1 are said to be well-conditioned. when flow 1 change its routing path, we list all possible routing transmission path in Table III. By calculating the condition number of all the possible routing transmission path, we select out data transmission path L_3 on the basis of the $K(A)$.

TABLE III: PARAMETER DESCRIPTION

Routing-Path	**Vector F_1**	$\|A\|$	$\|A^{-1}\|$	**K(A)**
$L_3 - L_4 - L_5$	$(0,0,1,1,1)^T$	4	4	16
$L_3 - L_4$	$(0,0,1,1,0)^T$	3	5	15
$L_2 - L_4$	$(0,1,0,1,0)^T$	3	∞	∞
$L_2 - L_5$	$(0,1,0,0,1)^T$	4	∞	∞
$L_1 - L_5 - L_4$	$(1,0,0,1,1)^T$	4	∞	∞
$L_1 - L_5$	$(1,0,0,0,1)^T$	4	∞	∞
L_3	$(0,0,1,0,0)^T$	3	4	12
L_2	$(0,1,0,0,0)^T$	3	∞	∞
L_1	$(1,0,0,0,0)^T$	3	∞	∞

V. CONCLUSION

In this paper, we propose Modified Multi-source Opportunistic Shortcut Routing Algorithm (MMOSRA). The modified MMOSRA algorithm is on the basis of the shortest remaining hops MOSRA algorithm, we add the new parameter ERH_i for achieving the purpose of balancing sensor nodes energy consumption. So when one flow change its routing path for some emergency, we can find a optimized routing path through the modified MMOSRA algorithm. In order to avoid that a slid change in one link causes a huge oscillation of all the network link, next we use the measured parameters that condition number $K(A)$ to evaluate the impact on the entire network link and select data transmission routing path finally. Compared with the MOSRA algorithm, the MMOSRA rationally utilize residual energy of each node to prolong the network life cycle. Example and simulation demonstrate that our proposed scheme has significantly increased the network lifetime and balanced energy utilization efficiency of all nodes.

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