Lifetime Based Routing Algorithm in Emergency Object Tracking

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Abstract: - Sensor networks have many applications, a typical setting is in nature environment monitoring, such as forest fire, tsunami, and earthquake. In order to be easily deployed in this environment, sensor device is design to have small form factor, and as lightweight as possible, thus, its battery capacity is limited. The issue of battery capacity is more important when applied in tracking moving objects, and when real time response of the system is critical where the routing algorithm do not need to perform data aggregation. This paper proposed a routing algorithm for tracking objects and perform emergency reporting when a situation occurred and at the same time reducing total energy consumption and thus prolonging the system lifetime. Our algorithm is called sensor on demand betweenness vector(SOBV). This algorithm is a multipath routing algorithm based on the characteristics of network topology.

Key-Words: - Betweenness, Network model, Routing algorithm, Object tracking

1 Introduction

Wireless sensor networks (WSNs)[1-2] consist of distributed sensor nodes which usually do not rely on static infrastructures or topologies. Applications [3] of WSNs are increasing due to its flexibility. Sensor equipments typically containing three modules: radio frequency module, data processing module and power supply module, as shown in figure 1. The function of radio frequency module is sensing and wireless communication, the function of data processing module is about data computing and routing. In order to achieve small form factor, the capacity is limited in the power supply module. Sensor nodes usually have few memory modules and no external storages. Sensor nodes collect information about its geographic location and monitor events it is designated to monitor, those information must be sent back to a sink by wireless transmission.

A typical application of WSNs is to monitor a region continuously and report to the sink when a certain event occurred. Sensor node can be deployed structured or unstructured in a region. By structured, we place sensor nodes at a pre-computed static location accounting for the distance of sensing and wireless transmission. The advantages of such approach are that data routing path can be calculated in advance and hardware failure can be detected and bypassed easily. Fewer nodes are used in this approach. By unstructured, we randomly place sensors within some region. WSNs must be self-configured in order to maintain connectivity while diagnostic node failure. In the case of node failure, an overlay network is used to bypass those failed nodes.

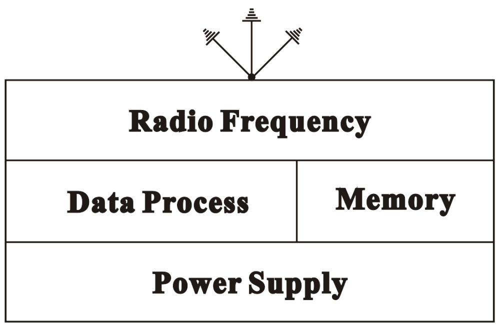

Fig. 1 Components of a sensor node.

1.1 Sensor network system design

Difference applications call for different sensor node deployment schemes and thus some specific routing protocol is used for data collection. The performance of a routing protocol is closely related to application and network topology. In the follow section we will discuss this issue.

1.1.1 Node Deployment

Difference services usually utilize difference nodes deployment schemes. For example, static node deployment scheme is used in detecting gas leaks and house fire. In both cases we know the network topology and a pre-determined route is employed to transmit the alert messages. However, in the situation of environmental monitoring where sensor nodes are randomly deployed in the field, sensors are required to automatically configure and detect their neighboring nodes and maintain network connectivity in the wild or in open water.

A particular type of nodes called sink is present in the sensor network while all other nodes are sensing nodes. All sensing nodes transmit messages back to the sink node, sensor nodes near the sink relaying messages more frequently than other nodes located at a distance from the sink, for this reason we usually place more sensing nodes near the sink node.

1.1.2 Routing Energy

The power required is in propotion to the square of distance of radio transmission, therefore, multi-hop transmission is more economic than a long distance radio link. However, multi-hop transmission incurrs some overhead for packet queueing and processing.

Based on power saving mechanisms and degree of emergency level, data delivery can be classified into four model: continuous, event driven, observer-initiated and hybrid[4]. Sensor nodes transmit data periodically at a given time interval in continuous model; when sensors detect the occurrence of certain event, messages are sent to the sink node in the event driven model; in the observer-initiated model, sensing nodes reply to the sink node's query message; if networks apply continuous, observer-initiated and observer-initiated model, it is called the hybrid model.

1.1.3 Time Synchronization

The issue of time synchronization is of particular importance when sensor networks are used in surveillance systems such as environmental monitoring, car traffics and military system. For example, in the instance of a forest fire, it is based on the time stamp in order to determine the precise moment when the fire breaks out and the chronological order of the occurrence. Sundararaman, Buy and Kshemkalyani [5] proposed three ways to synchronization clock efficiently: external time device (GPS) usage, mode of transmission, proactive versus reactive routing. Traditional protocols like NTP can use a global positioning system to synchronize the sensor network within certain accuracy.

1.2 Applications

There are many applications in WSNs such as military target tracking[6], traffic avoidance[7][8], environmental monitoring[9] and advanced human behavior[10] inactive with life. At war, soldiers can get the information about enemy and make correct attack policy; At parking, the monitor can show where parking spaces are empty; people can avoid the damage of flood, tsunami, earthquake and volcanic explosion; There are a framework combined human life with WSNs, anyone can use mobile devices to share and get adaptive information.

The topic of moving object tracking[11] is an important application of the sensor network. We want to detect the location of a given object in a period time. There are three steps in object tracking. Firstly, the object enters the detection area of a sensor. Secondly, sensors estimate the position and speed of the object. Lastly, sensing nodes send the information back to the sink node. Some sensor network has two sink nodes, one for regular data and the other for duplicated data. The whole sensing area are partitioned into evenly spaced grids and sensing nodes are deployed at random location within the grid, as shown in figure 2. Two important issues in moving object tracking are track missing and node failure during object tracking.

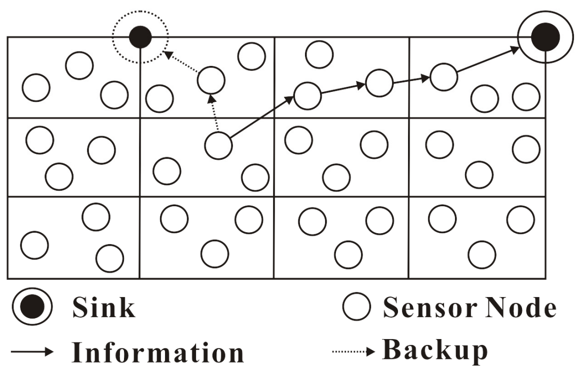

Fig. 2 Moving object tracking in WSN, black color are sink nodes, gray are sensing nodes.

1.3 Sensor Network Research Topics

Device in the wire network maybe have fast computing units, huge storage equipments, sufficient energy supply, high network bandwidth and static topology. But WSNs have limited resource included low battery capacity, low bandwidth, short communication distance, and limited computing ability and storage.

There are much technologies and issues will be discuss and designed, for example sensor nodes are coverage, localization, synchronization, transmission security, routing algorithm[12][13], power saving mechanisms[14][15]. For object tracking system requires a higher quality of coverage to track accurately, but the disadvantage is needed more sensor nodes. Time synchronization is also important, it effect the transmit data and nodes sleep scheduled. At a general classification of power saving, these techniques are duty cycling and data-driven approaches. Good routing strategies have to consider the issues of saving energy and efficient transmission, there are three routing styles depending on the application and network architecture as flat networks routing, hierarchical networks routing and location based routing between sensor nodes, in the section 2, we survey routing protocols for sensor networks and describe a classification for the various routing approach.

1.4 Network Model

Various networks[16] as social network, biological and social network[17] are presented different the properties. The properties[18] of network models are average path length, clustering coefficient, node degree distribution, betweenness. A network can be measured by network properties to understanding the characteristic of network structure. So we always classify an unknown network or build new network model by these characteristic.

Small-world networks[19] and scale-free network[20] are two type of network models. The concept of small-world model was originally from human social behavior. Watts and Strogatz proposed two characteristics of small-world network, average shortest path length and clustering coefficient[21]. Compare with random network, small world network has low average shortest path length and high density clustering coefficient.

A network with a power law distributed degree distribution is called sale-free network. The probability of a node with k edges is defined as $P(k)$. The relationship describing power-law distribution of $P(k)$ can be written as $P(k) \sim k^{-r}$ where γ is the tail index of the power-law distribution.

If a simple graph, the betweenness centrality $B(i)$ of node i is the number of shortest path between two node than passes through node i.

$$B(i) = \sum_{\substack{s,d \in V \\ s \neq d \neq i}} \frac{\sigma(s,i,d)}{\sigma(s,d)} \quad (1)$$

where $\sigma(s,d)$ represents number of shortest path between node s and d, and $\sigma(s,i,d)$ be the number of shortest path from node s to node d passed by node i. Node i with high betweenness mean this node that is important in the network, so this node has more times to be passed by any pair nodes of source and destination. But this node consumes its energy very fast. Node i will lose its function after battery exhausted.

2 Sensor Routing Algorithm

In general, routing algorithms can be classified as either address-centric or data-centric according to their data flow process. For example, two sources s_1, s_2 send data $data_1$, and $data_2$, respectively, to a single destination node d_1. In figure 3, we illustrate address-centric routing protocol.

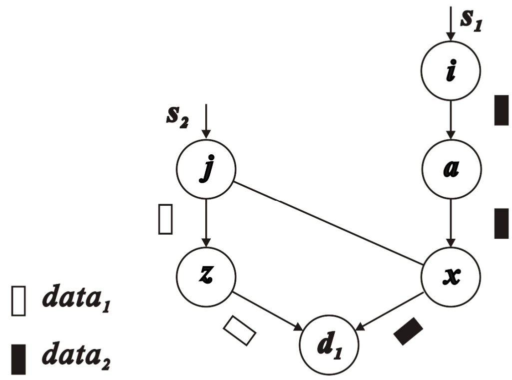

Fig. 3 Address-centric routing protocol: multiple sources send difference data through difference path to a destination d_1.

The two data follows different paths to the destination, $data_1$ passes through node j and z while $data_2$ passes through node i, a and x. In data-centric routing protocol, as illustrated in figure 4.

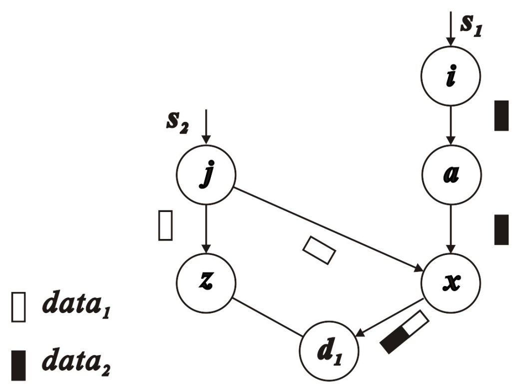

Fig. 4 data-centric protocol: multiple source send difference data through same path to destination d_1.

An intermediate node performs certain aggregation function to analyze the content of $data_1$, $data_2$, in this example node x, and aggregates $data_1$ and $data_2$ and sends the result to destination d_1.

Address-centric type routing protocols does not aggregate the data, so these protocol will spend more external data transmission cost such as power, but these protocol are adaptive the emergency or real time system. Data-centric type routing protocols take serious on data aggregation to power saving, but each nodes at routing will spend more time to wait data arrival from difference source.

2.1 Address Centric

Ad hoc on-demand distance vector(AODV)[22] is a well know address centric routing protocol. Each data flow passes through a different path. The power consumption of this algorithm is therefore not balanced within the network.

It is an on-demand algorithm. When a source node want to send data to a destination, the source will send request messages to its neighboring nodes to find routing path, and neighboring nodes forward messages to their neighbors excluding source node. When the request message arrives at destination node, the destination sends response messages back to the source following the reverse path. Intermediate nodes only record the next node that has the fastest response message. Finally source sends all data following this routing path as indicated in figure 5.

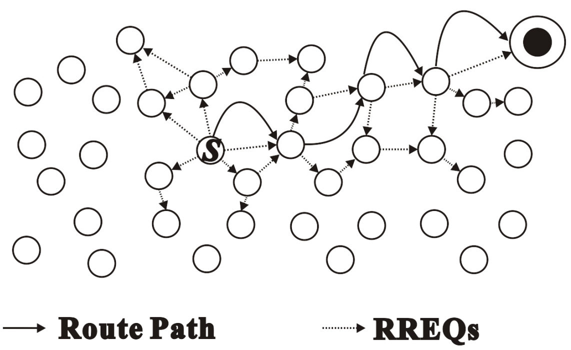

Fig. 5 AODV finds routing path, source will broadcast messages to the neighbour nodes.

2.2 Data Centric

Most sensor networks are deployed by random and sensor nodes do not have global information, so data is broadcasted from every sensor. This is very inefficient in terms of energy consumption. Efficient routing protocols take into account of a group of sensor nodes sending data and aggregate those data and pass through the same path. The data-centric routing algorithm is designed for this purpose.

Sensor protocols for information via negotiation(SPIN)[23] is a data centric routing algorithm, it uses meta data mechanism. In figure 6(a), the source will send advertisement message(ADV) to its neighbors before transmission. If the neighbor do not have the data and want to receive the data, the neighbor will reply a request message(REQ) as figure 6(b). Finally source will send the data to the neighbor after receiving the reply message. The intermediate nodes repeat this process, as shown in figure 6(d)-6(f), until the destination receives the data.

In SPIN algorithm, each node only needs to know one hop neighbors when the network topology changed. So the energy dissipation of SPIN is less than routing algorithm that uses flooding.

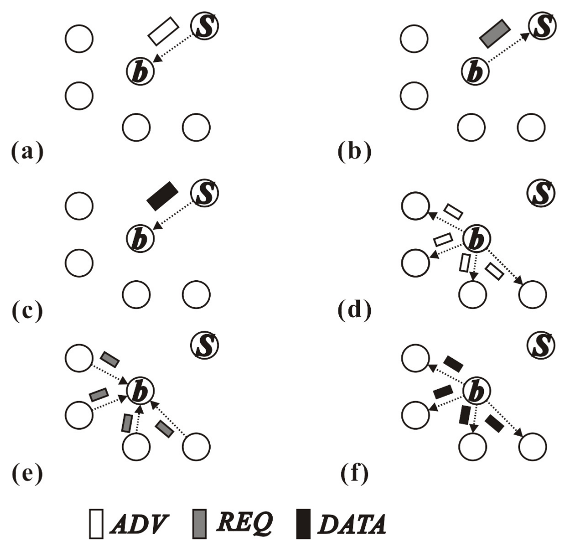

Fig. 6 SPIN protocol: ADV is advertisement message, REQ is request the data message.

Some papers[12] further added two sub class of data-centric type routing protocols: a hierarchical protocol, and a location-based protocol, we also illustrate two well-know routing protocols at follow subsection.

2.3 Hierarchical Protocol

As more sensor networks are deployed in everyday life, the scalability issue of network topology and routing protocol are becoming more prominent. When all nodes are organized in a single layer, some sensors may deplete their power before others due to overloaded network relay traffic. This network organization is not scalable for large sensor nodes in detecting or tracking objects in nature environments. A partitioned sensor network is one which sensor nodes are organized into groups and among those groups another level of super-groups can be created, thus formed a multi-layer sensor network. Each group or layer select a node as the leader by some selection algorithm, this leader node performs the data aggregation function within each group.

Low-energy adaptive clustering hierarchy (LEACH)[24] is one of the hierarchical routing protocols for sensor networks. In this protocol, sensors are partitioned into several clusters, each cluster select a node as cluster head as shown in figure 7. The algorithm uses a TDMA/CDMA MAC to reduce inter-cluster and intra-cluster collisions. A local cluster head node is selected at a certain time through a threshold function *T(n)*, such that the energy consumption remained more or less balanced within the cluster.
All nodes pick a random number between 0 and 1, and the node will be the cluster head if the number is less than *T(n)*.

$$T(n) = \begin{cases} \dfrac{p}{1 - p*(r \bmod \frac{1}{p})} & n \in G \\ 0 & otherwise, \end{cases} \quad (2)$$

where p is the percentage of cluster heads, r is the current round, and G is the set of nodes that have not been cluster heads in the last 1/p rounds.

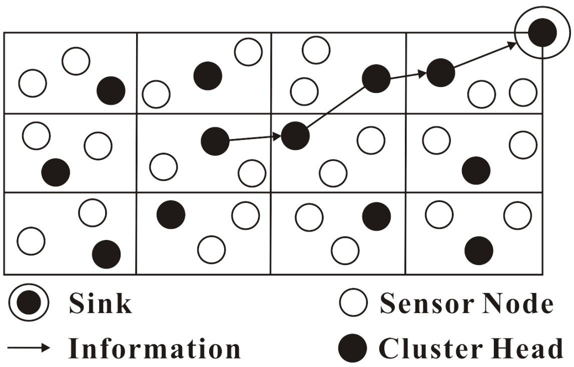

Fig. 7 LEAH: the black nodes are cluster head, each node in local cluster will transmit messages to the cluster head.

2.4 Location-based Protocol

Some sensor networks may have extra hardware to detect their location, including the use of global positioning system. Using exact location information sensor nodes can calculate the distance between neighboring nodes and utilize the information to design energy efficient routing algorithm.

Geographic adaptive fidelity(GAF)[25] is an energy aware location based routing protocol, each node has a GPS module. GAF minimizes the number of switches between energy usage states. These states are discovery, active, sleep. Discovery state is used in detecting neighbors in the network, active state is used for routing and transmitting data and radio module is turned off during sleep state. In figure 8, when source s want to send data back to sink node, the nodes a,b,c all can pass data to sink nodes. GAF use GPS to find the nearest node from sink node, so node s selects node b to pass data.

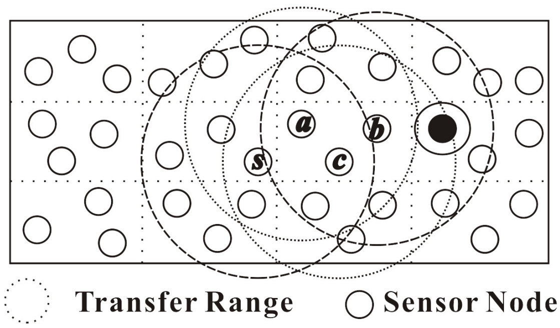

Fig. 8 GAF: source s selects the nearest node b from sink node by using GPS to pass data.

3 Betweenness

Table 1 Definition

Symbol	Description
s	Source node.
d	Destination node.
$G(V,E)$	A directed network graph G. V is a set of all nodes, E is a set of all edges.
$g_{s,d}(V',E')$	A directed graph of all possible shortest paths from s to d. $V' \subseteq V$ and $E' \subseteq E$. The compact form is denote by $g_{s,d}$.
$a^i_{s,d}$	Number of shortest paths from a to node d in $g_{s,d}$.
$a^o_{s,d}$	Number of shortest paths from a to node d in $g_{s,d}$.
$r_{s,d}(a)$	Number of shortest paths from s to d via node a.

Table 1 show notation for our mathematical formula development. By mathematical formula 1, we must get global network topology information to calculate betwneeness of each node, so it is too complexity in large network. So we propose an approximate betweenness formula.

Definition 1: Upstream paths
Upstream paths are those paths that from source node s to node a in $g_{s,d}$. The set of nodes in the upstream paths from node s to node a in $g_{s,d}$ is denoted by $B_p(a)$.

$$a^i_{s,d} = \sum_{k \in B_p(a)} k^i_{s,d} \tag{3}$$

Definition 2: Downstream paths
Downstream paths are those paths from node a leading to node d in $g_{s,d}$. The set of nodes in the downstream paths from node a to node d in $g_{s,d}$ is denoted by $B_c(a)$.

$$a^o_{s,d} = \sum_{k \in B_c(a)} k^o_{s,d} \tag{4}$$

Definition 3: Node betweenness
From definitions 1 and 2, the total number of approximate node betweenness value of node a in $g_{s,d}$ can be calculated as

$$r_{s,d}(a) = a^i_{s,d} \times a^o_{s,d} \tag{5}$$

3.1 Betweenness and Muticast
Node a is an intermediate node along some shortest path from node s and d. Figure 9 shows the betweenness of node a between node s and d. $B_p(a)$ is a set of previous nodes of node a from source node. $B_c(a)$ is a set of next nodes of node a to destination. At node a, there are a set $B_c(a)$ paths from node b to destination. For example if one node wants to send data to next node by one link which is selected by calculating the link betweenness used the definition 3. We use $r_{s,d}(a,x)$ and $r_{s,d}(a,y)$ to choose node x or y to join the shortest path. From s to d that includes the node b, then the node a.

In multicast communication, one source node send messages to a group of destination nodes, link betweenness can be used to select next node in multicast routing algorithm.

Figure 10 shows a multicast routing where source node s_1 which want to send data to the destinations nodes d_1, d_2. Using multicast routing algorithm, the data flows has been reached node a. It will select one of three next nodes to join the multicast tree. Because the value of (a,y) is larger than (a,x) and (a,z), the node y will select to join the multicast tree. It decreases number of transmission in the network.

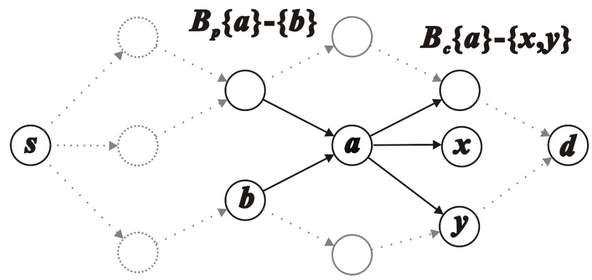

Fig. 9 betweenness of node a.

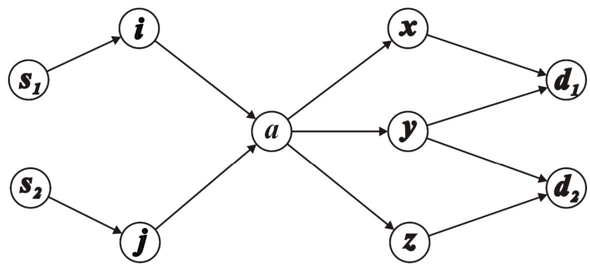

Fig. 10 Multicast routing. Source node s_1 creates a multicast tree to node d_1 and d_2.

4 Betweenness Routing Alogorithm
The proposed sensor on demand betweenness vector(SOBV) routing algorithm is discussed in this section and it involves three steps: path discovery, power consumption, path maintenance.

When source node want to send data to destination node, routing algorithm must find a path, this behavior be called path discovery. If any sensor node in the routing path is bad, routing algorithm must update routing tables to change path, it is called path maintenance.

Most routing algorithm will find the shortest path form one node to another node, such that the number of hops is minimized over all possible paths. But the shortest paths are defined other cost as faster response time, minimized battery consumption. In this paper, we only compare our algorithm with AODV, because the routing algorithms in section 2 are designed for data-centric type, they don't adaptive for emergency system. At follow section, we introduce our SOBV routing algorithm.

4.1 Path Discovery

In our approach, source node sends request message in the same way as AODV does, but intermediate nodes record not only the next node with shorter response time t but also nodes with response time less than $2*t$. This mechanism can collect multiple paths and betweenness of next nodes. For example, as shown in figure 11, AODV only record the path following nodes *s*, *2*, *4*, *6*, *8* , and *d*. But SOBV will record multipath including nodes *s*, *1*, 2, *3*, *4*, *5*, *6*, *7,8*. The routing table of node *s* is recording next nodes 1 and 2, and table of node 2 is recording nodes 3 and 4.

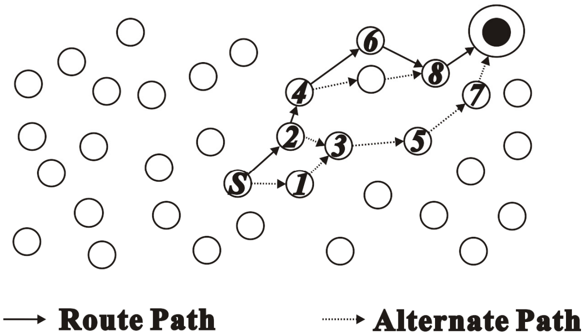

Fig. 11 Routing path build by SOBV routing algorithm.

4.2 Power Consumption

A node with high betweenness value indicates that it is involved in relaying messages more frequently and its battery is more likely to die out before other nodes along the path. When a sensor node is out of battery, it will be out of function, and the sensor will be unconnected, and this case will cause tracking failure in the tracking system.

Source nodes send data only through static routing path in AODV. So a group of nodes in the static routing path will be quickly out of power. But with SOBV, source node send data to its one hop neighbors and then data are forwarded to their next neighbors selected by their betweenness value. Every step will select one time again. We will show the step of SOBV algorithm. By table 2, we defined some symbols to help us to clearly describe the process. When node i will send m packet to destination node d, the short path distance is n hops form s to d. When each packet passes to next hop, this algorithm will selected the one edge H_{ik} in H, this edge is the maximum value in return value of the probability function $P(H_{ik})$. This function will be input the parameter of the betweenness $b(H_{ik})$ of edge $H_{ik.}$ and it will calculate the $b(H_{ik})$ with a random number and the battery of node k. A sample is in figure 11, one packet is sent form source, the packet will use probability function to select the edge H_{s1} or H_{s2} to pass and same as the edge H_{24} or H_{23}.

Each of packets maybe send to destination by difference shortest paths, such that SOBV can balance the power consumed at each node, our algorithm can improve lifetime better than AODV in the sensor network.

Table 2 Definition

Symbol	Description
i	Intermediate node
d	Destination
H	First edge set in all shortest path form i to d. H_{ik} one edge of node i.to k
H_{ik}	First edge set in all shortest path form i to d. H_{ik} one edge of node i.to k
$b(H_{ik})$	The betweenness of edge $H_{ik.}$
$P(H_{ik})$	$P(H_{ik})$, this function will be return the probablility of the edge H_{ik} be selected for input $b(H_{ik})$.

4.3 Path Maintenance

In AODV algorithm, if an intermediate node in the routing path is out of power, its preceeding node will send a path error message back to the source. When the source receives the messages, it will begin to re-send control messages to find a new routing path. These control packets will use a lot of energy and affect the performance of routing. The performance of a routing algorithm is usually characterized by delivery ratio, which is defined by the ratio of data sent by the source to the data arrived successfully in destination.

In the case of SOBV, when there is a node failure occurred, if the previous node has an alternative path recorded in its routing table, this alternative path will be used. There is no need to re-establish a new routing path.

5 Simulation Results

We use a grid random network in our object tracking system simulation. There are total N sensor nodes randomly distributed on a 2-dimensional plane. Each sensor node connects to other nodes which are within its transmission range. We randomly select source node in the network, the sink node is the destination node. Our algorithm use request message to know node betweenness at path discovery step. Before we start our simulation, we show the betweenness distribution of grid random networks in figure 12, the number of nodes in this network is 500.we know that most of nodes have low betweenness and a few nodes are high betweenness.

In figure 13, when the number of nodes is increase, the average short path length is decrease, but the number of short path is increase. By this result, we can know more the number of nodes, the power load balance is better by our routing algorithm.

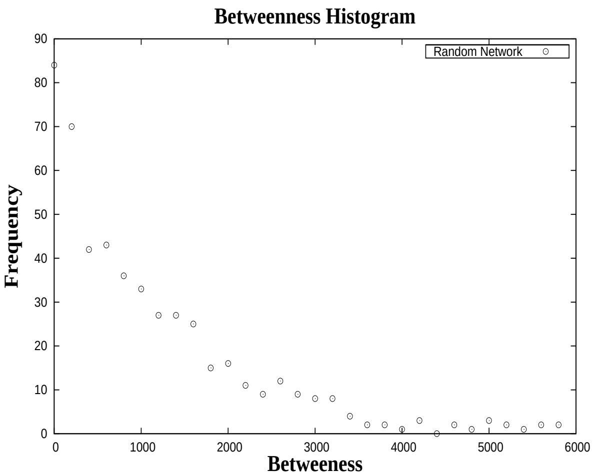

Fig. 12 Betweenness distribution. N=500. x-axis is betweenness of node..

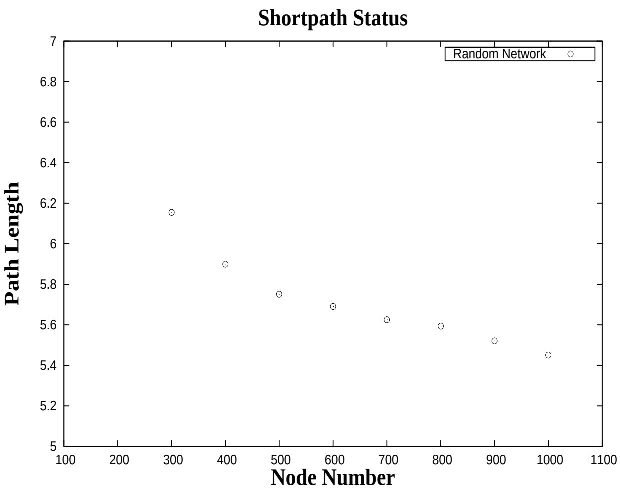

Fig. 13 The average short path between node of number 300~500.

For understanding the energy utility between AODV and SOBV algorithm in our simulation, we setup our simulation as follow. There are 300 nodes are distributed on a plane. At beginning, the battery capacity of a node is 500 units. Every packet included control and data message pass the node will be consumed some power. Each transmission is randomly chosen source and destination nodes from network. We run AODV routing algorithm at our network, figure 14 represent the results after 450 times transmissions.

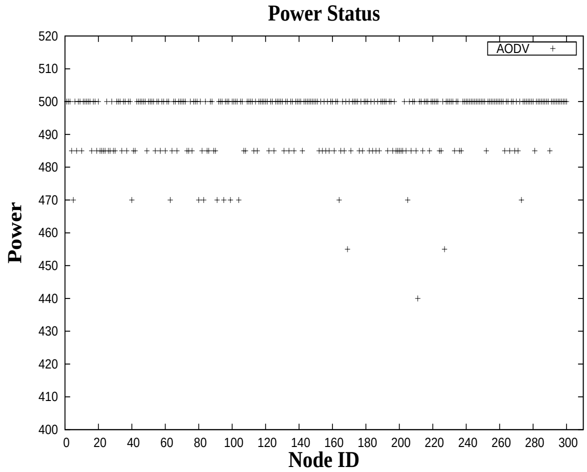

Fig. 14 Status of residual battery capacity of AODV, battery capacity is 500 units.

The figure shows some group battery capacities of nodes are quickly out of power at 485 area of battery capacity, because the AODV sends data only use static routing path form source to destination, it don’t not use multipath to balance the power consuming. By this trend, the alive nodes of network will be less. Figure 15 illustrates the result used our new routing algorithm(SOBV). By our rules, the data is transferred by multipath path. So the power of nodes will be balance at 480~500 area of battery capacity.

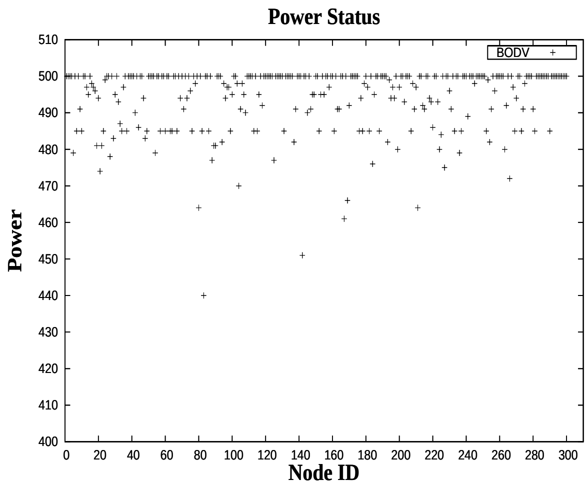

Fig. 15 Status of residual battery capacity of SOBV, battery capacity is 500 units.

Comparing figure 14 and figure 15, the SOBV routing algorithm improves lifetime of network batter than AODV algorithm. At final, we design anther simulation experiment to justify our routing again, we run 550 times transmissions with difference source and destination nodes. The following figure 16 shows that how many nodes are dead by this simulation. We can find less dead number of nodes at same transmission times comparing with AODV and SOBV. By the 200's, 300's and 400's transmission times, we also clearly show the advantage of balance of power consuming.

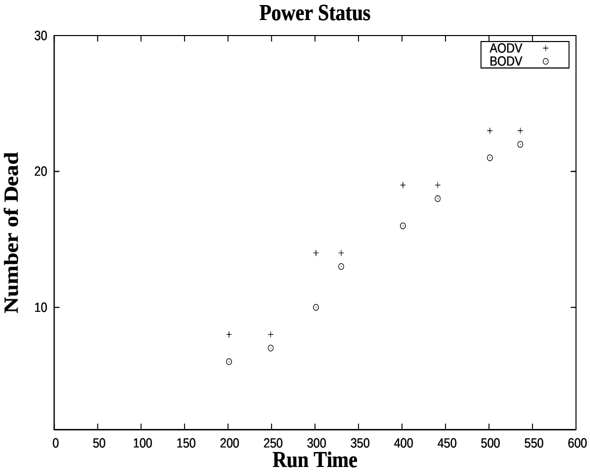

Fig. 16 X-axis shows transmission times. Y-axis illustrates number of dead number.

6 Conclusion

The important issues of emergency object tracking system in sensor network are improving lifetime of network and exactly tracking object. So the power consuming mechanism is the most important research. Our search teams focus on the properties of complex network and computer network.

In this paper, we design a new routing algorithm combing two research domain, In sensor routing, we keep the multipath information by betweenness in routing tables of each nodes.

When sensor nodes send data can pass through multipath to destination and select the next routing node depend on betweenness, so our routing algorithm(SOBV) can balance power consuming and improve lifetime of sensor network.

Finally we present the advantage of SOBV, we showed that our routing strategy work batter than AODV algorithm at figure 14, figure 15 and figure 16. The important contribution of our paper is our routing algorithm improves power consumed on multipath and increases the lifetime in sensor network.

References:

[1] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," *Computer Networks*, 52(12), 2008.

[2] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "Wireless sensor networks: a survey," *Computer Networks*, pp. 393–422, 2002.

[3] T. Arampatzis, J. Lygeros and S. Manesis, "A survey of applications of wireless sensors and wireless sensor networks," *Proc. 13th Mediterranean Conference on Control and Automation*, pp. 719-724, Limassol, Cyprus, June 27-29, 2005.

[4] S. Tilak, N. Abu-Ghazaleh, W. Heinzelman, "A taxonomy of wireless micro-sensor network models," *ACM SIGMOBILE Mobile Computing and Communications Review*, Vol 6, Issue 2 , pp. 28-36, 2002.

[5] B. Sundararaman, U. Buy and A. Kshemkalyani, "Clock synchronization for wireless sensor networks: a survey," *Ad Hoc Networks*, pp. 281–323, 2005.

[6] G. Simon, M. Maroti, A. Ledeczi, G. Balogh, B. Kusy, A. Nadas, G. Pap, J. Sa Sallai, K. Frampton, "Sensor network-based countersniper system", *in Proc. of the Second International Conference on Embedded Networked Sensor Systems (Sensys)*, Baltimore, MD,2004.

[7] J. Campbell, P.B. Gibbons, S. Nath, P. Pillai, S. Seshan and R. Sukthankar, "IrisNet: an Internet-scale architecture for multimedia sensors," *in Proc. of the ACM Multimedia Conference*, 2005.

[8] Min-yu Ku, Chuang-Cheng Chiu, Huang-Tsung Chen and Shun-Huang Hong, "Visual Motorcycle Dectection and Tracking Algorithms," *WSEAS Transactions on ELECTRONICS*, Vol. 5, Issue 4, pp. 121-131, 2008.

[9] G. Wener-Allen, K. Lorincz, M. Ruiz, O. Marcillo, J. Johnson, J. Lees. M. Walsh, "Deploying a wireless sensor network on an antive volcano, Data-Driven Applications in Sensor Networks," *IEEE Internet Computing* , March 2006

[10] Md. A. Rahman, A. El Saddik, and W. Gueaieb, "SenseFace: A Sensor Network Overlay for Social Networks," *I2MTC* 2009.

[11] Mararculescu A, Nikoletseas S, Powell O, Rolim J., "Efficient tracking of moving targets by passively handling traces in sensor networks.," *in Proc. of the IEEE Global*

Telecommunications Conference, New Orleans, LA, U.S.A., 2008.
[12] K. Akkaya and M. Younis, "A survey on routing protocols for wireless sensor networks," *Ad Hoc Networks*, vol. 3, pp. 325-349, 2005.
[13] Taewook Kang, Jangkyu Yun, Hoseung Lee, Icksoo Lee, Hyunsook Kim, Byunghwa Lee, Byeongjik Lww and Kijun Han, "A Clustering Method for Energy Efficient Routing in Wireless Sensor," *in Proc. of the 6th WSEAS Int. Conf. on Electronics, Hardware, Wireless and Optical Communications*, Greece, 2007.
[14] G. Anastasi, M. Conti, M. Francesco and A. Passarella, "Energy conservation in wireless sensor networks: A survey," *Ad Hoc Networks* 7(3), pp.537–568, 2009.
[15] Icksoo Lee, Jinsuk Pak, Sooyeol Yang, Hoseung Lee, Keuchul Cho, Hyunsook Kim and Kijun Han, " An Energy-Efficient MAC Protocol in Track-Based Wireless Sensor Networks," *in proc. of the 8th WSEAS International Conference on Evolutionary Computing*, Canada, 2007.
[16] R. Albert and A. L. Barabási, "Statistical mechanics of complex networks," *Rev. Mod. Phys*. 74, pp.47–97, 2002.
[17] Yihjia Tsai, Ping-Nan Hsiao, "Using Caveman Network to Construct Social Network," *WSEAS Transactions on Information Science and Applications*, Vol. 4, Issue 4, pp. 719-724, 2007.
[18] L.d Costa, F.A. Rodrigues, G. Travieso and P.R.V. Boas, "Characterization of complex networks: A survey of measurements," *Adv. Phys.* 56, pp. 167–242, 2007.
[19] D. J. Watts and D. H. Strogatz, "Collective dyanmics of small-world networks," *Nature* 393, pp.440-442, 1998.
[20] A. L. Barabási and Eric Bonabeau (2003), "Scale Free Networks," *Scientific American*, May, pp.50-59, 2003.
[21] Yihjia Tsai and Ping-Nan Hsiao, "A Growing Network Model with High Hub Connectivity and Tunable Clustering Coefficient," *WSEAS Transactions on Information Science and Applications*, Vol. 4, Issue 12, pp. 1447-1452, 2007.
[22] Charles E. Perkins and Elizabeth M. Royer. "Ad hoc On-Demand Distance Vector Routing," *in Proc. of the 2nd IEEE workshop on Mobile Computing Systems and Application*, New Orleans, LA, pp. 90-100, 1999.
[23] W. Heinzelman, J. Kulik and H. Balakrishnan, "Adaptive protocols for information dissemination in wireless sensor networks," *in Proc. of the 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking* , Seattle, 1999.
[24] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient communication protocol for wireless sensor networks," *in Proc. of the Hawaii International Conference System Sciences*, Hawaii, 2000.
[25] Y. Xu, J. Heidemann and D. Estrin, "Geography-informed energy conservation for ad hoc routing," *in Proc. of the 7th Annual ACM/IEEE International Conferenc*e, Rome, July 2001.