Journal of Theoretical and Applied Information Technology
20th March 2013. Vol. 49 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

STUDY IN THE ROUTING ALGORITHM IMPROVEMENT ON MULTI-CHANNEL MULTI-HOP WIRELESS SENSOR NETWORK

[1]WEI HUANG, [2]HUAJUN WANG, [3*]GQIAN ZOU
[1] Assoc. Prof., Department of Information, Chengdu University of Technology, Chengdu, China
[2] Prof., Department of Information, Chengdu University of Technology, Chengdu, China
[3] Assoc. Prof., Department of Information, Chengdu University of Technology, Chengdu, China
* Corresponding author
E-mail: [1]39189550@qq.com , [2]63918058@qq.com , [3]sissizou@qq.com

ABSTRACT

This paper analyzes the characteristics of Wireless sensor networks through the history of the development of wireless sensor networks. We propose a new wireless sensor network nodes algorithm based on the study of Wireless sensor network routing mechanism and the transmission model .This algorithm improves the protocol performance, reduces the network communication cost and optimizes the transmission link by choosing the best path of transmission. Experiment results show that the algorithm is able to find the shortest path in the real-time in the dynamic network environment, and the stability of the wireless transmission is enhanced.

Keywords: *Sensor Networks, Routing Algorithm, Nodes, Transmission Model, Protocol Stack*

1. INTRODUCTION

The researches on wireless sensor network routing algorithm promote the interoperability, perception and intelligent decision-making ability of the network information. Wireless sensor network consists of a large number of sensor nodes in the monitoring area. The sensors are able to monitor target’s light intensity, motion, pressure, wind, speed, direction, etc, by measuring its thermal [1], infrared, sonar, radar signals, etc. The advantages of wireless sensor network[2] are: Flexible deployment with wide coverage; A large amount of nodes increases the quality sharply as clouds of nodes which are close to the target permit obtaining integrated information with multi-angles[3], multi-faces, high accuracy; Low-cost, highly redundant network guarantee high reliability; Distributed ad hoc networks support multi-mode multi-user concurrent access. Wireless sensor networks can also be effectively used for event detection, target locating, tracking and identification thus its scope of application is very broad in the field of military defense, security, counter-terrorism[4], environment monitoring, traffic management, health and industry manufacturing area.

Multi-hop routing localizes the bandwidth usage during communication [5], which improves the efficiency in the use of communication bandwidth of the whole system, and the multi-hop routing distance is several times as that of the direct communication [6].

2. DEVELOPMENT OF THE WIRELESS SENSOR NETWORKS

Modern research on sensor networks started around 1980 with the Distributed Sensor Networks (DSN) program at the Defense Advanced Research Projects Agency (DARPA). Funded by DARPA[9], more applications of military relevance are demonstrated in the project- Smart Dust. In the following years, several laboratories from the University of California(UCLA) and Berkeley [10], such as: BWRC (Berkeley Wireless Research Center), the NEST (Network Embedded Systems Technology), BARWAN (Bay Area Research Wirel ess Access Network),WEBS (Wireless Embedded System), conducted in-depth studies of different aspects of wireless sensor networks and have made a lot of successes.

Massachusetts Institute of Technology (MIT) [7], funded by ARPT, engaged in the study of very low-power wireless sensor networks, whose SPIN (Sensor the Protocols for Information Via Negotiation) protocol attracted industry's wide interests[8]; And the CENS (Center for Embedded Net Sensing) laboratory of UCLA, Wireless Sensor

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Network Laboratory of the University of Stanford are established and also evolved in the related research area. March 9-th, 2010, China "standard joint working group of Internet of things "prepare commission is held in Beijing[9].

3. FEATURES OF THE WIRELESS SENSOR NETWORK.

The main features of wireless sensor networks are: ad hoc networks, multi-channel, multi-hop and self-healing, etc[10]. Energy consumption is an important issue in the ZigBee technology based wireless sensor network, which works in all-weather[14], all-round monitoring of objectives.

Up to now, the protocols mainly focus on energy saving sacrificing; if necessary, some network performance for getting higher power efficiency. Most of the energy consumption inside sensor unit is used for computing and communication while the energy consumption of the sensing module is much lower. For keeping necessary communication [11], the sensor nodes should be effectively controlled. Some improvements of the routing protocol should be made in how to reduce the flood of redundant data in the network, how to improve the robustness of the network link and how to reduce sensor network energy consumption. Fig. 1 shows the energy consumption of nodes, e.g. Node Sleeping can greatly reduce the energy consumption, while the sending/receiving and idle time will consume a lot of energy.

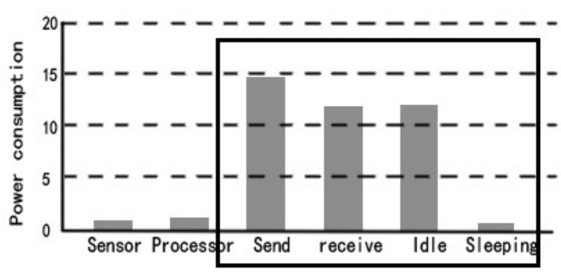

Figure.1 Scheme of node energy consumption

We summary the following features of the wireless sensor network:

3.1 Numerous Nodes

Currently, wireless sensor networks always consist of a large number of sensor nodes, with high density [12], e.g. the number of nodes per square meter is several orders of magnitude than traditional wireless networks.

3.2 Self-Organization In Wireless Sensor Network

Self-organization Nodes is very important in the wireless sensor network since Wireless sensor networks require that sensor nodes can self-organize, which means the node can automatically configure with respect to the dynamic nature of the communication process, and automatically forward data to the nodes outside of the communication which is called multi-hap[13].

3.3 Effects Of Dynamically Changing Network Topology On The Routing Protocol

Conventional routing protocols are designed for fixed wire line network, usually does not take into account the dynamically changing network topology. The protocol takes a very long time and a high cost to reach the convergence state when the topology changes, worst case is that the algorithm has not yet reached the convergence state of when the network topology has changed, the host spent a very high cost (such as network bandwidth, energy, CPU resources, etc.) but just received the old routing information, and the network often stays in non-convergence routing protocol state.

3.4 Fault Tolerance Of Wireless Sensor Network

Wireless sensor network has a certain degree of fault tolerance and survivability.

Since the environment for nodes is always very poor, sensor nodes may be disturbed and fail down because of some unknown reasons. And because of the high number of nodes and wireless sensor network is often used in remote areas[14], it is difficult to replace the batteries of the sensor nodes. Thus the energy of nodes is limited, which directly determines that the life of the sensor nodes' and network's is limited, and this becomes one of the most critical issue in the wireless sensor network design.

4. ROUTING MECHANISM IN THE WIRELESS SENSOR NETWORK

Routing protocol is an important factor for the network performance, and it is the key issue to determine the success of wireless sensor networks, because the advantages of Wireless sensor networks towards other similar technology are brought by the routing protocol.

After investigation, we find that wireless sensor network nodes have different types (Mobile Router and Mobile Client), and they have different mobility[15], energy constraints and business model, which make the nodes need different routing

Journal of Theoretical and Applied Information Technology
20th March 2013. Vol. 49 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

protocols. The main desired aspects of the routing protocol are: scalability, reliability, connectivity of mobile users, QoS and efficient basic network routing access.

4.1 A flood routing

This is a very traditional routing protocol. Flood routing doesn't maintain the network topology and routing related calculations, and it is only responsible for forwarding packets in broadcast mode, so the efficiency of this protocol is not high enough.

4.2 SPIN

SPIN is a consultation and agreement based protocol and with adaptive function of power. The nodes determine whether they need to send a signal by the consultation between each other, and change the operating mode by real-time monitoring of the energy load in the network. The above two protocols are both flat routing protocols, in accordance with these protocols; nodes are not classified into different partitions.

4.3 LEACH

LEACH is a layered network protocol; it selects the head node of the nodes cluster looply, and evenly distributed the energy load to each sensor node of the whole network, so as to reduce the energy consumption. Let's say more about the "cluster", which is the concept of hierarchical routing protocols. According to the hierarchical routing protocol, the network is divided into different clusters, each cluster composed by a cluster head and other cluster members, more than one cluster for a senior network cluster. The head node is not only responsible for information collection and fusion from the below cluster(s), but also responsible for forwarding the data between clusters.

4.4 PEGASIS

PEGASIS can be described as the upgrade version of LEACH. In accordance with its definition, only the closest nodes communicate with each other and nodes communicated with the Rendezvous Point in turn. When all nodes have communicated with the Rendezvous Point, the nodes then start a new round of rotation communication [16].

5. COMPARISON OF THE WIRELESS SENSOR NETWORK TRANSMISSION MODELS

5.1 Direct Transfer Model

The direct transfer model is defined as such: the sensor nodes send collected data by the larger power hop transmission to the Sink node for centralized processing, as shown in Figure 2. The disadvantage of this method is: the sensor nodes which are far from the Sink node need to consume much power for the communication with the sink node. Since the communication distance of sensor nodes is limited, the nodes which are far from Sink node are often unable to reliably communicate with Sink node. And this cannot be accepted. Yet, it needs a lot of energy to complete the long distance communication between the Sink node and other nodes, this consume nodes' energy so very fast. All the above make this kind of sensor network difficult to use in practice.

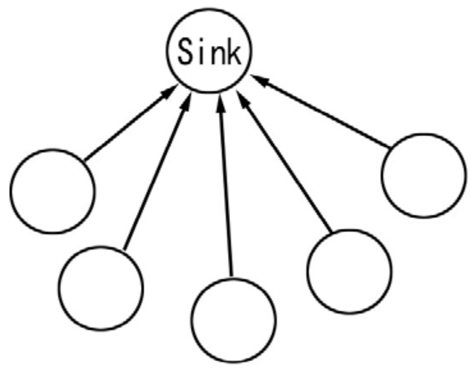

Fig.2. Direct transfer model

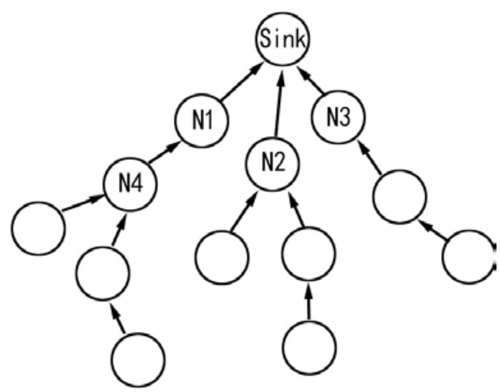

Fig.3. Direct transfer model

5.2 Multi-hop transmission model

This model is similar to the AD-Hoc network model, as shown in Figure 3. Nodes do nothing with the collected data by itself, only adjust the transmit power and transmit the data to the Sink node with in multi-hop. Multi-hop transmission model improves the direct transmission of the defect, which make energy use more efficient.

The disadvantage is that: when the network size is large, there will be a problem called "hot point",

Journal of Theoretical and Applied Information Technology
20th March 2013. Vol. 49 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

which is the nodes located in two or more paths cross and the one-hop node from the Sink node (bottleneck node), such as the nodes: N1, N2, N3, N4 in Figure 3, in addition to their selves transmission, but also acted as an intermediary in the multi-hop transmission. In this case, the energy of these nodes will be exhausted fast. For sensor networks, energy saving is top issue, it is obviously not a very effective way.

5.3 Data Fusion Technology In The Wireless Sensor Network

In the large-scale wireless sensor networks, due to the fact that the scope of monitoring and reliability of each sensor is limited, in order to enhance the robustness and accuracy of the collected information inside the entire network, monitoring range of the sensor nodes should overlap each other. This makes the collected data in wireless sensor networks have a certain degree of spatial correlation, that is, the data from closed nodes has a certain redundancy. In the traditional mode of data transmission, each node will transfer all of the sensing information, which contains a large amount of redundant information and a considerable part of the energy for unnecessary data transmission. The energy consumption for transferring data is much larger than the energy consumption of data processing. Therefore, in the large-scale wireless sensor networks, each node does the data fusion process first before it multi-hop transmits the data to the Sink node. Since it is very necessary, data fusion technology came into being.

5.4 Architecture Of The Wireless Sensor Network

The basic architecture of the wireless sensor network system consists of three parts. The first part is a wireless transceiver chip, whose role is to convert the digital information to high frequency radio signals for transmission and convert the received high frequency radio signal back into digital information. IEEE 802.15.4 standard provides the best solution for wireless sensor applications transceiver chip selection, this is because the IEEE 802.15.4 specification may be the primary and the only practical standard. A number of companies provide this transceiver chip. Such as TI's CC2420/CC2520 and other chips are particularly suitable for low power consumption of the button cell battery and low energy applications. A typical wireless sensor network nodes and routers can take multi-chip solutions, as shown in Figure 4, composed by a wireless transceiver and a microcontroller (MCU), and low-power MSP430 can be selected as the microprocessor and CC2520/CC2420 used for the wireless chip.

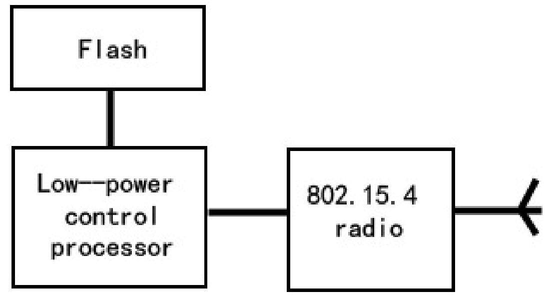

Figure 4 A typical wireless sensor network node or router

With the continuous development of technology, more and more companies integrated the wireless transceiver chip, microcontroller and wireless transceiver into system on chip (SOC), such as TI's 8051 in core CC2430/CC2431 and other ZigBee wireless microcontrollers. For the wireless sensor network computing capacity requirements, Free-scale also produced a ZigBee wireless microcontroller with 32 bits ARM core recently. This makes the wireless sensor node in a smaller size, lower power consumption and lower prices by using these wireless SoC single-chip to design the wireless sensor networks; And the technology partner of TI in China-wireless Dragon Technology, also provides these chips, development tools and technical support.

The ZigBee Alliance is an independent standards organization composed by a number of technology suppliers and developers. It’s the world's largest Union provides the standard based on the IEEE 802.15.4 platform network software protocol stack. The organization from ZigBee2004, ZigBee 2006, and ZigBee2007…, now provides two network stacks: the ZigBee and ZigBee PRO. The ZigBee stack is very suitable for a small network of ten to hundreds of nodes. ZigBee PRO is a superset of ZigBee, it adds some features, network expansion and better responds to wireless interference from other wireless communication, and can be adapted to larger networks with more reliable routing and communication algorithms and reliable in the wireless communications.

6. PROTOCOL STACK IN WIRELESS SENSOR NETWORK

Z-Stack is used as a software protocol stack (network stack) in the wireless sensor networks, it passes through the ZigBee Alliance reorganization and used by many developers and it is loaded in an IAR based project on of development environment.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Z-Stack is built from the idea of the operating system, and it uses the event polling mechanism.

Z--Stack is a layered software architecture, which uses a hardware abstraction layer (HAL) drivers for the various hardware modules, including Timer, universal I / O port the GPIO, universal Asynchronous Receiver Transmitter UART, analog to digital converter ADC Application Programming Interface API, etc. The operating system abstraction layer (OSAL) achieves an easy-to-use operating system platform, providing multitasking mechanism by the round-robin function task scheduling. The user can call OSAL provided API for multi-tasking programming and run the application as a separate task.

The Z-stack file structure is described as follows:

Hal: hal file folder for the abstraction layer of the hardware platform, including common, include, target.

Mac: high_level, include, low_level.

Mt: debug files.

Osal: osal contains the files for the abstraction layer of the operating system, contains the common, include, mcu.

Service: saddr, sdata.

Stack: af (application framework), the nwk (network layer), the sapi(simple application interface), sec (Security), the sys (system header files), zcl (ZigBee Cluster Library), zdo (ZigBee device object).

zmac: contains export file of the mac layer in z-stack

MAC: Include the directory that contains the MAC layer parameter configuration files, and C, LIB function library Interface file; High Level and Low Level stands for the MAC layer is divided into high and low two-tier.

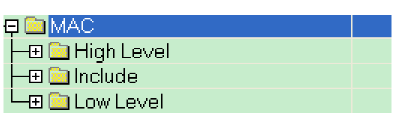

Fig.5. Features of MAC

MT: monitors debug layer directory, mainly for debugging, direct interacting within the layers, by the serial port debugging.

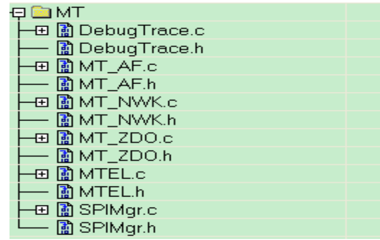

Fig.6. Features of MT

NWK: directory of the network layer, including the network layer configuration parameter file and the network layer function library interface file, and APS layer library function interface.

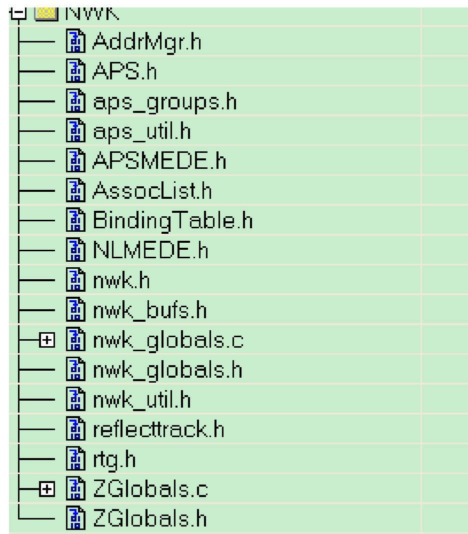

Figure 7 Features of NWK

For example: addressing design in z-stack: In order to send data to a device in the network application layer, generally use AF_DataRequest () function. The destination's device type (afAddrType_t) is defined in "ZComDef.h:

```
typedef struct
{
  union
  {
    unit16 shortAddr;
    ZlongAddr_t extAddr;
  }addr;
    Byte addrMode;
}zAddrType_t;
```

Parameters of Address mode: Note: In addition to this network address, the address mode parameters

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

need to be specified. Destination address mode may have the following values (AF address mode is defined in AF.h "):

```
Typedef enum
{
  afAddrNotPresent=AddrNotPresent;
  afAddr16Bit      =Addr16Bit;
  afAddrGroup      =AddrGroup;
  afAddrBroadcast=AddrBroadcast;
}afAddrMode_t;
```

The address mode parameter is necessary because in ZB, transmission, packets can be sent in Unicast, multicast or broadcast transmission. Unicast is sent to a single device, multicast transmission is sent to a group of devices, broadcast transmissions are generally sent to all devices in the network.

7. ALGORITHM IMPROVEMENT FOR THE NODES IN THE WIRELESS SENSOR NETWORK

Overview: Periodic broadcast is conducted, to clear the neighbor state to determine the link quality, and provide information for routing screening and selection. The service notice mechanism means the data node publish their own service information by inhibition of flooding to the surrounding nodes. This decreases the costs of maintenance, towards to the GRPH mechanism (MAODV).

The route discovery process and route selection process construct the multicast shared tree. In the route discovery phase, the source node or intermediate node which receives the RREQ request just send the RREQ request to to their neighbor nodes with the transmission constraints (transponders); the multicast group member nodes will respond to the message and feedback RREP packets when they receive the RREQ. The source node or intermediate node select the best link to send MACT message to establish the reverse route, base on the link status, Table 1 shows a setting of the partial function format.

Table 1: Shows A Setting Of The Partial Function Format

Domain Name	Domain Type	Valid values range	Description
Extended address	Integer	64 bits valid IEEE address	Each device has a unique 64-bit IEEE address. If the neighbor device is the parent device or sub-equipment, in the presence of the sub-domain
Network address	Network address	0x0000 -0xffff	16 bits network address of the neighbor device. The sub-domain exists in a neighbor table
Device type	Integer	0x00-0x02	Type of neighbor device: 0x00 for ZigBee coordinator; 0x01 for ZigBee router; 0x02 for ZigBee end devices
RxOnWhenIdle	Boolean	TRUE or FALSE	Stands for whether the neighbor device is working when it is in the gap of idle period and super frame activities. TRUE: receiver closed FALSE : receiver open

The algorithm is updated below:

```
#if defined (RTR_NWK)
  //change this using a different stack profile…
  //Cskip array
unit16*Cskip;
#if (STACK_PROFILE_ID)= = HOME_CONTROLS)
 byte CskipRtrs[MAX_NODE_DEPTH+1] = {6,6,6,6,6,0};
byte CskipChldrn[MAX_NODE_DEPTH+1] = {20,20,20,20,20,0};
#elif (STACK_PROFILE_ID= =GENERIC_STAR)
```

Journal of Theoretical and Applied Information Technology
20th March 2013. Vol. 49 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

```
byte CskipRtrs[MAX_NODE_DEPTH+1] = {5,5,5,5,5,0};
byte CskipChldrn[MAX_NODE_DEPTH+1] = {5,5,5,5,5,0};
#elif (STACK_PROFILE_ID= =NETWORK_SPECIFIC)
byte CskipRtrs[MAX_NODE_DEPTH+1] = {5,5,5,5,5,0};
byte CskipChldrn[MAX_NODE_DEPTH+1] = {5,5,5,5,5,0};
#endif // STACK_PROFILE_ID
#endif //RTR_NWK
```

8. SIMULATION

We test the improved algorithm in the simulation with a simulated analog signal transmission and Shock size. We use the following situations: still, repeatedly shaking, move back and forth, Move around to simulate the static and the acceleration move along tri-axial. And we get the A / D value corresponding to the time axis and tri-axial accelerometer change (voltage value). Here is the comparison:

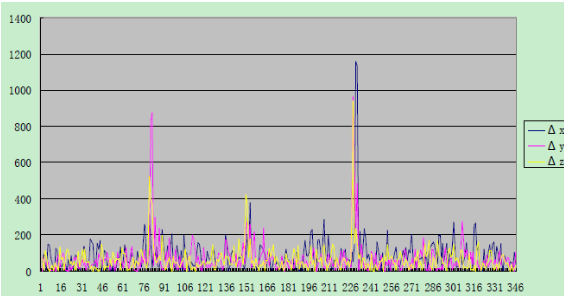

Fig.8 Result of 3 strong signal input.

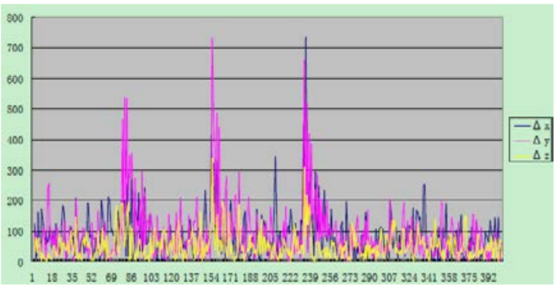

Fig.9 Result of 3 week signal input.

ADC_GAP=1,ADC_COUNT=1,g_AD_Set_Print_GAP=1

X	△x	Y	△y	Z	△z
4880	97	3986	11	2209	1
4943	63	3744	242	2184	25
5022	79	3999	255	2203	19
4904	118	3896	103	2191	12
4956	52	3952	56	2183	8

The figures and data show that the largest part of the voltage from the map and the corresponding data in the middle of the role of vibration in the y-axis Value, here is Δy, is quite different, indicating that the sensitivity of the chip meets the requirements. It means this is possible to distinguish the arrival of the signal by setting Upper and lower threshold with the output voltage range.

When the node is still, the signal voltage before and after difference- Δy have no significant difference from which we can say the object is in the stationary state.

Workflow of the wireless network construction: First of all, the nodes power up to complete the self-test function and the central control center finds the least disturbance operating frequency range within the channel and establishes a network. The remaining nodes automatically find the center and apply for the network. The control center sends network parameters to the nodes, the nodes join in the network with saving the parameters. When a node cannot communicate directly with the center due to distance / interference problem, broadcasts its own information around the node. By evaluating the surrounding nodes to the center, the node determines which node as its parent node, thus joins in the network process.

9. CONCLUSION

Since the wireless sensor network environment is an uncertain and constantly changing network; the arbitrary movement of nodes tends to interrupt the connection link and needs to re-establish a connection. Route re- establishment always needs to re-initiate the routing process, which consumes large amounts of network resources, introduces the delay and loss; this highly affects the multicast performance. When streaming media and other business data transmit in real time broadcast, it requires the receiving node moves quickly when the location of the node changed to re-join the multicast group. From a whole view of the network, as long as the transmission source exists, there is always convergence node to be chosen.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

We know that the key to improve the overall performance of wireless is how to control the sensor network nodes. This paper proposed an improvement algorithm to enhance the functionality of the wireless sensor network. From the simulation, we can find that the multicast group link can be optimized, network communication cost can be reduced and the performance improvement can be optimized by the request path filtered and the feedback path. Performance and stability in a mobile environment are improved by using the Path stability as a parameter.

ACKNOWLEDGEMENTS

This work was supported by Foundation of Guizhou Province Science and Technology . Item Number: J [2012]2020. Foundation of Guiyang Province . Item Number: [2012HK] 209-22.

REFRENCES:

[1] Dorigo, M., Maniezzo, V., Colorni, "The Ant System: Optimization by a Colony of Cooperating Agents", *IEEE Transactions on Systems, Man, and Cybernetics-Part B*, Vol. 26, No. 1, 1996, pp. 29-41.

[2] Rajagopal Iyengar, Biplab Sikar, "Scalable and distributed GPS free positioning for sensor Networks", Proceeding of IEEE Intel Conference, IEEE Computer Society, February 10-15, 2003, pp. 338-342.

[3] J. T. Brassil, S. Low, N. F. Maxemchuk , "Copyright protection for the electronic distribution of text documents", *Proceedings of IEEE*, Vol. 12, No. 12, 1999, pp. 1181-1196.

[4] D. Huang, H. Yan, "Inter word distance changes represented by sine waves for watermarking text images", *IEEE Transactions on Circuits and Systems for Video Technology*, Vol. 3, No. 11, 2001, pp. 1237-1245.

[5] V. RodoPlu, T. H. Ming, "Minimum Energy Mobile Wireless Networks", *IEEE Journal of Selected Areas in Communications*, Vol. 17, No. 8, 1999, pp. 1333-1344.

[6] Niculescu D, Nath B, "Ad hoc positioning system (APS) using AOA", *IEEE Computer and Communications Societies*, Vol. 3, No.11, 2003, pp. 1734-1743.

[7] Yaman, R., Gethin, D.T., and Clarke, M.J., "Effective sorting method for facility layout construction", *International Journal of Production Research*, Vol. 31, No. 2, 1993, pp. 413-427.

[8] Balakrishnan, J., Cheng, C.H., and Conway, G., "An improved pair-wise exchange heuristic for the dynamic plant layout problem", *International Journal of Production Research*, Vol. 38, No.13, 2000, pp. 3067-3077.

[9] Baykosoglu, A. Gindy, N.N.Z., "A simulated annealing algorithm for dynamic facility layout problem", *Computers and Operations Research*, Vol. 28, No.8, 2001, pp. 1403-1426.

[10] Deepak Ganesan, Ramesh Govindan, Scott Shenker, Deborah Estrin, "Highly-resilient, energy-efficient multipath routing in wireless sensor networks", *Mobile Computing and Communications Review*, Vol. 4, No. 5, 2001, pp. 11-25.

[11] Baruch Awerbuch, Reza Curtmola, David Holmer, Herbert Rubens, Cristina Nita-Rotaru, "On the survivability of routing protocols in ad hoc wireless networks", *IEEE Computer Society Press*, Vol. 1, No. 29, 2005, pp. 327–338.

[12] Joo-Han Song, Vincent W. S. Wong, Victor C. M. Leung, "Secure position-based routing protocol for mobile ad hoc networks", *Ad Hoc Networks*, Vol. 1, No. 5, 2007, pp. 76–86.

[13] Bharath Sundararaman, Ugo Buy, Ajay D. Kshemkalyani, "Clock synchronization for wireless sensor networks: a survey", *Ad Hoc Networks*, Vol. 3, No. 3, 2005, pp. 281–323.

[14] Massimo Franceschetti, Olivier Dousse, David N. C. Tse, Patrick Thiran, "Closing the gap in the capacity of wireless networks via percolation theory", *IEEE Transactions on Information Theory*, Vol. 3, No. 53, 2007, pp. 1009–1018.

[15] S. Boyd, A. Ghosh, B. Prabhakar, D. Shah, "Randomized gossip algorithms", *IEEE Transactions on Information Theory*, Vol. 6, No. 52, 2006, pp. 2508–2530.

[16] Stefan Ruhrup, Hanna Kalosha, Amiya Nayak, Ivan Stojmenovic, "Message-efficient beaconless georouting with guaranteed delivery in wireless sensor, ad hoc, and actuator networks", *IEEE/ACM Transactions Networking*, Vol. 1, No. 18, 2010, pp. 95-108.