SICE Annual Conference 2010
August 18-21, 2010, The Grand Hotel, Taipei, Taiwan

# The Health Monitoring System based on Distributed Data Aggregation for WSN used in Bridge Diagnosis

Haitao Xiao [1], Tansheng Li [1], Harutoshi Ogai [1], Xiaohong Zou [2],
Takenari Otawa[2], Shinya Umeda[2], Takunori Tsuji[2]
E-mail: xiaohaitao@fuji.waseda.jp, ogai@waseda.jp

1 The Graduate school of Information, Production and Systems, Waseda University
(2-7 Hibikino, Wakamatsu-ku, Kitakyushu-shi, Fukuoka 808-0135, Japan)
2 Logical Product Corporation
(Platinum Bldg.2F.2-10-5 Hirao Chuou-ku 810-0014 Fukuoka Japan)

***Abstract*—Wireless sensor network are deployed today to monitor the environment, but their own health status is relatively opaque to network administrators, in most cases. In bridge diagnosis system, we develop a wireless sensor network to gather the vibration data of bridge. In past field bridge diagnosis experiment, node failure and data packets loss always occurred in the WSN and can not be detected. It causes some collected data is broken and cannot be used to analyze the health status of bridge. Furthermore, in field experiment it is always difficult to set the location of nodes in order to ensure the quality of link is good. In this paper, we consider the problem of monitoring the health of nodes, the quality of links and the healthiness of bridge diagnosis data from active end-to-end measurements in wireless sensor networks. Our system, DAMS (Distributed data Aggregation active Monitoring System), provides failure detection and symptom alerts, while being frugal in the use of energy and bandwidth. In order to improve the performance of active monitoring method we use distributed data aggregation to reduce the amount of communication and energy consumption. The monitoring system contains three functions, monitoring the health of nodes, monitoring the link quality and monitoring the healthiness of bridge diagnosis data. Key performance measures of this system include high detection accuracy (low false alarm probabilities), high responsiveness (low response latency), low energy consumption and low complexity. We debug the system in the wireless sensor network developed for bridge diagnosis and obtain the result in field experiment.**

***Keywords-Wireless Sensor Networks; Data Aggregation; packet loss rate; Brige Diagnosis***

## I. INTRODUCTION

A wireless sensor network (WSN) is a network made of numerous small independent sensor nodes, which consist of a battery, radio, sensors, and a minimal amount of onboard computing power. These nodes do not have a pre-programmed network topology that gives them the flexibility of self-organizing into a network but are low on resources. These nodes are built with power conservation in mind because of lack of resources such as electrical energy etc. Advances in silicon radio chips, coupled with cleverly crafted routing algorithms and network software are promising to eliminate those wires and their installation and maintenance costs.

Along with the rapid development of technology, wireless sensor networks have been widely used in a variety of purposes. Event detection application and data-gathering application are two most important applications. In bridge diagnosis system, the wireless sensor network is used for data-gathering. In past field bridge diagnosis experiment, node failure and data packets loss always occurred and can not bee detected in the WSN. It causes the collected data is broken and can not be used to analyze the health status of bridge. So, it is always difficult to set the location of nodes in order to ensure the quality of link is good in field experiment. In this paper we propose an efficient and practical health monitoring method, distributed data aggregation active monitoring method. The data aggregation occurs in repeater nodes, which aggregate their own data with the data of their child nodes. Based on the method we build a health monitoring system for the wireless sensor network used in bridge diagnosis.

## II. THE WSN USED IN BRIDGE DIAGNOSIS SYSTEM

Bridge Diagnosis System is a smart system that could evaluate the healthy level of the bridge based on the measured data of the whole bridge in real time. Bridge diagnosis system includes the technology of wireless sensor network, signal processing, structure analysis, and detection of a running vehicle. The structure of this wireless sensor network is shown as Fig. 2.1.

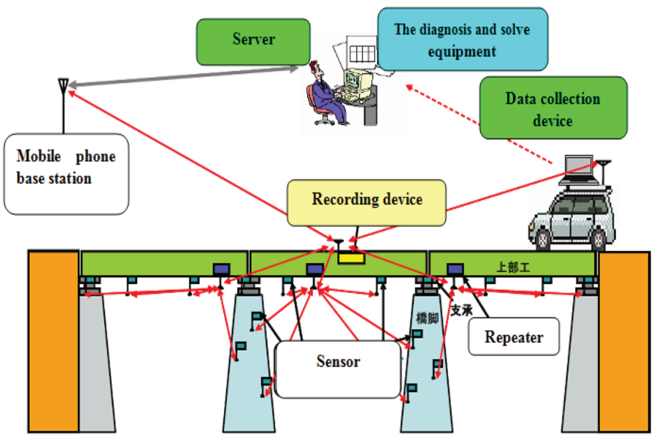


Figure 1. The wireless sensor network used in bridge diagnosis

- The wireless sensor nodes (usually placed on the pier and beam of the bridge) could measure vibration and distortion data when car is crossing the bridge.
- There are two types sensor: Acceleration wireless sensor (measure vibration and distortion data) and Trigger sensor (Figure 2).
- All the measured data would be send to the data recorder automatically by wireless sensor network.
- We could collect the stored data from data recorder anytime.

Acceleration wireless sensor    Trigger sensor

Figure 2. Sensors

The wireless sensor network system contains five phases: the sleep phase, the wake up phase, the node health and link quality monitoring phase, the measuring phase and the data collection phase. In the wireless sensor network, it contains 3 layers (The left figure of Figure 2): the first layer is data collection device, repeaters belong to second layer and the third layer is composed of sensors. Sometimes in order to extend the transmission distance, we add the multi-hop repeaters in second layer (For example in The rigth figure of Figure 2).

The topology of the wireless sensor network shows as Figure3.

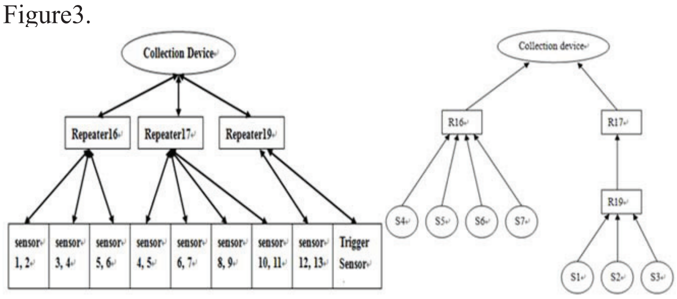


Figure 3. The topology

The WSN in field experiment shows as Figure 4

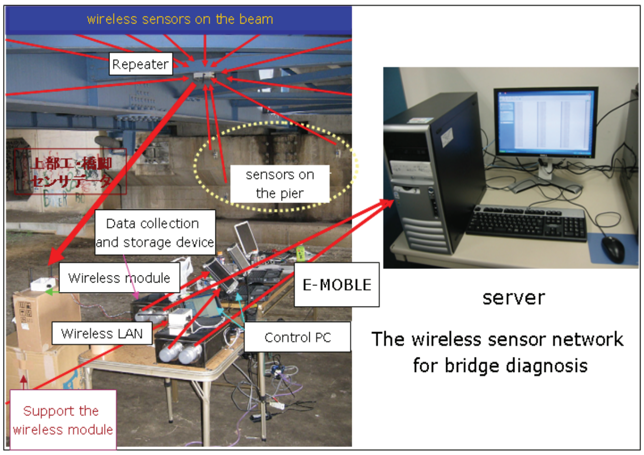


Figure 4. Wireless sensor network

When the car pass through the bridge, the trigger sensor sent a trigger signal to repeater and the repeater transmit the trigger signal to data collection device. Then the data collection device broadcast the start measuring command to all the repeaters. Repeaters transmit the command to sensors. The sensors start to measure at the same time and the measuring time is 15s. After 15s all the sensors sent the data to repeaters and repeaters transmit the data to data collection device. And then the data collection device sends the data to server.

## III. THE MONITORING SYSTEM FOR WSN

In the past, main monitoring technology was passive monitoring, ordinary active monitoring, and combining active and passive monitoring. They have their own issues. Passive monitoring is good at low energy consumption of a passive monitoring method, but the responsiveness and reliability is not good. Because ordinary active monitoring consists of having sensors continuously send existence messages to inform the control center of their existence. The problem with ordinary active monitoring is the amount of traffic it generates and energy consumption. The combining monitor contents the advantage of active and passive. But it requires sensors and routers have more additional function. The problem with the combining monitoring is the complexity of wireless sensor network and the energy consumption. So in a wireless sensor network with low complexity, low energy consumption, high responsiveness and reliability, the technology described above is not suitable for monitoring its status (The WSN used in bridge diagnosis system belongs to this kind of network).

One of the key points in the monitoring system of WSN is the health status monitoring of the network itself. Node failures and link quality should be captured by the system and reported to administrators. In this paper we describe the design and implementation of Distributed data Aggregation active Monitoring System (DAMS), a network monitoring system for the wireless sensor networks that meets the goals mentioned above.

Currently, wireless sensor network deployments can be categorized by their application scenario: data-gathering applications and event detection applications. For data-gathering systems, health status monitoring is quite straight forward. Monitoring information can be forwarded to the monitoring system control center by specific health status packets. In here, we consider a low complexity network active monitoring approach tailored specifically for the wireless sensor networks. Distributed Data Aggregation Active Monitoring System is a network monitoring systems for the wireless sensor network been used in data-gathering application in bridge diagnosis system. In Distributed Data Aggregation Active Monitoring System, the repeaters (or routers) in the network aggregates the status data from distributed nodes. If the node is alive it will send status data to repeater. In repeater the status data of sensors and itself is aggregated in one status data. Then the aggregated status data is sent to monitoring system center. And also we use the status data to test the packet loss rate of links for get link quality of wireless sensor network. Based on the aggregated status data Administrators can usually diagnose the network with a helper program.

Since event detection deployments do not have regular traffic to send to the system control center, the solutions for data-gathering deployments are not suitable. In this case, health status monitoring can be quite challenging and has not been discussed explicitly in the paper.

The Distributed data Aggregation active Monitoring System (DAMS) has two parts, the control part of the monitoring system and the graphical user interface (GUI). The control part is used to control system to monitor the health status of nodes and the quality of links in the wireless sensor network. The GUI (graphical user interface) is used to display the health status of the wireless sensor network and facilitate user.

In The Distributed data Aggregation active Monitoring System (DAMS), we used general active monitoring method to broadcast active monitoring message in wireless sensor network to let the live sensor and repeater to make a response to inform the control center of their existence.

### *A. The Active monitoring method*

In general, active monitoring refers to the active interaction with the system under observation. Thus, the system behavior is being influenced by the monitoring actions. To accomplish self-monitoring of wireless sensor networks, the control center of the monitoring system perform active monitoring, which consists of having sensors continuously send existence messages to inform the control center of their existence. If the control center has not received the information from a sensor for a pre-specified period of time (timeout period), it may infer that the sensor is dead and shows the sensor death alarm.

### *B. Distributed data aggregation*

In order to reduce the amount of traffic and energy consumption we improve the active monitoring method though applying distributed data aggregation technique. In the process of data aggregation, before a repeater sends its data to the wireless module, it waits to receive status data from all of its child sensors in the tree until a specified period of time has elapsed. The repeater then aggregates its own status data with the status data it has received from its child nodes, and then forwards this aggregated data to the wireless module of the data collection device via the tree. Information about which sensor' status data is present in the aggregated data. Thus, data fusion saves communication overhead at the cost of additional computation, amount of traffic and memory resources.

Figure 5 depicts a simple example of a sensor network using the data aggregation paradigm. To understand how data aggregation may conserve communication overhead, consider the simple example of the wireless module collecting data from repeater A, sensor B and C. Node B sends it status data, (B), destined for the wireless module of the data collection and storage device, to repeater A. Node C similarly sends its status data, (C), destined for the wireless module of the data collection and storage device to repeater A. repeater A then aggregates its own status data, (A), with that of nodes B and C, and sends the fused data, (A,B,C) to the wireless module of the data collection and storage device. With data aggregation, each node is only required to transmit once per data collection round. However, without data aggregation, repeater A would have to transmit three times per data collection round: once to send its own status data to the sink, once to forward sensor B's status data, and once to forward node C's status data.

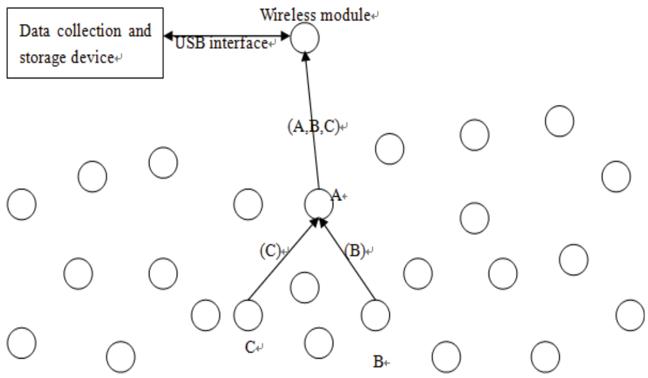


Figure 5. Status data aggregation in wireless sensor network

### *C. Monitor the health status of nodes*

The flow chart of the health status of nodes monitoring and the link quality monitoring:

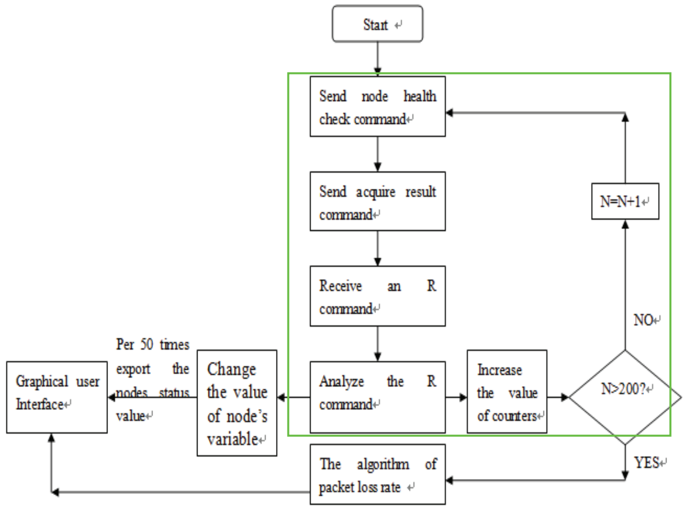


Figure 6. Flow chart

The monitoring system sends the node health check command to monitor nodes. After receiving the command all the sensors send their status data (ACK response) to their father repeaters. Then repeaters aggregate their own status data with the status data of their child sensors and save as R command. After a timeout the wireless module sends the acquiring result command to get the status data. Then control center of the monitoring system receives the R command (show as Figure 6).

Next, the control program analyses the R command and changes the value of node's variable. In control program, each node corresponds to a variable and the initial value is 0. Repeat 1 -> R [1], Repeat n ->R [n], Sensor 1 -> S [1], Sensor n -> S [n]. For example, the R command contains the repeater n's ID and the sensor n's ID. The control program changes the value of node's variable like that: R [n] =1, S[n] =1 (0 means broken and 1 means living). Then the control program export the variables and the graphical user interface will display the status of nodes.

### *D. Monitor the link quality*

In the active monitoring method, in order to monitor nodes status the monitoring system must continuously broadcast the checking message (the node health check command). During the control program of monitoring system continuously broadcast the checking message, the checking message loss or status data of nodes loss may occur in wireless sensor network. We catch the packets loss rate and use the packet loss rate to show the link quality.

In order to catch the packets loss rate the monitor system performs the operation surrounded by the green dashed in Fig.3.1. In control program of the monitoring system each node corresponds to a counter, Repeat 1 -> R [1], Repeat n -> R [n], Sensor 1 -> S [1], Sensor n -> S [n].

For example, the R command contains the repeater n's ID and the sensor n's ID. The value of counters changes like that: R [n] = R [n] + 1, S [n] = S [n] +1. The value of link quality (packet loss rate) shows as (1) and (2):

$$LQ[R[n]] = 1 - (R[n] / 200)*100\% \quad (1)$$

$$LQ[S[n]] = 1 - (S[n] / R[n])*100\% \quad (2)$$

The LQ[R[n]] and LQ[S[n]] shows as Figure 7.

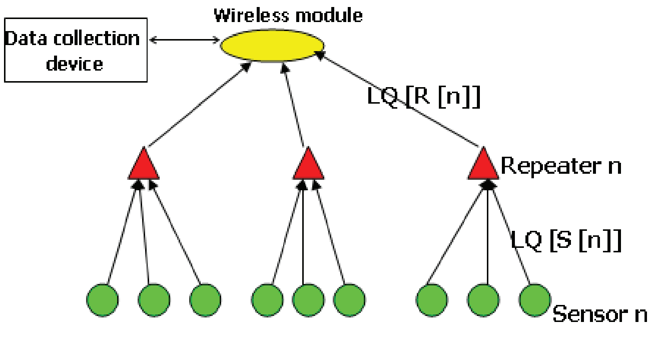


Figure 7. Link quality

## IV. THE MONITORING SYSTEM IN FIELD EXPERIMENT

### A. *The monitoring system (no multi-hop)*

The field experiment was conducted in 2009. In this field experiment, the wireless sensor network contains 1 data collection and storage device, 1 control computer, 3 repeaters and 8 sensors.

Figure 8. The full view of the Bridge

*1) The first condition: All the nodes are alive and the wireless sensor network deployment shows as Figure 9.*

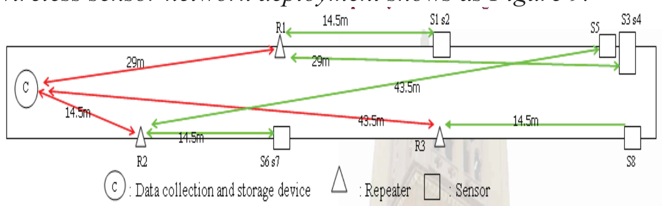


Figure 9. The wireless sensor network deployment

The result of monitoring system show as Figure 10.

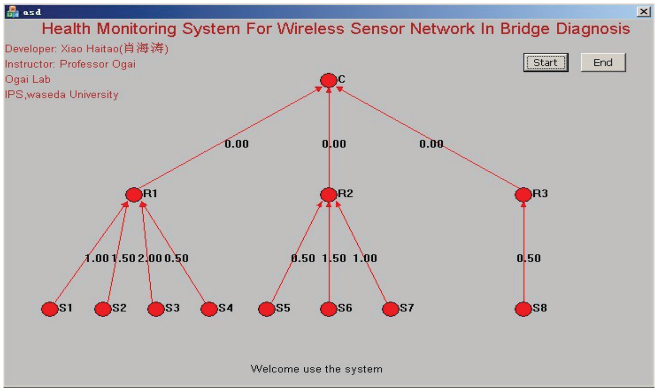


Figure 10. The monitoring system

The red means the node is alive and the gray means the node is broken. The values showed on red line are the packet loss rate of the links (all the values are percent). From the Figure 10, we could see all the nodes are alive. The packet loss rate of the links from repeater to the data collection and storage device is 0% which shows there are no packets losses and the quality of the links is very good. The Values of the packet loss rate of the links from sensors to their father repeaters are less than 2% and we could infer the quality of the links is very good. According to value of the link quality we could further confirm the node is healthy and the distance between nodes is suitable. Because the health of nodes will direct impact the packet loss rate of the links. For example, if the energy of node is shortage the signal strength of the node will be weakened and the packet loss rate will become large.

*2) We set the sensor 8 is broken and the R3 is far away from D and place the nodes on the beam of the bridge as Figure 11.*

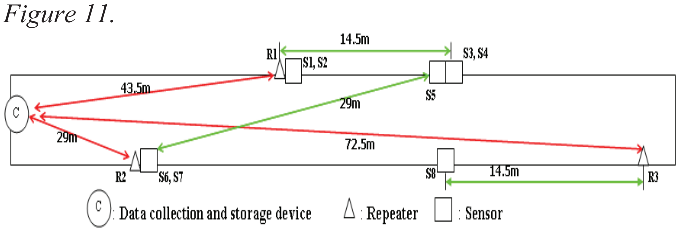


Figure 11. The wireless sensor network deployment

When the external force is added in the bridge by the running vehicle such as the large-size cars, trucks and so on, the vibration data are measured by the kinds of sensors.

The monitoring system shows as Figure 12.

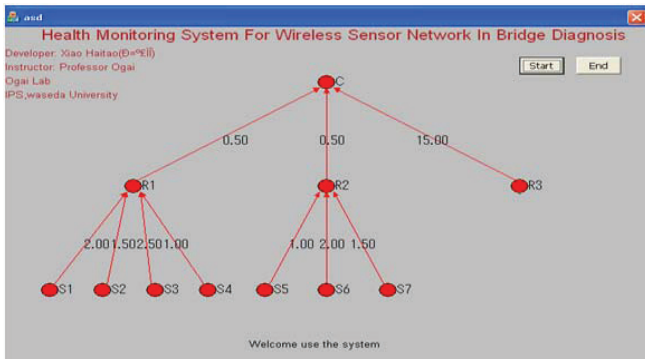


Figure 12. The monitoring system

From the result of the monitoring system, we can find the sensor 8 have vanished from Fig.4.5 which mean broken.

As a result of R3 too far away from C (in network deployment is D), the packet loss rate of the link is obvious bigger than others. And the value of the link from R3 to C is bigger than 10, it means the quality is bad and not suitable for transmitting the data sensed by sensor nodes. So according the value of the packet loss rate, we must shorten the distance from R3 to C if we wan to use the link to transmit data.

From the result of the monitoring system we find the system successfully captured the node failures and packet loss. And it accurately showed the status of nodes and links of the wireless sensor network in graphical user interface.

*B. The monitoring system used in multi-hop wireless sensor network (contain the multi-hop repeater)*

The monitoring system contains three functions:

- It can capture the nodes joining and leaving in time and real-time display the status of nodes in graphic user interface.
- It can accurately monitor the change of routes and real-time update the topology of the WNS in graphic user interface.
- It can capture the packet loss and calculate the link quality and show the quality of links.

The system will update the monitoring data and the figure of the GUI once every 30 seconds. During the system operation, the GUI will update the figure of status 4 times. The GUI will display a dynamical figure. It will dynamically change with the status of WSN.

In experiment, at the beginning I turn off the sensor 4, 5, and 6. The result shows as Figure 13.

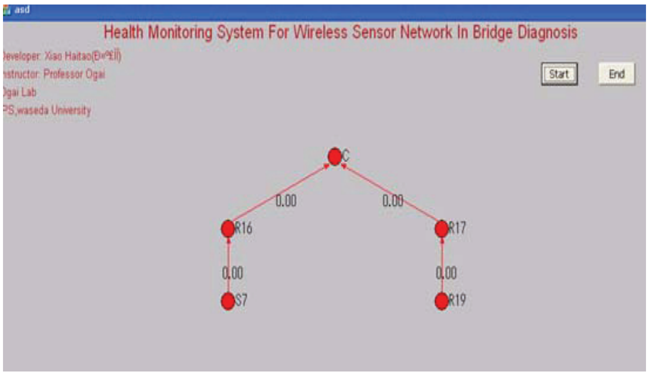


Figure 13. The monitoring system (contain the multi-hop repeater)

After 45s, I turn on the sensor 4, 5 and 6. Then the second updated figure shows as Figure 14.

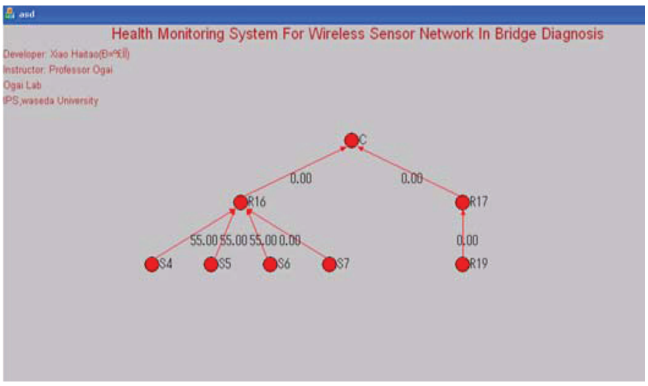


Figure 14. The monitoring system (contain the multi-hop repeater)

Then, after showing the second updated figure I turn off the sensor 7. The third updated figure shows as Figure 15.

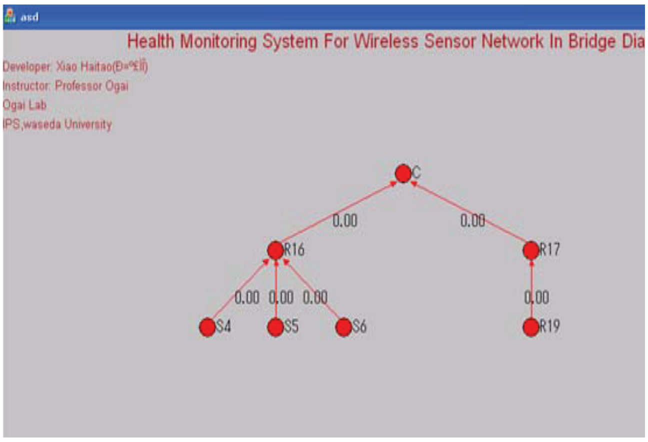


Figure 15. The monitoring system (contain the multi-hop repeater)

## V. CONCLUSIONS

In this paper we presented DAMS (Distributed data Aggregation active Monitoring System) especially designed for the wireless sensor network used in bridge diagnosis. We greatly enhance the performance of the active monitoring method by using distributed data aggregation. Due to reduce the amount of communication and energy consumption, comparing with other monitoring method the active monitoring method based on distributed data aggregation has the characteristics of high detection accuracy, high responsiveness, low energy consumption and low complexity which is very important because of the simple function of the sensor nodes used in bridge diagnosis. We have successfully done the experiment by putting the nodes on the bridge. The DAMS can accurately monitor the nodes health status and link quality in the wireless sensor network.

## VI. ACKNOWLEDGMENT

This study receives support from Japan Regional Innovation Strategy Program and financial support from Health Monitoring Business Limited Liability Partnership

## REFERENCES

[1] Wireless Sensor Networks: Architectures and Protocols, by Edgar H., Jr. Callaway, Edgar H. Callaway ISBN: 0849318238.

[2] Andreas Meier, Mehul Motani, Hu Siquan, and Simon Künzli. DiMo: Distributed Node Monitoring in Wireless Sensor Networks. MSWiM'08, October 27–31, 2008, Vancouver, BC, Canada.

[3] K.-J. Wong et al. Speckmac: low-power decentralised MAC protocols for low data rate transmissions in specknets. In Proc. 2nd Int'l workshop on Multi-hop ad hoc networks: from theory to reality (REALMAN '06), 2006.

[4] A. Meier, T. Rein, et al. Coping with unreliable channels: Efficient link estimation for low-power wireless sensor networks. In Proc. 5th Int'l Conf. Networked Sensing Systems (INSS 2008), 2008.

[5] Junzhao Du, Weisong Shi, Kewei Sha. Asymmetry-Aware Link Quality Services in Wireless Sensor Networks. Department of Computer Science, Wayne State University, Detroit, MI 48202, USA. Software College, Xidian University, Xi'an, Shaanxi 710071, P.R. China.

[6] N Ramanathan, K. Chang, R. Kapur, L. Girod, E. Kohler, and D. Estrin, "Sympathy for the Sensor Network Debugger," in 3rd ACM Conference on Embedded Networked Sensor Systems (SenSys 2005), San Diego, California, November 2005, pp. 255–267.

[7] Haitao Xiao, Tansheng Xiao, Ogai Harutoshi : A health monitoring system for wireless sensor network in bridge diagnosis, SICE 10th Annual Conference on Control Systems March 16-18 2010, Kumamoto.