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STUDY OF ROUTING PATH RELIABILITY FOR STATIC OUTDOOR WIRELESS SENSOR NETWORK IN ECOLOGICAL MONITORING

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Abstract: Wireless sensor network (WSN) technology has become one of the fast developing technologies in recent years. Sensor nodes continue shrinking due to the advancement in micro-electro-mechanical, communication, and embedded processing technologies. In addition, sensor nodes have the advantages of low power consumption and high-performance computing. The related studies regarding WSNs are therefore flourishing.

The studies on WSNs generally involve several issues including routing protocols, media access control, coverage, security, and localization. Received Signal Strength Indication (RSSI), a built-in parameter in the low-power radio frequency (RF) chip, is taken into account in many algorithms. RSSI is usually used to determine localization of sensor nodes and estimate the distance between sensor nodes. The RSSI value may vary because of the differences in radio frequency power levels, distances, environments, weather conditions, and topography.

In this study, we have analyzed the relationship between the successful data receiving ratios and the RSSI according to the experiments conducted on a deployed WSN monitoring system for the oriental fruit fly in Chiayi area, Taiwan. The experiments are to record the RSSI of every received packet on every sensor node. The successful data receiving ratio increases when the routing path with a higher RSSI is chosen. In the future, we will use the analyzed results and incorporate them into the Balanced Low-Latency Convergecast Tree (BLLCT) algorithm with a static fixing scheme. Such an algorithm can be practically used in a monitoring system.

Key Words: Reliable route, Received Signal Strength Indication (RSSI), Network lifetime

INTRODUCTION

Wireless Sensor Network (WSN) is one of the most popular technologies in recent years. Nowadays, the technologies of Micro Electro Mechanical Systems (MSMS), communication, and embedded system have rapidly developed, so more and more researchers pay attention to these micro technologies and apply them to areas including ecological monitoring and health-care. For instance, some outdoor applications of WSN have been successfully employed in ecological and environmental surveillance (Jiang et al., 2008; Mainwaring et al., 2002). Complicated problems may arise and bother the researchers when WSN is widely used in the field. Although the node is tiny and low–energy consuming, many constraints – such as the insufficient computing ability of microprocessors and the limited memory and sources of power supply – can still affect network lifetime. Previous studies have dealt with these issues by using different algorithms.

In this study, we report the evaluation outcomes of the successful data receiving ratio through a routing path and its corresponding value of RSSI, according to the recorded data generated from a static outdoor WSN-based monitoring system of oriental fruit fly (*Bactrocera dorsalis* (Hendel)). We also propose a feasible modification for an existing algorithm: the balanced low-latency convergecast tree (BLLCT) algorithm with a static fixing scheme (Tseng, 2008). The performance evaluation of the BLLCT algorithm will become our future work. Expectably, the performance of the algorithm and the successful data receiving ratio will be improved.

MATERIALS AND METHODS

1. Balanced Low-Latency Convergecast Tree (BLLCT) algorithm with a static fixing scheme

When deploying a WSN to the field, the network encountered a lack of sources of power supply. The BLLCT algorithm attempts to solve the limited energy problem and prolongs the network lifetime. This routing algorithm focuses on how to balance the loading of every node. It evaluates and balances the loading of a node by taking the number of nodes which link to it into consideration. However, the results couldn't guarantee the balance of loading of the network, as shown in Fig. 1. In our previous work, we found some problem in the unbalanced sub trees while applying the algorithm to an outdoor environment. In order to overcome the problems in the BLLCT algorithm, we proposed and implemented a static fixing scheme to solve the problem of unbalanced loading of nodes.

In fact, the entire data packet collected by nodes need to be transmitted to the gateway in a hop-by-hop manner. The first layer nodes must consume more energy to relay a great amount of data. Therefore, the algorithm focused on the loading condition of the first layer nodes. The BLLCT can reduce the loading of the first layer nodes and prolong the lifetime of the whole network. In this algorithm, it includes two parts: node selection and parent selection. The gateway will broadcast an establishing packet to the nodes and then the nodes will rebroadcast the packet to the other nodes until all the nodes in the network receive the packet. After finishing the topology collection procedure, the gateway will determine the routing path between nodes in the two neighboring layers and balance the loading of nodes in each layer. The BLLCT chooses a node in the first layer with minimum loading or fewer children nodes, until all the nodes connect to their upper-layer nodes.

In the static fixing scheme for the BLLCT, a node in a sub tree can shift its routing path to a node in another sub tree, from the one with the heaviest loading to another one with the smallest loading. At first, the BLLCT identifies the sub tree Ψ with the heaviest loading of first layer nodes. Secondly, it tries to seek other sub trees which are inside the communication range of the nodes in Ψ and then chooses the node group η with the least loading. Finally, the BLLCT compares the loading difference between Ψ and η to identify a new node group of which the loading is smaller than the loading difference. If there are two or more node groups satisfying with the proceeding condition, the fixing scheme will choose the one with the heaviest loading and then shift the node group from Ψ to η, as the flowchart is shown in Fig. 2.

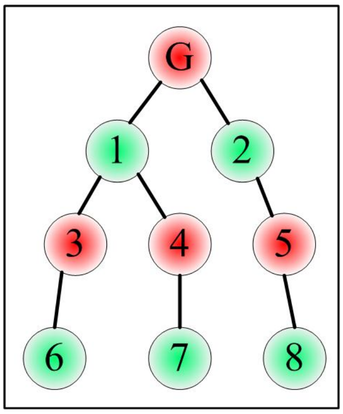


Figure 1 Unbalanced loading condition.

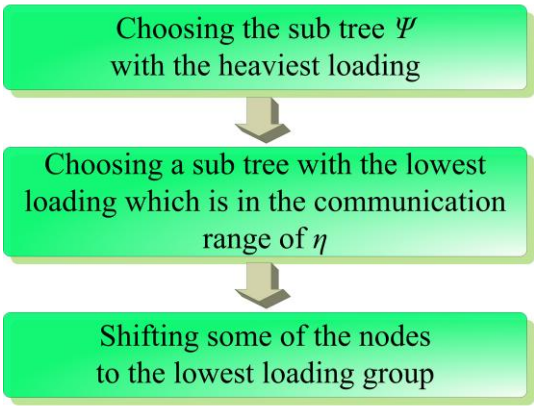


Figure 2 The flowchart of static fixing scheme.

2. Received Signal Strength Indicator (RSSI)

Received signal strength indicator is one of the link quality estimators. It could measure the received radio signal power. According to *Friis* equation described in Eq. (1), the received signal strength which is acquired from the radio frequency transceiver can be formulated as follows (Friis, 1946)

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \qquad (1)$$

where P_r is the received signal strength, P_t is the transmitting power level (dBm), G_t is the antenna gain value of the transmitting node (dB), G_r is the antenna gain value of the receiving node (dB), λ is the electromagnetic wavelength (nm) and d is the distance between nodes (m).

The wireless sensor node (Octopus II) is equipped with the CC2420 transceiver. The CC2420 provides an 8-bit digital built-in RSSI value so that the value is easily fed into a digital microprocessor. However, the value from CC2420 is not a regular unit. RSSI should be converted into the units of dBm (USA: Texas Instruments, 2007) by Eq. (2), Note that the dynamic range of RSSI is from – 100 dBm to 0 dBm, and the accuracy is ± 6 dBm.

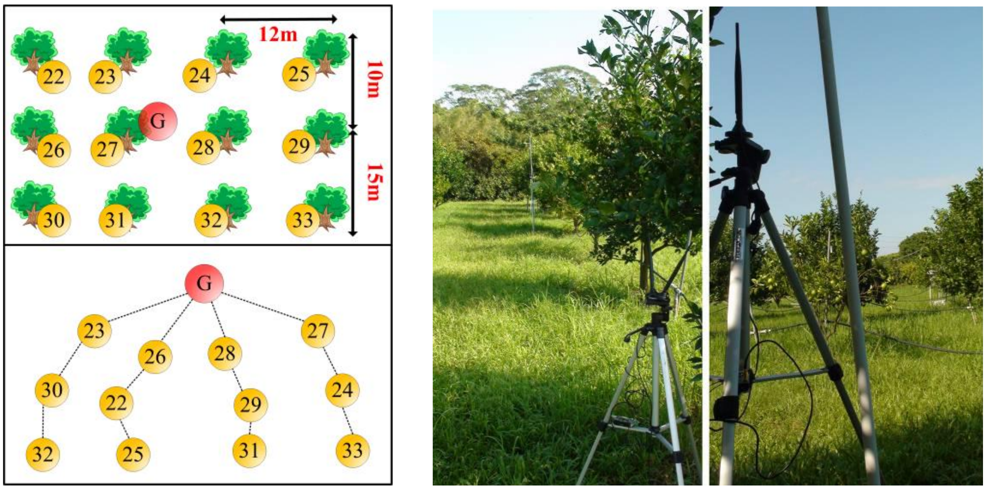
$$P_r(d) = \begin{cases} RSSI + RSSI_{offset} & \text{if } RSSI < 127, \\ RSSI - 256 + RSSI_{offset} & \text{otherwise,} \end{cases} \qquad (2)$$

where P_r is the received signal strength (dBm), and $RSSI_{offset}$ is the offset constant gain which is equal to – 45 dBm.

3. Modification of the BLLCT algorithm

We have deployed a wireless sensor network to monitor the population of the oriental fruit fly in Chiayi area, Taiwan. The routing algorithm which is running on our system is the BLLCT algorithm. Although the BLLCT algorithm could balance the loading of the first layer nodes, we still encounter other difficult problems. Balancing loadings of the first layer nodes does not mean the improvement in the reliability of data transmission; the BLLCT attempts to balance the loading of first layer nodes but does not consider the physical location of nodes. Therefore, the transmission distance between nodes may become longer, and the unsuccessful data receiving ratio may increase, shown as Fig. 3. If the unreliable routing path is constructed, as the environment or weather changes, the data losing ratio becomes higher. As mentioned above, the long transmission distance decreases the successful data receiving ratio. For this reason, the purpose of this study is to conduct a study on increasing the successful data receiving ratio while maintains the network lifetime instead of reestablishing all the routing paths in the network. Reestablishing all the routing paths in the network not only consumes additional energy but also wastes much time.

In the proposed modification, each node establishes a routing table regarding the RSSI value from the received packet sent by other nodes. The flowchart of establishing the routing table based on the RSSI is shown in Fig. 4. Fig. 5 exhibits the routing table in the gateway after establishment.



(a) (b)

Figure 3 (a) Network deployment and special topology. (b) Actual deployment in the field.

Firstly, the gateway sends 100 testing packets to nodes, and the nodes record the node ID numbers and RSSI after receiving the packets. According to the CC2420's datasheet, the accuracy of RSSI is roughly ± 6 dBm; thus, we average the RSSI value from 100 packets to increase the accuracy. The routing table would be updated when every 100 packets are received. The nodes in the network repeatedly send the testing packets after a delay time for setting the routing table. By doing these tests and establishing the routing table, we can roughly estimate the link quality between nodes through the RSSI. Secondly, the gateway sends an establishing packet to the nodes which are inside gateway's communication range. The node that receives the establishing packet for the first time will set its node layer as the first layer and then transmits the packet to other nodes until all the nodes get its own node layer. After setting the node layer, each node sends its layer number to its upper node. By this way, the gateway will obtain network topology through the linkage condition of nodes. By contrast, the original BLLCT algorithm starts the task of balancing node loading with node selection. The node selection procedure merely considers the balance condition of the first layer nodes. However, we plan to determine the routing path not only by the loading of the node but also the link quality between nodes in this study. By establishing the routing table, we are able to increase the successful data receiving ratio and maintain the network lifetime.

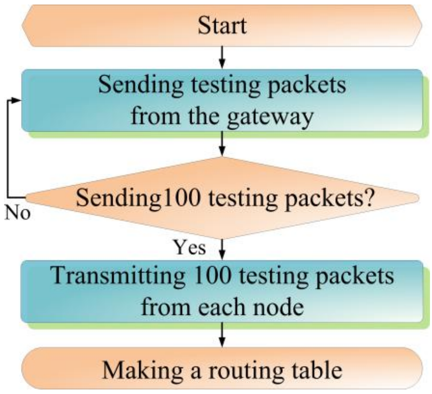


Figure 4 The flowchart of the establishment of the routing table.

Node id	1	2	3	4	5
1	x	– 70	– 54	– 77	– 70
2	– 45	x	– 83	– 60	– 84
3	– 70	– 73	x	– 41	– 89
4	– 65	– 80	– 70	x	– 70
5	– 75	– 85	– 75	– 70	x

Figure 5 The result of the routing table.

RESULTS AND DISCUSSION

Before revising the BLLCT algorithm, we incorporated the RSSI value into the data packet. In the testing round, the deployed network includes 10 nodes. The system collected sensing data every 30 min, between Dec. 18 and 29, 2009. The system collected more than 500 packets, and more than 10 types of topology were established by the BLLCT algorithm. We analyzed the relationship between the topology and the successful data receiving ratio. The analysis was sorted by the node layer, the routing path (parent node), the successful data receiving ratio, and the RSSI. From the analysis results, the drawback of the BLLCT algorithm was found. The statistics of the nodes are listed in Table 1. The nodes used a variety of routing paths to transmit data back to the gateway. Node No. 25 had a lower successful data receiving ratio when transmitting the data to Node No. 28. The reason could be that Node No.25 in that round belongs to the third layer, so the multi-hop transmission would decrease its successful data receiving ratio. However, the successful data receiving ratio significantly increased as the RSSI increased.

Table 1 The relationship between data received successful ratio and RSSI.

Node ID number	Node layer	Parent node	Successful data receiving ratio(%)	RSSI (dBm)	Standard deviation of RSSI
25	3	28	76.92	– 79.33	7.98
	2	26	50	– 89	0.816497
30	1	Gateway	100	– 66	7.33
	2	23	35.71	– 81.44	6.444205
31	1	Gateway	100	– 64.67	18.92793
	2	23	70	– 80	9.315629

The proposed algorithm was applied to a static outdoor wireless sensor network; that is, the physical location of the nodes was never changed. As a result, the RSSI is an appropriate a reference when establishing the routing table for such a simpler environment. The possible improvements in data receiving ratios are listed in Table 2. By adopting the RSSI, Node No. 25 and No. 30 increased their successful data receiving ratios by roughly 10%. Because the original receiving ratio was high, Node No. 31 only had a 5% increase. On the other hand, the data losing ratio of Node No. 31 decreased by 50%. For the nodes with the lowest successful data receiving ratio, Node No. 33 significantly improved its ratio by approximately 20%. According to Table 2, the average node layer is larger than 1. This means that the chance of all the nodes that were assigned node layer by the gateway is higher than that of the unlisted nodes

Table 2 The improvement after adopting the RSSI in the BLLCT algorithm.

Node ID number	**Average node layer**	**Improvement of the successful data receiving ratio (%)**
23	2	5.8
24	2	7.9
25	2.3	3.9
29	2	10.6
30	1.75	10.2
31	1.8	4.7
33	2	20.4

CONCLUSIONS

For the static outdoor wireless sensor network, the possible factors that influence the RSSI can be reduced after using the proposed algorithm. When the gateway acquires the great a amount of the RSSI values, the gateway can determine and establish the most reliable routing path using the modified BLLCT algorithm. By incorporating the RSSI into the practical applications, the proposed algorithm will not only raise the successful data receiving ratio but also maintain network lifetime.

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