Master's Thesis

Title

Design, Implementation, and Evaluation of Robust Data Gathering Scheme for Sensor Networks in Unstable Environments

Supervisor

Professor Masayuki Murata

Author

Shuntaro Kashihara

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Department of Information Networking

Graduate School of Information Science and Technology

Osaka University

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Shuntaro Kashihara

Abstract

In this thesis, we propose a data gathering scheme for a wireless sensor network constructed in a building. Our system consists of parent nodes, which have power supply and a wired connection to a monitoring PC, and child nodes, which operate on a battery and have the capability of radio communications. Sensor information is periodically gathered from all child nodes via parent nodes to a monitoring PC. For saving energy consumption, emission of sensor information is synchronized among child nodes so that the next-hop node only needs to turn on its radio transceiver before its own emission to receive sensor information from distant nodes. Due to shadowing and fading, radio communications in a building become unstable and unreliable. In our scheme, a sensor node chooses the next-hop node among parent nodes, which collect sensor information from child nodes in their vicinity, and child nodes which provide a path to a parent node, in accordance with the stability of radio communications. We confirmed that stable data gathering with more than 80% gathering ratio can be accomplished in a sensor network in unstable environments.

Keywords

Sensor Networks, Data Gathering, Synchronization

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1 Introduction

The development of low-cost microsensor equipment having the capability of wireless communications [1] has caused sensor network technology to attract the attention of many researchers and developers. One can obtain information on behavior, condition, and position of elements in a region by deploying a network of battery-powered sensors there. Each node in such a sensor network is equipped with one or more sensors, a general purpose processor with a limited computational capacity, a small amount of memory, and a radio transceiver. Sensor information gathered by sensors is transmitted directly or indirectly to a base station and provided to users there or accessing the base station through the Internet.

Since a sensor node is typically powered by a battery that cannot be replaced often, a sensor network must use a data gathering scheme that is energy-efficient. The scheme must also adapt to the addition, removal, and movement of sensor nodes automatically without any manual operations of users or administrators. In addition, because sensor nodes are often deployed and distributed in an uncontrolled way, the data gathering scheme cannot be a centralized scheme with a single node or server maintaining all the information and having all the control functions. Data gathering schemes such as LEACH [2], the chainbased protocol [3], and CMLDA [4] cannot function without such global information as the number of sensor nodes deployed, their locations, the predetermined optimal number of clusters, and the residual energy of all sensor nodes. They therefore need additional, possibly expensive and unscalable, communication protocols for collecting and sharing the global information, and they cannot easily adapt to the addition, removal, or movement of sensor nodes.

We previously proposed a scalable, robust, and energy-efficient scheme for periodic data gathering in sensor networks [5, 6]. It has the scalability to the number of sensor nodes and the extent of a monitored region, is robust to failures of sensor nodes, adapts to the addition, removal, and movement of sensor nodes, consumes less energy, and does not use a centralized control mechanism. Each sensor node appropriately determines its timing of data emission by observing behavior of surrounding nodes, so that it can emit sensor information in synchrony with others to the same next-hop node. With such syn-

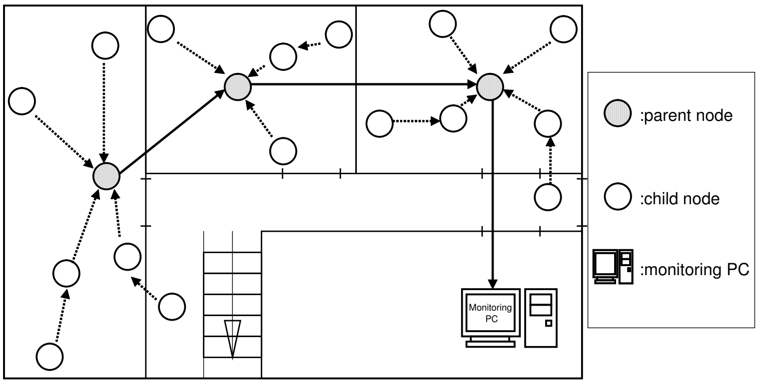

Figure 1: A sketch of a proposed system

chronized data emission, a sensor node can efficiently turn off a transceiver component when it is not necessary [7-9]. To realize such a control mechanism without any additional signaling mechanisms, we adopted a pulse-coupled oscillator model [10-12] based on biological mutual synchronization such as that observed in flashing fireflies, chirping crickets, and pacemaker cells. We implemented the scheme on an actual system [13]. Results of experiments on a roof with few obstacles showed the practicality of the scheme.

However, in an actual environment, wireless communication becomes unstable and unreliable due to shadowing and fading. With such a wireless communication, a node would lose a link to the next-hop node, have an unidirectional link from the next-hop node, and accidentally establish a link to the wrong node. As a result, a system cannot gather sensor information from all sensor nodes at the desired gathering ratio. In this thesis, we designed a data gathering system to gather sensor information in a sensor network built in unstable communication environments, by taking into account the reliability and stability of wireless links.

In our system, a sensor network consists of parent nodes, child nodes, and a monitoring PC as illustrated in Fig. 1. We considers an application which periodically gather sensor information of all child nodes to a monitoring PC through parent nodes. Since outlets can be available in a building, parent nodes have power supply and wired connection to the monitoring PC. A child node powered by a battery chooses the next-hop node among parent nodes which collect sensor information from child nodes in their vicinity and child nodes which provide a path to a parent node, in accordance with the reliability and stability of radio communications. It means that there are two types of communications from a child node to a parent node, that is, a direct and single-hop communication, and an indirect and multi-hop communication relayed by other child nodes.

We built a prototype system by using off-the-shelf sensor nodes with IEEE 802.15.4 MAC protocol, and conducted experiments. We confirmed that data gathering could be accomplished and our scheme adapted to the addition and removal of child nodes, changes of communication environments, and overlapping of beacon signals.

The rest of this thesis is organized as follows. In Section 2,we explain the outline of our robust data gathering scheme, and in Section 3, we describe the sensor network we implemented and show results of our experimental evaluation. Finally, in Section 4, we briefly summarize the thesis and discuss our plans for future works.

2 Robust Data Gathering Scheme for Sensor Networks

In this section, we propose a data gathering scheme for a sensor network under unstable and unreliable radio environments such as in a building. First, the outline of the proposal is described. Then, an algorithm to choose the best next-hop node by a cost function will be given. Then, mechanisms to distribute the timing of packet emissions to avoid collisions will be proposed for distribution among child nodes and among parent nodes.

2.1 Outline of a proposed system

Figure 1 illustrates our proposed system. A proposed system consists of a monitoring PC as a sink of sensor information, parent nodes with power supply and wired connections, and child nodes with limited battery power and a wireless transceiver. In a proposed system, a parent node emits beacon packets at regular intervals to gather sensor information from all child nodes at the application-specific frequency.

Each child node maintains a timer, based on whose phase it emits sensor information. Firstly, timers keep different phases among child nodes. A child node determines the next-hop node among parent nodes and child nodes in its vicinity and then it adjusts its timer to be synchronized with timing of packet emission of the next-hop node. After the synchronization it only needs to turn on its transceiver slightly before its packet emission to receive packets from further child nodes, then sends its own packet, and turns off the transceiver after reception of a packet from the next-hop node as illustrated in Fig.2. Therefore, with a synchronized control, child nodes can save power consumption.

The next-hop node is determined based on the reliability and stability of radio communication, which is quantified as a communication cost, with a neighbor node. The algorithm to calculate a cost value is given in section 2.2. If it can receive beacon packets from a parent node with sufficient stability, i.e., low cost, it chooses the parent node as the next-hop node and directly sends packets to the parent node. Otherwise, it decides to perform the multi-hop communication to a parent node by mediation of other child nodes. Each child node has its cost value indicating the goodness of communication to a parent node. A new child node decides one of child node with the lowest cost in its vicinity as the next-hop node. The details are as follows.

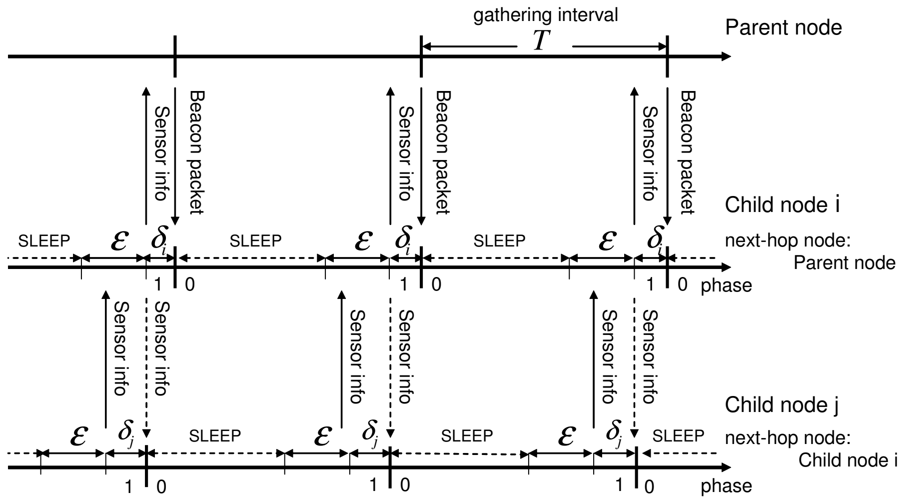

Figure 2: An example of transmission timing

First time that a child node is introduced into a sensor network, its state is initialized and the next-hop node is not determined. Its cost value is initialized to 255. It also has a neighbor table which consists of addresses of nodes from which it receives packets, At first, the table is empty. A new child node keeps awake to probe the surrounding conditions by receiving beacon packets for five gathering cycles while updating a neighbor table. Then, it calculates communication costs for each of parent nodes of beacon packets. According to the distribution of nodes, a child node may receive beacon packets from more than two parent nodes. If the radio communication with a parent node is stable and reliable enough and the cost is lower than a predetermined threshold C_{th}, which is set at 20 in experiments, then it considers the parent node with the lowest cost as the next-hop node and adjusts its timer. When we assume a timer keeps the same frequency of data gathering and its phase shifts from zero to one, a timer is adjusted so that the phase becomes one when it receives a beacon packet from the designated parent node.

On the other hand, if a child node could not receive beacon packets at all or with a cost low enough, it tries to choose a neighboring child node as the next-hop node for multi-hop communication to a parent node. It keeps awake for additional five gathering cycles to receive packets from child nodes in its vicinity, updates a neighbor table, and calculates a communication cost for each of child nodes. Then, it chooses one with the lowest cost as the next-hop node and adjusts its timer to be synchronized with packet emission of the chosen child node.

Once a child node determines its next-hop node, it is scheduled to send a packet slightly before the phase of its timer becomes one as shown in Fig. 2. The offset is noted as δ_i ($0 < \delta_i < \epsilon < 1$, $0 < \delta_i + \epsilon < 1$) for child node i and determined by an algorithm described later in 2.3. To receive packets from farther sensor nodes, it turns on a transceiver component at the timing slightly before its packet emission by ϵ. Sensor information contained in received packets is buffered to aggregate with its own sensor information and send together to the next-hop node. For example, in Fig. 2, child node j chooses child node i as the next-hop node. Child node j adjusts its timer so that the phase becomes one when child node i emits a packet, and it sends a packet while child node i is awake. Child node i composes a packet from sensor information of its own and one from child node j and sends it to a parent node. A packet contains the sensor information, a cost value from itself to a parent node, an identifier of the next-hop node, and identifiers of parent nodes from which it can receive beacon packets. Since a packet contains an identifier of the next-hop node, a node can discard redundant packets which it occasionally receives.

After emission of a packet, a transceiver component is kept on until the phase becomes one to receive a packet from the next-hop node. On receiving the packet, a child node adjusts the timer and updates its cost value if the cost value of the next-hop node changes. It also examines the received packet to see whether sensor information it emitted is contained or not. If a child node does not see its sensor information in five successive packets from the next-hop node, it considers communication becomes unidirectional from the next-hop node to itself. Then, a child node marks the next-hop node as behind a unidirectional link in a neighbor table, initializes its state, and restarts finding the next-hop node from surrounding nodes except for ones behind unidirectional links. If a child node does not receive packets from the next-hop node more than three times in the last five gathering cycles, it considers the link to the next-hop node is lost due to the movement of itself or the next-hop node, a drastic change in radio environments, or a failure of the next-hop node. Then, it initializes the state and restarts finding the next-hop node. In both cases of re-establishment of a path, a child node skips probing parent nodes and immediately

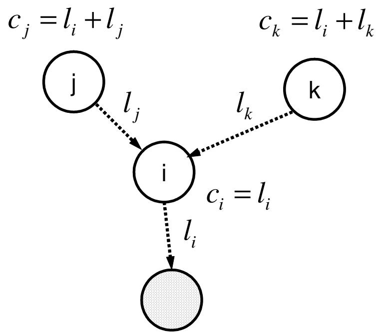

Figure 3: Example of cost calculation

examines child nodes, if its neighbor table does not have any addresses of parent nodes.

When a child node can successively receive packets from the next-hop node for five cycles, it considers the synchronization is established and starts a sleep mode. A child node turns on a transceiver component for only duration of $(\epsilon + \delta_i)T$ in a data gathering cycle of an interval of T as shown in Fig. 2.

2.2 Calculation of communication cost

A cost value measures the reliability and stability of radio communication and is derived from the number of failed receptions of packets and the received radio signal strength. In a proposed scheme, to accomplish the stable and reliable data gathering, a node with which the received radio signal strength is low but the number of failed reception of packets is small must be considered better than a node with which the received radio signal strength is high but the reception often fails.

In addition, to evaluate the goodness of multi-hop communication, a communication cost is determined hop by hop. For example, in Fig. 3, a grey circle stands for a parent node. Cost c_i of child node i is determined by the quality of a wireless link from node i to a parent node, i.e., link cost l_i. A communication cost c_j of node j to a parent node via child node i is then calculated as the sum of cost c_i and link cost l_j, i.e., $l_i + l_j$. As a result, a communication costs of a child node with a larger hop count to a parent node becomes higher than that of a child node with a smaller hop count, if link costs are identical.

We assume that IEEE 802.15.4 MAC protocol for low-speed communication is used

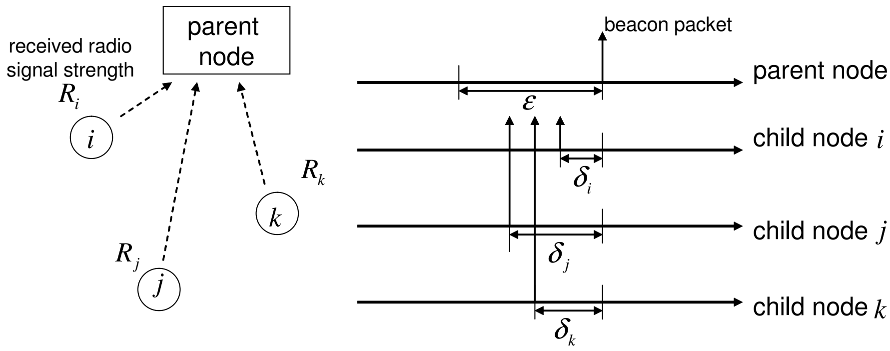

Figure 4: Example of distribution of offset δ by using the received radio signal strength

in a sensor network. Since the expected maximum hop count is at most four in a sensor network with tens child nodes per parent node, we defines a cost value as an eight-bits variable.

The communication cost for child node i to communicate with a parent node through child node p is given as follows.

$$C\left(S, R, C_p\right) = Round((S + (1 - \frac{R_i - R_{min}}{R_{max} - R_{min}})) \times 10) + C_p \tag{1}$$

In the equation, S stands for the number of reception failures in the last five gathering cycles, which corresponds to the stability of a wireless link. R_i is the received radio signal strength of child node i from child node p. R_{max} and R_{min} stand for the maximum and minimum bounds of the received radio signal strength depending on a transceiver component, respectively. C_p is a communication cost of child node p. The equation (1) weighs the stability of a wireless link ten times larger than the received radio signal strength in a cost value. The initial value of a communication cost is set to be 255. A communication cost of a child node which directly communicates with a parent node is calculated by using Eq. (1) with $C_p = 0$.

2.3 Distribution of packet emission among child nodes

To avoid collisions of radio signals among child nodes whose next-hop node is the same, we distribute offset δ_i by using the received radio signal strength as shown in Fig. 4. The

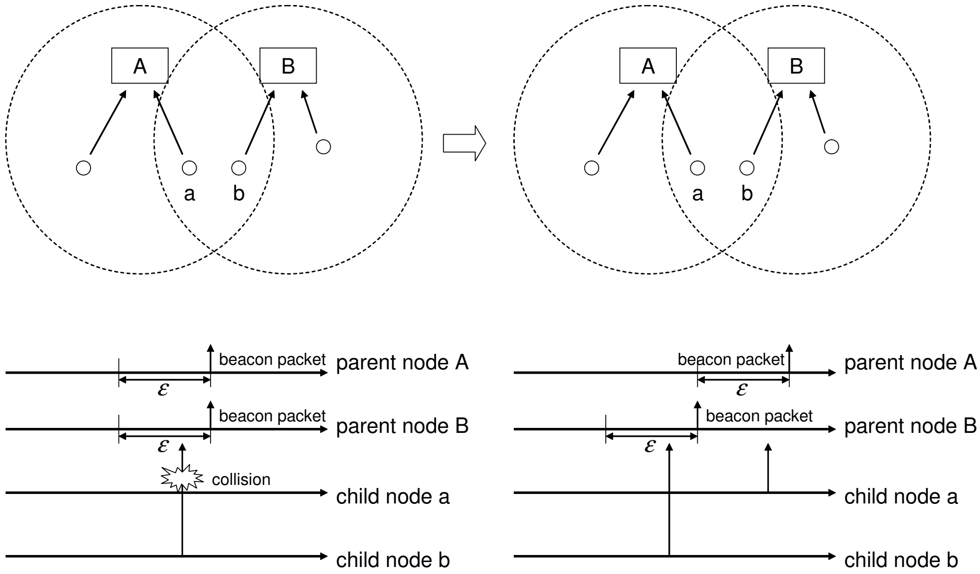

Figure 5: Example of distribution of beacon packets among parent nodes by ϵ

offset δ_i of child node i is given as below.

$$\delta_i = \frac{\epsilon}{R_{max} - R_{min}} \times (R_{max} - R_i), \tag{2}$$

where ϵ gives the maximum bound of the offset $(0 < \delta_i < \epsilon)$. A child node whose received radio signal strength is close to the maximum R_{max} emits a packet right before the packet emission of the next-hop node, whereas a child node with the minimum strength emits a packet the earliest.

2.4 Distribution of beacon emission among parent nodes

If transmission ranges of radio signals overlap with each other among parent nodes and they emit beacon packets at the same timing, collisions are expected to occur among child nodes even with a offset distribution scheme. To avoid such collisions, we also shift timing of emission of beacon packets among parent nodes by ϵ as illustrated in Fig. 5. However, if timing is changed among all parent nodes by ϵ, it takes ϵN to gather all sensor information from all N parent nodes. If ϵN is larger than one, the next cycle of data gathering begins before the preceding data gathering is finished. Therefore, we only control timing of emission of beacon packets among parent nodes whose ranges of radio signals overlaps with each other.

The distribution of emission of beacon packets is scheduled by a monitoring PC. A packet emitted by a child node contains identifiers of parent nodes from which it receives beacon packets. A monitoring PC identifies parent nodes whose ranges of radio signals overlap with each other and make them emit beacon signals at timing different from each other by ϵ. If N_o parent nodes have overlapping range of radio signals among N parent nodes, the required time for data gathering is reduced by $\frac{N_o}{N}$.

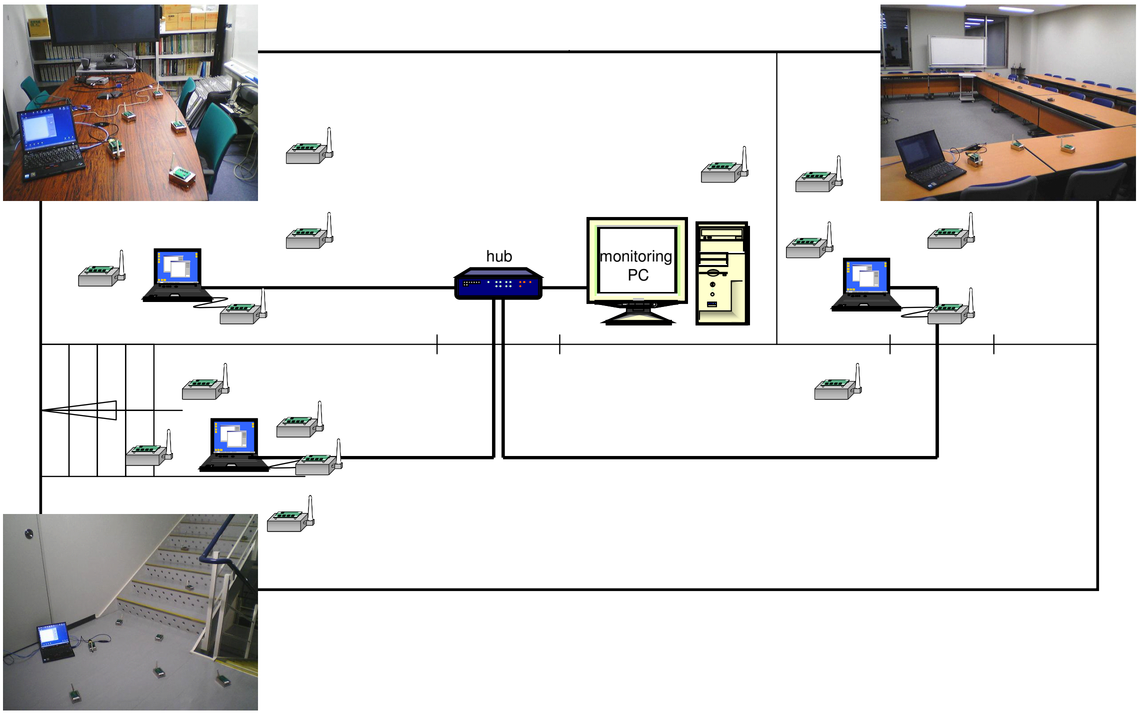

Figure 6: An implemented system

3 Implementation and Evaluation

To verify the practicality of the proposed scheme, we built an experimental system in an indoor environment (Fig. 6).

The implemented system was composed of one monitoring PC, parent nodes, each of which consisted of one sensor node and one control PC, and child nodes, each of which consisted of one sensor node. We adopted Ubiquitous Device [14] developed by Oki Electric Industry as sensor nodes. MAC layer protocol of Ubiquitous Device was IEEE 802.15.4 (2.4GHz, non-beacon mode). The range of radio signals was set at 5 meters in an open space by controlling transmission power. A sensor node of a parent node was connected to a control PC with a RS-232C cable, through which it received a control message to adjust timing of emission of beacon packets and sent received sensor information to the control PC. A control PC sent the sensor information received from a connected sensor node to the monitoring PC through wired connections, i.e., Ethernet. The monitoring PC specifies the timing to emit beacon packets to parent nodes, recorded sensor information received from parents nodes, and showed them on a monitor.

We first conducted an experiment to verify the basic operations of the system. Next we considered the case with addition and removal of child nodes. Then, we also verified the adaptability of the system to a drastic change in radio communication environments caused by an obstacle. We further configured the system with two parent nodes whose range of radio signals overlapped with each other. Finally, we conducted an experiment in a more realistic scenario with many nodes and obstacles.

An interval of data gathering is set at 20 or 100 seconds. The maximum offset value ϵ is set at 0.3, i.e., from 6 to 30 seconds.

3.1 Verification of basic operations

In the experiment, one parent node and 30 child nodes were placed in a meeting room as illustrated in Fig. 7. Nodes were on tables of 80 cm height. The density of child nodes was about 1.2 node/m^2.

Figure 8 shows timing of packet emission of sensor nodes. The interval of data gathering was set at 20 seconds. PN stands for a parent node, and identifiers from A0 to C9 stand for child nodes. "×" and "■" correspond to instants when child nodes sent packets by single-hop and multi-hop communication, respectively. When a parent node could occasionally receive a packet from a child node which intended multi-hop communication to the parent node, it is marked as a single-hop packet in the figure.

Firstly, all child nodes sent packets based on their own timers. At this time, child node A8 could not directly communicate with a parent node. At about 180 seconds, all sensor nodes determined their next-hop nodes, adjusted their timers appropriately, and constituted a sensor network of periodic data gathering. Then, periodic data gathering was started. However, because of changes in wireless communication environments, for example, child node C8 reset its state afterward for failures of receiving beacon packets and established a multi-hop path to the parent node at 840 seconds.

Figure 9 illustrates the transition of the data gathering ratio, which is defined as the ratio of the number of sensor information that a parent node can receive from child nodes which determined their next-hop nodes to the number of child nodes. The 9th cycle corresponds to 180 seconds when all child nodes attained the synchronization. At the

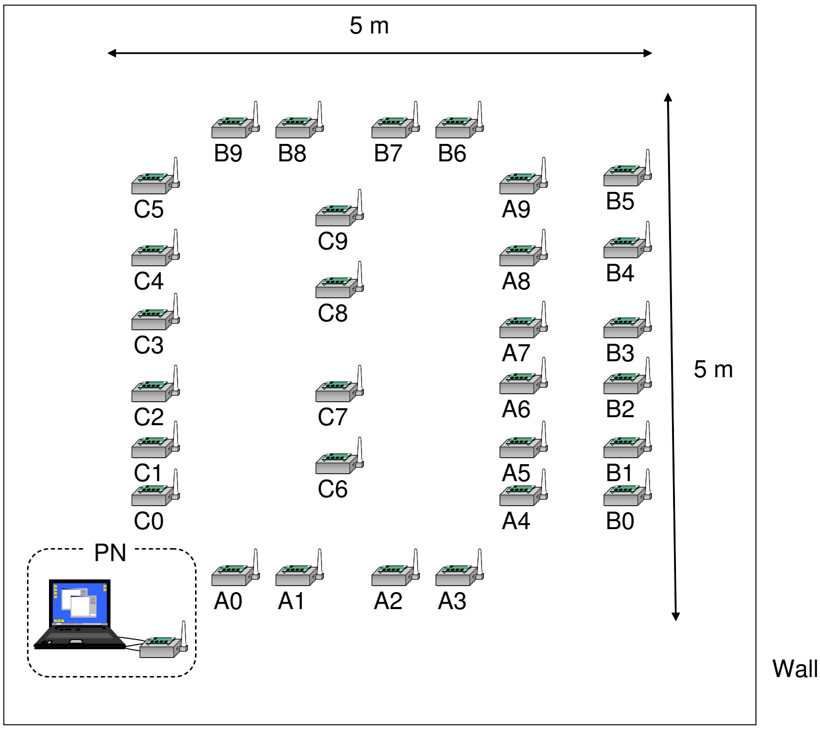

Figure 7: Location of sensor nodes (basic operations)

beginning, the data gathering ratio was zero, but it gradually increases as time passes. The average data gathering ratio was 77.7% after the synchronization. Instantaneous decreases of the data gathering ratio observed in Fig. 9 are for the loss of packets carrying multiple sensor information on a multi-hop path.

Results of the case without distribution of timing of packet emission among child nodes are shown in Figs. 10 and 11. The average data gathering ratio was 42.4% after the synchronization. Comparisons to Figs. 8 and 9 show the effectiveness of our proposed distribution scheme to avoid collisions among child nodes.

However, as shown in Fig. 9, we cannot completely avoid collisions even if timing of packet emission is distributed among child nodes. One possible way to reduce collisions is to have a longer gathering interval or a larger offset value and extend the range of distribution of offset. For example, Figs. 12 and 13 show results of the case with the interval of 100 seconds. In this case, an offset ranges from 0 to 30 seconds and the average data gathering ratio becomes 88.2%.

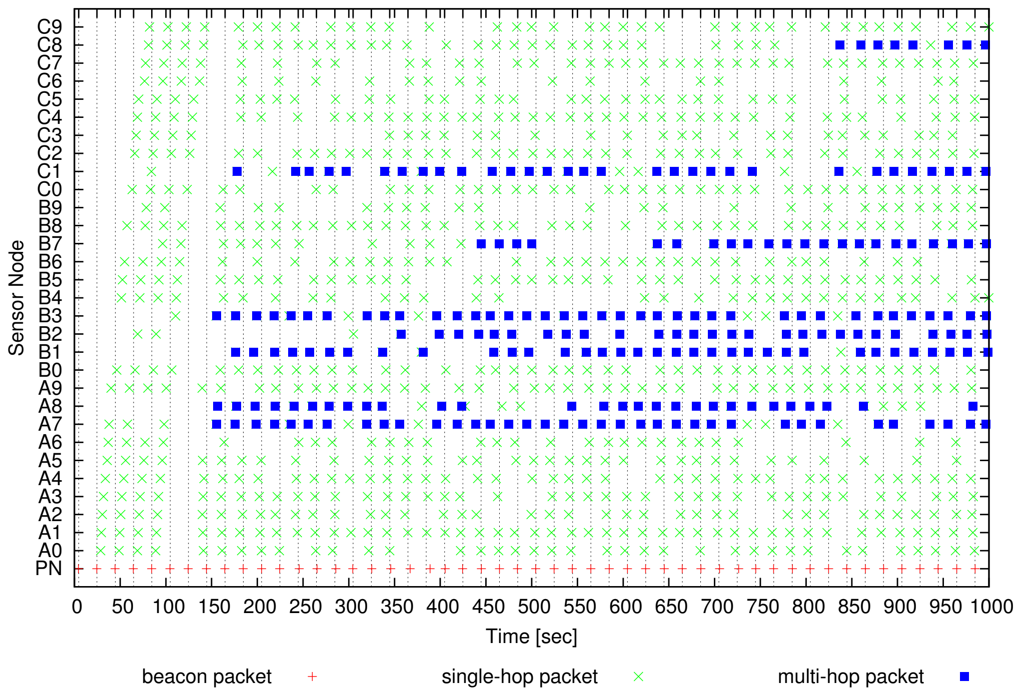

Figure 8: Timing of packet emission (with offset distribution, 30 child nodes, 20 second interval)

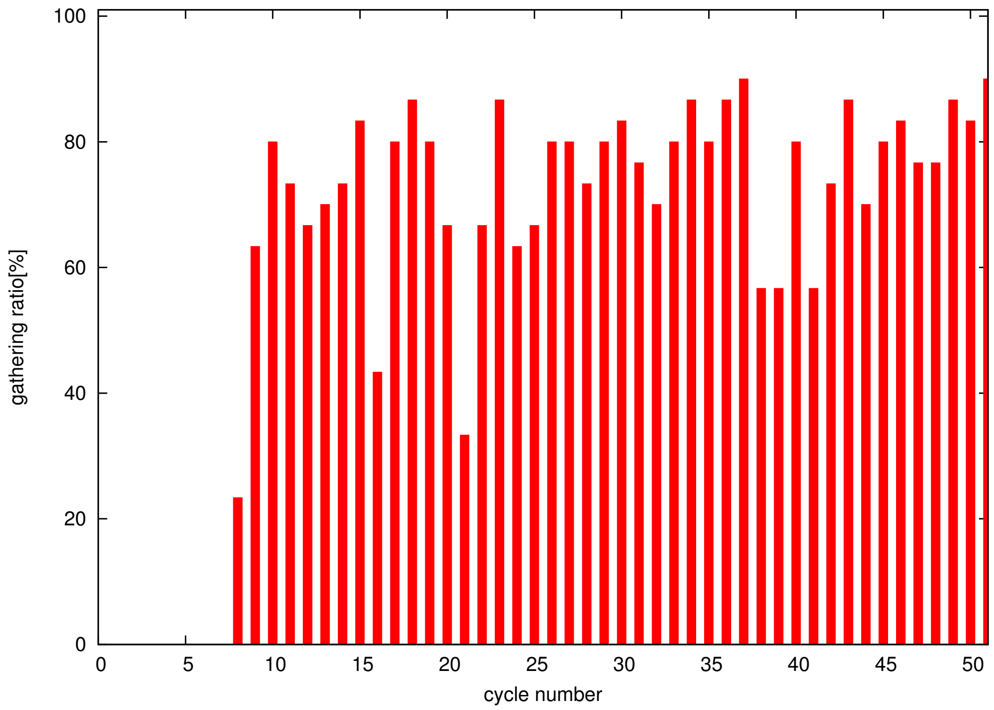

Figure 9: Data gathering ratio (with offset distribution, 30 child nodes, 20 second interval)

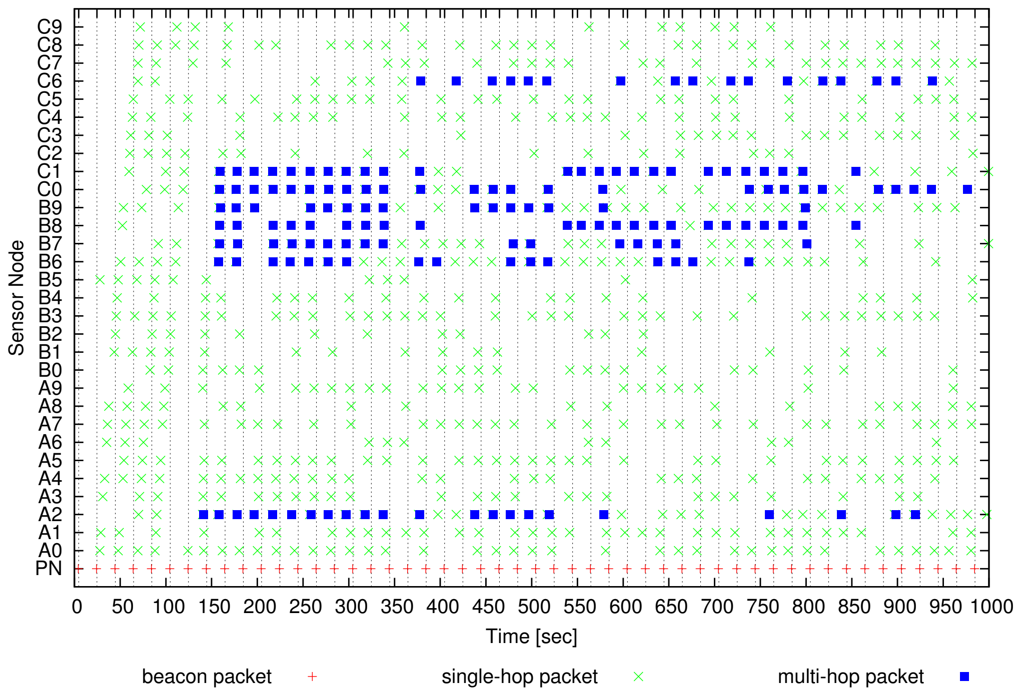

Figure 10: Timing of packet emission (without offset distribution, 30 child nodes, 20 second interval)

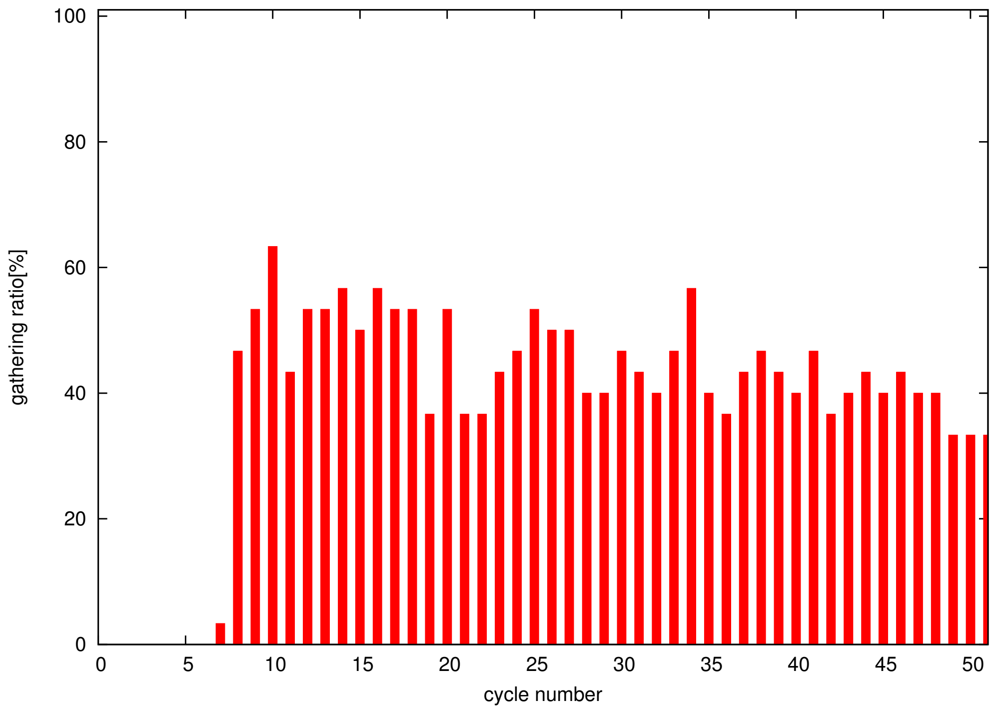

Figure 11: Data gathering ratio (without offset distribution, 30 child nodes, 20 second interval)

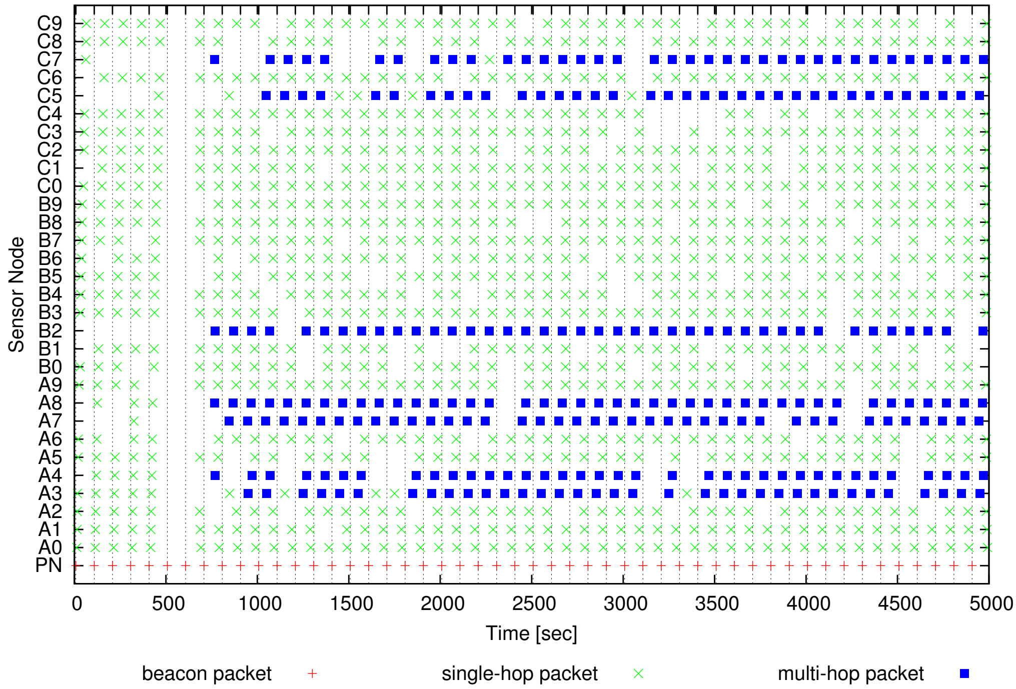

Figure 12: Timing of packet emission (with offset distribution, 30 child nodes, 100 second interval)

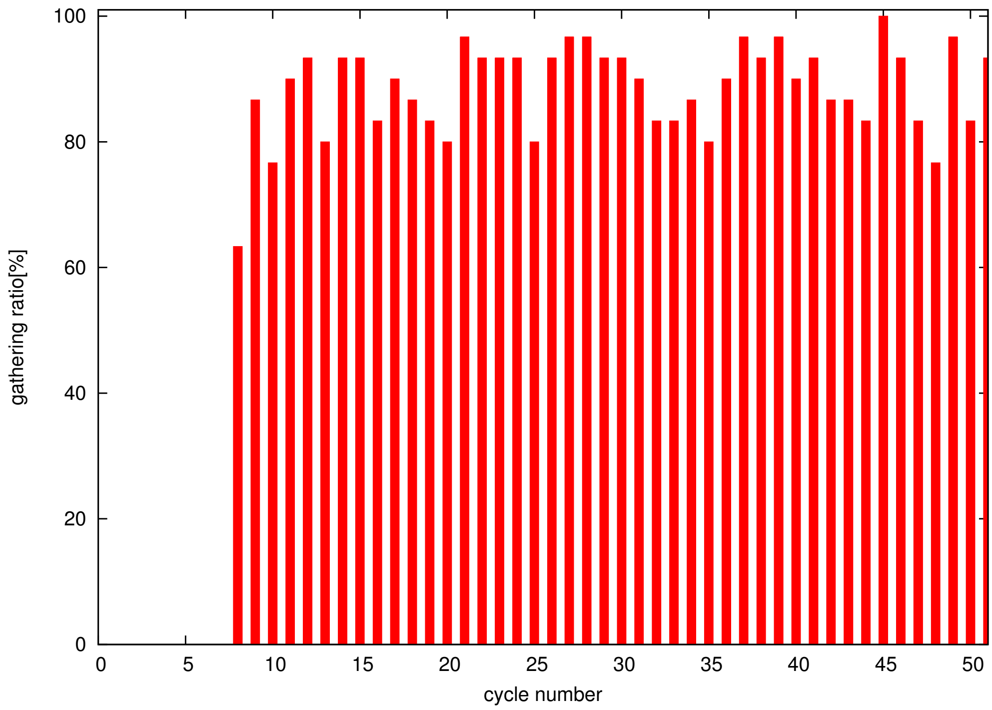

Figure 13: Data gathering ratio (with offset distribution, 30 child nodes, 100 second interval)

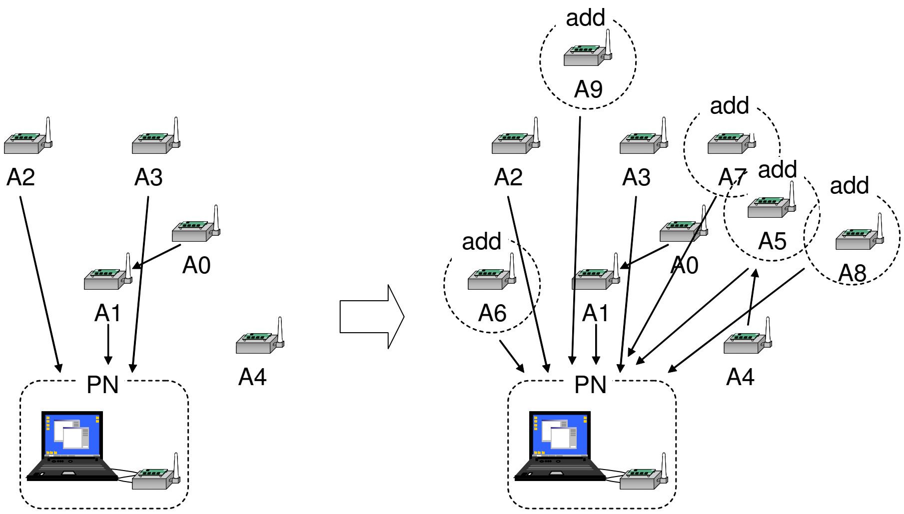

Figure 14: Location of sensor nodes (addition of child nodes)

3.2 Addition and removal of child nodes

To evaluate the adaptability of the proposed scheme to addition of child nodes, we conducted the experiment in a room with many obstacles. Child nodes and a parent node were placed as illustrated in Fig. 14 and their heights were from 0 cm to 100 cm. Arrows in Fig. 14 indicate next-hop nodes of each child node. Figure 15 shows the behavior of data gathering in the experiment. At First, child nodes A0 through A4 were placed in a room. Child nodes from A0 to A3 established the synchronization and their sensor information was received by the parent node. Because of obstacles, child node A4 could not receive either of beacon packets nor packets of other child nodes. Then, it was isolated. At about 250 seconds, the other child nodes were additionally introduced into a sensor network. Child nodes newly added began to determine next-hop nodes by observing radio signals around and then attained the synchronization at about 400 seconds. The isolated child node A4 could establish a multi-hop path to the parent node with mediation of a new child node A5. As a result, all sensor information was gathered by the parent node.

Next, we conducted the experiment to verify the adaptability of the proposed scheme to removal of child nodes. Nodes were arranged as illustrated in Fig. 16. The result is shown in Fig. 17. After the synchronization was attained, child node A0 was removed at about 230 seconds. At this time, child node A0 was responsible for sensor information

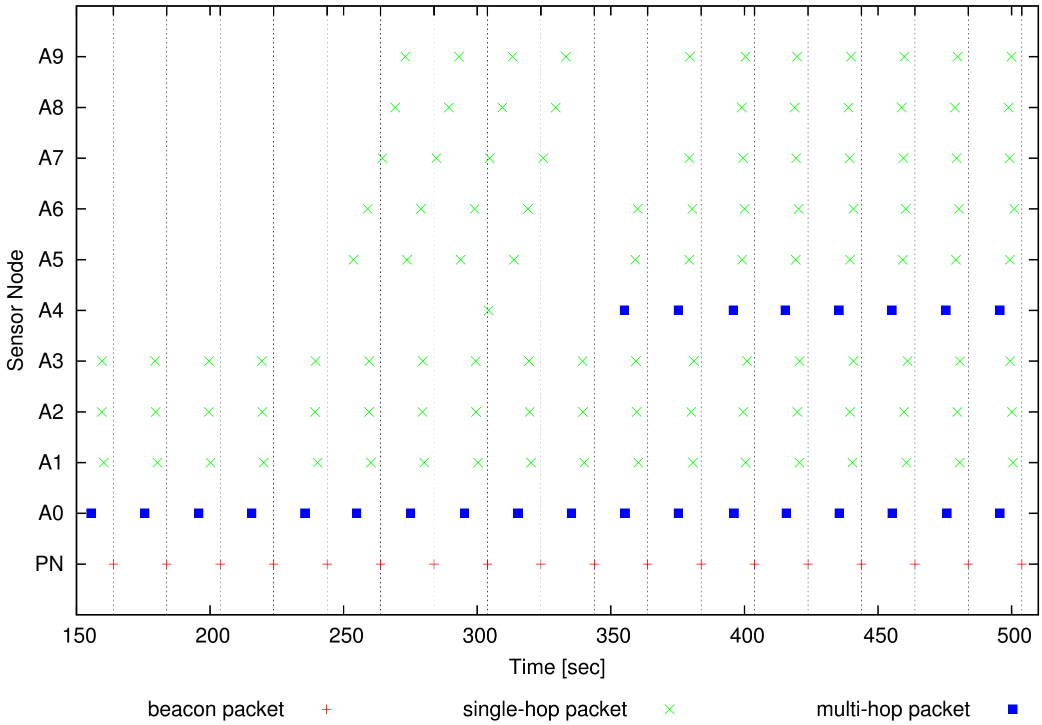

Figure 15: Timing of message emission (addition of child nodes)

of child nodes A5, A6, and A9, as an intermediate node of their multi-hop paths. Child nodes A5 and A6 detected the removal of child node A0 due to continuous failures of receiving packets from child node A0 for five times. Therefore, they initialized their states and began to search for new next-hop nodes. Child node A9 also detected the loss of the path by observing that the cost value of child node A5 became 255 due to initialization. Eventually, they determined their next-hop nodes as illustrated in Fig. 16 at about 500 seconds. Then, sensor information began to be gathered by the parent node from all child nodes.

The reason that it took rather long time to adapt to the change is that a node spends five gathering cycles to detect a loss of the next-hop node, five cycles to probe communication with parent nodes, and additional five cycles to find a good child node if multi-hop communication is needed. In this case, child nodes A5, A6, and A9 do not have an address of parent node PN, receive any beacon packets, so they tried to find a child node for multi-hop communication without searching for parent nodes. Therefore, the delay

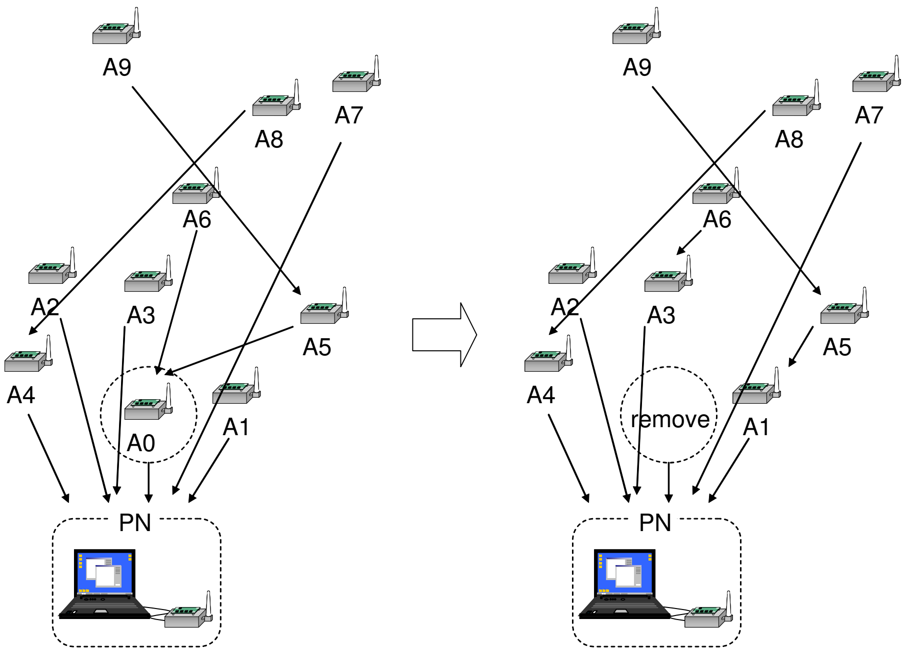

Figure 16: Location of sensor nodes (removal of child nodes)

consists of 11 or 12 cycles for detection of a link failure, finding the next-hop node, and one cycle for the synchronization. The delay can be shorten by reducing the number of data gathering cycles for observations, but it leads to frequent changes of a topology doe to unstable radio environments.

3.3 Changing radio communication environments

To verify the adaptability of the proposed scheme to a change in radio communication environments, we put a barrier into a sensor network as illustrated in Fig. 18. The experimental result is shown in Fig. 19. At about 420 seconds, after the synchronization had been attained, a barrier was put between the parent node and child node A4. Since child node A4 could not receive beacon packets any more, it first initialized its state. Then, at about 670 seconds, child node A4 chose child node A5 as the next-hop node and the synchronization was established again.

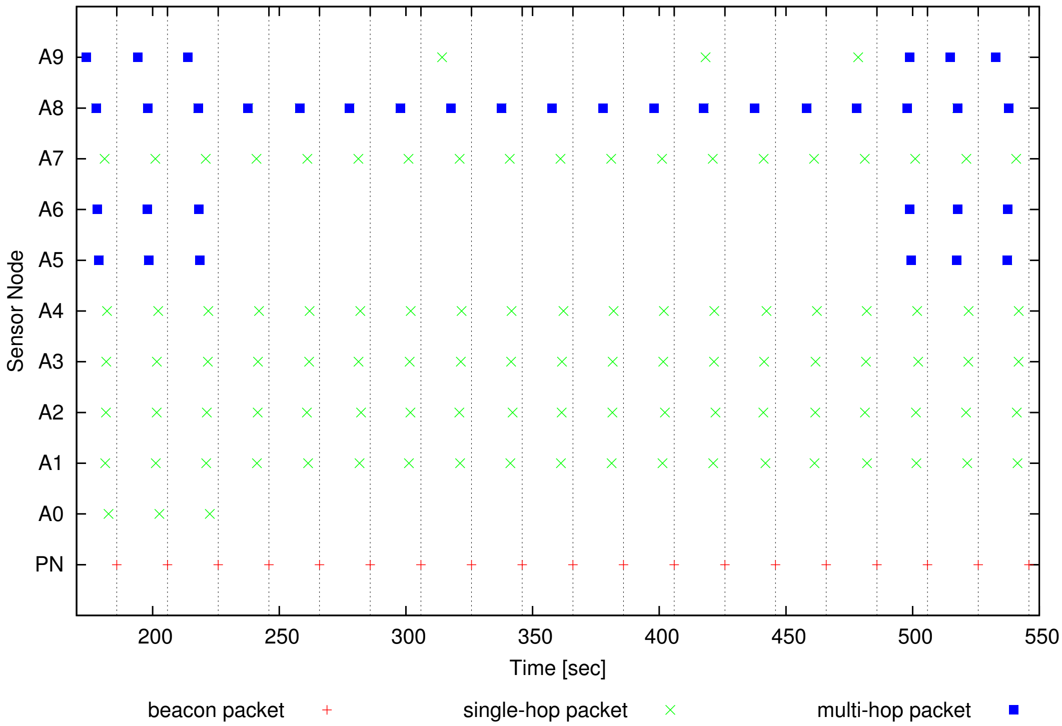

Figure 17: Timing of message emission (removal of child nodes)

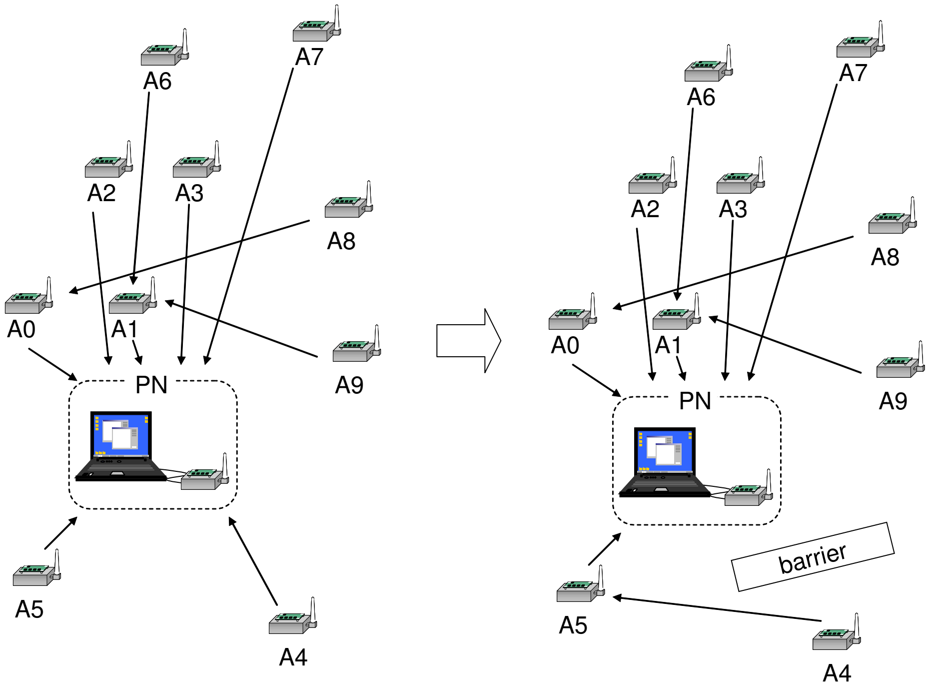

Figure 18: Location of sensor nodes (change of communication environments)

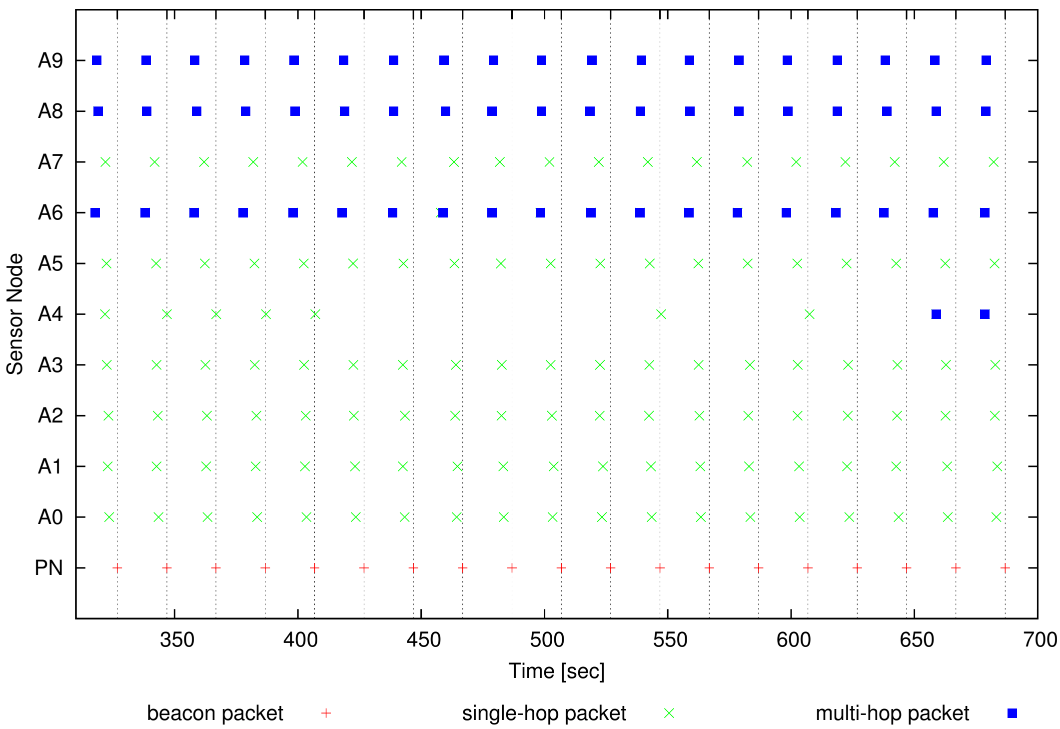

Figure 19: Timing of message emission (change of communication environments)

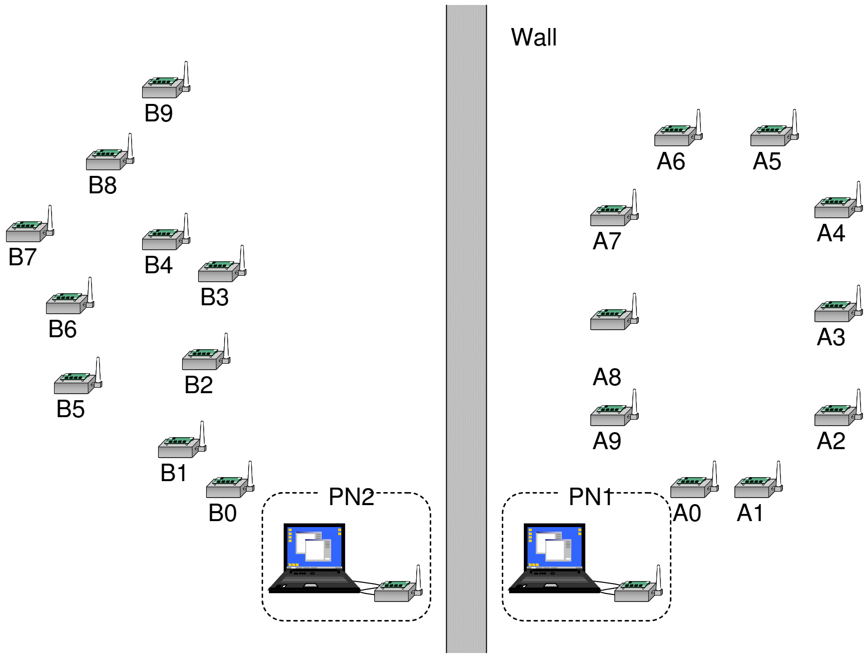

Figure 20: Location of sensor nodes (overlapping of range of radio signals among parent nodes)

3.4 Overlapping of ranges of radio signals among parent nodes

We placed two parent nodes as their ranges of radio signals overlapped with each other as illustrated in Fig. 20. Child nodes were placed around two parent nodes. Many of child nodes could receive beacon packets from both parent nodes PN1 and PN2. As shown in Figs. 21 and 22 for parent node PN1 and PN2, respectively, most of child nodes A0 through A9 chose parent node PN1 as the next-hop node and those B0 through B9 did parent node PN2.

The monitoring PC controlled timing of emission of beacon packets between two parent nodes, so that parent node PN1 emitted beacon packets earlier than parent node PN2 by six seconds ($T \times \epsilon = 20 \times 0.3$). As a result, collisions among child nodes for different parent nodes were avoided. In addition, since a parent node which is not chosen as the next-hop node also received packets from child nodes, the average data gathering ratio of 91.5% was accomplished.

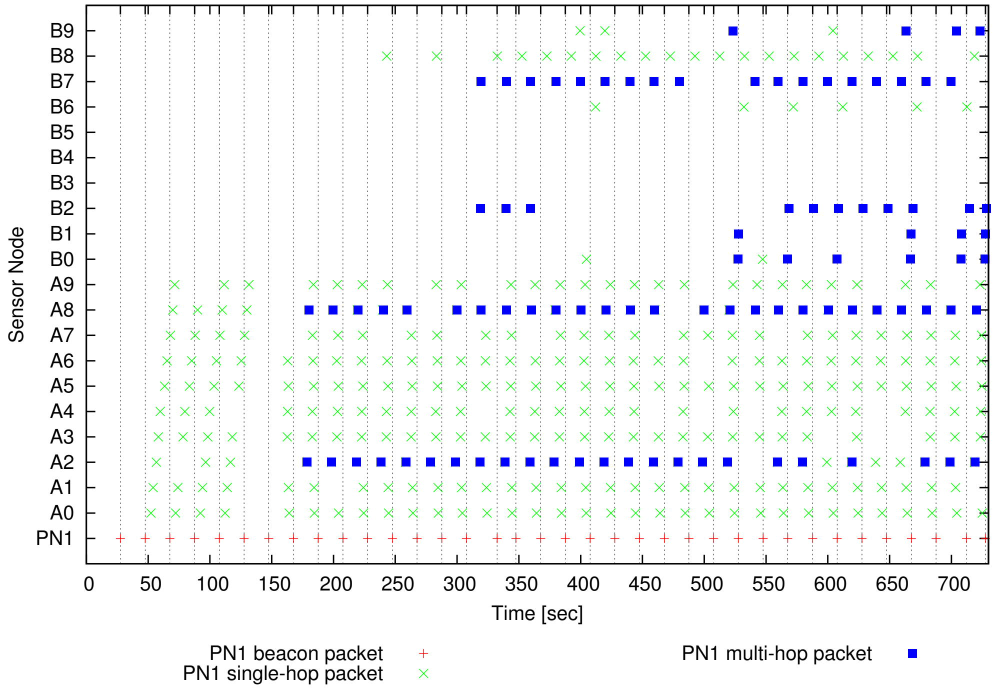

Figure 21: Timing of message emission (overlapping of ranges of radio signals of parent nodes, PN1)

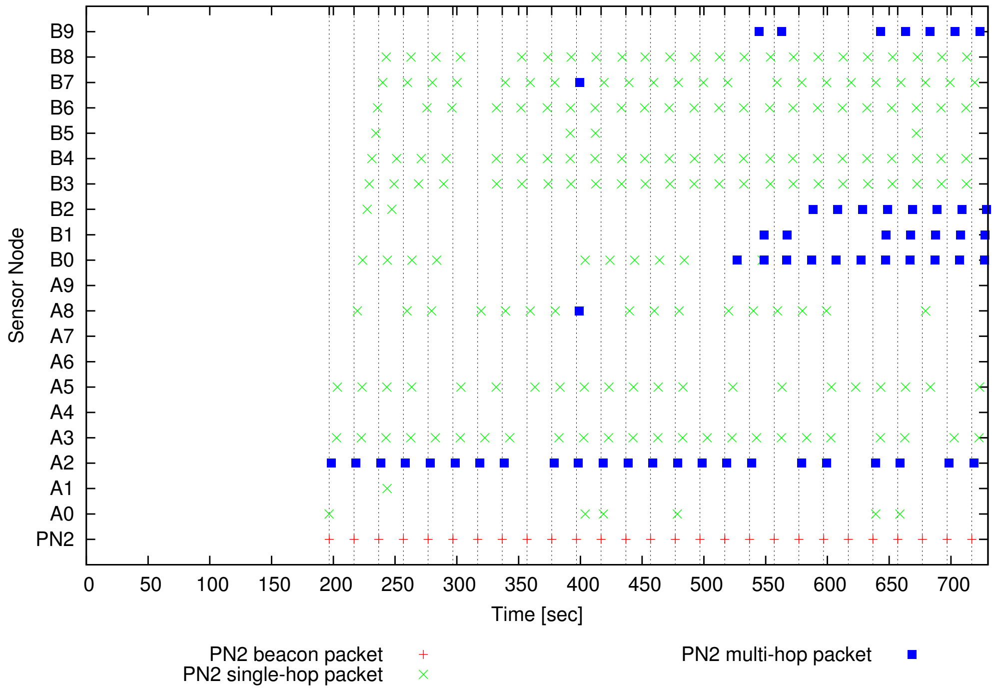

Figure 22: Timing of message emission (overlapping of ranges of radio signals of parent nodes, PN2)

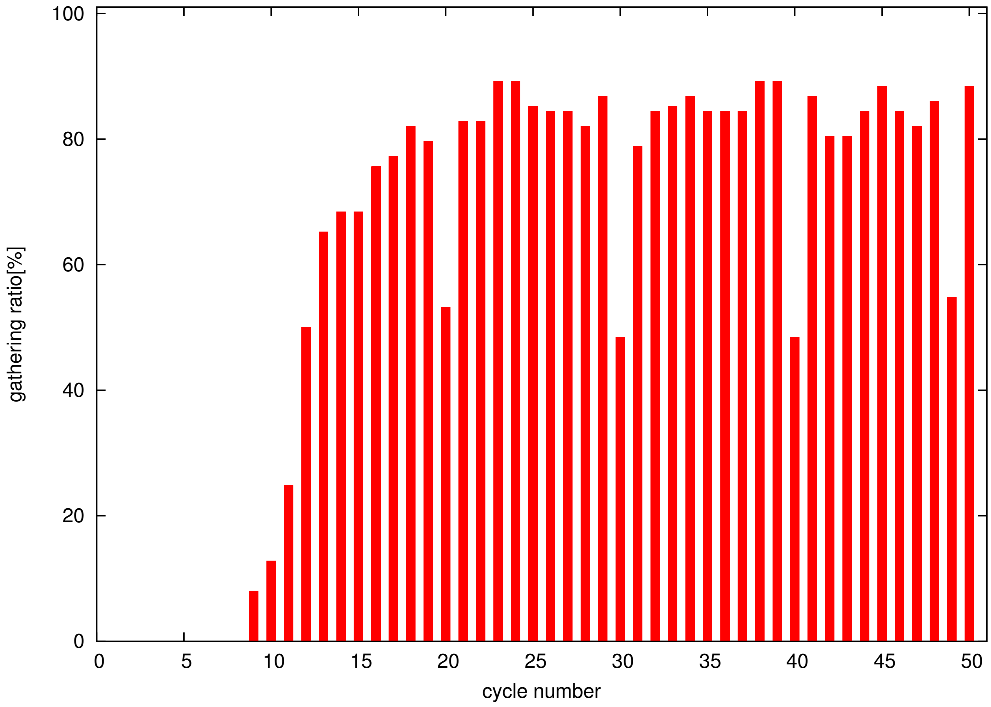

Figure 23: Data gathering ratio (3 parent nodes, 50 child nodes, 20 second interval)

3.5 An example of a practical scenario

We finally placed fifty child nodes and three parent nodes as illustrated in Fig. 24 in a room with many obstacles and moving people. As sensor information, each child node observes the received radio signal strength of beacon packets in a data gathering interval and reports the highest value indirectly or directly to a parent node. Figure 25 illustrates a snapshot of received sensor information where the height and color indicate the received radio signal strength. In the figure, we can see that the average of received radio signal strength is high around parent nodes.

Figure 23 illustrates the transition of the data gathering ratio, The average data gathering ratio was 81.6% after the synchronization. The reason why the gathering ratio is lower than one of the experiment in section 3.4 is that thirty child nodes chose parent node PN1 as their next-hop node in the environment and collisions often occurred in transmissions of data packets from child nodes to parent node PN1.

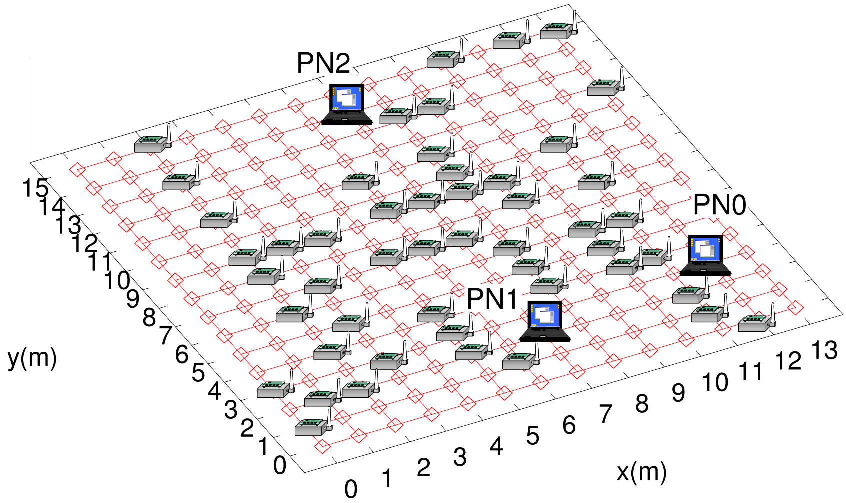

Figure 24: Location of sensor nodes (practical scenario)

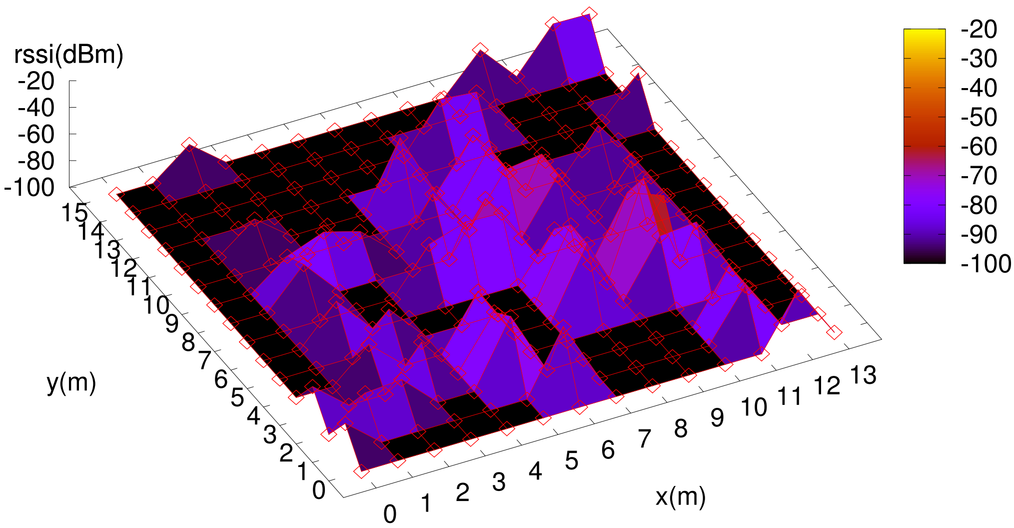

Figure 25: Distribution of received radio signal strength

4 Conclusion

In this thesis, we proposed the robust data gathering scheme for sensor networks in unstable environments such as in buildings. Our proposed scheme can construct a sensor network for periodic data gathering, which adapts to the addition and removal of sensor nodes, changes in communication environments, and overlapping ranges of radio signals among parent nodes.

We evaluated the practicality of our proposed scheme in sensor networks consisting of commercial and off-the-shelf wireless sensor units. The results showed that our scheme could gather sensor information from distributed sensor nodes at the average gathering ratio of 77.7 % to 88.2 % depending on a setting with a single parent node, adapt to changes in environments, and work well with multiple parent nodes.

By distributing timing of packet emission among sensor nodes, the number of collisions was decreased in our scheme. However, there still exist collisions which deteriorated the data gathering ratio. To attain a higher data gathering ratio for more critical applications such as security, we consider to introduce a retransmission mechanism.

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