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A Study on Ad-hoc Network with BLE Advertisement

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Abstract

In Japan, there is a high chance of getting damage from earthquakes, tsunamis, and typhoons, so we need to get information about where to evacuate quickly. However, in such situations, communication infrastructures such as base stations of 3G, LTE are broken. Even if they are available, many people try to access the Internet or make a phone call, network congestion occurs. As a result, their ways of communication are limited. Under such a situation, weak people at a disaster, who called CHECT (Children, Handicapped, Elderly people, Chronically ill, Tourists), usually receive a disadvantage. We have been developed a support system for hearing-impaired people in a disaster since 2007 because they are hard to get information because a lot of emergency information is delivered by sound. For them, information by vision is more suitable. Now, we are testing our disaster information delivery system in Miyagi-Prefectural School for the Deaf. The system is constructed by several LED displays and connected by the ad-hoc network. To install our system, we are now trying to use Bluetooth Low Energy (BLE) Advertisement. In this paper, we will explain the outline of our system and the result of the experiment of the performance of the ad-hoc network with BLE Advertisement. The performance includes the reachability of transmitted packets, the routability of the routing protocol we developed. As a result, we can conclude that BLE Advertisement based ad-hoc network is feasible to construct a disaster information system for hearing-impaired people.

Keywords: Disaster Information, Bluetooth, Bluetooth Low Energy, Ad-hoc network, BLE Advertisement

1 Introduction

This study aims to construct low-cost, low energy consumption, and non-breaking-off network using BLE Advertisement to deliver emergency information to deaf people when wire communication cable or base stations for cell phones are damaged. In the Tohoku earthquake in Japan, 2011, 29 thousand base stations were stopped, and very limited communication was possible [15, 22].

In Japan, there is a high chance of getting damage from earthquakes, tsunamis, and typhoons, so we need to get information about where to evacuate quickly. However, in such situations, communication infrastructures such as base stations of 3G, LTE are broken. Even if they are available, many people try to access the Internet or make a phone call, and network congestion occurs. As a result, their ways of communication are limited. Under such a situation, weak people at a disaster, who called CHECT (Children, Handicapped, Elderly people, Chronically ill, Tourists), usually receive disadvantages. We have been developed a support system for hearing-impaired people in a disaster since 2007 because they are hard to get information because a lot of emergency information is delivered by sound. For them, information by vision is more suitable. We made a survey of individuals with auditory handicaps requiring support after the Great Hanshin-Awaji earthquake [20] and received 185 replies. We found that many of the hearing-impaired people were left without support during the disaster. Some of them were left in a house and could not go to a shelter. From our survey, 58.1% of the hearing-impaired people were informed of the disaster immediately: however, 49.1% knew of the disaster with a delay of half a day, and 3.7% knew about the disaster after a week. Even in a shelter, their life was not comfortable since important information usually delivered by voice.

For providing disaster information quickly to hearing-impaired, we set the following requirements to design the system [11].

- Requirement1: Accurate information rapidly for deaf people
- Requirement2: Appropriate information according to an individual situation
- Requirement3: Robust equipment to display information definitely
- Requirement4: Applicable for use in daily life
- Requirement5: No complicated operation
- Requirement6: Works during a blackout

One solution to satisfy the requirements were designing LED displays with a battery connected by the ad-hoc network, as shown in Figure 1 and testing at Miyagi-Prefectural School for the Deaf since 2012. One of the LED displays receive information from cloud (by SMS or GCM (Google Cloud Messaging)) or a smartphone of a teacher and delivers to other displays [10] by using an ad-hoc network. Each LED display has a battery, and we calculated the capacity of the battery for a one-day operation. Also, the ad-hoc network had a routing protocol [22] based on OLSR [11]. The routing protocol is required to keep the reachability of disaster information. For example, If a closed firewall cuts a connection between LED displays, it is required to change the information delivery route.

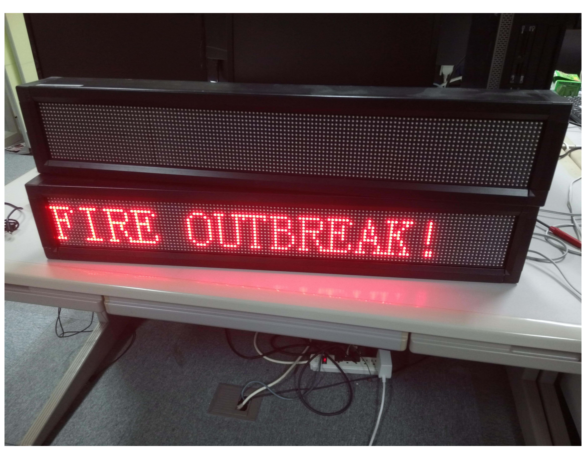

Figure 1: LED displays of our system.

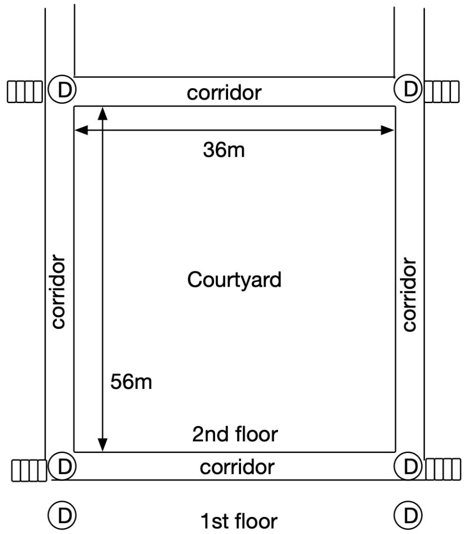

Figure 2: The layout of corridor of of Miyagi-Prefectural School for the Deaf.

However, there was a problem. Figure 2 shows the layout of the school. In the figure, "D" means the location of an LED display.

We tested the connectivity between neighbor LED displays on the second floor. Unfortunately, we could not connect any segment by using WiFi (IEEE802.11). Also, we tested connectivity between displays on the 2nd floor and on the first floor through the stairs by using WiFi. We tried to use several different dongles and small WiFi AP. However, the connection over 20m was impossible in this location. If we use high power, large AP, it might be possible. However, there is "Requirement6: Works during blackout", so that we should suppress the power consumption. We used Raspberry Pi 3 as a CPU of the LED display. It consumes around 2W. WiFi dongle consumes around 1-2W, on the other hand, large AP consumes over 10W. Another possibility was using relay nodes in the middle of the corridor. This solution makes the system complicated and decreases maintainability. Also, we tested Bluetooth 2.1. However, it also did not work. So, we needed to find low power and long reach method.

Finally, we found that the BLE Advertisement could reach over 56m in the corridor and also displays on different floor through stairs.

We assume that the difference in packet length of WiFi and BLE Advertisement caused the difference. For example, MAC frame of 802.11n contains 22 Octet MAC header + 4 Octet FCS + Frame Body (20 Octet IP header + data), so at least 46 fixed Octet is required (up to 1500 Octet). On the other hand, the packet length of BLE is 47 Octet if PDU (Protocol Data Unit) is max. So, the packet size of WiFi is longer than BLE. In the situation of Miyagi-Prefectural School for the Deaf, the corridor is a 56m long concrete tunnel, so there is much reflection of a radio wave. We think that a longer packet may be affected by the reflection. The detailed consideration of why WiFi did not work is further study.

According to the above discussion, we updated the communication function of the disaster information delivery system with an LED display using the BLE Advertisement based ad-hoc network.

In this paper, we discuss the performance of the BLE Advertisement based ad-hoc network and routing protocol that we implemented.

Firstly, related works on the ad-hoc network and our previous works are explained in section 2. An outline of the short-range wireless communication, such as BLE and IEEE802.11, is explained in section 3. In sections 4 and 5, we explain the problem and our solution, respectively. The result of the experiments is explained in section 6. In section 7, we mention the evaluation and discussion. Finally, the conclusion is presented in section 8.

2 Related Works

2.1 Related Works on Ad-hoc Network

There is one example of an autonomous network that is useful when 3G or LTE is unavailable [17]. In this study, with smartphones with MANET (Mobile Ad-hoc NETwork) and DTN (Delay Tolerant Network) technology, a message is transmitted for 2.5km long. This study uses Wi-Fi as a physical layer. There is also an ad-hoc network study that uses Bluetooth 2.1 [24] and a study that combines Bluetooth and Wi-Fi [13]. Another study uses a BLE advertisement when establishing the connection of Bluetooth Classic [23]. The goal of this paper is to construct an ad-hoc network that can broadcast data rapidly, so we used only a BLE advertisement because Wi-Fi consumes a lot of electricity, and DTN can have a long delay.

2.2 Related Works on disaster information system

There are several research papers about the situation of hearing-impaired people under the blackout. "Giving and Receiving of Information by Hearing-Impaired Persons after the Earthquake Disaster: From an Interpersonal Communication Point of View" [12] told "the Symposium of Earthquake Communication clearly show the need to examine the giving and receiving of information after a disaster. We need to reconsider the use of "Mieru-radio/Teletext-broadcasting [19]". However, the service named "Mieru-radio" has already closed. Because visible contents on the web-sites using smartphones are increasing day by day, and many people inclosing hearing-impaired ones use them instead of special Teletext broadcasting. Those smartphone applications are useful for normal lives. Communication traffics apt to occur in a disaster, and it would be hard to get information by smartphones. "Eye Dragon 4" [1] is a subtitle system of the TV for hearing-impaired people. However, if electricity fails on the disaster, TV does not work at all.

The daily lives of people, including hearing-impaired people, have been more convenient. However, the situation for hearing-impaired people on disasters has been worse. We have studied the information system for 14 years [20, 21, 9, 10, 8, 4, 7, 5] and have to continue our project to support hearing-impaired people under disasters.

3 Short Range Wireless Communication

While there are many short-range wireless communication standards, Bluetooth and IEEE802.11 are suitable for delivering information to deaf people because the hardware for them are easy to get and low cost. Bluetooth Low Energy (BLE) is one of the wireless communication standards, which is added since Bluetooth version 4.0. BLE consumes less electricity than standard Bluetooth does. Instead, BLE doesn't support Enhanced Data Rate (EDR), which makes it possible to communicate in up to 3Mbps. In addition, the BLE advertisement uses three channels (channel 37: 2402MHz, channel 38: 2426MHz, channel 39: 2480MHz) [16], and this reduces the consumption of electricity. From another point of view, if the density of BLE nodes is high, the more likely collisions occur.

3.1 Bluetooth Low Energy

Bluetooth Low Energy (BLE) has two communication modes: connection-oriented mode and connectionless mode.

BLE Connection is a connection-oriented communication standard. Because the connection-oriented protocol is not suitable for long-distance communication due to the necessity of re-connection, we didn't pick this as a communication protocol for an information delivery system for deaf people.

In connectionless mode, a sender node "advertises" data to neighbor nodes. A receiver node "scans" advertised packets.

BLE Advertisement transmits a small packet, as described in section 1, to nodes in the near filed. This function is designed to send small data such as temperature data from a thermometer, so we can't transmit large data in one shot [18]. Instead, we can set an advertising interval (interval between one advertisement to the next advertisement). We can set this in the range from 20ms to 10,240ms. With shorter advertising intervals, a receiver is more likely to receive large data. However, the power consumption of BLE should be increased. Also, it is possible to set the interval at random from 0ms to 10ms. This function is used to avoid a collision when there are two advertising nodes with the same advertising interval [3].

The BLE scan function is used to catch the transmitted data from other advertising nodes. It has two modes: Active scan and Passive scan. In an active scan, a scanner requests an advertiser to advertise. In a passive scan, a scanner waits until the data is transmitted. In this paper, we chose a passive scan for receivers because transmitter nodes are expected to have long data to send, and the receivers don't need to request sending data.

3.2 IEEE802.11

IEEE802.11 is probably the most widely used wireless communication standard. The first IEEE802.11 standard was developed in 1997. Today, many IEEE802.11 standards, such as 11b, 11g, 11n, 11ac, are used. The max communication speed of the first standard was 2Mbps. With IEEE802.11ac, it is possible to communicate in 6.9Gbps (although this is almost not supported in real products.) Compared to BLE, IEEE802.11 is faster and consumes much electricity than BLE does.

4 Problems

We had been working on developing an information delivery system for deaf people in Miyagi-prefectural school for the deaf. The requirement is to have at least 56 meters of communication range. At first, we had been working with IEEE802.11, not BLE, as a physical layer for our information delivery system. We had switched to use BLE from Wi-Fi because the communication range with Wi-Fi didn't satisfy the requirement. By using BLE, the short communication range problem had been solved. However, the new problem had broken out: routing.

For Wi-Fi, there are many exiting routing protocols available (e.g., OLSR.) In the BLE advertisement, OLSR is not available because Internet Protocol (IP) is not implemented in the BLE advertisement. In the BLE advertisement, there is no known routing protocol (problem A).

Also, BLE advertisement performance is unclear (problem B). To develop a new routing protocol for the BLE advertisement, we had to understand the performance of the BLE advertisement clearly, such as the packet receive ratio.

5 The Solution

As written above, there are already many routing protocols existing. OLSR [6] is one of them. OLSR is not available in the BLE advertisement environment because it's not aware of Internet Protocol (IP). We chose to develop a new routing protocol for BLE advertisement because there is no known routing protocol for BLE advertisement (solution for problem A.)

To know the performance of the BLE advertisement, we can test the packet reach rate of the BLE advertisement. Just calculate the number of received packets, and the number of transmitted packets do (solution for problem B.)

6 Experiments

In this study, we did three experiments:

Experiment 1
: Examine packet reach rate with 5 BLE nodes to determine suitable times for transmitting a packet. This experiment was performed to solve problem B.

Experiment 2

Examine packet reach rate in a building (one of Utsunomiya University building) to know what percentage of packets can reach to other nodes. This experiment was also performed to solve problem B.

Experiment 3

Check whether the routing table of a node was correctly created when it moves with our original routing protocol. This experiment was performed to solve problem A.

6.1 Experiment 1: Examine the packet reach rate outside

In this experiment, we evaluated BLE communication performance. Each BLE node is Raspberry Pi with a Bluetooth adapter (ELECOM LBT-UAN05C1), which has class 1 transmit power. The max transmission power of Bluetooth class 1 is 100mW [2], and the Japanese radio act doesn't allow 100mW tx power with Bluetooth, so the actual tx power is smaller than 100mW. Raspbian was installed on them. A program that transmits and receives packets written in javascript runs on node.js on each node. There are two merits of using BLE advertisement:

- It's very common standard and easy to support.
- It consumes a tiny amount of electricity and available on devices run with a button battery.

We had experimented on the grounds of Utsunomiya University. In this experiment, we set five nodes on red cones, as described in Figure 3. The distance between two consecutive nodes was 70 meters (in Figure 4). The node's height from the ground is about 60 centimeters. The data is transmitted from the first node (Node 1) to the last node (Node 5) by hopping each intermediate node. The first 6 bytes of the data were a BD address (Bluetooth Device address (or BD_ADDR) is a unique 48-bit identifier assigned to each Bluetooth device by the manufacturer [14]) of the next-hop node. The next 4 bytes were sequence number. We set that the sequence number was incremented at every 210ms. The data (BLE Advertisement packet) was transmitted 8.5 times in 210 ms. The advertising interval was set as 20ms in this experiment. This value is the shortest interval supported by the standard. However each advertisement interval should have random delay (0-10ms) to avoid collision, so the real average transmission interval was $(20ms + (0 + 10)/2)ms = 25ms$. So, in 210 ms, the same BLE Advertisement packet was sent 8.5 times on average.

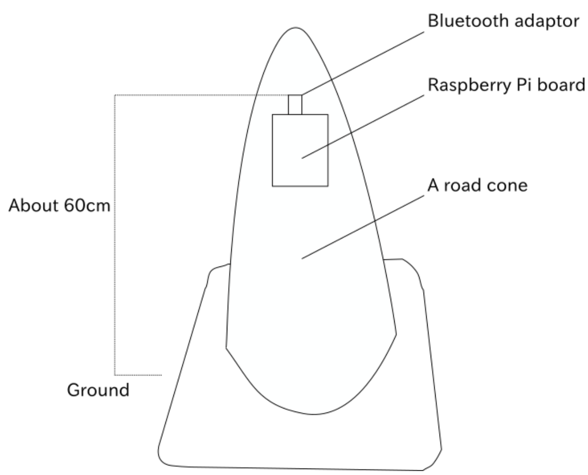

Figure 3: A fixed node on a cone

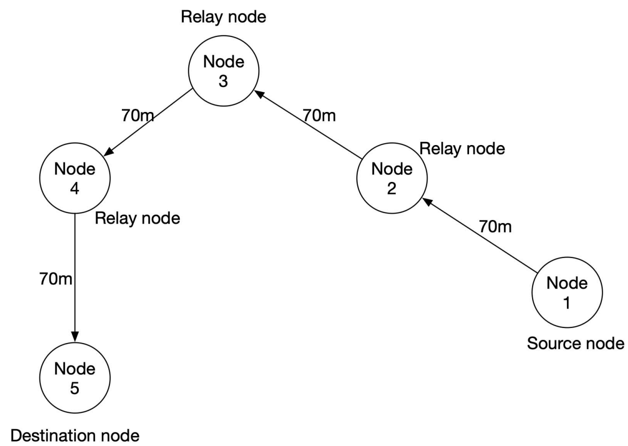

Figure 4: The arrangement of nodes

We waited 14 minutes for 4000packets to be transmitted. We didn't count the duplicate sequence number receive. As a result, the proportion of arrived packets was 69.975%. The number of reached packets for each section, and the total reached packets are described in Table 1.

Table 1: Packet Reach Rate for Each Section

Section	**Number of reached packets**	**Reach rate**	**Total reach rate**
Node 1 to 2	3014	75.35%	75.35%
Node 2 to 3	2864	95.02%	71.6%
Node 3 to 4	2860	99.86%	71.5%
Node 4 to 5	2799	97.86%	69.975%

6.2 Experiment 2: Examine the packet reach rate in a building

In this experiment, we evaluated BLE communication performance in a building, which is one of Utsunomiya University buildings. Each BLE node was Raspberry Pi with a Bluetooth adapter (ELECOM LBT-UAN05C1), which has class 1 transmit power. The max transmission power of Bluetooth class 1 is 100mW [2]. However, the Japanese radio act doesn't allow 100mW tx power with Bluetooth, so actual tx power is smaller than 100mW. Raspbian was installed on them. A program to transmit and receive packets was written in C language. We set 5 points, as shown in Figure 5.

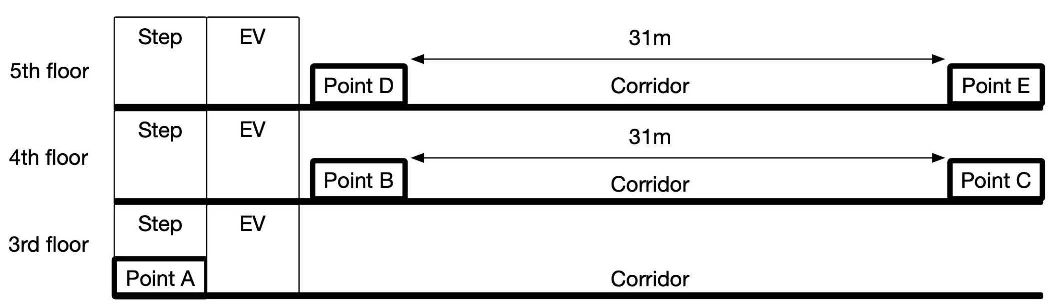

Figure 5: The arrangement of points.

With these points, we measured BLE Advertisement reachability in 10 sections:

- Point A to B.
- Point A to C.
- Point A to D.
- Point A to E.
- Point B to C.
- Point B to D.
- Point B to E.
- Point C to D.
- Point C to E.
- Point D to E.

The reversed paths like 'Point B to A' or 'Point D to B' was NOT tested! We set the advertising interval to 20ms. Considering random interval injection (0 to 10ms), the average advertising interval is 25ms. 24000 packets were expected to be received by the receiver because we did each measurement for 10 minutes:

$$10min/25ms = 24000 \tag{1}$$

The result is in Table 2.

Table 2: Packet Reach Rate for Each Section

Section	**Number of reached packets**	**Reach rate**	**Avg. RSSI [dBm]**	**Mode of RSSI**
Point A to B	22599	94.16%	-69	-62
Point A to C	9244	38.52%	-77	-77
Point A to D	7055	29.40%	-72	-73
Point A to E	0	0%	-	-
Point B to C	21290	88.70%	-69	-66
Point B to D	22592	94.13%	-64	-61
Point B to E	5483	22.85%	-80	-81
Point C to D	6350	26.46%	-79	-80
Point C to E	22382	93.26%	-50	-52
Point D to E	14773	61.55%	-63	-66

We plotted packet reach rate by mode of RSSI (Figure 6).

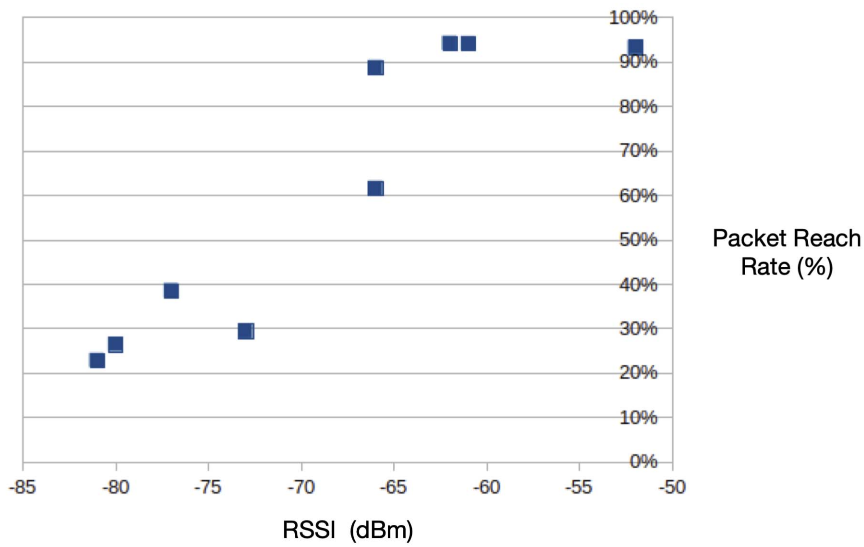

Figure 6: Packet reach rate by RSSI

6.3 Experiment 3: Check the performance of the routing protocol for BLE

To communicate effectively, we had implemented routing protocol for BLE ad-hoc network. OLSR and AODV are not implementable because IP addresses are unavailable on BLE advertisement, and the 31-octet limit of BLE Advertisement data is too short of implementing them.

To construct a routing table, we introduce NEIGHBOR_ADVERTISEMENT packet described in Table 3. NEIGHBOR_ADVERTISEMENT packet has at least 8 octets and stored in the Protocol Data Unit (PDU) of the BLE Advertisement packet. This packet is used for advertising the existence of the sender node and its neighbor nodes.

Table 3: The Structure of NEIGHBOR_ADVERTISEMENT Packet

offset 0:	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
offset 8:	(I)	(margin)						

OLSR has four messages, HELLO, TC, MID, and HNA. HELLO, and TC is important. The behavior of these messages is defined in RFC3626 [6] as follows.

- HELLO-messages, performing the task of link sensing, neighbor detection, and MPR signaling
- TC-messages, performing the task of topology declaration (advertisement of link states).

In our case, the number of LED displays is limited (less than 20), and each display has a connection up to 4 displays. So, we optimized and merged the function of HELLO and TC into one message as NEIGHBOR_ADVERTISEMENT. The definition of each element of NEIGHBOR_ADVERTISEMENT is as follows.

(A) is a network ID. It is possible to operate multiple networks in the same area with different network IDs.

(B) is a sender node ID.

(C) is a destination node ID. In the NEIGHBOR_ADVERTISEMENT packet, in our implementation, this data is ignored because it is intended to receive by all neighbor nodes.

(D) is next-hop node ID. In the NEIGHBOR_ADVERTISEMENT packet, this parameter is also ignored because it is intended to receive by all neighbor nodes.

(E) is a sequence number. To avoid the same data is processed multiple times by receiver, only the first packet of the same sequence number is processed by a receiver.

(F) is a protocol ID. 0x02 means BLE routing protocol id.

(G) is a Time To Live (TTL). This parameter is decreased by one when a packet hops. When this reaches 0, the packet should be destroyed.

(H) is a last hopped node ID. By checking this ID, the receiver can know its neighbor node ID.

(I) is a list of IDs of neighbor nodes of the sender node. The length of (I) is variable and is equal to the sender node's neighbor nodes. It can be 0.

The behavior is as follows. First, all nodes send the NEIGHBOR_ADVERTISEMENT packet using the BLE Advertisement. A node that received the NEIGHBOR_ADVERTISEMENT put the id at (H) to its neighbor node list. Also, it adds the IDs in (I) to the neighbor list of the sender node. Furthermore, it resends the packet after replacing (H) with its self-id. According to this procedure, a neighbor node list information is spread to the network. Figure 7 is an activity diagram of each node. Table 4 is an example of how a neighbor node list is updated. In this example, Node A and B, Node B, and C and Node C and D are directly reachable to each other, as described in Figure 8.

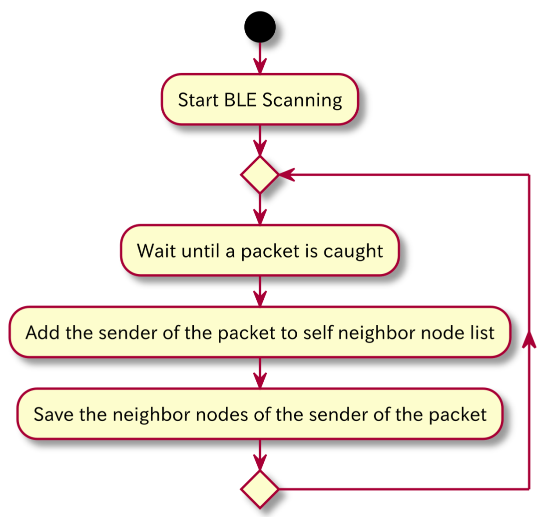

Figure 7: Activity diagram of each node when receiving a NEIGHBOR_ADVERTISEMENT.

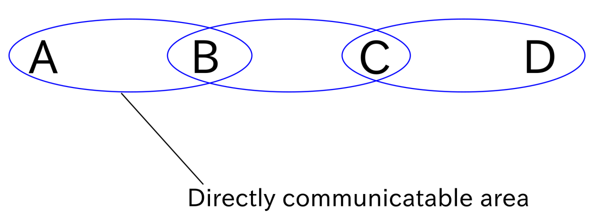

Figure 8: The arrangement of example nodes.

Table 4: Neighbor node list by each step

Step	0	1	2	3	4	5	6
Node A	-	-	-	-	-	-	B
Node B	-	A	A, C	A, C	A, C	A, C	A, C
Node C	-	-	-	B	B, D	B, D	B, D
Node D	-	-	-	-	-	C	C

0. At first, Node B doesn't know neighbor nodes of any node.
1. Node B receives a NEIGHBOR_ADVERTISEMENT from Node A.
2. Node B receives a NEIGHBOR_ADVERTISEMENT from Node C.
3. Node C receives a NEIGHBOR_ADVERTISEMENT from Node B.
4. Node C receives a NEIGHBOR_ADVERTISEMENT from Node D.
5. Node D receives a NEIGHBOR_ADVERTISEMENT from Node C.
6. Node A receives a NEIGHBOR_ADVERTISEMENT from Node B.

NEIGHBOR_ADVERTISEMENT contains the sender's neighbor node information. Thus, after enough time has passed, all nodes are supposed to know what nodes are neighbors of what node.

Neighbor node information gets older by elapsed time. If nodes are moving, neighbor node information gets older more quickly. For this reason, each node removes the old neighbor information periodically.

Each node needs to construct a routing table with received neighbor node information. One is created with the next step:

1. If the destination node is directly communicable, it's the next-hop node.
2. Get each node's neighbor node list and pick one with the next hop-filled and shortest distance.
3. Do (2) until the routing table is filled.

We explain an example of a 7 nodes case. Let's assume the Neighbor node information as follows.

1. Node 1: 2, 3
2. Node 2: 1, 3, 6
3. Node 3: 1, 2, 4, 5
4. Node 4: 3
5. Node 5: 3
6. Node 6: 2, 7
7. Node 7: 6

With this condition, we'll describe how to construct a routing table for node 1. Table 5 shows the initial value of a the routing table.

Table 5: Routing Table (1)

Destination	Next hop	(Distance)
Node 2	2	1
Node 3	3	1

At this point, a route to nodes 4, 5, 6, and 7 is unknown. A next-hop to node 4 is node 3 because node 4 is a neighbor of node 3. A route to node 5 is also node 3. A route to node 6 is node 2 because node 2 is a neighbor of node 6. The routing table becomes Table 6.

Table 6: Routing Table (2-1)

Destination	Next hop	(Distance)
Node 2	2	1
Node 3	3	1
Node 4	3	2
Node 5	3	2
Node 6	2	2

At this time, a route to node 7 is unknown. A route to node 7 is node 2. Node 6 is not a neighbor node of node 1. The obtained routing table was in Table 7.

Table 7: Routing Table (2-2)

Destination	Next hop	(Distance)
Node 2	2	1
Node 3	3	1
Node 4	3	2
Node 5	3	2
Node 6	2	2
Node 7	2	3

A node that received a packet to other nodes decrease TTL of it by 1 and relay this packet. The experiment was done under the conditions below:

1. three fixed nodes and one moving node.
2. Fixed nodes are put at an interval of 100 meters.
3. Each node transmitted NEIGHBOR_ADVERTISEMENT every 500ms. At that time, the interval between BLE advertisements was set to 20ms (the minimum interval specified in the standard).
4. Neighbor node information life is 5s or 1s.
5. A tester walked from node 3 to node 1 via point A and B, as described in Figure 9. The reverse route is also tested.

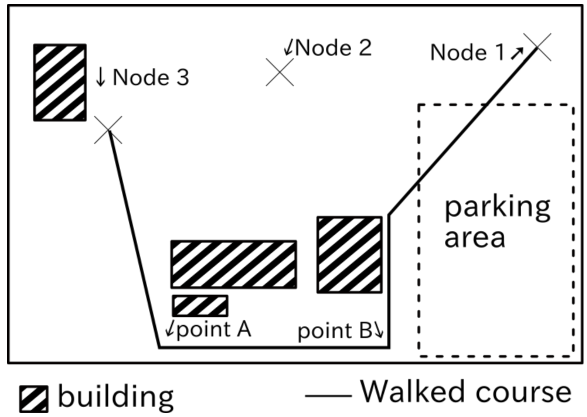

Figure 9: The path the experimenter walked during the experiment.

The result of neighbor node information after 5s is shown in Table 8.

Table 8: Routing Table for Each Point

Point	Destination	Next hop	(Distance)
Node 1	Node 1	Node 1	1
	Node 2	Node 2	1
	Node 3	Node 3	1
Point B	Node 1	Node 1	1
	Node 2	Node 2	1
	Node 3	Node 3	1
Point A	Node 2	Node 2	1
	Node 3	Node 3	1
Node 3	Node 1	Node 1	1
	Node 2	Node 2	1
	Node 3	Node 3	1
Point A (Reverse)	Node 1	Node 1	1
	Node 2	Node 2	1
	Node 3	Node 3	1
Point B (Reverse)	Node 1	Node 1	1
	Node 2	Node 2	1
	Node 3	Node 1	2
Node 1 (Reverse)	Node 1	Node 1	1
	Node 2	Node 2	1
	Node 3	Node 3	1

Node X/Point X on the table means that the place where the node is. At all points except for point A, the moving node had routes to all nodes. At point A, it didn't have a route to Node 1 because it couldn't receive neighbor node information from Node 1.

The result with 1s neighbor node information lifetime is in Table 9.

Table 9: Routing Table for Each Point (1s neighbor node information lifetime)

Point	Destination	Next hop	(Distance)
Node 1	Node 1	Node 1	1
	Node 2	Node 2	1
	Node 3	Node 3	1
Point B	Node 1	Node 1	1
Point A	Node 2	Node 2	1
	Node 3	Node 3	1
Node 3	Node 2	Node 1	2
	Node 3	Node 3	1
Point A (Reverse)	Node 1	Node 1	1
	Node 3	Node 3	1
Point B (Reverse)	Node 1	Node 1	1
	Node 2	Node 2	1
	Node 3	Node 1	2
Node 1 (Reverse)	Node 1	Node 1	1
	Node 2	Node 2	1
	Node 3	Node 3	1

7 Evaluation and Discussion

7.1 Evaluation for Solution A (Routing protocol for BLE)

The moving node couldn't always receive neighbor node information from other nodes. Although the lifetime of neighbor node information was 5s, this may be too short to maintain its routing table. If it can't get neighbor node information when the lifetime of neighbor node information is extended, we may need to extend the sending time of NEIGHBOR_ADVERTISEMENT. The routing table was reconstructed every 5s, which didn't affect the program's performance. With more nodes, it can affect.

7.2 Evaluation for Solution B (BLE performance)

In the first experiment, the throughput was 47Bytes/s because 10-byte packet was sent every 210ms (10B / 210ms = 47Bytes/s). The throughput was 33Bytes/s (47 * 69.975%) when the reach rate (69.975%) was taken into account. The geometric mean reach rate of every hop was 91% which is calculated by:

$$0.69975^{\frac{1}{4}} = 91\% \tag{2}$$

This means that when one packet transmitted 8.5 times, the probability of one or more packets is received was 91%. A single packet was received at the possibility of 24.67%. This implies that we should transmit one same packet multiple times. This implies that we should transmit one same packet multiple times. Although the throughput we mentioned above is far slower than 3G or LTE, a short message to escape from a building such as "A fire broke out! Escape from this building!" which is 44 bytes, is split into two packets. The possibility of two packets being received is:

$$(91\%)^2 = 82.81\% \tag{3}$$

With 10 LED displays, the possibility of all 10 displays receiving the two packets at one time is:

$$(82.81\%)^{10} = 15.16\% \tag{4}$$

To deliver the entire data to all nodes at the possibility of more than 90%, we need to transmit the data more than 15 sets of times:

$$100\% - (100\% - 15.16\%)^{15} = 91.50\% \tag{5}$$

So, about 3,150ms (15 multiplied by 210ms) is needed to deliver all the data to all the displays.

According to the result of Section 6.2, we can say that BLE Advertisement can deliver information over floors. In this experiment, we could deliver information, even over two floors.

8 Conclusion

The experiment result of 5 nodes and 4 hops experiment (Section 6.1) shows BLE advertisement is practical to send short messages such as "Escape immediately," but in routing protocol experiment, the moving node couldn't always receive neighbor node information and some of its routes to other nodes disappeared. To solve this issue, I think the lifetime of neighbor node information needs to be extended, or sending time of neighbor node information needs to be extended. In the experiment without routing protocol, the packet reach rate was not satisfactory (<20%) in some sections. However, this is not so problematic because this is recoverable with transport layer protocols. As we showed in Section 6.2, BLE Advertisement packets reach widely even in a building. We have to develop a better routing protocol for BLE to improve communicability. As future work, we will update the software of LED display installed in Miyagi-Prefectural School for the Deaf and measure the performance in the reallocation. Also, we would like to perform a subjective evaluation by users such as teachers and students. Also, we would like to perform a detailed consideration of why WiFi did not work in Miyagi-Prefectural School for the Deaf.

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