EVALUATION OF NETWORK QUALITY IN WIRELESS LANDSLIDE SURVEILLANCE SYSTEM

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Abstract − The quality of Wireless Sensor Node Network System (WSNNS) in landslide surveillance is mostly depending on network topology since it covers a wide range of area and has limitation in data transmission. Through real experiment and data analysis, we evaluate network quality in WSNNS by concerning three aspects: robustness of network, data latency and loads balance in network.

Keywords: network quality, landslide surveillance, WSNNS

1. INTRODUCTION

Landslide is one of the most dangerous natural hazards which give a great impact upon occurrence, cause huge damages to infrastructures as well as loss of human life. The scale of landslide impacts depends on the factor that lead to this disaster occurrence such as geological, morphological and human causes. Even though man power can be used to observe this pattern of disaster, it is very risky. Therefore, a system that can monitor this disaster is necessary.

As landslide disasters damage monitoring system easily, one major demand in landslide surveillance is the flexibility and robustness of the system to evaluate condition of the monitored area in real-time. For various reasons, Wireless Sensor Node Network System (WSNNS) can provide an important contribution to reach that aim. Wireless Sensor Node Network System (WSNNS) is widely used in environment surveillance and other many applications. We believe WSNNS can be a very applicable system in order to monitor landslide disaster. In this system, acceleration sensors and GPS are deployed in sensor nodes. Location information by GPS, enable the system to estimate network topology and to perceive location information in emergency by monitoring the node mode. Acceleration sensors deployment, capacitate this system to detect slow mass movement that can lead to landslide occurrence. Once deployed, sensor nodes self-organize into an autonomous wireless ad hoc network.

In this paper, we demonstrate the evaluation of network quality of WSNNS in landslide surveillance as shown in Section (3). From this evaluation method, we are able to analyse the network quality, number of gateway needed and its ideal position by balancing all the three aspects depending on the system requirements. We believe this evaluation method may also be useful in other applications of WSNNS.

2. WSNNS CONFIGURATION

Fig. 1 (a) shows configuration of WSNNS for landslide surveillance. WSNNS is structured into Local Network (LN), "Cloud" System (CS) and Host System (HS).

Local Network consists of a host node and plural distributed sensor nodes. Fig. 1 (b) shows a prototype of sensor node. Sensor node is a node which is capable of gathering measurement data required in landslide detecting and it can perform asynchronous communication with other connected nodes in Local Network. Host node is a gateway of Local Network for receiving commands from Host System and transmitting measurement data from sensor nodes in Local Network to the Host System. The structure of host node is same as sensor node but it has an android inside it. The communication between host node and sensor nodes is performed by long range wireless unit MU-1 while the communication between host node and Host System is performed through "Cloud" System via internet provided by the Android (smartphone).
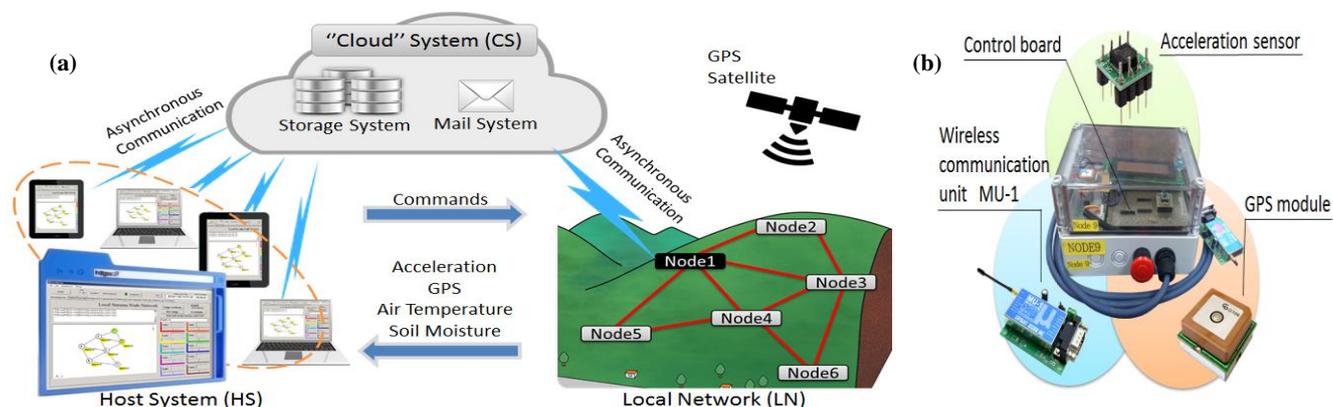

Fig. 1. (a) Configuration of WSNNS for landslide surveillance, (b) a prototype of sensor node

3. EVALUATION OF NETWORK QUALITY

In our landslide surveillance concept, sensor nodes and host node will be dropped from a helicopter to an area to be monitored. Although we can predict the network topology of Local Network, there is still a possibility for the network topology to change. A new sensor node or host node might be inserted to the existed topology in the middle of landslide surveillance. Existed nodes which are in range with this new inserted node must be able to detect its existence. Similarly, during landslide occurrence, some nodes may experience death, damages and fail to transmit or relay the measurement data, and some nodes might be changed in position due to the landslide movement. The evaluation of this changed topology is necessary to determine the change of network quality so that new range of area can be monitored, measured and data transmission success percentage can be expected. Prior to that, it is very important for us to decide the arrangement of sensor nodes and host node before placing them in the monitored area. This decision process is very crucial as the quality of network is mostly depending on network topology.

There are several methods on evaluating network quality but in our research, we evaluate network quality based on network topology by concerning three aspects; robustness of network, data latency, and load balance in network.

3.1. Robustness of network

From the basic of radio communication and the inherent power limitation of radio communications follows a limitation on the feasible distance between a sender and a receiver. Because of this limited distance, direct communication between host node and sensor nodes is not always possible, especially in landslide surveillance system which is intended to cover a lot of ground and operate in difficult radio environments with strong attenuation.

During landslide occurs or even in standby mode, there is a possibility for a node to be damaged or communication failed to a node. This will affect data transmission route. However, although there is a change in network topology, the whole communication of network cannot be failed just because a limited number of nodes run out of energy or because their environment changes and severs existing radio links between two nodes. These failures have to be compensated by finding other routes. Non-damaged sensor nodes must be able to continue the data transmission to host node. Therefore, we assume that the robustness of network can be determined as the sustainability of network with dynamic topology. This can be derived from the number of possible communication link possess by nodes. A node must have several neighbour nodes to have path diversity during data transmission. In our evaluation, the more number of link possessed, the more robust the connection of a sensor node to the host node, and thus the more robust the network.
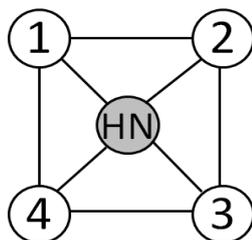

Fig. 2. Example of network topology (1)

Fig. 2 shows an example of network topology consists of four sensor nodes and one host node. We can see in Fig. 2 that Node1, Node2, Node3 and Node4 are connected directly to three nodes including host node (HN). Table 1 shows the details of connected nodes on each sensor node.

Table 1. The details of nodes connected on each sensor node.

Sensor node	Nodes directly connected	No. of links, l_n
Node1	Node2, Node4 & HN	3
Node2	Node1, Node3 & HN	3
Node3	Node2, Node4 & HN	3
Node4	Node1, Node3 & HN	3

Let total number of nodes in topology as N (including sensor nodes and host node), number of links possessed by a sensor node as l_n, and number of host node in topology as n_h. Then, average number of possible communication link possess by sensor nodes, l_{avg} can be given as in (1).

$$l_{avg} = \frac{\sum l_n}{N - n_h} = \frac{3+3+3+3}{5-1} = 3 \qquad (1)$$

We assumed that this network topology will be in its most robust condition if every sensor node can communicate directly with all nodes. Then, maximum number of possible communication link possess by nodes, l_{max} is when each l_n is equal to $N - n_h$. In other word, l_{max} is equal to the number of sensor nodes as given in (2).

$$l_{max} = N - n_h = 4 \qquad (2)$$

Therefore, percentage of number of links possessed can be given as in (3).

$$P_l = \frac{l_{avg}}{l_{max}} \times 100 = 75.00\% \qquad (3)$$

The larger area to be monitored, the less number of nodes connected directly to a sensor node. It is nearly impossible to get network robustness to be 100% unless the network is in mesh-formation and the monitoring area is small. All routes shown are not the routes that must be used for data transmission but at least the route connection is possible whenever needed in case of emergency. The availability of these routes can be confirmed by sending on-demand command to each sensor node.

3.2. Data latency in network

In monitoring landslide, one of the most important aspects to be considered is the time taken for emergency data to be received by Host System. The connection from a sensor node to Host System involves many layers including from sensor node to host node, from host node to Android, from Android to mail server and from mail server to Host System. In order to analyse data transmission speed of network, we are more concerned toward data transmission speed from sensor node to host node layer. This is because other layers may not vary with network topology, but connection of sensor nodes to host node layer is absolutely depending on network topology. The shorter path between a sensor node and host node, the shorter time data arrive at host node as shown in Fig. 3 (b). In our research, we represent these paths length by number of

hops necessary for a data transmission from a sensor node to host node.
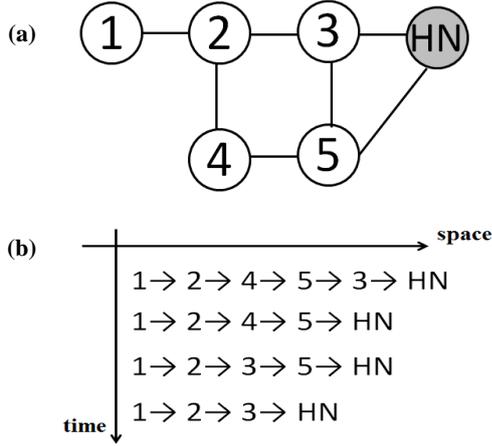

Fig. 3. (a) Example of network topology (2), (b) Relationship between number of hops with time for a data transmission

Fig. 3 (a) shows an example of network topology consists of five sensor nodes and one host node. We can see that the shortest path for a sensor node to transmit data toward host node is different according to their position as shown in Table 2.

Table 2. The shortest route from each sensor node to host node

Sensor node	The shortest route to host node (HN)	No. of hops, H_n
Node1	$1 \to 2 \to 3 \to HN$	3
Node2	$2 \to 3 \to HN$	2
Node3	$3 \to HN$	1
Node4	$4 \to 5 \to HN$	2
Node5	$5 \to HN$	1

Let total number of nodes in topology as N (including sensor nodes and host node), and the shortest route possible for data transmission from a sensor node to host node in term of number of hops as H_n. Then, average number of hops for data transmission H_{avg} can be given as in (4).

$$H_{avg} = \frac{\sum H_n}{N - n_h} = \frac{3+2+1+2+1}{6-1} = 1.8 \qquad (4)$$

We assumed that data latency can be minimized if the shortest path for every sensor node to transmit data to host node, H_n is 1. Then, minimum number of hop, H_{min} is equal to 1 as given in (5).

$$H_{min} = \frac{\sum H_n}{N - n_h} = \frac{1+1+1+1+1}{6-1} = 1 \qquad (5)$$

Therefore, efficiency percentage of number of hops for data transmission from sensor nodes to host node, P_H can be given as in (6).

$$P_H = \frac{H_{min}}{H_{avg}} \times 100 = 55.56\% \qquad (6)$$

The larger area to be monitored, the more number of hops needed for data transmission from sensor nodes to host node as the distance between host node and sensor nodes increases.

It is nearly impossible to get this percentage to be 100% due to geographical condition and limitation of radio transceiver. However, by conducting this evaluation, data latency in a network can be expected.

3.3. Load balance in network

Evaluation of load balance in network is necessary in order to determine the longevity of network lifetime. Basically, the most energy consumer in a node is CPU board. In our evaluation, we are more concerned toward energy consumption at radio transceiver rather than at CPU board because our aim is to evaluate the network energy consumption which is varies within distance and topology, not the lifetime of a node itself.

Radio transceiver of a node has two tasks which are transmitting data (its own data and relay neighbour data toward host node) and receiving data (command from host node and data to be relayed from neighbour nodes). During transmitting data, energy consumed by a transmitter is due to two sources: One part is due to electric components necessary for frequency conversion, frequency synthesis, filters and etc. (basically constant). A second part is due to RF signal generation (mostly depends on chosen modulation plus target distance) and hence on the transmission power (power radiated by the antenna), P_{tx}. P_{tx} is the crucial decisions when transmitting a packet. The transmitted power is generated by the amplifier of a transmitter. Therefore, we assumed that the more loads on each sensor nodes (including its own data and neighbour data) to be transmitted toward host node, the more energy will be consumed.
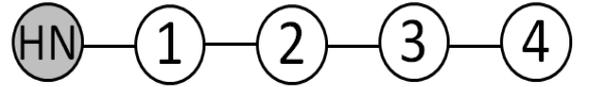

Fig. 4. Example of network topology (3)

Fig. 4 shows an example of network topology consists of four sensor nodes and one host node. Node1 is the nearest node to host node (HN) while Node4 is the farthest node. Table 3 shows loads on each sensor nodes in this topology (including its own data and its neighbour data).

Table 3. The loads on each sensor node

Sensor node	Loads	No. of loads, L_n
Node1	Data from Node1, Node2, Node3 & Node4	4
Node2	Data from Node2, Node3 & Node4	3
Node3	Data from Node3 & Node4	2
Node4	Data from Node4	1

Assume that every sensor node transmit its own data toward host node via all routes available. Let total number of nodes in topology (including sensor nodes and host node) as N, and number of loads on each sensor node as L_n. Then, average number of loads of all sensor nodes in the network, L_{avg} can be given as in (7).

$$L_{avg} = \frac{\sum L_n}{N - n_h} = 2.5 \qquad (7)$$

In Table 3, Node1 shows the largest number of loads compared to other sensor nodes. Then, maximum number of loads on sensor node, $L_{n(max)}$ is as given in (8).

$$L_{n(max)} = L_1 = 4 \qquad (8)$$

Therefore, percentage of load balance in network P_L can be given as in (9).

$$P_L = \frac{L_{avg}}{L_{max}} \times 100 = 62.5\% \qquad (9)$$

If only some nodes have high number of loads, these nodes will be running out of power faster than nodes with less number of loads. This might affect the whole network communication lifetime. Therefore, nodes must be positioned in an arrangement where number of loads on each sensor nodes can be balanced in order to get longer network lifetime.

After calculating the quality percentage on each aspects (robustness of network, data latency and load balance in network), the results are compared with rating system provided in Fig. 5 below. It is expected that each aspects percentage must be higher than 40% in order to get high quality of network for wireless landslide surveillance system. The evaluation result is shown in a triangle graph as shown in Fig. 5 for easy comparison.
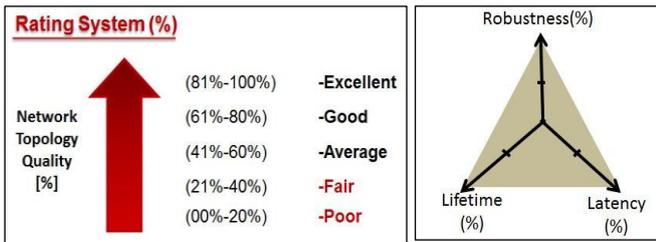

Fig. 5. Rating system for network topology quality

4. EXPERIMENT

The purpose of this experiment is to demonstrate the relationship between sensor nodes topology and network quality. The relationship between positions of host nodes and changes in network quality is also studied. Real experiments were conducted in Ritsumeikan University at two different locations and arrangements as shown in Fig. 6 (a), (b), (c) and Fig. 6 (d), (e), (f) . The details of experiments can be summarized as follows.

Location (1): Seven sensor nodes (SN 19, 13, 15, 5, 17, 12, 14) and a host node (HN101) are arranged as shown Fig. 6(a). Next, HN101 is removed from the topology and HN102 is inserted at different position as shown in Fig. 6(b). Then, both HN101 and HN102 are inserted to the topology as shown in Fig. 6(c).

Location (2): Eight sensor nodes (16, 5, 8, 10, 14, 4, 12, 11) and a host node (HN101) are arranged as shown Fig. 6(d). Next, HN101 is removed from the topology and HN102 is inserted at different position as shown in Fig. 6(e). Then, both HN101 and HN102 are inserted to the topology as shown in Fig. 6(f).

On each topology, experiment is started by sending START-command from Host System to all sensor nodes. After receiving GPS data and adjacent information from sensor nodes, routing data and network topology is continuously monitored at the Host System. The routing data resulted from each topology of both locations are analysed and the network quality (robustness, data latency, loads balance) are evaluated using method proposed in Section 3. Analysis of routing data and network topology performed are shown in Section 5 (Table 4 and Fig. 7).

In this experiment, we also demonstrated the relationship between number of host node used in topology and changes in network quality by using both host nodes before closing the experiments.
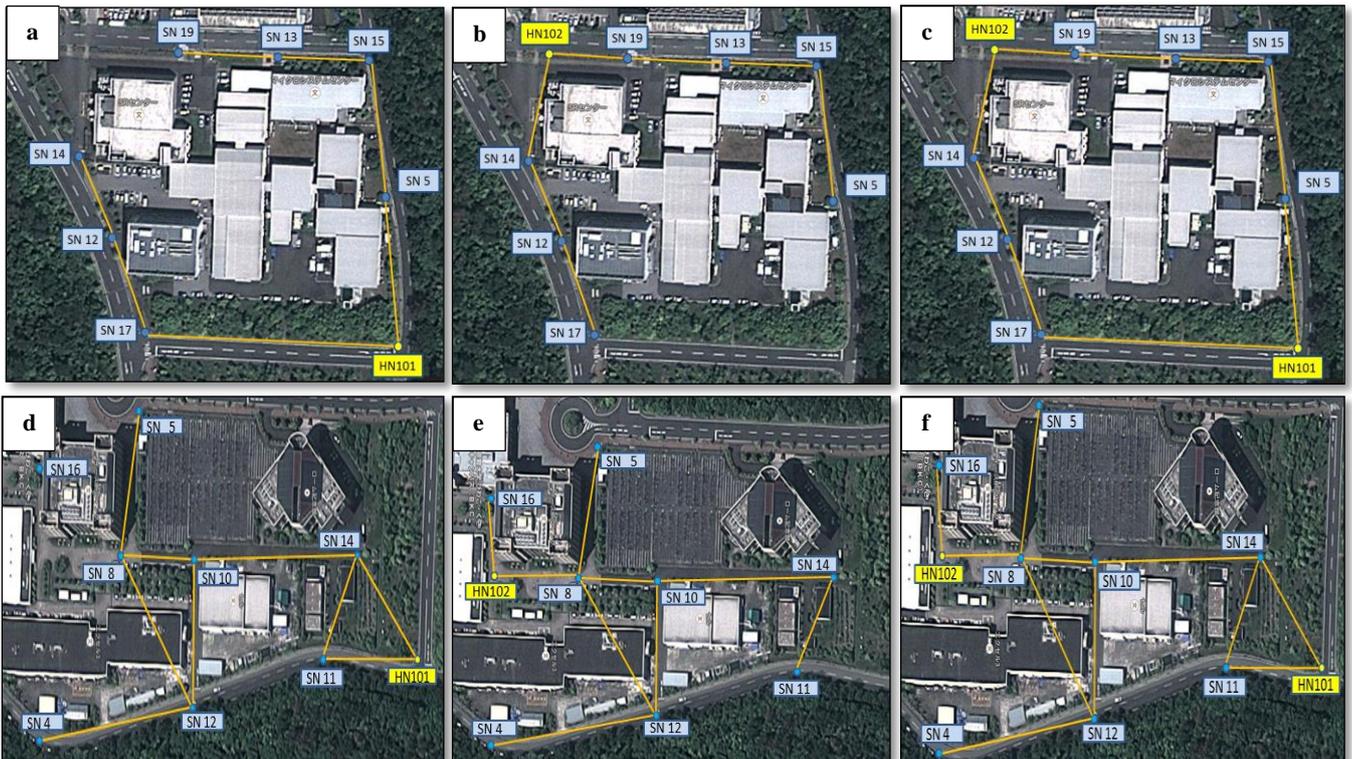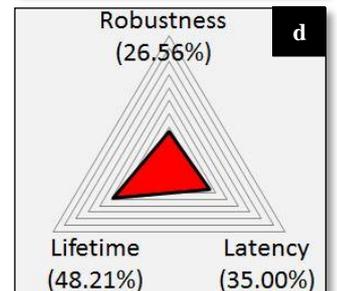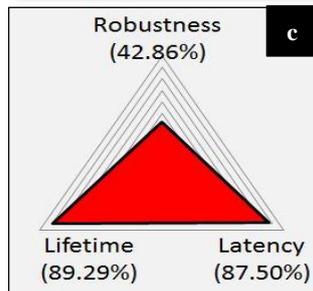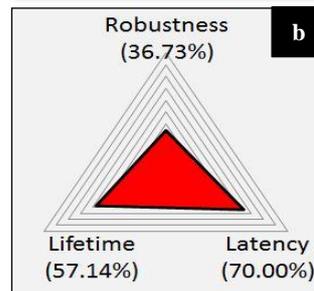

Fig. 6. Nodes topologies using one host node and multiple host nodes. Location 1: (a), (b), (c), Location 2: (d), (e), (f)

5. RESULT

Table 4. Routing data details categorized to (a), (b), (c), (d), (e) and (f) related to the topology provided in Fig. 6.

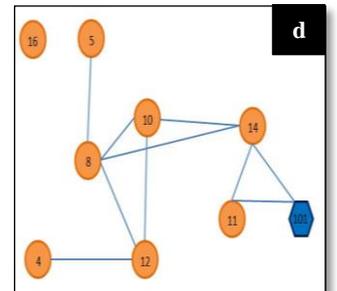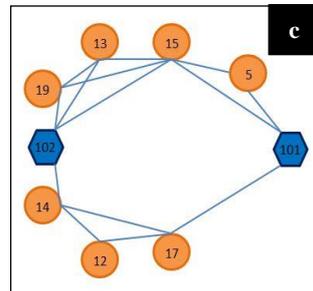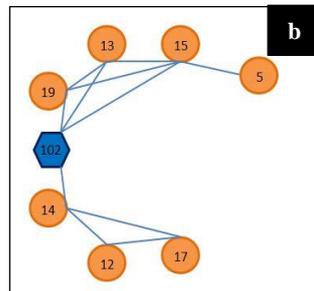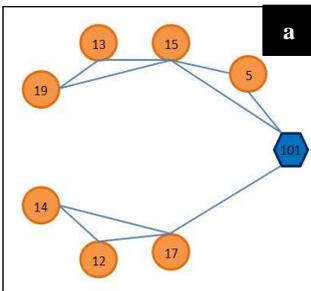| Location 1: (a)			
SN	Connected SN	Shortest route	Loads (SN)
19	13, 15	19>15>101	19
13	19, 15	13>15>101	13, 19
15	19, 13, 5, 101	15>101	15, 13, 19
5	15, 101	5>101	5, 15, 13, 19
17	14, 12, 101	17>101	17, 12, 14
12	14, 17	12>17>101	12, 14
14	12, 17	14>17>101	14

Location 1: (b)			
SN	Connected SN	Shortest route	Loads (SN)
19	13, 15, 102	19>102	19, 13, 15, 5
13	19, 15, 102	13>102	13, 15, 5
15	19, 13, 5, 102	15>102	15, 5
5	15	5>15>102	5
17	12, 14	17>14>102	17
12	14, 17	12>14>102	12, 17
14	12, 17, 102	14>102	14, 12, 17

Location 1: (c)			
SN	Connected SN	Shortest route	Loads (SN)
19	13, 15, 102	19>102	19, 13, 15, 5
13	15, 19, 102	13>102	13, 19, 15, 5
15	13, 19, 5, 101, 102	15>101	15, 13, 19, 5
5	15, 101	5>101	5, 15, 13, 19
17	12, 14, 101	17>101	17, 12, 14
12	14, 17	12>14>102	12, 14, 17
14	12, 17, 102	14>102	14, 12, 17

Location 2: (d)			
SN	Connected SN	Shortest route	Loads (SN)
14	8, 10, 11, 101	14>101	14, 11, 8, 5, 10, 4, 12
11	14, 101	11>101	11, 14, 8, 5, 10, 4, 12
10	8, 12, 14	10>14>101	10, 8, 5, 12, 4
12	4, 8, 10	12>10>14>101	12, 4
4	12	4>12>10>14>101	4
8	5, 10, 12	8>10>14>101	8, 5, 12, 4
5	8	5>8>10>14>101	5
16	-	-	-

Location 2: (e)			
SN	Connected SN	Shortest route	Loads (SN)
14	8, 10, 11	14>8>102	14, 11
11	14	11>14>8>102	11
10	14, 12, 8, 102	10>102	10, 14, 11, 12, 4
12	4, 8, 10	12>8>102	12, 4
4	12	4>12>8>102	4
8	12, 14, 10, 5, 102	8>102	8, 5, 10, 12, 4, 14, 11
5	8	5>8>102	5
16	102	16>102	16

Location 2: (f)			
SN	Connected SN	Shortest route	Loads (SN)
14	8, 10, 11, 101	14>101	14, 11, 8, 5, 10, 4, 12
11	14, 101	11>101	11, 14, 8, 5, 10, 4, 12
10	14, 12, 8, 102	10>102	10, 14, 11, 8, 5, 12, 4
12	4, 8, 10	12>8>102	12, 4
4	12	4>12>8>102	4
8	12, 14, 10, 5, 102	8>102	8, 5, 10, 12, 4, 14, 11
5	8	5>8>102	5
16	102	16>102	16

Robustness (34.69%) — Lifetime (57.14%) — Latency (63.64%) — a

Robustness (36.73%) — Lifetime (57.14%) — Latency (70.00%) — b

Robustness (42.86%) — Lifetime (89.29%) — Latency (87.50%) — c

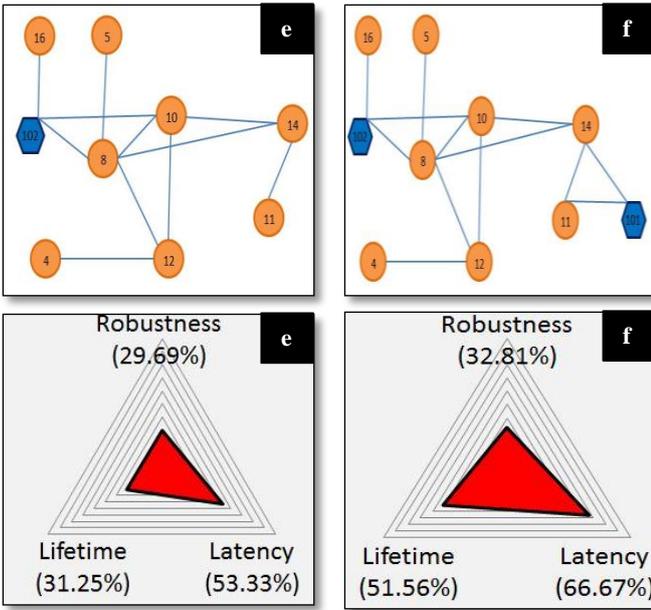Robustness (26.56%) — Lifetime (48.21%) — Latency (35.00%) — d
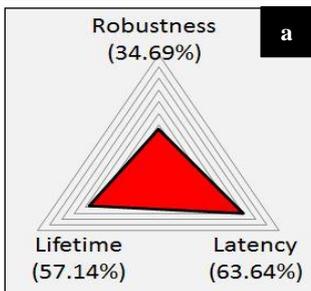
Fig. 7. Network topology performed and network quality

5. DISCUSSION

Table 5. Summarization of network quality on each topology

Location 1	(a)	(b)	(c)
Link possession (%)	34.69	36.73	42.86
Load balance (%)	57.14	57.14	89.29
No. of hop (%)	63.64	70.00	87.50

Location 2	(d)	(e)	(f)
Link possession (%)	26.56	29.69	32.81
Load balance (%)	48.21	31.25	51.56
No. of hop (%)	35.00	53.33	66.67

The network quality of each topology is summarized as shown in Table 5. Network quality of topology (a) and (b) have no large differences because although host node HN101 and HN102 were set up at different locations, both host nodes were in the middle of sensor nodes respectively. However, network quality of topology (d) and (e) are slightly different especially on the load balance in network and data latency. This is because host node (HN101) were located at the position where it can communicate directly with only two sensor nodes (SN11, 14) while host node (HN102) were located at the position where it can communicate with almost all sensor nodes. Here, we can see that different topology will result in different network quality.

Moreover, network quality of (c) is higher than (a) and (b) with percentage differences from 8.17% to 32.15%. In the same way, network quality of (f) is higher than (d) and (e) with percentage differences from 6.25% to 31.67%. This proves that implementation of multiple host node is an efficient way to increase quality of the network. Furthermore, network quality of (c) is higher than (f). This shows that

although number of host nodes increases, changes in network quality is strongly related to its position and nodes topology.

5. CONCLUSIONS

In a nutshell, we demonstrated method for evaluation of network quality (robustness, data latency, load balance in network) through real experiments and analysis of routing data from network topology. Evaluation of network quality and implementation of multiple host nodes in topology are very efficient methods to enhance the reliability of wireless landslide surveillance system.

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