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Performance increase of sensor network using bio-inspired network topology

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ABSTRACT

This research proposes a bio-inspired, scale-free network topology for the wireless sensor network systems. Compared to the traditional mesh network, the scale-free network mimicking the biological network showed better performance at end-to-end packet transmission. Increase of performance when the throughput of the hub nodes were upgraded and high robustness at the random node failure were also observed by the simulation.

1. INTRODUCTION

A sensor network composed of a large number of nodes has been studied for a long time with the expansion of the ubiquitous paradigm, and has been applied mainly to environmental and regional monitoring applications (Miyazaki 2016). Recently, short-range wireless communications such as Bluetooth and Zigbee have been mainly used. (Raza 2015) (Zhou 2007) Recently, it is being reviewed in the form of Internet of Things (IoT) with installation of wireless terminals such as smart phones and IEEE 802.11 wireless infrastructure. For wireless sensor networks, various researches have been conducted from software platforms such as TinyOS and Nano Qpuls (Amjad 2016) (Jeong 2011) to communication standards. Network configuration and routing are also important issues (Zhao 2016).
Until IEEE 802.11 based networks and equipments were downsized, devices based on IEEE 802.15 standards, commonly called Zigbee, were used as the primary communication means. For Zigbee, most of the modules that are used are configured to automatically configure the network, and the most common type is the mesh network. Even though there is no line of sight through the mesh network, data transmission is

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possible through several nodes, and packet routing is possible through other nodes in case of failure of some nodes.

Recently, research on the network topology has been conducted through the study of complex system physics. In Barabási (2004), the authors have analyzed the phases of networks that exist in various realities such as internet connection and social relations. As a result, we have confirmed that most of these networks are called scale-free networks. Protein interaction networks, etc. (Kim 2009) This scale-free form has been observed in biological networks. In the case of living organisms, factors favorable to survival are constantly preserved under the pressure of natural selection, and the presence of these bio signaling systems in common in most living organisms seems to have some merit in this phase structure.

In this study, we have created a simulated sensor network with the topology simulating such a biomedical network and studied the merits of the simulated sensor network over communication simulation.

2. Materials and Methods

2.1 Network topology generation

For simulation, we have created two types of networks with mesh and scale-free structures. In the case of mesh networks, a random regular graph which all nodes have *n* connections (degree) was generated by an algorithm of Python networkx package, excluding self-loop and parallel edges (Steger 1999). Scale-free network with 50 nodes was generated by using the scale-free network generation algorithm of the same package (Bollobás 2003). We used the values of 0.5, 0.4, and 0.1 for the alpha, beta, and gamma parameters for the scale-free network generation that indicates the probability that an edge will occur between the two existing nodes and the probability that a new node will be added without following the Power-law distribution. The comparison of the two generated networks with the existing mesh and the biomedical protein network is shown in Fig. 1 below.

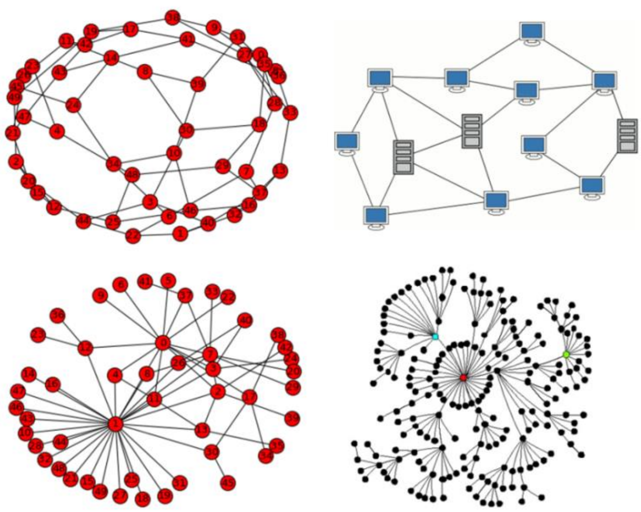

Fig. 1 Mesh network (up) and scale-free network(down)

2.2 Network structure analysis

The biggest difference between a scale-free network and other network structures is the presence of hubs and bottlenecks. If the number of edges connected to this network node is degree, then the degree distribution of all nodes follows the power law and the number of edges is concentrated on a few nodes due to the distribution characteristics. When nodes are sorted in descending order of degree, the nodes in the top rank are called hubs.

The degree of involvement of a particular node k among all shortest distances in a network is defined as Betweenness Centrality (BC). In general, hub nodes have higher BC values, but certain nodes have low degree and higher BC values, which are mainly responsible for connecting hubs. These are called bottleneck nodes and play an important role in connectivity with hubs in scale free networks Take it. Five hubs and bottlenecks were selected in the scale-free network generated.

Finally, the element used for the analysis is the shortest path. This means the minimum number of nodes that must be taken to move from one node to another node when selected. The shortest path values between all nodes in the mesh network and the scale-free network were obtained and used for further analysis.

2.3 Performance analysis

Simulation conditions were set to measure the performance difference according to the phase difference of the two generated networks. We collected node pairs with the shortest path value of the two networks. After the start of the simulation, we picked one of the node pairs collected at random and confirmed that one node pinged another node and received a response. After simulation for a certain period of time, the number of successful pings was collected and used for performance comparison. The probability of successful communication (PRR) between each node is set to 95%, and the signal strength (RSSI) is set to -10dBm for all nodes equally, and no physical constraints due to crosstalk or distance between nodes.

2.4 Simulation under various conditions

We measured the performance of each network when the prr value of a certain number of nodes was increased (the throughput of specific nodes increased within a limited cost) in a situation where the overall PRR was lowered (assuming that the network performance was insufficient). The PRR value was reduced to 80%, and the performance of the five hub / bottlenecks selected in the above structural analysis was adjusted for a scale-free network with a PRR of 99% for random 5 nodes in Mesh.

The simulation is performed assuming the fault condition that a specific node is down. We randomly set the PRR of 5 nodes to 30%, set the PRR of the remaining nodes to 95%, and assume that the hub / bottleneck is down in the case of scale-free and the situation where the random nodes other than these are down Simulation was carried out.

Virtual wireless sensor network experiment was conducted using Cooja Simulator (Banh 2015). The experimental screen shot is shown in Fig 2 below.

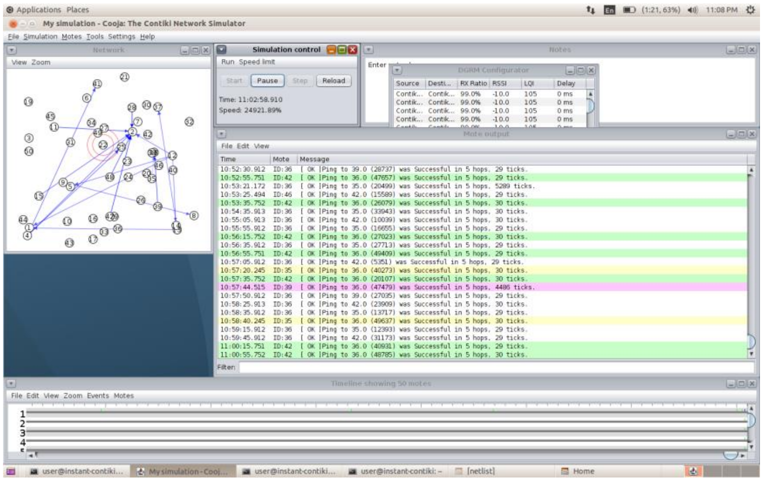

Fig. 2 Screenshot of the Cooja simulator

3. RESULTS AND DISCUSSION

The two network connection data were given as an input to the Cooja simulator and the performance according to the phase difference of the two networks is estimated by measuring the number of successful pings per unit time between nodes having the longest distance. We randomly selected pairs of longest distance node pairs for simulated time and confirmed the ping success. As a result, 156 ping succeeded in mesh network and 822 ping succeeded in scale-free network. Scale-free networks show roughly five times the performance of existing networks.

One of the features of a scale-free network is the small world effect. In the case of scale-free network, the arithmetic mean of the shortest path between all node-nodes is concentrated in about 3-4, and the maximum value of the shortest path is lowered due to the presence of hubs connecting a large number of nodes. In fact, it was confirmed that the longest shortest path of the generated mesh network had a length of 8 steps, while a scale-free network had a length of 6 steps. Due to the nature of the ping, the actual distance between the two nodes is 16 steps and 12 steps. Since the probability of successful communication between nodes is 95%, the probability of successful communication is 16% and the probability of successful communication is about 44%. However, when it goes through 12 steps, it has an arithmetic success rate of 54%. In the case of the scale-free network topology, it has the effect of reducing the shortest distance connecting two nodes when selecting any two nodes, and it is estimated that the communication success rate is higher than the mesh network.

After the communication success probability (PRR) was adjusted to 80%, simulation was performed for 12 hours in simulator time. After that, in the case of scale-free network, the PRR of 5 nodes including hub and bottleneck was increased to 99%. In the case of mesh networks, we could not identify these major nodes and adjusted the performance of random 5 nodes.

In the first simulation, the number of successes was 15 for the mesh network and 152 for the scale-free. One of the problems of the mesh network described above is that the maximum value of the shortest path increases. When the success rate is simply calculated as the squared step number of the PRR, the squared value becomes large, so that if the PRR becomes small, the success rate drops sharply . In the case of scale-free, we can confirm that the communication success rate is relatively better even in this situation.

In the real network, the communication performance and bandwidth of the router and the specific node can be improved, and the PRR of the specific node is adjusted according to this. As a result of adjusting the major nodes of the scale-free network, the performance explosively increased and the performance difference was about 8 times that of the mesh network. Hubs are connected to a large number of nodes. In the case of bottlenecks, these hubs play a role in connecting the hubs. Therefore, if the success probability of these nodes increases, the overall success rate increases. The benefit of scale-free networks is that topology-critical hubs and bottlenecks can be computed, so it is possible to calculate the performance of a given node, which is more mathematically more sophisticated than a mesh network.

Due to the nature of sensor networks in which a plurality of communication terminals are installed externally, there is always a probability that some terminals will fail, and in some cases it is impossible to access the terminal for repair or replacement according to the installation method (installation of military sensors Etc.) It is very important that the network maintains its performance even in the event of some node failure. This performance degradation situation was simulated by modifying the PRR value of a specific sensor node to 30%. For the degraded node, two conditions are assumed. In the case of mesh network, five random nodes were adjusted. In the case of scale-free, five nodes were randomly selected, not hub nodes and bottleneck nodes.

As a result of the simulation, if all the nodes have PRR of 95%, the success rate of both types of networks is drastically reduced considering that 800 or 150 pinges have succeeded in a simulation of only 2 hours. However, even if a random node fails, the scale-free network showed much better efficiency and fault tolerance than the mesh network. However, if all five failed nodes are hub / bottleneck, the scale-free network is inoperable and only one ping has been successfully transmitted as a result of a 12-hour simulation.

Because most nodes are connected to hubs, scale-free networks are much better resistant to random failures, because hubs and hubs can be quickly bypassed using hubs and bottlenecks, even if there are several failures and performance degradation. The cellular protein network in living organisms is also exposed to a random failure in which the genes that make up each protein are mutated, and it is presumed that they evolved to have scale-free characteristics in this situation. We applied these advantages to wireless sensor networks and confirmed that performance degradation is less in case of failure. On the other hand, when hub nodes are damaged, the damage is much bigger than mesh network, so network security and maintenance priority can be decided.

4. CONCLUSIONS

Due to the rise of IoT, the importance of wireless communication network is getting attention as the system of sensor network, smart home, etc. is reexamined. In this study, we applied a scale-free network topology, which is observed mainly in life and nature, instead of existing mesh topology, and confirmed that it has advantages over existing mesh networks in various situations. Due to the nature of the scale-free network, it is possible to mathematically design the layout of major nodes and nodes.
The mesh network is mainly used for the sensor network, but various configurations such as star topology and hierarchical are possible. A study on selection and repetition of various random nodes will be carried out later in order to compare with this structure and to estimate the performance.

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