2-5 Research and Development on the Large-Scale Mesh Management Technologies for Building-Sensing Applications

Fumihide KOJIMA and Verotiana RABARIJAONA

This article reports on the NICT's R&D activities on the high-capacity data collection network that is defined as one of capabilities for the wireless-grid systems where several radio devices are connected in the grid-like topology and realizes a harmonized data relaying among a lot of radio nodes. In these R&D activities, Layer 2 Routing (L2R) technology that is defined in IEEE 802.15.10 recommended practice and realizes effective data frame routing control via non-IP protocols with low overhead on the wireless Personal Area Network (PAN) is employed in order to achieve the suitable mesh structure construction and management. As the result, NICT's activities including several experimental proof tests confirm that our developed techniques, such as an autonomous mesh construction for automatic route establishments, a data concatenation for data collision reduction and a radio virtualization for the diversified service support, all work effectively and feasibly in the assumed wireless grid structures.

1 Introduction

Although SUN, the most typical embodiment for the wireless grid structure which is one study theme of NICT, was at first based on the application to smart meters, it is easily expected that the application of SUN will not be exclusive to the smart meter system[1]–[4]. In other words, if SUN is developed so as to have such characteristics as long-term action due to low-energy action, etc. and the low-speed and low-capacity communications found in the smart meter use, it is expected to be utilized in infinitely various fields. The IoT (Internet of Things) and M2M (Machine-to-Machine) fields whose significance is of current interest are no exception. The applied areas for the SUN radio are expected to become diversified depending on the diversification of the future radio communication service demand or the diversification of applications.

Figure 1 shows the concept of the extended SUN from such a standpoint. Figure 1 shows three diversification forms in concrete terms. That is, 1. "High capacity data

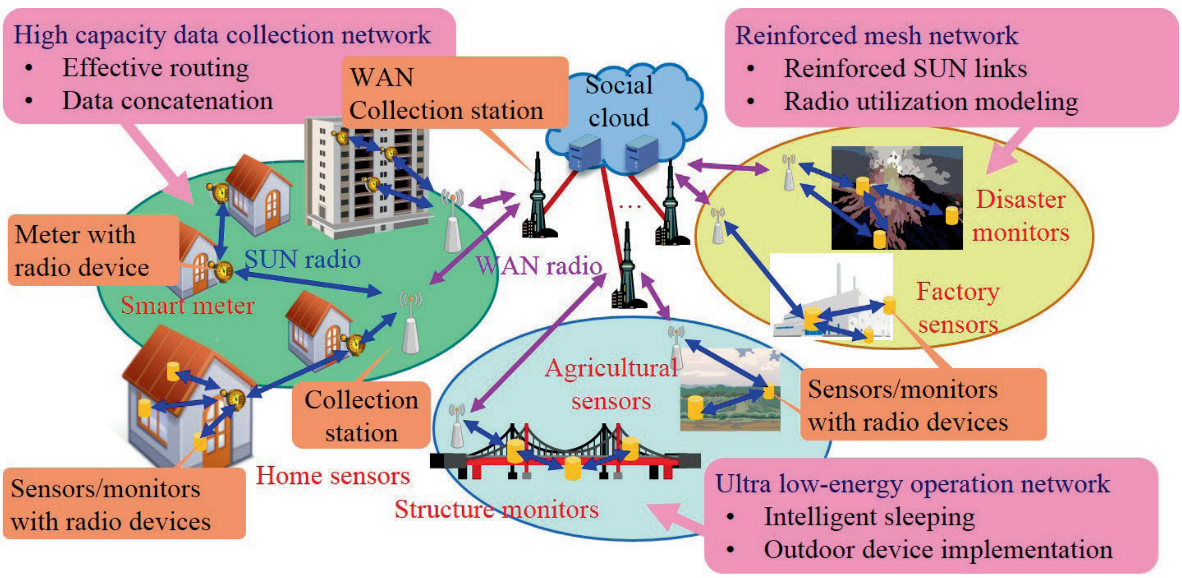

Fig. 1 Concept of extended SUN

collection network” where the power supply is especially not limited and which is characterized by mesh topology with many radios; 2. “Ultra-low-energy operation network” which is characterized by low power consumption assuming the time of battery driving, etc.; and 3. “Reinforced mesh network” which assumes service development in the environment, such as a devastated district and plants, where the application of radio communication links has not been assumed in the past. This paper especially assumes the high capacity data in item 1 and describes the research and development concerning the effective routing technology on said form.

2 Layer 2 Routing control study

2.1 Principle of Layer 2 Routing control

The greatest characteristic of the routing control technology in this study is to control the action of the information exchange between terminals and so on by using the control by MAC layer known as Layer 2 in the Personal Area Network[5]. Therefore, the information to be handled is described by IE (information element), an information unit handled by the MAC layer, and is exchanged and handled by the function of the MAC layer. It is believed that this reduces the redundancy compared to the conventional routing control handled by IP (internet protocol), as Layer 3, and simple handling becomes possible[6]–[8].

We describe the main technologies of the Layer 2 Routing (L2R) control for which we implemented research and development and a demonstration from the next subsection.

2.2 Autonomous mesh topology construction

This function allows each radio device, which composes a mesh structure, to sense the whole mesh structure by regularly sending out a mesh topology construction signal including one’s own information — connecting to other radios and so on — and by receiving the same signal from other radios. The radio which sends out the first mesh topology construction signal is called the mesh route, and signals from other devices are composed on the basis of those from the mesh route.

Figure 2 shows an operating example of the mesh topology construction signal exchanges in the mesh by mesh root R. In Figure 2 (i), the mesh root R which attempts to construct a mesh sends out the first mesh-topology construction signals including the information of R, and devices A and B receive the signals. This allows A and B to detect the presence of a mesh and the presence of R adjacent to them at the same time. Furthermore, they can ascertain the communication quality between R and them based on the received mesh-building signal.

Next, A and B send out the mesh topology construction signals with an aim to provide the same information to other devices including R (refer to Fig. 2 (ii)). Devices C and D which receive the signals implement the same procedure (refer to Fig. 2 (iii)). Eventually, five devices, R, A, B, C, and D, build a mesh, ascertain adjacent devices, reachable devices and the communication quality between them, and can establish the proper relay path with a special radio as a destination, as shown in Fig. 2 (iv).

2.3 Data concatenation

This function reduces the number of data frames by combining multiple data frames addressed to the same destination and by relaying them as one data frame to a next device, and prevents performance degradation of data collection by the reduction of bottleneck blockage and

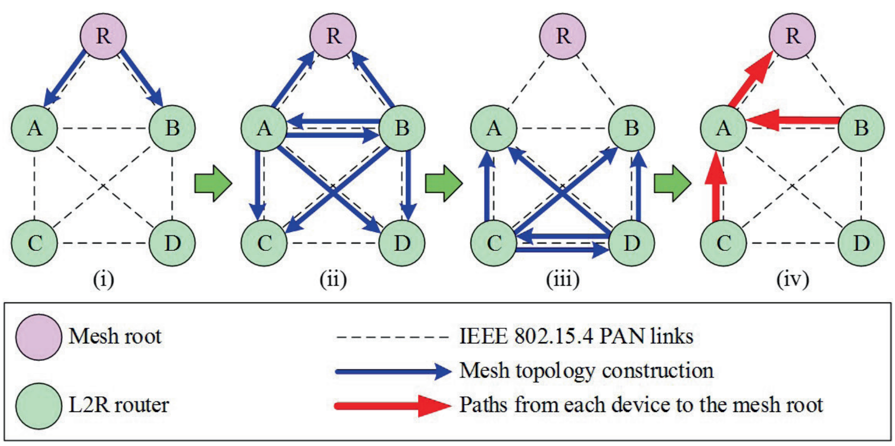

Fig. 2 Autonomous mesh topology construction

collision.

Figure 3 shows an operating example for the data concatenation function. Here, in the same mesh as in Fig. 2, the case is indicated that devices A, B, C, D, excluding the mesh root R, send the respective data frames to R and the frames are relayed through the route in Fig. 2 (iv). In ordinary circumstances, it sometimes occurs that the four data frames from the radios reach R almost at the same time, and collision of frames occurs at that time and the R side cannot successfully receive them. On the other hand, in the data frame coupling function as shown in Fig. 3, for this example, one data frame combines the data frame of the same destination, and the one data frame which is relayed while combining the four data frames accordingly reaches R. Therefore, performance degradation due to the collision as described above can be avoided.

2.4 Support for multiple services

This function differentiates data frames depending on the assumed applications, and the devices properly handle the respective data frames — selectively construct the routes to the mesh root.

Figure 4 shows an operating example of this function. The case in this function is indicated that two mesh root devices, R1 and R2, compose respective meshes and they provide different services. In this case, the radios, A, B, C, and D, can join in any two meshes at the same time, and the data frames related to the respective services are relayed according to the routes on the respective meshes.

3 Demonstration of L2R control

3.1 Application demonstration of home energy management system

This subsection describes a verification example of the L2R control in NICT.

Figure 5 shows the system concept of the Home Energy Management System (HEMS) to manage the home energy consumption form.

HEMS is a system where a HEMS controller is connected to a smart meter and various home electrical appliances with an upper communication protocol, ECHONET Lite[9][10], visualizes power consumption and collects data from electrical appliances to control them. Among these, it is considered that the SUN radio link implements route B, the connection between the HEMS controller and the smart meter, and the HAN (Home Area Network), the connection between the HEMS controller and home electrical appliances. Figure 6 shows a radio application demonstration example to implement HAN.

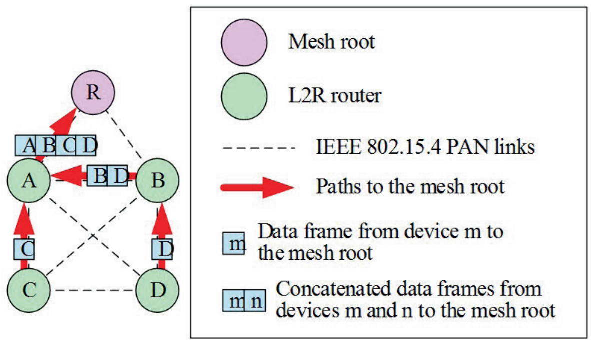

Fig. 3 Data concatenation

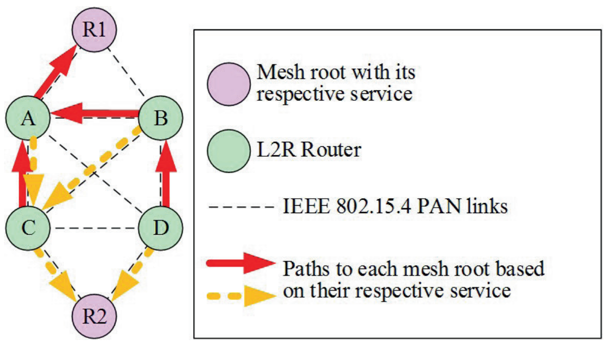

Fig. 4 Support for multiple services

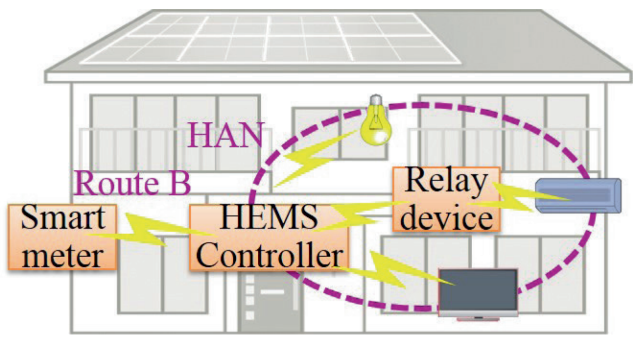

Fig. 5 System concept of HEMS

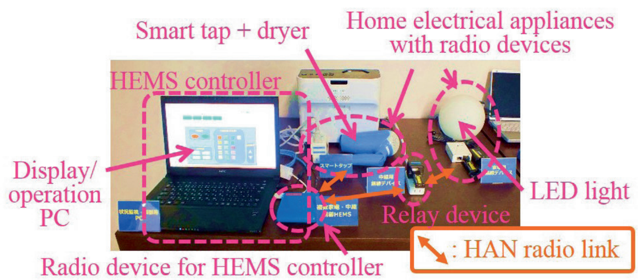

Fig. 6 Radio application demonstration example to implement HAN

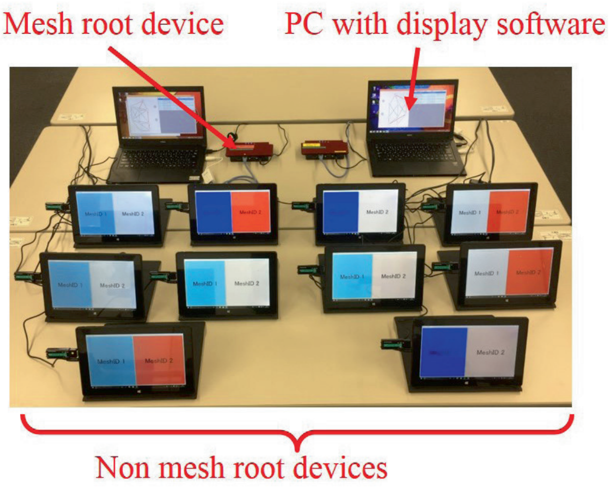

Fig. 7 Equipment for L2R control evaluation

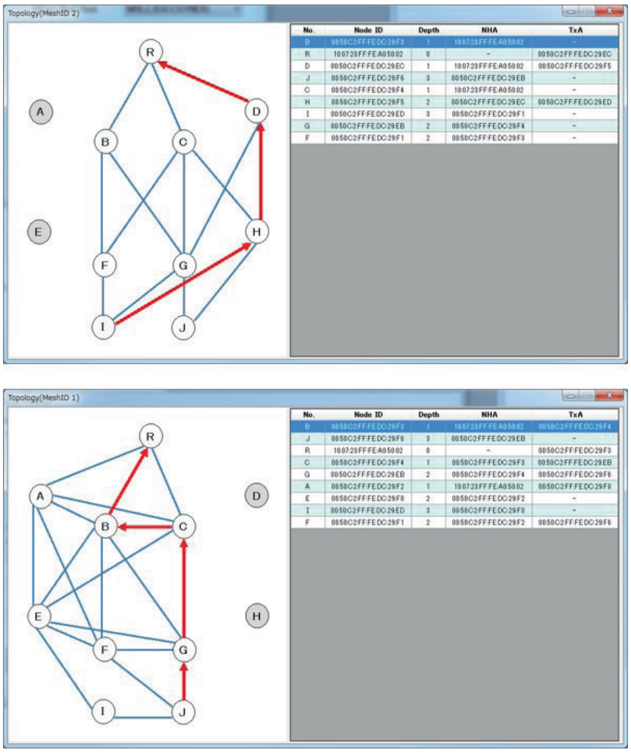

Fig. 8 Action indication example of radio communication virtualization function

3.2 Development of evaluation equipment

We have developed the evaluation equipment with an aim to comprehensively evaluate the L2R control functions described in Section **2**. Figure 7 shows the appearance of the evaluation equipment. This study evaluated the operating characteristics for the building and operation of the mesh structure by the MAC layer control as described above on PAN which is composed of two devices, which have the mesh route functions, and ten non-mesh route devices. Figure 8 shows an action indication example of the multiple services supporting function among the previously mentioned functions. This action diagrammatically presents the Layer 2 Mesh structure like Fig. 2 in which the mesh structures are respectively different due to two mesh routes within the same PAN. In addition, Fig 8 shows that some devices (B, C, F, G, I and J) take part in the mesh structures which any mesh roots define, and contribute to both routing.

3.3 Implementation of evaluation test

To evaluate the L2R control function, we have conducted data collection experiments in indoor and outdoor environments using the evaluation equipment in the above subsection. The experiments were conducted around the National Institute of Information and Communications Technology (NICT), Yokosuka City in Kanagawa prefecture. Figure 9 shows the layouts of two mesh structures to evaluate the operating characteristics of the multiple services supporting function as Figs. (a) and (b), respectively. Table 1 shows the results. This experiment implemented

Table 1 Experimental results of the outdoor operation evaluation for multiple services supporting function

	Mesh 1	Mesh 2
Data collection success rate	91%	95%

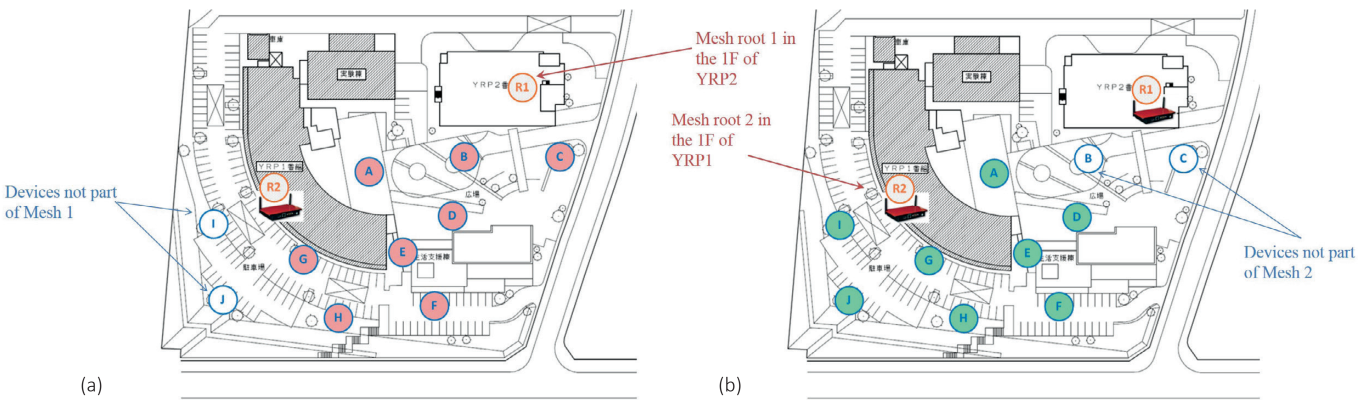

Fig. 9 Experimental setup for outdoor operation evaluation for multiple services supporting function

the data collecting operation from ten terminals, A-J in Fig. 9, to two mesh root terminals, R1 and R2 in Fig. 9 (construct mesh 1 and mesh 2, respectively). Consequently, as shown in Table 1, we found that both meshes could implement a data collection success rate of 90% or more.

4 Conclusions

This report described the research and development concerning the high-capacity data collection network as one operation mode of the wireless grid structure in which many terminals relay data in a coordinated manner.

This research and development studied the proper building and operation of the radio mesh structure by the application of the L2R technology, and evaluated the implementation and operation of the autonomous mesh topology construction function, data concatenation function and multiple services supporting function. A future agenda item is the further sophistication of L2R technology in response to the application diversification anticipated in the future.

Acknowledgments

The recommended practice of IEEE 802.15.10 was standardized by Verotiana RABARIJAONA, a researcher of NICT (at that time) and Hiroshi HARADA, a professor at Kyoto University (at the present day)[6][7]. In addition, Verotiana RABARIJAONA conducted the evaluation experiments described in this report when she was a researcher. Furthermore, SUN has been standardized by Hiroshi HARADA as IEEE 802.15.4g[4], and the social development of SUN is being promoted through the establishment of Wi-SUN Alliance[9], a standard certification body.

References

1 Y. Rachlin, R. Negi, and P. Khosla, “Sensing capacity for discrete sensor network applications,” in Conf. Rec. 2005 IEEE Information Processing in Sensor Networks, pp.126–132.

2 W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energyefficient communication protocol for wireless microsensor networks,” in Conf. Rec. 2000 Hawaii International Conference on System Sciences,pp.1–10, vol.2.

3 Q. Li, J. A. Aslam, and D. Rus, “Online power-aware routing in wireless ad-hoc networks,” in Conf. Rec. 2001 MOBICOM, pp.97–107.

4 IEEE802.15.4 g, “Part 15.4 : Low-Rate Wireless Personal Area Networks(LR-WPANs), Amendment 3 : Physical Layer (PHY) Specifications for Low-Data-Rate, Wireless, Smart Metering Utility Networks,” 2012.

5 IEEE802.15.4, “Part 15.4 : Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low- Rate Wireless Personal Area Networks (WPAN),” 2009.

6 IEEE 802.15.10, “IEEE Recommended Practice for Routing Packets in IEEE 802.15.4 Dynamically Changing Wireless Networks,” 2017.

7 Verotiana Rabarijaona, Fumihide Kojima, Hiroshi Harada, and Clint Powell, “Enabling Layer 2 Routing in IEEE std 802.15.4 Networks with IEEE Std 802.15.10,” IEEE Communications Standards Magazine, vol.1, no.1. pp.44–49, March 2017

8 Verotiana Rabarijaona, Fumihide Kojima, and Hiroshi Harada, “Hierarchical Mesh Routing Implementation for Indoor Data Collection,” IEEE 27 th International Symposium on Personal, Indoor and Mobile Radio Communication (PIMRC’16), Valencia, Spain, Sept. 2016

9 Wi-SUN alliance, “Wi-SUN alliance,” http://www.wi-sun.org/

10 ECHONET CONSORTIUM, “ECHONET Lite Specification ver. 1.00,” 2012.

Fumihide KOJIMA, Dr. Eng.

Director, Wireless Systems Laboratory, Wireless Networks Research Center
Wireless communcation, Wireless access control

Verotiana RABARIJAONA, Dr. Eng.

Former: Researcher, Wireless Systems Laboratory, Wireless Networks Research Center
Wireless routing, Wireless access control