Enhanced Wireless Grid Technologies for the Harmonized Devices in Future IoT Systems

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Research Article

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Abstract

The paper proposes the enhanced wireless grid technologies for the future Internet of Things (IoT) systems. The paper shows a realization of the wireless grid by suitably exploiting the existing wireless Smart Utility Networks (SUN) that is standardized by IEEE 802.15.4g/4e task groups and is certified by Wi-SUN alliance. Medium Access Control (MAC) layer functions that is mainly defined by IEEE 802.15.4e standard and IEEE 802.15.10 recommended practice are effectively modified according to the assumed IoT services and satisfy the requirement of harmonized mesh activities by massive radio devices. In order to realize this function, SUN radio devices that exploit Layer 2 Routing (L2R) control scheme in IEEE 802.15.10 are employed to realize the autonomous mesh management function as well as the multiple service supporting function. The performance is evaluated through the experiments by employing the developed SUN devices as well as simulator evaluations. The paper also proposes novel data retransmission schemes by exploiting the data concatenation functions in IEEE 802.15.10 as well as evaluating its performances by computer simulations and experiments. Consequently, this paper confirms that the obtained results through both simulator evaluations and experiments matches to each other.

1. Introduction

The next generation terrestrial wireless communication systems (5G; 5th Generation) or the beyond 5G systems (B5G) is strongly expected to heterogeneously realize typically diversified performances, such as high-data-rate, high-mobility, low-latency, high-capacity, massive-connectivity and low-energy, in order to satisfy the highly diversified system or application requirements in the future [1]. Such diversified systems especially including IoT systems that require radio communication between or among machines and are considered to become one of the most popular services assume system designs and evaluations by introducing Cyber-Physical System (CPS) emulators such as DARPA's Colosseum [2]. Among such IoT applications, SUN [3] is a system that enables automatic meter readings, status monitoring and suitable controlling by employing radio device equipped meters, as known as smart meters, and effective radio links among the meters. SUN is already standardized as a global standard by IEEE 802 standardizing committee. IEEE 802.15.4g [4] task group has standardized the Physical (PHY) layer specifications by finalizing the amendments required for the existing IEEE 802.15.4 standard [5] that include effective Start Frame Delimiter (SFD), PHY frame modification and PHY mode for PAN co-existence. Alternatively, IEEE 802.15.4e [6] task group has been engaged in the standardization of the MAC layer specification amendments that include several low-energy MAC functions. Furthermore, IEEE 802.15.10 task group [7] has been engaged in the standardization of the required routing functions for IEEE 15.4 PAN that are conducted in MAC layer as known as L2R control. IEEE 802.15.4g/4e standards and IEEE 802.10 recommended practice are referred in the certification framework for the Wi-SUN alliance [8] that is the world first SUN certification body for the sake of effective promotion of such IEEE 802.15.4g compliant SUN systems.

In this paper, the wireless grid structure that is defined as a grid like topology constructed by several radio devices and activated to realize harmonized functions among the devices is proposed and applied to such highly diversified applications in the future by employing the SUN systems with suitable specification customization according to the requirements in order to satisfy not only smart meter systems but also future diversified IoT systems. Thus, in this paper, effective specification customizations for the existing SUN systems in order to realize the required wireless grid applicable to the future IoT services are proposed and their performances are evaluated through field experiments employing developed SUN devices.

2. Wireless Grid Systems Exploiting Sun Systems

Fig. 1 shows a schematic of the wireless grid systems that exploit the SUN systems. Authors are engaged in the study on SUN specification enhancements as well as expansion of its applicable fields in order to satisfy the highly diversified functional requirements for IoT applications. Concretely speaking, Authors have focused on three fundamental categories of such diversified functions to support several and diversified applications. The three fundamental categories are:

1. The high-capacity data collection network
2. The ultra low-energy operation network
3. The reinforced mesh network

that are depicted in Fig. 1.

The high-capacity data collection network realizes a network structure made up by the large number of radio devices and does not necessarily forced to conduct a low-energy operation in the case power supply conditions are assumed good. On the other hand, this category typically requires an autonomous management such as mesh construction and maintenance, data concatenation to decrease the frame collision events and multiple services supporting functions to cope with several different data frames according to the variety of supported services [9][10]. The ultra low-energy operation network assumes the utilization under the situation where low-energy operation is mandated owing to its poor power supply conditions such as driven by batteries for example, which are often the cases in the outdoor operations such as those for agriculture and fishery applications. The reinforced mesh network means the expansions of the wireless grid applicable fields for which concrete network utility or detailed system parameters are not fully confirmed due to the very special characteristics of radio propagations.

Authors have been breaking down the concrete requirements for the wireless grid by taking those diversified applications and have summarized as in the following two major requirements that are expected to become typical functions in the future IoT systems:

- The harmonized mesh activities by massive radio device cooperation
- The flexible service supporting activities with low-energy operation capability

In the previous papers, those requirements are focused. In [8]-[10], IEEE 802.15.10 based routing control that could cope with the massive device operations are evaluated, but there are no challenges to validate the obtained evaluation results via both experiments and simulators. The contributions of this paper is to provide the suitable and feasible evaluated results comparisons between experiments and simulators, which could result in the effective system design without experimental costs.

3. Ieee 802.15.10 Customizations To Realize The Assumed Harmonized Mesh Activities

In order to realize the assumed harmonized mesh activities, effective routing control for more than one thousand radio devices is considered essential. One of the most typical features of the assumed routing control is that the necessary functions such as information exchanges among the radio devices are conducted by MAC layer by implementing IEEE 802.15.10 based protocol [6][8]-[10]. There, the required information are represented by Information Element (IE) that is a information unit processed by MAC layer, exchanged and processed by MAC layer functions [11]-[13]. Such L2R control not only enables simple and light processing with relatively smaller overhead such as frame headers compared with the conventional Internet Protocol (IP) based processing, but also realizes easy functional upgrade for the systems that implement such lower layer protocol stacks. Assuming that IEEE 802.15.10 based protocol includes several functions for the L2R control, that is, (i) the autonomous mesh construction function to realize suitable mesh topology management according to the situations, (ii) data concatenation function to decrease the frame collision events by decreasing the number of frames and (iii) multiple services supporting function to employ several L2R mesh in the single PAN each of which cope with each of different services.

Fig. 2 shows examples of such multiple services supporting functions that are included in IEEE 802.15.10 and considered very effective for the assumed L2R control. Fig. 2(a) showsBy this function, several L2R meshes can be defined in the single PAN, and each of those meshes is customized according to the proposed service. Those multiple mesh supporting function is expected to work effectively in the future diversified services applications or systems. One of the most typical applications are considered.

Fig. 2(b) shows an example of data concatenation functions. In Fig. 2(b) each of devices A, B, C and D is going to send its data frame according to the established route. The relaying devices such as A, B concatenate the relayed frame and their original frame as in Fig. 2(b). The data concatenation size that means the number of concatenated frames is determined by setting the parameter of DCatBuffTime. That is, if the relaying device has a data frame to send, the device holds the sending for the duration of DCatBuffTime and concatenate all arrived frames in the duration. By conducting such data frame concatenations, the number of forwarded frames in the PAN is reduced, thereby effectively reduce the frame collision events at the same time.

4. Evaluations Of The Assumed Mesh Activities Employing Experiments And Simulators

Fig. 3 shows the developed evaluation system for the harmonized mesh activities by employing developed SUN devices that construct L2R mesh based on IEEE 802.15.10. The setup includes several SUN devices that can behave as both mesh root and non mesh root devices. Besides the physical SUN devices, the setup includes SUN device emulators each of which can emulate up to several tens of SUN devices. In Fig. 3(a), two mesh root devices define two different L2R meshes in the single PAN. The six physical non mesh root devices are joining in both of two L2R meshes. Furthermore, the L2R emulator provides four non mesh root devices joining in only one L2R mesh (Mesh 2). Fig. 3(b) shows the monitored L2R meshes. The purple and green circles show physical devices and emulated devices respectively.

Fundamental performances for the assumed harmonized mesh activities employing L2R devices are evaluated through both experiments and simulator. Fig. 4 shows the employed mesh topologies. In the evaluations, not only a single mesh topology as in Fig. 4(a) but also multiple meshes topology as in Fig. 4 (b) that exploits the multiple services supporting function in Fig. 3 is employed. In the both topology cases, ten non mesh root devices with their own depth parameter [6] as in Fig. 4. In the multiple meshes case, two mesh root devices in order to define the multiple meshes are deployed. As for each topology, data frame exchange performances are evaluated through both simulator and experiments. In the simulator evaluation, all radio devices are implemented by the developed emulator as in Fig. 3(a). Specifications of the employed L2R devices are shown in Table 1.

Table 1. Specifications of the Employed L2R Device.

Frequency	920 MHz
Transmission power	20 mW
Modulation scheme	2GFSK
Data rate	100 kb/s

First, fundamental frame forwarding performances in the single mesh topology. In those evaluations, frame success rate for the data frame traffic from those ten non mesh devices to the mesh root as in Fig. 4(a) that is defined as upstream traffic is evaluated. Fig. 5 shows the frame success rate performances according to the average frame interval for each non mesh root device. Furthermore, frame success rate performances for different average frame length are also evaluated. Those evaluations are conducted as for both experiments and simulator as noted in the previous sections. Fig. 5 shows that shorter frame interval and longer frame length can provide higher data frame collision events thereby degrades the total frame success rate performances as in Fig. 5. Moreover, Fig. 5 shows that there is not much differences

between the experimental and simulator results. Such obtained result shows that the developed emulator in Fig. 3(a) can provide suitable emulated performances without a lot of physical devices deployment.

Next, multiple meshes topology as in Fig. 4(b) is also evaluated accordingly. In this evaluations, simultaneous data frame forwarding not only the forwarding from non mesh root devices to the mesh root devices as upstream frame traffic but also that from the mesh root to the non mesh root that is defined as downstream frame traffic are evaluated. Fig. 6 shows the frame success rate performance for upstream and downstream frame traffic according to the average frame interval by defining multiple meshes in a PAN as shown in Fig. 4(b). Those results show that those multiple meshes system also suffers from the performance degradations owing to the frame interval and frame length as in Fig. 5 case. Moreover, also in those evaluations, it is confirmed that the deployed simulator performances are much corresponding to the experimental results. From Fig. 5 and Fig. 6, there does not seem more than 5% differences in the frame success rate performances.

5. Dupulicated Transmission Using Data Concatenation

In this section, an improved data frame routing scheme that exploits the data concatenation function in Fig. 2. Fig. 7 shows a concept of proposed duplicated transmission. In the proposed scheme significant frames are duplicated and transmitted by concatenated with another frames as in the figure. An advantage of this proposed scheme is that it can increase success probability for the significant frame by not increasing the number of data frames that results in serious frame collisions.

Fig. 8 shows a computer simulation results. In the simulation 20% of offered frames are assumed to be treated as significant frames. The results show that the proposed duplicated transmission can achieves almost 100% success rate by not seriously increasing the number of data frames.

The proposed duplicated transmission using the data concatenation function is also evaluated in the experiments that deployed the developed devices as in Fig. 3. Fig. 9 shows experimental results for the proposed schemes. In this experiment, two types of the proposed schemes are employed, that is, a scheme that duplicates the significant frames only at the initiator device, and the other scheme that duplicates in all devices in the relaying route. The results in Fig. 9 confirm that the both proposed schemes can effectively increase the frame success rate and the scheme by duplicating in the relaying route provides further improved performance than the scheme with duplication only at the initiator device.

6. Conclusion

The paper shows a realization of the wireless grid by suitably exploiting the existing wireless SUN that is standardized by IEEE 802.15.4g/4e task groups and is certified by Wi-SUN alliance. MAC layer functions that is mainly defined by IEEE 802.15.4e standard and IEEE 802.15.10 recommended practice are effectively modified according to the assumed IoT services and satisfy the requirement of harmonized mesh activities by massive radio devices. In order to realize this function, SUN radio devices that exploit

L2R control scheme in IEEE 802.15.10 are employed to realize the autonomous mesh management function as well as the multiple service supporting function. The performance is evaluated through the experiments by employing the developed SUN devices as well as simulator evaluations. Consequently, this paper confirms that the obtained results through both simulator evaluations and experiments matches to each other. Further considerations of the detailed evaluations for the assumed harmonized mesh activities would be one of our future study.

Declarations

Acknowledgement

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Figures

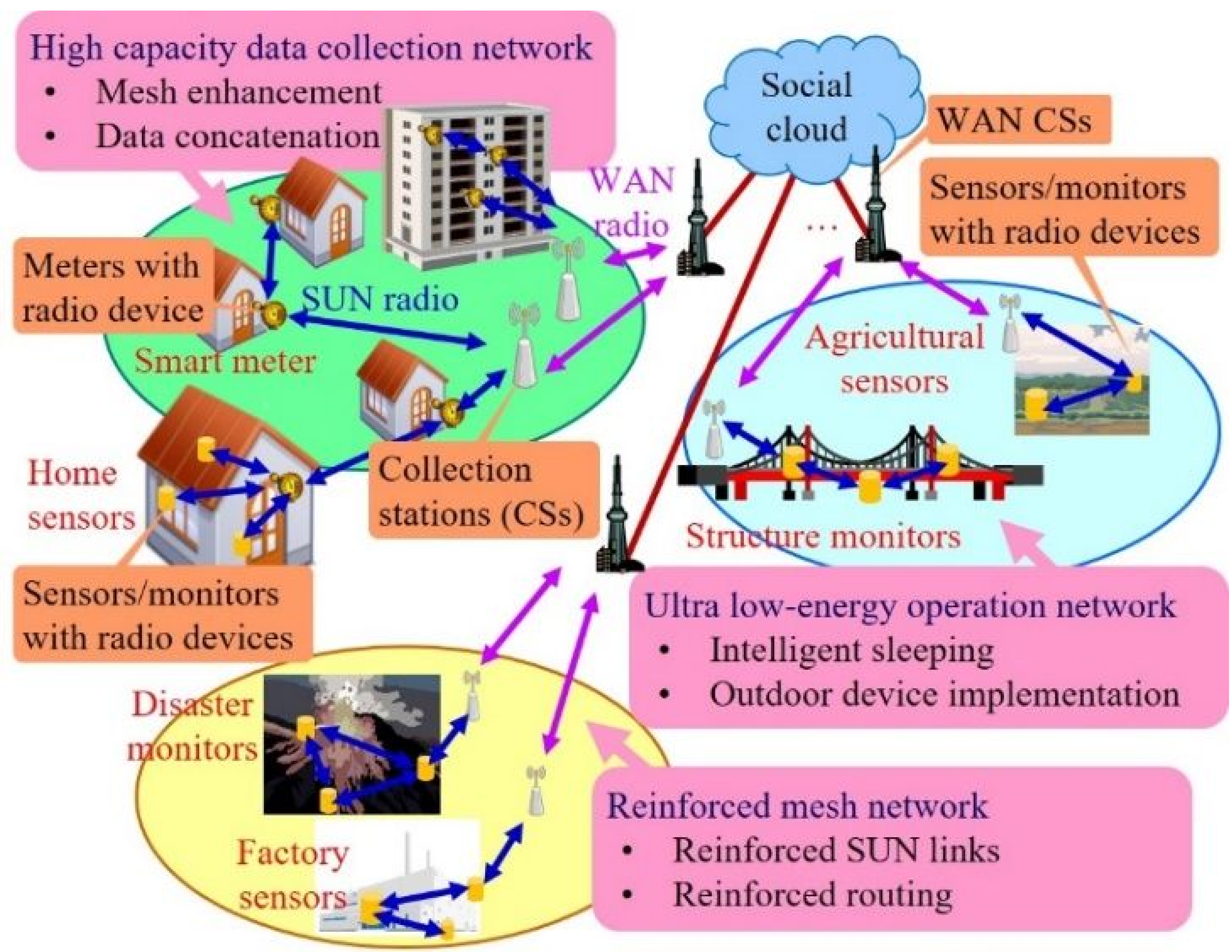


Figure 1

Fundamental categories for assumed wireless grid system exploiting SUN systems.

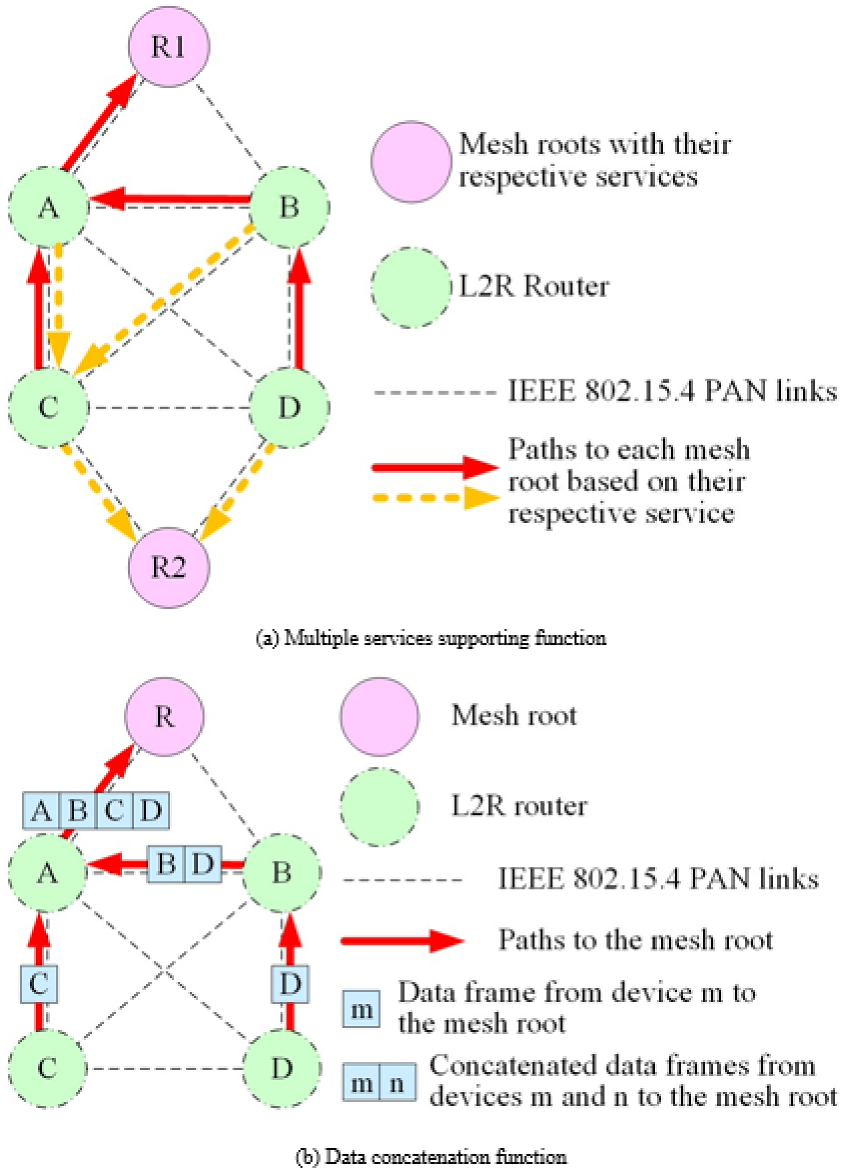
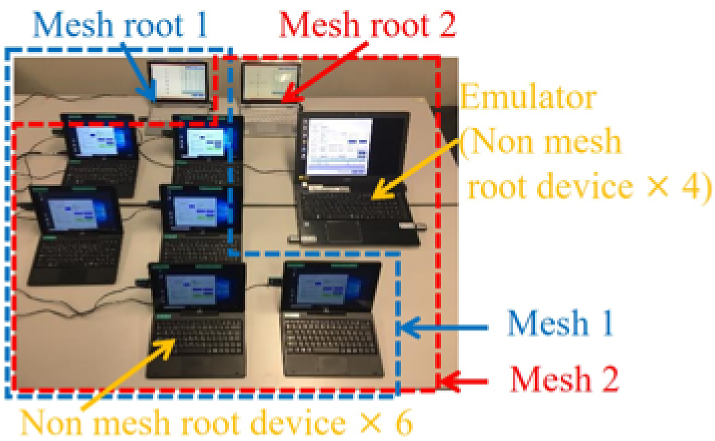
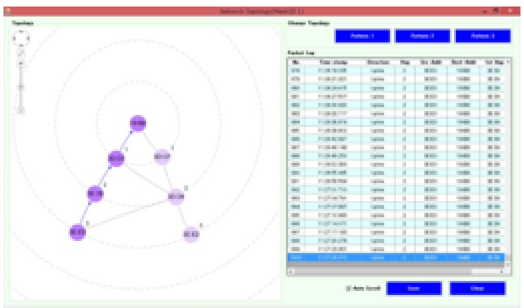


Figure 2

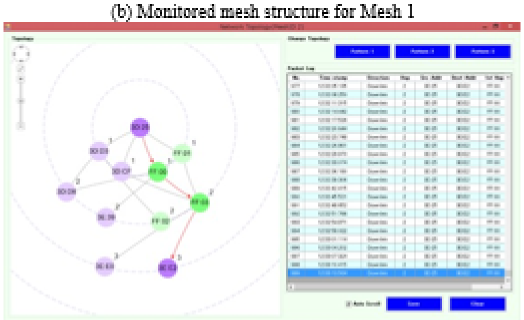
Examples of L2R control functions that are defined in IEEE 802.15.10.



(a) L2R meshes defined in a PAN with an emulator



(b) Monitored mesh structure for Mesh 1



(b) Monitored mesh structure for Mesh 2 that includes emulated devices

Figure 3

Setup of performance evaluation systems for L2R control.

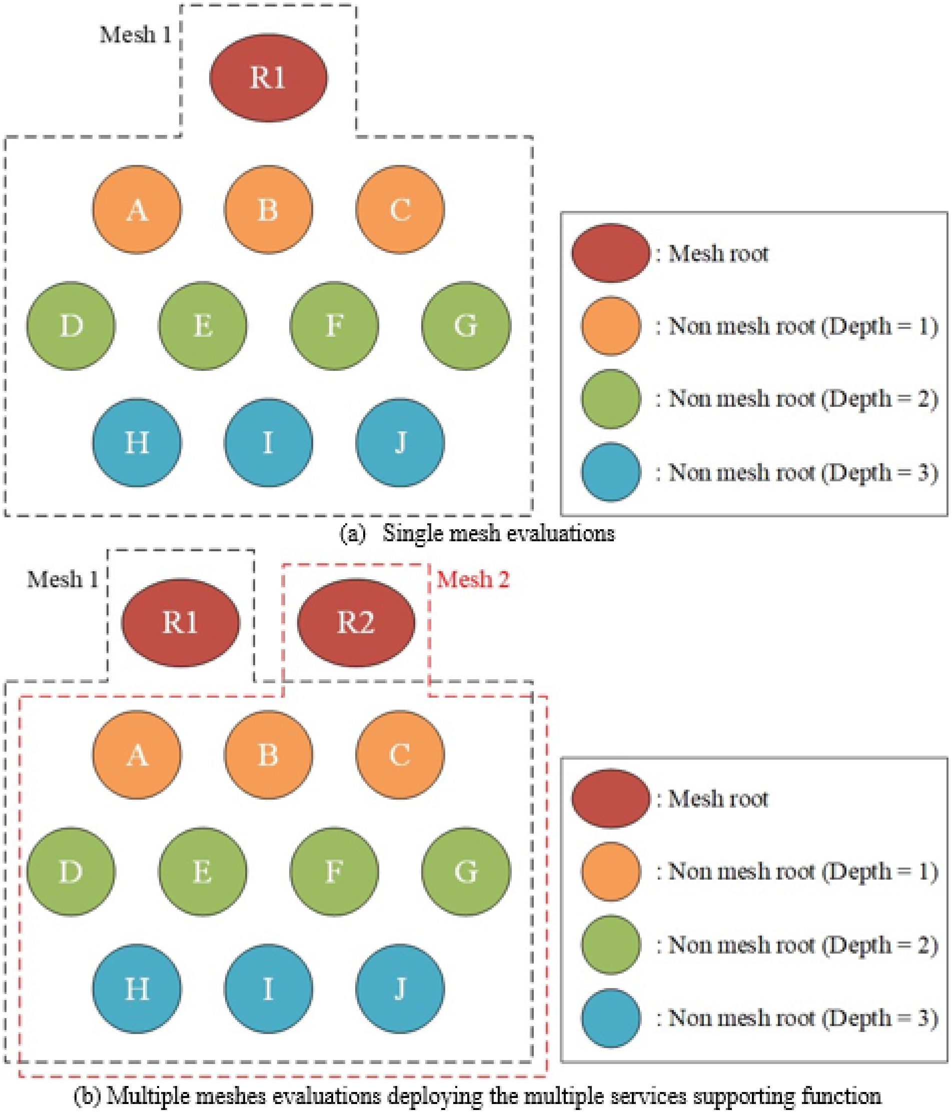


Figure 4

Employed mesh topologies in the fundamental performance evaluation.

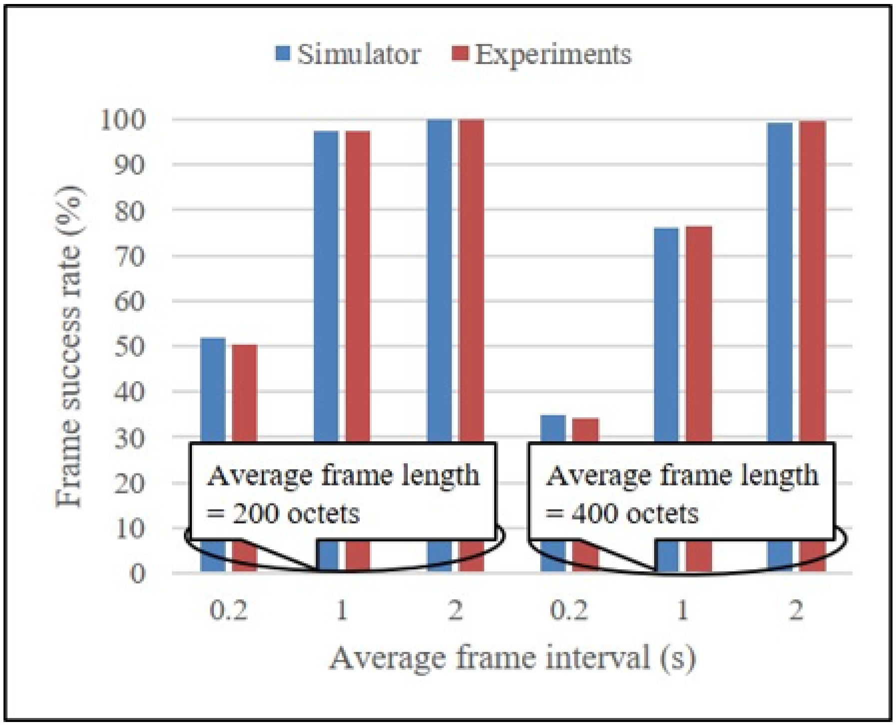
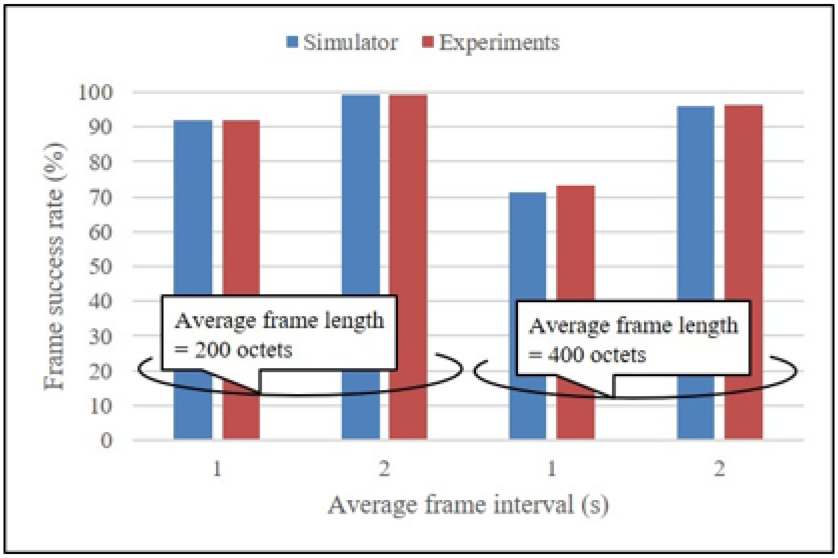
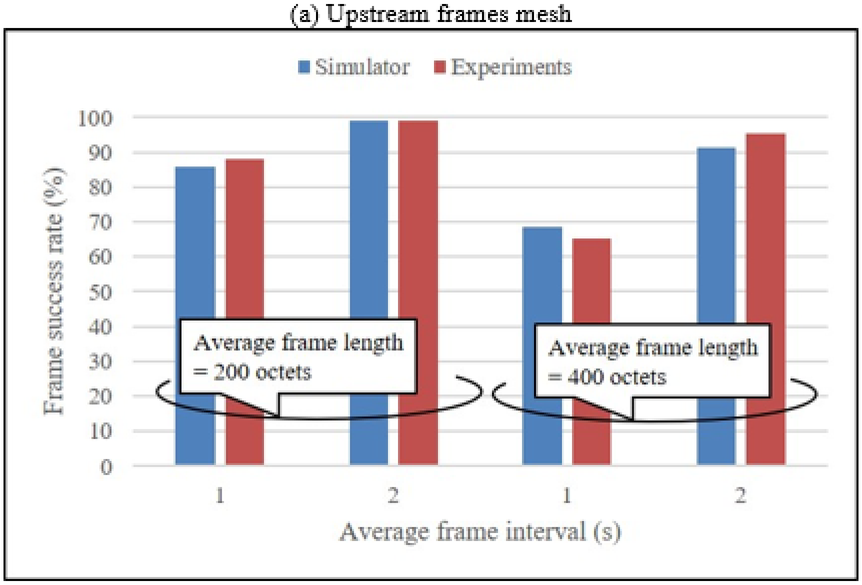


Figure 5

Frame success rate performance for upstream frame traffic according to the average frame interval in the single mesh topology.



(a) Upstream frames mesh



(b) Downstream frames mesh

Figure 6

Frame success rate performance for upstream and downstream frame traffic according to the average frame interval by defining multiple meshes in a PAN.

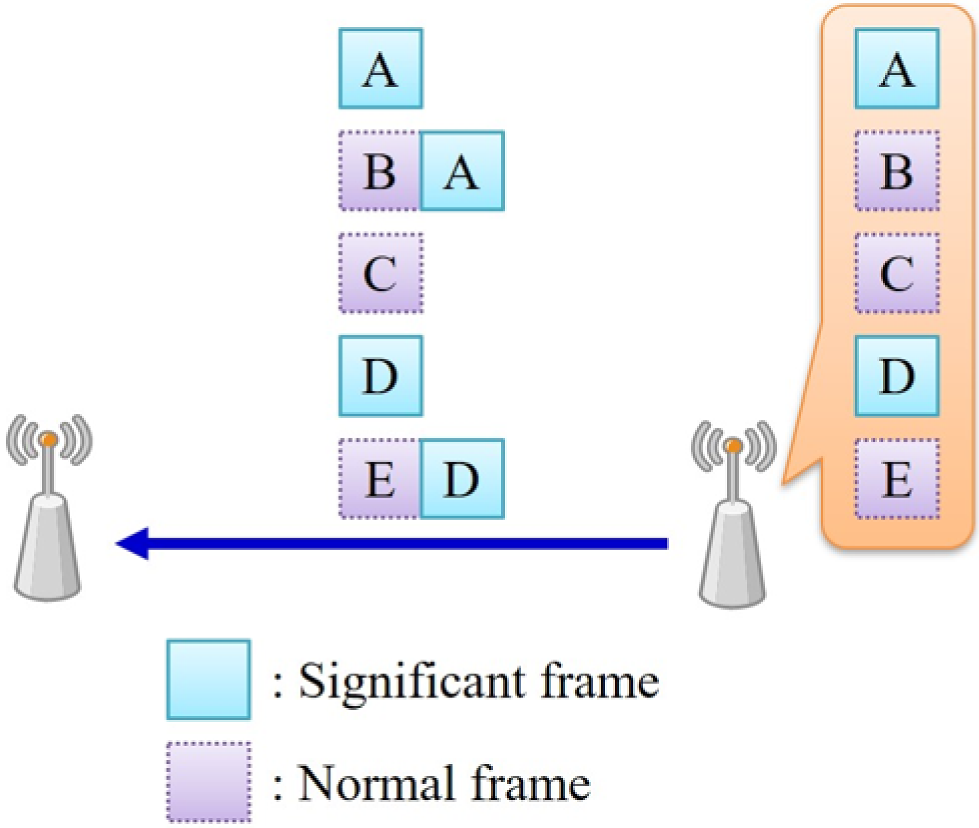


Figure 7

Concept of duplicated transmission using data concatenation.

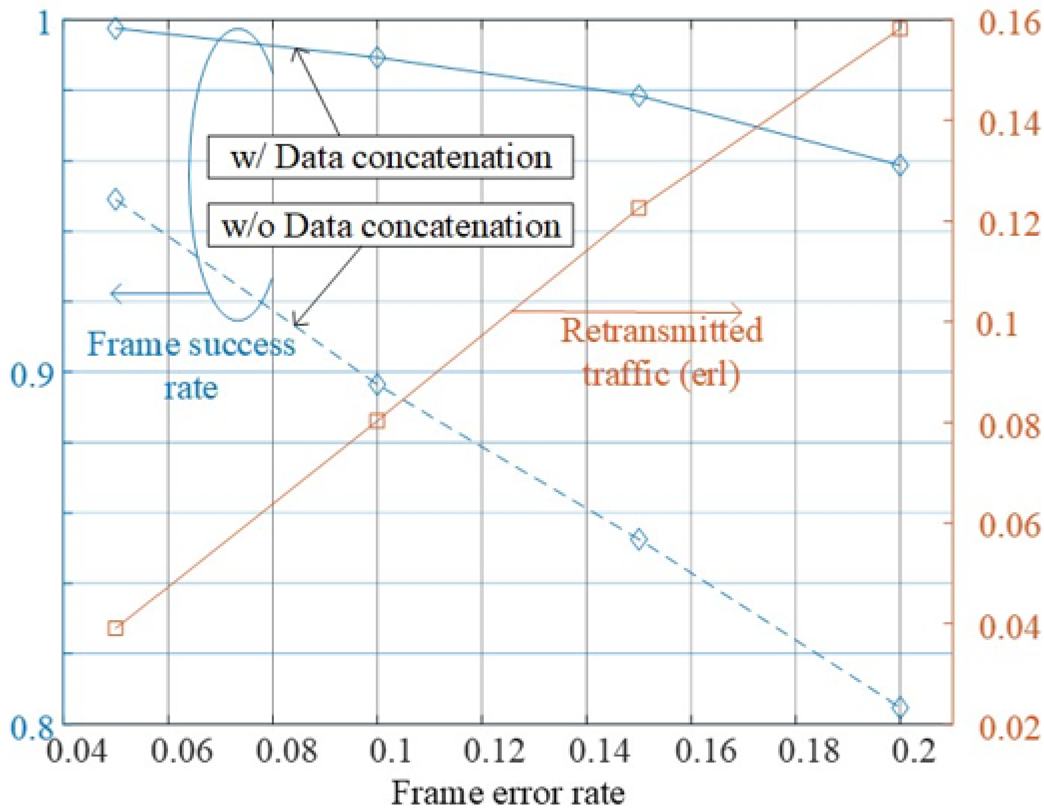


Figure 8

Computer simulation for duplicated transmission using data concatenation.

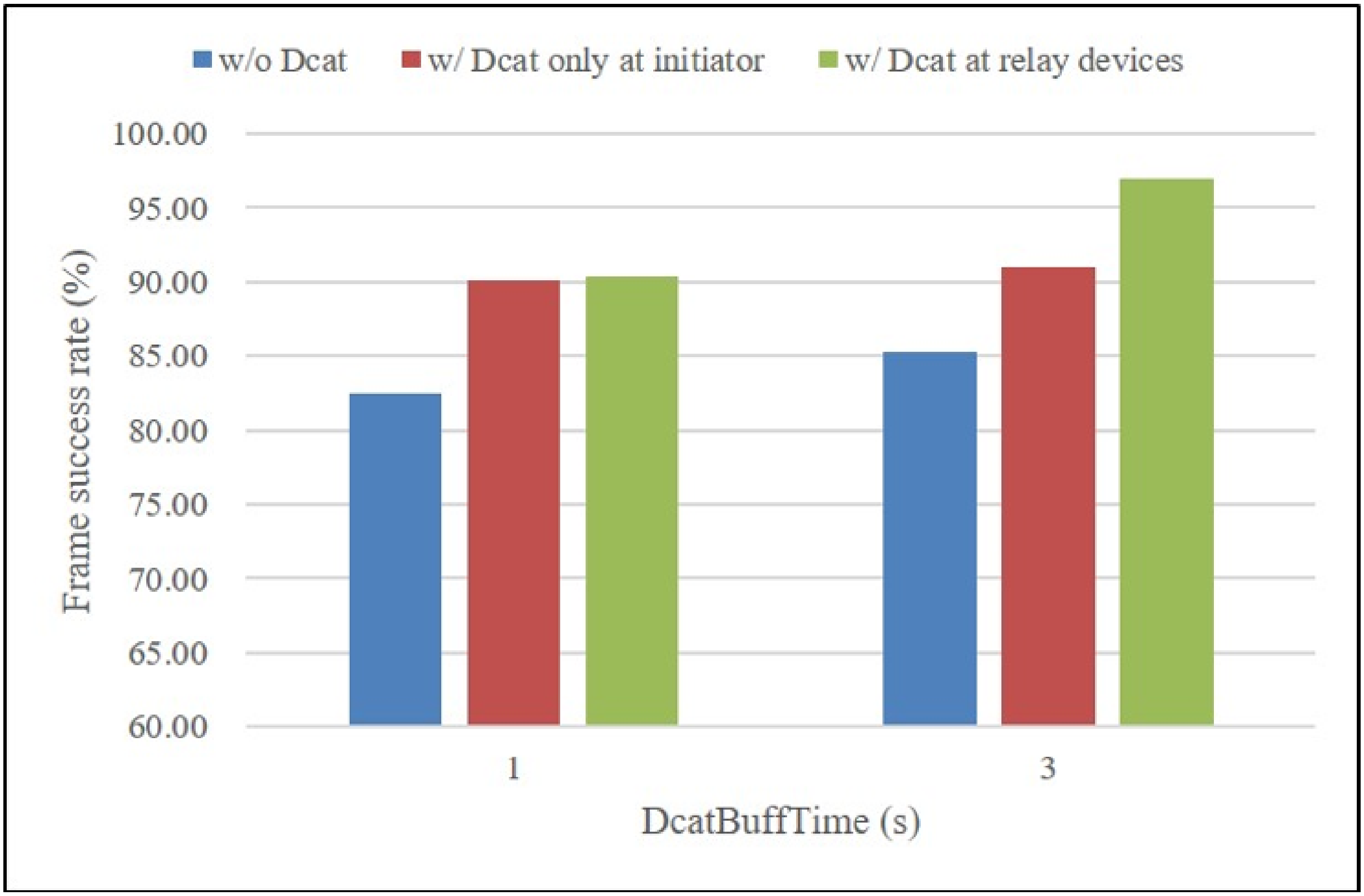


Figure 9

Experimental results for duplicated transmission using data concatenation.