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Performance evaluation of MAC layer of LnCP and LonWorks protocol as home networking system

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Abstract

Recently, various home network systems, such as LonWorks, Echonet, and LnCP, etc., are developed to enhance customer's comfort and convenience. However, it is not known that performance of any protocol is superior. Hence, this paper evaluates performance of LnCP (Living network Control Protocol) by LG Electronics and LonWorks by Echelon. For this purpose, we have developed simulation model using state diagram of LonWorks and LnCP, and simulation conditions through analysis of message to be generated in the smart home. Also, we evaluate performance, such as maximum transmission delay and mean transmission delay, of both protocols.
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Keywords: Home network; Control network; LnCP; LonWorks; Performance evaluation

1. Introduction

A home network is a communication network that connects various digital home appliances in order to offer its users convenient, secure and economical services. The emergence of home network is based on the convergence of numerous areas encompassing microprocessors, operating system (OS) for domestic home appliances, digital communication, and information technologies [1–3].

According to the service types it provides, a home network can be categorized into data network, entertainment network, and control network [4]. The data network provides communication services for data exchange among computers and their peripheral devices including Internet service while the entertainment network handles audio/video (A/V) information among entertainment devices. The control network provides a means for controlling and monitoring traditional white goods, home automation devices, and remote gas meters. The devices on data networks and entertainment networks usually have high-performance processors, and the protocols for these networks are required to handle a large amount of data at a high data rate. In contrast, the control network aims to handle very short messages for control and monitoring, and the devices on the network often have limited-performance processors. Therefore, the protocol for the control network should be designed to be efficient in handling short messages with limited resources.

Currently, various control network protocols have been developed to perform home appliance control, lighting control, temperature control, energy management, and home security by various companies or associations [5,6]. For example, the KNX standard introduced by Konnex Association was announced as a part of EN 50090 series, the European Standard for home and building electronic systems. The Echonet protocol was developed by Japanese home appliance companies. The LonWorks protocol developed by Echelon was published as the ANSI/CEA-709.1-B standards. Also, LnCP (Living network Control Protocol) was developed by LG Electronics. Moreover, wireless network protocols such as HomeRF, ZigBee, and IEEE 802.11 are being developed or have been developed for home network.

Despite these numerous developments, they have not been compared to find out which protocol is the best for certain home network. This comparison may consider various factors such as types of medium access control (MAC), supported transmission

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medium types, original motivation of the development and so on. Especially, the comparison may be very important under the circumstance of increasing competition for market share.

This paper presents performance evaluation of MAC layer of LnCP protocol [7], which was specifically developed for home appliance control and monitoring, and MAC layer of LonWorks protocol [8], which is being used for building automation and home network. Especially, the performance was compared by using discrete-event simulation [9,10]. A network was modeled by using a commercial simulation language (SIMAN) where numerous messages were generated, queued in a buffer, and then transmitted on to the network following the specific procedures of the protocol. The inputs to the model include the number of stations, the probability distribution of time gap between two consecutive messages, and the probability distribution of message lengths. The simulation model produces average transmission delay and throughput based on the observation during the simulation.

2. Overview of LnCP protocol

The LnCP protocol [7] presents a communication standard of control networks for networking among home appliances, which was developed by LG Electronics as noted in Table 1. This LnCP protocol consists of three parts; Part I defines the function for each layer, Part II defines message set used in the application layer and services that use this message set, and Part III defines the network management sub-layer and the network management station. In general, the LonWorks protocol has grown in popularity as a protocol for home networks after developing it for building automations or production automations. However, the LnCP was developed as a control network to implement it using a cheap microcontroller, which is installed in home appliances.

LnCP consists of four layers as shown in Fig. 1; physical layer, data link layer, network layer, and application layer. Every appliance can implement higher three layers within its microcontroller unit (MCU) so that it can communicate with other appliances via serial interface. Otherwise, interface module can connect the appliance to home network bus other than serial interface, which implements data link layer at the least and higher layers if applications related with home code are necessary [4].

Table 1
Overview of the LnCP protocol

Item	LnCP
Company	LG Electronics
Governing standard	–
Layer	4 layer
Media	power line, RS-485, RF, IEEE 802.11
Communication service	peer to peer, master/slave
Topology	free
Bit rate	4.8, 9.6, 19.2 Kbps
MAC	probabilistic Delayed CSMA
Message length	3–100 byte
Message service	Request–response, notification, repeated notification

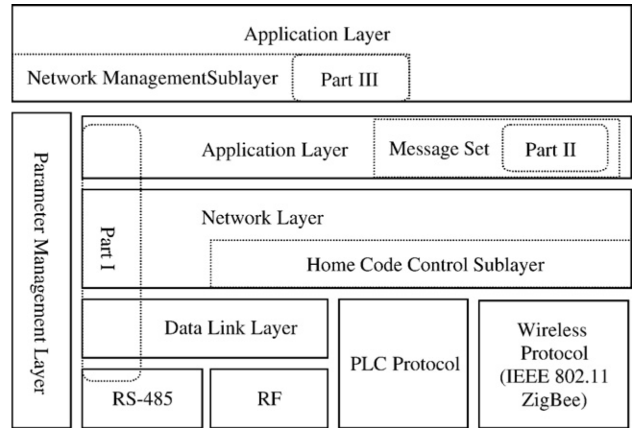

Fig. 1. Layered architecture of LnCP protocol.

The LnCP is able to use various transmission media such as RS-485, power line communications, and radio frequency (RF). Especially, the LnCP only defines frame structure, but it does not define encoding method in order to accommodate various demodulation methods specified in known protocol such as physical layer of IEEE 802.11 protocol. The LnCP station consists of three types; a mater station that controls and monitors the operation and status of other home appliances, a slave station that responds to the request of the master and broadcasts the status of slave itself, and a network manager that configures and manages the operational environment of home appliances. This network manager is also recommended to be implemented for their functions in a home appliance that have display devices, such as Internet refrigerator and TV.

When the LnCP network uses known physical layer such as power line communications or IEEE 802.11, corresponding data link layer functions should be done. However, when it uses a transmission medium such as RS-485 without its MAC, a p-DCSMA (probabilistic Delayed Carrier Sense Multiple Access) method [7] can be used.

The network layer defines the functions related to address management and transmission/reception control for reliable data transfer among devices. And, the application layer defines the transmission/reception control, and flow control for download and upload services for application software. In addition, the application layer defines a message set that can be used for network management and control and monitoring of appliances. Details of the message set are described in Part II of this specification.

3. Simulation models for MAC layer of LnCP and LonWorks protocol

This section presents the development of simulation models for the message exchange method between the data link layer and the application layer using the SIMAN Ver. 7.0 in order to evaluate the performance of LnCP and LonWorks protocols.

In order to develop simulation models for LnCP and LonWorks protocols in this paper, several assumptions are used as follows.

- Transmission delays in an application layer, network layer, data link layer, and interfaces between layers are neglected.

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This delay will be differed according to the OS and performance of application programs. In this paper, transmission delays caused by these factors in these two protocols are considered as the same value.

- Processing time in hardwares for each communication node can be assumed to be same because it is recommended to be 1 bit time [11].
- It is assumed that there are no errors in communication cables, hardwares, and application programs.
- The transmission speed is assumed as 9600 bps.
- The priority of the LnCP protocol can be classified according to four different levels, such as high, medium high, medium low, and low. However, in the case of the LonWorks protocol, the priority is determined as an option in which it can be configured within the slot time range of 0–127 for each node. Thus, the priority of the LonWorks protocol is defined according to four different levels as the same as the LnCP protocol by adjusting the slot time of the LonWorks protocol.
- The LnCP protocol uses request–response, notification, and download services to transmit messages. However, the LonWorks protocol uses request–response, AckD, and UnAckD services. In the simulation model, notification and download services of the LnCP protocol is matched to the UnAckD and multiple UnAckD services used in the LonWorks protocol, respectively, in order to establish an agreement of communication procedure between these two protocols.

3.1. Simulation model of MAC layer of LnCP protocol

Fig. 2 presents the flowchart of a simulation model of MAC layer of the LnCP protocol [7], which uses the p-DCSMA method.

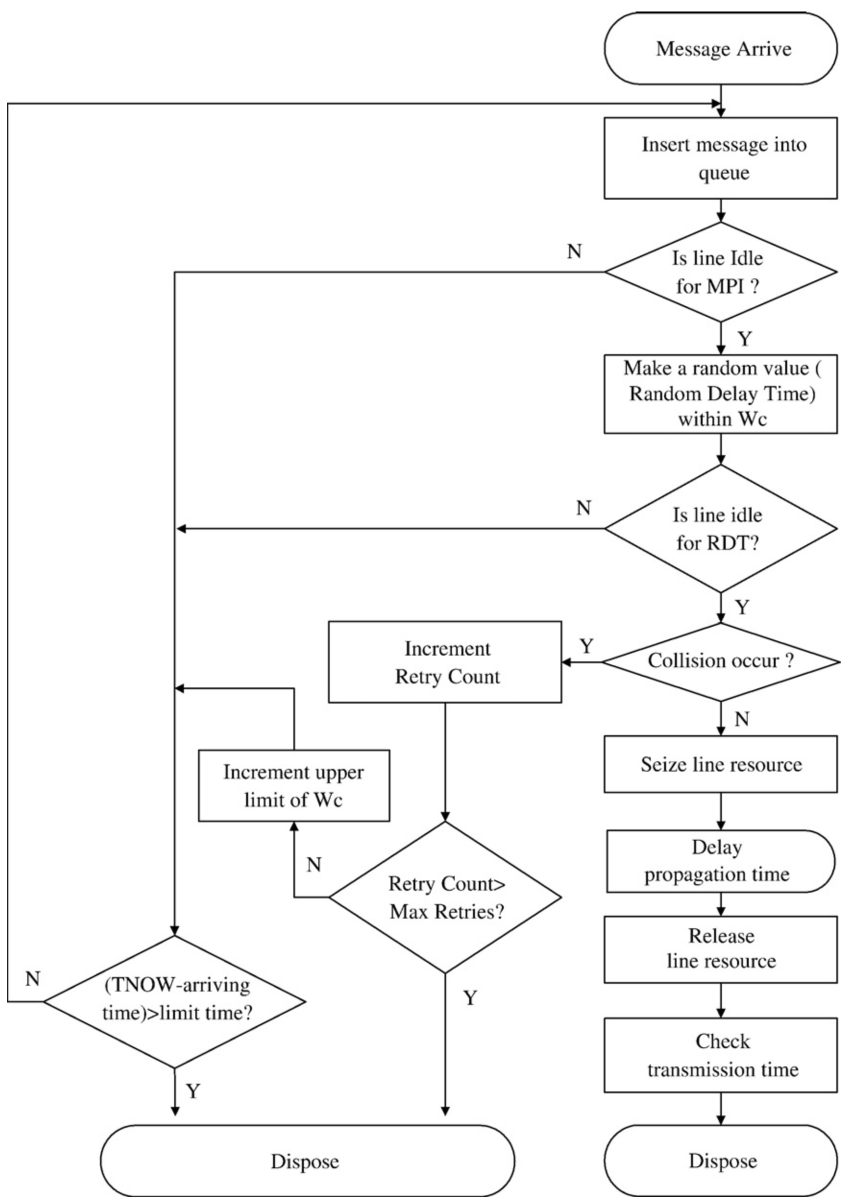

Fig. 2. Flowchart of simulation model of MAC layer of the LnCP.

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If a message is generated in an LnCP simulation model, a station will check the status of transmission media. This station continuously checks the status of transmission media during the minimum interval between two packets (MinPkInterval, MPI) unless the transmission media is busy. If the transmission media is busy, the check procedure will be continuously repeated. If the transmission media is not busy during the MPI time, the size of competition windows (Wc) can be determined according to the priority of packets (SvcPriority). And, a random delay time (RDT) can be generated as a unique distribution in the range of Wc. And then, the status of transmission media is to be continuously checked during the RDT interval.

If an UART (Universal Asynchronous Receiver and Transmitter) frame is recognized in transmission media during the RDT interval, a p-DCSMA algorithm will be executed again. If the transmission media is not busy during RDT interval, one packet should be transmitted. If the packet is not transmitted, the p-DCSMA algorithm will be repeated within the maximum number of retries and permitted execution time in a MAC algorithm, respectively. When the p-DCSMA algorithm is retried, the upper limit of Wc increases as much as the level of window shifts, which is defined according to the priority of packets. The transmission probability of packets in the p-DCSMA can be determined according to the Wc. The reason of this is to increase the transmission probability based on the high priority in the transmission or fast packet generation time.

In the case of the request–response message, when a response message is received, it is considered that a message is successfully

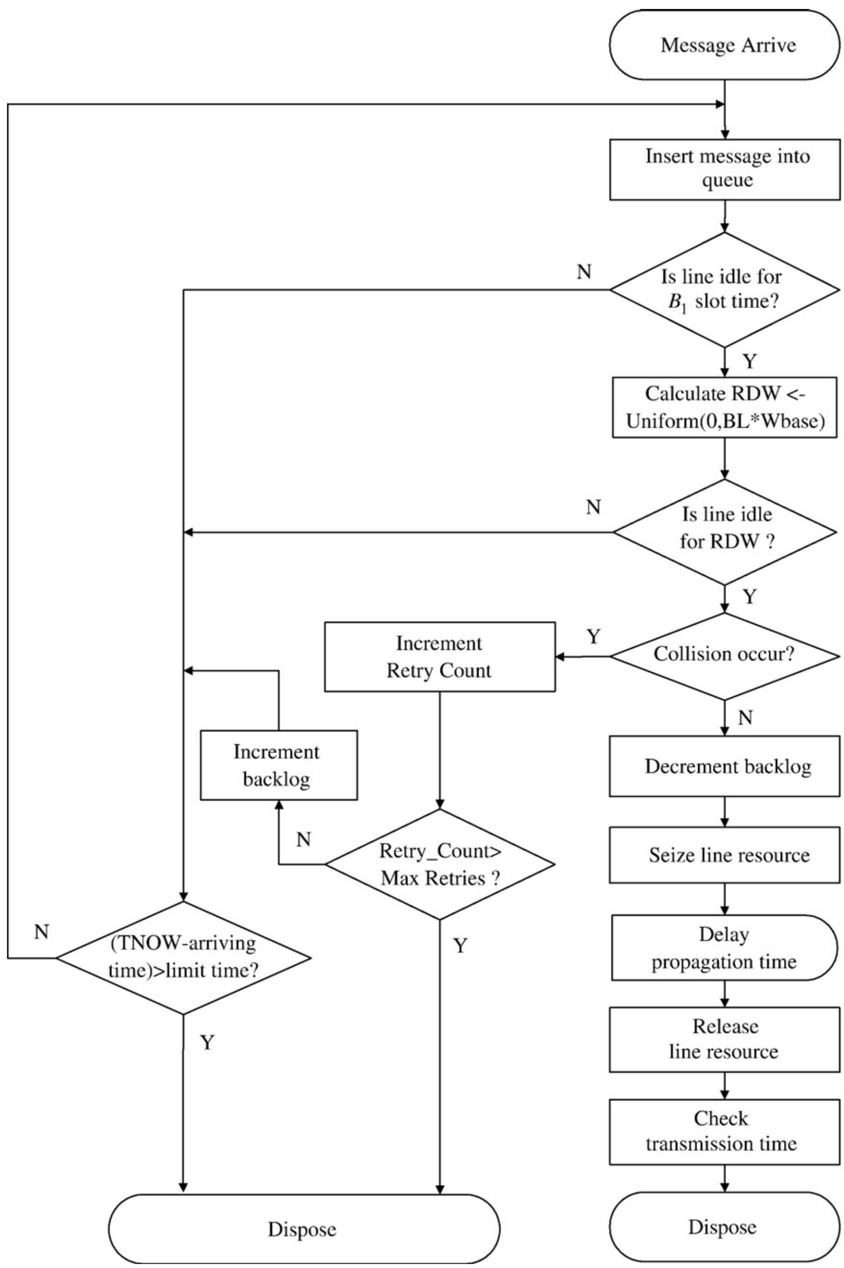

Fig. 3. Flowchart of simulation model of MAC layer of the LonWorks.

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transmitted. However, in the case of the notification message, when a message transmission is successfully terminated, it is considered that a message is successfully transmitted.

3.2. Simulation model of MAC layer of LonWorks protocol

Fig. 3 presents the flowchart of a simulation model of MAC layer of the LonWorks protocol [8], which uses the predictive p-persistent CSMA method.

In a LonWorks simulation model, a station that has a message, which is to be transmitted, verifies the status of transmission media during β1 interval. And, if the transmission media is not busy, a random delay window (RDW) value is generated. Here, a backlog used in this process presents the traffic condition of the present transmission media in which the value of this backlog increased when collisions occurred and decreased when collided packet is transmitted. In addition, a RDW generates real numbers between 0 and value, which can be obtained by multiplying backlog values to base windows value, according to the unique distribution. Here, the base window can be generated by reflecting backlog value to β2 that is the value of random slots. Finally, a station that attempts to transmit messages will transmit messages by verifying the status of transmission media during RDW interval if the media is not busy.

In a simulation model, if a certain transmission is attempted in other stations during the 1 bit time which is the same time for a message collision test, it can be assumed that there is a message collision. In addition, based on evidence collected from this investigation, whether or not the number of message retries exceeds the maximum number of MAC tries or time limit of the message transmission, it is necessary to increase the value of backlog and retry a retransmission if there are no excesses in that investigation.

In the case of the request–response message, when a response message is received, it is considered that a message is successfully transmitted. However, in the case of the UnAckD message, when a message transmission is successfully terminated, it is considered that a message is successfully transmitted.

4. Performance evaluation using a simulation

4.1. Analysis of the message generated in the home networking system

In a home networking system applied in a smart home, various messages can be generated from the operation, termination, and periodical status notification of home appliances such as microwave oven or other products.

These messages can be classified into three different types, as presented in Fig. 4. First, there is an urgent asynchronous control message as presented in Fig. 4(a). This is a type of irregularly generated message to control home appliances. For instance, any command executed in order to turn on the TV or control its volume in a network manager, which is installed in a refrigerator, are considered as this message type. These messages should be collected within the allowable transmission delay which is limited by the patience of users and have to instantly process user's requests. In the LnCP protocol, the allowable transmission delay that is limited in the patience of users is determined as 2 s [7]. It means that a normal transmission and reception can be performed within 2 s when the operation command from a network manager is generated.

Second, there is a periodic notification message, which is not a type of urgent message, as presented in Fig. 4(b). This message consists of two different messages; the first one is a type of notification message that notifies the status information of home appliances, such as operations or procedures in a home appliances, to a network manager, and the second one is a type of download message that downloads programs to home appliances in order to update their software. For instance, in a washing machine, the status of this washing machine, such as the present operation or process, can be transferred as a notification message to the network manager installed in a refrigerator. These messages present periodically transmitted characteristics and are not sensitive to the transmission delay. In addition, they don't significantly affect the safety of a smart home if the transmission is not properly terminated.

Finally, there is an urgent asynchronous event message as presented in Fig. 4(c). This is a type of event message that present problems or malfunctions in home appliances and is irregularly generated. For instance, any dangerous status in a gas range such as leakage or fire indication in a fire detector, can be considered as event messages. These messages are very sensitive to the transmission delay and can present some damages to users due to its delay. Thus, these messages should be preferentially transmitted.

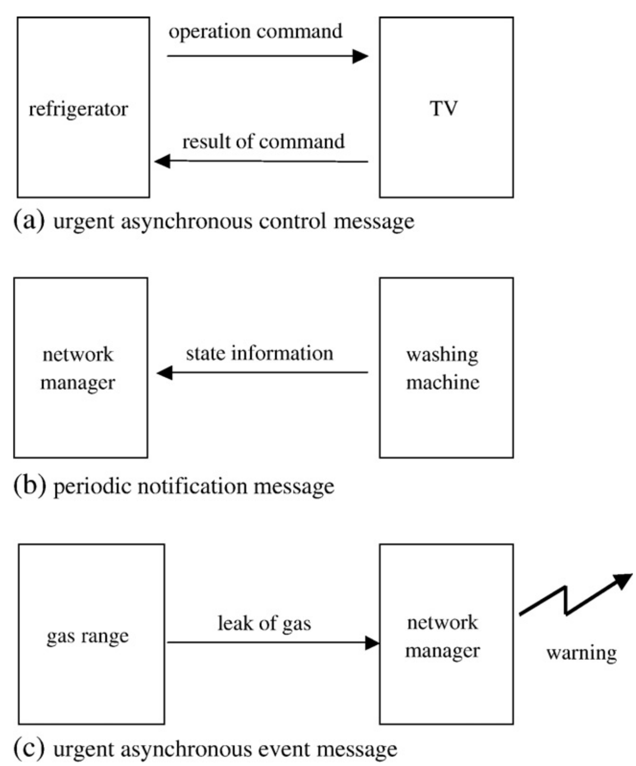

Fig. 4. Message type generated in the home networking system.

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Table 2
Message generation conditions of a home without download services

Service type	Request–Response	Notification	
Number of stations	20% of total Stations	80% of total Stations	
Priority	Medium High(1)	High 5%(0), Medium low 95%(2)	High 5%(0), Medium low 95%(2)
Generation period	60 s exponential	60 s exponential	600 s constant
User data length	10 bytes–1 byte	7 bytes	

4.2. Performance evaluation for a common environment without downloads

In this paper, several simulation conditions were configured by combining some messages generated in a smart home in order to evaluate the performance of LnCP and LonWorks protocols. Also, several simulations were performed, and then, the average transmission delay and maximum transmission delay were calculated for the message produced in a simulation model. Here, the transmission delay can be determined as the time required receiving a response message from a reception node after generating and transmitting this message. However, in the case of the notification message, it can be determined as the time required transmitting the generated message to a reception node after generating this message.

The first simulation presents a common smart home environment in which it presents the generation of a periodic notification message such as status information of a station, urgent asynchronous control message to control a station, and urgent asynchronous event messages like malfunctions.

Table 2 presents the message generation condition in a common smart home environment without any downloads. The master station generates request–response messages as noted in Table 2, and it was configured as 20% out of the total station in which the request message was considered as a type of urgent asynchronous control message, a generation period was configured as an exponential distribution for 60 s, and the priority was configured as a medium high level (1). A slave station generates two different notification messages and was configured as 80% out of the total station. One notification message is an urgent asynchronous event message in which the generation period was an exponential distribution for the average of 60 s, the priority level was configured as a high level (0), and the generation rate was configured as 5% out of the total notification message. The other message is a periodic notification message in which the generation period was a constant distribution for the average of 600 s, the priority level was configured as a low level (2), and the generation rate was configured as 95% out of the total notification message.

Fig. 5 presents the average transmission delay and maximum transmission delay for the message generated in a common smart home environment without any downloads. Fig. 5(a) presents the transmission delay of a message, which is generated in a slave and presents the priority level of 0. In Fig. 5(a), the maximum transmission delay of LnCP and LonWorks were 73 and 67 ms, respectively, for 20 stations as presented in Fig. 5 (b). When the number of stations increased to 100, the maximum transmission delay of LnCP and LonWorks were 87 and 138 ms, respectively. Fig. 5(b) presents the transmission delay in a message that presents a message, which is generated in a master and presents the priority level of 1. The maximum transmission delay of LnCP and LonWorks were 220 and 180 ms, respectively, for 20 stations as presented in Fig. 5(b). When the number of stations increased to 100, the maximum transmission delay of LnCP and LonWorks presented a very similar to one other, such as 360 ms.

Based on these results, the transmission delay of an LnCP presented a relatively lower than that of the LonWorks in the case of the urgent asynchronous event message that presents the priority level of 0. In general, because an urgent asynchronous event message used in a smart home in order to notify dangers should be transmitted as fast as possible, we can know that an LnCP presented a relatively better result in an urgent message compared to the LonWorks.

In addition, the transmission delay of LonWorks presented a relatively lower than that of the LnCP in the case of the urgent asynchronous control message that presents the priority level of 1. In general, it is recommended that the transmission delay in an urgent asynchronous control message used in a network manager presents no performance problems when the delay is lower than 2 s in an LnCP. Thus, in the case of the increase in the number of stations, because the maximum transmission

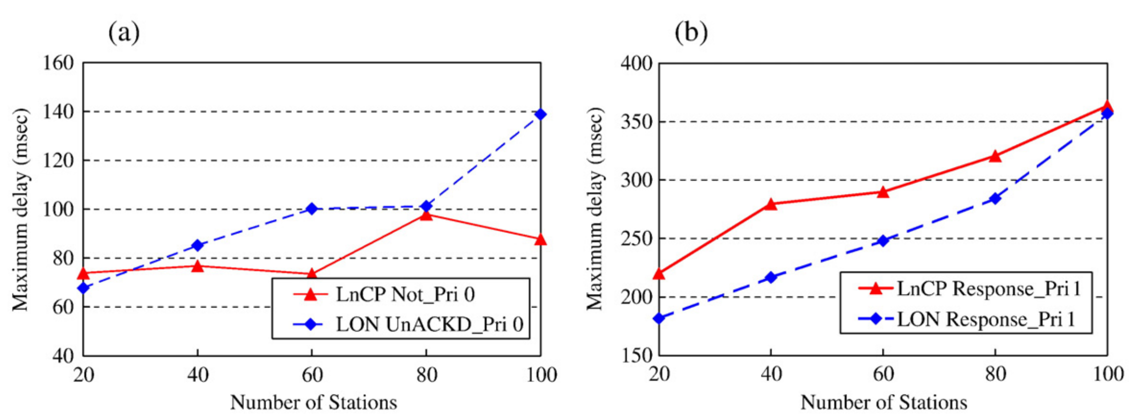

Fig. 5. Transmission delay of MAC layer of LnCP and LonWorks without download services. (a) maximum transmission delay of priority 0. (b) maximum transmission delay of priority 1.

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Table 3
Message generation conditions of a home with download services

Service type	Download	Request–response	Notification	
Number of stations	1 master station	20% of total Stations	80% of total Stations	
Priority	Low(3)	Medium High(1)	High 5%(0), Medium low 95%(2)	High 5%(0), Medium low 95%(2)
Message generation period	1 bit time (1/9600s)	60 s exponential	60 s exponential	600 s constant
User data length	64 bytes × 100	10 bytes/1 byte	7 bytes	

delay in these two protocols can be maintained as a very low level, these two protocols present no problems in processing urgent asynchronous control messages.

4.3. Performance evaluation for a high traffic environment with download services

The second simulation presents a high traffic environment in which a large scale download message is transmitted from a master station to a slave station. It can be used to evaluate the affection of an urgent asynchronous event message, such as danger signals, when messages are excessively generated in a certain station.

Table 3 presents message generation condition in a high traffic environment with downloads. First, a master station generates request–response messages as the same as noted in Table 2, and a slave generates notification messages as the same condition as noted in Table 2. In addition, a master station generates download messages as noted in Table 3. In the case of the download message, it is configured that 100 of 64 bytes message were generated. Also, the priority of download messages was configured as a low level (3).

Fig. 6 presents the maximum transmission delays of the message generated in a smart home with downloads. Fig. 6(a) presents the maximum transmission delay of the message that was generated in a slave, and presented the priority level of 0. As presented in Fig. 6(a), although the maximum transmission delay of an LnCP increased more than 2~3 times compared to that of a common smart home environment as presented in Fig. 5(a), it was maintained less than 100 ms. However, the maximum transmission delay of LonWorks significantly increased at the point that exceeds 80 stations and increased up to 310 ms for 100 stations. Fig. 6(b) presents the maximum transmission delay of the message that generated in a master and presented the priority level of 1. As presented in Fig. 6(b), the maximum transmission delay of LonWorks was maintained as about 1 sec, but the maximum transmission delay of LnCP increased in a very high level.

Based on these results, when a large-scale message such as download messages is transmitted in a home network, we know that an LnCP protocol abandons the transmission of low priority messages, and first transmits the highest priority message such as danger messages. However, we know that the LonWorks protocol fairly transmits the low priority message compared to that of the LnCP.

5. Summary and conclusions

This paper developed a simulation model using a SIMAN language, which is a type of discrete event simulation language, in order to evaluate the characteristics of MAC layer of LnCP and LonWorks protocols. In addition, this paper developed a simulation environment based on the characteristics of messages that occurred in a smart home, and calculated the average transmission delay and maximum transmission delay for each protocol by varying the number of stations.

The conclusion of this paper can be summarized from the results of the simulation applied in this paper as follows.

- In general, an urgent asynchronous event message generated to notify dangers in a smart home should be transmitted as fast as possible compared to other messages. In the case of the LnCP protocol, the transmission delays of an urgent asynchronous event message when download services occurred can be maintained as a constant level. However, the transmission delay of LonWorks protocol significantly increased. Thus, the urgent asynchronous event message

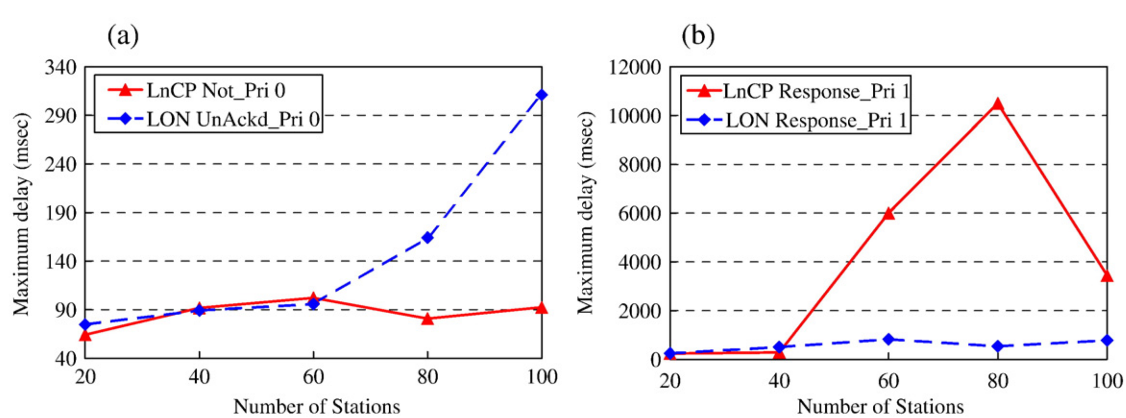

Fig. 6. Transmission delay of MAC layer of LnCP and LonWorks with download services. (a) maximum transmission delay of priority 0. (b) maximum transmission delay of priority 1.

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processing in an LnCP protocol presented a relatively higher than that of the LonWorks protocol.

- However, an urgent asynchronous control message used to control home appliances is necessary to complete a transmission within a maximum allowable delay by considering the perception time of users. For instance, it is clear that a message transmission service is successfully performed if a response message will be arrived within 2 s after applying a control command. In the case of the LonWorks, the transmission delay of request–response messages can be maintained within 2 s under when download services are required. However, the transmission delay of LnCP protocol significantly increased. Thus, the urgent asynchronous control message processing in a LonWorks protocol presented a relatively higher level than that of the LnCP protocol.
- In recent years, the LonWorks protocol has been widely used as a worldwide standard in various fields of factory and building automations, and presents a simplistic approach to implementation due to the use of neuron chips. However, because an LnCP protocol presents a more simple structure than a LonWorks protocol, it is possible to implement it at a low cost. In addition, it has the merit that LnCP protocol was first commercialized in a major company of home appliances throughout the world. Thus, it is necessary to properly select various properties, including the performance of protocols, when companies select a home network protocol.

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