Journal of information and
communication convergence engineering
http://jicce.org

J. Inf. Commun. Converg. Eng. 16(1): 31-37, Mar. 2018 Regular paper

Capacity Design of a Gateway Router for Smart Farms

Hoon Lee[*], ***Member*****,** ***KIICE***

Department of Information and Communications Engineering, Changwon National University, Changwon 51140, Korea

Abstract

In this work, we propose an analytic framework for evaluating the quality of service and dimensioning the link capacity in the gateway router of a smart farm with a greenhouse eco-management system. Specifically, we focus on the gateway router of an IoT network that provides an access service for smart farms. We design the link capacity of a gateway router that is used for the remote management of the greenhouse eco-management system to accommodate both time-critical and delay-tolerant traffic in a greenhouse LAN. For this purpose, we first investigate the ecosystem for smart farm, and we define the specification and requirements of the greenhouse eco-management system. Second, we propose a system model for the link capacity of a gateway that is required to guarantee the delay performance of time-critical applications in the greenhouse LAN. Finally, the validity of the proposed system is demonstrated through a series of numerical experiments.

Index Terms: Greenhouse eco-management system, IoT, Performance evaluation, QoS, Smart farm

I. INTRODUCTION

Recently, severe weather and unexpected natural disasters such as heavy storms or flooding have destroyed greenhouses overnight. In addition, as farmers become older, it is increasingly difficult for them to monitor the environment and protect their greenhouses from unexpected disasters in a timely manner. In the near future, it is envisioned that the penetration of Internet of Things (IoT) technologies will enable various kinds of sensors and control systems to monitor and control greenhouse ecosystems in terms of the temperature, humidity, light, and so on. Farmers may open windows in the ceiling to control the temperature or monitor the growth status and security of plants in real time via CCTV cameras. When unexpected events occur, such as the intrusion of persons or animals in the greenhouse, the farmer should be informed immediately. This requires a timely delivery of information.

However, it is not always easy for farmers to visit their greenhouses or remain there indefinitely to monitor the ecosystem. Thus, rather than requiring a physical visit, it would be better to monitor the ecosystem of the greenhouse online. The introduction of information and communications technology (ICT) to agriculture, especially in the planting systems of greenhouses, is considered to be one of the major solutions for protecting greenhouses from disasters as well as monitoring the ecosystem of the plant production system. Applying the principles of IoT to greenhouses, farmers would be able to monitor the status and have optimal control of the greenhouse whenever and wherever they wished using a mobile terminal such as a smartphone. Shin [1] argued that farmers could improve their welfare by building a common greenhouse eco-management system (G-EMS) that aggregates a number of small-scale plants, enabling control of the greenhouse ecosystem and the automated production and logistics of agricultural products. Ha [2] found that the time and cost of greenhouse management could be reduced by using the IoT: management time could be reduced from 180

Received 10 August 2017, **Revised** 06 November 2017, **Accepted** 08 November 2017

[*]**Corresponding Author** Hoon Lee (E-mail: hoony@cwnu.ac.kr, Tel: +82-55-213-3833)
Department of Information and Communications Engineering, Changwon National University, 20, Changwondaehak-ro, Uichang-gu, Changwon 51140, Korea.

Open Access https://doi.org/10.6109/jicce.2018.16.1.31 print ISSN: 2234-8255 online ISSN: 2234-8883

to 10 minutes and the cost could be reduced from KRW 270,000 to KRW 15,000 (1 USD = 1,100 Korean won [KRW]).

There are a number of studies promoting the use of IoT for smart farming [3]. The author summarized his recent research using a ubiquitous sensor network (USN) to support plant production in greenhouses. He advocated an Ethernet-based LAN for the greenhouse LAN (G-LAN) in terms of cost efficiency. Ethernet itself has generic performance limits for real-time traffic when implemented as a G-LAN, because it is operated using the CSMA/CD MAC protocol.

There are numerous alternatives for the implementation of a router that connects a G-LAN to the outside Internet. Some use a virtual private line with a high Quality of Service (QoS), although this approach has a high communication price, and others use a best effort (BE) Internet without any QoS guarantees. Nevertheless, it is very important to guarantee the QoS of traffic between the G-LAN and Internet. In particular, the timely arrival of information from the greenhouse to the farmer is very important, as we have described above.

However, to the best of the author's knowledge, the performance evaluation and link dimensioning of a router connecting the G-LAN to the outside Internet with guaranteed QoS has not previously been studied. This gap in the literature provided the motivation for this work.

This paper is composed as follows. In Section II, we describe the specification of the G-EMS. In Section III, we propose a system model for the router that connects the G-LAN to the Internet. In Section IV, we present the results of numerical experiments. Section V contains a summary of this study.

II. GREENHOUSE ECO-MANAGEMENT SYSTEM

First, we describe the specification of the G-EMS. We then discuss the requirements for the network equipment that connects the G-EMS to the Internet.

A. Greenhouse Eco-management System

G-EMS consists of four elements: server, core network, gateway, and area network [4]. The server (e.g., server in a cloud or a private server) is usually located at a remote site. The other extreme is the area network for G-EMS, consisting of all the sensors and controllers. The area network is connected to the core network via a gateway.

The basic operation of the G-EMS is as follows. Sensor information is generated by each sensor and transferred to the gateway. The gateway transfers the information to the server in real time via the core network. The server analyzes the information and determines an appropriate activity for the controller inside the G-EMS. The message for controller activation is transferred to the corresponding sensor, and is also transferred to the farmer for notification.

In the greenhouse, there may exist various controllers and sensors for monitoring the environment and controlling various equipment. There are two kinds of sensors: near-earth sensors and over-the-air sensors. Near-earth sensors monitor the earth temperature, humidity, and pH of the soil. Over-the-air sensors monitor air temperature, wind, humidity, light, density of CO_2, and so on.

The various controllers include webcams, ceiling controllers, curtain controllers, fan controllers, heat and light controllers, crop and shipping management systems, and so on. The number of sensors varies according to the scale of the greenhouse. Typically, as many as four sensors of each type are needed for a greenhouse of 1 ha (10,000 m^2) [3]. The number of controllers also differs with the scale: webcams are needed at every corner of the greenhouse and an arbitrary number of other controllers may be required. A variety of information is generated in the greenhouse: the webcams generate a continuous stream of video, some sensors transmit environmental information periodically, and other sensors and controllers generate sporadic bursts of data concerning changes in the ecosystem of the greenhouse.

The information generated from the G-EMS is divided into two categories: real-time information and non-real-time information. Real-time information requires the network system to serve the packets in real time, so that packets generated by information from the real-time sensors and controllers at the G-EMS must be treated in real time. Non-real-time information does not require the network system to serve the packets in real time, so packets generated by information from the non-real-time sensors and controllers at the G-EMS can be treated in the BE manner.

The monitoring and collection of information depend on the type of information, with the monitoring interval ranging from a few seconds to a few minutes. To network the sensors and controllers inside the greenhouse, an integrated wired and wireless LAN is used. Some devices are connected to a wired LAN and other devices are connected to a wireless LAN. It is envisioned that Ethernet will be used for the wired LAN with Wi-Fi for the wireless LAN.

Recently, LANs have been constructed inside greenhouses such that the sensors and controllers are equipped with a low-cost PC and are connected to the LAN using Ethernet or Wi-Fi. A G-LAN is connected to the Internet through a gateway, allowing the environment of the greenhouse to be monitored and controlled by the farmer from a remote site. For this environment to be realized, a low-cost switch hub and router must be located between the G-LAN and the Internet.

Summarizing our argument, the basic components of the G-LAN are sensors and ecosystem controllers (ECs), which are aggregated to the hub via Ethernet or Wi-Fi [3]. The aggregated traffic from the G-LAN is transferred to the Internet via a gateway router located between the hub and the Internet. Therefore, the gateway router is a potential bottleneck. Note that the end-to-end packet transmission path is composed of three areas: LAN, access network, and Internet. The latency is mostly affected by the performance of the access network, because the performance of the LAN is limited to its generic specification and the Internet backbone generally has sufficient capacity.

In terms of the bandwidth for the G-LAN, there exist two disparate points: inside the LAN and outside the LAN. First, as to the inside of the LAN, the G-EMS packets are generally small and have a low generation rate. Therefore, a 10-Mbps link is sufficient inside the G-LAN. Second, outside of the LAN, customers have to determine the link capacity between the gateway router and the Internet, because they must buy a service plan from an ISP that matches their traffic volume.

Customers with small-scale traffic requirements often use an asymmetric digital subscriber line (ADSL) connection to access the Internet. The achievable link capacity for ADSL1 (ADSL2) is 12 Mbps (24 Mbps) for downstream traffic and 1.8 Mbps (3.5 Mbps) for upstream traffic [5, 6]. Note that the uplink capacity is much lower than the downlink capacity. In contrast, the traffic from G-LAN is asymmetric in the reverse way, with the uplink traffic capacity much higher than that of the downlink. This presents a very serious problem to the customers, because they have no right to rearrange the upstream and downstream traffic rates.

Naturally, the higher the link rate, the higher the cost of the plan. Therefore, customers must carefully consider the uplink performance of the G-LAN. Latency is mostly affected by the quality (including capacity) of the access link, modem buffering, and cross traffic [7]. Therefore, the capacity of the access link has to be determined accurately by considering the cost and performance.

B. Requirements for G-EMS

There are a number of requirements for constructing the G-EMS. First, the cost of constructing the G-EMS should be as low as possible. At present, the cost of devices such as sensors and controllers, as well as the PC and network devices, is very low. This makes it possible for farmers to consider the introduction of IoT to the management of greenhouse ecosystems.

The information generated from the G-EMS has diverse QoS requirements. Some information has to reach the farmer in real time, whereas other information does not.

The problem lies in the conflict between the desire for low-cost devices and the strict QoS requirements of applications generated by G-EMS. This is a trade-off problem. As mentioned before, there is no alternative to constructing the LAN itself inside the G-EMS, except for using conventional wireless LAN. A certain number of Wi-Fi devices, sensors, and controllers are deployed according to the scale of the greenhouse.

The router is the only bottleneck between the G-EMS and the Internet. The best way to provide QoS for the G-EMS is to implement a high-performance router with a DiffServ (DS) function. A router with DS (usually called a DS router) classifies the arriving packets into a number of classes. The number of classes is not fixed: ITU-T Standard Y.1541 defines six classes (0–5) [8]. The Internet Engineering Task Force (IETF) prepares three bits of a DiffServ code point (DSCP) that can classify the packets into a maximum of eight classes [9]. IETF recommends only three per-hop behaviors (PHBs) such as BE, assured service (AS), and expedited forwarding (EF). There is an association for the QoS class between ITU-T and IETF [8]. Note that the gateway router has to be designed in a lightweight manner. Thus, we argue that the QoS should be further simplified into real-time and non-real-time classes to incorporate the time-critical aspects of certain applications.

Once the packets have been classified, they are buffered to the queue of the corresponding class. The link fetches those packets based on class, and the fetch mechanism is determined by the vendor.

Implementing a router with a DS function is relatively expensive, and it is unrealistic to apply it in the realization of low-cost G-EMS. An alternative is to use a BE router without a service class.

However, the strict requirements of real-time applications cannot be guaranteed if a BE router is used in G-EMS, because packets of different classes are treated equally at the router. To resolve this problem, the offered load of the traffic in the BE router must be limited to a certain level, as described later.

Summarizing the discussion on the requirements of a gateway router for G-EMS, we propose the following.

First, a gateway router for G-EMS has to offer lightweight packet treatment operations. Thus, the packet scheduler should be as simple as possible, and we propose using either strict priority (SP) or first-in-first-out (FIFO).

Second, the link capacity for the output port of the gateway router should be estimated in such a way that the delay target of time-critical applications from the G-EMS are guaranteed irrespective of the packet scheduling policy being operated.

Note that this study does not aim to recommend a single or optimal solution, which is almost impossible. Rather, we attempt to compare the two scenarios (SP and FIFO) for implementing the gateway router for G-EMS, and examine their performance regarding the link capacity required to guarantee a target delay performance.

III. SYSTEM MODEL

In this section, we present an analytic model for the gateway router. The purpose of modeling the router in the G-EMS is to evaluate the performance and decide the capacity of the router. Note that the delay performance of a router is determined by several factors, such as the offered load, mixing ratio of real-time and non-real-time traffic, link capacity of the output port, QoS requirements (packet delay or loss rate), and service policy. Among these, factors other than the link capacity are usually given as conditions for the system. Therefore, this study focuses on the link capacity of the router required to secure an optimal level of performance for the G-LAN.

As mentioned in Section II, the router can operate two policies: DS or BE. In a router with a DS policy, packets are classified into real-time packets (class 1) and non-real-time packets (class 2). The class 1 packets have priority over class 2 packets in terms of being served by a link.

There are various schedulers for the DS function. Among them, SP is the friendliest scheme for class 1 packets [10]. In a router with the BE policy, there is no priority in the packet service and packets are served in a FIFO manner. This study considers an SP scheme with non-preemptive service for the DS policy and a FIFO scheme for the BE policy. Under these conditions, we investigate the range of performance in the router with the best and worst QoS for class 1 packets. Note that almost all packet scheduling solutions in conventional routers lie in the range between these two policies.

Before describing the queuing model, we define some common parameters for the system. Let λ be the mean packet arrival rate to the router from the G-LAN. The packet arrival process used for environment monitoring applications is usually assumed to obey a Poisson distribution, because the arrival of packets from different sensors is independent and the number of packets from a large number of sensors is sufficiently large in a real environment [10]. Therefore, we assume that the arrival process of the packet to the router follows the Poisson distribution.

Let us assume that the packet service time is exponentially distributed, because the size of the packets in the G-EMS is usually small. Let us assume that the system has one server, because there is only a single link for each port of the router. Summarizing the assumptions described so far, the system can be modeled as an M/M/1 queue. In the following, we present a queuing model for each mode.

A. Router with DS Policy

Let us assume that a packet classifier divides the packets into two classes: class 1 for the real-time traffic and class 2 for the non-real-time traffic. Let us assume that λ_i ($i = 1$ or 2) is the mean arrival rate of packets generated from class i traffic. Let μ_D be the mean service rate of the packets in the output link. Let Q_1 and Q_2 be the buffer capacities for the class 1 and class 2 packets, respectively, which are assumed to be sufficiently large.

Let us focus on the delay performance of Q_1, where the packet delay requirements are very strict. Let $\overline{Q}_1$ be the mean length of Q_1 and let ρ_1 and ρ_2 be the mean offered loads of Q_1 and Q_2, respectively. We assume that $\rho_1 = (1 - \beta)\rho$, where β is the mixing ratio of the class 2 packets over the total offered load.

The mean sojourn time (MST, denoted by $\overline{S}_1$) of the class 1 packets, which is defined by the mean time spent by a packet in the system (buffer and server) is given as follows:

$$\overline{S}_1 = \frac{\overline{Q}_1}{\mu_D} + \frac{1}{\mu_D} + \frac{\rho_2}{\mu_D}. \tag{1}$$

In this formula, the first term is the mean delay of an arriving packet (AP) caused by serving the class 1 packets that have arrived before the AP. The second term is the mean service time of the AP, and the final term is the mean delay of an AP caused by serving a class 2 packet at the time of arrival of the AP (a delay due to the non-preemptive property of the scheduler).

From Little's law, we have

$$\overline{Q}_1 = \lambda_1 \overline{S}_1. \tag{2}$$

From (1) and (2), we obtain

$$\overline{S}_1 = \frac{1}{\mu_D}\frac{1+\rho_2}{1-\rho_1}. \tag{3}$$

Let us assume that the target MST (T-MST) of the class 1 packets in a router is δ. The purpose of the modeling is to determine the minimum link capacity of a router that satisfies the following condition:

$$\overline{S}_1 \le \delta. \tag{4}$$

From (3) and (4), we obtain the following result for the link capacity:

$$\mu_D \ge \frac{\delta(1-\beta)\lambda + 1 + \sqrt{(\delta(1-\beta)\lambda+1)^2 + 4\delta\beta\lambda}}{2\delta}. \tag{5}$$

Note that μ_D is determined by factors such as the mean arrival rate and mixing ratio of class 1 and class 2 packets, as well as the delay requirements of the class 1 packets.

B. Router with BE Policy

For a router with the BE policy, there is no service differentiation for the different packet types, so all packets are stored in a single queue and are served according to FIFO.

The mean arrival rate of packets from the aggregated class 1 and class 2 traffic is λ and μ_B is the capacity (or mean service rate) for the link that connects the router to the Internet. Q is the capacity of a buffer.

The formula for the MST of an M/M/1 queue with FIFO service is well known, so we do not elaborate on the mathematical derivation here (see [11] for detailed analysis).

In this case, the MST of packets for both class 1 and class 2 traffic is denoted by $\overline{S_C}$, where the index C implies 'common', and is given as follows [11]:

$$\overline{S_C} = \frac{1}{\mu_B - \lambda}. \tag{6}$$

The link capacity of the router is determined from the following condition:

$$\overline{S_C} \le \delta. \tag{7}$$

From the above formula, we obtain the following result for the link capacity:

$$\mu_B \ge \lambda + \frac{1}{\delta}. \tag{8}$$

IV. NUMERICAL EXPERIMENTS

To evaluate the performance and compute the required service rate (RSR) of a link in the router, we conducted a numerical experiment. Let us assume that the mean packet size is 100 bytes and the mixing ratio of the class 2 packets over the total offered load is $\beta = 0.5$ (these values are effective throughout this experiment).

First, note that the mixing ratio has negligible impact on the required capacity of the link or the delay performance of class 1 packets when an SP scheme is used for the router (for a detailed discussion, see [12]). Therefore, we can obtain the same results for any arbitrary value of the mixing ratio.

The T-MST (which is equal to δ) of a packet at a router is assumed to be a parameter. In [13], the delay budget is found to be distributed throughout the end-to-end route of a packet. However, there is no fixed rule for the determination of the delay budget; it depends on the policy of the network service provider. In general, the delay budget in a router ranges from a few milliseconds to a few tens of milliseconds. Therefore, let us assume a comprehensive range of T-MST (δ = 1, 5, 10, 20, and 100 ms).

Figs. 1 and 2 show the required link capacity of the router with the DS and BE policies, respectively. The x-axis represents the mean input rate of class 1 packets (50–450 kbps). The y-axis represents the T-MST of class 1 packets (1, 5, 10, 20, and 100 ms). The z-axis represents RSR in the router (in kbps). Clearly, RSR depends on the mean input rate of the class 1 packets and the T-MST. In particular, RSR increases significantly when the T-MST becomes very small. Note also that RSR with the BE policy is much greater than with the DS policy. This indicates that customers who adopt a low-cost router with the BE policy must prepare a much faster link for the gateway as compared with the input traffic if they wish to receive Internet access with strict real-time properties.

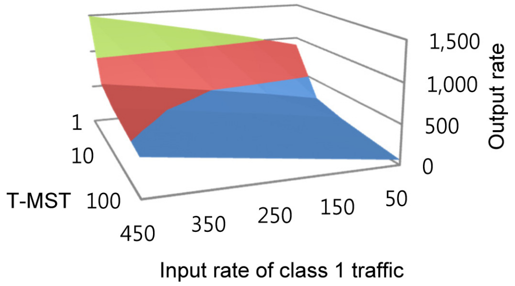

Fig. 1. Link capacity of the router with DS policy.

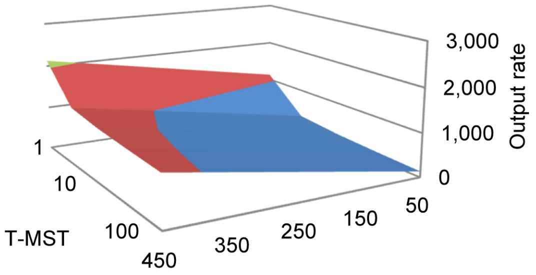

Fig. 2. Link capacity of the router with BE policy.

From Figs. 1 and 2, the difference between m_D and m_B becomes more evident as the mean input rate of the class 1 packets increases. This implies that bandwidth has to be provisioned more conservatively for the router with the BE policy, as the offered load to the system must be high to guarantee the delay QoS of the real-time traffic. The same trend can be obtained for different values of T-MST. Though not shown above, we also found that the delay performance of class 1 packets under the DS policy is independent of the offered load of class 2 traffic. This implies that we do not have to limit the offered load of class 2 traffic in the router with the DS policy to guarantee the T-MST of class 1 packets.

However, the story is different when it comes to the delay performance of class 1 packets in the router with the BE policy. As argued at the end of Section II, it is necessary for the

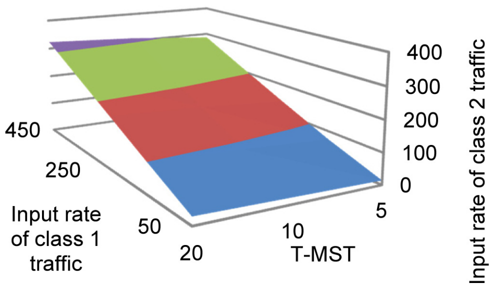

Fig. 3. Upper bound of the input rate for class 2 traffic.

offered load of the class 2 traffic in the BE router to be limited to a certain level if we wish to achieve the T-MST for the class 1 packets.

From Eqs. (6) and (7), we can obtain the upper bound of the input rate of the class 2 traffic, which is shown in Fig. 3.

The x-axis represents the mean input rate of class 1 traffic (50–450 kbps), the y-axis represents the T-MST (5, 10, and 20 ms), and the z-axis represents the upper limit of the input rate of class 2 traffic (in kbps).

Fig. 3 indicates that the input rate of class 2 traffic must be suppressed to a certain level to satisfy the T-MST of class 1 traffic: the lower the T-MST, the lower the input rate of class 2 traffic.

V. CONCLUSION

In this study, we have developed an analytic framework for evaluating the performance and dimensioning the link capacity of the gateway router connecting a G-LAN to the Internet. We summarized the specification and QoS requirements of the G-EMS, from which we argued the necessities of the performance evaluation for a gateway router. We then proposed an analytic model for the gateway router with best and worst delay performance for time-critical services under the G-EMS. Extensive numerical computations illustrated the validity of the proposed method.

The novelty of this work can be summarized as follows. First, we have investigated the performance issue of the G-EMS, which, to the best of our knowledge, is the first such attempt in this field. Second, we presented an analytic framework for the performance modeling of G-LAN gateway routers, which is the major contribution of this work. Finally, we determined several quantitative results for the performance of the G-LAN gateway router for both best- and worst-service scenarios, from which we obtained the operating range of the router. This has important implications for customers, because they can evaluate the performance of their G-LAN system and estimate the required capacity of the link in the access network between G-LAN and the Internet.

This work is considered to be a first step toward the comprehensive performance evaluation of G-EMSs with strict QoS constraints. Therefore, many studies that account for the real environment of greenhouses are expected in the near future.

In future research, we will investigate the attributes of sensors and controllers that are deployed in the field, from which we can fine-tune the arrival and service process parameters of the queuing system. It is also necessary to accumulate real-field data about the volume of traffic generated by a G-LAN, which will provide a new viewpoint for the modeling of the system.

We expect that this work could be extended to evaluate the performance and design of a more general purpose IoT system if more general analytic models for the traffic and system were developed; this is left for future research. An analysis on the cost of IoT services will be also needed, which is in line with the work in [14].

ACKNOWLEDGMENTS

This research was financially supported by Changwon National University in 2017–2018.

REFERENCES

[1] Y. S. Shin, "A way to make job opportunity for young people by using ICT," Chosunilbo, 2013 [Internet], Available: http://srchdb1.chosun.com/pdf/i_archive/read_body.jsp?Y=2013&M=02&D=12&ID=2013021200052.

[2] Y. H. Ha, "There is an answer in the converged creative farming," Chosunilbo, 2013 [Internet], Available: http://srchdb1.chosun.com/pdf/i_archive/read_body.jsp?Y=2013&M=02&D=18&ID=2013021800042

[3] T. Hoshi, "Plant production support in greenhouses by ubiquitous sensor networks," *Journal of the Institute of Electronics, Information, and Communication Engineers*, vol. 95, no. 9, pp. 779-783, 2012.

[4] T. Kinoshita, "Smart sensor network (Series No. 5): Wireless network that connects intelligent sensors with low power consumption," *Nikkei Communications*, pp. 78-81, 2012.

[5] International Telecommunication Union, *Asymmetric digital subscriber line transceivers*, ITU-T Recommendation G.992.1, 1999.

[6] International Telecommunication Union, *Asymmetric digital subscriber line (ADSL) transceivers – Extended bandwidth ADSL 2 (ADSL2plus)*, ITU-T Recommendation G.992.5, 2003.

[7] S. Sundaresan, W. De Donato, N. Feamster, R. Teixeira, S. Crawford, and A. Pescape, "Broadband internet performance: a view from the gateway," in *Proceedings of the ACM SIGCOMM Conferences*, Toronto, Canada, pp. 134-145, 2011. DOI: 10.1145/2018436.2018452.

[8] International Telecommunication Union, *Network performance objectives for IP-based services – Appendix VI: Applicability of the IETF differentiated services to IP QoS classes*, ITU-T Recommendation Y.1541, 2002.

[9] K. Nicholas, D. L. Black, S. Blake, and F. Baker, "Definition of the differentiated services field (DS field) in the IPv4 and IPv6 headers," The Internet Engineering Task Force (IETF), Fremont, CA, *RFC*

2472, 1998.

[10] F. M. Al-Turjman, H. S. Hassanein, and M. A. Ibnkahla, "Efficient deployment of wireless sensor networks targeting environment monitoring applications," *Computer Communications,* vol. 36, no. 2, pp. 135-148, 2013. DOI: 10.1016/j.comcom.2012.08.021.

[11] H. Lee, *Fundamentals on Queuing Theory*. Seoul: Bumhan Book, 2011.

[12] H. Lee, "Anatomy of delay performance for the strict priority scheduling scheme in multi-service Internet," *Computer Communications*, vol. 29, no. 1, pp. 69-76, 2005. DOI: 10.1016/j.comcom.2005.05.006.

[13] H. Lee, M. Hwang, C. Kang, S. Jang, J. Lee, H. Ha, D. Yeom, T. Lee, and M. Yoon, "A study on the guarantee of packet based end-to-end QoS," National Computerization Agency, Seoul, Korea, *Report No. NCA II-RER-03032*, 2003.

[14] D. H. Youm and V. Kuraku, "Cost of content services to hybrid computing," *Asia-Pacific Journal of Convergent Research Interchange*, vol. 2, no. 1, pp. 1-6, 2016. DOI: 10.21742/APJCRI.2016.03.01.

Hoon Lee

received the B.E. and M.E. degrees in electronics from Kyungpook National University, Korea in February 1984 and 1986, respectively. He received the Ph.D. degree in electrical and communications engineering from Tohoku University, Japan in March 1996. He worked at the KT R&D Center from 1986 to 2000 as a research staff. At present, he is a professor with Changwon National University, Korea. His research interests include traffic engineering and design of Internet.