

Burst-Polling Based Dynamic Bandwidth Allocation using Adaptive Minimum Guaranteed Bandwidth for EPONs

Wansu Lim, Changho Yun, Yeon-Mo Yang, Hyunju Lee, and Kiseon Kim

Abstract—In this paper, enhanced burst-polling dynamic bandwidth allocation (EBDBA) method is proposed to support broadband access networks based on quality of service (QoS) for ethernet passive optical networks (EPONs). EBDBA adaptively increases or decreases the minimum guaranteed bandwidth of the three traffic class—expedited forwarding (*EF*), assured forwarding (*AF*), and best effort (*BE*) traffic—according to the requested bandwidth of an optical network unit (ONU). Therefore, network resources are efficiently utilized and adaptively allocated to the three traffic classes for unbalanced traffic conditions. Simulation results using OPNET show that EBDBA outperforms conventional bandwidth allocation schemes in terms of the average packet delay (it decreases the maximum performance range to 68%) and the network throughput (it increases maximum performance range to 20%) at a given offered load of 1.2.

Index Terms—Dynamic bandwidth allocation (DBA), Ethernet passive optical network (EPON), Quality of service (QoS).

I. INTRODUCTION

Ethernet Passive Optical Networks (EPONs) can be considered one of the best candidates for next-generation access networks because of low cost Ethernet equipment, fiber infrastructure, and efficient broadband capabilities [1]. As defined in the IEEE 802.3 standard [2], an EPON uses a multi-point control protocol (MPCP) for resource distribution. In the upstream, every optical network unit (ONU) shares the same channel, so data collisions may occur; thus, an efficient bandwidth allocation strategy is required in order to ensure that the entire bandwidth is fully utilized.

To this end, Kramer et al. [3] proposed an optical line terminal (OLT)-based polling dynamic bandwidth allocation (DBA) method called interleaved polling

with adaptive cycle time (IPACT). In [4], when an OLT allocates bandwidth to ONUs, the minimum guaranteed bandwidth is used as the reference for each ONU's bandwidth allocation. According to the minimum guaranteed bandwidth [4], ONUs are divided into two groups: light-loaded and heavily loaded ONUs. For light-loaded ONUs, the requested bandwidth is smaller than the minimum guaranteed bandwidth, whereas in heavily loaded ONUs, the requested bandwidth is greater than the minimum guaranteed bandwidth. Thus, the heavily loaded ONUs request additional bandwidth from the light-loaded ONUs. [5] added one significant condition to the bandwidth allocation of [4]. If the total extra bandwidth demanded by the heavily loaded ONUs is smaller than the total excessive bandwidth of the light-loaded ONUs, the OLT does not allocate additional bandwidth to the heavily loaded ONUs. In particular, [6] suggested Delta DBA method that preferentially allocates the extra bandwidth to high priority traffic class for considering the quality of service (QoS) based on a class of service (CoS). It should be noted, however, that although the above DBA schemes improve network performance, they still use a *fixed* minimum guaranteed bandwidth. Hence, as they do not effectively deal with variations in network traffic, especially in burst traffic, network delays and throughput may actually worsen. Therefore, more effective DBA is required in order to overcome this problem.

In this paper, we propose enhanced burst-polling DBA (EBDBA), which adaptively changes the minimum guaranteed bandwidth according to the ingress traffic flow to minimize bandwidth wastage. Consequently, it is expected that packet delay would decrease and throughput increase. To verify the improvement in performance, the average packet delay and the network throughput for the three traffic classes defined in [7]—expedited forwarding (*EF*), assured forwarding (*AF*), and best effort (*BE*) traffic—are analyzed based on a series of simulations.

II. ENHANCED BURST-POLLING DBA (EBDBA)

The EBDBA scheme specifies that every ONU is polled periodically in a burst manner, OLT-based BP scheme [6]. With the BP scheme, three grants are

Wansu Lim and Kiseon Kim are with the Department of Information and Communications, Gwangju Institute of Science and Technology Oryong-dong, Buk-gu, Gwangju 500-712, Korea (e-mail: wansu99@gist.ac.kr)

Changho Yun is with Korea Ocean Research and Development Institute (KORDI), Sinseong-gu, Daejeon 305-343, Korea

Yeon-Mo Yang is the with School of Electronic Engineering, Kumoh National Institute of Technology, 1, Yangho-dong, Gumi, Gyeongbuk, 703-701, Korea

Hyunju Lee is with System part/Develoemnt Group 3, LG Electronics Corporation, Korea

sent to each ONU, corresponding to the *EF*, *AF*, and *BE*, respectively. We consider an EPON in which N ONUs are connected to the OLT. Let the transmission speed of the EPON be R_{bps} , which is the same for both the upstream and downstream links. We define the granting cycle time T_{cycle} as the time interval during which all active ONUs can transmit payload data and/or REPORT messages to the OLT. There are two limit points, T_{MIN} and T_{MAX} . When the requested size is less than one-fourth of T_{MAX} , T_{cycle} will be T_{MIN} else it is T_{MAX} . Guard intervals T_g are necessary to avoid collisions from the timing fluctuations of the ONUs. Furthermore, we define $B^M[i][n]$ as the minimum guaranteed bandwidth at the i^{th} ONU and n^{th} cycle. The important thing to note with regard to the EBDBA, which is different from [4]-[6], is that we adaptively change $B^M[i][n]$ according to the traffic flow. Details are presented below:

- *Step 1.* Let $R[i][n]$ ($=R^{EF}[i][n] + R^{AF}[i][n] + R^{BE}[i][n]$) be the sum of the *requested* bandwidth for each traffic class at the i^{th} ONU and n^{th} cycle, $K^L[i][n]$ be the number of consecutively light-loaded cases for the i^{th} ONU, $K^H[i][n]$ be the number of consecutively heavily loaded cases for the i^{th} ONU, TH^L be the threshold value of $K^L[i][n]$, and TH^H be the threshold value of $K^H[i][n]$. When an ONU satisfies $K^L[i][n] = TH^L$, we calculate an average value of all consecutive surplus bandwidth of corresponding light-loaded ONUs, $B_{light}^{avg}[i]$. Then, we obtain the sum of average values of all light-loaded ONUs, B_{total}^{rem} .

$$B_{light}^{avg}[i] = \frac{\sum_{j=1}^{TH^L} (B^M[i][n-j] - R[i][n-j])}{TH^L}, \quad (1)$$

$$B_{total}^{rem} = \sum_{i \in L} B_{light}^{avg}[i]$$

where L is the set of light-loaded ONUs. In addition, when an ONU satisfies $K^H[i][n] = TH^H$, we calculate an average value of all consecutive deficient bandwidth of corresponding heavily loaded ONUs, $B_{heavy}^{avg}[i]$. Then, we obtain the sum of average values of all heavily loaded ONUs, B_{total}^{req} .

$$B_{heavy}^{avg}[i] = \frac{\sum_{j=1}^{TH^H} (R[i][n-j] - B^M[i][n-j])}{TH^H}, \quad (2)$$

$$B_{total}^{req} = \sum_{i \in H} B_{heavy}^{avg}[i]$$

where H is the set of heavily loaded ONUs.

- *Step 2.* After calculating the above parameters in Step 1, if light-loaded and heavily loaded ONUs exist, we will change $B^M[i][n]$ as follows:
 - 1) The light-loaded ONU

$$B^M[i][n] = B^M[i][n-1] - B_{light}^{avg}[i] \quad (3)$$

- 2) The heavily loaded ONU

$$B^M[i][n] = B^M[i][n-1] + \frac{B_{heavy}^{avg}[i]}{B_{total}^{req}} \times B_{total}^{rem}. \quad (4)$$

The pseudocode for modification of the minimum guaranteed bandwidth is shown in Algorithm 1.

Let $B^g[i][n]$ be the *granted* bandwidth for the i^{th} ONU and n^{th} cycle. After adaptively changing $B^M[i][n]$, we allocate $B^g[i][n]$ to the i^{th} ONU as follows:

- *Step 1.* When $B^M[i][n] > R[i][n]$, we calculate a total *surplus* bandwidth, $B_{total}^{sur} = \sum_{i \in L} (B^M[i][n] - R[i][n])$. When $B^M[i][n] < R[i][n]$, we calculate a total *deficient* bandwidth, $B_{total}^{def} = \sum_{i \in H} (R[i][n] - B^M[i][n])$.
- *Step 2.* After calculating B_{total}^{sur} and B_{total}^{def} , OLT allocates the bandwidth to the ONUs as follows: if $B_{total}^{sur} \geq B_{total}^{def}$ or $R[i][n] \leq R^M[i][n]$, $B^g[i][n] = B^M[i][n]$; otherwise, $B^g[i][n]$ is as follows:

$$B^g[i][n] = R^M[i][n] + \frac{(R[i][n] - B^M[i][n])}{B_{demand}^{total}} \times B_{total}^{sur}. \quad (5)$$

The pseudocode for the inter ONU scheduling is shown in Algorithm 2. The calculated bandwidth will then be the input parameter to the intra ONU priority scheduling to calculate each grant size for the *BE*, *AF*, and *EF* slot sizes, respectively. Subsequently, after finishing the intra ONU priority scheduling at the OLT, the OLT only needs to send one GATE message that includes three grant sizes to each ONU.

III. PERFORMANCE EVALUATION

In order to validate the proposed scheme, we performed computer simulations similar to those in [3] for a scenario consisting of a simplified access PON network with 16 ONUs. To do this, we used the OPNET network simulator [8] [9] and then compared EBDBA method with three different DBA methods ([5]: ADBA, [6]: SDBA, and [7]: YDBA). Table 1 gives a qualitative comparison between EBDBA and some other typical DBA schemes introduced earlier. Finally, we choose two metrics to evaluate the performance of EBDBA: 1) the average packet delay, and 2) the network throughput.

A. Simulation Environments

For our simulations, the EPON consists of one OLT and 16 ONUs in a star topology connected by full-duplex 1 Gbps links. The following conditions are also used in this configuration. The fiber lengths between an OLT and each ONU are uniformly given as 20 km because the ranging problem associated with non-uniform distances can be reasonably compensated for by using a set of fiber spools in practice [3]-[5]. The transient state auto-discovery process has already finished, and each OLT knows the round-trip delay time (RTT) of all ONUs at the beginning of the simulation,

TABLE I

A COMPARISON OF DIFFERENT DBA SCHEMES (TOS: TYPE OF SERVICE, COS: CLASS OF SERVICE, N : THE NUMBER OF ONUS).

DBA	Polling scheme	Sharing the surplus bandwidth	Ingress/egress queue	Minimum guaranteed bandwidth	Time complexity	Comments
IPACT [3]	IPACT	Single ONU	Do not use	Do not use	$O(N)$	- Unsuitable for delay and jitter-sensitive service -Wastes downstream time due to frequent gating upon small-sized packets
ADBA [4]	Non-IPACT polling	Whole ONU	Do not use (ToS)	Fixed	$O(3N)$	- Minimizing packet delay in the <i>EF</i> traffic class -Higher-priority traffic may be transmitted later than lower-priority traffic
SDBA [5]	Non-IPACT polling	Whole ONU	Do not use (ToS)	Fixed	$O(3N)$	-This scheme essentially excludes potential overgranting to ensure higher bandwidth utilization
YDBA [6]	Burst polling	Delta scheduling	Use (ToS/CoS)	Fixed	$O(5N)$	- Supporting intra-ONU priority scheduling - Possible to design more sophisticated DBA with BP
EBDBA	Burst polling	Whole ONU	Use (ToS/CoS)	Variable	$O(5N)$	-Maximizing the network throughput for the <i>AF</i> and <i>EF</i> packets - Minimizing the average packet delay to the <i>EF</i> packet

Algorithm 1 Pseudocode for the modification of the minimum guaranteed bandwidth.

```

for ( $i \leq \text{NUM OF ONUS}$ ) do
   $B_{total}^{rem} = 0, B_{total}^{req} = 0;$ 

  if ( $K^L[i][n] = TH^L$ ) then

    Calculate  $B_{light}^{avg}[i]$  and  $B_{total}^{rem}$  according to Eq. (1)

  end if
  if ( $K^H[i][n] = TH^H$ ) then

    Calculate  $B_{heavy}^{avg}[i]$  and  $B_{total}^{req}$  according to Eq. (2)

  end if
end for

for ( $i \leq \text{NUM OF ONUS}$ ) do
  if ( $K^L[i][n] = TH^L$  and  $B_{total}^{req} > 0$ ) then

    Calculate  $B^M[i][n]$  according to Eq. (3)

  else
     $B^M[i][n] = B^M[i][n-1];$ 
  end if
  if ( $K^H[i][n] = TH^H$  and  $B_{total}^{rem} > 0$ ) then

    Calculate  $B^M[i][n]$  according to Eq. (4)

  else
     $B^M[i][n] = B^M[i][n-1];$ 
  end if
end for

```

given here as 35 μ s. Two groups of ONUs exist. One is a low-traffic group of ONUs (10 ONUs, light-loaded) generating a low traffic load, and the other is a high-traffic group (6 ONUs, heavily loaded) generating a high traffic load. T_{MAX} is 1.6 ms, and T_{MIN} is 0.41 ms. The guard time is 1.6 μ s. TH^L and TH^H are set to 5, respectively. In addition, the following information should be noted regarding traffic generation [9]. Each ONU in a traffic group generates three different traffic

Algorithm 2 Pseudocode for the inter ONU scheduling.

```

for ( $i \leq \text{NUM OF ONUS}$ ) do
   $R[i] = R^{EF}[i] + R^{AF}[i] + R^{BE}[i], B_{total}^{sur} = 0, B_{total}^{def} = 0;$ 

  if ( $B^M[i][n] > R[i][n]$ ) then
     $B_{total}^{sur} = B_{total}^{sur} + (B^M[i][n] - R[i][n]);$ 
  else
     $B_{total}^{def} = B_{total}^{def} + (R[i][n] - B^M[i][n]);$ 

  end if
end for

for ( $i \leq \text{NUM OF ONUS}$ ) do
  if ( $R_{total}^{sur} \geq R_{total}^{def}$  or  $R[i][n] \leq B^M[i][n]$ ) then
     $B^g[i][n] = R[i][n];$ 
  else

    Calculate  $B^g[i][n]$  according to Eq. (5)

  end if
end for

```

classes (*EF*, *AF*, and *BE* traffic), and each traffic class is modeled as a stochastic process governed by the Pareto distribution with the Hurst parameter (*HP*), such that $HP = 0.8$. *EF*, *AF*, and *BE* traffic classes generate 20%, 40%, and 40% of the ONU traffic, respectively. The size of the *EF* packet is only 64 bytes. The *AF* packet size is uniformly chosen from among 64, 512, or 1518 byte values. The packet size of the *BE* and *AF* packets are identical random variables.

B. Simulation Results

Fig. 1 compares the average packet delay of *EF* traffic with respect to the conventional ADDBA method of [4], the SDBA method of [5], and the YDBA method of [6]. Here, the average packet delay is defined as the average time measured in seconds between the generation of packets and their arrival in an OLT. As shown in Fig. 1, when the offered load is around

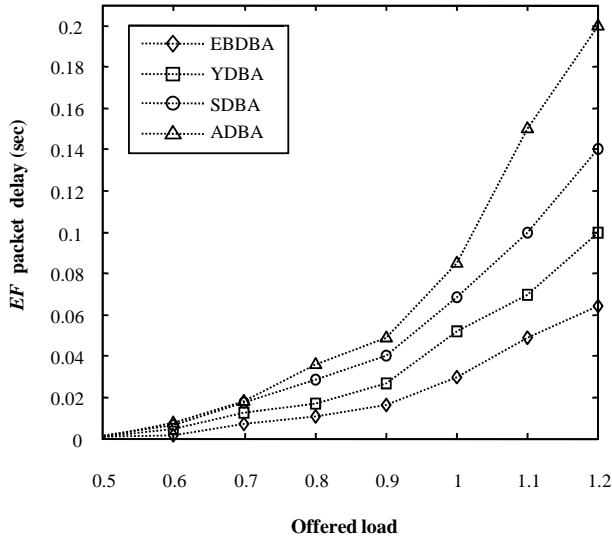


Fig. 1. Average packet delay for *EF* traffic class.

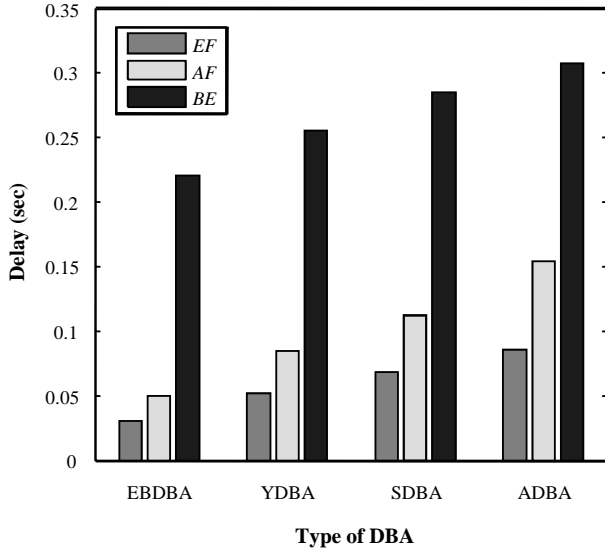


Fig. 2. Comparison of the average packet delay according to each DBA scheme when the maximum offered load is 1.0.

0.9, the average delay of *EF* traffic with ADBA rises to almost 0.05 s; however, the packet delay increase under EBDBA goes to 0.05 s at a load of 1.1, while still being lower than that of ADBA. Moreover, although EBDBA uses burst-polling, just as YDBA, the average packet delay in EBDBA decreases by almost 36% compared to YDBA. This is accomplished by changing the minimum guaranteed bandwidth when the offered load is high (1.2). This phenomenon is similar in both the *AF* and *BE* traffic classes. Fig. 2 shows the average packet delay according to each method of DBA when the offered load is 1.0. This load results in a considerable improvement in packet delay under the EBDBA scheme.

Fig. 3 shows the relationship between the network throughput and the entire network load (i.e., the offered load) under EBDBA, YDBA, SDBA, and ADBA.

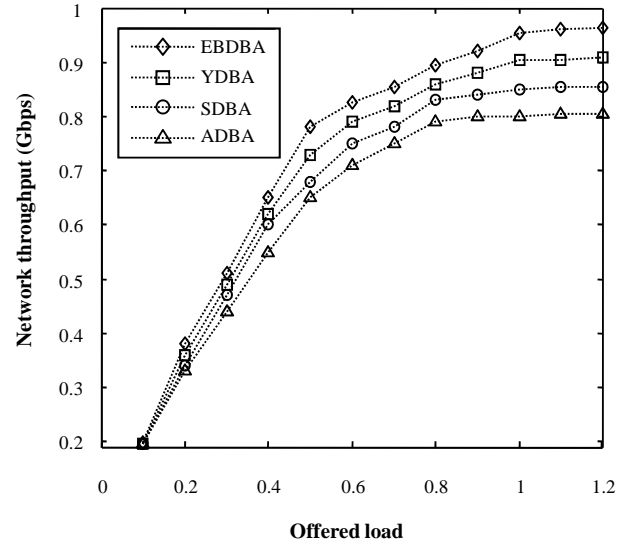


Fig. 3. Network throughput comparison between EBDBA and three other DBA methods.

The definition of network throughput is the sum of the bits arriving at an OLT in one second. In the figure, we observe that when the offered load is relative low (say, 0.3), the network throughput with EBDBA is similar to the other three DBA methods. Beyond a load of 1.0, however, EBDBA shows better performance than the other three DBA methods. The network throughput with EBDBA is similar to the other three DBA methods when the offered load is relatively low; beyond a load of 1.0, however, EBDBA increases to a value higher than that of all traffic classes for the other DBA methods. For example, at a given offered load of 1.2, the throughput using EBDBA increases by almost 7.8% when compared to YDBA. This higher throughput is achieved because EBDBA utilizes the surplus bandwidth more effectively in a burst traffic environment by changing the minimum guaranteed bandwidth.

IV. CONCLUSION

In this paper, we proposed an EBDBA method that considers QoS in EPONs. EBDBA improves the network performance by adaptively changing the minimum guaranteed bandwidth for EPONs, effectively allowing all ONUs to modify the minimum guaranteed bandwidth according to bandwidth demand. In other words, EBDBA ensures that all service classes proportionally share the bandwidth based on the ratio of demand for a single class to total demand. For example, the average packet delay with EBDBA decreases by 68% when compared to ADBA. Furthermore, the network throughput with EBDBA increases 20% for a given offered load of 1.2 when compared to ADBA. Based on these results, it is expected that EBDBA can both improve the overall network throughput and decrease the average packet delay when compared to the three other DBA methods under similar traffic

load environments. From our simulation results, it can be concluded that a burst-polling based bandwidth scheduling algorithm with adaptive minimum guaranteed bandwidth is an efficient DBA scheme for EPONs.

ACKNOWLEDGMENTS

This work was partially supported by the Center for Distributed Sensor Networks at the Gwangju Institute of Science and Technology (GIST), by the World Class University (WCU) program (R31-20008-000-10026-0), and by the Plant Technology Advancement Program (07SeaHeroB01-03) funded by the Ministry of Construction and Transportation, Korea.

REFERENCES

- [1] F. Effenberger, D. Clearly, O. Haran, G. Kramer, Ruo Ding Li, M. Oron, and T. Pfeiffer, "An introduction to PON technologies [topics in optical communications]," *IEEE Commun. Mag.* vol. 45, pp. s17–s25, Mar. 2007.
- [2] "IEEE standard for information technology — telecommunications and information exchange between systems — local and metropolitan area networks - specific requirements," *IEEE Std. 802.3ah* (2004).
- [3] G. Kramer, B. Mukherjee, "Interleaved polling with adaptive cycle time (IPACT): A dynamic bandwidth distribution scheme in an optical access network," *Photon. Netw. Commun.*, vol. 4, pp. 89–107, July 2002.
- [4] C.M. Assi and Y. Ye, "Dynamic bandwidth allocation for quality-of-service over ethernet PONs," *IEEE J. Sel. Areas Commun.*, vol. 21, pp. 1467–1477, Nov. 2003.
- [5] A. Shami and X. Bai, "QoS control schemes for two-stage ethernet passive optical access networks," *IEEE J. Sel. Areas Commun.*, vol. 23, pp. 1467–1478, Aug. 2005.
- [6] Y. Yang, B. Ahn, and J. Nho, "Supporting quality of service by using delta dynamic bandwidth allocations in ethernet passive optical networks," *J. Opt. Netw.*, vol. 4, pp. 68–81, Feb. 2005.
- [7] R. Bless and K. Wehrle, "IPMulticast in Differentiated Service (DS) Networks," *RFC 3754*, <http://www.rfc-editor.org/rfc/rfc3754.txt> (2004).
- [8] "OPNET Technology, Inc.," www.opnet.com.
- [9] J. Potemans, B. V. den Broeck, J. Theunis, P. Leys, E. V. Lil, and A. V. de Capelle, "Implementation of an advanced traffic model in OPNET Modeler," *OpnetWork 2003*, Washington D.C. USA (2003).



Wansu Lim received the B.S. degree in information and telecommunication engineering from Korea Aerospace University (KAU), in 2006, and the M.S degree in information and communications from Gwangju Institute of Science and Technology (GIST), Gwangju, Korea, in 2007. His research interests include the optical and wireless communication systems. Presently, he is pursuing the Ph.D. degree at GIST working on modeling of Ethernet passive optical networks (EPON) and the performance analysis of free space optical (FSO) systems.



Changho Yun was born in Busan, South Korea on Sept. 23, 1976. He received the M.S. and Ph. D. degrees in department of information and communication from Gwangju Institute of Science and Technology (GIST) in 2004 and 2007, respectively. He was a post-doc researcher in department of Computer Science in North Carolina State Univ. Currently, He is a senior researcher in the dept. of ocean engineering research from Korea Ocean Research & Development Institute (KORDI). He is also an assistant professor in dept. of underwater acoustic communication engineering from Univ. of Science and Technology (UST). His current research interests include broadband convergence network (BcN), next generation network (NGN), IP multimedia subsystem (IMS), as well as underwater acoustic network (UANet).

Hyunju Lee received the B.S. degree in electronics engineering from the Kyunghee University, in 2006, and the M.S degree in information and communications from Gwangju Institute of Science and Technology (GIST), Gwangju, Korea, in 2008. Her research interests include optical packet switching. Presently, she is working on System part/Development Group 3, LG Electronics Corporation, Korea.



Yeon-Mo Yang is a Professor in the department of Electronic Engineering, Kumoh National Institute of Technology, Gumi, Korea. He received the B. Eng in the field of electrical and electronic engineering from Korean Advanced Institute of Science and Technology (KAIST), Daejeon, Korea in 1990 and Ph.D. degree from Gwangju Institute of Science and Technology (GIST), Gwangju, Korea in 2006, in the field of optical networks. From 2005 to 2006 he was a post doctoral fellow in North

Carolina State University (NCSU), Raleigh in networks engineering. From 2006 to 2008, he was in Daegu-Gyeongbuk Institute of Science and Technology (DGIST) as a senior engineer where he has been a project leader of the developments of wireless sensor networks. His current research interests include wireless sensor networks analysis and implementation both at the physical layer and at the networks layer; dynamic bandwidth allocation schemes in passive optical networks; and realizations of hybrid embedded systems connected Mechanics and Information Technology.



Kiseon Kim received the B.Eng and M.Eng degrees, all in electronics engineering, from the Seoul National University, Seoul, Korea, in 1978 and 1980, and the Ph.D degree from the University of Southern California, Los Angeles, in 1987, in Electrical Engineering-Systems.

From 1988 to 1991, he was with Schlumberger in Texas as a senior development engineer where he has been involved in development of telemetry systems. From 1991 to 1994, he was a computer communications specialist for Superconducting Super Collider Lab, in Texas, where he has built data logging and analysis systems for high energy physics instrumentations. Since joining Gwangju Institute of Science and Technology, Korea, in 1994, he is currently a Professor. His current interests include wideband digital communications system design, analysis and implementation.