International Journal of Advanced Science and Technology
Volume 6, May, 2009

ELRR – Enhanced Limited Round Robin Mechanism using Priority Policy over Bluetooth Networks

Sunguk Lee[1], Haniph A. Latchman[1], and Byungjoo Park[2]

University of Florida, USA[1]
Hannam University, Daejeon, Korea[2]
{sunguk, latchman}@ufl.edu[1] and *bjpark@hnu.kr*[2]

Abstract

Bluetooth is a wireless communication technology that provides short-range, small-size, low-cost, and low-power connectivity among mobile devices. The MAC protocol for Bluetooth is based on a Time Division Duplex (TDD) scheme, where the master determines channel access to all other slaves in the piconet. Hence, the polling scheme used by the master has a significant effect on the Bluetooth system performance. Accordingly, this paper proposes an enhanced Limited Round Robin with a priority policy for Bluetooth. In simulations, the proposed scheduling algorithm demonstrates a better overall performance in a Bluetooth network.

Keywords: *Priority Policy, Bluetooth Networks, Robin Mechanism*

1. Introduction

Bluetooth is a wireless technology that allows communication devices and accessories to interconnect using a short-range, low-power, inexpensive radio. While initially developed to eliminate the numerous short-range cables involved in interconnecting mobile devices (laptops, mobile phones, headsets, PDAs, etc) in small networks, usually referred to as PANs (Personal Area Networks), Bluetooth has since expanded in scope to encroach on wireless LANs. As such, Bluetooth uses a fast frequency hopping (up to 1600 hops/sec) physical layer to resist the interference and is operated in a 2.4GHz ISM (Industrial Scientific Medicine) band. The band is divided into 79 channels of 1 MHz bandwidth. FEC (Forward Error Correction), ARQ (Automatic Repeat Request) and CRC (Cyclic Redundancy Check) are used to support adequate reliability on wireless environment [1].

The smallest Bluetooth unit is called a piconet, which is composed of one master node and several slave nodes (up to seven). In a piconet a Bluetooth device can be operate in active mode or sleep mode (Sniff, Hold and park mode). However just one master and seven active mode slaves are allowed in a piconet. If some nodes desire to switch the state to active mode, some active nodes should change the state from active mode to sleep mode when seven slaves are already operated in active mode. All nodes in a same piconet should follow same frequency hopping pattern. Multiple piconets can also exist in the same area and be connected via a bridge node, creating a scatternet. Figure 1 shows a piconet with one master and 5 slaves.

In a Bluetooth system, full-duplex transmission is supported using a master-driven TDD (Time Division Duplex) scheme to segment the channel into 625µs time slots, which are alternatively distributed between the master and the slaves. As such, the master sends a poll or data packet to a slave using the even-numbered slots, then the slave sends a packet to the master using an odd-numbered slot immediately after receiving a packet from the master [1]. Thus, the MAC scheduling in Bluetooth is controlled by the master and executed using master-slave pairs. All Bluetooth devices in a same piconet have to synchronize the clocking exactly and a node which has privilege of using the slot will not release the resource of transmission to other nodes even if it does not have any data to transmit. Hence Bluetooth seems to be inefficient but it can support more reliable connection. So Bluetooth is appropriate for high quality interconnection between mobile devices and many researchers have proposed algorithms to enhance the performance of Bluetooth network[2]-[6].

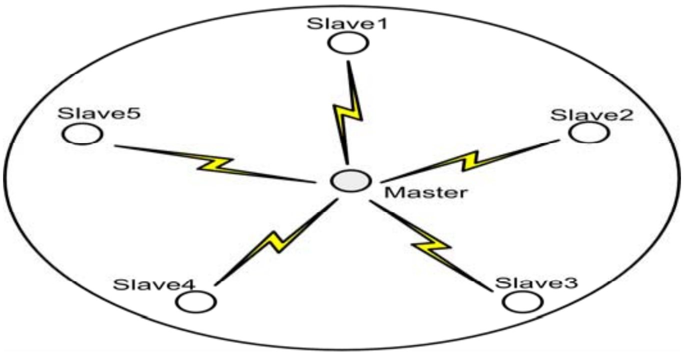


Figure 1. A Piconet with one master and 5 slaves

Bluetooth systems support two types of virtual data communication link between the master and slave: a Synchronous Connection Oriented (SCO) link and Asynchronous Connection-Less (ACL) link. An SCO connection supports a circuit-oriented service with a constant bandwidth using a fixed and periodic allocation of slots. An SCO connection is suitable for latency-sensitive multimedia traffic like voice traffic, whereas an ACL connection supports a packet-oriented service between the master and slave for data. An SCO connection only uses one time slot, while an ACL connection can use one, three, or five time slots according to the data packet size [1]. The Round Robin (RR) scheme is a default MAC scheduling algorithm for Bluetooth that uses a fixed cyclic order. The POLL packet does not have any information and just gives the polled slave the privilege of transmitting packet in next slot. If the polled slave does not have any data to transmit, it replies to the master by sending a NULL packet which also does not have any information. As a result, numerous slots can be wasted with POLL or NULL packet exchanges in the case of no data to transmit. Despite the introduction of several Bluetooth MAC scheduling algorithms to reduce these slot waste, problems still remain.

Accordingly, this paper proposes a simple and efficient MAC scheduling algorithm to reduce slot waste and enhance the performance of Bluetooth. The remainder of this paper is organized as follows: Section 2 presents previous work on Bluetooth MAC scheduling algorithms, then Section 3 discusses the proposed scheduling algorithm. Section 4 presents simulation results for the proposed algorithm, and final conclusions are given in Section 5.

2. Bluetooth MAC Scheduling Algorithm

The principal MAC protocol in Bluetooth is a polling scheme that uses a master-driven time division duplex (TDD). Here, a slave is only allowed to transmit a packet to the master immediately after receiving a packet from the master. Plus, the master can only use an even-numbered slot to send a packet to a slave, while the slave can only reply to this packet using an odd-numbered slot. The MAC scheduling scheme for a Bluetooth system is shown in Figure 2. The TDD slots are shared by the SCO and ACL link in this figure.

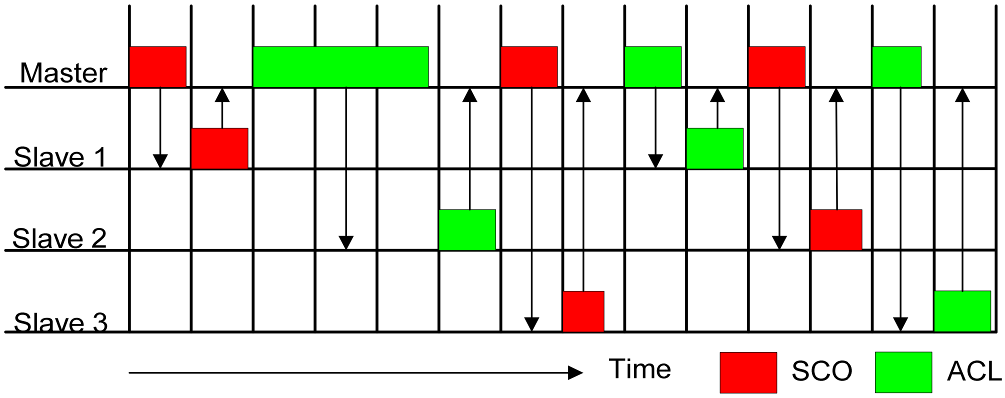


Figure 2. MAC Scheduling scheme of Bluetooth

In the Pure Round Robin (PRR) scheme, every slave has the same opportunity to send one data packet even when they have no packet to transmit. Once the master polls a slave, the next time slot is then assigned to the slave without reference to whether the slave has data to transmit or not. Consequently, numerous slots can be wasted when POLL packets are sent by the master and NULL packets are sent by the slaves in the case of no data packets to transmit. Therefore, the PRR scheme is an inefficient scheduling algorithm when the traffic in the network is asymmetric, and several Bluetooth MAC scheduling algorithms have already been proposed to improve the system performance [2]-[6]. Some works assume that the Master knows up-to- date information of slave's queue status [2]-[4]. Some approaches do not require this information [6]. Some researchers also proposed low power mode based scheduling policy [5].

In [2], a Master-Slave Queue-State-dependent Packet scheduling algorithm is proposed, where a free bit in the Bluetooth payload header is used by a slave to inform the master of the next available data. Based on this feedback bit, the master classifies all the master-slave pairs into one of four states, and a higher priority assigned to a pair that utilizes the slots more efficiently than the other pairs. However, this algorithm assumes that the master has updated information on the slave queue at all times, which is not actually available given the current Bluetooth specifications, as the slaves can only provide information on their queue state when they send a packet to the master. In addition, a slave starvation problem can occur for low priority pairs when higher priority pairs always have packets to transmit.

In [3], HOL-Priority Policy (HOL-PP) is proposed. This algorithm use similar priority policy with [2]. The master schedules on the basis of the head of line (HOL) packet size at the Master and slave queue. Additional two bits are required to distinguish 4 possible HOL packet size for classifying the master and slave pair into three classes by slot utilization. However this policy assumes the master has up-to-date information of slave queue's status like [2].

In [4], the authors use the similar priority policy as in [2] and [3] to improve the performance of the system considering both throughput and delay on each Master-Slave pair in scheduling decision. They use the amount of link utilization to assign a priority class based on queue status of master and slave pairs. But they also assume that the master knows up-to-date information of the slave-to-master queue status.

Some researchers proposed MAC scheduling policy to optimize power consumption and improve slot utilization by using a low power mode in Bluetooth [5]. In this research authors proposed variable sniff interval and variable serving time on the base of slot utilization. However this scheduling policy is not adequate for dynamic traffic and requires additional information.

In [6], several scheduling algorithms are compared. The Exhaustive Round Robin (ERR) is a simple scheduling policy that uses a fixed order like RR. Yet, since the master does not switch to the next slave until both the master and the slave queues are empty, there is a danger that the channel can be captured by stations generating a higher traffic than the system capacity. Thus, the Limited Round Robin (LRR) was proposed to solve this capture effect Although the LRR also has a fixed cyclic order and is exhaustive, like the ERR, parameter "t" is adopted to limit the number of transmissions (tokens) that can be performed by each pair per cycle. The maximum number of transmissions per cycle then limits the cycle length and avoids the capture effect. Nonetheless, despite an improved throughput and fairness when compared with the RR and ERR, the LRR still suffers from a slot wastage problem under asymmetric traffic conditions.

Accordingly, on the foundation of the MAC scheduling algorithms in [2] and [6], this paper proposes an enhanced Limited Round Robin with a priority policy (ELRR-PP) based on slot utilization to improve the performance. Plus, fairness is maintained using a maximum number of transmissions per cycle.

3. New ELRR-PP Algorithm

The proposed MAC scheduling algorithm (ELRR-PP) operates in accordance with the master-slave queue status. As such, four classes of priority are assigned to the master-slave pairs based on the existence of data in the respective queues, which is similar to the method in [2], except the proposed method uses the current queue status for the master and previous queue status for the slave.

Hence, additional information on the slave queue is not necessary, in contrast to [2]. This priority scheme is described in Table 1. Based on the classes, the slave with the highest priority is polled first. It is also assumed that class 2 has priority over class 3, as there is a possibility that the slave has no data to send to the master In the case of several pairs in the same class, the pair with the largest amount of data in the master queue has priority. But for the class 2, the pair with the smallest amount of data in the master queue has priority to relegate this pair to class 4. The ELRR-PP algorithm is described in figure 3.

Table 1. Priority Scheme

Priority	Queue status
Class 1	Master has packets in queue and the slave sent packets to the master during previous turn
Class 2	Master has packets in queue and slave did not send packets to the master during previous turn
Class 3	Master has no packets in queue and slave sent packets to the master during previous turn
Class 4	Master has no packets in queue and slave did not send packets to the master during previous turn

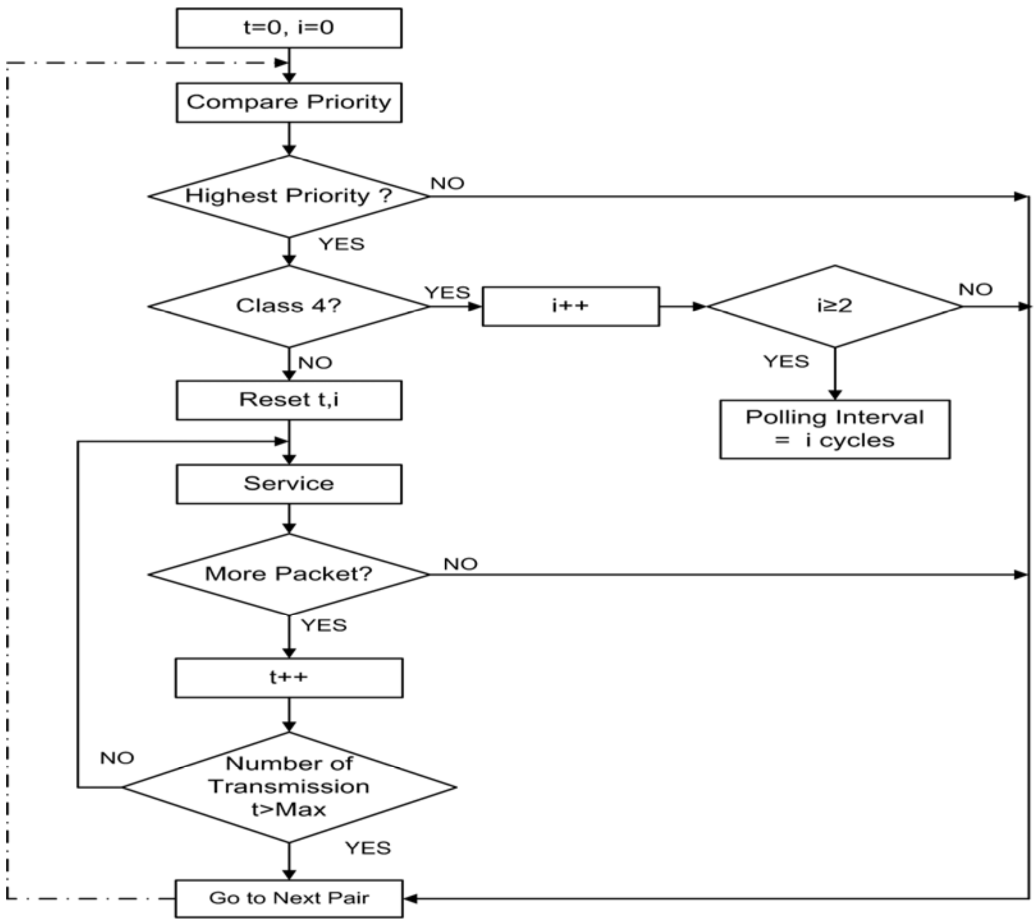


Figure 3. Flowchart of ELRR-PP

To avoid starvation of the low priority pairs, a maximum number of transmissions per cycle is adopted for each class, where Max1 is the maximum transmission number for class 1, and Max2, which is smaller than Max1, is the maximum transmission number for class 2 and class 3. Parameter “t” is used to count the number of transmissions in figure 2. To prevent slot waste, the polling interval for class 4 pairs is modified. For the first cycle, such an inactive pair has the same opportunity to be polled. But, if it still has no packets to send in the next cycle, the polling interval for this pair is increased linearly by one cycle to limit the chances of transmitting packets. Parameter “i” is used for this purpose in figure 3.

4. Performance Evaluation

To avoid starvation of the low priority pairs, a maximum number of transmissions per cycle is adopted for each class, where Max1 is the maximum transmission number for class 1, and Max2, which is smaller than Max1, is the maximum transmission number for class 2 and class 3. Parameter “t” is used to count the number of transmissions in figure 2. To prevent slot waste, the polling interval for class 4 pairs is modified. For the first cycle, such an inactive pair has the same opportunity to be polled. But, if it still has no packets to send in the next cycle, the polling interval for this pair is increased linearly by one cycle to limit the chances of transmitting packets. Parameter “i” is used for this purpose in figure 3.

To evaluate the proposed algorithm, a C++ discrete event simulator was used, and all the simulations were based on a single piconet consisting of one master and six slaves, where the master had a corresponding queue for each slave. The traffic mode considered was ACL. The traffic at the master and each slave was generated independently in accordance with a Poisson process. When comparing the proposed algorithm with other algorithms, the maximum number of transmissions per cycle for the LRR was set at 4, while for the proposed ELRR-PP it was set at 8 for class 1(Max1=8) and 4 for class 2 and class 3 (Max2=4).

Figure 4 shows the average delay when each master-slave pair had the same arrival rate. As shown in figure 4, the ELRR-PP produced a lower delay, however, the difference compared to the other algorithms was not significant.

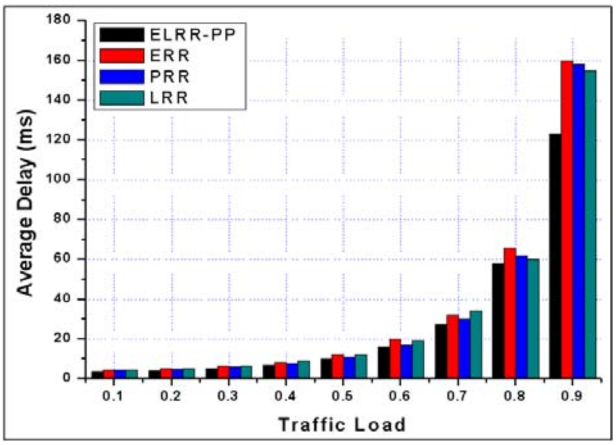


Figure 4. Average delay with same arrival rate

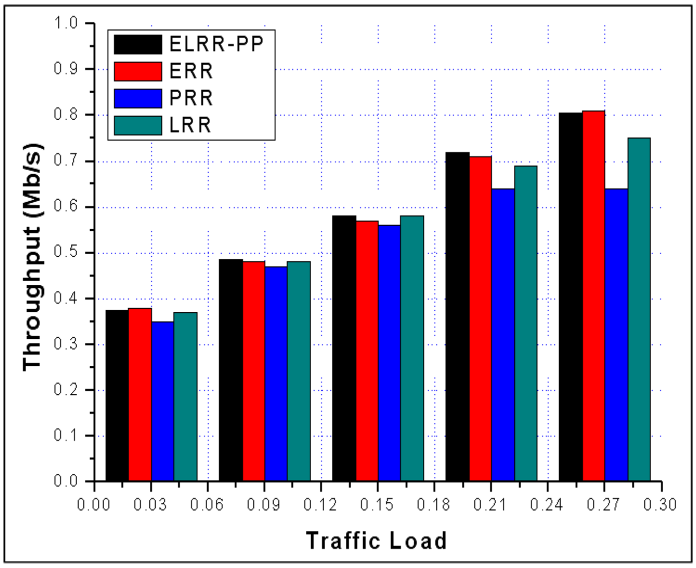


Figure 5. Throughput with variant traffic load

To evaluate the delay characteristics when each pair had a different traffic generation rate, the arrival rate was changed, as shown in table 2. The arrival rate of the 6th master-slave pair was changed from 0.03 to 0.27 to increase the system traffic from 0.4 to 0.88. As such, the arrival rate for slave 6 was increased from 0.03 to 0.27, while that for the master was selected randomly between 0.03 and 0.27.

Table 2. Traffic generation Parameter

Piconet	M1	S1	M2	S2	M3	S3
Arrival rate	0.2	0.02	0.05	0.007	0.007	0.05
Piconet	M4	S4	M5	S5	M6	S6
Arrival rate	0.001	0.002	0.002	0.001	**Variable**	**Variable**

Figure 5 presents the throughput for the 6th master-slave pair with a variant traffic load. As Expected, the PRR produced a lower throughput than the other algorithms due to the increased traffic load for slave 6. Meanwhile, the ELRR-PP produced a higher throughout than the LRR, and higher or similar throughput to the ERR.

Figure 6 shows the average delay with a variant traffic load for slave 6. The delay of the PRR suddenly increased when the traffic load for slave 6 increased. Also, the delay

of the LRR increased significantly as the traffic load increased The ELRR-PP produced a lower delay than the PRR and LRR, and comparable performance with the ERR.

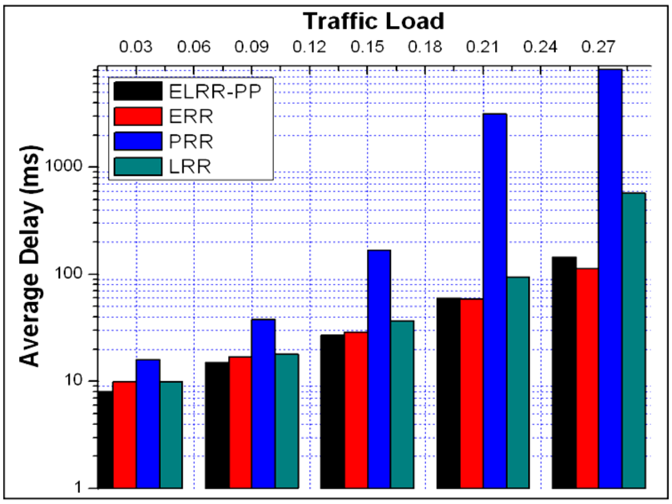


Figure 6. Average delay with variant traffic

5. Conclusions and Future Works

This paper proposed an enhanced Limited Round Robin with a priority policy for data exchange within a Bluetooth piconet, and its throughput and delay performances were evaluated. The proposed algorithm utilizes the status of the master and slave to schedule the slots effectively, yet additional information on the slave is not necessary. In simulations, the proposed ELRR-PP produced a better performance than the existing PRR and LRR scheme. In comparison between proposed ELRR-PP and conventional ERR, our proposed ELRR-PP has better or comparable performance when the ERR is vulnerable to a channel capture problems.

References

[1] Bluetooth Special Interest group, “Specification of the Bluetooth System,”1.1b,vol.1 and 2, Feb 2001

[2] M.Kalia, D.Bansal and R.Shorey, “Data Scheduling and SAR for Bluetooth MAC,” in Proc. Of IEEE Vehicular Technology Conference, 2000, pp.716-720

[3] M.Kalia, D.Bansal and R.Shorey, “MAC Scheduling and SAR Polices for Bluetooth: A Master Driven TDD Pico-Cellular Wireless System,” in Proc. Of IEEE International Workshop on Mobile Multimedia Communications,1999, pp.384-388

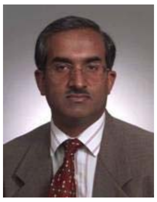
[4] Yang-Ick Joo, Jong Soo Oh, “ An Efficient and QoS-aware Scheduling Policy for Bluetooth”, in Proc. Of IEEE Vehicular Technology Conference 2002, pp 2445-2448

[5] S.Grag, M.Kalia and R.Shorey, “MAC Scheduling Policies for Power Optimization in Bluetooth: A Master Driven TDD Wireless System” in Proc. Of IEEE Vehicular Technology Conference, 2000, pp.196-200

[6] A.Capone, M.Gerla and R.Kapoor, “Efficient polling scheme for Bluetooth picocells,” in IEEE International Conference on Communication, June 2001,pp.1990-1994

Authors

Sunguk Lee received the B.S. degree in Electronics Engineering from Yonsei University, Seoul, Korea in 2002, and the M.S. degree (First Class Honors) in Electrical and Computer Engineering from University of Florida, Gainesville, USA, in 2004. He is currently working towards the Ph.D. degree in the Department of Electrical and Computer Engineering, University of Florida, Gainesville, USA. He is a student member of the IEEE and IEICE. His research interests include Home Networks, power line communication, mobility management and scalability issues in the next generation wireless/mobile networks. Specially, he is researching the performance of PLC based Network protocols. His email address is sunguk@ufl.edu. He is a corresponding author of this paper.



Haniph Latchman received the B.S. degree (First Class Honors) from the University of The West Indies, Trinidad and Tobago, in 1981 and the D.Phil.degree from Oxford University, Oxford, UK, in 1986. He was the 1983 Jamaica Rhodes Scholar. He joined the University of Florida, Gainesville, in 1987, where he teaches graduate and undergraduate courses and conducts research in the areas of Control Systems, Communications and Computer Networks and is Director of the Laboratory for Information Systems and Telecommunications and Co-director of the Research Laboratory for Control System and Avionics. He is also an Associate Editor for the IEEE Transactions on Education and served as Guest Editor for Special Issues of the International Journal of Nonlinear and Robust Control, the IEEE Communications Magazine and the International Journal on Communication Systems. Dr. Latchman has received numerous teaching and research awards, including several best-paper awards, the University of Florida Teacher of the Year Award, Two University-wide Teaching Improvement Program Awards, College of Engineering Teacher of the Year Awards, the IEEE 2000 Undergraduate Teaching Award, and a 2001 Fulbright Fellowship. Dr Latchman is a Senior Member of the IEEE and has published more than 85 technical journal articles and conference proceedings and has given conference presentations in the areas of his research in multivariable and computer control systems and communications and internetworking. He is the author of the books Computer Communication Networks and the Internet (McGraw-Hill, New York) and Linear Control Systems - A First Course (Wiley, New York). His email address is latchman@list.ufl.edu

Byungjoo Park received the B.S. degree in electronics engineering from Yonsei University, Seoul, Rep. of Korea in 2002, and the M.S. and Ph.D. degrees (first-class honors) in electrical and computer engineering from University of Florida, Gainesville, USA, in 2004 and 2007, respectively. From June 1, 2007 to February 28, 2009, he was a senior researcher with the IP Network Research Department, KT Network Technology Laboratory, Rep. of Korea. Since March 2, 2008, he has been a Professor in the Department of Multimedia Engineering at Hannam University, Daejeon, Korea. He is a member of the IEEE, IEICE, IEEK, KICS, and KIISE. His primary research interests include theory and application of mobile computing, including protocol design and performance analysis in next generation wireless/mobile networks. He is an honor society member of Tau Beta Pi and Eta Kappa Nu. His email address is vero0625@hotmail.com, bjpark@hnu.kr