J Electr Eng Technol Vol. 8, No. 1: 183-189, 2013
http://dx.doi.org/10.5370/JEET.2013.8.1.183

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

A Capacity Modeling of Bluetooth Access Points for Location Based Service with Mobile Phone and Bluetooth

In-Hwan Kim*, Soo Young Shin, Young-Ho Song*, Ki-Dong Chung*** and Gu-Min Jeong†**

Abstract – In this paper, we propose a capacity modeling method for Bluetooth based LBSs (Location Based Services) between Bluetooth APs(Access Points) and mobile phones. In order to do this, we consider the entrance and exit of the users to and from the AP. Using parameters such as the connection time, data transmission time and number of users in the AP zone, we analyze the capacity of a Bluetooth AP using an appropriate queuing model. The required number of APs in a certain zone is estimated from the number of users in the zone using the proposed queuing model. By performing simulations and experiments, the validity and applicability of the proposed method are verified.

Keywords: LBS, Bluetooth, Access point, Capacity, Queuing model

1. Introduction

An LBS is a service which provides users with useful information or content based on their location [1]. With the advent of the smartphone, the LBS has become an important application in wireless communication services [2-4].

Generally, GPS(Global Positioning System) and Cell-ID(Cell-Identification) have been used to determine the location. Following the commercialization of the smart-phone, WLAN(Wireless Local Area Network) has become an important technology for LBSs. For example, for indoor navigation, WLAN is a good candidate for location information. However, when it comes to determining the location, more precise algorithms are needed for more advanced services [3, 4].

Considering these facts, there have been various studies on the WPAN(Wireless Personal Area Network) based LBSs. Especially for indoor navigation, WPAN has been widely used [5-7]. WPAN based location services were known to be effective for precise determination of the location because of two reasons. First, the communication range of WPAN is shorter than that of WLAN, which could provide more accurate location information. Second, WPAN generally consumes less power than WLAN does, which makes it more suitable for sensor-related applications, including smartphone applications [8].

The characteristics of WPAN based LBSs is different from WLAN based LBSs. That is, because of the shorter communication range and lower capacity of WPAN compared to WLAN, we should consider the expected number of users for the services and derive the number of APs required for commercialized services.

In this paper, we propose a capacity modeling method for Bluetooth [9] based LBSs between a Bluetooth AP (Access Point) and mobile phones. In addition, we present a modeling method for determining the number of APs required for Bluetooth based LBSs. For the content download in the Bluetooth AP, we apply the proposed queuing model [10] and perform experiments on the AP and Bluetooth-enabled smartphones to validate the proposed model. Based on the connection time, data transmission time, the probability of the user being in the AP and so on, we derive an appropriate queuing model for Bluetooth LBSs. Then, we estimate the number of users that can download the contents within a predefined time. Using these parameters, we can induce the required number of APs in a certain area.

The validity and applicability of the proposed method are evaluated and proved by using simulations and experimental results obtained using smartphones.

The rest of this paper is organized as follows. In Section 2, we provide a brief overview of Bluetooth based LBSs. We revisit the Bluetooth related issues from the viewpoint of Bluetooth based LBSs in Section 3 and present a queuing model and analysis for Bluetooth APs in Section 4. In Section 5, we describe the simulation and experimental results obtained using smartphones and show the validity of the proposed method. The conclusion follows in Section 6.

† Corresponding Author: School of Electrical Engineering, Kookmin University, Korea. (gm1004@kookmin.ac.kr)
* SK Planet, Korea. (inhwan.kim@sk.com, syhf2000@nate.com)
** School of Electronic Engineering, Kumoh National Institute of Technology, Korea. (wdragon@kumoh.ac.kr)
*** School of Computer Science and Engineering, Pusan National University, Korea. (kdchung@pusan.ac.kr)
Received: August 9, 2011; Accepted: October 24, 2012

2. Bluetooth based LBSs

The smartphone platform provides Bluetooth APIs and a map database with location information for Bluetooth based LBS. Fig. 1 shows an example of Bluetooth based

LBSs.

Due to the relatively short communication range and small capacity of Bluetooth compared to WLAN, the aspect of the services in Bluetooth based LBS can be different. Although the short range of Bluetooth makes it difficult to cover a certain area, it could provide more accurate location related information. However, to provide LBS in a certain area, an LBS zone must be established with a number of Bluetooth APs. By using this LBS zone, when a user enters, we can push content or information based on the zone information. The problem is how many Bluetooth AP is required to build up a specific LBS zone and this is the motivation of this paper.

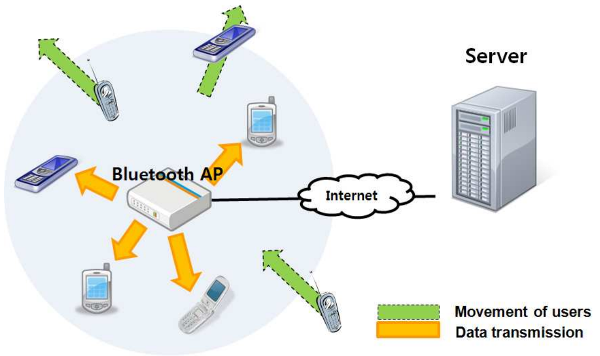

Fig. 1. Bluetooth based LBS.

To provide Bluetooth based LBSs, we should consider network related parameters such as capacity of the network, number of customers, connection / service time and etc. Based on these parameters, we propose a queuing model of Bluetooth based LBSs in order to derive the number of APs in a certain LSB zone.

3. Connection Time and Service Time in Bluetooth based LBSs

To provide LBS, the capacity of an LBS system should be sufficient to handle a number of customers in the service area. Since a Bluetooth piconet can simultaneously handle up to seven slaves, the number of Bluetooth masters determines the capacity of the Bluetooth LBS system, which is an important design issue. In this section, the basic modeling of Bluetooth is presented for further analysis.

3.1 Connection setup time

To provide LBSs at a certain place, a Bluetooth connection must be established between a Bluetooth AP(master) and the user(slave). The device discovery in Bluetooth involves two steps: inquiry and paging. The inquiry procedure is asymmetric. A potential master, here, the Bluetooth AP, must enter the INQUIRY state first, and the potential slave, i.e., the user device such as a handset, must enter the INQUIRY SCAN state. The master periodically broadcasts ID packets in every $T_{inquiry}$ interval.

These ID packets hop on 32 common channels. These 32 channels are divided into two sets, each with 16 channels. The ID packets are grouped into A trains and B trains, each of which uses one of the two sets of 16 channels exclusively. In an T_w inquiry interval, $N_{inquiry}$ A trains, $N_{inquiry}$ B trains, $N_{inquiry}$ A trains, and $N_{inquiry}$ B trains of ID packets will be sequentially transmitted, where $N_{inquiry}$ = 256. Each train consists of 16 slots (of length T_{train} = 10 ms).

Table 1. Timing parameters of inquiry and inquiry scan

Parameter	Description	Recommended value
$T_{inquiry}$	Inquiry interval	60s
$T_{w\_inquiry}$	Inquiry window length	10.24s
$T_{inquiryscan}$	Inquiry scan interval	1.28s
$T_{w\_inquiryscan}$	Inquiry scan window length	10ms
T_{train}	Length of a train	10ms
$N_{inquiry}$	Train repetition number	$\geq$256

Two ID packets on two different channels are placed in one 625-μs slot. So there are eight slots of ID packets interleaved by eight response slots reserved for slaves to reply. Consequently, T_w inquiry takes up to 10.24 seconds to complete (4×256 A/B trains, each ms), unless the master has collected enough($N_{inquiry}$ responses) responses and decides to abort the INQUIRY procedure earlier. The Bluetooth specification suggests that masters enter the INQUIRY state every one minute, i.e., $T_{inquiry}$ = 60 sec. A potential slave should enter the INQUIRY SCAN state to listen to the ID packets. It sequentially hops on the aforementioned 32 channels, but at a much slower speed. It takes $T_{inquiryscan}$ seconds to hop from one channel to another. In each hop, it only enters the listening status for $T_{w\_inquiryscan}$ = 10ms. Note that it is necessary that $T_{w\_inquiryscan} \geq T_{train}$ to guarantee that the slave can catch an ID packet from the master. The Bluetooth specification suggests that $T_{inquiryscan}$ should be no longer than 2.56 seconds, which equals the length of $N_{inquiry}$ A/B trains. Note that many vendors set $T_{inquiryscan}$ =1.28 seconds, and this value will also be adopted in this paper.

Table 1 summarizes all the above timing parameters. Upon receiving an ID packet from some channel, say i, a slave should perform a random backoff and then reply with a Frequency Hopping Synchronization (FHS) packet via the same channel. The backoff value is between 0 to 1023 slots to avoid possible collisions with other slaves. After the backoff, the slave should continuously listen to channel i and reply with an FHS immediately after the first ID packet (also on channel i) is heard. Note that the average backoff value is 512 slots, which equals 32 trains. This explains why A/B trains need to be repeated so many times.

Once the paging process is complete, the devices move into the connection state. The master sends a poll packet to the slave to verify that the transition from the page hopping sequence to the new hopping sequence is successful. If it is successful, the two devices continue frequency hopping in a pseudo random pattern based on the master device's address and clock for the duration of the connection.

Based on these paging and inquiry procedures, the time taken to complete a typical average successful Inquiry & Page operation and, thus, the typical time taken to setup a Bluetooth Link is shown in Table 2.

Table 2. Connection setup time.

Operation Type	Minimum Time	Maximum Time	Average Time
Inquiry	0.00125s	10.24-30.72s	3-5s
Paging	0.0025s	2.56s	1.28s
Total	0.00375s	12.8-33.28s	4.28-5.28s

Table 3. Bluetooth packet type.

Type	Payload header (bytes)	Payload (bytes)	FEC	CRC	Symmetric Max. Rates (kb/s)	Asymmetric Max. Rate(kb/s)	
						Forward	Reverse
DM1	1	0-17	2/3	yes	108.8	108.8	108.8
DH1	1	0-27	no	yes	172.8	172.8	172.8
DM3	2	0-121	2/3	yes	258.1	387.2	54.4
DH3	2	0-183	no	yes	390.4	585.8	86.4
DM5	2	0-224	2/3	yes	286.7	477.8	36.3
DH5	2	0-339	no	yes	433.9	723.2	57.6
AUX1	1	0-29	no	No	185.6	185.6	185.6

3.2. Service time

Once the connection is established, LBS related data such as local advertisement/information needs to be transmitted from the Bluetooth AP to the user's handset.

For a fixed amount of LBS data, the data transmission time is dependent on the packet type of Bluetooth, as defined in Table 3 under error-free condition.

4. Queuing Model for Bluetooth Based LBS

In this section, we evaluate the number of LBS users that can be supported by one Bluetooth piconet using queuing theory based on the modeling parameters described in the previous section.

4.1. AP model

In this study, a Bluetooth piconet is modeled as a processor sharing node with a queue.

Because the LBS related customers arrive in arbitrary ways, the arrival process of potential slaves (customers) can be assumed to follow a Poisson distribution without loss of generality. When a connection is established between a Bluetooth master (AP) and a slave (customer), a fixed amount of data is transmitted in one way from the AP to the customer for LBS services. Once the LBS data is transmitted, the connection is released and the customer will leave the system.

The total number of jobs in the Bluetooth based LBS system is limited to seven, because a piconet can communicate with up to seven active slaves simultaneously. Although the master sends data to more than one slave, it is assumed that the master will communicate with only one slave at a time. After sending all the data, the master sends data to another slave. Also, it is assumed that the packet transmissions are error-free. In the LBS scenario, in which data is only transmitted from the Bluetooth master to the slaves in one piconet, it can be modeled as a one server system with a limited number of waiting positions.

Based on these assumptions, the Bluetooth piconet's capacity can be modeled using the $M/G/1/K$ queuing model [10]. Fig. 2 shows the $M/G/1/K$ queue model used for the capacity analysis of the Bluetooth piconet.

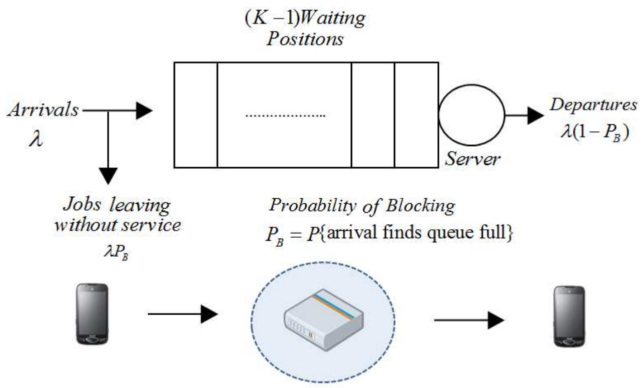

Fig. 2. $M/G/1/K$ queuing model.

K represents the maximum number of customers (or slaves) in a piconet, where one slave can receive LBS data from the master and at most $(K-1)$ slaves can wait in the queue to be served. Because a piconet can simultaneously support up to seven slaves at one time, if there are already seven slaves in it, newly arrived customers(slaves) have to leave without service and these are referred to as being lost or blocked.

4.2. Blocking probability

Let P_B be the probability that a customer is lost, which is the same as the probability that a newly arrived customer sees K users in the system. Assume that customers arrive following a Poisson distribution with λ. Once the data size to be transmitted is fixed, the service time distribution is deterministic as the sum of the average connection setup time (inquiry and paging time, i.e., 4.78s) and data transmission time. Here, the data service is assumed to be a one-way data transmission, i.e., from the master to the slave and, therefore, a DH5 type connection with a speed of 732kbps is assumed. The data size is variable with possible values of 100kbytes, 300kbytes, 500kbytes, 1 Mbytes, 3Mbytes, and 5Mbytes.

From Fig. 2, the probability of blocking P_B is obtained as follows:

$$P_B = 1 - \frac{1}{P_{d,0} + \rho}, \tag{1}$$

using $p_k, k = 0,1,\dots,K-1$,

$$p_k = \frac{1}{p_{d,0} + \rho} p_{d,k} \quad k = 0,1,\dots,K-1 \tag{2}$$

where $p_{d,k}$ is the probability that the arrival finds $k = 0,1,\dots,k$ customers in the system and $\boldsymbol{\rho}$ is the offered traffic to the system, i.e, $\lambda \cdot$(*mean service time*). Here *mean service time* will be determined from the average connection setup time and data transmission time. Then, the mean number of customers in the system can be calculated as follows:

$$N = \sum_{k=0}^{K} kp_k = \frac{1}{p_{d,0} + \rho} \sum_{k=0}^{K-1} kp_{d,k} + K\left(1 - \frac{1}{p_{d,0} + \rho}\right). \tag{3}$$

5. Experimental results

In this section, we present the simulation results obtained using MATLAB and the experimental results obtained using smartphones and Bluetooth AP for the presented capacity modeling method. Fig. 3 shows the scenario of the simulation and experiment. As illustrated in the figure, smartphone (customer) arrives in a Poisson manner, establishes connections with Bluetooth AP (inquiry procedure), receives LBS related data during the service time and finally releases the connection.

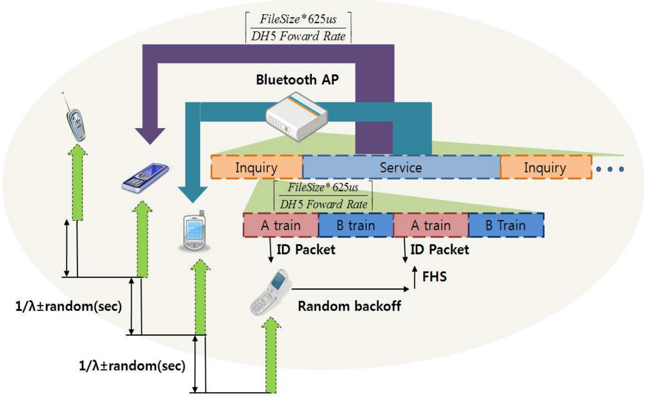

Fig. 3. Simulation and experiment scenario.

5.1. Simulation results

First, we perform a simulation of the Bluetooth network capacity. Using the $M/G/1/K$ queuing model and the assumptions made in the previous sections, we derive the number of users that can be serviced by one AP (one piconet) within 1 min. Various data sizes such as 100kbytes, 300kbytes, 500kbytes, 1Mbytes, 3Mbytes, and 5Mbytes are considered.

Fig. 4 shows the blocking probability according to the number of users in the AP. For example, if we consider a data size of 1Mbytes, blocking occurs when the number of users is over 3.75. This means that for one AP in one minute, the capacity of Bluetooth is 3.75; in other words, we can provide 3.75 users with the LBS. The average capacities of Bluetooth piconets with data sizes of 700 kbytes, 1Mbytes, 3Mbytes and 5Mbytes are 4.74, 3.75, 1.56 and 0.96, respectively.

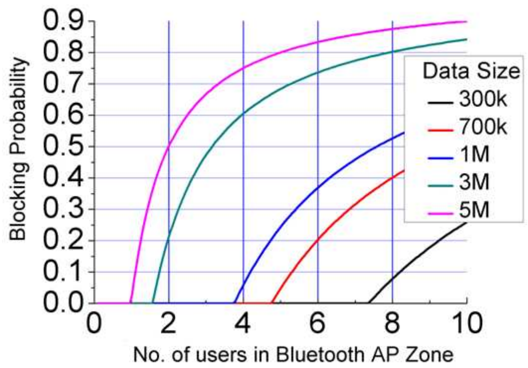

Fig. 4. Simulation results of presented model

5.2. Experimental results with mobile phones

In this experiment, we implement the Bluetooth AP environment using the CSR Bluetooth chipset and Blue Soleil SDK. Eight smartphones with three different types were used for the experiment to analyze the Bluetooth based LBS system.

Table 4 and Fig. 5 show the devices used in the experiment, the presented AP model and experimental setup, respectively.

Fig. 6 shows the average service times according to the data size and number of smartphones in one AP.

In the experiments, the smartphones arrive in a Poisson manner and the number of smartphones that could be served by a single Bluetooth AP within 1 min is counted.

Table 4. Devices used in experiments.

Smartphone	Samsung OMNIA2 SCH-M715	Samsung SPH-M4650	Samsung Galaxy SHW-M110S
Platform	Windows Mobile 6.5	Windows Mobile 6.0	Android 2.2
Number of phones	2	2	4

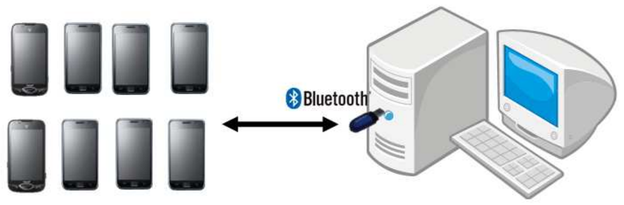

Fig. 5. Experimental setup using PC, Bluetooth and smartphone.

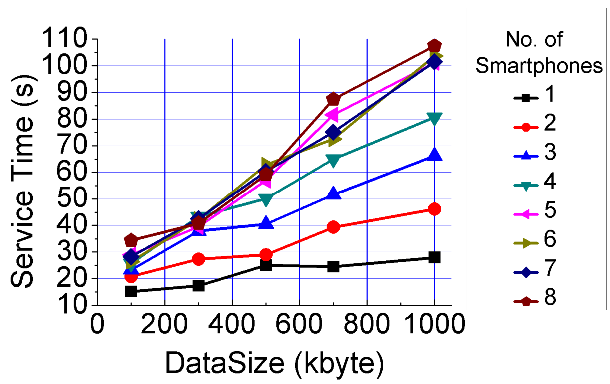

Fig. 6. Service time vs. data size according to number of phones.

From the experiment, the capacities of Bluetooth are derived as 3.63 and 2.68 for data sizes of 700kbytes and 1Mbyte, respectively. There are mismatches between the simulation results and the experimental results. This is because the actual transmission rate of DH5 packets was about 485 kbps, which is about 33% lower than the theoretical speed of 723 kbps. This is because of the transmission errors.

5.3. Adjustment of simulation results using the throughput from experiment

Considering the experimental transmission errors, we set the DH5 packet speed to 485 kbps and perform the simulation again under the same assumptions.

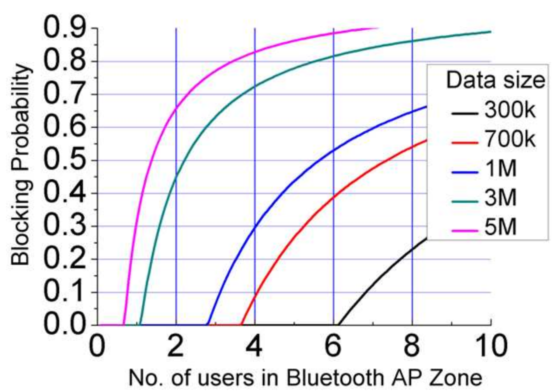

Fig. 7. Simulation result of the presented model considering transmission error.

Fig. 7 shows the modified blocking probability according to the number of users in the AP. The average capacities of Bluetooth piconets with data sizes of 700 kbytes, 1Mbytes, 3Mbytes and 5Mbytes are 3.65, 2.82, 1.08 and 0.66, respectively.

As can be seen in Table 5, the Bluetooth capacities obtained from the simulation and experimental results for a data size of 700 kbytes are 3.65 and 3.63, respectively. In addition, the Bluetooth capacities obtained from the simulation and experimental results for a data size of 1 Mbytes are 2.82 and 2.68, respectively. This demonstrates that the results obtained using the simulation model matches the experimental results well.

Table 5. Maximum number of users within a period of 1 min.

Data size	Simulation		Experiment
	723kbps	485kbps	
700kbytes	4.74	3.65	3.63
1Mbytes	3.75	2.82	2.68

5.4. Estimation of number of Bluetooth APs

Based on the possible number of customers that could be supported by single Bluetooth AP, the number of required Bluetooth AP for LBS can be estimated. For example, let us assume that the content size is 300kbytes and the residing time is 1 min. Then, if we want to provide LBS to 10 users, the number of required Bluetooth APs is approximately 1.63 and two APs are required to provide services. Table 6 shows the number of APs required based on the various circumstances, where we use the modified model with a DH5 packet speed of 485 kbps.

Table 6. Number of required APs when the residing time is 1 min.

Content size	5 users	10 users	20 users
300kbytes	0.82	1.63	3.27
700kbytes	1.37	2.74	5.48
1Mbytes	1.77	3.55	7.09

6. Conclusion

In this paper, we proposed a capacity modeling method for Bluetooth based LBSs between Bluetooth APs and mobile phones.

To do this, we considered the entrance and exit of the users to and from the AP. With network parameters such as connection time, data transmission time, number of users in the AP zone and so on, we analyzed the capacity of Bluetooth AP using $M/G/1/K$ queuing model.

Based on the queuing model, we analyzed the capacity of Bluetooth based LBSs and derived the number of users that can be serviced within a predefined period of time.

From the experiment on communication between smartphones and Bluetooth APs, we adjusted the parameters of the presented model and discussed the method for estimating the number of APs required. The simulation and experimental results showed the validity and applicability of the proposed method for Bluetooth based LBSs. This paper can be used as a guideline to design and implement a Bluetooth based LBS system.

For a multi-AP environment, we should consider the interference between the APs. This remains as a future work.

Acknowledgements

This work was supported in part by the research program of SK Telecom, Korea and also supported in part by the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program (NIPA-2012-H0301-12-2007) supervised by the NIPA(National IT Industry Promotion Agency)

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In-Hwan Kim received B.S. and M.S. degrees in computer science from Pusan National University in 1997 and 1999, respectively and finished Ph.D. course in computer science from the same university in 2001. He was a manager at SK Telecom, Korea from 2001-2011, and has worked for T store Business Team, Digital Contents Marketplace Business Unit in SK Planet, Korea since 2011. His research area includes mobile device platforms and various convergence services. Also, he is interested in emerging WPAN technologies such as UWB, ZigBee, RFID, etc.

Soo Young Shin was born in 1975. He received his B.S., M.S., and Ph. D degrees in Electrical Engineering and Computer Science from Seoul National University, Korea in 1999, 2001, and 2006, respectively. He was a visiting scholar in FUNLab at University of Washington, US, from July 2006 to June 2007. After 3 years working in WiMAX design lab. of Samsung Electronics, he joined to Kumoh National Institutue of Technology on September 2010. His research interests include wireless LAN, WPAN, WBAN, wireless mesh network, sensor networks, coexistence among wireless networks, cross-layer methodology, cognitive radio networks, and mobile wireless broadband networks.

Young-Ho Song received B.S. and M.S. degrees from School of Electrical Eng., Kookmin University, Seoul, Korea in 2009 and 2011, respectively. He has worked for Media Technology Team, Platform R&D Office in SK Planet since 2011. His research area includes mobile device platforms and various multimedia services such as N-screen streaming services based on converged network.

Ki-Dong Chung received the B.S. degree from Seoul National University, Seoul, Korea, in 1973, and M.S. and Ph.D. degree in computer science from the same university in 1975 and 1986. Since 1978, he has been a Professor of Computer Science at Pusan National University, Pusan, Korea. His research interests include VOD(Video On Demand), multimedia systems, and mobile multimedia communication.

Gu-Min Jeong received the B.S. and M.S. degrees from the Dept. of Control and Instrumentation Eng., Seoul National University, Seoul, Korea, in 1995 and 1997, respectively, and Ph.D. degree from School of Electrical Eng. and Computer Science, Seoul National University, Seoul, Korea in 2001. He was a Senior Engineer at NeoMtel, Korea from 2001-2004 and a Manager at SK Telecom, Korea from 2004-2005. Currently, he is an Associate Professor of School of Electrical Engineering, Kookmin University, Seoul, Korea and also a Visiting Associate Professor of Dept. of Computer Science, UC Irvine, USA. His research area includes embedded systems, wireless network, control theory, pattern recognition and their applications.