Mobile Small Cells for Further Enhanced 5G Heterogeneous Networks

Choong-Hee Lee, Sung-Hyung Lee, Kwang-Chun Go, Sung-Min Oh, Jae Sheung Shin, and Jae-Hyun Kim

A heterogeneous network (HetNet) is a network topology composed by deploying multiple HetNets under the coverage of macro cells (MCs). It can improve network throughput, extend cell coverage, and offload network traffic; for example, the network traffic of a 5G mobile communications network. A HetNet involves a mix of radio technologies and various cell types working together seamlessly. In a HetNet, coordination between MCs and small cells (SCs) has a positive impact on the performance of the networks contained within, and consequently on the overall user experience. Therefore, to improve user-perceived service quality, HetNets require high-efficiency network protocols and enhanced radio technologies. In this paper, we introduce a 5G HetNet comprised of MCs and both fixed and mobile SCs (mSCs). The featured mSCs can be mounted on a car, bus, or train and have different characteristics to fixed SCs (fSCs). In this paper, we address the technical challenges related to mSCs. In addition, we analyze the network performance under two HetNet scenarios — MCs and fSCs, and MCs and mSCs.

Keywords: HetNet, small cell, LTE, mobile small cell, 5G.

Manuscript received Jan. 31, 2015; revised Apr. 28, 2015; accepted May 14, 2015.

This work was supported by the ICT R&D program of MSIP/IITP (14-000-04-001, Development of 5G Mobile Communication Technologies for Hyper-connected smart services).

Choong-Hee Lee (choonghee.lee@lignex1.com) is with the Communication R&D Laboratory, LIG Nex1, Seongnam, Rep. of Korea.

Sung-Hyung Lee (xaviersr@ajou.ac.kr), Kwang-Chun Go (light3754@ajou.ac.kr), and Jae-Hyun Kim (corresponding author, jkim@ajou.ac.kr) are with the Department of Electrical and Computer Engineering, Ajou University, Suwon, Rep. of Korea.

Sung-Min Oh (smoh@etri.re.kr) and Jae Sheung Shin (sjs@etri.re.kr) are with the Communications & Internet Research Laboratory, ETRI, Daejeon, Rep. of Korea.

I. Introduction

An investigation in 2013 by the Korean Ministry of Science revealed that 38,160,077 people were using smartphones among 54,514,397 mobile subscribers in Korea. Moreover, 23,993,469 of them are LTE users [1]. Given LTE's short history, these figures reveal the explosive increase in the number of smartphone users in Korea. We think that this trend is a worldwide trend, given that Korea is a test-market country for IT products.

In the era of 5G, a large number of *mobile smart* and Internet of Things (IoT) devices will generate various sizes of data traffic, ranging from a few bytes to upwards of several gigabytes; for example, small sensing data of IoT networks, and ultra-high-definition video services, which have a resolution of 7,680 × 4,320. Such devices are likely to cause an explosion in dynamic data traffic volumes in mobile networks.

Many researchers have foreseen that data traffic will increase in the order of over 1,000 times the current rate over the next 10 years. Therefore, it is going to be almost impossible to handle 5G data traffic with the conventional networks of today. Moreover, 5G mobile network protocols need to be made more flexible so as to be able to operate within heterogeneous networks (HetNets).

1. Key Technologies toward 5G

Many researchers and commercial companies have their own visions for 5G wireless networks, of which there are some overlapping issues between them, as follows [2]–[9]:

- HetNet for cell densification
- new carrier type (NCT)

© 2015 ETRI

http://dx.doi.org/10.4218/etrij.15.2415.0022

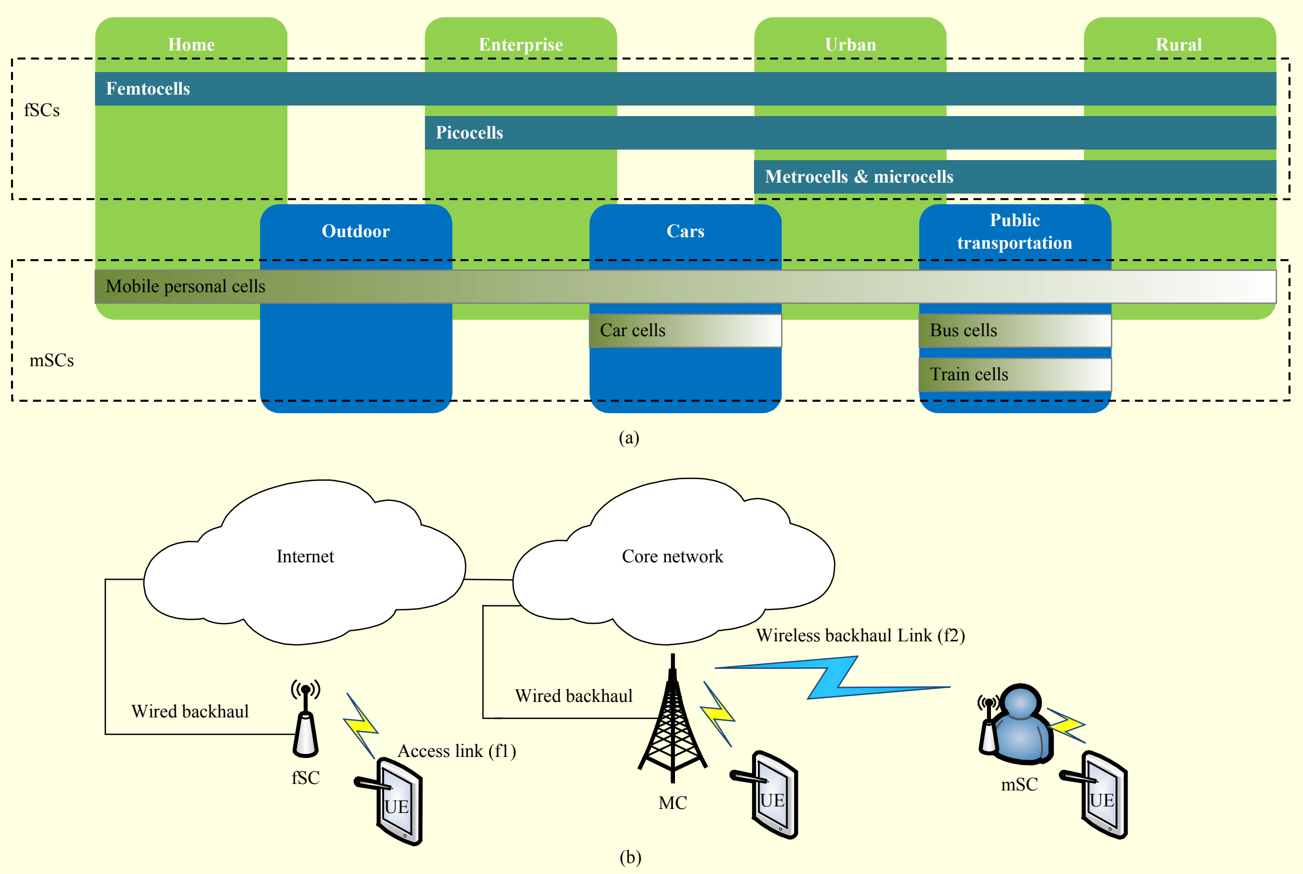

Fig. 1. Illustrations of (a) various types of SCs and (b) three-tier mobile HetNet architecture.

- massive multiple-input and multiple-output and array antenna technologies
- users/contents/network context-awareness network
- IoT: machine-type communications (MTC) and device-to-device (D2D) communication
- green networks: energy efficiency and cost effectiveness

In this paper, we will introduce mobile small cells (mSCs). Therefore, we address some of the key technologies related to mSCs.

2. HetNet

A HetNet is a network topology with a cell densification technology that overlays multiple tiers of mobile communication network cells; for example, if there are picocells and femtocells in the coverage of a macro cell (MC), then a three-tier HetNet is formed. The Small Cell Forum defines small cells (SCs) as "an umbrella term for operator-controlled, low-powered radio access nodes" [10]. In other words, an SC is defined to be a low-power mobile network cell that is under the control of mobile network operators. This is the difference between Wi-Fi access points (APs) and SCs. Additionally, the Small Cell Forum classifies SCs into four classes according to applications and the size of their coverage, as shown in Fig. 1(a); femtocells, having the smallest coverage, are used in the home, picocells are used for enterprises, metrocells and microcells, having the largest coverage, are used for public hotspots and rural mobile services, respectively. However, all of the SCs defined by the Small Cell Forum are not considered as mobile nodes.

The features of a HetNet are as follows:

- dense cell deployment with decreased cell size
- dynamic deployment and operation
- flexible backhaul
- access policy: closed subscriber group (CSG) and open subscriber group (OSG) modes.

Dense SCs increase network capacity and extend coverage, and are able to be deployed and operated at low costs. Moreover, SCs can be deployed and controlled adaptively according to certain situations and specific purposes by both mobile operators and users; for example, covering a temporal hotspot zone. Additionally, SCs operate regardless of the type of backhaul, because they are connected to a core network (CN) of an operator through their own Internet connection, as shown in Fig. 1(b). In other words, the backhaul link of an SC can be any Internet link; for example, an Ethernet or optical cable. This flexible backhaul is one of the most important differences between MCs and SCs, as SCs do not require the high-cost backhaul link of a mobile operator. Other important features of SCs are policy modes for mobile subscribers. There are two modes. The first is a CSG mode, which allows access only to subscriber group members; thus, only allowed users can be served by a CSG cell. The second mode is an OSG mode. An OSG cell provides service to any users in its coverage. OSG and CSG access policies can be combined; for example, an SC serves its members with higher priority and serves non-members with the remaining resources after scheduling the traffic transmissions of members.

3. NCT

The rapid increases in mobile data growth and use of mobile devices are creating unprecedented challenges for wireless service providers to overcome a global bandwidth shortage [11]–[12]. Therefore, it is essential to procure new spectrums and an efficient NCT technology. NCT technology is almost ready for practical use; for example, millimeter-wave technology [5]. The target carrier frequency of NCT is 5 GHz or higher. Therefore, we can expect higher throughput. However, there is a tradeoff. In other words, the higher frequency band can cause more attenuation. There are many challenges to enable NCT for small-cell backhaul [13]. Nevertheless, it is expected that various technologies currently being actively studied will overcome the challenges.

II. mSCs

We may use two types of carrier frequencies, concurrently, including NCT. In particular, SCs can use NCT technology as not only a backhaul link but also as an access link. Therefore, we propose the use of mSCs that have high-speed wireless backhaul links. Note that the use of an mSC in itself is not a novel concept; however, the deployment of mSCs has become more practical due to the introduction of NCT. We believe that the introduction of mSCs that have high-speed wireless backhaul links into a mobile HetNet can help bridge the gaps that exist between fixed SCs (fSCs), as shown in Fig. 1(a). The advantages of such mSCs are as follows:

- The distance between serving base stations (BSs) and users is shorter.
- Dynamic control is available.
- mSCs operate in a context-aware state.
- mSCs are an enabler of IoT.

First, distances between serving BSs and mSC users are closer than those of MCs and fSC users. This means that the required transmission power of both downlinks and uplinks is

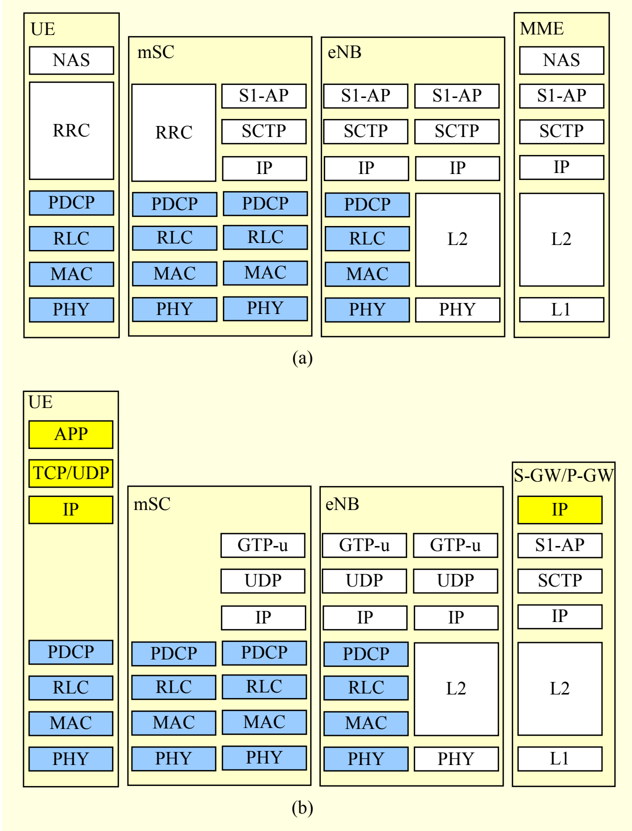

Fig. 2. Protocol stacks of (a) control and (b) user plane.

smaller. Transmission power is one of the most important parameters in mobile equipment because less transmission power results in a longer battery life. Second, mSCs can function as a private BS. Therefore, dynamic control is available. For example, owners of MSCs can turn *off* their mSC if the link conditions of neighboring cells are good enough. Alternatively, they can turn their mSC *on* if there are no available neighboring fSCs or the signal qualities of neighboring MCs are not suitable for sufficient services. Furthermore, mSC owners can provide communication links for neighboring users or their social network service (SNS) friends (in accordance with policy decisions). Third, a user can provide the necessary permissions so that dynamic controls, such as those mentioned above, may be performed automatically. Fourth, mSC can be a key technology for IoT. mSCs can provide low-cost access links to communicate with a CN or servers on the Internet with low cost for D2D and MTC. Moreover, mSCs may play a role as a cloud computing hub if they adopt to those mobile cloud computing service models presented in [14].

Figure 1(b) shows a network architecture of a three-tier HetNet with MCs, fSCs, and mSCs. MCs are connected to a CN of mobile operators through a wired backhaul link and have two types of access links, f1 and f2, for user equipment

http://dx.doi.org/10.4218/etrij.15.2415.0022

(UE) and mSCs, respectively. fSCs are connected to the Internet and the CN through a wired backhaul regardless of backhaul type. An MC supports connectivity between the CN and mSCs. In Fig. 1(b), mSCs use NCT technology as their wireless backhaul link and serve users via the access link, which is also used as an access link by MCs and fSCs. We assume that an mSC operates as a normal UE from the standpoint of an MC, while an mSC serves as a normal eNB for UEs. Figure 2 shows the protocol stacks of the featured mobile HetNet.

1. Applications of mSCs

We can use mSCs in various applications. Figure 3 shows examples of mSC applications. We can use mSCs as personal mobile BSs. In such a scenario, various personal devices can connect to the Internet or each other through an mSC. mSCs can also be used as mobile personal cloud servers if they were to include storage. Therefore, the personal devices of an owner can share information about contexts and service content. Moreover, an mSC can provide access links to neighboring users; for example, SNS friends who are within the coverage of its user, providing such a user grants them the necessary access. Another example of a suitable application is cars. An mSC in a car provides an access link to various devices within the car itself. In addition, it can connect with any in-built car safety information system or intelligent transport system infrastructure; thus, an mSC can be a car safety server. The last example in Fig. 3 is a public transportation application. This application is similar to that of a personal car application, except that it is for the purposes of the general public. In other words, mSCs can be openly accessed by passengers on a bus

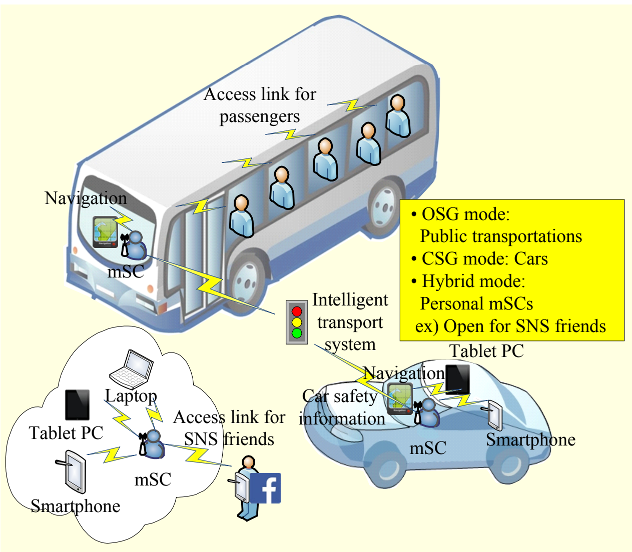

Fig. 3. Examples of mSC applications.

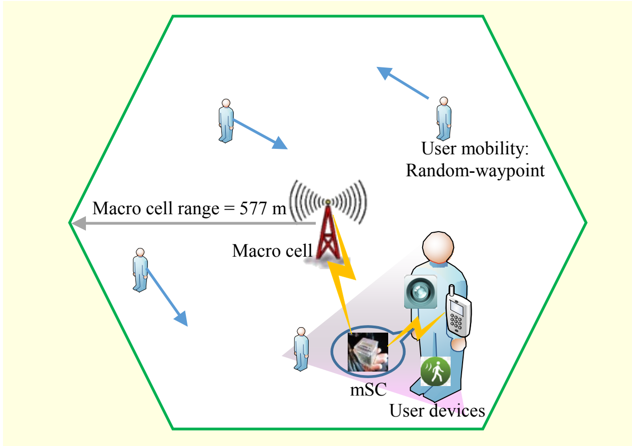

Fig. 4. Network topology.

or train. Moreover, the mSCs may provide travel information from precached data or by interworking with a navigation system or information transport system infrastructure.

2. Capacity Enhancement

The network capacity in a mobile network is mainly determined by system bandwidth and traffic volume. We performed simple simulations with an OPNET simulator to see the number of supportable UEs in both a homogeneous network and a mobile HetNet. Figure 4 shows the network topology of our simulation environment. An mSC has both a backhaul link and connected user devices. Table 1 describes a certain environment; that is, a minimal system.

In this paper, the system bandwidth of the 3GPP LTE specification is considered for simulation feasibility purposes. In addition, we have tried to scale down the bandwidth by 1.4 MHz because of hardware limitations [15].

mSCs operate at a different frequency to MCs. The mobility pattern of mSCs is assumed to be that found in the random waypoint model so as to cover all possible mSC applications. The mSC users follow their serving mSC. We have executed the simulation by using a workstation that has the following specification:

- CPU: Intel Core i7-4790, 3.60 GHz
- memory (RAM): 16 GB
- OS: Window 7 64-bit

Table 2 shows the simulation results of a homogeneous network scenario — one that is made up of only MCs without mSCs. We considered the following performance metrics, which would help us determine the number of supportable UEs: random access (RA) success ratio; channel utilization of physical downlink control channel (PDCCH) and physical uplink shared channel (PUSCH); and uplink (UL) latency. The results show that PUSCH is almost full and that UL latency

Table 1. Simulation parameters.

Parameters	MC	mSC	UE
Bandwidth	1.4 MHz		
Carrier frequency	2.110 GHz	3.5 GHz	N/A
Inter-site distance	1,732 m (3GPP Case 3)		
Speed of UEs and mSCs	3 km/h		
Mobility pattern	Random-waypoint model with group mobility		
Number of RA preambles	64		
Traffic model	10 bytes UDP packet created every 30 ms		
Number of nodes	19 cells × 3 sectors	10/20/30/40/50 per MC sector	10 per mSC
Max. TX power	46 dBm	30 dBm	27 dBm for MC/ –17 dBm for mPC
Path loss	ITU UMa	ITU UMi (LoS/NLoS)	N/A
Shadowing	ITU UMa	ITU UMi	N/A
Antenna height	25 m	10 m/1.5 m	1.5 m
Antenna configuration	2Tx 2Rx	2Tx 2Rx	1Tx 2Rx
Antenna gain	17 dBi	5 dBi	0 dBi
Antenna pattern	3GPP Case 3 3D antenna model	2D Omni-directional	

Table 2. Simulation results of MCs-only scenario.

Number of UEs	RA success ratio	Channel utilization				UL latency (s)	Mean UL throughput
		PDCCH		PUSCH			
		Avg.	Max.	Avg.	Max.		
4	100%	24.25%	25.67%	39.38%	41.71%	0.015	10 kbps
6	100%	34.35%	36.33%	58.14%	62.22%	0.011	15 kbps
8	100%	43.91%	45.45%	75.75%	78.57%	0.0115	21 kbps
10	100%	51.57%	53.13%	91.24%	94.18%	0.0156	26 kbps
12	100%	52.71%	55.17%	97.12%	100%	1.17	31 kbps
14	100%	53.17%	55.75%	97.17%	100%	4.65	36 kbps
16	100%	53.62%	55.50%	97.44%	100%	12.57	42 kbps

between UEs and eNB increases suddenly when the number of UEs exceeds ten. We can suppose that ten is the maximum number of supportable UEs for an MC eNB operating with 1.4 MHz bandwidth because the access network delay must be lower than 50 ms [16]. The UL throughput is 26 kbps at the maximum number of supportable UEs.

The results of simulations with a mobile HetNet scenario are represented in Table 3. UL latency does not increase rapidly

Table 3. Simulation results of mobile HetNet scenario.

Number of UEs	RA success ratio	Channel utilization				UL latency (s)	UL throughput
		PDCCH		PUSCH			
		Avg.	Max.	Avg.	Max.		
100	100%	54.09%	54.39%	96.07%	96.65%	0.013	264 kbps
200	99.48%	53.51%	54.19%	95.92%	97.03%	0.014	529 kbps
300	99.65%	52.06%	53.34%	97.13%	98.64%	0.018	793 kbps
400	96.48%	59.92%	51.86%	98.10%	99.51%	0.026	1,057 kbps
500	91.31%	46.93%	49.77%	98.80%	99.90%	0.043	1,318 kbps

even if the number of UEs increases to 500. However, the RA success ratio decreases because of interferences. Note that 500 UEs means that 50 mSCs operate within the same coverage of a single MC. The UL throughput is increased by up to 1,318 kbps in proportion with the number of UEs.

Although the simulation results show that the mobile HetNet expands network capacity with respect to the number of supportable users, a mobile HetNet still has several challenges, such as interferences. These challenges are described in the next section.

III. Challenges

A mobile HetNet with mSCs is one potential solution of 5G HetNets. However, there are challenges to commercialize this solution with optimized performance. In this section, we describe the challenging issues facing mSCs. Many previous studies addressed the differences between an MC tier and an fSC tier. Therefore, we focus on the differences between fSCs and mSCs to introduce mSCs.

1. Interferences in HetNet with mSCs

There have been many studies to mitigate interferences that occur within a HetNet [17]–[19]. In these studies, the main reasons for such interferences are the difference in transmission power level between MCs and SCs. However, there are additional issues in connection with interferences in a HetNet with mSCs that are related to the mobility of mSCs. Interferences will fluctuate dramatically compared with those found in a traditional HetNet without mSCs.

Figure 5 shows various types of interferences in a three-tier HetNet composed of MCs, fSCs, and mSCs. In Fig. 5, the yellow wireless link icons with solid lines and red icons with dotted lines represent desired signals from a serving cell and interferences from other cells, respectively. Furthermore, the arrows indicate the movements of mSCs.

http://dx.doi.org/10.4218/etrij.15.2415.0022

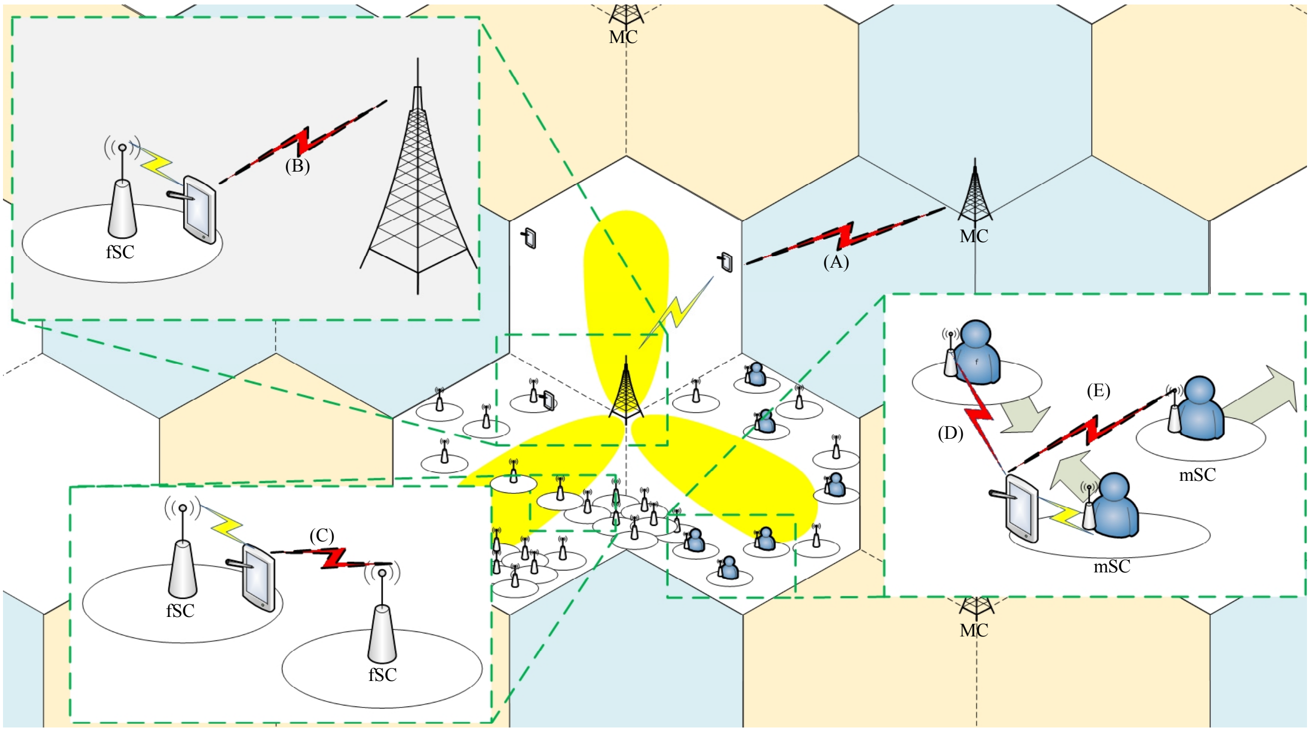

Fig. 5. Illustration of various downlink interferences in 3-tier HetNet; MCs, fSCs, and mSCs.

A. Inter-cell Interference

All interferences in Fig. 5, are inter-cell interferences. The inter-cell interferences occur between any cells regardless of the tier. The fact that both current and future OFDMA-based mobile communication networks would not have intra-cell interferences is further evidence of the fact that all the interferences in this three-tier HetNet are inter-cell interferences.

B. Inter-tier Interference

If a serving cell and an interferer cell are in different tiers to one another, then this type of interference is called *inter-tier interference*. In particular, if the serving cell is an SC and the interferer cell is an MC, as is the case in "(B)" in Fig. 5, then this interference is critical due to the difference in transmission power that exists between an MC and SC.

Various inter-cell interference coordination schemes have been researched [17]–[18]. Cell range expansion (CRE) and almost blank subframe (ABS) are popular solutions. CRE is a method to give association priority to an SC tier by adding an offset to the signal quality of SCs during cell selection. However, CRE can cause serious signal quality degradation because a UE is associated with an SC, even if the signal quality of the SC is significantly worse than that of an MC. Therefore, an ABS scheme is needed. ABS is a resource partitioning scheme; MCs sacrifice their resources in the time-domain for SCs by scheduling no traffic during certain subframes. However, both CRE and ABS lead to a decrease in spectrum efficiency.

C. Intra-tier Interference

Intra-tier interference is the opposite of inter-tier interference. If a serving cell and an interferer cell are in the same tier (for example, "(A)" and "(C)" in Fig. 5), then this type of interference is known as intra-tier interference.

D. Dynamic Interference

Dynamic interference is a newly defined term for the purposes of this paper, resulting from our introduction to mSCs. Dynamic interference occurs when either a serving cell or an interferer cell is a mobile node; for example, as in the cases "(D)" and "(E)" in Fig. 5. There is a remarkable difference between the two cases (D) and (E). The interference in case (D) will be stronger, because the serving cell and interferer cell are close to each other; and vice versa.

E. Semi-static Interference

All of the interferences that occur in the aforementioned studies are examples of non-dynamic interference. We could define such non-dynamic interferences as *static* interferences; however, we are choosing to define them as *semi-static* interferences due to the existence of user mobility and other variables; for example, fast fading.

F. Backhaul Interference

There can be interferences between backhaul links of mSCs that are connected to other MCs or other MC sectors. Backhaul interference may be similar to common inter-cell interference due to the fact that mSCs operate in a similar manner to UEs in our network architecture.

2. Network Mobility

In this section, we analyze network mobility; for example, handover and reassociation after link failure. In a traditional mobile network that only has MCs, most network mobility changes occur at the borders of cells. However, in a HetNet, network association changes may occur at any location, due to the dense and arbitrary deployment of SCs. Moreover, network mobility becomes a more complex problem because of mSCs.

An outline of network mobility procedures for current mobile communication network systems (for example, LTE) is as follows:

1) search for neighboring cells
2) system information measurement for detected neighboring cells
3) cell evaluations and mobility decisions
4) mobility execution upon decision

Therefore, UEs have to perform cell search and measurements for all the neighboring cells that meet a given cell detection threshold. Additionally, most SCs may trigger association changes because of a CRE offset; UEs try to handover to newly detected SCs even if the signal quality of an MC is better than that of a given SC. Thus, those UEs that are located outside of the coverage of fSCs or are not moving along the path of an mSC will trigger more association and handover, which will deteriorate user experience.

A. Simulation Results

We analyzed network mobility performance through simulations with OPNET. We modified the OPNET LTE model that is based on 3GPP LTE release 8; we developed fSC and mSC node models; a CRE offset; a 3GPP wireless channel model; a 3D antenna model [15]; and wireless backhaul for mSCs. We assume that building penetration loss and vehicle penetration loss are 20 dB and 10 dB, respectively [20].

In the simulation scenarios, network elements are deployed as shown in Fig. 5. SCs are located as far as possible from a central area of MC-sector coverages. And, mSCs start to move with random-waypoint mobility patterns at constant speed.

Simulations were performed under two scenarios. The first scenario only includes fSCs, and the second scenario only includes mSCs in the coverage of MCs because our purpose is to compare the performances of fSCs and mSCS. Table 4 shows the simulation parameters used [15]. The other parameters are shown in Table 1. The results from the fSCs-only and mSCs-only scenarios are marked as "(f)" and "(m)" in the legends of the graphs in Figs. 6 and 7.

Table 4. Simulation parameters.

Parameters	MC	fSC/mSC	UE
Bandwidth	10 MHz		
Carrier frequency	2.110 GHz		
Inter-site distance	1,732 m (3GPP Case 3)		
Speed of UEs and mSCs	3 km/h		
Mobility pattern	Random-waypoint model		
CRE offset	8 dB		
Number of nodes	19 cells × 3 sectors	2/4/6/8/10 per MC sector	60 per MC cell

Figure 6 shows the simulation results. Fig. 6(a) represents the service time ratio by MCs and SCs during the simulations. In the fSCs-only scenario, UEs are served by fSCs for a longer period, as fSC density increases. It can be inferred that a higher cell density leads to more MC offloading. In the mSCs-only scenario, the service time ratio of MCs is smaller than that of the fSCs-only scenario because the probability that UEs enter the coverage of an arbitrary SC is increased by the mobility of the mSCs. However, the MC service time ratio does not decrease continuously because of the complicated mobility patterns. Figure 6(b) shows the association rate, which is the average number of association changes of a UE in 1 s. Higher association rates reflect the fact that UEs change their association more frequently. The stacked bars show the association rates for each type of association change: MC-to-MC, MC-to-SC, SC-to-MC, and SC-to-SC.

We can observe that intra-tier association changes between SCs occur most frequently in both the fSCs-only and mSCs-only scenarios. MC-to-MC association changes occur the most rarely. Additionally, the mSCs-only scenarios show more than twice the number of association changes in comparison with that of the fSCs-only scenarios. In the mSCs-only scenarios, the relative speed between network nodes doubled because UEs and mSCs move in their own directions.

However, the results depend on not only the relative speed but also on the locations of nodes, the channel models, antenna patterns, and other factors.

B. Short Time-of-Stay (ToS) Problem

ToS is the duration of a service time during an association. We can easily predict that an SC, especially an mSC, has a very

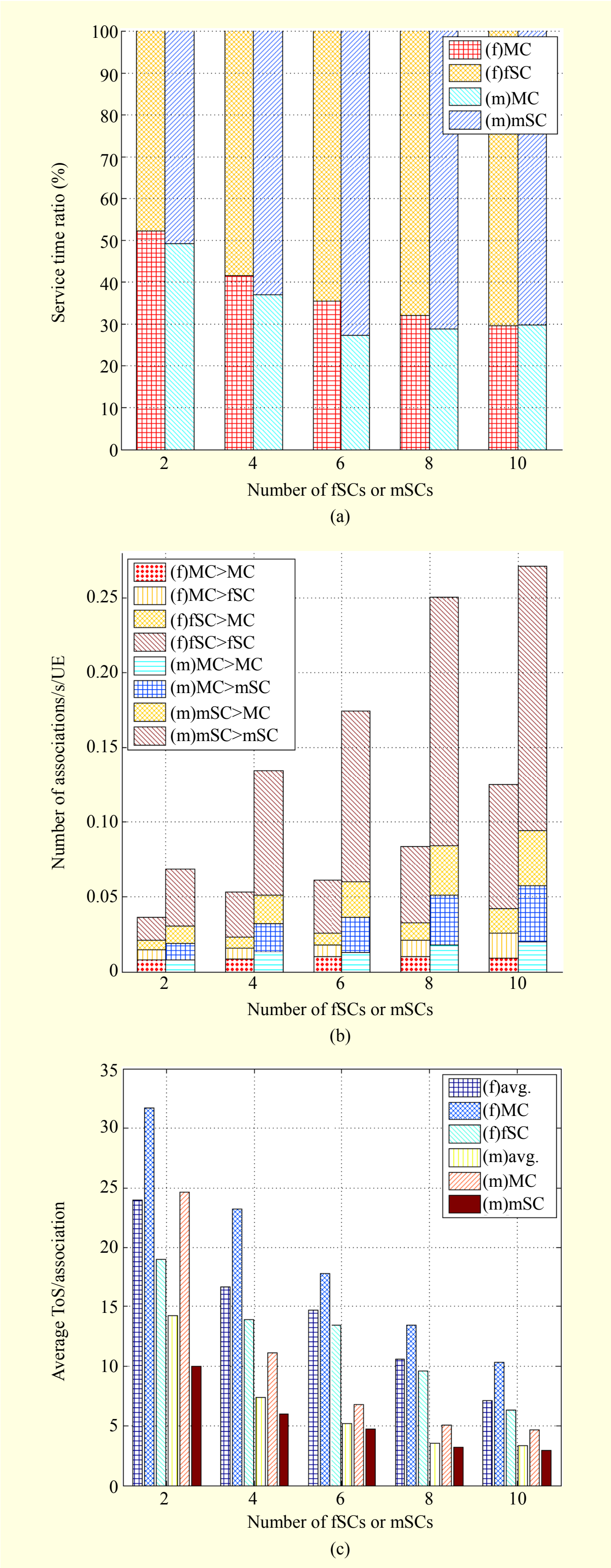

Fig. 6. Simulation results: (a) ratio of time served by each tier (MC/fSC/mSC) to total simulation time, (b) number of UE associations in 1 s, and (c) average ToS during an association.

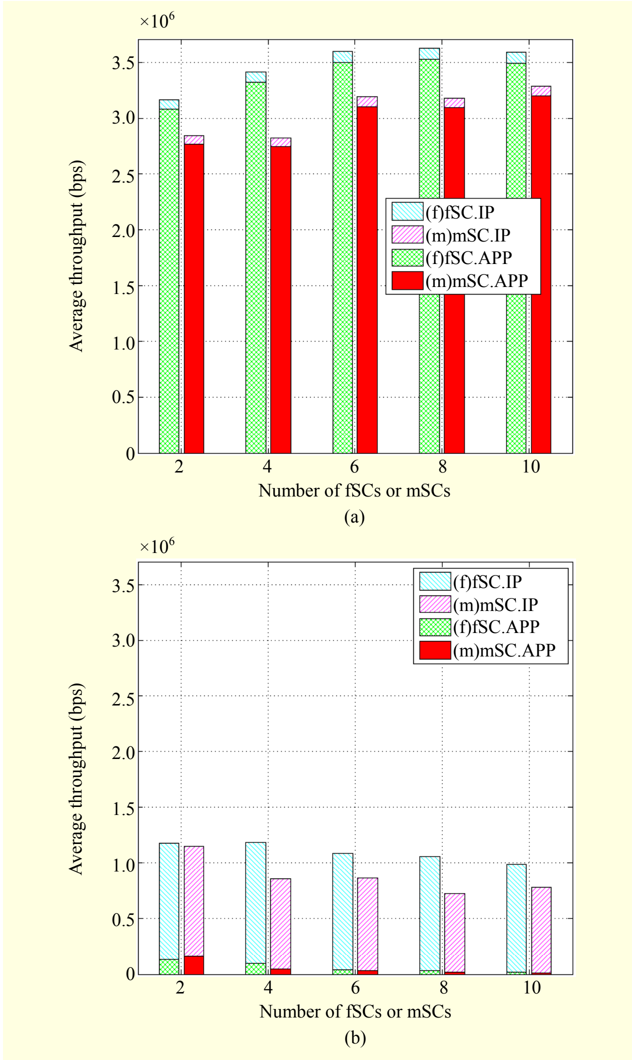

Fig. 7. Simulation results of IP-layer and application-layer throughputs: (a) with UDP traffic and (b) with FTP traffic over TCP.

small ToS from the results shown in Figs. 6(a) and 6(b). Figure 6(c) directly demonstrates this. The left three bars and right three bars are the results from the fSCs-only and mSCs-only scenarios, respectively. According to the results, UEs experience shorter ToS in a network with higher cell density. Moreover, the movements of SCs also decrease the ToS.

A short ToS is a challenging problem that must be solved. It would be better if users did not associate with a given cell that may cause short ToS. There are interruption times for a cell search, RA, and association execution during handovers or cell reselections. For example, the interruption time during a handover procedure in an LTE system is anywhere up to 130 ms [21]. The interruption time during a cell reselection is more than that of a handover. Moreover, such an interruption occurs in bursts. Therefore, a short ToS harms other network performances because frequent association changes lead to bursts of interruptions.

C. Impact on User Performance

In a HetNet, network capacity is enhanced by cell densification. Therefore, physical layer throughput is significantly increased, as shown in previous studies [17], [21]. However, an increment in physical layer throughput does not mean an increment in goodput, due to higher-layer protocol performance degradation by network mobility. If the proper interference coordination and serving cell selection mechanisms are not provided, then those users that are not moving with mSCs will experience poor levels of goodput from the increments from handovers and disconnections.

The mobility of SCs can increase the probability of misjudgment. Figure 7 shows the throughput results of OPNET simulations. The UEs do not contain interference coordination schemes but instead contain CRE, which is a setting that will cause many reassociations and handovers within a HetNet. In Fig. 7, bars appear in matching pairs and overlap with one another: the bars in front and the bars at the back represent the application-layer and IP-layer throughputs, respectively. Therefore, the throughput differences between lower-layer and higher-layer protocols can easily be seen. The mobility of SCs decreases throughputs in all cases of transport layer protocols. The main reason for this decrement of throughput is the increased service disruption during disconnection, reassociation, and handover. In Fig. 7(a), we can observe that the gaps between throughputs of the higher layer and lower layer are small. However, we are able to observe large differences in Fig. 7(b). This phenomenon is mainly due to the TCP behavior. TCP cannot distinguish between errors in links and congestions in networks. Therefore, if the link quality of a UE is poor because of CRE offset, absence of an interference coordination scheme, and bursts of interruption time due to frequent association changes, then the TCP retransmission timeout timer will increase until it reaches a maximum. Then, the session will be disconnected and re-established, repeatedly. In the simulation with TCP traffics, although there was a large number of traffic transmissions in the lower layer, most were retransmissions in the higher layer. Moreover, there is another interesting phenomenon. The lower-layer throughput also decreases even if there is a large amount of traffic retransmission. This is because of the duration from the start of the TCP retransmission count to the retransmission timeouts. This duration acts as inter-arrival time of packets. New traffic is transmitted at rare intervals because of continuing TCP retransmission timeouts.

IV. Required Technologies

In this section, we will discuss the required research issues for a HetNet with mSCs.

1. Further Enhanced Interference Coordination Schemes

Interference coordination schemes are essential for both fSCs and mSCs in a HetNet. Additionally, CRE and ABS schemes are key technologies to mitigate interferences in mobile HetNets. However, both need to be modified for mSCs.

A static CRE offset may not be appropriate to handle a highly dense HetNet that comprises fSCs and mSCs. We can consider a classified adaptation of different CRE offsets for each cell tier or cell, or dynamically optimized CRE offsets in the case of self-organizing networks. There are a number of ABS variances in many research papers and technical documents. However, mSCs require a more dynamic scheme to operate effectively.

2. Network Mobility Management Schemes for Hyper Dense and Highly Mobile HetNets

A dense HetNet causes frequent network mobility situations — neighboring cell search, system information measurements, handovers, link failure, and reassociation. Moreover, it will be more critical with the introduction of mSCs. Therefore, a 5G mobile HetNet requires more advanced mobility management technologies. For example, we can reduce the system information measurements after a cell search by estimating the ToS. Or, we can use the ToS as a variable for cell selection.

3. Dense HetNet Adaptable Higher-Layer Protocol Design

To assure end-to-end user performance in 5G mobile communication networks, further enhanced higher-layer studies are needed as well as lower-layer research. An example is TCP optimization or modification to mitigate frequent short interruptions due to the nature of highly dense HetNets, with consideration of cross-layer protocols. Currently, many researchers are focused on the lower layer, because we are still at the beginning of 5G communication research. However, studies of both the higher layer and the cross layer are also urgently needed.

4. Context-Centric Association Policy

The mSCs that are introduced in this paper are appropriate for application in user- or context-centric network schemes. Therefore, our current research issues are focused on such schemes.

The context-centric changeable mobile cell is one of our main research issues. The idea behind this cell is that user devices and neighboring network elements organize and

http://dx.doi.org/10.4218/etrij.15.2415.0022

change their networks through consideration of a given user's contexts while conventional network cells are following the operational policies of service providers.

V. Summary

In this article, we introduced mSCs for further enhancements of a 5G mobile HetNet. We compared an mSC-applied HetNet with a conventional HetNet having only MCs and fSCs from the point of view of looking at overall network performance in consideration of higher-layer protocols.

In conclusion, a HetNet may increase the lower-layer network performances. However, more enhanced studies are required to deal with higher-layer network issues; for example, network mobility solutions and higher-layer protocol design. Therefore, we pointed out the challenges and required research issues for 5G HetNet and mSC technology. Our currently ongoing studies and future works are also mentioned in the last section of this paper.

References

[1] Y. Park, *5G Vision and Requirements of 5G Forum*, Feb. 2014. Accessed July 7, 2015. https://www.itu.int/oth/R0A0600005F/en

[2] K. Flynn, *ETSI Summit on Future Mobile and Standards for 5G*, 3GPP, Nov. 2013. Accessed July 6, 2015. http://www.3gpp.org/news-events/conferences/1515-etsi-summit-on-future-mobile-and

[3] N. Bhushan et al., "Network Densification: The Dominant Theme for Wireless Evolution into 5G," *IEEE Commun. Mag.*, vol. 52, no. 2, Feb. 2014, pp. 82–89.

[4] P. Demestichas et al., "5G on the Horizon: Key Challenges for the Radio-Access Network," *IEEE Veh. Technol. Mag.*, vol. 8, no. 3, July 2013, pp. 47–53.

[5] W. Roh et al., "Millimeter-Wave Beamforming as an Enabling Technology for 5G Cellular Communications: Theoretical Feasibility and Prototype Results," *IEEE Commun. Mag.*, vol. 52, no. 2, Feb. 2014, pp. 106–113.

[6] H. Boostanimehr and V.K. Bhargava, "Unified and Distributed QoS-Driven Cell Association Algorithms in Heterogeneous Networks," *IEEE Trans. Wireless Commun.*, vol. 14, no. 3, Mar. 2015, pp. 1650–1662.

[7] T.S. Rappaport et al., "Millimeter Wave Mobile Communications for 5G Cellular: It will Work!," *IEEE Access*, vol. 1, May 2013, pp. 335–349.

[8] S. Chen et al., "A Vision of IoT: Applications, Challenges, and Opportunities with China Perspective," *IEEE Internet Things J.*, vol. 1, no. 4, Aug. 2014, pp. 349–359.

[9] X. Ge et al., "Energy Efficiency of Small Cell Backhaul Networks Based on Gauss-Markov Mobile Models," *IET Netw.*, vol. 4, no. 2, Mar. 2015, pp. 158–167.

[10] *Small Cell Definition*, Small Cell Forum. Accessed July 6, 2015. http://www.smallcellforum.org/aboutsmallcells-small-cells-what-is-a-small-cell

[11] T.S. Rappaport, J.N. Murdock, and F. Gutierrez, "State of the Art in 60 GHz Integrated Circuits & Systems for Wireless Communications," *Proc. IEEE*, vol. 99, no. 8, Aug. 2011, pp. 1390–1436.

[12] Z. Pi and F. Khan, "An Introduction to Millimeter-Wave Mobile Broadband Systems," *IEEE Commun. Mag.*, vol. 49, no. 6, June 2011, pp. 101–107.

[13] L. Wei et al., "Key Elements to Enable Millimeter Wave Communications for 5G Wireless Systems," *IEEE Wireless Commun.*, vol. 21, no. 6, Dec. 2014, pp. 136–143.

[14] D. Huang, T. Xing, and H. Wu, "Mobile Cloud Computing Service Models: A User-Centric Approach," *IEEE Netw.*, vol. 27, no. 5, Sept. 2013, pp. 6–11.

[15] 3GPP TR 36.812, *Evolved Universal Terrestrial Radio Access (E-UTRA); LTE TDD 2,600 MHz in US Work Item Tech. Report (Release 10)*, 3GPP, France, 2011.

[16] 3GPP TR 36.814, *Evolved Universal Terrestrial Radio Access (E-UTRA); Further Advancements for E-UTRA Physical Layer Aspects (Release 9)*, 3GPP, France, 2014.

[17] K.I. Pedersen et al., "Enhanced Inter-cell Interference Coordination in Co-channel Multilayer LTE-Advanced Networks," *IEEE Wireless Commun.*, vol. 20, no. 3, June 2013, pp. 120–127.

[18] D. Lopez-Perez et al., "Enhanced Inter-cell Interference Coordination Challenges in Heterogeneous Networks," *Wireless Commun.*, vol. 18, no. 3, June 2011, pp. 22–30.

[19] J. Huang et al., "Grouping Based Inter-cell Interference Coordination in LTE-A Dense Small-Cell Networks," *IEEE Int. Symp. Microw., Antenna, Propag. EMC Technol. Wireless Commun.*, Chengdu, China, Oct. 29–31, 2013, pp. 78–83.

[20] E. Tanghe et al., "Evaluation of Vehicle Penetration Loss at Wireless Communication Frequencies," *IEEE Trans. Veh. Technol.*, vol. 57, no. 4, July 2008, pp. 2036–2041.

[21] 3GPP TS 36.133, *LTE; E-UTRA; Requirements for Support of Radio Resource Management*, 3GPP, France, 2014.

Choong-Hee Lee received his BS, MS, and PhD degrees in electrical engineering from the Department of Electrical and Computer Engineering, Ajou University, Suwon, Rep. of Korea, in 2006, 2008, and 2015, respectively. He is currently with the Communication R&D Lab., LIG Nex1, Seongnam, Rep. of Korea. His research interests include 4G/5G telecommunications, HetNets, small cells, location-based services, and GPS augmentation.

Sung-Hyung Lee received his BS and MS degrees in electrical engineering from the Department of Electrical and Computer Engineering, Ajou University, Suwon, Rep. of Korea, in 2007 and 2009, respectively. He is currently pursuing his PhD degree in electrical engineering at Ajou University. His current research interests include protocol design for VoIP and multimedia contents, and network simulations.

Kwang-Chun Go received his BS and MS degrees in electrical engineering from Ajou University, Suwon, Rep. of Korea, in 2008 and 2010, respectively. He is pursuing his PhD degree in electrical engineering at Ajou University. His research interests include cross-layer design, satellite networks, and QoS performance analysis.

Sung-Min Oh received his BS, MS, and PhD degrees in electrical engineering from the Department of Electrical and Computer Engineering, Ajou University, Suwon, Rep. of Korea, in 2004, 2006, and 2011, respectively. He joined ETRI, in 2011 and is currently a senior member of the engineering staff. His research interests include radio resource management and protocol design for moving networks and massive devices.

Jae Sheung Shin received his PhD degree in computer engineering from the Department of Computer Science and Engineering, Pennsylvania State University, USA, in 2007. He has worked for ETRI, since 1993 and is currently the head of the Wireless Transmission Research Section 3 of the Communications Internet Research Laboratory. His research interests include resource allocation and radio access protocol design for 5G mobile communications; massive device communication including M2M and D2D; and mobile small cells.

Jae-Hyun Kim received his BS, MS, and PhD degrees in computer science and engineering from Hanyang University, Ansan, Rep. of Korea, in 1991, 1993, and 1996, respectively. In 1996, he was with the Communication Research Laboratory, Tokyo, Japan, as a visiting scholar. From April 1997 to October 1998, he was a postdoctoral fellow with the Department of Electrical Engineering, University of California, Los Angeles, USA. From November 1998 to February 2003, he worked as a member of the technical staff at Performance Modeling and QoS Management Department, Bell laboratories, Lucent Technologies, New Jersey, USA. He has been with the Department of Electrical Engineering, Ajou University, Suwon, Rep. of Korea, as a professor, since 2003. His research interests include QoS issues and cross-layer optimization for high-speed wireless communications.

http://dx.doi.org/10.4218/etrij.15.2415.0022