Improving Beam Distribution Evenness in 3-Dimensional Beamforming with Carrier Aggregation

Jun-woo Kim, Gosan Noh, Jang-won Moon, Youn-ok Park, Ilgyu Kim

Communications & Internet Research Laboratory, *ETRI (Electronics and Telecommunications Research Institute), Daejeon 34129, Korea*

jwkim74@etri.re.kr, gsnoh@etri.re.kr, jwmoon@etri.re.kr, parkyo@etri.re.kr, igkim@etri.re.kr

***Abstract*— The 3-dimensional beamforming is a highly attractive issue in 5G telecommunication. Equipped with 2-dimensional antenna arrays, it allows vertical sectorization within a cell as well as horizontal one, by making a beamforming zone for the corresponding sector. However, there is considerable inequality among the areas of beamforming zone. Since the farther from the base station, the bigger the beamforming zone area is, the farther beamforming zone area is likely support more users than nearer beamforming zone.**

In this paper, we propose to utilize carrier aggregation (CA) from additional base stations for relieving the uneven beamforming zone area problem and prove this method is more efficient in improving cell throughput especially in mmWave environment. Even if the additional base station is more simple type which offers only a few beamformings, it can effectively improve the equality of UE's radio resource occupation.

***Keyword*—3-Dimensional Beamforming, Carrier Aggregation, 5G Telecommunication**

I. INTRODUCTION

THE 3-DIMENSIONAL beamforming allows both horizontal and vertical beam pattern adaption in order to enhance system performance over the conventional beamforming techniques [1][2]. Lots of recent researches in 5G communication also consider adopting 3-dimensional beamforming for mmWave systems [4][5].

In 3-dimensioanl beamforming, each beam is formed and controlled by antenna arrays. Then each cell can be split into multitude of beamforming zone as shown in Fig. 1.

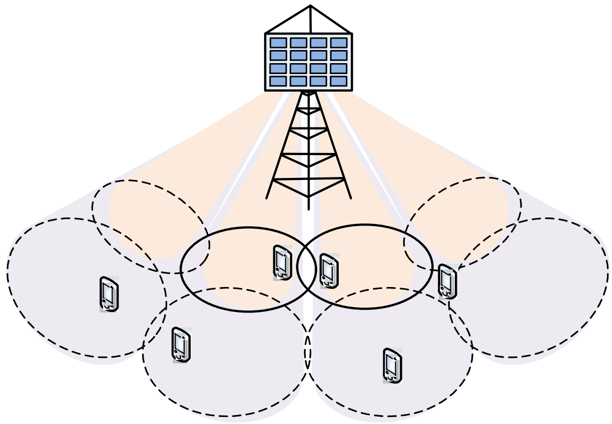


Fig. 1. Multiple beamforming zones using 3-dimensioanl beamforming.

One of the expected problems of 3-dimensional beamforming is its inequality of each beamforming zone area [3][4]. Since the farther from the base station, the bigger the beamforming zone area is, the farther beamforming zone area is likely support more users than nearer beamforming zone. Even though the considered cell sizes are small due to the propagation limitation of mmWave, most part of the cell area was covered by only a small portion of 3-dimensional beamformings [4]. Generating sharper beamforming for farther area may be a solution [10]. But even if downlink beamforming inequality problem is solved by this method, since UE cannot make as sharp uplink beamforming as that of downlink, the uplink beamforming still remains as a problem to solve [12].

This inequality of beamforming zone area causes inequality of users each beamforming supports, i.e. uneven average radio resource occupation of each user equipment (UE) since many UEs in wide area are likely supported from a small number of beamformings in far region from the BS.

Prior researches considered relay systems to be adopted in this situation. Relays are helpful in filling coverage holes but they also can interfere neighbor beamforming zone area [4]. In this paper, we will show this inequality of radio resource

Manuscript received October 9, 2015. This work is a follow up of the invited journal of the accepted conference paper for the 17th International Conference on Advanced Communication Technology. This research was supported by 'The Cross-Ministry Giga KOREA Project' of The Ministry of Science, ICT and Future Planning, Korea. [GK15N0100, 5G mobile communication system development based on mmWave]

Jun-woo Kim is with the Communications & Internet Research Laboratory, Electronics and Telecommunications Research Institute (ETRI), Daejeon 305-700, Korea (Corresponding Author phone: +82-42-860-6682; fax: +82-42-861-1966; e-mail: jwkim74@etri.re.kr).

Gosan Noh is with Electronics and Telecommunications Research Institute (ETRI), Korea (e-mail: gsnoh@etri.re.kr).

Jang-won Moon is with Electronics and Telecommunications Research Institute (ETRI), Korea (e-mail: jwmoon@etri.re.kr).

Youn-ok Park is with Electronics and Telecommunications Research Institute (ETRI), Korea (e-mail: parkyo@etri.re.kr).

Ilgyu Kim is with Electronics and Telecommunications Research Institute (ETRI), Korea (e-mail: igkim@etri.re.kr).

occupation can be alleviated by installing other BSs for carrier aggregation (CA) [6] at adequate places.

The additional BS for CA can be the same type of the main BS or simpler type with a few steering beamforming. While the high-capacity BS for carrier aggregation can greatly improve the unequal radio resource occupation problem, the simpler BS with steering beamforming can moderately improve this problem with less expensive installations.

The CA technology is frequently adopted to multiply the cell capacity. But this paper shows it can be used to alleviate resource occupation inequality also.

II. The Inequality of 3-Dimensioanl Beamforming Zone

A. *The downward tilt angle and the beamforming zone area*

The area of beamforming zone can be varied due to the height, downward tilt angle, vertical and horizontal beamforming angles of base station (BS) antenna. This relation is shown in Fig.2 and equation (1). The beam radius R can be calculated from the BS antenna height *H*, downward tilt angle ω, and vertical beamforming angle θ. The horizontal beamforming angle is assumed to be the same with the vertical beamforming angle.

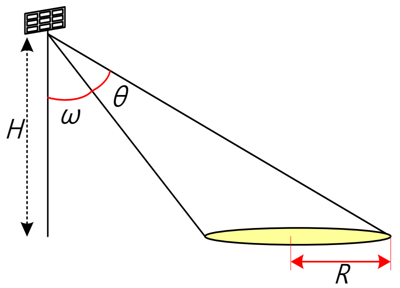


Fig. 2. The relation between 3-dimensioanl beamforming zone and downward tilt angle.

$$R = \frac{H \times [\tan(\theta + \varpi) - \tan(\varpi)]}{2} \quad (1)$$

Since the area of beamforming zone is dictated by the beamforming radius R, it also increases rapidly depending on the downward tilt angle especially when the downward tilt angle is greater than π/4. Fig.3 shows the increase of beamforming zone diameter as per downward tilt angle. The BS antenna height *H* is assumed to be 50 m and beamforming angle θ is 30°.

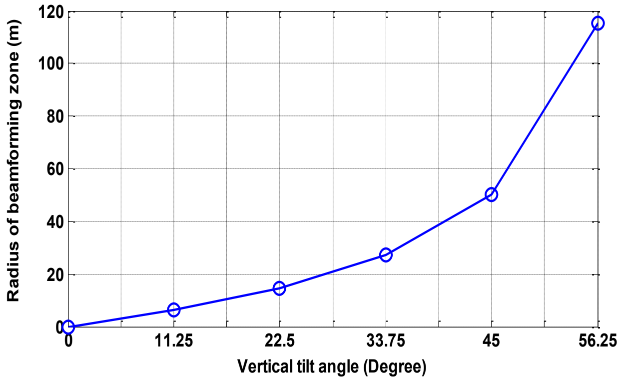


Fig. 3. The beamforming zone diameter as per downward tilt angle.

B. *Our exemplary system*

If the BS antenna configuration is as shown in Table I, the expected beamforming zone of that cell in flat terrain is as depicted in Fig. 4 and Table II. The vertical beamforming is composed of 3 layers whose vertical beamforming angles are all the same and downward tile angles are different from those of others.

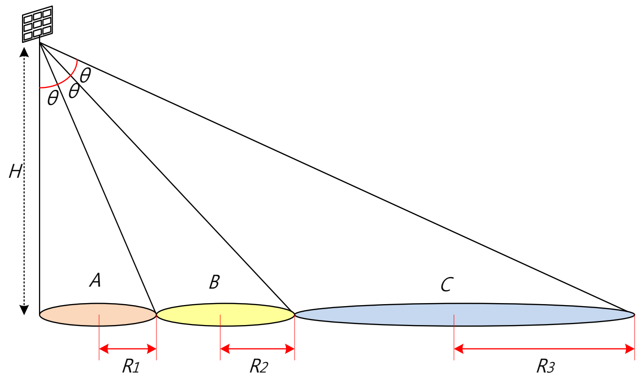
TABLE I
BS Configuration Parameters.

Symbol	Parameter	Value
H	BS antenna height	50m
θ	Vertical beamforming angle	π/8
ω	Downward tilt angle	0, π/8, 2π/8
φ	Horizontal beamforming angle	π/8
L	Number of vertical layers	3
R_1	Beam radius (1st vertical layer)	10.36 m
R_2	Beam radius (2nd vertical layer)	14.64 m
R_3	Beam radius (3rd vertical layer)	35.36 m

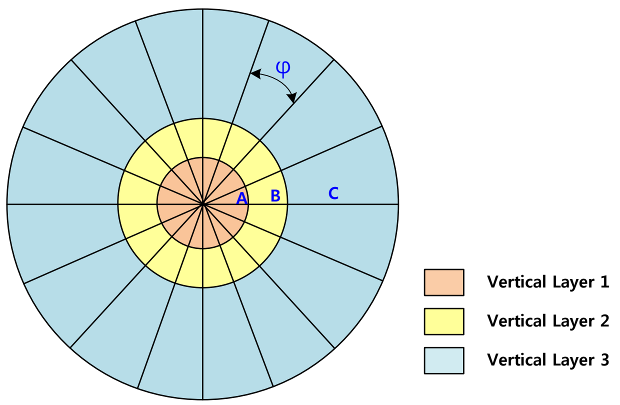
Fig. 4 clearly shows that the relation between the distances from BS and the area of beamforming zone. The calculated area of each beamforming zone A, B and C under the parameter of Table I also certifies it as is shown in Table II.

The (a) of Fig.4 shows the lateral view of 3-dimensional beamforming and the (b) is the ground plan of it.

In real cell deployment, each cell radius is much greater, every beamforming angle is varied or steerable, and each beamforming zone shapes oval and surrounded by interference zone [4]. However we apply simpler model of beamforming zone as shown in Fig. 4 for convenient verification of proposed method.



(a) Vertical view of beamforming layers



(b) Horizontal view of beamforming layers

Fig. 4. The deviation of beamforming zone area with the distance.

While the transmission data rate of each beamforming does not vary widely, its coverage is quite different according to the vertical layer it belongs to. Table II shows the beamforming zone of belonged to 3rd vertical layer is as wide as 28-fold of that belonged to 1st vertical layer.

TABLE II
BEAMFORMING ZONE AREAS OF DIFFERENT VERTICAL LAYERS.

Vertical Layer	1st Layer (A)	2nd Layer (B)	3rd Layer (C)
Single beamforming zone area (m^2)	1347.5	6506. 5	37,922.4
Total beamforming zone area (%)	2.94	14.21	82.84

These unequal areas between beamforming zones cause uneven service quality per equal area in the same cell. If users are evenly distributed in that cell, 82.84% of users are supported by beamformings of 3rd vertical layer while only 2.94% of users receive service of 1st vertical layer beamforming.

Fig. 5 shows the uniformly distributed 1,000 user's occupation of radio resources under this circumstance. All users in each beamforming are supposed to share the equal portions of radio resources.

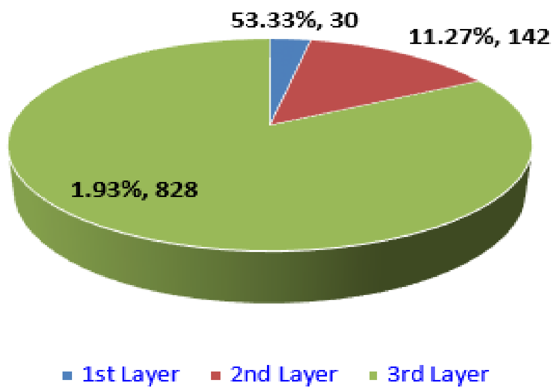


Fig. 5. Occupied Radio Resource per UE (%), Number of UEs.

Fig. 5 depicts occupied radio resource by each UE according to its belonged beamforming layer. Since each layer is assumed to be composed of 16 beamformings as shown in Fig. 4, among 1,000 thousand of uniformly distributed UEs, only 30 UEs are supported by 1st vertical layer and they can occupy about 53.33% radio resource of each beamforming, and 142 UEs are supported by 16 2nd layer beamformings while most UEs - 828 UEs- are belonged to 3rd vertical layer. Since 828 UEs have to share the resources of 16 beamformings in 3rd layer beamforming zone, each UE can occupy only 1.93% of radio resources of each beamforming in average.

In this system, even if the serving BS offers CA with 2 more frequency band, the benefit of CA converges to only 17.16 percent of UEs in the cell and overall resource occupation of UE does not varied.

III. USING CA FOR RELIEVING BEAMFORMING ZONE DEVIATION

A. A CA-BS of the same BS type with the main BS

Many remedies can alleviate this resource occupation inequality. They are the sharper beamforming [10], heterogeneous networking (HetNet) [7][11], relaying [4][5], etc. CA can be one of those solutions also.

Generally, CA is used to improve data rates for UEs and many scenarios are proposed of its deployment [6]. If CA is offered by the same BS with the main serving BS, the benefit is concentrated only a few UEs which are adjacently placed to BS in 3-dimensional beamforming system.

However, if extra CA base station (CA-BS) is located adequately apart, it can reduce the inequality of user service quality because its highly concentrated service zone is not overlapped with that of main BS.

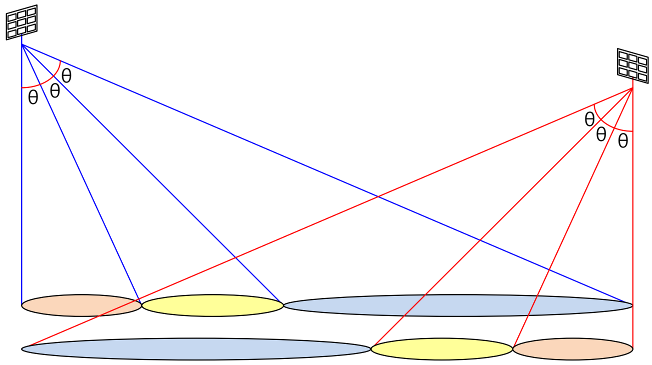


Fig. 6. The effect of CA for relieving beamforming zone area deviation.

Fig. 6 is the lateral view of the proposed CA-BS disposition. It shows that adequately located another CA-BS can offer effectively dense beamformings in large part of thin 3rd layer beamforming zone area by means of carrier aggregation.

Fig. 7 depicts ground plan of an exemplary CA-applied cells. Each CA-BS is supposed to be the same type with the main service BS but they use different component carrier band. This figure shows a large part of cell edge region can be supported by CA -BS.

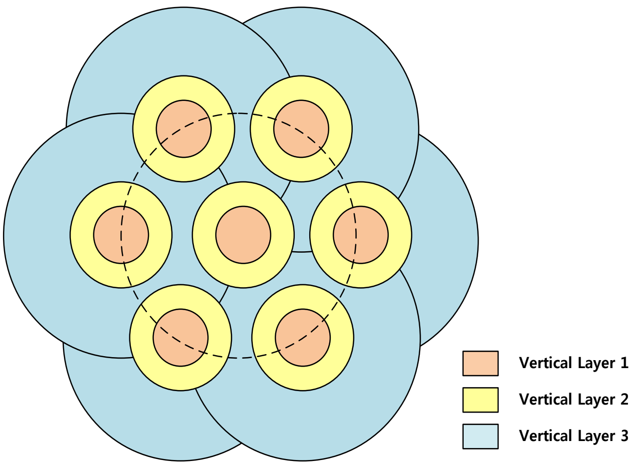


Fig. 7. Beamforming layer of CA-applied cell.

Fig. 7 depicts the situation of CA with 3 different component carrier (CC) frequency bands are used. Each CA-BS is supporting two adjacent neighbor cells also and its 3rd vertical layer beams can be adjustable to avoid inflicting interference to particular UEs.

With the cooperation of CA-BS, more than half of the UEs of our exemplary system can be supported by either 1st or 2nd vertical layer signals as shown in Table III.

TABLE III
BEAMFORMING ZONE AREAS UNDER CA CIRCUMSTANCES

CA type	1st Layer + 3rd Layer	2nd Layer + 3rd Layer	3rd Layer + 3rd Layer
Total beamforming zone area (%)	8.82	42.64	48.55

Fig. 8 depicts the calculated number of UEs and their radio resource occupation in each beamforming. Among uniformly distributed 1,000 UEs, now 486 UEs are supported by solely 3rd vertical layer, and they can occupy 9.88% of beamforming's radio resource.

88 UEs are supported by the 1st layer and as many as 426 UEs are supported by the 2nd layer beamformings. This means more than half of UEs in the cell can occupy more than moderate part of radio resources.

The resource occupation of UEs in the 1st layer and the 2nd layer does not much increase as the addition of component carriers. This means that our proposed method is for improving frequency resource sharing equality rather than enhancing data rate for small number of users through carrier aggregation.

Although the exact radio resource occupation percentage can be varied with different resource assignment strategy or CA-BS parameters, this picture shows that each UE can occupy at least about 10 % of radio resource of each beamforming, and can enjoy better degree of freedom in resource assignment.

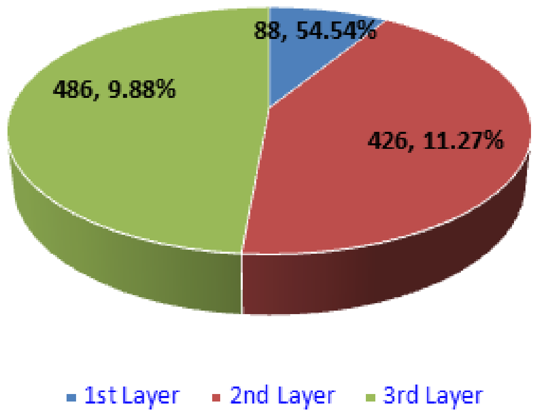


Fig. 8. Occupied Radio Resource per UE (%), Number of UEs with CA.

B. A CA-BS of the different BS type with the main BS

The CA-BS can be more simplified form compared to main BS. While main BS have to cover all its service zone with densely packed beamforming zones not to miss any unsupported UE, CA-BS can offer a few steering beams to support a small most-needed area [13]. It can dynamically change its beamforming's tilt angle and beamforming angle vertically and horizontally which dictates the location and sharpness of beamforming.

Fig. 9 shows this kind of CA-BS can support the required area flexibly. Since in most cases UEs are not evenly distributed but tend to be concentrated in relatively small area [9], so a small number of steering beams from CA-BS can be effective in supporting this hot-zone.

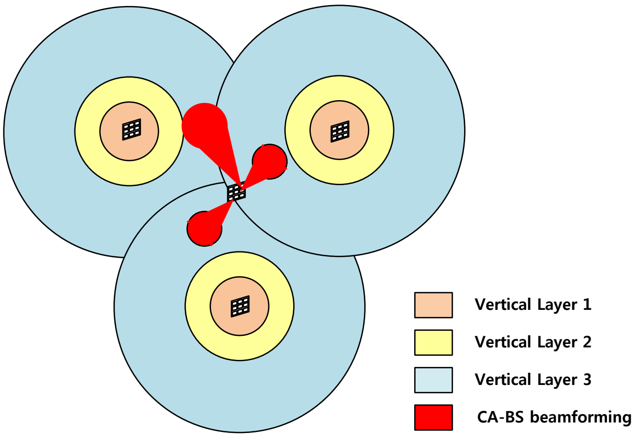


Fig. 9. The CA-BS with Dynamic steering beamforming.

When the CA-BS offers dynamically steering beamformings as shown in Fig. 9, the resultant improvement is shown in Fig.10. The capacity of CA-BS is assumed to be the same with the vertical layer 2. Although in this case, CA beamforming can afford only a small number of UEs compared to the case of Fig. 7, this kind of CA-BS can cover wide range of area with its steering beamformings.

This kind of CA-BS has relatively small capacity and it offer only one component carrier of frequency resource. However it is also helpful in supporting moderate data rate to many disadvantageous UEs.

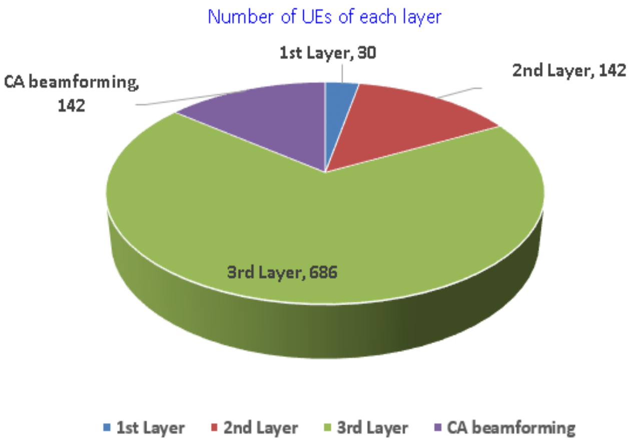


Fig. 10.Number of UEs in each beamforming layer with dynamic steering beamforming.

This displacement of extra CA-BSs is more desirable in mmWave system. Since the propagation limitation of mmWave is sterner compared to other commercial band signal [8], its cell size is relatively small and the extra CA-BSs' signal can easily cover the wide range of each cell, while any possibility can be evaded by beam steering.

Generally CA signals are transmitted from the same serving BS to enhance user data rate. However in the aspect of beamforming zone area inequality in 3-dimensional beamforming, we can see that offering CA by separated BS is desirable.

The separated CA-BSs are also important in the case of propagation deterioration such as rainfall attenuation, since mmWave is especially vulnerable to the effect of rainfall [14], separated CA-BSs can fill the coverage gap between the diameter-reduced cells in the rainy condition.

IV. Conclusions

In this paper, we showed the reason and the seriousness of the inequality of 3-dimensional beamforming zone area and its solution from adopting additional CA base station. Since the area of each beamforming becomes wider according to the distance from the base station, a large part of cell cannot help being supported from only a small number of beamformings.

Our research is about effectively alleviating this inequality to share cell capacity more evenly. Whether the CA base station's beamforming is the fixed beamforming or steering beamforming, if it is adequately placed, the radio resource occupation equality is greatly improved. Usually the CA is used to multiply the capacity of cell, but our research shows it can be used to alleviate resource occupation inequality also.

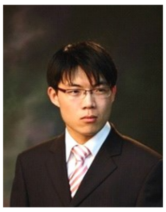
Various terrain, UE distribution, and service environment influence the most efficient cell disposition, and our research shows cooperation with remote CA base station is also vital in user service quality in 3-dimensioanl beamforming environment.

References

[1] J. Koppenborg, H. Halbauer, S. Saur, C. Hoek, "3D beamforming trials with an active antenna array," *Smart Antennas (WSA), 2012 International ITG Workshop on*, 7-8 March 2012, pp. 110-114
[2] B. Ku, D. Ahn, S. Lee, A. Shishlov, A. Reutov, S. Ganin, A. Shubov, "Radiation Pattern of Multibeam Array Antenna with Digital Beamforming for Stratospheric Communication System: Statistical Simulation," *ETRI Journal*, vol. 24, no. 3, Jun. 2002, pp. 197-204.
[3] J. Jung, "Method and apparatus for jointly transmitting/receiving a signal in a mobile communication system," K.R. Patent 10-2013-0127192, Nov. 22, 2013.
[4] J. Bae, Y. Choi, J. Kim, M. Chung, "Architecture and Performance Evaluation of MmWave Based 5G Mobile Communication System," *ICTC 2014*, 22-24. Oct. 2014, pp.847-851
[5] J. Bae, H. Park, S. Lee, Y. Choi, Jun Suk Kim, Min Young Chung, "System Coverage of MmWave Based 5G Mobile Communication System," *APCC 2014*, October 1-3, 2014, pp.1-4
[6] Z. Shen, A. Papasakellariou, J. Montojo, D. Gerstenberger, F. Xu, Overview of 3GPP LTE-advanced carrier aggregation for 4G wireless communications. *IEEE Communications Magazine*, 50(2), 2012, pp. 122-130.
[7] J. Wang, J. Liu, D. Wang, J. Pang, G. Shen, "Optimized Fairness Cell Selection for 3GPP LTE-A Macro-Pico HetNets," *Vehicular Technology Conference (VTC Fall)*, 5-8 Sept. 2011, pp.1-5
[8] M. Kim, S. Hong, Y. Kim, J. Kim, "Analysis of Resource Assignment for Directional Multihop Communications in mm-Wave WPANs," *ETRI Journal* vol.35, no.1, pp. 120-130, Feb. 2014.
[9] K. Son, S. Chong, "Dynamic Association for Load Balancing and Interference Avoidance in Multi-Cell Networks," *Wireless Communications, IEEE Trans.*, Volume 8, July 2009, pp. 3566-3576
[10] W. Roh, et al. "Millimeter-wave beamforming as an enabling technology for 5G cellular communications: theoretical feasibility and prototype results," *IEEE Communications Magazine*, 52(1), 2014, pp.106-113
[11] J. Kim, Y. Han, S. Lee, "An Efficient Downlink Coordinated Beamforming for Heterogeneous Networks," *The 78th Vehicular Technology Conference (VTC Fall)*, Sept. 2013
[12] B. K. Chalise, A. Czylwik, "Robust uplink beamforming based upon minimum outage probability criterion," *Global Telecommunications Conference (GLOBECOM),* Nov. 2004, Vol.6, pp.3974-3978
[13] S. Ha, Y. Jung, Y. Kim, C. Jung, "Reconfigurable Beam-Steering Antenna Using Dipole and Loop Combined Structure for Wearable Applications," *ETRI journal*, vol. 34, no. 1, Feb. 2012, pp. 1-8.

[14] C.Enjamio, E. Vilar, F. Perez-Fontan, "Rain Scatter Interference in mm-Wave Broadband Fixed Wireless Access Networks Caused by a 2-D Dynamic Rain Environment," *IEEE transactions on wireless communications*, Vol. 6, July 2007, pp.2497-2507

Jun-woo Kim received the B.S. degree in electronics engineering from Kyongpook National University, Daegu, Korea, in 1996, the MS from KAIST, Daejeon, Korea in 1998, and the Ph.D degree from Chungnam National University, Daejeon, Korea in 2013.
From January 1998 to September 2001, he was a researcher of Dacom Corporation. Since October 2001, He has been working in ETRI, Daejeon, Korea, where he currently works in a Giga wireless transmission research section as a senior engineer. His current research interests are VSLI, on-chip communication architecture, and various modem design.



Gosan Noh received the B.S. and Ph.D degrees in Electrical and Electronic Engineering from Yonsei University, Seoul, Korea, in 2007 and 2012, respectively.
From March 2012 to February 2013, he was a Postdoctoral Researcher at the School of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea. Since March 2013, he has been with the Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea, where he is a Senior Researcher. His research interests include millimeter wave transmission and polarization diversity/multiplexing techniques.

Jang-won Moon received the BS degree in electronics engineering from Shibaura Institute of Technology, Tokyo, Japan, in 2007, the MS degree in wireless communication engineering from Waseda University, Tokyo, Japan in 2009. Since 2010, He has been working in ETRI, Daejeon, Korea, where he currently works in a Giga wireless transmission research section as a senior engineer. His current research interests are VSLI, on-chip communication architecture, and various modem design.

Youn-Ok Park received the B.S. degree in Electronic Engineering from Hanyang University, Seoul, Korea, in 1986, M.S. and Ph.D degrees in Information and Communication Engineering from Chungnam National University, Daejeon, Korea in 1997 and 2011 respectively.
From December 1985 to January 1987, he was a researcher of Samsung Electronics. Since February 1987, He has been with the Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea, where he is a Principal Member of Technical Staff of Giga wireless Transmission Research Laboratory Section.

Il-gyu Kim received the B.S. and M.S. degrees in electronics engineering from the Seoul City University, Seoul, Korea, in 1993 and 1995, respectively. In 1995, he joined the Network Implementation Section of Shinsegi Telecomm, Inc. (STI), Seoul, where he was involved in the implementation of CDMA cellular systems. Since 2000, He has been working in ETRI, Daejeon, Korea, where he currently works in a Giga wireless transmission research section as a Section Leader.