An Access Strategy for Downlink and Uplink Decoupling in Multi-channel Wireless Networks

Takumi Uekumasu, Makoto Kobayashi, Shunsuke Saruwatari, and Takashi Watanabe
Graduate School of Information Science and Technology, Osaka University, Japan
Email: {uekumasu.takumi, kobayashi.makoto, saru, watanabe}@ist.osaka-u.ac.jp

***Abstract*—With the increasing popularity of smartphones and Internet of Things (IoT) devices, there has been an increase in the amount of mobile traffic on networks. In this paper, we discuss an access strategy for downlink/uplink decoupling (DUDe) with multiple frequency channels to enable the efficient use of frequencies in wireless networks. DUDe is a wireless communications scheme that effectively utilizes frequencies when communicating by connecting the uplink and downlink to different base stations. We propose two base station selection methods, i.e., signal-to-interference-plus-noise ratio (SINR)-based decoupling with re-association (SBD-RA) and SINR-based decoupling with first-come first-association (SBD-FCFA). Based on the evaluation results obtained by event driven simulations, we show that both SBD-FCFA and SBD-RA provide higher throughput by utilizing frequencies more efficiently than DUDe when using the same channel, or without using DUDe. We also show that SBD-RA achieves a high throughput although SBD-RA has a larger computational complexity than SBD-FCFA.**

I. Introduction

In recent years, with the rapid spread in the use of devices such as smartphones, tablets, and Internet of Things (IoT) devices, the demand for wireless communication capacity has continued to increase. Various efforts have been made to cope with increasing wireless communication capacity, such as the development of 5G technology [1]. In this paper, of the different approaches to realizing 5G, we focus on the downlink/uplink decoupling (DUDe). DUDe is a scheme that is used to improve throughput by independently selecting the source base station of the downlink and the destination base station of the uplink in a network having multiple types of base stations [2], [3]. The basic idea of DUDe is shown in Fig. 1, Fig. 2. In Fig. 1, Fig. 2, we assume that the distance between a small cell base station and a device is closer than the distance between the macro cell base station and the device.

Fig. 1 illustrates a normal connection method. In a normal connection, scheme connects both the uplink and the downlink to the base station that has the higher downlink received signal strength indicator (RSSI) at the device. In the same frequency band, we assume that the macro cell base station transmits data with high transmission power, and the small cell base station and the device transmit data with low transmission power. In Fig. 1, because the signal from the macro cell base station has a stronger RSSI at the device, both the uplink and downlink to the device are connected to the macro cell base station. On the other hand, in DUDe, scheme improves the throughput by making a connection to the higher RSSI on the receiving side. Fig. 2 shows an example of how to connect with DUDe. As mentioned above, the macro cell base station transmits data with high power, so in Fig. 2, the RSSI on the device is larger than that of the small cell base station. In this case, for the downlink, the device connects to the macro cell base station. On the other hand, in Fig. 2, the small cell base station is closer to the device than the macro cell base station, and therefore, the RSSI on the small cell base station is higher than that on the macro cell base station. In this case, for the uplink, the device connects to the small cell base station.

Previous research on DUDe has assumed that both the uplink and downlink are in the same frequency band. However, in this study, we consider the case where the uplink and downlink use different frequency bands. Owing to advances in semiconductor technology and the miniaturization of wireless modules, current smartphones are capable of supporting multiple interfaces such as WiMAX, wireless local area network (LAN), Bluetooth, and NFC. In addition, tethering can be achieved with current technology, enabling the use of multiple wireless interfaces simultaneously. Devices can connect the uplink and the downlink on different frequency channels technically, if we show that the frequency utilization efficiency can be improved, DUDe can be applied on different frequency channels in future.

To this end, in this paper, we propose two base station selection methods in DUDe using multiple frequency channels. One is the signal-to-interference-plus-noise ratio (SINR)-based decoupling with re-association (SBD-RA), and the other is SINR-based decoupling with first-come first-association (SBD-FCFA). The SBD-RA approach uses the actual SINR as an index for selecting

978-1-5386-3531-5/17/$31.00 © 2017 IEEE

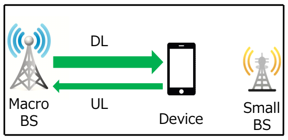

Fig. 1. Connect both the downlink and uplink to the macro cell base station (case1)

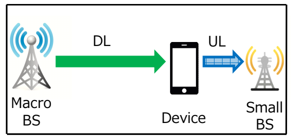

Fig. 2. Connect the downlink to the macro cell base station, and the uplink to the small cell base station (case2)

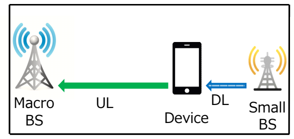

Fig. 3. Connect the uplink to the macro cell base station, and the downlink to the small cell base station (case3)

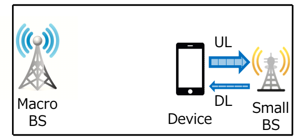

Fig. 4. Connect both the downlink and uplink to the small cell base station (case4)

a base station, and selects the type of base station to which each device connects, i.e., the macro cell base station or the small cell base station. We introduced a mechanism to reduce the number of calculations required for brute-force computations. The SBD-FCFA is a base station selection method that further reduces the number of calculations, as opposed to the SBD-RA, without changing the base station. As a result of the evaluation using simulations, we find that both the SBD-FCFA and SBD-RA have a higher throughput compared to existing methods. In addition, we find that the SBD-RA achieves a high throughput although it has a larger number of calculations compared to the SBD-FCFA.

The rest of the paper is organized as follows. In Section II, we review the system model of DUDe in heterogeneous wireless networks. Then, in Section III, we describe the proposed SBD-RA, and in Section IV, we describe the proposed SBD-FCFA. In Section V, we present and discuss the performance evaluation results obtained by simulation, and we confirm the effectiveness of the proposed methods. We conclude the paper in Section VI.

II. System Model

In this paper, we assume DUDe using different frequency bands for uplink and downlink. We assume that the transmission power of the macro cell base station is larger than that of the small cell base station.

A. Base station selection method

Figs. 1 to 4 show examples of connections in DUDe where macro cells and small cells use multiple frequency channels, as assumed in this paper. The green arrow represents the macro cell frequency band, and the blue arrow represents the communication in the small cell frequency band. In DUDe using multiple frequency channels, the following four types of connection methods to base stations are conceivable.

- case1: Both the downlink and uplink to the macro cell base station (Fig. 1)
- case2: The downlink to the macro cell base station, and the uplink to the small cell base station (Fig. 2)
- case3: The uplink to the macro cell base station, and the downlink to the small cell base station (Fig. 3)
- case4: Both the downlink and uplink to the small cell base station (Fig. 4)

TABLE I
Interference in DUDe using the same frequency channels [4]–[9]

			Receiver			
			Macro cell		Small cell	
			BS	UE	BS	UE
Transmitter	Macro cell	BS	×	✓	×	✓
		UE	✓	×	✓	×
	Small cell	BS	×	✓	×	✓
		UE	✓	×	✓	×

TABLE II
Interference in DUDe using multiple frequency channels

			Receiver			
			Macro cell		Small cell	
			BS	UE	BS	UE
Transmitter	Macro cell	BS	×	✓	×	×
		UE	✓	×	×	×
	Small cell	BS	×	×	×	✓
		UE	×	×	✓	×

B. Comparison of interference model with previous research

In DUDe, using the multiple frequency channels handled in this paper, we see that the interference model is different from the existing research [4]–[9], which is based on the assumption that the current macro cell base station and the small cell base station communicate in the same frequency band. [4]–[9] deals with the base station selection problem on the premise that the frequency channels are the same on the uplink and downlink in DUDe. Table I shows the interference between the base station and the device assumed in [4]–[9]. In Table I, the BS is the base station, and the UE is the device. ✓ represents the case with interference and × represents the case with no interference. In [4]–[9], base stations and devices are assumed to interfere with each other because they are transmitted in a time-division manner based on scheduling by the base station. For example, [4] defines a system model on the premise that the frequency channel is the same on the uplink and the downlink in DUDe, and it shows that the throughput of the whole system improves by using DUDe.

On the other hand, in DUDe, considering the use of multiple frequency channels in this paper, we assume an interference model where the macro cell base station and the small cell base station do not interfere with each other. Table II shows the interference model assumed in this paper. As can be seen from the table II, in the interference model, the macro cell base station and the small cell base station do not interfere with each other.

However, the interference model considered in this paper uses an ideal model that does not interfere with the uplink and downlink in a small cell base station. For example, assuming a wireless LAN as a small cell, the uplink and downlink interfere with each other. However, if we use the frequency band of the wireless LAN, controlling wireless LAN is technically impossible. if the interference between the uplink and downlink does not occur by using a technology such as licensed-assisted access (LAA), controlling wireless LAN is possible. We also consider the simplicity of comparisons with previous studies assuming that macro cell base stations and small cell base stations perform DUDe on the same frequency channel.

C. Interference model

In this paper, we define the SINR model of DUDe using multiple frequency channels related to the SINR model defined in [4]. Φ_{M}, Φ_{F}, and Φ_{d} are the set of points representing the positions of macro cell base stations, small cell base stations, and devices, respectively, which are randomly positioned.

$x_{\mathrm{M}_j}\,(\in \Phi_{\mathrm{M}}), x_{\mathrm{F}_l}\,(\in \Phi_{\mathrm{F}}), x_{\mathrm{d}_m}\,(\in \Phi_{\mathrm{d}})$ are the positions of the jth macro cell base station (M_j), the locations of the lth small cell base station (W_l), and the position of the mth device (d_m), respectively. j, l, and m are natural numbers that are assigned to base stations or devices that exist in countless numbers for convenience. We define P_{M}, P_{F}, and P_{d} as the transmit powers of the macro cell base station, the small cell base station, and the device.

We consider the downlink received power and SINR from the base station, focusing on the mth device (d_m). The downlink receive power ($S^{\mathrm{D}}_{\mathrm{M}_j\mathrm{d}_m}$) from the jth macro cell base station (M_j) at the device is $S^{\mathrm{D}}_{\mathrm{M}_j\mathrm{d}_m} = P_{\mathrm{M}} h_{\mathrm{M}_j\mathrm{d}_m} \|x_{\mathrm{M}_j} - x_{\mathrm{d}_m}\|^{-\alpha}$, The downlink receive power ($S^{\mathrm{D}}_{\mathrm{F}_l\mathrm{d}_m}$) from the lth small cell base station (W_l) is $S^{\mathrm{D}}_{\mathrm{F}_l\mathrm{d}_m} = P_{\mathrm{F}} h_{\mathrm{F}_l\mathrm{d}_m} \|x_{\mathrm{F}_l} - x_{\mathrm{d}_m}\|^{-\alpha}$. $h_{\mathrm{M}_j\mathrm{d}_m}$ and $h_{\mathrm{F}_l\mathrm{d}_m}$ represents Rayleigh fading, which is caused by radio wave propagation from the macro cell base station (M_j) and the small cell base station (F_l) at the device (d_m). $h_{\mathrm{M}_j\mathrm{d}_m}$, $h_{\mathrm{F}_l\mathrm{d}_m}$ are independent exponential distributions with an average of 1. $\|x_{\mathrm{M}_j} - x_{\mathrm{d}_m}\|$ and $\|x_{\mathrm{F}_l} - x_{\mathrm{d}_m}\|$ are the distances between the macro cell base station (M_j) and the device (d_m), and the distance between the small cell base station (F_l) and the device, respectively.

In DUDe, by using multiple frequency channels, the SINR at the device when the mth device (d_m) connects to the $\hat{j}$th macro cell base station ($\mathrm{M}_{\hat{j}}$) on the downlink is

$$\mathrm{SINR}^{\mathrm{D}}_{\mathrm{M}_{\hat{j}}\mathrm{d}_m} = \frac{S^{\mathrm{D}}_{\mathrm{M}_{\hat{j}}\mathrm{d}_m}}{\sum_{x_{\mathrm{M}_j} \in \Phi_{\mathrm{M}} \setminus \{x_{\mathrm{M}_{\hat{j}}}\}} S^{\mathrm{D}}_{\mathrm{M}_j\mathrm{d}_m} + \sigma^2}$$

the SINR at the device when the mth device (d_m) connects to the $\hat{l}$th small cell base station ($\mathrm{W}_{\hat{l}}$) on the downlink is

$$\mathrm{SINR}^{\mathrm{D}}_{\mathrm{F}_{\hat{l}}\mathrm{d}_m} = \frac{S^{\mathrm{D}}_{\mathrm{F}_{\hat{l}}\mathrm{d}_m}}{\sum_{x_{\mathrm{F}_l} \in \Phi_{\mathrm{F}} \setminus \{x_{\mathrm{F}_{\hat{l}}}\}} S^{\mathrm{D}}_{\mathrm{F}_l\mathrm{d}_m} + \sigma^2}$$

σ^2 represents the noise.

The interference in the uplink in DUDe using multiple frequency channels depends on whether each device is connected to a macro cell base station or a small cell base station. Specifically, the device connected to the macro cell base station in the uplink is not affected by the interference caused by the device connected to the small cell base station. It is necessary to treat devices that are connected to the macro cell base station and the small cell base station separately. Therefore, we define a set of device locations connecting the uplink to the macro cell base station as $\tilde{\Phi}_{\mathrm{Md}}\,(\in \Phi_{\mathrm{d}})$, and a set of device locations connecting the uplink to the small cell base station as $\tilde{\Phi}_{\mathrm{Fd}}\,(\in \Phi_{\mathrm{d}})$. They satisfy $\tilde{\Phi}_{\mathrm{Md}} \cap \tilde{\Phi}_{\mathrm{Fd}} = \phi$.

Like the downlink, the uplink received power ($S^{\mathrm{D}}_{\mathrm{M}_j\mathrm{d}_m}$) from the mth device (d_m) in the macro cell base station (M_j) is $S^{\mathrm{D}}_{\mathrm{M}_j\mathrm{d}_m} = P_{\mathrm{M}} h_{\mathrm{M}_j\mathrm{d}_m} \|x_{\mathrm{M}_j} - x_{\mathrm{d}_m}\|^{-\alpha}$. $h_{\mathrm{M}_j\mathrm{d}_m}$, $h_{\mathrm{F}_l\mathrm{d}_m}$ represents the Rayleigh fading caused by radio wave propagation from the macro cell base station (M_j) and the small cell base station (F_l) at the device (d_m), respectively. $h_{\mathrm{M}_j\mathrm{d}_m}$, $h_{\mathrm{F}_l\mathrm{d}_m}$ are independent exponential distributions with the average of 1. $\|x_{\mathrm{M}_j} - x_{\mathrm{d}_m}\|$ and $\|x_{\mathrm{F}_l} - x_{\mathrm{d}_m}\|$ are the distances between the macro cell base station (M_j) and the device (d_m), and the distance between the small cell base station (F_l) and the device.

The SINR at the macro cell base station when the $\hat{m}$th device ($\mathrm{d}_{\hat{m}}$) connects to the jth macro cell base station (M_j) on the uplink is

$$\mathrm{SINR}^{\mathrm{U}}_{\mathrm{d}_{\hat{m}}\mathrm{M}_j} = \frac{S^{\mathrm{U}}_{\mathrm{d}_{\hat{m}}\mathrm{M}_j}}{\sum_{x_{\mathrm{d}_m} \in \tilde{\Phi}_{\mathrm{Md}} \setminus \{x_{\mathrm{d}_{\hat{m}}}\}} S^{\mathrm{U}}_{\mathrm{d}_m\mathrm{M}_j} + \sigma^2}$$

The SINR at the small cell base station when the $\hat{m}$th device ($\mathrm{d}_{\hat{m}}$) connects to the lth small cell base station (F_l) on the uplink is

$$\mathrm{SINR}^{\mathrm{U}}_{\mathrm{d}_{\hat{m}}\mathrm{F}_l} = \frac{S^{\mathrm{U}}_{\mathrm{d}_{\hat{m}}\mathrm{F}_l}}{\sum_{x_{\mathrm{d}_m} \in \tilde{\Phi}_{\mathrm{Fd}} \setminus \{x_{\mathrm{d}_{\hat{m}}}\}} S^{\mathrm{U}}_{\mathrm{d}_m\mathrm{F}_l} + \sigma^2}$$

III. SBD-RA

In the system model shown in Section 2, if the number of devices is m, the number of macro cell base stations is j, and the number of small cell base stations is l. The combination of the devices and the base station is $\mathcal{O}((j+l)^m)$. If $(j+1)^m$ combinations are tried, we determine all of the connections of the devices with the maximum total throughput. However, because the number of combinations of devices and base stations exponentially increases as the number of devices increases, it is not realistic to try $(j+1)^m$ combinations of devices and base stations in a real environment having a large number of devices.

To reduce the computational complexity at the time of connection, we propose a base station selection method called the SBD-RA. The SBD-RA first determines whether to connect the uplink of each device to the macro cell base station or the small cell base station. If the number of devices is m, the number of macro cell base stations is j, and the number of small cell

Algorithm 1 SBD-RA base station selection method.

1: **for all** $\mathrm{d}_o \in \tilde{\Phi}_{\mathrm{Md}} + \tilde{\Phi}_{\mathrm{Fd}}$ **do**
2: **for all** $B \in \Phi_{\mathrm{M}} + \Phi_{\mathrm{F}}$ **do**
3: $\mathrm{Th}^{\mathrm{D}}_{B\mathrm{d}_o} \leftarrow \mathrm{calcDLThroughput}(B, \mathrm{d}_o, \Phi_{\mathrm{M}}, \Phi_{\mathrm{F}})$
4: **end for**
5: $B^{\mathrm{D}}_{\mathrm{d}_o} \leftarrow \underset{B \in \Phi_{\mathrm{M}}+\Phi_{\mathrm{F}}}{\arg\max}\, \mathrm{Th}^{\mathrm{D}}_{B\mathrm{d}_o}$
6: d_o connect to the station ($B^{\mathrm{D}}_{\mathrm{d}_o}$) in the downlink
7: **end for**
8: **for all** R_o **do**
9: decideUEway(R_o)
10: **for all** $\mathrm{d}_o \in \tilde{\Phi}_{\mathrm{Md}} + \tilde{\Phi}_{\mathrm{Fd}}$ **do**
11: **if** $\mathrm{d}_o \in \tilde{\Phi}_{\mathrm{Md}}$ **then**
12: **for all** $B \in \Phi_{\mathrm{M}}$ **do**
13: $\mathrm{Th}^{\mathrm{U}}_{\mathrm{d}_o B} \leftarrow \mathrm{calcULThroughput}(B, \mathrm{d}_o, \tilde{\Phi}_{\mathrm{Md}}, \tilde{\Phi}_{\mathrm{Fd}})$
14: **end for**
15: **end if**
16: **if** $\mathrm{d}_o \in \tilde{\Phi}_{\mathrm{Fd}_o}$ **then**
17: **for all** $B \in \Phi_{\mathrm{F}}$ **do**
18: $\mathrm{Th}^{\mathrm{U}}_{\mathrm{d}_o B} \leftarrow \mathrm{caluULThroughput}(B, \mathrm{d}_o, \tilde{\Phi}_{\mathrm{Md}}, \tilde{\Phi}_{\mathrm{Fd}})$
19: **end for**
20: **end if**
21: **end for**
22: **if** $(\sum_{B\in\Phi_{\mathrm{M}}+\Phi_{\mathrm{F}}} \mathrm{Th}^{\mathrm{U}}_{\mathrm{d}_o B} > \mathrm{Th}_{MAX})$ **then**
23: $Th_{MAX} \leftarrow \sum_{B\in\Phi_{\mathrm{M}}+\Phi_{\mathrm{F}}} \mathrm{Th}^{\mathrm{U}}_{\mathrm{d}_o B}$
24: $\mathrm{R}_b \leftarrow \mathrm{R}_o$
25: **end if**
26: **end for**
27: decideUEway(R_b)
28: **for all** $\mathrm{d}_o \in \tilde{\Phi}_{\mathrm{Md}} + \tilde{\Phi}_{\mathrm{Fd}}$ **do**
29: $B^{\mathrm{U}}_{\mathrm{d}_o} \leftarrow \underset{B \in \Phi_{\mathrm{F}}}{\arg\max}\, \mathrm{Th}^{\mathrm{U}}_{\mathrm{d}_o B}$
30: d_o connect to the station ($B^{\mathrm{U}}_{\mathrm{d}_o}$) in the uplink
31: **end for**

base stations is l. The number of combinations of each device connecting to each base station in the uplink is $\mathcal{O}(m(j+l)2^m)$.

Algorithm 1 shows the selection method of a base station to which the SBD-RA is connected. B is a base station, d_o is a device, and $B^{\mathrm{D}}_{\mathrm{d}_o}$ and $B^{\mathrm{U}}_{\mathrm{d}_o}$ are base stations selected by the device d_o in the downlink and uplink, respectively. R_o is an arrangement that stores the type of macro cell base station or small cell base station to which the device connects in the uplink, and R_b is the array with the highest throughput of the sequences that store which type of macro cell base station or small cell base station to which the device connects in the uplink. Φ_{M} andΦ_{F} are the set of positions of the macro cell base station and small cell base station, as defined in Section II-C. $\tilde{\Phi}_{\mathrm{Md}}$ and $\tilde{\Phi}_{\mathrm{Fd}}$ are the set of devices that are connected to the macro cell base station and the small cell base station defined in

Algorithm 2 SBD-FCFA base station selection method.

1: **for all** $B \in \Phi_{\mathrm{M}} + \Phi_{\mathrm{F}}$ **do**
2: $\mathrm{SINR}^{\mathrm{D}}_{B\mathrm{d}_o} \leftarrow \mathrm{calcDLSINR}(B, \mathrm{d}_o, \Phi_{\mathrm{M}}, \Phi_{\mathrm{F}})$
3: $\mathrm{SINR}^{\mathrm{U}}_{\mathrm{d}_o B} \leftarrow \mathrm{calcULSINR}(B, \mathrm{d}_o, \tilde{\Phi}_{\mathrm{Md}}, \tilde{\Phi}_{\mathrm{Fd}})$
4: **end for**
5: $B^{\mathrm{D}} \leftarrow \underset{B \in \Phi_{\mathrm{M}}+\Phi_{\mathrm{F}}}{\arg\max}\, \mathrm{SINR}^{\mathrm{D}}_{B\mathrm{d}_o}$
6: connect to the station (B^{D}) in the downlink
7: $B^{\mathrm{U}} \leftarrow \underset{B \in \Phi_{\mathrm{M}}+\Phi_{\mathrm{F}}}{\arg\max}\, \mathrm{SINR}^{\mathrm{U}}_{\mathrm{d}_o B}$
8: connect to the station (B^{U}) in the uplink

II-C, respectively. $\mathrm{calcDLThroughput}(B, \mathrm{d}_o, \Phi_{\mathrm{M}}, \Phi_{\mathrm{F}})$ is a function that is employed to calculate the throughput of the downlink from the base station (B) to the device (d_o). $\mathrm{calcULThroughput}(B, \mathrm{d}_o, \tilde{\Phi}_{\mathrm{Md}}, \tilde{\Phi}_{\mathrm{Fd}})$ is a function to calculate the throughput of the uplink from the device (d_o) to the base station (B), and decideUEway(R_o) is a function that is used to calculate the throughput of the macro cell base station or the small cell base station, and to decide whether to connect.

Algorithm 1 first calculates the throughput on the downlink between each device and all base stations. In the first to fourth lines of **Algorithm 1**, each device calculates the throughput on the downlink between all of the base stations. In lines 5 and 6 of **Algorithm 1**, the device is connected downlink to the base station with highest downlink SINR. Next, each device verifies whether to connect the uplink to the macro cell base station or the small cell base station on a brute-force basis. The idea of SBD-RA is to decide in advance to which of the macro cell base station or small cell base station the device should be connected. In the 9th line of **Algorithm 1**, method determines whether each device connects to macro cell base station or a small cell base station. After that, each device obtains the maximum throughput from either the macro cell base station or the small cell base station. the device connects to the macro cell base station obtains the maximum uplink throughput in the 11th to 15th lines of **Algorithm 1**, and the device connects to the small cell base station obtains the maximum uplink throughput in the 16th to 20th lines of **Algorithm 1**. Finally, devices connect by a combination in which maximizes the total of uplink throughput in all devices in uplink.

IV. SBD-FCFA

In the SBD-RA shown in Section III, although SBD-RA reduces the number of calculations when compared with the case of using the brute-force approach for all of them, the number of calculations remains large as $\mathcal{O}(m(j+l)2^m)$. In real networks, devices repeat addition and exit operations, so the number of calculations may be problematic depending on the scale of the network.

In the DUDe for heterogeneous wireless networks, the SINR of the device uplink depends on the type of connected base station of the other device. When we use the RSSI base in a heterogeneous wireless network, the interference increases and the throughput of the uplink decreases. Specifically, in a heterogeneous wireless network, when using the RSSI base when the number of small cell base stations is larger than the number of macro cell base stations, the device that connects its uplink to the small cell with a large number of base stations is connected to the device. When many devices connect their uplink to a small cell, the interference at the small cell base station increases, and the throughput of the device connected to the small cell base station decreases. To improve the throughput, we should select the base station for all of the devices based on the SINR in the uplink.

However, it is not realistic to determine the uplink destination base station for all devices on a brute-force basis. In the case of the brute-force approach, assuming that the number of devices is m, the number of macro cell base stations is j, and the number of small cell base stations is l, there are $(j+1)^m$ combinations of streets. As the number of devices increases, the number of computation increases exponentially. In a wireless network in which a large number of wireless devices exists and fluctuate dynamically, it is necessary to select base stations based on the SINR using a small number of calculations.

In this paper, we propose a base station selection method, SBD-FCFA. SBD-FCFA reduces the number of calculations by not changing the destination base station of the device that is connected to the base station once in the wireless network. Specifically, when each device connects, method selects the base station based on the SINR considering only the interference of the devices already connected to the base station. Further, by not changing the base stations once connected, SBD-FCFA reduces the computational complexity.

Algorithm 2 shows the base station selection method of SBD-FCFA. B is an arbitrary base station, d_o is the newly connected device, and $B^{\mathrm{D}}$and B^{U} are the base stations selected for the downlink and the uplink, respectively. $\Phi_{\mathrm{M}}, \Phi_{\mathrm{F}}$ is the set of macro cell base stations and small cell base station positions defined in Section II-C, $\tilde{\Phi}_{\mathrm{Md}}, \tilde{\Phi}_{\mathrm{Fd}}$ represents the set of devices connected to the macro cell base station, and small cell base station, respectively. $\mathrm{calcDLSINR}(B, \mathrm{d}_o, \Phi_{\mathrm{M}}, \Phi_{\mathrm{F}})$ is a function to calculate the downlink SINR from the base station B to the device d_o. $\mathrm{calcULSINR}(B, \mathrm{d}_o, \tilde{\Phi}_{\mathrm{Md}}, \tilde{\Phi}_{\mathrm{Fd}})$ is a function to calculate the uplink SINR from the device d_o to the base station B.

First, the method calculates the downlink and uplink SINR with all base stations. Specifically, the method estimates the SINR between all of the base stations on lines 14 of **Algorithm 2**. When method calculates the SINR of the uplink, method considers to which base station the other device connects macro cell base station or small cell base station. Subsequently, in lines 5 and 6 of **Algorithm 2**, the device makes a downlink connection to the base station that achieves the highest downlink SINR. Finally, in lines 7 and 8 of **Algorithm 2**, the device makes an uplink connection to the base station that achieves the highest uplink SINR.

If the number of devices is m and the number of base stations is $j+l$, there are $m(j+l)$ combinations in SBD-FCFA. This is less than $m(j+l)2^m$ in SBD-RA, and the number of calculations decreases. In addition, even if the number of devices increases, the amount of computations does not increase exponentially, so we consider that it can be applied to a large-scale network.

V. EVALUATION

In this section, we show the effectiveness of the proposed method using computer simulations to describe the performance evaluation. Specifically, we verify the effectiveness of SBD-RA and SBD-FCFA by evaluating the average throughput for each device in a small-scale network and a large-scale network.

A. Evaluation environment

We evaluated the throughput of the uplink and downlink by performing computer simulations of the proposed method. The transmission power of the macro cell base station was 46 [dBm], the transmission power of the small cell base station was 20 [dBm], and the transmission power of the device was 20 [dBm]. We set the noise σ^2 to -90 [dBm], and the path-loss coefficient α to 4. The traffic model was the full-buffer model. The throughput was the average of the Shannon capacities between the devices and base stations. We performed the simulation 1000 times, and we used the average as the throughput.

We used downlink reference signal received power (DRP) and RSSI base as comparison targets. DRP is a method that is used to connect the uplink and the downlink to the same base station based on the downlink received power, as described in Section II-C. RSSI Base is a method used in [4], and independently connects the uplink and downlink to base stations based on the received power. We perform comparisons using the four methods, which include the proposed methods SBD-FCFA and SBD-RA.

B. Evaluation in small networks

We randomly placed base stations and devices within the range 1×1 [km^2]. Then, we set two macro cell base stations and five devices. We evaluated the average throughput by varying the number of small cell base stations from 2 to 10. In Fig. 5, we show the downlink throughput. From the figure, we observe two things. First, SBD-FCFA and SBD-RA improved the downlink throughput by up to 1.2 [bps/Hz] compared with the DRP and RSSI Base. This is because the device selected the

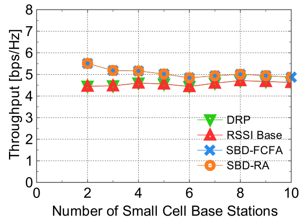

Fig. 5. Average downlink throughput in small networks.

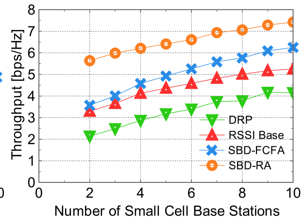

Fig. 6. Average uplink throughput in small networks.

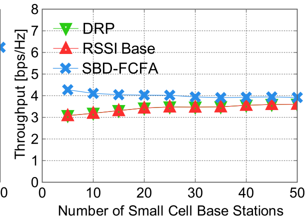

Fig. 7. Average downlink throughput in large networks.

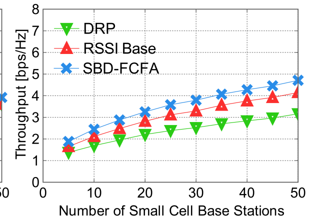

Fig. 8. Average uplink throughput in large networks.

base station with little interference by other devices by the SBD-FCFA. Second, SBD-FCFA achieved the same downlink throughput as SBD-RA. This is because the interference does not change in the downlink even if the base station to which the device is connected changes.

Fig. 6 shows the uplink throughput. From the figure, we observe two things. First, the SBD-FCFA improved the uplink throughput by up to 2.2 [bps/Hz] compared with DRP, and by up to 1.1 [bps/Hz] higher than the RSSI Base. Second, the SBD-RA improved the uplink throughput by up to 2.3 [bps/Hz] compared with SBD-FCFA. This is because devices do not change base station in the SBD-FCFA when a new device is connected, so method does not consider the interference of the newly added device. Therefore, the device that was connected earlier could not connect to the base station with the maximum SINR.

C. Evaluation in large networks

We randomly placed base stations and devices in the range 2×2 [km^2]. We set 10 macro cell base stations and 25 devices. We evaluated the average throughput by varying the number of small cell base stations from 5 to 50. Because the SBD-RA calculations are complicated, we compared DRP, RSSI Base, and SBD-FCFA.

In Fig. 7, we show the downlink throughput. From Fig. 7, SBD-FCFA improved the downlink throughput by up to 1 [bps/Hz] compared to DRP and RSSI Base. This is because the device selected the base station with little interference by the SBD-FCFA.

Fig. 8 shows the uplink throughput. From Fig. 8, SBD-FCFA improved the uplink throughput up to 1.6 [bps/Hz] compared to DRP, and up to 0.7 [bps / Hz] compared to RSSI Base. This is because the device selected the base station with little interference by the SBD-FCFA.

VI. Conclusion

In this paper, we proposed DUDe using different frequency bands for the uplink and downlink, and we proposed two base station selection methods, SBD-RA and SBD-FCFA. SBD-RA reduces the number of calculations required to obtain the maximum throughput by routing all kinds of base stations in the uplink in each device. SBD-FCFA is an extension of RSSI Base used in DUDe in cellular. By using SINR as the base station selection index, SBD-FCFA selects the base station considering interference using a small number of calculations. We evaluated the performance of the effectiveness of SBD-RA and SBD-FCFA by performing computer simulations.

Acknowledgments

We acknowledge the support received by JSPS Science Research Grant JP16H01718 and NTT Access Network Service Systems Laboratories.

References

[1] P.L.D. Almeida, R.M. De, N. Barreto, B. Faria, E. Almeida, and I. Rodriguez, "5G Wireless Communications for 2020," Journal of Communication and Information Systems, vol.31, no.1, pp.146–163, 2016.

[2] H. Elshaer, F. Boccardi, M. Dohler, and R. Irmer, "Downlink and Uplink Decoupling: A Disruptive Architectural Design for 5G networks," Proceeding of IEEE Global Communications Conference (IEEE GLOBECOM'14), pp.1798–1803, Dec. 2014.

[3] F. Boccardi, J. Andrews, H. Elshaer, M. Dohler, S. Parkvall, P. Popovski, and S. Singh, "Why to Decouple the Uplink and Downlink in Cellular Networks and How To Do It," IEEE Communications Magazine, vol.54, no.3, pp.110–117, Feb. 2016.

[4] K. Smiljkovikj, P. Popovski, and L. Gavrilovska, "Analysis of the Decoupled Access for Downlink and Uplink in Wireless Heterogeneous Networks," IEEE Wireless Communications Letters, vol.4, no.2, pp.173–176, Apr. 2015.

[5] D.M. Kim, and P. Popovski, "Reliability Improvement of Uplink Communication through Double Association in Wireless Heterogeneous Networks," ArXiv e-prints, pp.1–4, May. 2015.

[6] L. Zhang, G. Feng, W. Nie, and S. Qin, "A Comparison Study of Coupled and Decoupled Uplink-Downlink Access in Heterogeneous Cellular Networks," Proceeding of IEEE Global Communications Conference (IEEE GLOBECOM'15), pp.1–7, Dec. 2015.

[7] X. Sui, Z. Zhao, R. Li, and H. Zhang, "Energy Efficiency Analysis of Heterogeneous Cellular Networks with Downlink and Uplink Decoupling," Proceeding of IEEE Global Communications Conference (IEEE GLOBECOM'15), pp.1–7, Dec. 2015.

[8] F.J. Martin-Vega, G. Gomez, M.C. Aguayo-Torres, and M.D. Renzo, "Analytical Modeling of Interference Aware Power Control for the Uplink of Heterogeneous Cellular Networks," IEEE Transactions on Wireless Communications, vol.15, no.10, pp.6742–6757, Oct. 2016.

[9] H. Elshaer, F. Boccardi, M. Dohler, and R. Irmer, "Load & Backhaul Aware Decoupled Downlink/Uplink Access in 5G systems," Proceeding of IEEE International Conference on Communications (IEEE ICC'15), pp.5380–5385, Jun. 2015.

[10] R. Li, K. Luo, T. Jiang, and S. Jin, "Uplink Spectral Efficiency Analysis of Decoupled Access in Multiuser MIMO Communications," ArXiv e-prints, pp.1–30, May. 2016.

[11] H. Elshaer, M.N. Kulkarni, F. Boccardi, J.G. Andrews, and M. Dohler, "Downlink and Uplink Cell Association With Traditional Macrocells and Millimeter Wave Small Cells," IEEE Transactions on Wireless Communications, vol.15, no.9, pp.6244–6258, Sep. 2016.

[12] J. Park, S.L. Kim, and J. Zander, "Tractable Resource Management With Uplink Decoupled Millimeter-Wave Overlay in Ultra-Dense Cellular Networks," IEEE Transactions on Wireless Communications, vol.15, no.6, pp.4362–4379, Jun. 2016.