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5G를 위한 동적 대역폭 할당 NOMA-OMA

이 만 희•, Leung C. M. Victor*, 신 수 용°

Dynamic Bandwidth Allocation of NOMA and OMA for 5G

Man Hee Lee•, Victor C. M. Leung*, Soo Young Shin°

요 약

여기는 국문 요약입니다. Non-orthogonal multiple access (NOMA)는 5세대 통신에서 무선 접속 기술 중에 유력한 후보로 제안되고 있다. 전력 도메인의 다중화를 통해서 통신용량을 증대시키고 successive interference cancellation (SIC)를 이용하는 방법이다. 그러나 기존의 통신장비의 경우, SIC를 수행할 수 없기 때문에 NOMA를 적용하는데 있어서 호환성 문제가 발생할 수 있다. 본 논문에서는 orthogonal multiple access (OMA)가 이용가능한 통신 단말에서 NOMA의 호환성을 위한 동적 대역폭 할당 알고리즘을 제안한다. 제안하는 알고리즘은 효율적인 대역폭 할당, 기존의 단말과의 호환성, imperfect SIC에 의한 간섭 감소를 제공할 수 있다. 제안하는 알고리즘의 유효성을 검증하기 위하여 모의실험을 통해 OMA, NOMA의 통신용량을 비교하였고, SIC의 확실성을 불확실성과 확실성 두 가지로 나누어 비교하였다. 제안하는 알고리즘이 OMA에 비해 약 2 bps/Hz의 통신용량 이득이 있었다.

Key Words : Non-orthogonal Multiple Access (NOMA), Orthogonal Multiple Access (OMA), Future Radio Access (FRA), 5G, Backward Compatibility

ABSTRACT

Non-orthogonal multiple access (NOMA) is proposed as a promising candidate of radio access technologies for 5G and beyond. It exploits power domain multiplexing concept to increase capacity combined with successive interference cancellation (SIC). However, there could be a compatibility issue because legacy devices cannot perform SIC which is a necessary step for applying NOMA. In this paper, we suggest a new dynamic bandwidth adjusting algorithm for NOMA to provide the backward compatibility for orthogonal multiple access (OMA). The suggested algorithm can provide backward compatibility, efficient bandwidth allocation, and robustness against imperfect SIC. To verify the performance of suggested algorithm, sum capacity is compared to OMA and NOMA. Simulations are also performed under perfect and imperfect SIC to validate the effectiveness of suggested algorithm. It is shown that the proposed algorithm has 2 bps/Hz capacity higher than OMA.

Ⅰ. Introduction

The swiftly increasing connectivity demands of devices using numerous multimedia applications have created need of a technological shift from 4G to 5G. In the era of next generation (5G) and

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• First Author : Department of IT Convergence Engineering, Kumoh National Institute of Technology, lmh910420@gmail.com, 학생회원
° Corresponding Author : Department of IT Convergence Engineering, Kumoh National Institute of Technology, wdragon@kumoh.ac.kr, 종신회원
* Electrical and Computer Engineering, University of British Columbia, vleung@ece.ubc.ca
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beyond, the communication network will be able to provide higher capacity, lowest latency and more consistent experience. It is imperative to design wireless communication systems that can fulfill these demands with reliability of data. Furthermore, it is necessary to connect massive devices to the wireless network due to the development of Internet of Things (IoT). The requirements of 5G aim to satisfy massive machine type communications (mMTC) for massive connectivity and highly efficient small packets delivery. To achieve these performance requirements, exploiting multiple access technology as future radio access (FRA) is considered as a key development dimension of 5G[1].

The previous four generations of cellular technology have been a major paradigm shift that has broken backward compatibility. Definitely, 5G will also require a paradigm shift that includes very high carrier frequencies, massive bandwidths, huge number of antennas and massive connections. However, it will be expected to be highly integrative and backward compatible, i.e. any new 5G air interface and spectrum together with LTE and WiFi to provide seamless user experience[2].

Non-orthogonal multiple access (NOMA) is considered as one of the promising candidates of 5G radio multiple access technology with higher spectral efficiency and accommodating more users than orthogonal multiple access (OMA)[3]. Generally, NOMA schemes can be categorized into two groups, power-domain multiplexing[4] and code-domain multiplexing[5]. This paper focuses on the power-domain multiplexing NOMA that superposes multiple users in power domain and exploits the channel gain difference between multiplexed users. For power-domain multiplexing, NOMA utilizes superposition coding (SC) at the transmitter and successive interference cancellation (SIC) at the receiver. SC allows the transmitter to transmit multiple users' information using the same resource block. To decode information from the SC at each receiver, SIC technique is used. This means that after one user's signal is decoded and subtracted from SC, then the other user's signal is decoded[6].

Previous literatures mainly focused on increasing capacity and spectral efficiency compared to OMA concatenating antenna technology and orthogonal frequency division multiplexing (OFDM). For cell edge user, antenna information is used to reduce interference in [7] and OFDM based NOMA system is proposed in [8] where transmission to multiple users is done using SC. The problem of user selection, power allocation among the selected users and across the sub-bands while reducing noise problem[9]. But the focus can be shifted to the backward compatibility issue which is common to apply new radio access. The legacy devices with 4G/LTE located near base station (BS) are the major area of concern as these are the devices that need to perform SIC if they use NOMA. To the best of author's knowledge, there is no research on the backward compatibility issue among NOMA and OMA.

In this paper, we want to have backward compatibility with suggested algorithm that is a dynamic bandwidth allocation for NOMA and OMA. Coexistence of OMA and NOMA users in the same cell can help exploit flexible bandwidth allocation because they use separate bands. OMA is used to cover legacy devices which cannot perform SIC but allotting efficient bandwidth for NOMA. Suggested algorithm has benefits from dynamic bandwidth allocation, full power transmission for a legacy device and robustness against imperfection.

For comparison purposes, sum capacity and capacity per user of the proposed algorithm are compared to those of conventional OMA and NOMA. In addition to that different SIC conditions such as perfect and imperfect are considered for performance evaluation of NOMA.

The rest of paper is organized as follows.

Section Ⅱ describes system model and proposed algorithms. Section Ⅲ explains backward compatibility issue and imperfect SIC. In th Section Ⅳ, simulation results are shown as evaluation metrics in different environments. Finally conclusion is drawn in the Section Ⅴ.

Ⅱ. Dynamic Bandwidth Allocation

In this section, we present a generalized system model and a simplified system model for analysis. Moreover, different algorithms are presented to be compared with proposed algorithm.

2.1 System Model

A generalized system model consisting of N near users and M far users in a cell and shown in Fig. 1, where $n(n<N)$ near users and $m(m<M)$ far users can be legacy devices. For the mth far user legacy device, it can readily get paired among N near users because it does not need to perform SIC. Contrary to this, nth near user legacy device cannot get paired using NOMA due to impossibility of SIC.

To completely understand this pairing issue and effect of SIC, a simplified system model is shown in Fig. 2. It consists of a BS and three users (UE1, UE2 and UE3). Let us assume that each user has different distances from BS such that $d_3 > d_2 > d_1$. Correspondingly, their channel gains are in the order $|h_1|^2 > |h_2|^2 > |h_3|^2$. The users are referred as near user (UE1), a middle user (UE2) and a far user (UE3). According to different distances, each

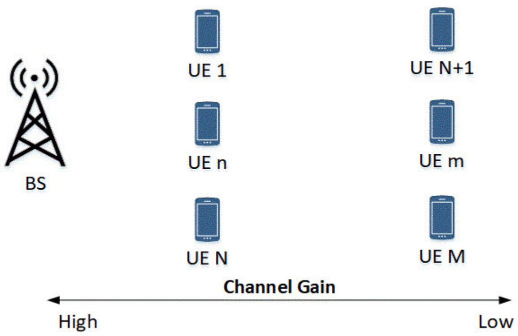

Fig. 1. Generalized system model

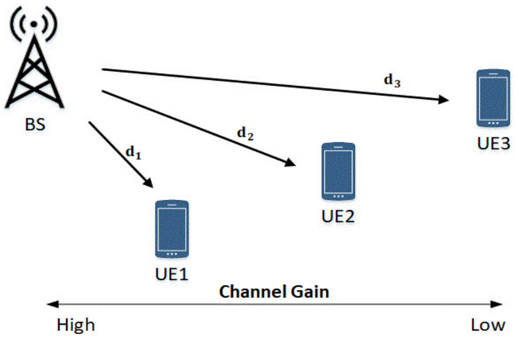

Fig. 2. Simplified system model

channel with independent Rayleigh flat fading is considered as $h_1 \sim CN(0, \lambda_1 = d_1^{-v})$, $h_2 \sim CN(0, \lambda_2 = d_2^{-v})$ and $h_3 \sim CN(0, \lambda_3 = d_3^{-v})$ with variance λ_1, λ_2 and λ_3 where d_n represents distances from BS and path loss v is exponent.

2.2 Available Algorithms

We have considered three algorithms that are conventional OMA, NOMA and the proposed. The algorithms are shown in Fig. 3. For notation, we define that total bandwidth is given as B, total power P_t and three users should be linked with BS. Following colors (Blue, Green and Red) are denoted as UE1, UE2 and UE3 individually. In addition that,

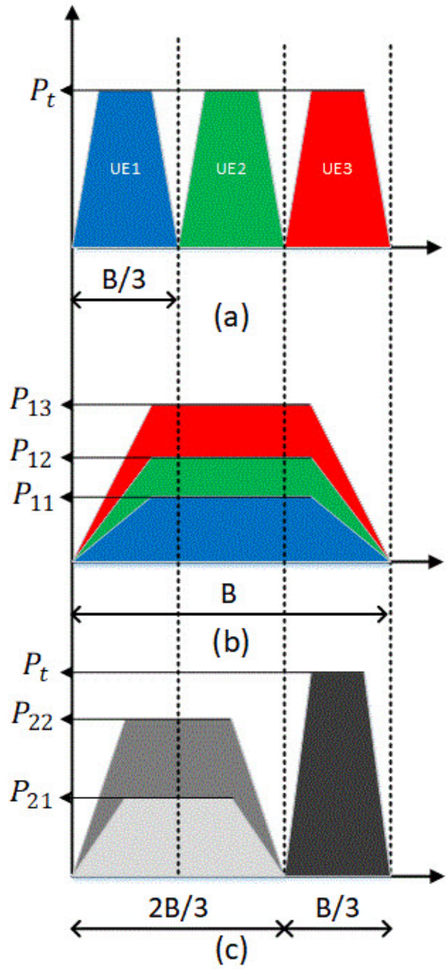

Fig. 3. Available algorithms: (a)OMA, (b)NOMA, (c)The proposed

the number of sub-carriers n, total number of sub-carriers N, the number of user k and total number of users K are expressed, respectively.

2.2.1 OMA

OFDM is representative of OMA scheme which spectrum usage is shown in Fig. 3(a). It is used to support scattered users in a cell while different band of frequencies are shared. Equal bandwidth $B/3$ is allotted for three users. Due to use of orthogonality, kth block of having N sub-carriers can be allocated for every user without overlapping. OMA do not have interference each user because separate frequency bands are used. During transmitting signals, same power P_t is distributed to each user to have maximum sum capacity. The sum capacity of OMA, $R_{k,OMA}$ is represented as

$$\begin{aligned} R_{1,OMA} &= \frac{B}{3}\sum_{n=1}^{N}\omega_{1,n}\log_2(1+\frac{\rho|h_{1,n}|^2P_t}{N_{0,1}}) \\ R_{2,OMA} &= \frac{B}{3}\sum_{n=1}^{N}\omega_{2,n}\log_2(1+\frac{\rho|h_{2,n}|^2P_t}{N_{0,2}}) \\ R_{3,OMA} &= \frac{B}{3}\sum_{n=1}^{N}\omega_{3,n}\log_2(1+\frac{\rho|h_{3,n}|^2P_t}{N_{0,3}}) \end{aligned} \tag{1}$$

where ρ means the transmit signal to noise ratio (SNR), $N_{0,k}$ has kth power density of AWGN with zero mean and unit variance. $\omega_{k,n}$ represents portion of sub-carriers n assigned to user k. This parameter has powerful effect on deciding how many sub-carriers should be used to satisfy the condition, $\sum_{k=1}^{K}\omega_{k,n} \le 1$ for all n in [10].

2.2.2 NOMA

We illustrate bandwidth allocation for conventional NOMA as shown in Fig. 3(b). The overall bandwidth is shared with every user equally. Due to difference of channel gains, all users can get paired within same bandwidth and perform SIC to cancel farthest user's signal. The capacity of each paired user, $R_{k,NOMA}$ is represented as

$$\begin{aligned} R_{1,NOMA} &= B\log_2(1+\frac{\rho|h_1|^2P_{11}}{N_{0,1}}) \\ R_{2,NOMA} &= B\log_2(1+\frac{\rho|h_2|^2P_{12}}{\rho|h_2|^2P_{11}+N_{0,2}}) \\ R_{3,NOMA} &= B\log_2(1+\frac{\rho|h_3|^2P_{13}}{\rho|h_3|^2P_{11}+\rho|h_3|^2P_{12}+N_{0,3}}) \end{aligned} \tag{2}$$

Two far users (UE2 and UE3) are affected by power allocation which is a kind of interference seen in (2). By dividing factors of this, total capacity of users can be flexible and under control.

2.2.3 Proposed Algorithm

Let us assume that 5G devices can accomplish NOMA and legacy devices are only available with OMA. NOMA makes incompatibility because it should have SIC functionality on devices. To solve this problem, we employ the proposed algorithm as adjusting bandwidth allocation of NOMA and OMA. Exploiting OMA makes flexible bandwidth allocation so that proposed algorithm can have dynamic approach. For a legacy device as a near user which cannot perform SIC, OMA is recommended to serve this user while allocating large bandwidth. Generally, NOMA has higher gain than OMA because it uses broad bandwidth with power multiplexing. So proposed algorithm allocates $2/3B$ for NOMA user devices. But a near user legacy device is allowed to use full power transmission out of rule on NOMA it derives another gain for proposed algorithm.

For proposed algorithm, it is recommended to make pairs between 5G devices as near users and legacy devices as far users. Unless this condition is satisfied, we exploit OMA for covering near user legacy devices because it is unnecessary to perform SIC. In Fig. 3(c), it is shown that near users are paired as NOMA and farthest user get exploited as OMA. This is outmost way to increase sum capacity sharing large bandwidth with NOMA. The sum capacity of proposed strategy for multiple users, $R_{k,PROP}$ is represented as

$$
\begin{aligned}
R_{1,PROP} &= \frac{2B}{3}\log_2\left(1+\frac{\rho|h_1|^2 P_{21}}{N_{0,1}}\right) \\
R_{2,PROP} &= \frac{2B}{3}\log_2\left(1+\frac{\rho|h_2|^2 P_{22}}{\rho|h_2|^2 P_{11}+N_{0,2}}\right) \\
R_{3,PROP} &= \frac{B}{3}\sum_{n=1}^{N}\omega_{3,n}\log_2\left(1+\frac{\rho|h_{3,n}|^2 P_t}{N_{0,3}}\right)
\end{aligned} \quad (3)
$$

where UE1 and UE2 are paired and allocated power allocation factors $P_{22} > P_{21}$ whereas UE3 has full power allocation value as P_t.

Ⅲ. Challenges and Environments

3.1 Backward Compatibility

We consider that there are legacy and 5G devices freely scattered in a cell. It is necessary how to connect users as a pair with increasing sum capacity. In the Table 1, following pairings can be divided by the locations of legacy and 5G devices. Among near and middle users unless there is a 5G device like pairing 1 and 2, NOMA is unavailable on these pairings. OMA is recommended for every user in this case. Therefore, the proposed algorithm supports almost pairings with backward compatibility with having spectral efficiency due to NOMA.

Table 1. Scenario of possible pairings

Pairing	Near UE	Middle UE	Far UE
1	legacy	legacy	legacy
2	legacy	legacy	5G
3	legacy	5G	legacy
4	5G	legacy	legacy
5	legacy	5G	5G
6	5G	5G	legacy
7	5G	legacy	5G
8	5G	5G	5G

3.2 Imperfect SIC

Generally, it is supposed that UE1 can decode and cancel the signal of UE2 and UE3 perfectly. Assuming perfect SIC means that difference between channel gain and power allocation is enough for decoding far users' signal at the near users. But proximity of power allocation for both users incurs interference for SIC process. As a result of imperfect SIC, the capacity of NOMA and the proposed $\overline{R}_{1,NOMA}$, $\overline{R}_{2,NOMA}$ and $\overline{R}_{1,PROP}$ are given as

$$
\begin{aligned}
\overline{R}_{1,NOMA} &= B\log_2\left(1+\frac{\rho|h_1|^2 P_{11}}{N_{0,1}+\rho\gamma}\right) \\
\overline{R}_{2,NOMA} &= B\log_2\left(1+\frac{\rho|h_2|^2 P_{12}}{\rho(|h_2|^2 P_{11}+\gamma)+N_{0,2}}\right) \\
\overline{R}_{1,PROP} &= \frac{2B}{3}\log_2\left(1+\frac{\rho|h_1|^2 P_{21}}{\rho\gamma+N_{0,1}}\right)
\end{aligned} \quad (4)
$$

where γ denotes incurred interference from decoding with imperfect SIC. This factor decreases achievable sum capacity. This interference is caused from lack of difference between channel gain and power allocation on the paired users. In NOMA, UE1 is affected by decoding two users' signal during SIC process. Otherwise there is no SIC process in OMA. Correspondingly, it does not have effect from SIC imperfection.

The influence of imperfect SIC is associated with the count of SIC process because SIC imperfection is accumulated to paired users. In terms of imperfect SIC, it give less effect on our proposed algorithm. Unlike NOMA, there is only one SIC process among three users that introduces upturning sum capacity.

Ⅳ. Simulation Results

In this section, we demonstrate simulation results for evaluating performance of the proposed algorithm in comparison with conventional OMA and NOMA. According to statement of users, interference and bandwidth make significant effect on results. Finally sum capacity is shown to analyze the relative capacity gain achieved by the proposed algorithm by considering both perfect and imperfect SIC.

For imperfect SIC case, we assume interference parameter $\gamma = -30$ dB to display impact. Following simulation parameters are used. The distances between BS and UE1, UE2, UE3 are normalized to unit value. UE1, UE2 and UE3 have distances such as $d_1 = 0.3$, $d_2 = 0.7$, $d_3 = 1$ and path loss factor $v = 4$ when bandwidth B is given to 1. These distances and path loss factor decide channel coefficient over each link $h_1 \sim CN(0, \lambda_1 = 0.3^{-4})$, $h_2 \sim CN(0, \lambda_2 = 0.7^{-4})$ and $h_3 \sim CN(0, \lambda_3 = 1^{-4})$. Based on each link, we designated power allocation parameters separately as follows. For OMA, every user uses $P_t = 1$. For convetional NOMA, UE1, UE2 and UE3 use $P_{11} = 0.1$, $P_{12} = 0.35$ and $P_{13} = 0.55$. For proposed algorithm, UE1, UE2 and UE3 use $P_{21} = 0.3$, $P_{22} = 0.7$ and $P_t = 1$. It is assumed that noise power density of $N_{0,1}$, $N_{0,2}$ and $N_{0,3}$ are unit value. The number of sub-carrier N is set to 16 and range of transmit SNR is 0 and 45 dB.

As shown in Fig. 4, it is obvious that ergodic sum capacity of NOMA, OMA and the proposed for UE1 is in proportion to transmit SNR with perfect SIC. Sum capacity of the proposed algorithm has OMA as a lower boundary and NOMA as a upper boundary. When transmit SNR, ρ is equal to 30 dB, capacity of the proposed has 3.2 bps/Hz lower than NOMA but 4.2 bps/Hz greater than OMA, respectively.

Following the Fig. 5, capacity for UE2 upturns chasing increase of transmit SNR with perfect SIC. However interference from UE1 for NOMA and the proposed makes capacity saturation 2.17 bps/Hz and 1.16 bps/Hz at transmit SNR, ρ = 45 dB.

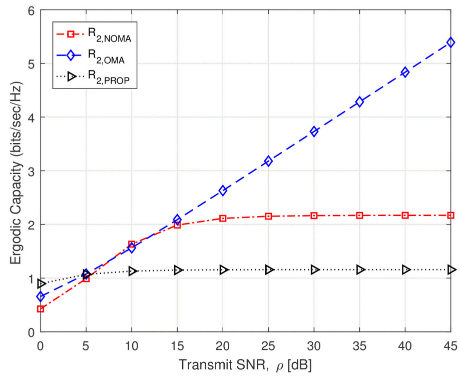

Fig. 5. Capacity comparison for UE2 with respect to transmit SNR, perfect SIC

Fig. 6 shows our proposed strategy has same benefit with OMA because of different bandwidth allocation. It is subject to have saturation of capacity for UE3 that NOMA get interference which drive on 1.15 bps/Hz.

In Fig. 7, sum capacity of NOMA, OMA and the proposed is compared with showing that our proposed has middle value because of different resource usage.

For the view of imperfect SIC, it is shown in Fig. 8 that sum capacity of OMA is coincident with perfect SIC case. But NOMA and the proposed are interfered by factor of imperfect SIC, γ. In the graph, there are two exchange points when capacity of OMA is better than other algorithms. Capacity of OMA overwhelns rather than NOMA and the proposed when the transmit SNR, ρ is over about 42 dB and 37 dB. From 0 to 30 dB, sum capacity

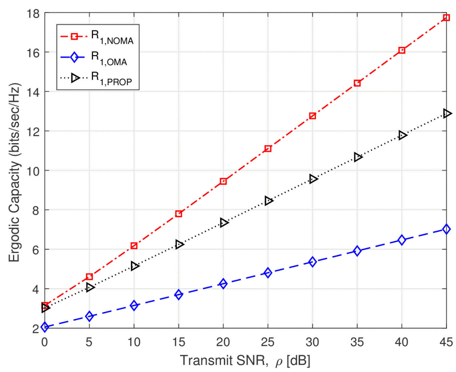

Fig. 4. Capacity comparison for UE1 with respect to transmit SNR, perfect SIC

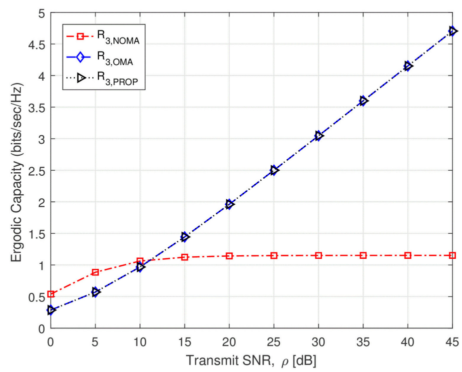

Fig. 6. Capacity comparison for UE3 with respect to transmit SNR, perfect SIC

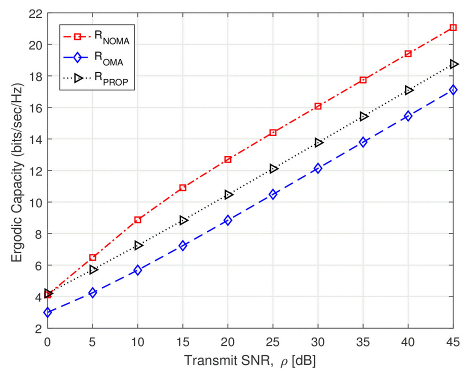

Fig. 7. Sum capacity comparison with respect to transmit SNR, perfect SIC

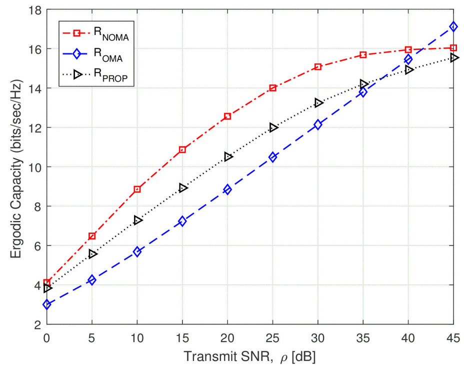

Fig. 8. Sum capacity comparison with respect to transmit SNR, imperfect SIC

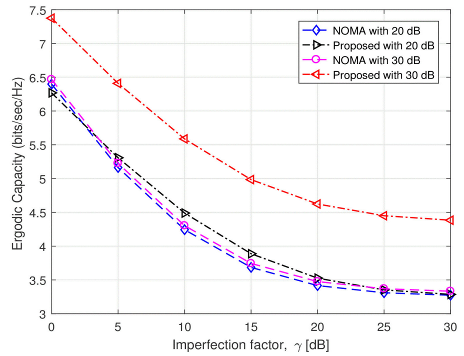

Fig. 9. Sum capacity comparison with varying factor of SIC imperfection γ

of the proposed algorithm is dominant than NOMA in whole area.

V. Conclusion

In this paper, we have proposed dynamic bandwidth allocation for NOMA and OMA having two benefits (1) backward compatibility and (2) efficient bandwidth allocation. Coexistence of OMA and NOMA users in the same cell can help exploit flexible bandwidth allocation because they use separate bands. Proposed algorithm has gain from dynamic bandwidth allocation by exploiting OMA and full power transmission for a legacy device. Due to reduced SIC processes, this has robustness against imperfect SIC. Efficiency of the proposed algorithm is derived in terms of comparisons like sum capacity, capacity per user, capacity following imperfect SIC. The proposed algorithm has 2 bps/Hz capacity higher than OMA with backward compatibility.

For the future literature, developing switching mode for pairing cases based on target rate, appropriate user scheduling and maximizing the number of pairing can be extended for our proposed algorithm.

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이 만 희 (Man Hee Lee)

2015년 2월 : 국립금오공과대학교 전자공학부 졸업

2016년 3월~현재 : 국립금오공과대학교 IT융복합공학과 석사과정

<관심분야> Next Generation Network (5G), Future Radio Access

빅 터 (Victor C. M. Leung)

1977년 : BASc degree in Electrical Engineering from the University of British Columbia (UBC)

1982년 : PhD degree in Electrical engineering from UBC

1999년~현재 : Professor of Electrical and Computer Engineering, UBC

<관심분야> Wireless networks and mobile systems, ICT applications, cloud computing, etc.

신 수 용 (Soo Young Shin)

1999년 2월 : 서울대학교 전기공학부 졸업

2001년 2월 : 서울대학교 전기공학부 석사

2006년 2월 : 서울대학교 전기컴퓨터공학부 박사

2010년~현재 : 국립금오공과대학교 전자공학부 교수

<관심분야> 5G and FRA, Wireless Communication/Network, Internet of Things, signal processing, etc.