Super High Bit Rate Radio Access Technologies for Small Cells Using Higher Frequency Bands

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Abstract — This paper overviews super high bit rate radio access technologies using higher frequency bands for future radio access for 5G. In small cells using higher frequency bands based on the Phantom Cell concept in which radio links for the control (C)-plane and user (U)-plane are separately connected to a macro cell and small cell, radio access technologies employing Massive Multiple-Input Multiple-Output (MIMO) are described that achieve super high bit rate transmission. Specifically, on the basis of 11 GHz band 8x16 MIMO and 24x24 MIMO preliminary investigations, we estimate the required transmission power for 20 Gbps transmission in 20 GHz band Massive MIMO. In addition, we show the basic performance of 20 GHz band Massive MIMO based on link level simulations.

Index Terms — Future radio access, Phantom Cell concept, super high bit rate, Massive MIMO, higher frequency bands.

I. INTRODUCTION

Commercial services for mobile communication systems based on Long-Term Evolution (LTE), which is developed by the 3rd Generation Partnership Project (3GPP) and is specified in its Release 8 document series [1], have been launched in many countries. In Japan, NTT DOCOMO initiated LTE commercial service in December 2010. As the evolution of LTE, 3GPP finished standardization of Release (Rel.) 10 and Rel. 11, which are the first two document series of LTE-Advanced (LTE-A). Currently, LTE-A commercial systems based on the specification in Rel. 10 are being developed.

On the other hand, against to the rapid growing of mobile data traffic that the spread of smart phones and various mobile applications and services cause, higher-capacity transmission becomes urgent. 3GPP Rel. 12 aiming at further improvement in frequency efficiency is being standardized [2], [3]. In order to prepare for the anticipated 1000-fold increase in the volume of data traffic in the next 10 years, dramatic performance enhancements in radio access technologies and networks are required for mobile communication networks beyond 2020 [4].

This paper overviews super high bit rate radio access technologies that employ higher frequency bands to achieve mobile communication networks with super high bit rates and super high capacity as the 5th generation (5G) mobile communication system. We focus on radio access technologies for small cells using higher frequency bands. More specifically, Massive Multiple-Input Multiple-Output (MIMO) technologies [5]–[7] based on the Phantom Cell concept [8] that is characterized by overlaying a small cell using higher frequency bands onto a macro cell of an existing cellular system will play an important role. We verify the feasibility of 30 Gbps throughput based on computer simulations of 30 Gbps transmission using measured 11 GHz band 24x24 MIMO channel data. From the above 11 GHz band investigation, we estimate the transmission power for 20 GHz band 20 Gbps Massive MIMO, and show the basic performance of Massive MIMO.

II. PHANTOM CELL CONCEPT

Fig. 1 shows the Phantom Cell concept in which a small cell is overlaid onto a macro cell. As shown in Fig. 1, the existing macro cell guarantees coverage and mobility using the UHF band such as 800 MHz and 2 GHz, and the small cell provides a super high bit rate through broadband transmission using higher frequency bands such as the super high frequency (SHF) and extremely high frequency (EHF) bands. In addition, in the Phantom Cell concept, the macro cell establishes a connection link in the control plane (C-plane), which provides call and mobility controls while the small cell establishes a connection link in the user plane (U-plane), which is specified by best-effort user data communications.

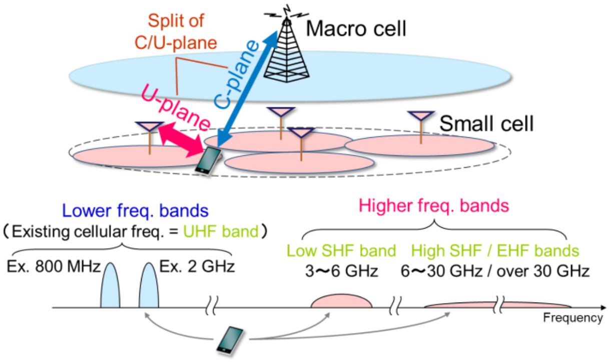

Fig.1. Phantom Cell concept.

III. SUPER HIGH BIT RATE RADIO ACCESS TECHNOLOGIES

A. Super High Bit Rate Transmission Using Massive MIMO

It was considered to be difficult to apply MIMO spatial-division-multiplexing to an SHF band higher than 6 GHz in mobile environments due to the increase in path loss. However, in December 2012, in an environment comprising an 11 GHz band uplink employing 8x16 MIMO with a 400 MHz bandwidth, 10 Gbps transmission experiments succeeded in the world's first 10 Gbps experiment in an outdoor mobile environment [9]. The feasibility of MIMO transmission using high SHF bands over 10 GHz was verified based on these experiments. In the experiments, the transmission power per antenna was 25 dBm and 10 Gbps transmission was achieved by spatially multiplexing 8 streams. Moreover, as an advanced MIMO investigation, computer simulations using measured channel data in 11 GHz band 24x24 MIMO propagation experiments were conducted, and the feasibility of 30 Gbps 24x24 MIMO transmission was verified [10]. Fig. 2 shows the measurement course in the propagation experiments, and it is the same as that in the 10 Gbps outdoor transmission experiments. The measurement vehicle travels along the measurement course at an average speed of 10 km/h, and uplink channel impulse responses are measured in vertical and horizontal polarization. By utilizing the measured channel data, the throughput performance in the downlink for 24x24 MIMO-OFDM eigenmode (EM) transmission was evaluated based on computer simulations. The transmission parameters were the same as those in the 10 Gbps transmission experiment, and noise was added in the computer simulations to set the mean of the average SNRs (Signal-to-Noise Ratios) for the entire measurement course to Γ_C. The throughput performance is shown in Fig. 3. The peak throughput for 24x24 MIMO was 35.3 Gbps. With $\Gamma_C = 20$ dB, over 30 Gbps throughput is achieved around position D, and with $\Gamma_C = 30$ dB, throughput exceeding 30 Gbps was achieved in the area where the average SNR exceeding 18 dB is observed.

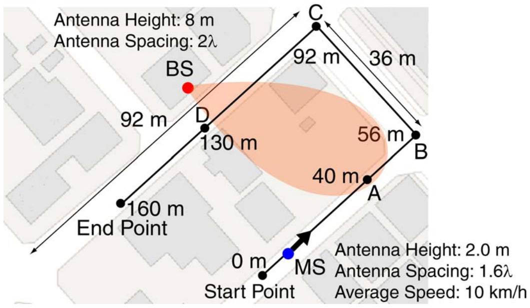

Fig. 2. Measurement course for 24x24 MIMO propagation experiment.

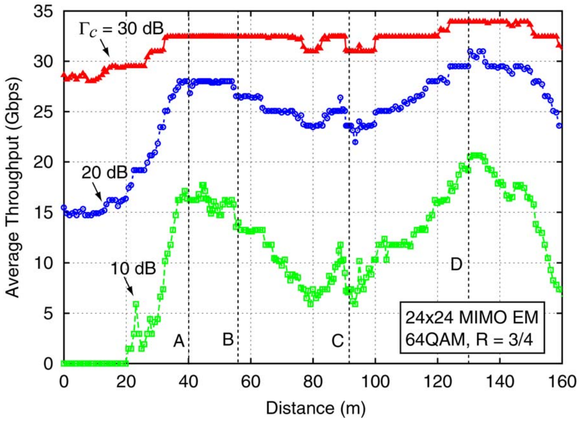

Fig. 3. Throughput performance of 24x24 MIMO.

On the basis of the 11 GHz band super high bit rate investigation, we consider introducing super high bit rate radio access technologies into small cells. As shown in Table I, when the transmission (Tx) power per stream is 25 dBm, spatially multiplexing 16 streams by 16 Tx antennas, which achieves 20 Gbps, requires the total Tx power of 37 dBm. Therefore, the Tx power should be reduced because it exceeds 30 dBm, which is the target Tx power of a base station (BS) in a small cell [3].

For example, in the 20 GHz band, Massive MIMO is introduced by increasing the number of Tx antennas, N_T, and beamforming (BF) is applied to each stream. The total Tx power levels of 20 GHz band Massive MIMO are added in Table I to maintain the reception quality when the Tx power per stream is 25 dBm in the 11 GHz band. In the derivation, we consider that the path loss for 20 GHz is 5 dB higher than that for 11 GHz. As N_T increases, a higher BF gain is obtained. When N_T is greater than or equal to 256, the total Tx power is reduced to 30 dBm or less. Meanwhile, the Tx power per antenna is less than 10 dBm, and thus a Si based semiconductor is applicable to the high power amplifier. In addition, on the assumption that the Tx antenna array is a uniform planar array with the antenna spacing of 0.5λ (λ is the wavelength), with $N_T = 1024$, the antenna size becomes 24.0 cm x 24.0 cm, which is applicable to the small cell BS.

TABLE I
TRANSMISSION POWER LEVELS IN MASSIVE MIMO

Transmission scheme	Freq. (GHz)	No. of Tx ants.	No. of streams	BF gain (dB)	Tx power / stream (dBm)	Tx power / antenna (dBm)	Total Tx power (dBm)
16x16 MIMO	11	16	16	0	25	25	37
Massive MIMO	20	64	16	6	24	18	36
		256	16	12	18	6	30
		1024	16	18	12	-6	24

B. Basic Performance of Massive MIMO

Link level simulations are performed to basically evaluate the feasibility of the 20 Gbps transmission employing 20 GHz band massive MIMO. The parameters used for the simulations are given in Table II. A MIMO-OFM EM transmission using ideal channel status information (CSI) is employed as a preceding scheme. The main transmission parameters are the same as those in the 10 Gbps experiment, and the maximum bit rate reaches 23.5 Gbps according to the parameters set where the modulation and coding scheme is 64QAM with the coding rate, R, of 3/4 for the turbo code. Adaptive modulation and coding (AMC) is used ideally. We assume a uniform planar array for both the transmitter and receiver antennas, and the Rician factor, K, is assumed to be 10 dB for the Nakagami-Rice fading channel.

Fig. 4 shows the throughput performance of the Massive MIMO when N_T is set to 16, 64, and 256. In order to keep the entire antenna array size, the Tx antenna spacing is changed to 2λ, 1λ, and 0.5λ for each N_T. The total Tx power is constant regardless of N_T. Compared to $N_T = 16$, $N_T = 64$ obtains the diversity gain in addition to the BF gain. With $N_T = 256$, the additional BF gain can reduce the required SNR by 6 dB and 17 dB to achieve 20 Gbps throughput compared to $N_T = 64$ and $N_T = 16$, respectively.

TABLE II
SIMULATION PARAMETERS FOR MASSIVE MIMO

Transmission scheme	MIMO-OFDM EM transmission
Signal bandwidth	400 MHz
No. of FFT points	4096
No. of active subcarriers	Pilot: 32, data: 2000
No. of antennas	Transmitter: 16, 64, 256 Receiver: 16
No. of data streams	16
Modulation scheme	QPSK, 16QAM, 64QAM (w/ AMC)
Channel coding	Turbo code, R = 1/2, 2/3, 3/4 (w/ AMC)
Antenna array structure	Uniform planar array
Antenna spacing	Transmitter: 2λ, 1λ, 0.5λ Receiver: 0.5λ
Angular power spectrum	Laplacian distribution
Average angle (azimuth, zenith)	Departure: (90 degrees, 90 degrees) Arrival: (90 degrees, 90 degrees)
Angular spread (azimuth, zenith)	Departure: (5 degrees, 5 degrees) Arrival: (20 degrees, 20 degrees)
Channel model	Kronecker model
Fading model	Nakagami-Rice (K = 10 dB), 16 path

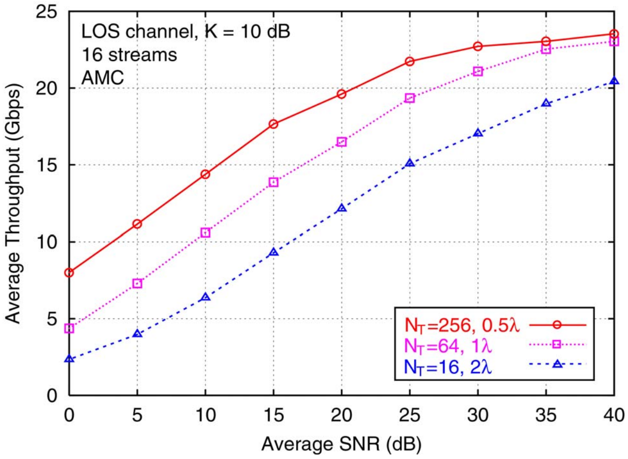

Fig. 4. Throughput performance of Massive MIMO.

The throughput performance with the Tx antenna spacing is shown in Fig. 5. The SNR is set to 20 dB. The Tx antenna spacing is changed from 0.5λ to 4λ at an interval of 0.5λ. The diversity gain with $N_T = 16$ increases when the antenna spacing is up to 3λ. When $N_T = 64$ and 256, the diversity gain improves when the antenna spacing is up to 2λ and 1λ, respectively. Note that optimization of the antenna spacing depends on the channel model, and there exists a trade-off between the entire antenna array size and the diversity gain.

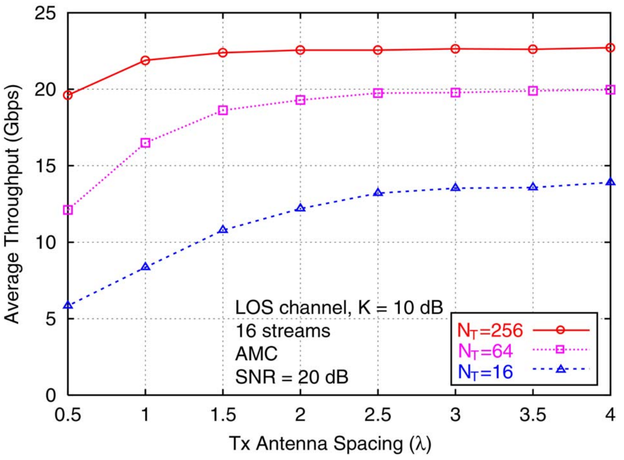

Fig. 5. Throughput performance with Tx antenna spacing.

C. Technical Issues in Massive MIMO

The experimental and simulation results show that the Massive MIMO technologies achieve a super high bit rate using the higher frequency bands. The combination of the Phantom Cell concept and the Massive MIMO is one of the most promising technologies for future radio access because control channels can be exchanged through the macro cell. However, there are some technical issues that need to be addressed. For example, assuming the use of BF in Massive MIMO, the coverage of the synchronization signal (SS) and reference signal (RS) is limited. This is because BF generally requires partial CSI, but CSI is not obtained until the SS and RS are transmitted.

IV. CONCLUSION

This paper introduced Massive MIMO for small cells using higher frequency bands as a super high bit rate radio access technology for future radio access for 5G. On the basis of 11 GHz band 10 Gbps experiments and 30 Gbps simulations, we estimated required transmission power of 20 Gbps transmission in 20 GHz band Massive MIMO. In addition, we showed that the 20 GHz band Massive MIMO with $N_T = 256$ can reduce the required SNR by 17 dB to achieve 20 Gbps throughput compared to the conventional MIMO with $N_T = 16$ based on the link level simulations. Finally, some challenges to introducing the Massive MIMO were mentioned.

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