2-2 Advanced Wireless Packet Cellular System using Multi User OFDM-SDMA/Inter-BTS Cooperation with 1.3 Gbit/s Downlink Capacity

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To realize the 4 th generation mobile communications system, we have been developing elements of advanced wireless signal processing technologies for space, time and frequency domain, that are MU-OFDM (Multi User Orthogonal Frequency Division Multiplexing) technology, Cryogenic RF front-end technology, SDMA (Space Division Multiple Access) and space-time inter BTS (Base Transmission Station) scheduling using multi beamforming technology. This report proposes MU-OFDM-SDMA/Inter BTS cooperation packet cellular system with integration of the technology elements. We also report that the downlink transmission performance and spectral efficiency by simulation using the elements technology results achieved 1.3 [Gbit/s] and 18 [bit/s/Hz/cell], respectively.

Keywords
MU-OFDM, SDMA, Inter BTS cooperation, Cryogenic RF front-end,
4 th generation mobile communications system

1 Introduction

The introduction of a third-generation mobile communication system has allowed for expansion of the capacity of mobile communications. At this stage, in order to make rapid progress toward fourth-generation broadband mobile communication systems, spectral efficiency must be improved. Since the peripheral technologies that support mobile transmission technologies—such as high-speed, energy-efficient signal-processing devices and high-capacity batteries—are expected to be highly developed by 2010, we believe that now is the time to develop the elements of advanced mobile signal processing in the time, space, and frequency domains.

In this report we propose, as a fourth-generation mobile communication system, the MU-OFDM-SDMA/Inter BTS (Base Transmission Station) cooperation packet cellular system, which integrates advanced signal processing technologies with current mobile communication systems, achieving transmission rates of 100 Mbit/s at mobility speeds exceeding 200 km/h. Further, we will discuss system capacity and user-throughput characteristics, estimated using system-level simulations based on the results of experiments on the elemental technologies and link-level simulations. We will also describe the applicable field of the SDMA and Inter-BTS cooperation technologies[1].

2 Advanced signal-processing mobile communication system

2.1 MU-OFDM-SDMA/Inter BTS cooperation mobile communication system

For a fourth-generation mobile communication system, we envisioned a packet cellular system configuration capable of providing a peak downlink capacity of 100 Mbit/s, mobility speeds of 200 km/h, FDD (Frequency Division Duplexing), and a frequency reuse factor of 1. Figure 1 shows the configuration of an MU-OFDM-SDMA/Inter-BTS cooperation system that integrates advanced signal-processing technologies for such a fourth-generation mobile communication system. The proposed system features the adoption and integration of advanced signal processing technologies in the time, space and frequency domains: (1) mobile accessing technology based on MU-OFDM (Multi User Orthogonal Frequency Division Multiplexing), which allows high-grade communication services even in high-speed multipath fading environments (mobility speeds greater than 200 km/h); (2) a superconducting filter technology with sharp frequency cutoff characteristics, enabling the suppression of guard bands for adjacent channels (or bands); (3) SDMA (Space Division Multiple Access) technology, which suppresses the inter-beam interference attributable to simultaneous transmission allocations to multiple users; and (4) inter-BTS cooperation technologies, in order to reduce interference at the cell boundaries between adjacent BTSs.

The major system parameters of the MU-OFDM-SDMA/Inter BTS cooperation system are shown in Table 1. The downlink center carrier frequency is set at 4.0 GHz, which falls within the 3-5 GHz band planned for use in fourth-generation mobile communication systems. The occupied bandwidth of 72.828 MHz is divided into 16 sub-bands, with each band allocated to a user. The BTS antenna consists of a 12-element circular array antenna, and either the SDMA or the inter-BTS cooperation method is used. The maximum output power of the BTS is 47 dBm (per element), and a two-element omni antenna is used for the mobile antenna.

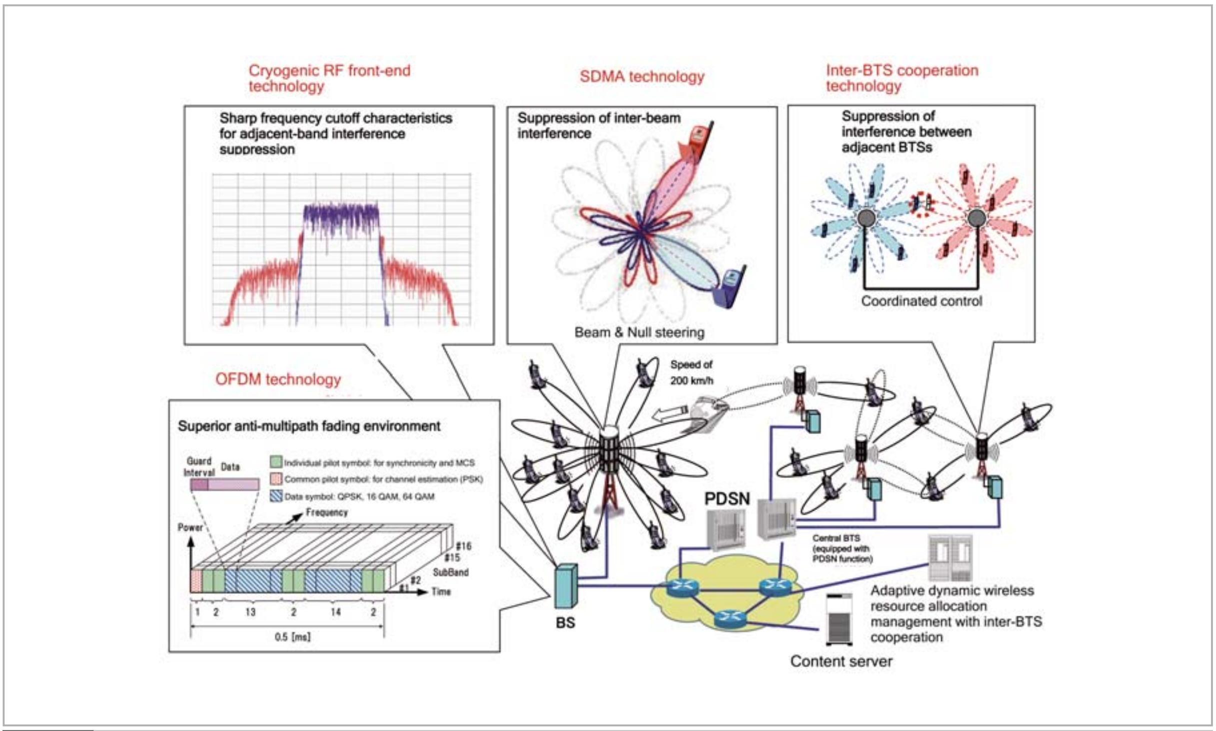


Fig. 1 *OFDM-SDMA/Inter-BTS cooperation system configuration and MU-OFDM frame format*

Table 1 *Major system parameters of the MU-OFDM-SDMA/Inter BTS cooperation system*

Center carrier frequency	4.0GHz
Bandwidth	72.828MHz
Duplexing Method	FDD
Downlink modulation method	OFDM
BTS antenna	12-element circular array antenna
BTS output power	47 dBm/element
BTS antenna gain	20 dBi/element
AT antenna	2-element dipole antenna
AT antenna gain	−1 dBi/element
AT noise figure	6dB

(1) Multi-user OFDM (MU-OFDM)

For the most efficient transmission of the transmit signal, we apply the MU-OFDM method, which performs frequency multiplexing for each sub-band based on the superior anti-multipath fading of OFDM. When combined with a powerful forward-error-correction method, the MU-OFDM performs well even at frequency reuse factor of 1. In particular, this method reveals excellent performance for high-speed mobile communications[2][3]. Table 2 presents the specifications for our MU-OFDM system, and its sub-band and frame format are shown in Fig. 1. The number of data symbols per frame is set at 28, and a common pilot is used for synchronization during beam steering and MCS (Modulation & Coding Set) determination. In the front, middle, and end of the frame, two dedicated pilot symbols are inserted, and advanced channel estimations are carried out using the average of the two successive pilot symbols and by linear time-directional interpolation. Turbo coding is compliant with the 3 GPP 2. In this paper, the frequency synchronization, FFT timing synchronization, and transmission timing synchronization among all of the BTSs were assumed to be ideal. Figure 2 shows the throughput performances relative to instantaneous SIR at mobility speeds of 40 km/h (f_D = 150 Hz) and 200 km/h (f_D = 750 Hz), which is used as the switching SIR threshold of MCS for the adaptive modulation method.

Table 2 *MU-ODFM Specifications*

Sampling frequency	83.232MHz
Number of subcarriers used	896
Number of IFFT/FFT points	1024
OFDM symbol duration	14.706μs
Guard interval length	2.403μs
Frame duration	0.5ms
Number of symbols	34 symbols/frame (Individual pilot: 6; common pilot: 1; data: 27)
Number of sub-bands	16
Modulation type	QPSK / 16QAM / 64QAM
Encoding rate	1/5, 1/4, 1/3, 1/2, 2/3, 3/4
Coding/decoding	Turbo encoding (constraint length: 4) Max-Log-MAP decoding (decoding repetition: 8)
Channel estimation	ZF-FAV (D=1) + mean time of 2 successive pilots (linear time-direction interpolation)

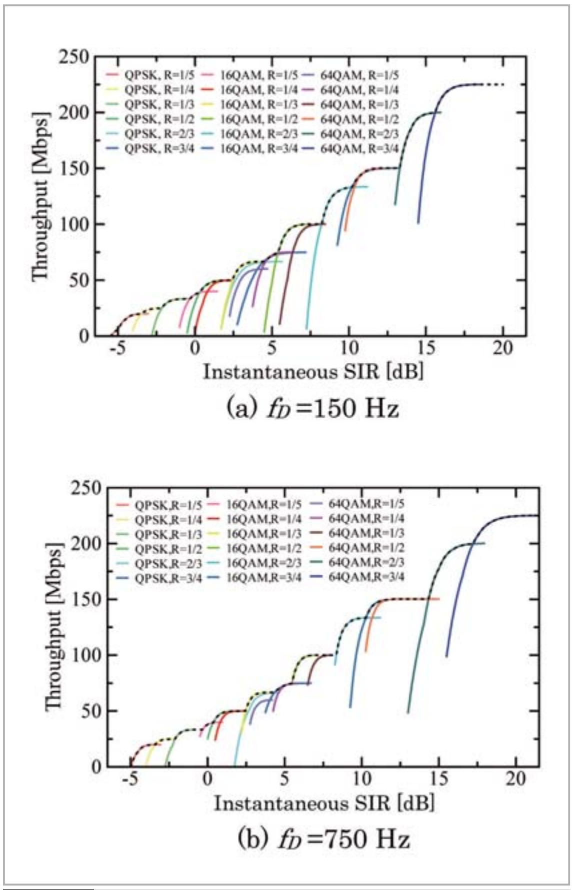


Fig.2 *Instantaneous SIR versus throughput performances*

(2) Superconducting filter

Figure 3 shows an example of a superconducting transmitted-RF filter designed based on frequency characteristics, which is expected to display low insertion loss (in-band), sharp frequency cut-off characteristics, and high out-of-band compression characteristics at levels similar to the superconducting receiving-RF filters for the BTSs[4][5]. The superconducting transmitted BPF (Band Pass Filter) was designed to feature a transmission bandwidth of 72.828 MHz(a -3-dB bandwidth) and a suppression ratio greater than 25 dB, at frequencies 41.41 MHz apart from the center frequency (assuming 5-MHz guard bands).

(3) SDMA system

The 12-element circular array antenna was used to create a transmitted beam pattern that suppresses inter-beam interference between multiple users, and improvements were made in the density of spatial use by enabling simultaneous multiple-beam transmission. The direction of arrival were estimated with the correlation matrix from the uplink (assuming FDD), and the correlation matrix for the downlink was calibrated with the calibration data, then the transmission array weight was determined for the beam and null steering[6]. In the system simulations, the errors in the estimation of directional of arrival and beam control, determined with reference to the results of field experiments, were taken into account[7]. Further, in terms of packet scheduling, the weight priority method[8]—which selects a user combination for simultaneous transmission—was applied to each sub-band using the PF (Proportional Fairness) method based on the measured CIR (Carrier to Interference power Ratio) for the common pilot.

(4) Inter-BTS cooperation system

The 12-element circular array antenna was used to produce the two types of patterns shown in Fig. 4, featuring six beams with beam half-widths of 45 degrees arranged at 60-degree intervals. When inter-beam interference from the desired BTS is large, it is not possible to improve the received SINR by inter-cell interference reduction. Thus, the inter-BTS interference is suppressed by setting the interference suppression ratio between adjacent beams (at 60-deg. intervals) to a value greater than 25 dB. In addition, additional interference from adjacent BTSs is suppressed by inter-BTS cooperation control. For this control, the access terminals must report on interference conditions for each directional beam output from adjacent BTSs, so that the BTSs can carry out coordinated control—determining the transmission timing that will eliminate interference for each access terminal by cross-checking the reported interference conditions against the output timing of directional beams emitted from adjacent BTSs[9]. The packet scheduling method adopted was based on the PF method, as in the SDMA method, with user selection added for coordinated controls.

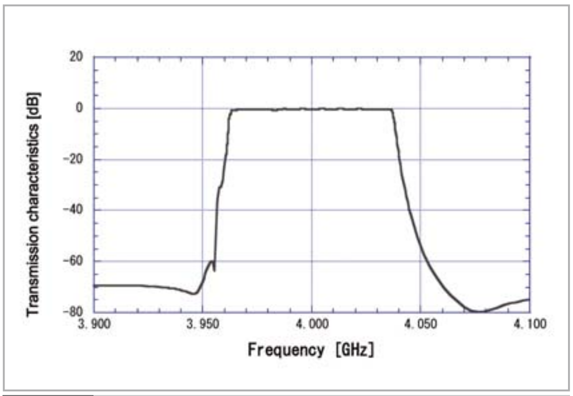


Fig.3 *Transmission characteristics of a superconducting transmitted-filter (example of design)*

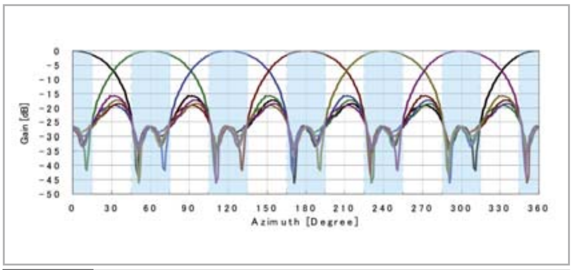


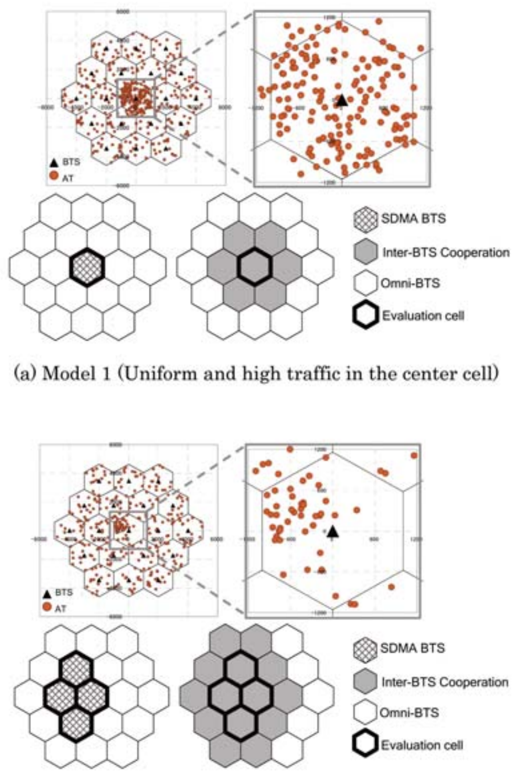
Fig.4 *Beam-steering characteristics for the Inter-BTS cooperation method*

2.2 System simulation

Table 3 shows the parameters of simulations, in order to clarify the applicable range and the system transmission capacity characteristics for the SDMA and inter-BTS cooperation methods in the present system.

Table 3 Simulation parameters

Cycles of simulation	5000 [frame]
Data traffic	Full buffer
BTS allocation	Inter-BTS cooperation: 7 center cells SDMA: Central cell (SDMA) Omni BTS: Other cells
BTS distance	2 [km]
Access terminal density	Low traffic: 16 AT/Cell High traffic: 128 AT/Cell
Access terminal speed	40 [km/h] (Doppler shift frequency f_D = 150 [Hz])
Propagation model	
Path loss model	40log(d) - 30log(Hb) + 28log(f) + 58 [dB] d [m]: (Distance from BTS) Hb: 50 [m] (BTS antenna height) F: 4 [GHz] (Carrier frequency)
Shadowing	Log-normal distribution
Standard deviation	8.9 [dB]
Correlation	0.5
Correlation distance	20 [m]
Fading	Rayleigh fading (12 paths exponential decay, Delay spread 400 ns)
Angular spread	3 [deg]
Adaptive modulation	Adaptive modulation and coding based on measured CINR at AT
Access terminal receiver	
Thermal noise	-174 [dBm/Hz]
Noise figure	6 [dB]
Number of mobile antennas	2
Inter-BTS cooperation	
Maximum transmission power	47 dBm/element
Antenna beam gain	16 dBi
Time constant	1024
Maximum transmission beam number	6
Scheduling	Cooperation with 7 cells of center area
Threshold of interference pilot level	0.2
Number of interference pilot reports	1
SDMA BTS	
Maximum transmission power	47 [dBm/element]
Antenna element gain	20 [dBi]
Common pilot beam offset	7 [dB]
Scheduling	Weight priority scheduling
Time constant	1024
AT directional separation condition	30 [deg]
Maximum transmission beam number	12
SDMA beamforming	Based on DOAs and angular spread
Beamforming noise	-10 [dB]
Beam control error	
Level setting error	1.1 [dB p-p] (uniform distribution)
Phase setting error	11.4 [deg p-p] (uniform distribution)
DOA estimation error	2.0 [deg p-p] (uniform distribution)
Omni BTS (Interference station)	
Maximum transmission power	47 [dBm]
Antenna gain	16 [dBi]



(a) Model 1 (Uniform and high traffic in the center cell)

(b) Model 2 (High traffic at cell-boundary)

Fig.5 Comparative models for the SDMA and Inter-BTS cooperation methods

2.2.1 Application of the SDMA method and the Inter-BTS cooperation method

(1) Access terminal deployment dependency (traffic model)

The SDMA and Inter-BTS cooperation methods were assumed to be suited for highly uniform traffic in the cell and high cell-border traffic; accordingly, we compared the traffic (access terminal) distribution model shown in Fig. 5 for the simulation.

(a) Model-1

Under the SDMA method, the SDMA BTS is located only in the center cell with high traffic, and the 18 cells surrounding the center cell are omni BTSs in order to evaluate SDMA BTS throughput performance. Under the inter-BTS cooperation method, the seven cells surrounding the center cell are controlled, and the 12 cells surrounding the first seven are set as the omni BTSs. The access terminal (AT) in the center cell is assigned higher density relative to the surrounding cells. The numbers of ATs in the high-traffic and low-traffic cells are set at 128 AT/cell and 16 AT/cell, respectively.

(b) Model-2

Under the SDMA method, four SDMA BTSs are located in center cells, which have high traffic at the cell boundary. Under the inter-BTS cooperation method, the BTSs are positioned as 14 cells surrounding the four cells at the center. The numbers of access terminals in the high-traffic and low-traffic cells are set at 24 AT/cell and 16 AT/cell, respectively.

Table 4 shows the results of comparison between the SDMA method and the inter-BST cooperation method. In Model 1, showing uniformly high traffic in the cell, SDMA allowed

Table 4 Comparison of the SDMA and Inter-BTS cooperation methods

Deployment model	Model-1		Model-2	
Method	SDMA	Inter-BTS	SDMA	Inter-BTS
Cell throughput [Mbit/s]	63.3	55.3	30.0	31.2
Average number of channels in space division multiplexing	8.8	6.0	4.5	4.1
Average transmission rate [Mbit/s]	7.0	8.7	6.2	8.0

the accommodation of a high number of multiple access users (using average number of space division multiplexing channels) with low interference, through the use of adaptive beam control. Thus, the SDMA method featured approximately 14 % greater throughput relative to the inter-BTS cooperation method. In Model 2, showing concentrated high traffic at the cell boundary, the advantages of SDMA as space division multiplexing were reduced. At the same time, the suppression of the interference of beams from adjacent BTSs was improved with the inter-BTS cooperation method. Thus, the inter-BTS cooperation method obtained cell throughput performance equivalent to the SDMA method.

(2) Angular spread dependency

In the traffic model comparison, the angular spread was set at approximately 3 degrees on average, based on the results of the field trial in Fujimino City in Saitama Prefecture[10]. However, in multipath environments such as urban areas, the angular spread will increase, which will most likely lead to a significant increase in errors in estimating direction of arrival and degradation in D/U (Desired to Undesired power ratio). In this section, the angular spread was evaluated using Model 1.

Figure 6 shows the cell throughput performance of the SDMA and inter-BTS methods as angular spread dependency. In terms of cell throughput, the relative superiority of the two methods switches at an angular spread of 12 degrees. Since the angular spread is affected by the surrounding conditions of BTSs such as the structures of buildings, switching

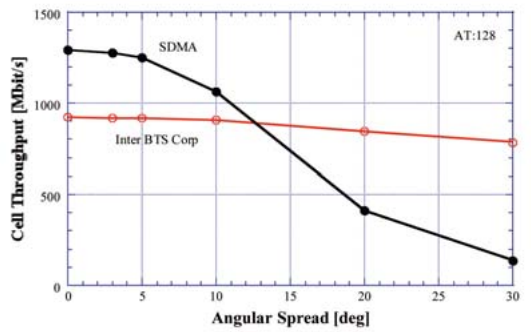


Fig.6 Cell throughput performance of the SDMA and Inter-BTS cooperation methods by angular spread dependency

the BTS control method can improve cell throughput performance.

2.2.2 Average throughput performance

Simulations were carried out on the throughput performance of the SDMA method and the inter-BTS cooperation method. To create comparison conditions equivalent to those used for the inter-BTS method, the number of SDMA cells was set at seven.

Figure 7 shows the throughput performance of the MU-OFDM-SDMA method and the MU-OFDM-inter-BTS cooperation method. When the number of ATs is ten or less, a maximum cell throughput 200 Mbit/s and average-user throughput 60 Mbit/s were obtained, respectively. Further, even with numbers of ATs exceeding 100, cell throughput remained high at 1.3 Gbit/s (spectral efficiency of approximately 18 bit/s/Hz/cell).

3 Conclusions

As a fourth-generation mobile communication system, we proposed an MU-OFDM-SDMA/Inter-BTS cooperation system that integrates advanced technologies for wireless signal processing in the time, space, and frequency domains. Through simulations, the system performance was confirmed to achieve a maximum user throughput of over 200 Mbit/s and cell throughput of 1.3 Gbit/s (spectral efficiency of approximately

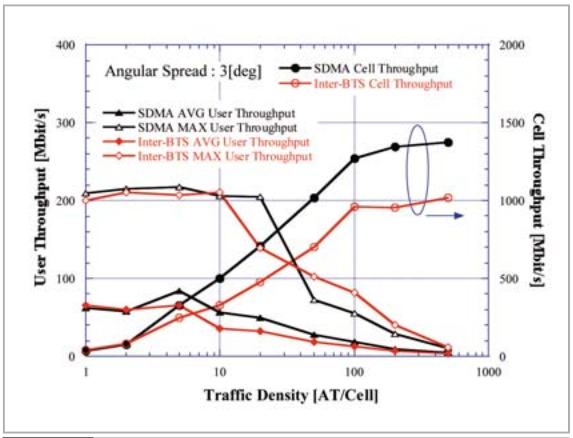


Fig.7 *Throughput performance of the MU-OFDM-SDMA/Inter-BTS cooperation system*

18 bit/s/Hz/cell). Further, it was clarified that it would be possible to determine the operation guidelines for the SDMA and inter-BTS cooperation method using angular spread characteristics.

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