LTE-Advanced MIMO Antenna

Technology Reports

Smart Vertical MIMO Increasing Quality in LTE-Advanced Using Single-size Antenna

Four or more streams of MIMO transmission are needed to achieve data rates in excess of 1 Gbps in LTE-Advanced systems. However, accommodating more antennas for four or more streams of MIMO transmission means that a rise in costs and the difficulty of securing the space for additional antennas must be dealt with. This article describes NTT DOCOMO's new transmission technology, Smart Vertical MIMO, for LTE-Advanced systems for achieving four streams of MIMO transmission with one antenna and presents the results of evaluating this technology by a field experiment.

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1. Introduction

The radio interface specifications for the mobile communications system commonly called LTE has been in commercial service in Japan since December 2010 after being completed at the 3rd Generation Partnership Project (3GPP) under the name of LTE Release 8 (hereinafter referred to as "LTE Rel. 8") [1] [2]. To handle future growing demand for mobile communications, radio interface specifications called LTE-Advanced (LTE Rel. 10 and beyond) are now being standardized as an extension to LTE Rel. 8 at 3GPP [3] [4].

One key feature of LTE-Advanced is its objective of providing higher data rates and capacity while maintaining backward compatibility. In terms of Multiple-Input Multiple-Output (MIMO)*1 transmission on the downlink, LTE-Advanced has introduced a user-specific DeModulation Reference Signal (DM-RS) for use in suppressing inter-user interference and has improved the performance of Multi-User (MU)-MIMO*2 that performs simultaneous MIMO spatial multiplexing for multiple users. The maximum number of MIMO antennas has also been extended from four to eight [5].

At present, the plan at 3GPP is to study technologies called Elevation Beam Forming (BF)*3 and Full Dimension (FD)-MIMO*4 for controlling directivity of the antenna beams using antenna elements arranged in the horizontal and vertical directions, and in preparation for that study, a propagation model that takes the horizontal and vertical directions into account has been investigated [6].

LTE-Advanced is a specification achieving a peak data rate in excess of 1 Gbps in the downlink. Base station antenna configurations for achieving this data rate in LTE-Advanced are shown in **Figure 1**. In these configurations, at least four streams*5 of MIMO

*1 **MIMO**: A signal transmission technology that improves communications quality and spectral efficiency by using multiple transmitter and receiver antennas for transmitting signals at the same time and same frequency.

*2 **MU-MIMO**: A technology that improves spectral efficiency by applying MIMO multiplexed transmission to the signals for multiple users.

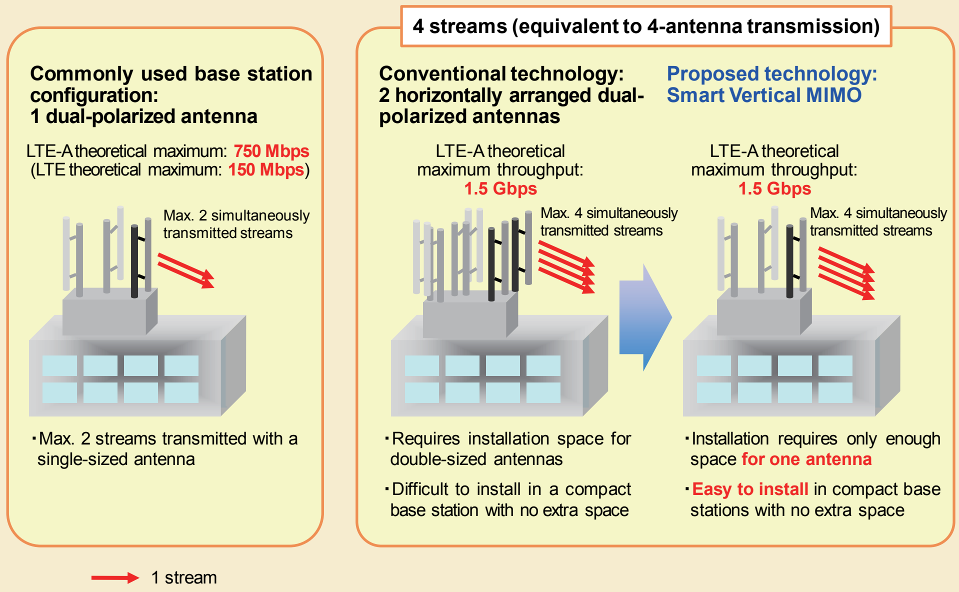


Figure 1 Base station antenna configurations for achieving 1 Gbps

transmission must be supported on the base station side to provide a data rate in excess of 1 Gbps. However, the maximum number of MIMO transmission streams with one antenna when using conventional polarization technology*6 is only two so that at least two antennas are needed to achieve four streams of MIMO transmission. This increase in the number of antennas means that more space is needed for antenna installation and that costs rise accordingly.

NTT DOCOMO has proposed Smart Vertical MIMO as an antenna transmission technology that can solve this antenna-installation issue. This technology performs MIMO transmission using antenna elements that are adaptively grouped in the vertical direction according to the channel quality at the receiving mobile terminals [7] [8]. Combined with polarization technology, it can provide up to four streams of MIMO transmission while requiring an antenna installation space equivalent to only one antenna. However, Smart Vertical MIMO technology has so far been validated mainly through simulations—no testing of field propagation characteristics has been performed.

In this article, we present an overview of this Smart Vertical MIMO technology and present the results of a field experiment.

2. Overview of Smart Vertical MIMO

A conceptual diagram of each Smart Vertical MIMO mode (showing antenna configuration and transmission-beam/stream configuration) is shown in **Figure 2**. Smart Vertical MIMO technology adaptively groups antenna elements in the vertical direction according to the channel quality of receiving mobile terminals. This approach provides a communications environment with even higher speeds oriented to LTE-Advanced requirements without having to change antenna size.

1) Mode B

This mode targets mobile terminals with high channel quality and achieves up to four streams of MIMO transmission by dividing a single antenna into two groups—an upper group and lower group—and using polarization technology.

Mode B enables spatial multiplexing

*3 **Elevation BF**: Technology for controlling antenna directivity (see *9) using antenna elements arranged in the horizontal and vertical directions (up to eight antenna ports).

*4 **FD-MIMO**: Technology for controlling antenna directivity (see *9) using antenna elements arranged in the horizontal and vertical directions (more than eight antenna ports).

*5 **Stream**: A data sequence transmitted or received over a propagation channel using MIMO transmission.

*6 **Polarization technology**: Existing antenna technology achieving transmission/reception equivalent to two antennas using quadrature polarization in horizontal and vertical or ±45° directions.

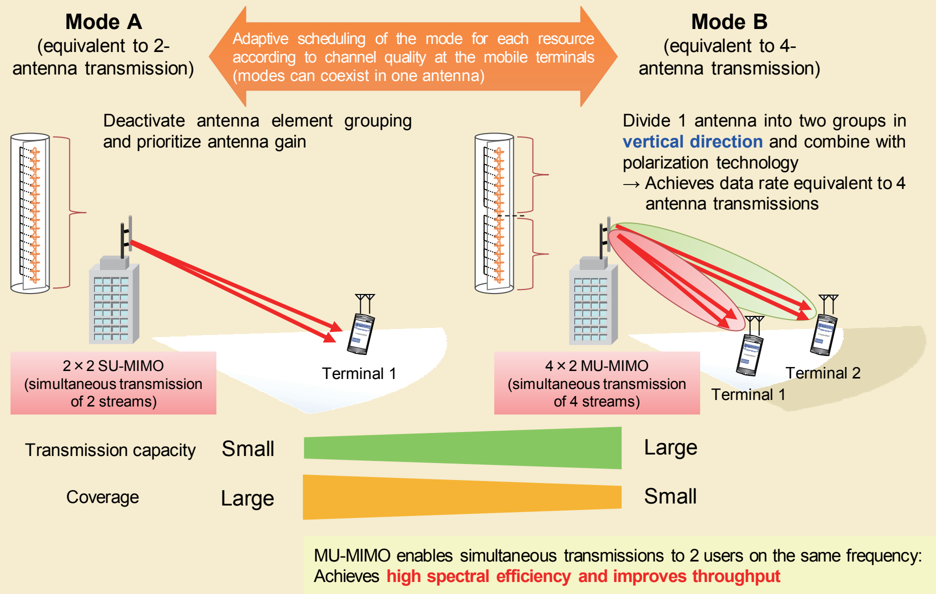


Figure 2 Concept of Smart Vertical MIMO

to be applied to many transmission streams targeting mobile terminals using the same time and frequency resources thereby improving frequency Spectral efficiency[*7] and throughput[*8]. With this mode, however, dividing the antenna into two groups of elements means that the antenna gain of each antenna group becomes low. This is because shortening antenna length broadens the beam width of antenna directivity[*9] and lowers the antenna gain[*10] near the cell edge.

2) Mode A

This mode places a priority on antenna gain for mobile terminals with low channel quality. It deactivates antenna grouping and achieves up to two streams of MIMO transmission. Mode A can achieve the same coverage as that of existing LTE. It can be used for transmitting broadcast control signals or pilot signals to all mobile terminals in the coverage area and for transmitting signals to mobile terminals that support only LTE.

3) Transmission Mode Control

Mode allocation according to channel quality at the mobile terminal is accomplished by using the Channel Quality Indicator (CQI)[*11] fed back to the base station from the mobile terminal. This quality information is used as a basis for dynamically allocating Mode A and Mode B transmission modes using frequency and time resources on the base station's baseband[*12]. Thus, since either mode can be established by baseband allocation, these modes can coexist on one base station antenna.

In summary, Smart Vertical MIMO can achieve a maximum of four streams with one antenna by allocating the most optimal transmission mode according to channel quality at the mobile terminal. This technology makes it possible to construct coverage areas supporting MIMO transmission in LTE-Advanced with antenna installations that save on space and costs.

3. Field Experiment

3.1 Experiment Overview

Major radio link parameters of the implemented transceiver are given in **Table 1**. The transceiver is based on LTE-Advanced (LTE Rel. 10) specifications

*7 **Spectral efficiency**: The number of data bits that can be transmitted per unit time over a particular frequency spectrum.

*8 **Throughput**: The amount of data transferred through a system without error per unit time.

*9 **Antenna directivity**: One of the radiation characteristics of an antenna. The directional characteristics of the radiated or received strength of the antenna.

*10 **Antenna gain**: A measure of the sharpness of antenna directivity usually expressed as the ratio of radiated power to that of an isotropic antenna.

*11 **CQI**: An index of reception quality measured at the mobile station expressing propagation conditions on the downlink.

*12 **Baseband**: The signal band before modulation and after demodulation on the carrier wave of a radio signal.

and implements the explicit feedback transmission technique from the mobile terminal to the base station proposed in Rel. 12. In the downlink, the carrier frequency is 3.9 GHz and system bandwidth is 100 MHz. We employ Carrier Aggregation (CA)*13 using five Component Carriers (CC)*14 with contiguous spectrum allocation. We conducted field experiments using Smart Vertical MIMO and two measurement vehicles each equipped with a mobile station equivalent to mobile terminals. In the experiments, we carried out measurements in two types of propagation environments: a suburban area in Yokosuka City and an urban area in Sagamihara City, both in Kanagawa prefecture, Japan. The antenna installation setup at the base station, view of the measurement environment from the base station, and measurement locations for each of these environments are shown in **Figures 3** and **4**.

The Yokosuka measurement environment was essentially an open area with line-of-sight conditions between the base station and mobile stations. The root mean squared delay spread*15 was 0.11 μs, which means an environment with a relatively small delay spread.

The Sagamihara measurement environment featured rows of buildings between the base station and mobile stations and both line-of-sight and non-line-of-sight conditions. The root mean squared delay spread within the measurement course was 0.17 μs.

Table 1 Main specifications of experimental equipment (downlink)

Radio access	OFDMA
Center frequency	3.92625 GHz
System bandwidth	100 MHz (20MHz × 5CCs)
Total transmission power	10W (40dBm)
Number of antenna ports	BS : 4, MS : 2
Number of mobile stations	2
Channel coding/decoding	Turbo coding / Max-Log-MAP decoding
MIMO signal separation	MLD

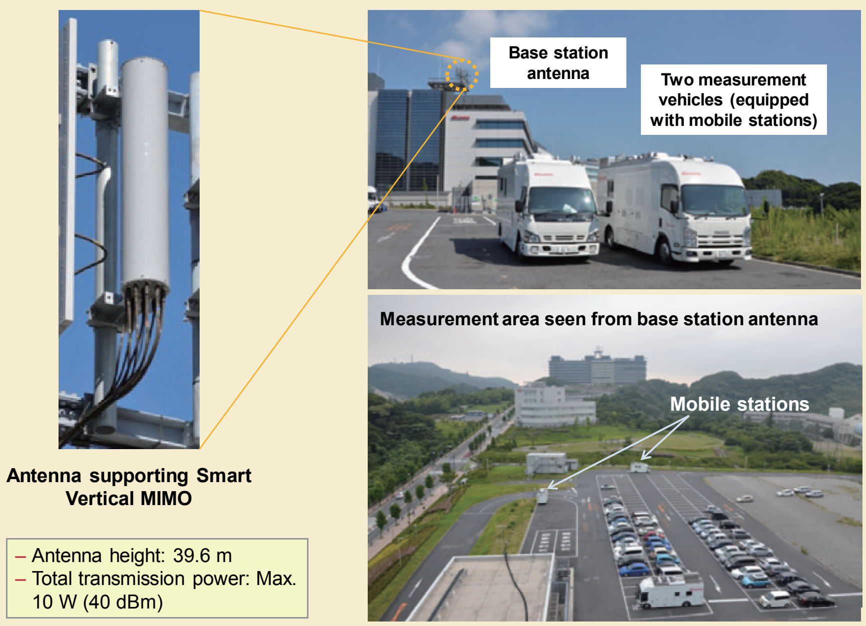


Figure 3 Experiment configuration (Yokosuka city)

*13 **CA**: A technology for increasing bandwidth while maintaining backward compatibility by simultaneously transmitting and receiving multiple component carriers.

*14 **CC**: A frequency block having a maximum bandwidth of 20 MHz as a component of system bandwidth; an LTE terminal can connect multiple CCs.

*15 **Delay spread**: The spread in delay times of waves arriving late as a result of reflection and diffraction off of buildings and other obstacles.

3.2 Transmitter/Receiver Configuration

The configuration of implemented transmitter and receiver is shown in **Figure 5**. In the base station transmitter, information binary data sequence is turbo coding*16 and modulated using Quadrature Phase Shift Keying (QPSK)*17, 16 Quadrature Amplitude Modulation (16QAM)*18, or 64 Quadrature Amplitude Modulation (64QAM)*19. After multiplexing the data sequence and the DeModulation Reference Signal (DM-RS)*20, the signal is multiplied by the precoding vector*21 calculated from feedback information sent from the two

Figure 4 Experiment configuration (Sagamihara city)

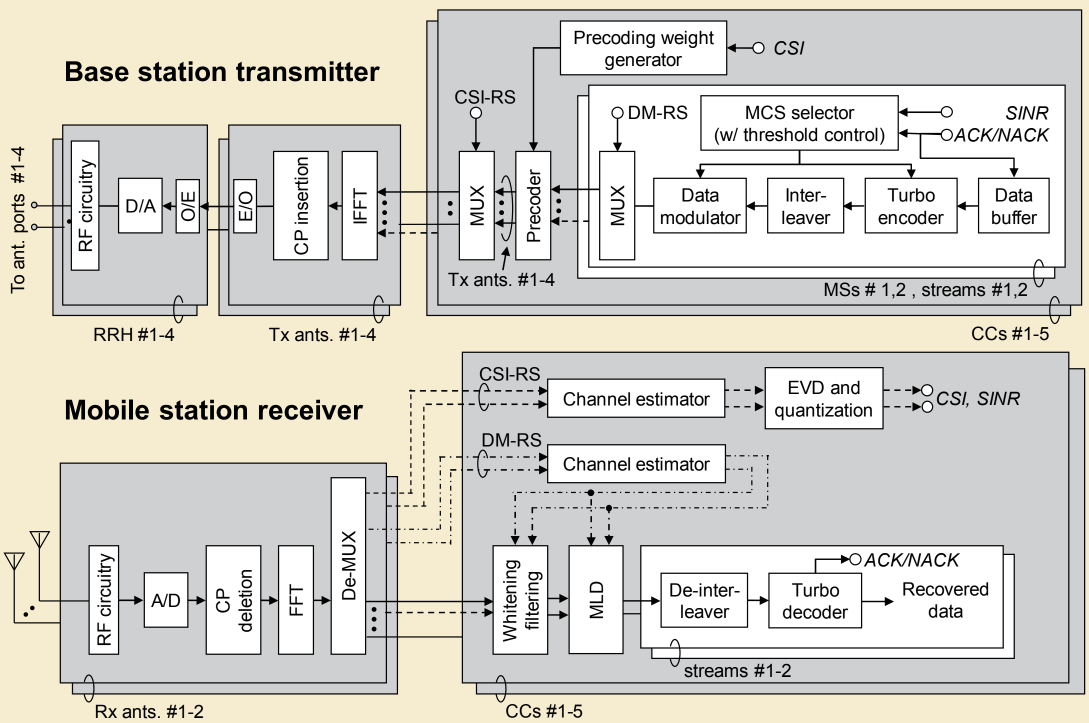


Figure 5 Transmitter/receiver configuration

*16 **Turbo coding**: A kind of error correction coding. The reliability information in the decoded results can be used for iterative decoding to obtain powerful error correction capabilities.

*17 **QPSK**: A digital modulation method that uses a combination of signals with four different phases to enable the simultaneous transmission of two bits of data.

*18 **16QAM**: A digital modulation method that enables the simultaneous transmission of 4 bits of information by assigning one value to each of 16 different combinations of phase and amplitude.

*19 **64QAM**: A digital modulation method that enables the simultaneous transmission of 6 bits of information by assigning one value to each of 64 different combinations of phase and amplitude.

*20 **DM-RS**: A user-specific reference (pilot) signal known by the base station and mobile station for estimating the fading channel used for data demodulation.

*21 **Precoding vector**: A vector that includes phase and amplitude and by which the signal before transmission is multiplied in a MIMO system.

mobile stations to the base station. The precoding vector is calculated for each Sub-Band (SB)*22 based on Minimum Mean Square Error (MMSE)*23 criteria. The Channel State Information Reference Signal (CSI-RS)*24 is then multiplexed for each transmitter antenna. After D/A conversion and quadrature modulation, the modulated signal is up-converted into a Radio Frequency (RF) signal*25.

At the mobile station receiver, in turn, the received RF signal is down-converted into an Intermediate Frequency (IF)*26 signal, amplified by an Automatic Gain Control (AGC)*27 amplifier (within the RF circuit), and converted by a quadrature detector. The in-phase and quadrature signals are converted into a digital format using 14-bit A/D convertors. Feedback information for MU-MIMO transmission is then calculated using the received CSI-RS. Next, Maximum Likelihood Detection (MLD)*28 is performed to separate the two streams that are transmitted to the target users. Finally, the sequence after MLD is soft-decision*29 turbo decoded using the Max-Log-Maximum A Posteriori (Max-Log-MAP)*30 algorithm, and the transmitted bit sequence is recovered.

Here, the SB size and the transmission period of the CSI-RS for the MU-MIMO precoding vector are set to 900 kHz and 5 ms, respectively. In the field experiment, we evaluated the throughput performance when applying Adaptive Modulation and Coding (AMC)*31 and Hybrid Automatic Repeat reQuest (HARQ)*32. The AMC, for which 12 Modulation and Coding Scheme (MCS)*33 sets are used, is performed on the basis of the instantaneous received Signal-to-Interference plus Noise power Ratio (SINR)*34 fed back from the mobile station.

Control delay for AMC and precoding were both 10 ms.

3.3 Base Station and Mobile Station Antenna Configurations

The base station antenna configuration is shown in **Figure 6**. This configuration enabled the elements of this dual-polarized antenna to be divided into two groups in the vertical direction. Mode allocation in this configuration was performed in a fixed manner.

The employed base station dual-polarized linear antenna consists of vertically-polarized (V) and horizontally-polarized (H) antennas. The total transmission power of the base station was set to a maximum of 10 W (40 dBm*35). The heights of the base station antennas were 39.6 m and 56.5 m in Yokosuka and Sagamihara, respectively. Each mobile station used a dual-polarized antenna installed on the ceiling of the

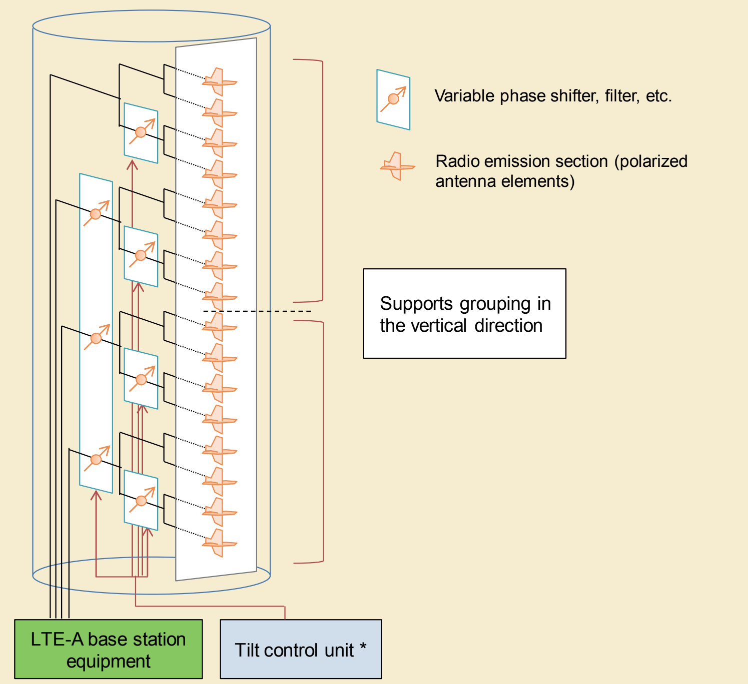


Figure 6 Base station antenna configuration

*22 **SB**: A frequency unit making up part of the entire frequency band. CSI-RS (see *24) feedback and common precoding is applied to each SB.

*23 **MMSE**: A method for signal computation that minimizes mean square error.

*24 **CSI-RS**: A known signal transmitted for each antenna to measure the state of the radio channel.

*25 **RF signal**: A Radio-frequency band signal.

*26 **IF**: A frequency to which a high-frequency signal is converted to enable demodulation.

*27 **AGC**: A function for automatically adjusting amplification in a receiver's power amplifier so that the amplitude of the output signal is constant.

*28 **MLD**: A MIMO signal detection method in which the transmission signal pattern with a maximal likelihood is searched.

*29 **Soft-decision**: A type of decoding that adds reliability information to received symbols and uses the value itself of the received signal based on that information. Compared to hard-decision decoding that decodes the received signal into a binary result (0 or 1), soft-decision decoding achieves higher error correction performance.

*30 **Max-Log-MAP**: A channel-decoding algorithm that can achieve nearly equivalent characteristics of Maximum A posteriori Probability (MAP), an optimal decoding algorithm, while significantly reducing computational complexity by using approximations in computing a posteriori probability.

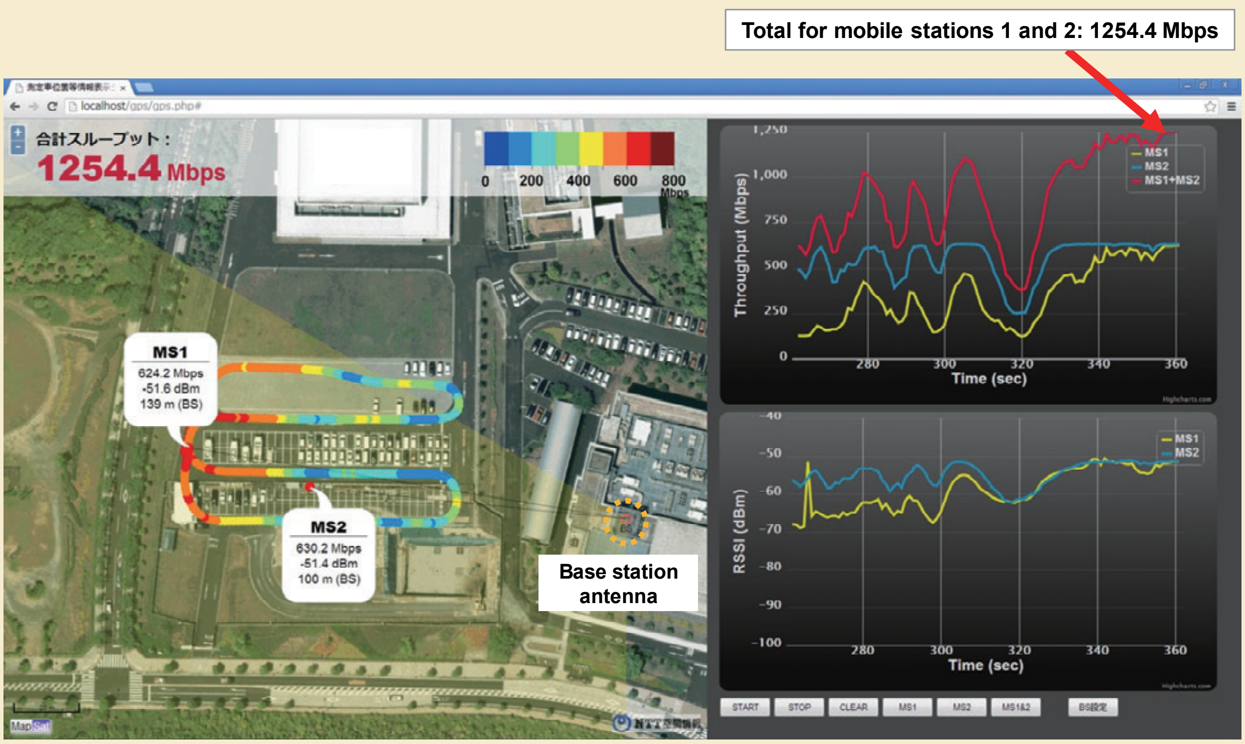
measurement vehicle (antenna height: 3.1 m) with an omni-directional beam pattern in the azimuth direction.

3.4 Experimental Results

The field experiment was performed in July 2013 in Yokosuka and in November 2013 in Sagamihara. To evaluate MU-MIMO, we had one mobile station (MS#1) move at a speed of 5–10 km/h and the other mobile station (MS#2) remain stationary and measured throughput for each in Mode B. In the Yokosuka environment, MS#2 parked at a distance of approximately 100 m from the base station resulting in a view with an angle of depression of approximately 16°, and MS#1 traveled in a range of approximately 50–150 m from the base station resulting in an angle of depression in the range of approximately 12–30°. In the Sagamihara environment, MS#2 parked at a distance of approximately 300 m from the base station resulting in an angle of depression of approximately 11°, and MS#1 traveled in a range of approximately 200–500 m from the base station resulting in an angle of depression in the range of approximately 6–15°.

In this experiment, we successfully performed MIMO transmission at total data rates in excess of 1.2 Gbps for two mobile stations using only one base station antenna in both the Yokosuka and Sagamihara environments. Measurement results for the Yokosuka suburban environment are shown in **Figure 7**.

For MS#1, this data rate of 1.2 Gbps was achieved under conditions of approximately 140 m from the base station and an angle of depression of approximately 12° in the Yokosuka environment and approximately 500 m from the base station and an angle of



RSSI: Received Signal Strength Indicator

Figure 7 Experimental results (suburban environment: Yokosuka City)

***31 AMC**: A method for adaptively controlling data rate by selecting the most appropriate MCS according to the quality of received signals based, for example, on SINR.

***32 HARQ**: A technology that combines Automatic Repeat request (ARQ) and error

***33 MCS**: A predetermined combination of data modulation and channel coding rate when performing AMC.

***34 Received SINR**: The ratio of desired-signal power to the total power from interference from other users in the same cell, interference from other cells and sectors, and from noise within the received signal.

***35 dBm**: Power value [mW] expressed as 10log (P). The value relative to a 1 mW standard (1 mW=0 dBm).

depression of approximately 7° in the Sagamihara environment. In either environment, the difference in angles of depression between the two mobile stations was approximately 4°. At these points, fading correlation*36 was measured between the vertical antenna branches and found to be high at approximately 0.96 in either environment.

Thus, for Mode B of Smart Vertical MIMO in a real propagation environment using antenna branches with high correlation, we confirmed that interference between a pair of mobile stations having an angle-of-depression difference of approximately 4° could be decreased and a total data rate of 1.2 Gbps could be achieved.

4. Conclusion

We described Smart Vertical MIMO technology for achieving 4-stream MIMO transmission with only a single-size antenna and presented the results of a field experiment. The practical implementation of Smart Vertical MIMO technology will make it possible to achieve high-speed, high-capacity MIMO transmission equivalent to four antennas with only a single-size antenna thereby facilitating the construction of space-saving and cost-saving coverage areas.

Future research topics include further validation testing of the feedback method and mode-allocation method. After the launch of LTE-Advanced in Japan, we plan to step up the development of Smart Vertical MIMO technology toward early implementation.

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*36 **Fading correlation**: In this article, an index indicating the correlation of fading between different antennas used in MIMO transmission.