EBF/FD-MIMO AAS BS IRC

Technology Reports

Special Articles on LTE-Advanced Release 13 Standardization

LTE-Advanced Release 13 Multiple Antenna Technologies and Improved Reception Technologies

To respond to the traffic increases of recent years, 3GPP has been studying further enhancements for radio base stations. LTE-Advanced Release 13 specifies technologies to achieve two-dimensional radio base station antenna port mapping and increase the number of ports, radio performance requirements for AAS for more flexible area construction with combined antenna-transmission/reception functions, as well as performance requirements for interference suppression enabled by interference rejection combining receivers to minimize uplink interference from neighboring cells. This article describes the technical characteristics of these, and 3GPP standardization trends.

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1. Introduction

With the spread of terminals such as smartphones and tablets, and the advanced functions of these terminals in recent years, traffic has dramatically increased due to use of high-volume content such as high-definition video services and video calling. For this reason, The 3rd Generation Partnership Project (3GPP) is studying further enhancements to radio base stations to enable services with larger volumes and higher speeds.

LTE-Advanced*1 Release 13 specifications (hereinafter referred to as "Release 13") prescribe Elevation Beam-Forming/Full Dimension-Multiple Input Multiple Output (EBF/FD-MIMO*2) to expand antenna port mapping on base stations from one dimension to two dimensions, and increase port numbers. These can be achieved using Active Antenna System (AAS) technology in which antennas are combined with transceiver units to make base stations that are more compact, more energy efficient, and that enable greater flexibility in configuring coverage areas. 3GPP also prescribes requirements for AAS, and requirements for Minimum Mean Squared Error-Interference Rejection Combining (MMSE-IRC) receivers, which use advanced signal processing to suppress uplink interference from neighboring cells*3.

This article describes implementation of these new technologies and equipment, an overview of their requirements, and the future outlook in 3GGP.

*1 **LTE-Advanced:** A developmental radio interface in LTE (Releases 8, 9), standardized as a specification from Release 10 onward.

2. EBF/FD-MIMO

LTE has been continuing downlink MIMO technical enhancements through successive releases. **Table 1** and **Figure 1** briefly describe Releases 12 and 13 downlink MIMO technologies and closed-loop*4 precoding MIMO multiplexing transmission, respectively. Release 13 prescribes EBF/FD-MIMO functions, which enable control of vertical and horizontal transmission beams using two-dimensional base station antenna ports arranged in the horizontal and vertical directions.

2.1 Downlink MIMO Technology in Release 12

Release 12 supports a maximum of eight transmission antenna ports for downlink MIMO. This enables different data streams*5 to be simultaneously transmitted from each antenna port, which maximizes the peak data rate (MIMO spatial multiplexing). In addition, multiplying different complex weights*6 with combination data stream/transmission antennas enables precoding transmission which gives directionality*7 to transmission signals. Release 12 achieved horizontal precoding transmission using MIMO antenna ports arranged in the horizontal direction. For appropriate precoding control, Channel State Information (CSI)*8 has to be acquired by the transmitter. Two methods are adopted in LTE for this purpose.

(1) CSI-RS-based method

The first method uses feedback information from terminals. In this method, the base station sends a CSI-Reference Signal (CSI-RS)*9

Table 1 Release 12 and 13 downlink MIMO technologies

	Release 12	Release 13
Number of transmission antenna ports	1, 2, 4, 8	1, 2, 4, 8, 12, 16
Transmission antenna configuration	One dimension (horizontal direction arrangement)	Two dimension (horizontal and vertical direction arrangement)
Number of SU-MIMO streams	Max. 8	Max. 8
Number of MU-MIMO streams	Max. 4 (Max. 4 mobile terminals, max. 2 streams per mobile terminal)	Max. 8 (Max. 8 mobile terminals, max. 2 streams per mobile terminal)

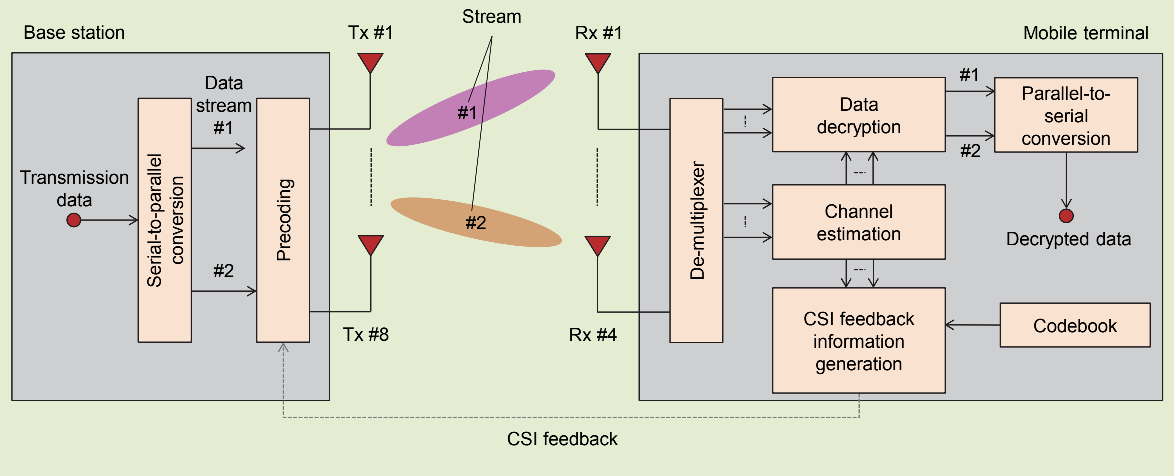

Figure 1 Closed-loop precoding MIMO multiplexing (e.g. 8 × 4 MIMO, 2 stream transmission)

*2 **MIMO:** Technology to improve data rate and reception quality by using more than one transmitter (transmission antenna) and receiver (reception antenna).

*3 **Cell:** The smallest area unit for sending and receiving radio signals between a mobile communication network and mobile terminals.

*4 **Closed-loop:** A method of using feedback information from receivers.

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

*6 **Complex weight:** Complex signals multiplied with transmission signals for the purpose of obtaining a precoding gain.

*7 **Directionality:** A radiation characteristic of data streams.

*8 **CSI:** Information describing the state of the radio channel.

from each antenna port. The terminal then estimates the channel state information based on the received CSI-RS and selects a suitable precoding weight from predetermined candidates (Codebook*10), and then feeds back the selected index as a Precoding Matrix Indicator (PMI)*11. In addition to PMI, CSI feedback information consists of the Rank Indicator (RI)*12 that controls the number of transmission streams, and a Channel Quality Indicator (CQI)*13 for applied modulation encoding.

(2) SRS-based method

This method is based on the physics of channel reciprocity, which assumes that the uplink and downlink channel states are the same in principle. The base station can estimate downlink CSI from the received Sounding RS (SRS)*14, which is an uplink reference signal for channel sounding. This method is particularly effective with Time Division Duplex (TDD)*15, which uses the same frequency band for uplink and downlink, but requires accurate calibration of antennas and Radio Frequency (RF)*16 circuits.

There are two types of LTE MIMO transmission schemes - Single-User MIMO (SU-MIMO) and Multi-User MIMO (MU-MIMO). For SU-MIMO, multiple data streams are transmitted towards a single terminal, whereas data streams are spatially multiplexed to multiple terminals in MU-MIMO. Release 12 supported up to eight and four data streams for SU-MIMO and MU-MIMO, respectively.

2.2 Three-dimensional Beamforming

1) Overview

In recent years, enhancements in active antenna technology has enabled increases in the number of MIMO transmission antennas, and improved calibration accuracy of antennas and RF circuits. Particularly with precoding control in the vertical direction, it is necessary to calibrate vertical circuits with high accuracy to prevent unexpected interference from neighboring cells. Hence, Release 13 specifications enable horizontal and vertical precoding control using two-dimensional horizontal and vertical base station antenna ports. This technology controls beam direction in three dimensions in a rectangular coordinate system, and is referred to as three-dimensional beamforming.

2) Two CSI Report Methods

Release 13 specifications introduce two CSI report methods (called Class or eMIMO-Type) in which CSI-RS transmission method and CSI feedback information are different (**Figure 2**).

(1) Class A reporting method

The Release 13 Class A CSI reporting method supports up to 16 CSI-RS antenna ports two-dimensional CSI feedback. This method assures 12 or 16 CSI-RS resources (mapping in time and frequency domains) as multiple Release 12 CSI-RS resources, and adopts a two-dimensional codebook for CSI feedback in the horizontal and vertical directions. This codebook follows the double codebook structure*17

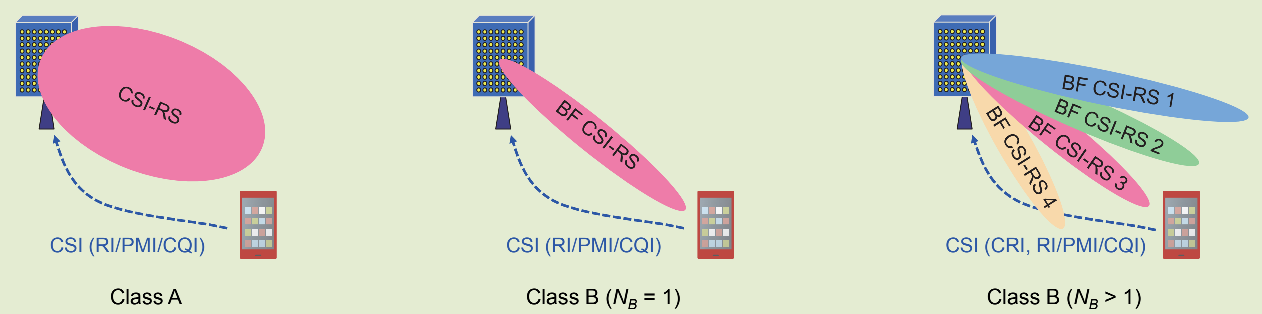

Figure 2 Release 13 CSI report method

*9 **CSI-RS:** A signal transmitted to measure CSI.

*10 **Codebook:** A set of predetermined precoding-weight matrix candidates.

*11 **PMI:** Information fed back from the mobile terminal to specify a suitable downlink precoder. Notifies the index selected from the codebook.

*12 **RI:** Information returned from the mobile terminal to specify a suitable number of transmission streams.

*13 **CQI:** An index of reception quality measured at the mobile terminal indicating downlink channel reception conditions.

*14 **SRS:** Uplink reference signal for measuring channel quality and reception timing etc. with the base station.

adopted in Releases 10 and 12 [1]. Also, this codebook is designed to notify antenna configurations with higher layer signaling to enable application to various antenna configurations (different numbers of horizontal/vertical antenna ports, and antenna spacing etc.) and deployment environments. For the Class A report method, CSI-RS overhead increases in proportion to the number of antenna ports. In addition, if the total base station transmission power is constant, transmission power for each CSI-RS antenna port is reduced correspondingly with the increase in the number of antenna ports.

(2) Class B reporting method

The Class B reporting method assumes beamformed CSI-RS to reduce CSI-RS overhead and expand CSI-RS coverage. This technology is presumed to have two major applications to suit the number of CSI-RS beams (N_B).

- If $N_B = 1$, it is possible to transmit CSI-RS with mobile terminal-specific beamforming. For example, based on preliminary CSI by channel reciprocity, the base station applies beamforming to CSI-RS. The mobile terminal measures CSI based on the beamformed CSI-RS and returns the CSI to the base station. In this way, CSI-RS overhead is reduced in the subsequent Class B report method ($N_B = 1$).
- On the other hand, when N_B is greater than 1, CSI feedback is performed for CSI-RS beam selection. Specifically, the base station transmits multiple CSI-RSs with different beams applied. The terminal selects a suitable CSI-RS beam from among those, and returns its index as a CSI-RS Resource Index (CRI). In addition, the terminal also returns CSI for the selected CSI-RS beam. In this method, even though there are overhead increases with multiple CSI-RS transmissions, beamforming suppresses those increases.

Release 13 specifications support Class B CSI reporting with a maximum N_B of 8. The Class B reporting method holds promise as a more effective technology in dealing with potential 5G (5th generation mobile communications systems) coverage issues, as it uses higher frequency.

2.3 Advanced MU-MIMO

Release 13, which improves precoding control flexibility, promises high spatial separation capacity between transmission beams, and hence enables more useful MU-MIMO operations. Release 13 expands the downlink data DeModulation Reference Signal (DM-RS)*18 functions to support MU-MIMO with up to eight streams (max. eight terminals, two streams per terminal). Specifically, it ensures up to four orthogonal layers by using a code multiplexing sequence length of four for DM-RS.

2.4 Technical Enhancements for TDD Systems

As described above, one of the CSI acquisition schemes is channel reciprocity using SRS. SRS is mainly designed for link adaptation applied to uplink data transmission, however higher accuracy channel estimation and high reference signal density is required if this reference signal is used for CSI acquisition for downlink precoding. Also with dense SRS scheduling, there is a concern that the SRS interference level from adjacent cells will rise and channel estimation accuracy will deteriorate. For this reason, Release 13 involved discussions on increasing SRS capacity to prevent insertion density expansion and overly dense scheduling. More specifically, Release 13 increases the number of SRS symbols*19 and enhances SRS multiplex technologies in TDD systems.

2.5 Future Outlook

While Release 13 studied EBF/FD-MIMO assuming operations below 6 GHz, wide bandwidth above 6 GHz will be crucial for future cellular networks including 5G, and there are demands for further advancements to MIMO beamforming and diversity*20 technologies for high frequency bands where radio wave propagation loss is large.

*15 **TDD:** A bidirectional transmit/receive system. This system achieves bidirectional communications by allocating different time slots to uplink and downlink transmissions on the same frequency.

*16 **RF:** The frequencies used in radio communications, and frequencies used for radio signaling channels.

*17 **Double codebook structure:** A codebook structure designed to express radio channels as combinations of long-cycle, wide-band data and short-cycle, narrow-band data.

*18 **DM-RS:** A known signal transmitted to measure the state of a radio channel for data demodulation.

*19 **Symbol:** A time unit of transmitted data, consisting of multiple sub-carriers with Orthogonal Frequency Division Multiplexing (OFDM). Multiple bits (2 bits in the case of Quadrature Phase Shift Keying (QPSK)) are mapped to each sub-carrier.

Achieving surface and distance coverage for sharing signals such as control signals in cells could also present a new challenge. The difficulty of RF circuit implementation for enlarged bandwidth is also a known issue. Studies are also required for high-gain MIMO equipment configurations and transmission technologies with low-cost RF circuitry (e.g. the number of RF circuits).

3. AAS

3.1 Requirements for AAS

To achieve beam control employed in EBF/FD-MIMO, AAS which integrates multiple transceiver units and a composite antenna including a radio distribution network and an antenna array is considered to be an effective way. However, since the composite antenna characteristics are not included in existing 3GPP base station RF specifications that are for their transceiver unit performance, AAS RF specifications have been specified in Release 13 [2] as new antenna-integrated 3GPP base station RF specifications.

Figure 3 shows configurations and scopes covered by RF specifications for existing base stations and AAS. AAS is expected to operate with higher power efficiency compared to existing base stations because of decreasing power loss by removing coaxial cables connected between transceiver units and the composite antenna. Furthermore, as shown in **Figure 4**, AAS also enables more flexible coverage area construction because it is possible to steer a main beam direction in the horizontal and vertical directions by adjusting the amplitude and phase of transmission/

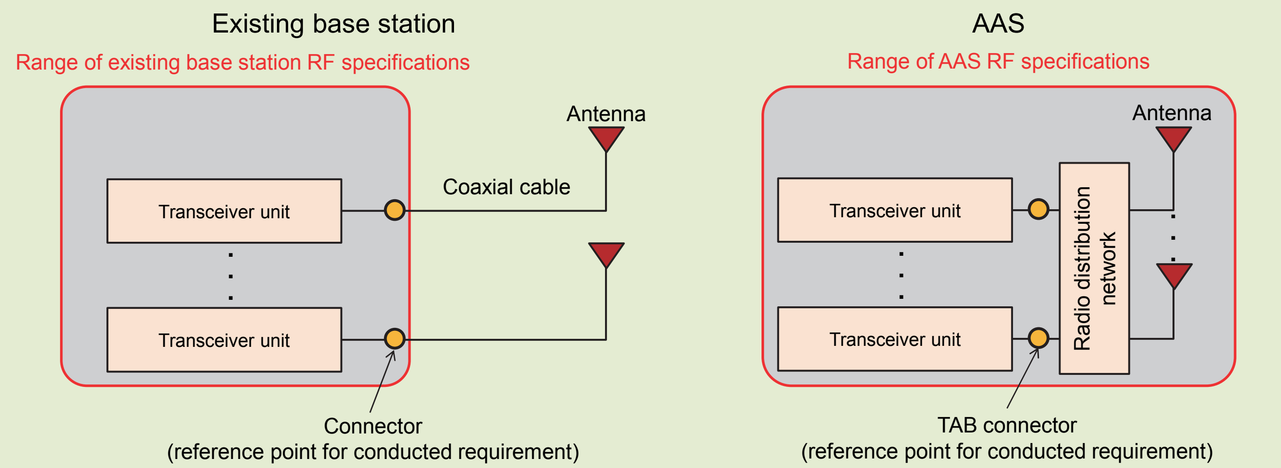

Figure 3　Configurations and scopes covered by RF specifications for existing base stations and AAS

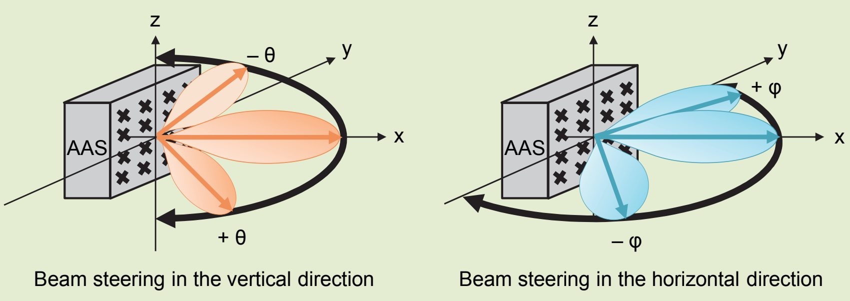

Figure 4　Steering main beam directions with AAS

*20 **Diversity:** A general name for technologies designed to improve the quality and reliability of communications using MIMO antennas. In particular, non-closed loop types.

reception signals. In addition, AAS can form multiple beams with different main beam directions simultaneously to cover multiple cell areas. As just described, AAS can offer functions not available with existing base stations.

3.2 AAS Specification Characteristics

Compared to existing base station RF specifications, there are two notable differences in AAS RF specifications in Release 13.

- Firstly, requirement reference point*21 is different. In existing base station specifications, the conducted requirement reference point (hereinafter requirements at this point referred to as "conducted requirements") is specified at a physical connector existed between the transceiver unit and the composite antenna, which is called as a Transceiver Array Boundary (TAB) connector. Then, antenna I/O signal characteristics at the conducted requirement reference point are also specified. In AAS specifications, in addition to the conducted requirement reference point, a new radiated requirement reference point (hereinafter requirements at this point referred to as "Over The Air (OTA) requirements") is specified in the antenna radiation space. Then some combined antenna radiation characteristics at the radiated requirement reference point are also specified. In particular, (1) radiated transmit power accuracy requirement*22 and (2) OTA sensitivity requirement*23, are specified as OTA requirements. OTA requirements enable evaluation on some performances of base stations that integrate the transceiver units and the composite antenna.
- Secondly, the specified unit is extended for some conducted requirements. In existing base station specifications, all radio requirements are specified at each conducted requirement reference point. In contrast, in AAS RF specifications, some radio requirements are specified not only for the amount at each TAB connector but also for the total amount of some TAB connectors.

1) OTA Requirement Details

(1) Radiated transmit power accuracy requirement

Radiated transmit power accuracy is considered to be the OTA requirement corresponding to the transmit power accuracy in the conducted requirements. To make these two accuracies equivalent, the antenna gain and its deviation*24 must be taken into account in the radiated transmit power accuracy requirement. For this reason, Equivalent Isotropic Radiated Power (EIRP)*25 [2] [3] is used as an evaluation indicator. The OTA requirement for the radiated transmit power accuracy is applied to the maximum value of EIRP. A beam direction achieving the maximum EIRP is referred to below as "beam peak direction." **Figure 5** shows examples of EIRP and deviation corresponding to various beam peak directions. Radiated transmit power accuracy is specified as the allowable deviation of EIRP in the beam peak direction. The specified range of accuracy is +/− 2.2 dB as indicated in Fig. 5. Also, each AAS has a different beam peak direction with its inherent antenna gain and deviation. Therefore, AAS vendors also declare the range of directions that satisfy radiated transmit power accuracy requirements. Here, the declared range is called as "EIRP accuracy directions set," and is shown in **Figure 6**. Radiated transmit power accuracy must be within the specified range. Testing to confirm the specified accuracy is performed in the representative five directions, namely one direction in which the absolute EIRP value is at its maximum and four directions in which θ or φ becomes the maximum or minimum within EIRP accuracy directions set because it is impractical to test for every point within the EIRP accuracy directions set. The specifications cover all AAS configurations that can steer the beam peak direction in both θ and φ directions,

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*21 **Reference point:** Point locations for prescribing base station RF specifications. Measuring the characteristics of I/O signals to/from the antenna and characteristics of the radio radiation/reception space at the reference point confirms whether the base station satisfies 3GPP specifications.

*22 **Radiated transmit power accuracy requirement:** The requirement for transmission power accuracy at the radiated requirement reference point in antenna radio radiation space.

*23 **OTA sensitivity requirement:** The requirement for reception sensitivity at the radiated requirement reference point in antenna radio reception space.

*24 **Deviation:** An indication of variation in antenna gain.

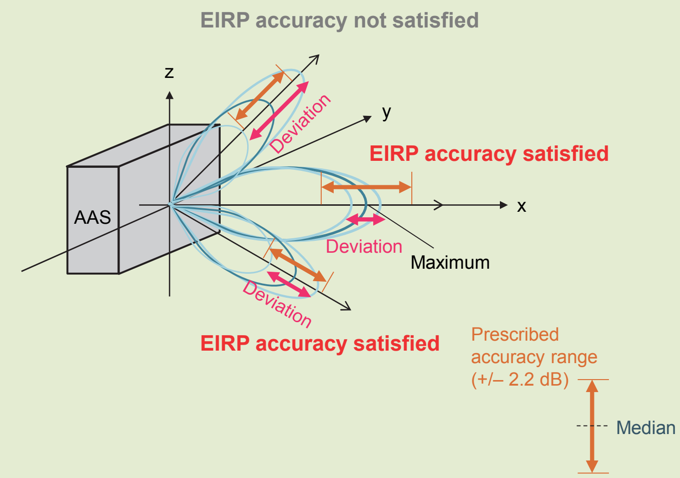

Figure 5　EIRP accuracy corresponding to steered beam peak directions

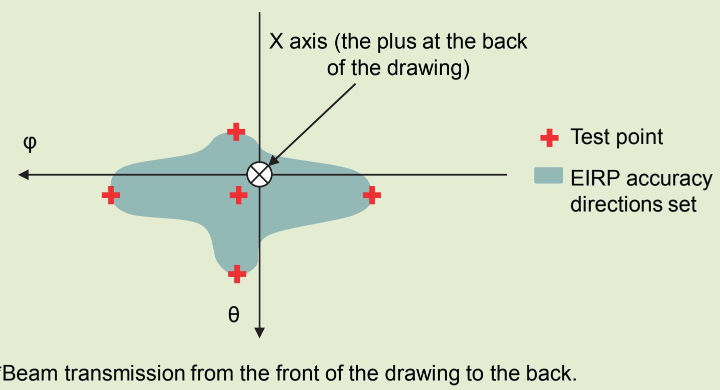

Figure 6　Range satisfying EIRP accuracy and test points

either θ or φ direction, and neither θ nor φ direction. Fig. 6 shows an EIRP accuracy directions set for a general AAS with beam peak directions steered in both θ and φ directions.

(2) OTA sensitivity requirements

Equivalent Isotropic Sensitivity (EIS)*26 [2] is used as an indicator for OTA sensitivity for similar reasons as radiated transmit power accuracy. The beam direction in which the receiving antenna gain is at its maximum is referred to below as the "OTA sensitivity direction". OTA sensitivity is specified as the minimum received power which throughput*27 of signals received from terminals achieves 95% of the maximum. Whether this requirement is satisfied is dependent on the relationship between the received beam direction and the actual arrival direction of signals from terminals and the EIS value. AAS vendors declare the EIS value, and the receiver target redirection range where the OTA sensitivity is achievable with the declared EIS value. **Figure 7** shows an example. The sensitivity Range of Angle of Arrival (RoAoA) is defined as OTA sensitivity directions that satisfy OTA sensitivity requirements. The receiver target redirection range is defined as the collective sensitivity RoAoA when changing the OTA sensitivity direction. Because it is impractical to test at every point, testing is performed in the five representative directions in the receiver target redirection range, similar to the test of radiated transmit power accuracy.

These two OTA requirements specify radio characteristic requirements which include composite antenna characteristics and enable evaluation of the requirements, but are not in existing specifications.

2) Requirements for the Total Amount at Multiple TAB Connectors

Allowable values for unwanted emission requirements (unwanted power radiated outside the desired frequency range) are specified as the total amount at multiple TAB connectors. In existing base station specifications, unwanted emission requirements are defined for each connector as discussed above. In

*25 **EIRP:** The transmission power at the reference point in radio radiation space.

*26 **EIS:** The received power at the radiated requirement reference point in radio reception space.

*27 **Throughput:** The amount of data transmitted without error per unit time.

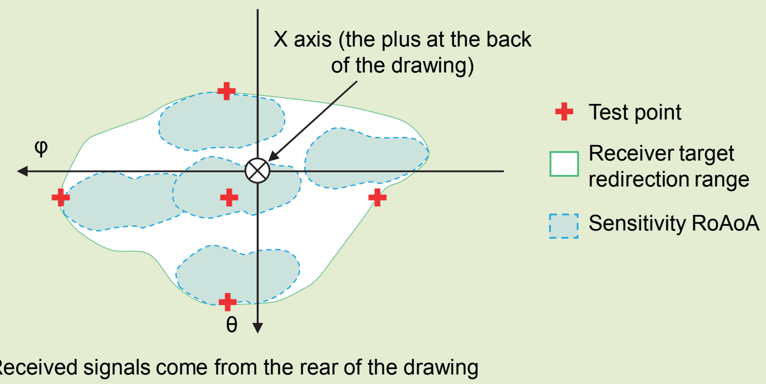

Figure 7 Range satisfying OTA sensitivity requirements and test points

contrast, for AAS, since multiple TAB connectors are implemented, there is a concern that applying the existing requirements defined for each TAB connector would result in large increases of total allowable unwanted emissions. Thus, requirements state that (1) total unwanted emission level for AAS shall not exceed the allowable amount for eight antenna ports, which is equivalent to the total amount of unwanted emission level for the maximum number of streams that can be simultaneously transmitted in existing specifications, and (2) if one AAS covers more than one cell, unwanted emission requirements are to be specified per cell to prevent bias in the amount of unwanted emissions between cells.

These requirements are described below.

- To be the number of transceiver units or the number of cells × 8 as $N_{TXU, counted}$, whichever is smaller (the latter to be the maximum if the number of transceiver units is larger than cells × 8).
- $N_{TXU, countedpercell}$ to be $N_{TXU, counted}$/the number of cells
- Multiple TAB connectors which transmit and receive for a cell are to be grouped, and the allowable amount of unwanted emissions is then the existing allowable amount of unwanted emissions × $N_{TXU, countedpercell}$ for that group.

3.3 Future Work

The OTA requirements and the total amount requirements at multiple TAB connectors have been newly included in AAS RF specifications. However, as mentioned above, OTA requirements are only for radiated transmit power accuracy and OTA sensitivity. Because there are other requirements for TAB connectors between transceiver units and composite antennas, Physical TAB connectors must be installed and measurements at these connectors are required with AAS RF specifications. On the other hand, super multi-element AAS is considered to be an effective approach to construct commercial massive MIMO base stations being developed for 5G etc. In this kind of AAS, implementing physical TAB connectors with all transceiver units would not be practical. Furthermore, since removing physical TAB connectors promises to make AAS equipment more compact, the needs of AAS RF specifications with only OTA requirements are growing. There are ongoing discussions on the OTA requirements in Release 14.

4. Uplink MMSE-IRC Receiver

To handle the increase in traffic due to the rise in smartphone popularity of recent years, cells are becoming denser, especially in urban areas, which means interference from neighboring cells is increasing. In these areas, the power of interference from neighboring cells is larger than noise power*28, and has the potential to degrade throughput.

3GPP has been studying a variety of technologies in recent years to reduce the abovementioned neighboring cell interference at receiver side. In particular with downlink, advanced radio signal processing for terminals has been studied, and Release 11 specified performance requirements for MMSE-IRC receiver based on Minimum Mean Square Error (MMSE) criteria*29 with the aim of suppressing neighboring cell interfer-

*28 **Noise power:** The noise power in the receiver. This consists of the sum of thermal noise power originating in the mobile terminal, and the small power that comes from afar due to interference signals between cells.

*29 **MMSE criteria:** A method of calculating antenna combination weight. A standard requiring the minimum mean square error of the received signal after antenna combination, so that the reception SINR after combination can be maximized.

ence [5] [6]. In Release 12, the Network Assisted Interference Cancellation and Suppression (NAICS) receiver, a further enhancement of the interference reduction process for mobile terminals based on some control information about neighboring cell interference (e.g. transmission power) signaled from serving base station, was studied and the performance requirements for the receiver were specified [5] [7].

In contrast, advance radio signal processing for uplink has been considered in Release 13 for the first time. Specifically, the performance requirements for base station were specified with the assumption that the MMSE-IRC receiver studied in Release 11 is deployed in base stations [8].

4.1. MMSE-IRC Receiver Characteristics

1) MMSE Receiver Issues

In LTE Release 8 specifications, the uplink performance requirements for base station were specified assuming the MMSE receiver as radio signal processing technology [3]. The MMSE receiver detects desired signal according to the MMSE criteria, but it assumes that interference signals from neighboring cells are equivalent to white noise*30 in the radio signal process. Thus, since neighboring cell interference cannot be realistically suppressed, uplink throughput will be limited due to neighboring cell interference in areas where base stations are densely positioned.

2) MMSE-IRC Receiver Installation in Base Stations

Here, as discussed above, Release 13 considered the inclusion of MMSE-IRC receivers in base stations with the aim of suppressing neighboring cell interference. The MMSE-IRC receiver entails multiple reception antennas in base stations, and received signals at each antenna are combined so that neighboring cell interference is suppressed in base station radio signal processing. More specifically, an uplink reference signal (DM-RS) is used to estimate not only the channel matrices of the desired signal but also statistical characteristics of neighboring cell interference. Both these pieces of information are used to adjust the phase of received signals at each antenna and combine it to generate a null*31 point (where antenna gain drops) in the direction of the incoming neighboring cell interference (**Figure 8**). Refer to [6] for more details about the MMSE-IRC receiver reception algorithm. Orienting a null toward main interference signals, in other words interference signals that particularly degrade throughput, improves the Signal to Interference plus Noise power Ratio (SINR)*32 in receivers and thus improves throughput. This receiver also offers another advantage of being relatively easy to deploy in base stations already in service, because it uses technology that only improves radio signal processing.

4.2 Uplink Throughput Improvement Effects

Figure 9 shows the uplink throughput improvement effects of the MMSE-IRC receiver. This is a simulation of a macro base station environment in which two reception antennas are deployed, and in which two high-power interference waves arrive from two interfering mobile terminals in neighboring cells. The simulation also assumes that each mobile terminal is fitted with one transmission antenna, and that the optimal MCS (Modulation and Coding Scheme) of the desired signal is adaptively selected to suit the reception environment.

From this simulation, we found that the MMSE-IRC receiver promises a 1.5

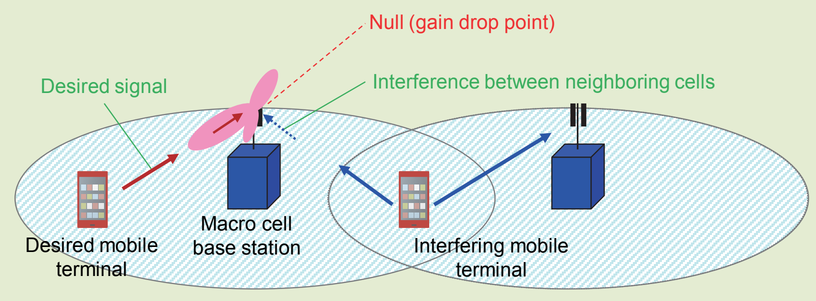

Figure 8 MMSE-IRC receiver operations

*30 **White noise:** A noise component in the receiver. White noise is characterized by constant power spectral density across the entire frequency spectrum.

*31 **Null:** A direction in the beam pattern in which the antenna gain is at a local minimum.

*32 **SINR:** The ratio of desired-signal reception power to the sum of power of all other interference-signals and noise. However, in this article, the power of minor interference signals arriving from afar is regarded as a noise.

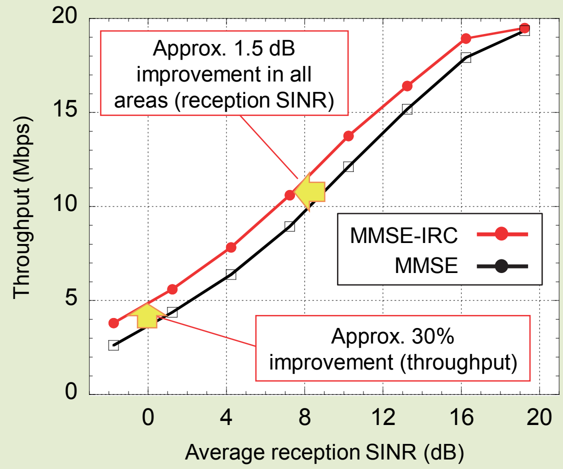

Figure 9 Throughput improvements with the MMSE-IRC receiver

dB (SINR conversion) improvement in all SINR areas compared to existing MMSE receivers, and particularly, with an average reception SINR of 0 dB, it also promises a 30% throughput improvement.

4.3 Future Outlook

Aiming for further performance improvements from Release 14 onward, it was proposed that receivers equivalent to Release 12 NAICS be deployed in base stations. While further performance improvements can be expected with these receivers, continued discussions are required as base station reception loads and installation costs could increase.

5. Conclusion

This article has described the advances in base station equipment technologies introduced with LTE-Advanced Release 13 specifications. Aiming to provide high-quality service areas into the future, we will continue to drive standardization of technologies to further improve base station equipment.

References

[1] T. Kawamura and Y. Kakishima: "Standardization trends and demonstration experiments of Multi-user MIMO in LTE-Advanced," Institute of Electronics, Information and Communication Engineers magazine, Issue 1079, Apr. 2014 (in Japanese).

[2] 3GPP TS37.105 V1.0.0: "Active Antenna System (AAS) Base Station (BS) transmission and reception," Mar. 2016.

[3] 3GPP TS36.104 V13.2.0: "Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception," Jan. 2016.

[4] 3GPP TSG RAN#71 RP-160548: "Further Enhancement of Base Station (BS) RF and EMC requirements for Active Antenna System (AAS) core part," Mar. 2016.

[5] 3GPP TS36.101 V13.2.1: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception," Jan. 2016.

[6] Y. Sagae et al.: "Improved Interference Rejection and Suppression Technology in LTE Release 11 Specifications," NTT DOCOMO Technical Journal, Vol.15, No.2, pp.27-30, Oct. 2013.

[7] K. Takeda et al.: "Higher Order Modulation, Small Cell Discovery and Interference Cancellation Technologies in LTE-Advanced Release 12," NTT DOCOMO Technical Journal, Vol.17, No.2, pp.47-55, Oct. 2015.

[8] 3GPP TR36.884 V1.0.0: "Performance requirements of MMSE - IRC receiver for LTE BS," Mar. 2016.