SCE NAICS Advanced SU-MIMO Receiver

Technology Reports

Further Development of LTE-Advanced—Release12 Standardization Trends—

Higher Order Modulation, Small Cell Discovery and Interference Cancellation Technologies in LTE-Advanced Release 12

In order to handle the rapid traffic increase in recent years, there have been a lot of studies on technologies to increase the network capacity by using small cells with low transmission power. However, when small cells are deployed with high density, interference from the neighboring cells increases dramatically and it becomes difficult to obtain the desired improvement in capacity. In this article, we describe related new technologies introduced in LTE Release 12, including higher order modulation, small cell discovery, and techniques to suppress and cancel interference from the neighboring cells.

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1. Introduction

Recently, with the spread of smartphones and tablets as well as the expansion of high-resolution video services and video telephony, mobile data traffic has been increasing radically. In order to deal with this increase, there has been intensive study of technologies that improve network capacity by increasing cell density, and particularly the number of small cells*1 with low transmission power. Small cell environments have different characteristics from conventional macro cell*2 environments: fewer users per cell, extremely good radio quality due to receiving signals directly from nearby base stations (called line-of-sight environments), and ability to accommodate users with low mobility only. As cell density is increased to further boost network capacity, the amount of interference from neighboring cells rises as well. Thus, it has become more difficult to achieve the desired capacity. Another issue is in the spatial domain, where Multiple-Input Multiple-Output (MIMO)*3 with spatial multiplexing is being used to achieve high-speed transmission. However, this can result in interference between trans-

*1 **Small cell:** A general term for the transmission area covered by base station transmitting at low power compared to a macro cell base station.

*2 **Macro cell:** An area in which communication is possible, covered by a single base station, and with a radius from several hundred meters to several tens of kilometers.

mission streams within the cell. Considering the interference situations above, methods to reduce interference between individual small cells, between small cells and macro cells, and also within macro cells are being studied.

In this article, we describe new technologies introduced in the 3GPP LTE Release 12 specifications (hereinafter referred to as "Rel. 12"), including higher order modulation, small cell discovery, and inter-cell interference suppression.

2. SCE Technologies

2.1 SCE Scenarios

LTE Advanced Rel. 12 specifies requirements for small cells [1], and a basic Study Item (SI) regarding Small Cell Enhancements (SCE) was initiated in January 2013, in Radio Access Network (RAN)*4 Working Group 1 (WG1). During the SI phase, discussions were held and consensus was reached among operators regarding hypothetical scenarios for the evaluation of SCE, and as a result a co-signed document was successfully submitted [2]. According to this document, the following four scenarios were agreed upon:

(1) Scenario #1 (same frequency/outdoor environment)
- Small cells are deployed on top of an overlaid macro cell
- Outdoors
- Use the same carrier frequency as the macro cell

(2) Scenario #2a (different frequency/outdoor environment)
- Small cells are deployed on top of an overlaid macro cell
- Outdoors
- Use a different carrier frequency from the macro cell

(3) Scenario #2b (different frequency/indoor environment)
- Small cells are deployed on top of an overlaid macro cell
- Indoors
- Use a different carrier frequency from the macro cell

(4) Scenario #3 (isolated cell environment/indoor environment)
- No overlaid macro cell
- Indoors

Technologies for small cells in the above identified evaluation scenarios were proposed by various operators and vendors. Meanwhile, simulations for evaluation were also conducted on specific techniques such as higher order modulation and suppression of interference between small cells. The results of these evaluations were summarized in a technical report [3], recognizing their effects on increasing peak data rate and capacity in the small cell scenarios. In the Work Item (WI) phase, in which the specifications of LTE Advanced Rel.12 were completed, the aforementioned simulation results led to and helped in specifying the techniques of 256 Quadrature Amplitude Modulation (QAM)*5, small cell on/off control, and small cell discovery.

2.2 Advanced Modulation Schemes

In Rel. 8 to 11 specifications, Quadrature Phase Shift Keying (QPSK)*6, 16QAM, and 64QAM were supported as modulation schemes. Modulation schemes with larger modulation multiplicity*7 (number of bits that can be sent with one symbol*8), can be used under conditions with higher received Signal to Interference and Noise Ratio (SINR)*9. The received SINR is high for indoor environments and outdoor environments with Line-Of-Sight (LOS) conditions, so modulation schemes with high multiplicity are more likely to be usable than in conventional macro cell environments. Thus, a new modulation scheme that is able to send up to 8 bits per symbol, called 256QAM, was introduced in Rel. 12 to increase the downlink peak data rate. Specifically, the base station decides on a Modulation and Coding Scheme (MCS)*10, which is a combination of a modulation scheme and an error correction coding scheme*11, based on the Channel Quality Indicator (CQI)*12 received from the UE, which is related to the value of SINR. In order to avoid increases in the amount of uplink CQI feedback as well as the amount of downlink control information on the MCS due

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*3 **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.

*4 **RAN:** The network consisting of radio base stations and radio-circuit control equipment situated between the core network and mobile terminals.

*5 **QAM:** A type of digital modulation in which carrier amplitude and phase correspond to a bit array. There are various types, according to the number of patterns defined, such as 16QAM and 64QAM.

*6 **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.

*7 **Modulation multiplicity:** The number of signal phase points in data modulation. For example, four with QPSK, and 16 with 16QAM.

*8 **Symbol:** A unit of data for transmission. In OFDM, it comprises multiple subcarriers.

*9 **Received SINR:** The ratio of desired-signal power to the sum of all other interference-signal power and noise power.

*10 **MCS:** Combinations of modulation scheme and coding rate decided on beforehand when performing AMC.

to the introduction of 256QAM, some of the existing CQI and MCS values were replaced by new CQI and MCS values for 256QAM, as shown in **Figure 1**. As a result, both the conventional CQI/MCS tables without 256QAM values and the new CQI/MCS tables with 256QAM values are supported in Rel.12. Higher layer signaling is used to switch between the conventional tables and the new tables. For example, if the results of User Equipment (UE) reception quality measurements are better than pre-determined threshold values, the CQI and MCS tables including 256QAM values are used. In indoor and LOS environments with good quality reception, for instance, 256QAM can be used to achieve higher downlink peak throughput [4].

2.3 Small Cell ON/OFF Switching and Discovery Technologies

1) Issues

For SCE in Rel. 12, it is assumed that small cells are deployed in scenarios with much higher density than the Heterogeneous Networks (HetNets)*13 in Rel. 10 and 11. Correpondingly, technologies to facilitate efficient operation of such high-density small cells were studied. In high-density small cell environments, each cell has a smaller coverage area than in conventional macro cell environments. Therefore, traffic tends to concentrate in only some of the small cells in certain areas at times, as shown in **Figure 2**. Even through some small cells have no traffic, control information such as the Synchronization Signal (SS) and Cell-specific Reference Signal (CRS)*14 continue to be sent in these conditions, to ensure UEs can discover the cells and perform measurement on the channel quality at any time. In particular, the CRS sent in each subframe can result in significant interference to downlink transmission in neighboring cells. The interference due to CRS transmission will continuously increase with the density of the small cells, and will contradict the original intention of introducing more

Table switched according to upper-layer signaling

Existing CQI table

CQI index	Modulation format	Coding rate (×1024)	Frequency utilization (bps/Hz)
0	Out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

CQI table specified in Rel. 12

CQI index	Modulation format	Coding rate (×1024)	Frequency utilization (bps/Hz)
0	Out of range		
1	QPSK	78	0.1523
2	QPSK	193	0.3770
3	QPSK	449	0.8770
4	16QAM	378	1.4766
5	16QAM	490	1.9141
6	16QAM	616	2.4063
7	64QAM	466	2.7305
8	64QAM	567	3.3223
9	64QAM	666	3.9023
10	64QAM	772	4.5234
11	64QAM	873	5.1152
12	256QAM	711	5.5547
13	256QAM	797	6.2266
14	256QAM	885	6.9141
15	256QAM	948	7.4063

Figure 1 Change of CQI tables when introducing 256QAM

*11 **Coding scheme:** The proportion of data bits to the number of coded bits after channel coding. For example, if the code rate is 3/4, for every 3 data bits, 4 coded bits are generated by channel coding.

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

*13 **HetNet:** A network deployment that overlays nodes of different power. It typically mixes-in, links and integrates base stations of lower transmission power than conventional base stations.

*14 **CRS:** A reference signal specific to each cell for measuring received quality in the downlink.

small cells, i.e. to increase the system capacity.

2) Small Cell ON/OFF Switching and Discovery Technologies

In order to solve this issue, Rel. 12 SCE specifies a small-cell ON/OFF switching technology [5]. As shown in **Figure 3**, a small cell stops transmitting reference signals when it has no traffic (OFF state) to decrease interference to neighboring cells that are transmitting data to UEs, thereby improving the throughput. However, if the transmission of SS and CRS stops completely when a small cell is in the OFF state, UEs will not be able to detect the OFF state cell and make measurements on the channel quality by using the legacy cell detection procedure. Therefore, the cell cannot quickly return to the ON state and establish communication with an active UE when UE approaches the OFF state cell and cannot detect and measure the cell. Consequently, a long transition time before communication can start will be required. In order to enable ON/OFF small cells to be detected efficiently, a small cell discovery technology that uses a new cell discovery signal was also specified. An overview of small cell ON/OFF switching using the discovery signal is shown in **Figure 4**.

Small cells with ON/OFF switching transmit a discovery signal periodically at intervals of 40 ms or greater. The discovery signal is sent even if a cell is OFF, to ensure that a UE approaching the cell in the OFF state can detect the cell and report it to the network. After receiv-

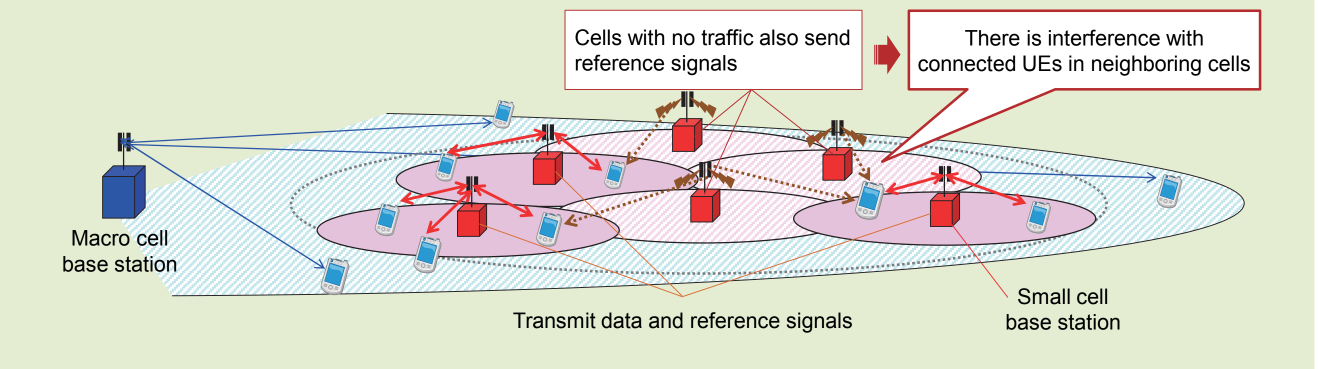

Figure 2 Traffic tendencies in dense small-cell environments

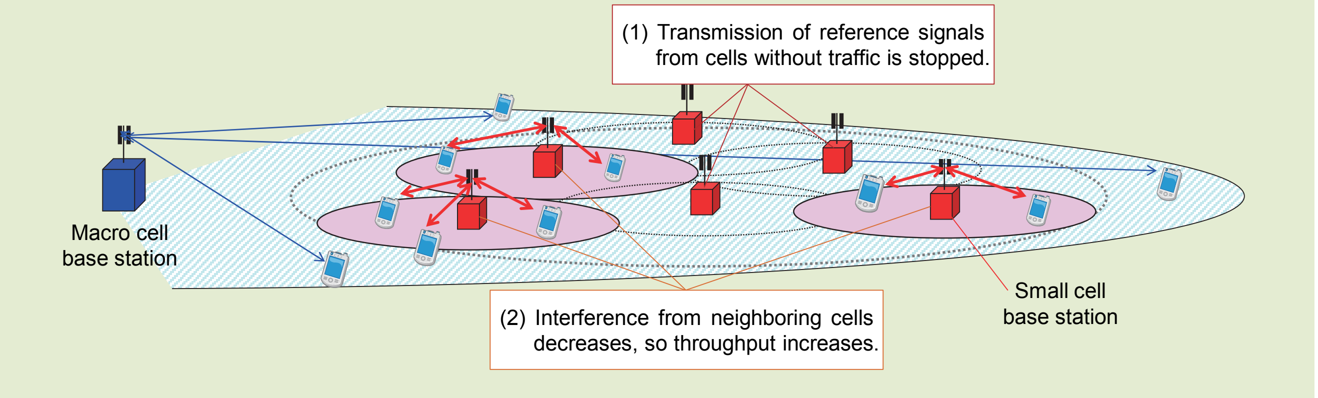

Figure 3 Small cell ON/OFF

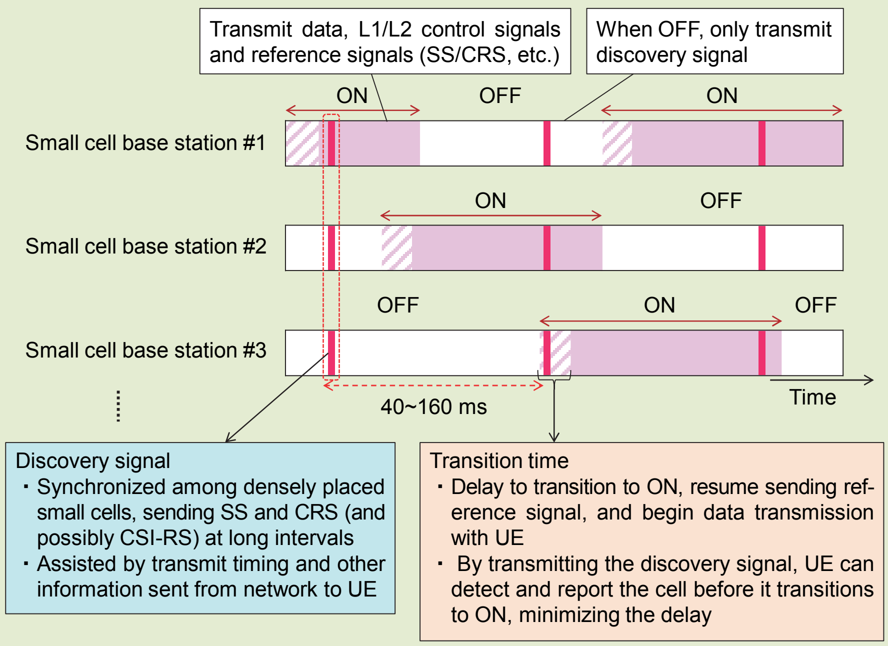

Figure 4　Small cell ON/OFF using a discovery signal

ing the report, the cell can transit to the ON state at an appropriate time, to minimize the transition time before starting communication with the UE. Compared to small cells without ON/OFF switching and discovery signals (i.e., using legacy CRS in every subframe), cells sending discovery signals at long intervals in the OFF state cause much less interference to neighboring cells.

The discovery signal is composed of SS and CRS which are synchronized with neighboring small cells and sent at long intervals. The UEs are notified by their connected cells (e.g., the macro cell) with assistance information consisting of transmission interval and starting time of the discovery signal. This information helps UEs to receive discovery signals from multiple surrounding small cells simultaneously without significant power consumption or loading. The Channel State Information-Reference Signal (CSI-RS)*15 can also be included in the discovery signal with long-interval transmission in addition to the SS and CRS to support efficient shared-cell-ID operation (i.e., the same cell ID*16 for multiple small cells). With this design of discovery signal, the same SS and CRS are used among small cells with the same cell ID, which is correlated to the transmission resources of the CRS. Therefore, there is no resource collision between the CRS of specific small cells and the data signals in neighboring cells, so CRS interference can be avoided. Meanwhile, UEs do not need to detect and measure each small cell based on the SS and CRS, since they can identify individual small cells and make corresponding measurements based on the CSI-RS in the discovery signal [6].

3. Interference Cancellation Technologies for Mobile Terminals

As shown in **Figure 5**, the interference between macro cells has increased due to denser deployment. Moreover, in SCE scenario #1 as explained in Section

*15 **CSI-RS:** A reference signal transmitted from each antenna to measure the state of the radio channel.

*16 **Cell ID:** Identifying information assigned to each cell.

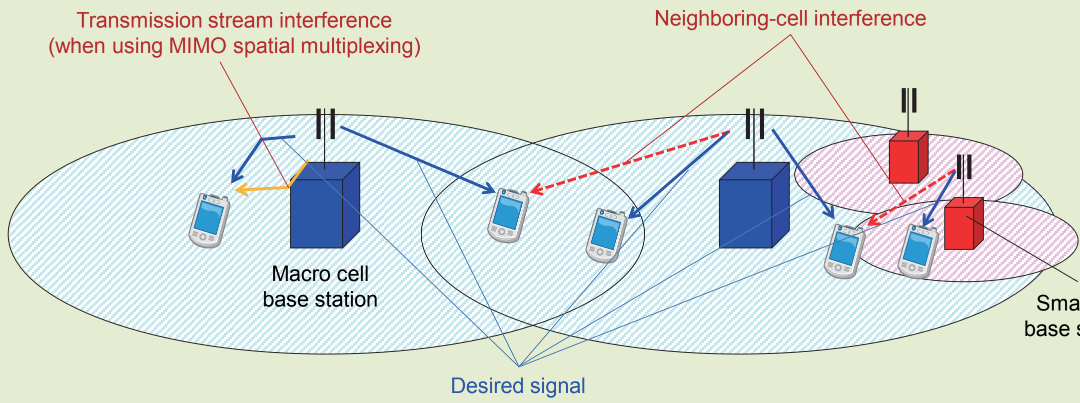

Figure 5 Interference from neighboring cells and transmission streams

2.1, interference between macro cells and small cells is also expected to become more serious. Although interference from neighboring cells is smaller for UEs near the connected base station, as also shown in Fig. 5, interference between transmission streams will still be an issue, assuming MIMO spatial multiplexing is applied to improve throughput.

In Rel. 12, both Network Assisted Interference Cancellation and Suppression (NAICS) and Single User-MIMO (SU-MIMO) receivers were studied to reduce the interference from neighboring cells and between transmission streams in the receiver as described above.

3.1 NAICS Receiver Reducing Neighboring-cell Interference

1) Conventional MMSE/MMSE-IRC Receivers

In the Rel. 8 specifications, UE performance requirements were specified assuming a Minimum Mean Squared Error (MMSE)*17 receiver. But the standard MMSE receiver cannot suppress interference signals from neighboring cells because they are generally assumed to be equivalent to white Gaussian noise in the reception process of the MMSE receiver. Consequently, the UE throughput could be limited due to inter-cell interference, especially in areas with high interference, such as at cell edges. In order to reduce this interference, the MMSE Interference Rejection Combining (IRC)*18 receiver was studied [7], and UE performance requirements based on this MMSE-IRC receiver were specified [8] in the Rel. 11 specifications. The MMSE-IRC receiver uses multiple receiving antennas to suppress interference signals by creating antenna gain*19 and null*20 points in their arrival direction. By using this receiver, UE throughput could be improved especially near cell edges [9]. Another benefit is that the MMSE-IRC receiver can be used on Rel. 8 LTE based systems, so the interference suppression capability can be obtained on Rel. 8 LTE networks that have already begun commercial services.

2) NAICS Receiver Features

In the Rel.12 specification, more advanced interference cancellation technologies were studied for NAICS receivers, to further improve cell edge UE throughput. Specifically, application of Successive Interference Cancellation (SIC)*21 [10] and Maximum Likelihood Detection (MLD)*22 [11] were investigated, which are reception technologies that generally promise much better interference cancelling effect than MMSE-IRC receivers. However, in order to apply these reception technologies, the interference signal must be demodulated to the transmission symbol level on the UE side. For example, SIC is able to

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*17 **MMSE:** A method for demodulating a signal that minimizes mean square error.

*18 **IRC:** A method for rejecting an interference signal by creating an antenna-gain drop point with respect to the arrival direction of that signal.

*19 **Antenna gain:** The power emitted by an antenna relative to an ideal antenna.

*20 **Null:** A direction in the beam pattern for which the antenna gain is very small.

*21 **SIC:** A MIMO signal separation method in which multiple signals combined in a received signal are successively detected and cancelled out of the signal one at a time. It usually yields better performance than Zero Forcing (ZF) or Minimum Mean Square Error (MMSE).

*22 **MLD:** A method for separating MIMO multiplexed signals by comparing all sequences of received signals with those that could possibly be received and finding the combination nearest the received pattern.

cancel the interference signal effectively by subtracting a replica of the interference, which is generated from the received signal by demodulating the interference in symbol level and using an estimated channel matrix*23. However, base stations under Rel. 8 to 11 specifications do not provide signaling*24 containing control information from neighboring cells, which is needed to demodulate the interference signals. Therefore, it is difficult to perform the interference subtraction process as described above. Accordingly, the NAICS technology supports a new function which provides signaling from the connected base station to the UE with control information for neighboring cells, so they can demodulate the interfering signals to the transmit symbol level*25 [12]. In order to reduce signaling overhead, only some of the control information from neighboring cells needs to be sent (physical cell ID, CRS data, etc.), and any other remaining information is blindly estimated by the UE itself. Thus, the control information obtained through both signaling and blind estimation can be used to when applying SIC or MLD to the interference signal. As a result, interference signals from neighboring cells can be greatly reduced.

3) Throughput Improvement due to NAICS Receiver

Results of throughput improvement by using the NAICS technique are shown in **Figure 6**. Here, we simulated a case with a macro cell and two neighboring cells with sufficiently large Interference-to-Noise power Ratio (INR). For the desired signal, MIMO transmission diversity*26 was applied assuming the UE near the cell edge and the MCS scheme was QPSK (coding ratio of 1/3). MIMO spatial multiplexing and 64QAM was assumed for the interference signal. The results showed that, compared to the existing MMSE-IRC receiver, the NAICS receiver can achieve approximately 1.0 dB improvement in the reception SINR required to achieve 70% of the maximum throughput (approx. 10% on the throughput characteristic).

3.2 SU-MIMO Receiver Reducing Interference Between Transmission Streams

1) Features of Conventional MMSE/SU-MIMO Receiver

In the Rel. 8 specifications, UE performance requirements for MIMO spatial multiplexing were specified assuming the MMSE receiver. As mentioned in section 3.1, the MMSE receiver is unable to suppress interference from neighboring cells. However, when MIMO spatial multiplexing is applied, the MMSE receiver is able to suppress interference between transmission streams by using multiple receiver antennas.

For the SU-MIMO receiver in the Rel. 12 specification, advanced reception processing to further reduce the aforementioned interference between transmission streams was studied, to yield improvements in throughput for the UEs near the base station. Specifically, UE performance requirements were specified, assuming that the inter-stream interference when assuming MIMO spatial multiplexing would be cancelled using MLD [8]. It is noted that, similar to the MMSE-IRC receiver, if the network is based on Rel. 8, the SU-MIMO receiver can be used without any particular configuration on base stations. Moreover, different from the NAICS receiver, the SU-MIMO receiver does not require any new signaling to be specified, so the interference cancellation capability can be obtained on Rel. 8 LTE based networks.

2) Throughput Improvements due to SU-MIMO Receivers

Throughput improvements due to the SU-MIMO receiver are shown in **Figure 7**. Here, MIMO spatial multiplexing was applied assuming the UE was near the connected base station, and 16QAM (coding rate 1/2) was assumed for the MCS scheme for the desired signal. All interference from neighboring cells was also assumed to be equivalent to white Gaussian noise in this evaluation. It is shown that, the SU-MIMO receiver can improve SINR by approximately 1.7 dB (approximately a 30% improvement in throughput characteristic) compared to the existing MMSE

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*23 **Channel matrix:** A matrix composed of the changes in amplitude and phase on the channels between each transmit and receive antenna pair.

*24 **Signaling:** The sharing of information necessary for communication between base station and mobile terminals before such communication can begin (e.g. frequency band, coding and modulation formats, etc.).

*25 **Transmit symbol level:** A digitally modulated signal (symbol). Here, this refers to decoding a received signal to a digitally modulated signal.

*26 **Transmission diversity:** Technology which utilizes the differences in channel fluctuation between transmission antenna channels to obtain diversity gain.

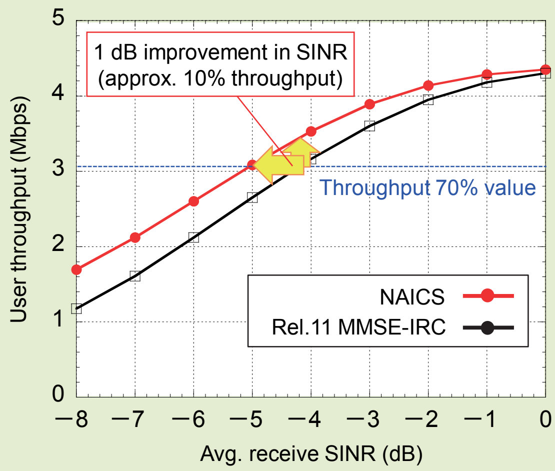

Figure 6 Throughput improvement using a NAICS receiver

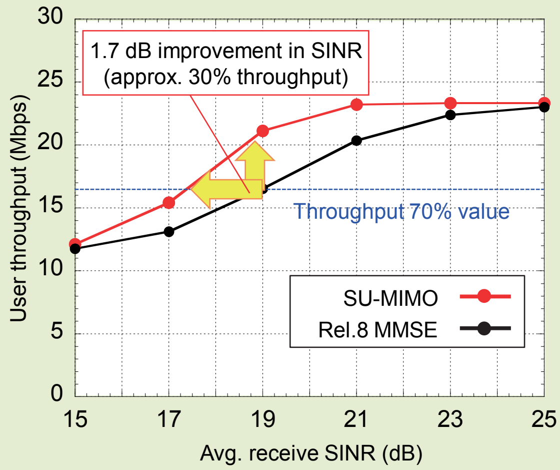

Figure 7 Throughput improvement using a SU-MIMO receiver

receiver.

4. Conclusion

In this article, we have described technologies introduced in the LTE-Advanced Rel. 12 specification to increase user throughput*27 and network capacity, including higher order modulation, small cell detection, and suppression of interference between cells. In order to handle future increases in mobile traffic, we will continue standardizing radio interface technologies to increase user throughput and system capacity.

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*27 **User throughput:** The amount of data that one user can transmit without error per unit time.

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