LTE-Advanced | CA | Advanced C-RAN

Technology Reports

Special Articles on PREMIUM 4G—Introduction of LTE-Advanced—

Commercial Development of LTE-Advanced Applying Advanced C-RAN Architecture —Expanded Capacity by Add-on Cells and Stable Communications by Advanced Inter-Cell Coordination—

*In March 2015, NTT DOCOMO launched the PREMIUM 4G^TM*1 service in Japan using LTE-Advanced as an evolved form of the LTE mobile communications system. This deployment includes the introduction of Advanced C-RAN architecture that combines macro cells and small cells through CA to increase transmission speeds, expand capacity, and provide stable communications for a more satisfying user experience. In this article, we overview the features, effects, and control procedures of Advanced C-RAN architecture.*

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1. Introduction

Recent years have seen a dramatic increase in network traffic thanks to the expanded use of smartphones and the popularity of large-capacity content such as images and video. The need has therefore been felt for even higher communication speeds and greater capacities in the radio network. The 3rd Generation Partnership Project (3GPP) began work in 2008 on formulating specifications for the LTE-Advanced*2 system to improve the speed and capacity performance of LTE and extend LTE functions. As a result of these efforts, standardization of LTE-Advanced was completed in 2011 [1].

To achieve an effective rollout of the LTE-Advanced system, NTT DOCOMO proposed Advanced Centralized Radio Access Network (C-RAN) architecture and commenced development of base station equipment supporting this architecture in February 2013 toward commercialization [2]. Then, in March 2015, NTT DOCOMO introduced LTE-Advanced using Advanced C-RAN architecture and began the commercial provision of high-speed transmission in the downlink at a maximum data rate of 225 Mbps under the name of PREMIUM 4G. Advanced C-RAN architecture achieves high-speed and large-capacity communications by combining two key technologies of LTE-Advanced: Carrier Ag-

*1 **PREMIUM 4G™:** A trademark of NTT DOCOMO.

*2 **LTE-Advanced:** Name of IMT-Advanced in 3GPP. IMT-Advanced is the successor to the IMT-2000 third-generation mobile communications system.

gregation (CA) and Heterogeneous Network (HetNet)*3. Advanced C-RAN is also being studied as a basic architecture for the next-generation 5G*4 mobile communications system now attracting attention throughout the world [3]. In this article, we overview the features, effects, and control procedures of LTE-Advanced based on Advanced C-RAN architecture.

2. Advanced C-RAN Architecture

As stated above, CA is a key technology of LTE-Advanced enabling a terminal to simultaneously connect to multiple LTE carriers (component carriers) operating on different frequencies. Achieving bandwidth extension in this way makes for higher communication speeds [4]. Furthermore, in addition to increasing the data rate, NTT DOCOMO also uses CA to expand radio capacity and improve communications stability by enabling a terminal to simultaneously connect to a macro cell*5 and small cell*6 added to that area (hereinafter referred to as an "add-on cell"). CA requires coordination between cells that a terminal is to be simultaneously connected to, and as a result, specifications dictate that the same base station be used to control those cells. Consequently, to increase capacity and improve stability through add-on cells, macro cells and add-on cells installed at different points must be controlled by the same eNodeB (eNB)*7.

To this end, while base station equipment normally consists of a baseband*8 processing unit and radio unit, NTT DOCOMO separates the baseband processing unit from the base station leaving only the radio unit to be installed at the base station site*9. C-RAN architecture consolidates multiple baseband processing units in high-density baseband processing equipment thereby reducing the space needed for installing base station equipment and decreasing facility investment. NTT DOCOMO has been operating C-RAN architecture since 2003 [5]. Furthermore, by leveraging the features of this C-RAN architecture and adopting a new architecture that accommodates a macro cell and multiple add-on cells in the same baseband processing unit, flexible coordination between a macro cell and add-on cells through CA has become possible. This new architecture is called Advanced C-RAN architecture (**Figure 1**), which is facilitating a smooth rollout of LTE-Advanced and an expansion of radio capacity.

We consider the use of Advanced C-RAN architecture to have the following three effects, each of which are described below.

- Higher transmission speeds and improved spectral efficiency by CA
- Expanded capacity by add-on cells

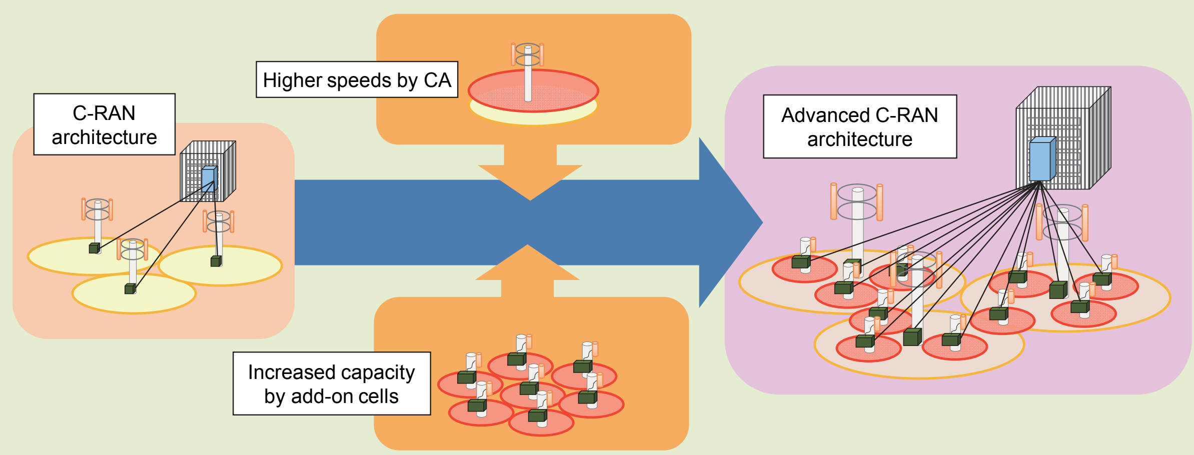

Figure 1 Overview of Advanced C-RAN architecture

*3 **HetNet:** A network configuration that overlays nodes of different power. A network that mixes, links, and integrates base stations of relatively low transmission power.

*4 **5G:** A next-generation mobile communications system succeeding the 4G mobile communications system.

*5 **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.

*6 **Small cell:** Generic name for a cell covering a small area and having low transmission power relative to a macro cell.

*7 **eNB:** A base station for the LTE radio access system.

*8 **Baseband:** The circuits or functional blocks that perform digital signal processing.

- Improved stability in communications

Additionally, while CA is assumed between a macro cell and add-on cell as described above, Advanced C-RAN also supports CA using two macro cells. For example, in a suburban area having no need of extending radio capacity by installing add-on cells, the goal may be to provide users with higher transmission speeds by CA using macro cells. Advanced C-RAN can be applied in a flexible manner according to area conditions.

2.1 Higher Transmission Speeds and Improved Spectral Efficiency by CA

1) Simultaneous Connection to Multiple Carriers

Since the launch of NTT DOCOMO's LTE-Advanced service in March 2015, CA has been achieved by simultaneous connection to two LTE carriers. Maximum transmission speed in the downlink is determined by the total frequency bandwidth of these simultaneously connected LTE carriers (**Table 1**). In this regard, 3GPP specifications call for a maximum downlink speed of 300 Mbps by simultaneous connection to two LTE carriers, but this specification is for a total frequency bandwidth of 40 MHz. NTT DOCOMO, however, uses either of two combinations of carriers to achieve a total frequency bandwidth of 30 MHz, that is, the 2 GHz (15 MHz bandwidth) + 1.5 GHz (15 MHz bandwidth) bands or the 800 MHz (10 MHz bandwidth) + 1.7 GHz (20 MHz bandwidth) bands. The standard calls for a maximum downlink speed of 225 Mbps in this case. NTT DOCOMO has also been conducting field trials in an outdoor commercial environment using a total frequency bandwidth of 35 MHz through a combination of the 800 MHz (15 MHz bandwidth) + 1.7 GHz (20 MHz bandwidth) bands. In those trials, it was found that a maximum downlink speed of 240 Mbps could be achieved (**Figure 2**).

In addition, LTE-Advanced speci-

Table 1 Improved throughput by CA

Total frequency bandwidth (MHz)	Maximum downlink speed (Mbps)
5	37.5
10	75
15	112.5
20	150
25	187.5
30	225
35	262.5
40	300

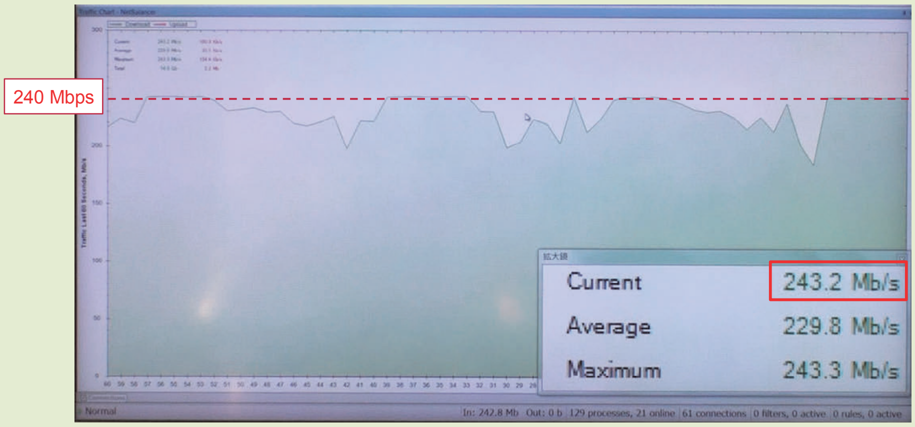

Figure 2 Achieving 240 Mbps in a commercial environment

*9 **Site:** The location installing base station antennas.

fications prescribe CA for a maximum of five LTE carriers (total bandwidth of 100 MHz). Our plan is to extend CA to three or more LTE carriers toward even higher transmission speeds. Advanced C-RAN architecture, which is capable of accommodating and controlling many cells with a single baseband processing unit, has a configuration that makes such CA extension relatively easy to achieve.

2) Load Balancing Between Cells

CA is effective not only for increasing transmission speeds but also for achieving load balancing*10 between cells. In a commercial environment, the distribution of users, imbalance in frequency bands supported by mobile terminals, difference in radio propagation characteristics among frequency bands, etc. can result in a bias in the degree of congestion among frequency carriers. Accordingly, terminals that support multiple frequency bands should be controlled so as to connect as much as possible to an LTE carrier with a low level of congestion. However, in conventional LTE, a HandOver (HO)*11 procedure is needed to switch cells, so if the degree of congestion fluctuates in short time periods, switching that can keep up with such rapid fluctuation becomes difficult. In contrast, the use of CA means that the terminal is already connected to multiple carriers, which means that an LTE carrier can be instantaneously selected according to carrier-congestion conditions even if those conditions are changing rapidly. An improvement in spectral efficiency can therefore be expected (**Figure 3**).

2.2 Expanded Capacity by Add-on Cells

HetNet technology is attracting attention throughout the world as a means of increasing the radio capacity of a system [6]. This is accomplished by offloading traffic within a macro cell to low-power add-on cells installed at spots where traffic concentrates within that macro-cell area. To link macro cells and add-on cells by CA in a HetNet, NTT DOCOMO uses separate frequency bands for a "coverage band" that covers a macro-cell area and a "capacity band" for increasing radio capacity using an add-on cell. For example, the 2 GHz or 800 MHz band may be used as a coverage band and the 1.5 GHz or 1.7 GHz band as a capacity band.

1) Evaluation by Simulation

We here explain the results of computer simulations of the capacity-expansion effect of add-on cells. In this evaluation, coverage bands were arranged only as macro cells, and capacity bands

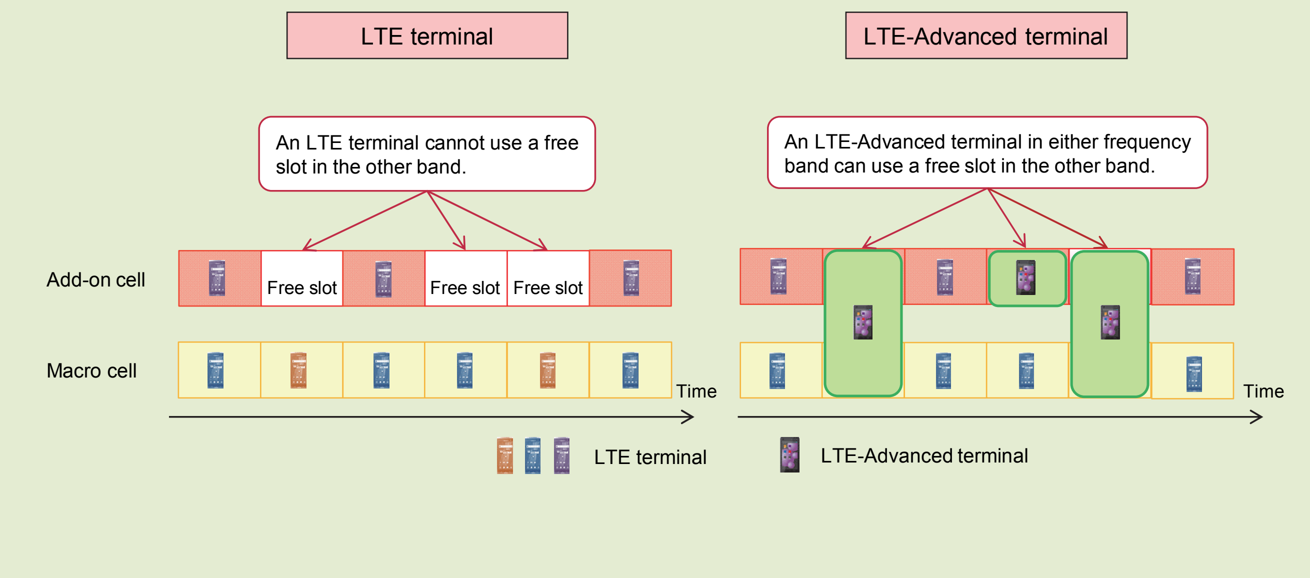

Figure 3 Load balancing by CA

*10 **Load balancing:** The process of distributing traffic load among cells.

*11 **HO:** The process of switching the base station connected to the UE.

were installed either as macro cells in the same manner as coverage bands (Case 1 in **Figure 4**) or as add-on cells (Case 2 in the figure). We compared the results of these two cases. In both cases, the area covered by a single macro base station was divided into three sectors and the frequency bandwidth of either a coverage band or a capacity band was 10 MHz.

Furthermore, in case 2, multiple add-on cells were positioned within a single macro cell and users were located in the vicinity of those add-on cells. In short, this evaluation was performed assuming that such add-on cells could be installed exactly in areas where users would concentrate.

2) Evaluation Results

Evaluation results are shown in **Figures 5** and **6**. First, sector capacity (total of capacity of coverage-band cell and capacity of all capacity-band cells within that sector) for Case 1 and Case 2 is shown in Fig. 5. In the figure, sector capacities are normalized against that of Case 1 to reflect the capacity-expansion effect of add-on cells. For Case 2, a capacity-expansion effect of approximately 2.5 times was obtained for an installation of four add-on cells showing that increasing the number of add-on cells could increase capacity. Next, capacity per add-on cell for Case 2 is shown in Fig. 6. These results show that capacity per add-on cell decreases as the number of add-on cells increases. This is because interference between add-on cells increases as more add-on cells are installed. As a consequence, the capacity-expansion effect and cost-effectiveness per add-on cell decreases if too many add-on cells are installed.

Given the conditions of this evaluation, four or six add-on cells per sector could be taken to be an optimal number. This value, however, could change depending on the antenna configuration of the add-on cells (beam width, installation height, etc.), macro cell radius, and other conditions.

2.3 Improved Stability in Communications

As described above, cell capacity increases by simply adding add-on cells, but installing multiple add-on cells within an area also means an increase in the number of cell edges. In such an environment, a moving user will frequently straddle two add-on cells at their edges, and if these add-on cells are installed without using CA, the user will experience a drop in communications quality at this time owing to interference between those cells and HO processing. In contrast, Advanced C-RAN architecture enables a terminal to be simultaneously connected to an add-on cell and macro cell through CA, which means that stable communications can be ensured via the macro cell and noticeable degradation in quality while moving can be suppressed.

We here explain in detail the above stability effect in communications using

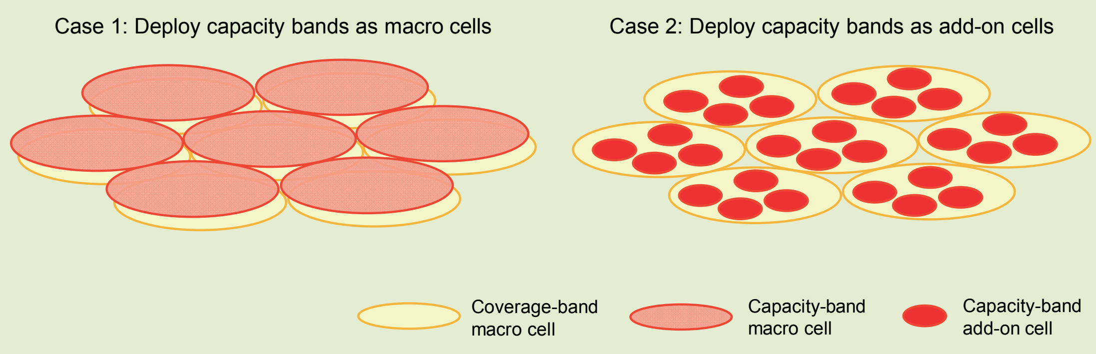

Figure 4 Simulation scenarios

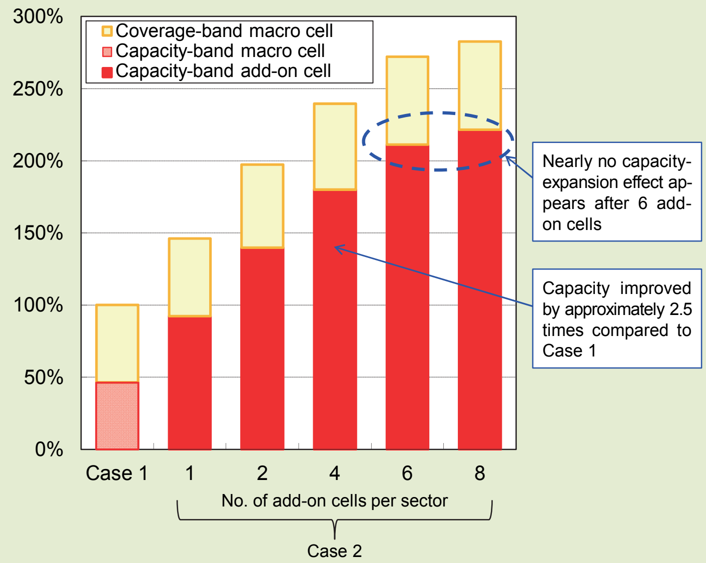

Figure 5　Capacity-expansion effect of add-on cells

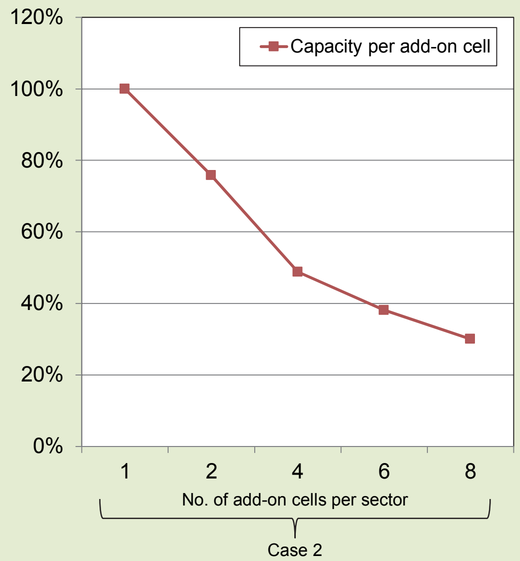

Figure 6　Capacity per add-on cell

Figure 7. At point 1 in the figure, an LTE terminal connects to add-on cell A and achieves the throughput provided by LTE. An LTE-Advanced terminal, in contrast, lies in both a macro cell and add-on cell A, which means that it can achieve higher throughput than the LTE terminal by simultaneously connecting to those cells through CA. Now, on moving to point 2 at the edge of add-on cells A and B, the LTE terminal experiences a drop in throughput due to interference between the add-on cells and HO processing. The LTE-Advanced terminal, however, though also switching between add-on cells A and B, is simultaneously connected to the macro cell, which prevents a dramatic deterioration in throughput and enables a certain level of communications quality to be maintained. In short, Advanced C-RAN architecture enables flexible switching between add-on cells while keeping an LTE-Advanced terminal connected to a macro cell thereby achieving high-speed and stable communications. This effect has been verified by tests performed in an outdoor commercial environment (**Figure 8**).

3. SCell Control in Advanced C-RAN

In CA whereby a mobile terminal connects to multiple LTE carriers simultaneously, the primary carrier is called the Primary Component Carrier (PCC) while the secondary carrier is called the Secondary Component Carrier (SCC). In addition, the cells connected to the terminal via PCC and SCC are called the PCell and SCell, respectively [7].

Since multiple add-on cells can exist within a macro cell in Advanced C-RAN architecture, a control process is needed to select which of those add-on cells is to be set as a SCell for a mobile terminal connected to the macro cell according to that terminal's position.

Furthermore, since the optimum add-on cell will change as the mobile terminal moves, the terminal will switch to another add-on cell to be set as the SCell at such a time. Moreover, if no add-on cell can offer a sufficient level of quality making it useless for a mobile terminal to connect to a SCell, the SCell setting will be deleted for the sake of battery savings on the mobile terminal. NTT DOCOMO achieves the above controls by "SCell add," "SCell change," and "SCell delete" procedures using mobile-terminal radio quality measurements and measurement reports to eNB as prescribed in 3GPP specifications [8]. These procedures are described below.

3.1 SCell Add

For a mobile terminal in a state connected only to a macro cell (non-CA state), the control procedure for adding a SCell is shown in **Figure 9** (1). First, the eNB commands the mobile terminal to make measurements to ascertain whether an add-on cell exists in the neighborhood. If a neighboring add-on cell does exist, the mobile terminal returns a report to the eNB on the radio quality of that add-on cell. Now, if the reported radio quality satisfies certain conditions, the eNB commands the mobile terminal to add that add-on cell as a SCell. On doing

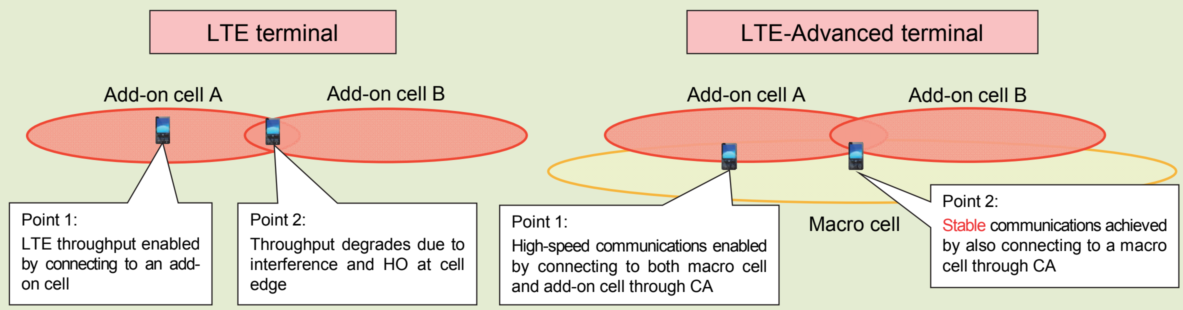

Figure 7 Communications by Advanced C-RAN architecture

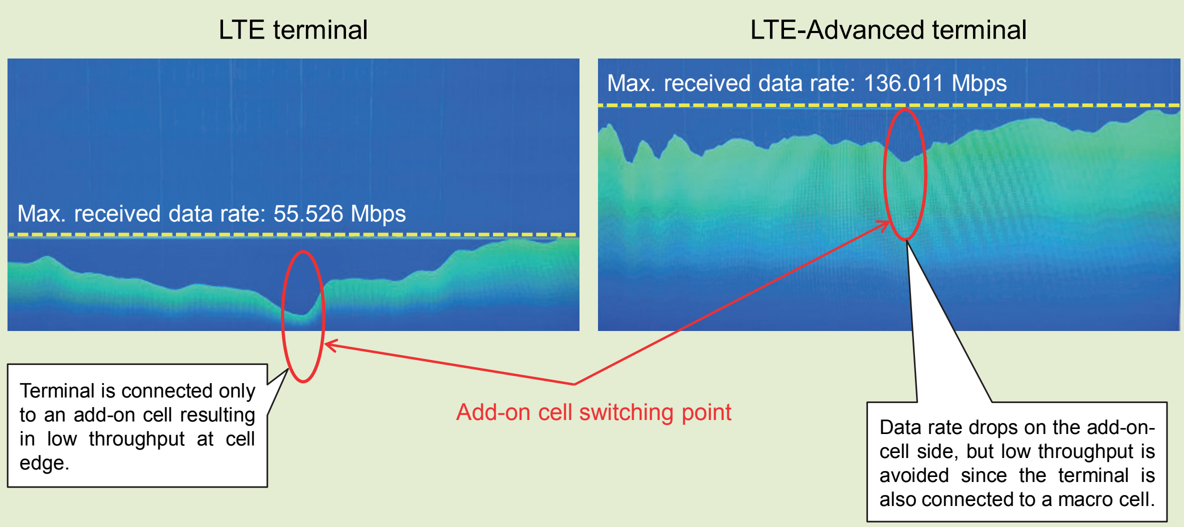

Figure 8 Comparison between LTE/LTE-Advanced terminals moving between add-on cells in a commercial environment

so, the mobile terminal enters the CA state, which enables it to be simultaneously connected to a macro cell and add-on cell. In this way, the most optimum add-on cell can be set as a SCell according to the position of the mobile terminal.

3.2 SCell Change

Next, for a mobile terminal connected to both a macro cell and add-on cell (CA state), the control procedure for changing the SCell if the mobile terminal should move into the area of another add-on cell is shown in Fig. 9 (2). At the time of "SCell add" as described in section 3.1, the eNB commands the mobile terminal to make measurements (event A6 measurements) so that an eNB report can be made if a cell of the same frequency as the existing SCell and with better radio quality comes to exist. Now, when the mobile terminal currently connected to the macro cell and add-on cell #1 moves into the boundary area between add-on cell #1 and add-on cell #2, the radio quality of the SCell (add-on cell #1) deteriorates while the radio quality of neighboring add-on cell #2 improves. The mobile terminal now reports the radio quality of add-on cell #2 to eNB based on event A6 measurements as described above. On the basis of this report, eNB commands the mobile terminal to change to add-on cell #2 having better radio quality than the current SCell. The above procedure makes it possible to keep up with the movement of the mobile terminal and set the most optimum add-on cell as the SCell.

3.3 SCell Delete

Finally, for a mobile terminal in CA state moving out of an add-on cell area, the control procedure for deleting the SCell is shown in Fig. 9 (3). At the time of "SCell add" as described in section

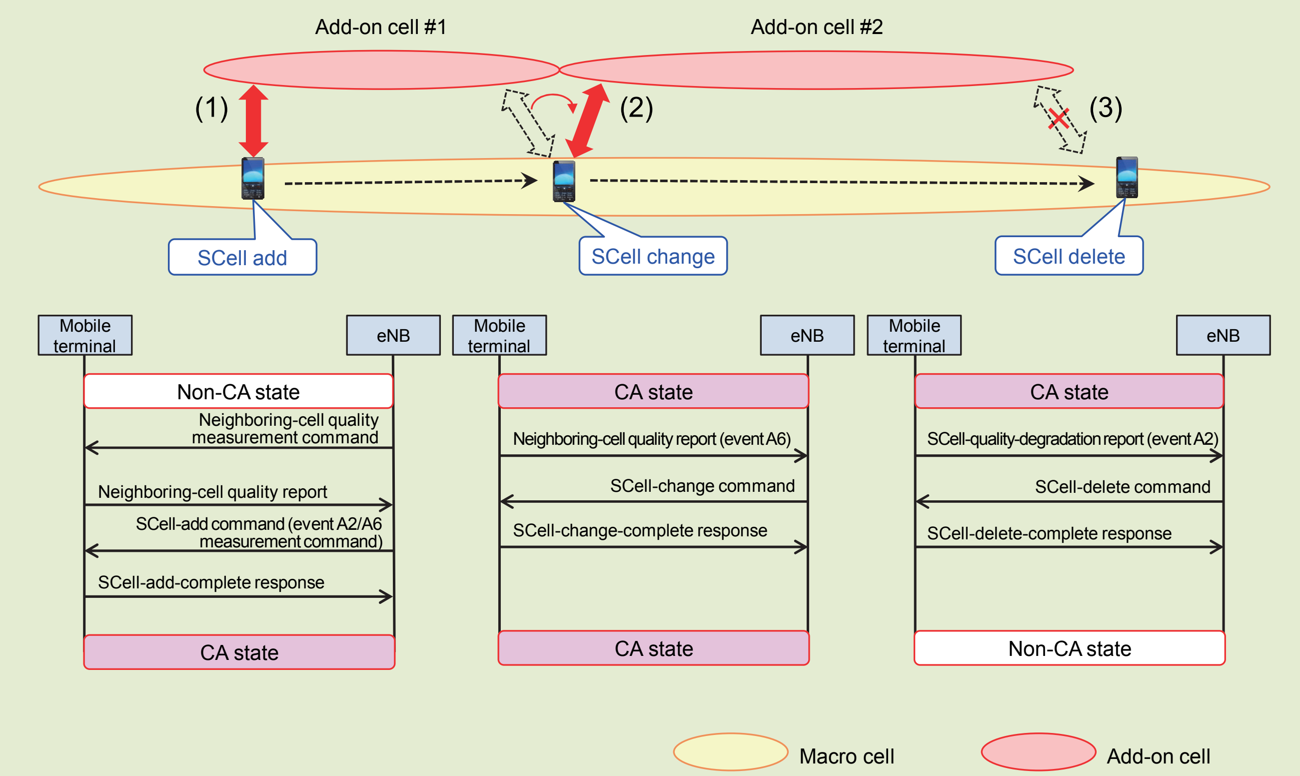

Figure 9 SCell control in Advanced C-RAN

3.1, the eNB commands the mobile terminal to make measurements (event A2 measurements) so that an eNB report can be made if the radio quality of the existing SCell should deteriorate below a specific threshold. These event A2 measurements are to be continued even if SCell should change. Now, if the mobile terminal currently connected to the macro cell and add-on cell #2 moves out of the area of add-on cell #2, radio quality will deteriorate. The mobile terminal therefore reports to eNB that the radio quality of add-on cell #2 has deteriorated based on event A2 measurements described above. On the basis of this report, eNB commands the mobile terminal to delete that SCell. The CA state is therefore cancelled and the mobile terminal enters a conventional LTE communications state (non-CA state). Cancelling the CA state in this way when appropriate can reduce the use of eNB resources and save battery power on the mobile terminal.

4. Conclusion

In this article, we described LTE-Advanced features with a focus on Advanced C-RAN architecture, presented capacity expansion effects on the basis of simulations, and overviewed control procedures. Advanced C-RAN architecture can increase radio capacity through the use of add-on cells while maintaining high-speed and stable communications befitting an LTE-Advanced system. The net result is an improved user experience. Going forward, we plan to study means of achieving even higher transmission speeds and improving radio spectral efficiency.

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