Executive Summary

Various innovations are expected to drive the evolution of cellular systems towards the 5th generation (5G). In this paper, we propose a new concept, virtualization of cells. This concept is based on Centralized/Cloud-Radio Access Network (C-RAN) and advanced techniques in spatial domain. The proposed architecture helps to fully exploit the radio resources and efficiently utilize network processing resources. We discuss the benefits of a massive-element antenna implementation to virtualized small cells. The experimental results from a proof of concept (PoC) demonstrated that our enhanced beamforming achieved high system throughput. NEC will continue to address the challenges of 5G cellular networks leveraging the proposed architecture.

1. Introduction

Recently, the increasing numbers of smart devices and richer Internet content have led to an exponential increase of the amount of data traffic [1]. This situation has attracted much attention from industry and academia in the move from current cellular systems toward 5G. Although the requirements, use cases and potential architectures are still under discussion, it is expected that 5G networks will support 1000 times higher wireless area capacity compared to current long term evolution (LTE)/LTE-advanced (LTE-A) systems, up to 1Gbps individual user data rate and a massive number of connected devices [1][2]. Additionally, lower latency, reduced energy consumption and improved mobility robustness are widely agreed to be key requirements for 5G cellular networks. In order to meet the challenges of 5G, radio access networks (RAN) should be developed with the following two main principles in mind.

Full exploitation of radio resources

Various new ways to exploit the radio resources from different dimensions (time, frequency, space, power level etc.) have been proposed for 5G. From the frequency domain perspective, increasing bandwidth is a straightforward way to increase capacity. However, most of the frequency bands lower than 3.5GHz are currently fully employed. The use of higher frequencies to provide larger bandwidth has therefore been put forward as a solution. In the spatial domain, techniques based on multiplexing and diversity, such as coordinated multipoint transmission and reception (CoMP), massive multiple input multiple output (MIMO) and dense small cell deployment have been considered as chief candidates to improve radio resources efficiency.

Efficient utilization of network processing resource

To support a diversity of smart devices and a wide variety of Internet services, mobile networks have to fulfill multiple QoS/QoE requirements handling both temporal and spatial variations of traffic patterns. However, current network structures were designed for a few typical traffic models, and so are not able to handle the fluctuation of required processing resources efficiently. Novel network architectures, such as base band (BB) resource pooling, C-RAN, Network Function Virtualization (NFV) and Mobile-edge Computing, have the potential to achieve a better utilization of network processing resources, reduced energy consumption and lower latency.

2. Virtualization of Cells

To fully exploit the advantages of the above techniques and architectures, NEC proposes a new concept; virtualization of cells. In cellular networks today, a cell is coupled with the geographical coverage of a single radio antenna site. On the other hand, in our concept, physical sites are virtualized to increase flexibility of cell coverage. Creating cell coverage by flexibly combining several virtual sites enables efficient provisioning of radio resources. This flexible architecture helps to provide sufficient radio resources for users’ services and improve the users’ QoE even if communications traffic varies widely over time and place.

Figure 1 represents an example of our concept. A digital unit (DU) accommodates a large number of radio units (RU) connected through front haul. This
enables the centralized DU to handle the fluctuation of the required processing resources efficiently. In addition, a heterogeneous architecture that consists of a high-power RU and low-power RUs will help to fulfill the various service requirements more efficiently. Specifically, the high-power RU mainly undertakes broadcast tasks and control-plane tasks such as initial access and handover to ensure wide and seamless connectivity. The low-power RUs mainly transmit user-plane traffic coordinating with each other to fulfill QoS requirements through DU control. The inter-site coordination will be realized by various emerging technologies, such as CoMP and inter-site carrier aggregation (CA). These technologies help to increase system capacity by focusing radio resources on geographical hotspots and dynamically reducing inter-site interference. In addition, total power consumption can be saved by switching RUs on and off depending on the traffic load, even when a huge number of RUs are densely deployed.

The efficiency of radio resource usage can be further improved if a massive-element antenna is deployed at the low-power RU site. This enables spatial multiplexing techniques such as 3D beamforming and Massive MIMO to enhance the effects of inter-site coordination.

3. Massive-Element Antenna for Small Cells

Currently, dense small cell deployment is considered by operators to be a key strategy for 5G networks. In such a deployment, small cells overlap with macro cells in regions where both wide coverage and high capacity are needed. However, in the dense small cell deployment, there are implications for site acquisition and maintenance and front haul and back haul planning. Also it requires careful attention to be paid to inter-cell interference (ICI) management and mobility robustness as shown in Figure 2.

NEC’s virtualization of cells concept proposes the use of a massive-element antenna for small cells. This will both address the challenges and leverage the advantages of small cell deployment. A massive-element antenna provides more accurate beamforming and enhanced spatial multiplexing by deploying a large number of antenna elements in both horizontal and vertical directions.

The use of massive-element antennas together with virtualization of cells enables flexible cell deployment which leads to a lower total cost of ownership (TCO) for operators. It also allows adjustment of coverage areas as well as better mobility control which together decrease the triggering of handover events so as to improve QoS/QoE at the cell edge. Coordinated massive-element antennas assist ICI mitigation and CoMP and support inter-site CA. Furthermore, with massive-element antennas, multi user (MU)-MIMO techniques based on beamforming can be implemented in a straightforward manner for intra-cell capacity enhancement. Figure 3 depicts the advantages of MU-MIMO. In this figure, by using four beams which are orthogonal in the spatial domain, the cell capacity is increased up to four times compared to the conventional omni-antenna case. With more orthogonal beams the massive-element antenna can increase capacity even further.

To meet the challenges of 5G, NEC is developing a massive-element antenna for C-RAN based small cells.
Figure 2. Challenges in dense small cell deployment

Figure 3. Intra-cell capacity enhancement on MU-MIMO with massive-element antenna

Figure 4. Massive-element antenna deployment scenarios

deployed in various scenarios. Figure 4-A shows one massive-element antenna unit set on the wall of small room. This massive-element antenna unit could typically have 16 antenna elements with cross polarization. MU-MIMO technologies simultaneously accommodate multiple users while reducing interference, and beamforming technologies optimize 3D directionality based on user movements.

To enhance beamforming and multiplexing capabilities, several massive-element antenna units can be concatenated as one large scale massive-element antenna. Figure 4-B shows six massive-element antenna units arranged in a cylindrical fashion on a lamppost to support all horizontal directions. Figure 4-C shows four massive-element antenna units arranged into a square on the ceiling of conference room. Figure 4-D shows four massive-element antenna units formed into a line on the side of a bus or tram stop.

4. Massive-Element Antenna PoC Development and Evaluation

NEC has developed a massive-element antenna PoC demonstrator consisting of a RF front end and an antenna feed unit which support 64 antenna elements with dual cross polarizations operating at 5.2GHz [4][5]. This work was done in collaboration with NTT DOCOMO as part of a trial of 5G mobile communication technologies [6].

Figure 5 shows the massive-element antenna PoC. It consists of an 8x8 matrix of planar antenna elements with half-wavelength spacing (in orange color in Figure 5) and power amplifiers. Each antenna element
is configured with +/-45 cross polarization. In our demonstrator, up to eight orthogonal horizontal beams (A1 to A8) per polarization are generated by eight columns of eight antenna elements. At each column, a distinct phase shift is applied to the signal, which forms the desired beam shape and direction. The measured effective isotropic radiated power (EIRP) patterns of eight orthogonal beams in the horizontal plane are shown in Figure 6.

In Figure 7, we suppose that eight independent signal streams with equal power are transmitted through beams A1 to A8. The signal to interference ratio (SIR) of A1 is then calculated by treating A2-A8 as interference. The blue curve in the figure shows the theoretical SIR prediction results of beam A1 based on EIRP measurements while the red points indicate the measured SIR of A1. The maximum theoretical value of the SIR around 20dB appears at around -57 degrees, where the main lobe of beam A1 aligns with the nulls of the other beams. The measured SIR values are consistent with the theoretical predictions.

Further experiments evaluated the downlink user throughput performance when eight user signals are multiplexed on eight beams simultaneously. Eight independent 20MHz bandwidth LTE signal streams are generated and input to the eight orthogonal beams of the massive-element antenna at the transmitter. The experimental results showed that a maximum downlink throughput of 63.8Mbps was achieved on each beam.

5. Conclusion

NEC has demonstrated our concept of massive-element antenna deployment and virtualization of cells. This concept enables the exploitation of advanced spatial domain technologies in order to use radio spectrum and network processing resources in an efficient fashion. NEC’s massive-element antenna demonstration system has provided experimental results which prove the viability of enhanced beamforming. The massive element antenna architecture is a future-proof investment and will be a key component of 5th generation mobile networks.

References
[2] Network Evolution toward 2020 and Beyond, White Paper, NEC Corporation

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