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学 位 論 文 の 要 旨

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学位論文題目

Study on Energy-Efficiency Enhancement Techniques for 5G Cellular Networks

（英訳又は和訳　5G セルラネットワークにおけるエネルギー効率向上技術に関する研究　）

5G New Radio (NR) cellular network is expected to provide three major services including enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and massive Machine Type Communication (mMTC). eMBB applications aim to achieve extremely high data rates. URLLC supports low-latency transmissions of small payloads with very high reliability. Meanwhile, mMTC targets to support the connectivity of billions of Internet of Things (IoT) devices. Importantly, this thesis focuses on achieving eMBB and URLLC services from the viewpoint of system-level solution.

As the world adopts greener technologies and reduces energy waste, energy efficiency in wireless networks has become more important than ever. The 5G NR network is designed to improve energy efficiency, making research and network design a crucial component. 5G NR network is expected to meet the requirements for eMBB and URLLC. Several technologies are being integrated into 5G networks to meet the diverse needs of users. Such a complex network design will increase energy consumption. Consequently, energy efficiency becomes of the highest importance.

Considering that 5G NR cellular networks need to achieve eMBB services while ensuring seamless integration with all existing and emerging technologies, one of the most promising strategies for addressing these challenges involves the densification of base station (BS) deployments through the use of heterogeneous cellular networks (HetNets). HetNets consist of various tiers of base stations, which include both macro base stations (MBSs) and small base stations (SBSs). Typically, the SBS tier overlays on the MBS tier within HetNets. Consequently, the deployment of a HetNet, which combines MBSs and SBSs, can significantly improve the performance of 5G eMBB by increasing capacity, coverage, spectral efficiency, and overall user experience. Nevertheless, the dense implementation of SBSs within the MBS coverage results in a negative impact, such as an increase in energy consumption due to the inclusion of several SBSs, which can result in a decrease in energy efficiency on the network side. Therefore, various techniques for reducing energy consumption and enhancing energy efficiency in 5G NR cellular networks have been suggested. Despite the fact that these techniques can reduce energy consumption and improve energy efficiency, they may lead to a degradation in system throughput when compared to the no-sleep control system.

5G NR also provides URLLC services that satisfy the stringent latency and reliability requirements for one-way latency of 1 ms with 99.999% reliability. To satisfy URLLC requirements, grant-free (GF) transmissions with the *K*-repetition transmission (*K*-Rep) have been introduced. Due to its repeated operation,

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the *K*-Rep scheme significantly increases the number of packet transmissions. Consequently, an excessive increase in packet transmissions causes severe interference at the receiving BS, resulting in degraded reliability. Moreover, the increase in packet transmissions on the *K*-Rep scheme results in a significant increase in energy consumption, leading to the early depletion of the battery and a decrease in energy efficiency on the user equipment (UE) side.

To address the first problem, this thesis proposes an enhanced algorithm for SBS sleep control based on energy efficiency as a decision criterion for SBS operating state, with a primary focus on supporting eMBB services. Using energy efficiency as a decision criterion, the proposed sleep control algorithm aims to achieve a balance between reducing power consumption and maintaining system performance. The proposed algorithm employs a 2-phase control procedure, where the first phase selects tentative sleep SBSs based on their energy efficiency and the second phase activates additional SBSs from the sleep state to improve energy efficiency while maintaining system throughput. The results of computer simulation evaluation indicate that the proposed sleep control scheme can provide improved performance for both energy efficiency and system throughput simultaneously. In other words, it effectively enhances energy efficiency while maintaining practically the same system throughput as the no-sleep control system.

To overcome the second problem of severe interference and reduced energy efficiency on the UE side resulting from an increase in packet transmissions in GF URLLC, this thesis proposes two innovative adaptive *K*-Rep control schemes. These schemes employ site diversity reception with the primary objective of reducing the number of packet transmissions. The first of these adaptive *K*-Rep control schemes, presented as adaptive *K*-Rep control scheme I, assigns a different number of associated cells to each UE. Meanwhile, the second scheme, known as adaptive *K*-Rep control scheme II, assigns a constant number of associated cells for all UEs. In adaptive *K*-Rep control scheme I, the number of packet transmissions for each UE is dynamically adjusted based on the specific number of associated cells for all UEs, whereas in adaptive *K*-Rep control scheme II, the dynamic adjustment of packet transmissions based on the variation in the reference signal received power (RSRP) levels. The performance evaluation demonstrates that the proposed adaptive *K*-Rep control schemes significantly improve communication reliability and reduce transmission energy consumption compared with the conventional *K*-Rep scheme, thereby satisfying the URLLC requirements while reducing energy consumption and enhancing energy efficiency at the UE side.

From the numerous computer simulation results at the system level evaluation, it is confirmed that the proposed schemes present in this thesis can be employed as solutions to enhance energy efficiency for eMBB services at the network side and for URLLC services at the UE side within the context of a 5G NR cellular network.