Graduate School of Fundamental Science and Engineering
Waseda University

博　士　論　文　概　要
Doctoral Dissertation Synopsis

論　文　題　目
Dissertation Title

Study on Virtual Energy Borrowing Scheme Using D2D Communication in 5G Cellular System

５Gセルラシステムにおける D2D通信を用いた仮想電力貸借方式に関する研究

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Abstract

Currently, 5th generation (5G) is being commercially deployed and expanded, and several discussions exist beyond 5G. The main pillars of 5G services are enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable and low-latency communication (URLLC). These features enable its applications for various purposes and scenarios, such as 4 K videos, smart cities, and self-driving cars. These technologies allow users to enjoy convenient experience. In addition, 5G and beyond 5G is garnering attention and expectations owing to new services and innovative technologies. However, there are still several complaints about smartphones in current cellular network services. One of the significant challenges in next-generation communication is actively resolving the dissatisfaction among existing users. Among them, dissatisfaction with battery life is particularly high, and in the results of “The survey on smartphone satisfaction and dissatisfaction” (Media Marketing Data labo, 2015), over 70% of the users responded that "long-lasting batteries" was the feature they desired in future smartphones. In addition, a survey conducted in 2021 showed that approximately 30% of users felt that their batteries run down quickly after about six months of purchase (Mobile Market, Smartphone Fatigue Survey Questionnaire, 2021).

This result indicates that battery depletion has remained a problem in both the past and present. From the user's perspective, the battery life is important for 5G and beyond. As its use cases expand, we will see improvements in functionality and performance.

As mobile communication becomes more closely connected to our daily lives, the importance of the battery life of smartphones is likely to become crucial. Therefore, this thesis titled “Study on Virtual Energy Borrowing Scheme Using D2D Communication in 5G Cellular Systems” proposes a low-energy consumption

communication with Device-to-Device (D2D) communication for 5G and beyond 5G systems.

In this thesis, we attempt to improve user satisfaction for battery performance by using D2D communication to achieve low-power consumption.

Accordingly, Chapter 2 introduces the basics of D2D communication, such as protocols and communication schemes. Previous research has proposed D2D communication based on 3GPP specifications for cellular communication and Wi-Fi for D2D (Wi-Fi Direct, IEEE 802.11). We studied essential D2D communication by extending and combining the 3GPP communication model and the Wi-Fi communication method. In this chapter, we introduce the cooperative communication model and the basic mechanism combining cellular communication and D2D.

Chapter 3 presents an energy borrowing (EB) transmission scheme that is used to conserve the battery life of a UE, such as a mobile phone. EB is based on D2D communication and cellular networks, particularly out-band D2D and 5G networks. This study proposes an energy-borrowing transmission scheme using D2D communication over Wi-Fi direct that borrows and lends energy among cooperating UEs. This process extends the service operating time of the UEs with a small battery reserve. EB performance was examined via measurements and simulations. In addition, the energy consumption and data acquisition rates were measured using the LTE and D2D links. Their relationship was clarified according to the communication quality. Similarly, we analyzed the volume of data received during communication for each quality level of LTE and D2D from various perspectives, such as energy consumption, battery life, and battery depletion time. Furthermore, simulations based on these experimental results verified the increase in the service operating time provided by the EB scheme. In our performance evaluation, we verified that EB can extend the battery operation time longer than LTE without EB in a train cabin.

In Chapter 4, we propose an EB transmission scheme that further extends the scheme in the previous chapter, to consider the power burden and fairness of UEs that lend their own battery resources. The proposed system in Chapter 3 does not consider the fairness and burden of the lenders, and it is essential to focus on lenders, to improve the efficiency of the system. We propose a scheme with high fairness that reduces the burden on the UEs that lend their own battery resources compared to the existing scheme. This scheme selects the best UE from the neighboring UEs to avoid a heavy burden on the UEs that lease power. When the borrowing UE has multiple candidates for the lending UEs, the borrowing UE selects the most suitable UE by considering the remaining battery power of the other UE and parameters, such as the communication status of D2D and 5G. In this study, we measured the power consumption of the UE on the lending and borrowing sides, then simulated and evaluated the performance using the actual measurement results.

In Chapter 5, we conclude the paper and suggest possible future research directions. In this study, we proposed the concept of borrowing battery resources via communication and designed a scheme accordingly. In the future, various developments are expected, including a scheme that considers user behavior and an analysis of overall cellular system performance. In this chapter, we introduce these expectations for the future of this research.

List of research achievements for application of Doctor of Engineering, Waseda University

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Journal	○ **齋藤恵**, 仲沢隼斗, パン・ジェニー, 劉江, 嶋本薫 , "D2D通信を用いた電力貸借通信における電力負担を考慮した端末選択手法の研究" 日本シミュレーション学会和文論文誌 14巻1号 pp. 54-70, 2022.
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