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論　文　要　旨

With the remarkable proliferation of mobile devices (e.g., smartphones and portable tablets) embedded with various sensors, such as camera, GPS, digital compass, gyroscope, and thermometers, more and more devices are used for collecting message from surrounding environment, and then deliver the collected message (e.g., photos or videos of the points of interest) to the control center for further processing, which drive the development of a new research paradigm on data uploading. Data uploading, which can provide mission-critical messages collected by mobile devices, and then make quick responses during flooding, hurricanes, earthquakes, or other natural disasters, is regarded as a critical issue in cellular networks. Various applications have been proposed based on data uploading, including public safety, healthcare, disaster response, environment monitoring, and traffic management. In such applications, as the data collected by the devices is delay-sensitive, data uploading may be required to be performed within a specified time frame. In practice, however, little attention has been paid to latency-aware data uploading. As a consequence, for an efficient support of mobile applications, it is of great importance to design low-latency data uploading scheme in cellular networks.

Extensive research efforts have been devoted to data uploading in cellular networks. Most of them focused on traditional cellular networks with no cooperation, where the devices directly deliver their data to the cellular infrastructure. In these

works, to deliver data to the cellular infrastructure, the devices need to have uplink channels with good quality. That is to say, it is difficult for a device suffering from a poor quality uplink channel to directly deliver data to the cellular infrastructure. In light of this, device-to-device (D2D) communication among the devices is considered to be one promising solution to this limitation, where the devices in proximity can build D2D cooperation so that the device with poor quality uplink channel can select a device with good quality uplink channel to serve as a relay for data uploading. Our work focuses on the data uploading in D2D-enabled cellular networks.

The available studies on the data uploading in D2D-enabled cellular networks suffer from three major limitations. First, in these studies, D2D cooperation is only limited to devices with uploading data, while the devices without uploading data do not participate in D2D cooperation, which usually leads to a large data uploading latency. Second, these studies mainly consider cooperation scenario with full trust where cooperative devices have full trustworthy relationships with each other, which largely neglects the effect of human social relationships on the cooperation behaviors and may result in a low data uploading reliability. Third, these works lack of an incentive mechanism to stimulate devices to actively participate in the D2D cooperation, which may degrade the data uploading performances in terms of reliability and latency. To overcome the above limitations, this thesis investigates the low-latency data uploading in D2D-enabled cellular networks with the help of device cooperation, human social relationship and incentive mechanism.

Firstly, we propose a generalized cooperative data uploading scheme which considers D2D cooperation among both the devices with and without uploading data, so that the data uploading latency can be reduced. This scheme covers the conventional schemes where D2D cooperation is only limited to devices with uploading data as special cases. In this scheme, to motivate D2D cooperation among all available devices, we organize the devices within communication range by offering them rewards to construct multi-hop D2D chains for data uploading. Specifically, we formulate the problem of chain formation among the devices for data uploading as a coalitional game. Based on merge-and-split rules, we develop a coalition formation algorithm to obtain the solution for the formulated coalitional game with convergence on a stable coalitional structure. Extensive numerical results show the effectiveness of our proposed scheme in reducing the average data uploading latency.

Considering the data uploading reliability, we further investigate the impact of human social relationships on cooperative behaviors, where the nearby devices with mutual trust can build D2D cooperative relationships. To model D2D cooperation, a

coalition game is first developed, and then we devise a coalition formation algorithm to construct D2D chains by the bottom to top mode. Simulation results show that our proposed approach can effectively reduce the average data uploading latency compared with the state-of-the-art approaches under the real network scenario.

Under the social network scenario, an incentive mechanism is then proposed to motivate more devices to participate in D2D cooperation, such that data uploading latency can be reduced and data uploading reliability can be enhanced. With this incentive mechanism, the nearby devices can obtain rewards such that they are willing to construct a multi-hop D2D chain to assist the other devices in data uploading. To this end, we adopt coalitional game to formulate D2D chains with careful consideration of social-aware data uploading, where each device acts as a player and the individual reward is modeled as the utility function. We further design a coalition formation algorithm with merge-and-split rules to determine the solution for the proposed coalitional game. Extensive simulations are conducted to illustrate that the performance gain of our incentive mechanism outperforms that of non-incentive mechanism.

Finally, we summarize our contributions, which can provide the following insights. Firstly, the data uploading schemes developed in this thesis indicate that by carefully exploring the device cooperation, human social relationship and incentive mechanism, a low data uploading latency can be usually achieved while a high data uploading reliability is ensured. Then, the results obtained in this thesis provide an important guideline for designing low latency data uploading schemes in D2D-enabled cellular networks. Finally, we introduce our future works. In this thesis, we consider D2D cooperation among static devices, one interesting future direction is to further explore the impact of device mobility on cooperative behaviors. We study how to deliver data with high-reliability and low-latency, it will be an interesting direction to recruit devices to collect data while satisfying the coverage probability over the field of interest. We focus on cooperative D2D data uploading in 4G LTE cellular networks, it will be an interesting topic to exploit the cooperative D2D data uploading in 5G cellular networks.

審査結果の要旨

This thesis studies the low-latency data uploading in D2D-enabled cellular networks with the help of device cooperation, human social relationship and incentive mechanism. To reduce the data uploading latency, the thesis first proposes a generalized cooperative data uploading scheme, which

considers D2D cooperation among both the devices with uploading data and the devices without uploading data. The thesis further investigates the impact of human social relationships on cooperative behaviors, where the nearby devices with mutual trust can build D2D cooperative relationships, so that the data uploading reliability can be enhanced. Finally, under this social network scenario, an incentive mechanism is then proposed to motivate more devices to participate in the D2D cooperation, such that the data uploading latency can be reduced and data uploading reliability can be enhanced. All schemes were carefully validated with extensive simulation results. It is expected that the results obtained in this thesis can provide an important guideline for the designs of a low latency data uploading schemes in D2D-enabled cellular networks, and the data uploading schemes developed in this thesis can achieve a low data uploading latency while guaranteeing a high data uploading reliability.

・論文の構成

Chapter 1 Introduction
Chapter 2 Related Works
Chapter 3 Preliminaries
Chapter 4 Generalized Cooperative D2D Data Uploading
Chapter 5 Social-aware Cooperative D2D Data Uploading
Chapter 6 Social-aware Cooperative D2D Data Uploading with Incentive Mechanism
Chapter 7 Conclusion
Appendices A, B, C

・研究目的の妥当性，従来の手法との比較においての有意性，および理論・実験手法の新規性

This thesis studies the low-latency data uploading in D2D-enabled cellular networks with the help of device cooperation, human social relationship and incentive mechanism, which serves as a critical research issue for the future cellular networks.

The available studies on data uploading in D2D-enabled cellular networks suffer from three major limitations. First, D2D cooperation there is only limited to devices with uploading data, while the devices without uploading data do not join in the D2D cooperation, which usually leads to a large data uploading latency. Second, these studies mainly consider cooperation scenario with full trust where cooperative devices have full trustworthy relationships with each other, which largely neglects the effect of human social relationships on the cooperation behaviors and may result in a low data uploading reliability. Third, these works lack of an incentive mechanism to stimulate devices to actively participate in the D2D cooperation, which may degrade the data uploading performances in terms of reliability and latency.

To overcome the above limitations, this thesis first proposes a generalized cooperative data uploading scheme, which considers D2D cooperation among both the devices with uploading data and the devices without uploading data, so that the data uploading latency can be reduced. Considering the data uploading reliability, this thesis further investigates the impact of human social relationships on cooperative behaviors, where the nearby devices with mutual trust can build D2D cooperative relationships. Under this social network scenario, an incentive mechanism is then proposed to motivate more devices to participate in the D2D cooperation, such that the data uploading latency can be reduced and data uploading reliability can be enhanced.

・得られた知見のシステム情報科学の分野における意義

The results of this thesis provide the following insights.

1. The results obtained in this thesis provide an important guideline for the designs of low latency data uploading schemes in D2D-enabled cellular networks.

2. The data uploading schemes developed in this thesis indicate that by carefully exploring the device cooperation, human social relationship and incentive mechanism, a low data uploading latency can be usually achieved while a high data uploading reliability is ensured.