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論　文　要　旨

The mobile ad hoc networks (MANETs) are a class of infrastructure-less self-organizing networks consisting of mobile devices communicating with each other over peer-to-peer wireless links. Due to their distinctive feature of robustness, self-organization, quick deployment and reconfiguration, MANETs hold great promises for many important application scenarios, like disaster relief, battle field communications, and wide area sensing, and are thus increasingly becoming an indispensable component for the next generation (5G) networks. To efficiently support these critical applications with stringent performance requirements, it is of great importance to thoroughly understand the fundamental performance of such networks, like the delivery delay and throughput capacity.

This work focuses on the performance studies of an important class of MANETs with erasure coding and packet redundancy (*f*-cast), i.e., each coded packet at source node is transmitted to at most *f* distinct relay nodes. The erasure coding and packet redundancy are two promising techniques that have been extensively studied in the literature for improving the packet delivery performance in MANETs. On one hand, previous studies showed that erasure coding technique can considerably reduce the delay variance in MANETs, while it may lead to a relatively large packet delivery delay, since the early arrived coded packets in destination node have to wait a long time for the arrivals of other coded packets from distinct relay nodes. On the other hand, packet

redundancy technique can efficiently reduce the packet delivery delay due to the fact that multiple relays will carry redundant copies of a packet, increasing the chance of the packet being received by its destination; however, it usually incurs high variance of packet delivery delay. Thus, we consider a combination of erasure coding and packet redundancy in MANETs to have a flexible trade-off between packet delivery delay and delay variance.

We combine these two techniques together and study the packet delivery delay and throughput capacity in MANETs, under a general two-hop relay routing algorithm with unicast traffic pattern, i.e., a source node has only a destination node, which covers available routing algorithms with pure erasure coding or pure packet redundancy as special cases. To analyze the packet delivery delay, we propose a Markov chain model to depict the packet delivery process under this routing algorithm, with which we derive the analytical expressions for the mean value and variance of packet delivery delay. To analyze the throughput capacity, we propose two Markov chain models to depict the fastest packet distributing process and fastest packet receiving process at source and destination nodes, respectively, with which we derive the analytical expression for the throughput capacity. Extensive simulation and theoretical results are provided to validate the accuracy of our theoretical performance analysis as well as our findings.

Then, we study packet delivery delay of MANETs adopting a two-hop relay routing algorithm with packet redundancy, and multicast traffic pattern, where a source node has multiple destination nodes. To this end, we propose a Markov chain model to capture the packet delivery process under the routing algorithm, with which we derive the analytical expressions for the mean value and variance of packet delivery delay. Extensive simulations demonstrate the efficiency of our theoretical delay results.

審査結果の要旨

This thesis studied the fundamental packet delivery performance of an important class of mobile ad hoc networks (MANETs) with erasure coding and packet redundancy in terms of their delivery delay and throughput capacity. For MANETs with a generalized two-hop relay routing algorithm combining the erasure coding and *f*-cast packet redundancy techniques, the thesis first proposed a powerful Markov chain-based theoretical framework to analytically study their unicast delivery delay/throughput capacity and to explore the inherent tradeoff between these performance metrics. The thesis further extended packet delivery performance study to MANETs with multicast traffic pattern and *f*-cast relay, and employed the Markov chain-based theoretical analysis to derive the analytical expressions for multicast delivery delay there. All theoretical results were carefully validated with extensive simulation results. It is expected that the results developed in this thesis can

provide instruction guidelines for the design and optimization of future MANETs and can be helpful for packet delivery performance study in other MANET scenarios as well.

・論文の構成

Chapter 1 Introduction

Chapter 2 Related Work

Chapter 3 Preliminaries

Chapter 4 Unicast Delivery Delay Study for MANETs with Erasure Coding and *f* -cast Relay

Chapter 5 Throughput Capacity Study for MANETs with Erasure Coding and *f*-cast Relay

Chapter 6 Multicast Delivery Delay Study for MANETs with *f*-cast Relay

Chapter 7 Conclusion

・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 studied the fundamental performance of an important class of MANETs with erasure coding and *f*-cast packet redundancy in terms of their delivery delay and throughput capacity, both of which are critical performance metrics and serve as the instruction guideline for the design and optimization of future MANETs.

Available studies on unicast delivery delay/throughput capacity performances in MANETs mainly adopted erasure coding and packet redundancy techniques separately, so they might not be able to take the full advantages of these two techniques to provide a more flexible tradeoff between these performances. Different from these works, this thesis combines these two techniques together and establishes a complete theoretical framework based on the Markov chain theory to study the unicast delivery delay/throughput capacity in such a MANET and to demonstrate the flexible performance tradeoff there. It is expected such a study will significantly enhance the ability of future MANETs to support various applications with different performance requirements.

Available works on multicast delivery delay analysis in MANETs mainly explored the asymptotic bounds on the multicast delivery delay as network size scales, which tell us little about the real multicast delivery delay performance. Different from these works, this thesis conducts study on the exact multicast delivery delay of MANETs based on the Markov chain theory to explore the real achievable multicast delivery delay in MANETs.

・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 promising method of combining erasure coding and packet redundancy will provide a

flexible and strong performance guarantee for various unicast-intensive applications in future MANETs.

2. The exact multicast delivery delay study in this thesis will be helpful for supporting multicast applications in future MANETs with one-to-many communication pattern, like the information exchanges among a group of soldiers in battlefield communication, emergency communications among the rescuers in disaster relief, real-time monitoring, etc.
3. The novel theoretical frameworks developed in this thesis could provide precious insights for the study of delivery delay/throughput capacity performances in other MAENT scenarios as well.