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論　文　要　旨

Three-dimensional mobile ad hoc networks (3D MANETs) are a class of peer-to-peer networks, where nodes moving in three-dimensional space communicate with each other via wireless link without any pre-existing infrastructure and central management. As 3D MANETs can be easily deployed and flexibly reconfigured, they are used in many fields, such as (1) modern warfare, aircrafts in the sky, troops on the land, fleets on the sea, communicate with each other for cooperative combat, (2) ocean surveillance, underwater vehicles communicate with each other for data collection and transmission, (3) disaster monitoring, unmanned aerial vehicles communicate with each other for data collection and transmission.

However, there is still a long way to go before 3D MANETs could be widely commercialized and implemented. The very roadblock that has been stunting the application of 3D MANETs is the lack of a general network information theory, which is expected to establish a thorough understanding on the fundamental performances in such networks, like the delivery probability, delivery delay, throughput capacity, etc. The available works on this line mainly focus on two-dimensional network scenario, which cannot tell us about the fundamental performances in 3D MANETs. Towards such a target in 3D MANETs, we develop theoretical frameworks to analytically study the MANET delivery probability, delay and the throughput capacity performances in this thesis. Specifically, we focus on an important class of 3D MANETs—the two-hop relay 3D MANETs, i.e., the MANETs adopting the popular and efficient two-hop relay algorithms for packet routing.

Firstly, we study packet delivery probability in 3D MANETs. We develop a Markov chain theoretical framework to depict packet delivery process under two-hop relay algorithm with packet

redundancy. With the help of the theoretical framework, the analytical expression was derived for packet delivery probability. We further present extensive simulation and numerical results to validate our theoretical framework and to show our findings. We also attempt to simulate the packet delivery probability over the broadcast channel mode. When a node gets a transmission opportunity, it broadcasts the copies of the packet to the nodes which locate in the same cell or its 26 adjacent cells. The number of the broadcast is set to f for each packet. The simulation results show that the delivery probability of using broadcast is higher than using unicast. Although the simulation results show that the delivery probability performance under broadcast is better than that under unicast. This thesis does not adopt the broadcast traffic pattern. This is because under such a traffic pattern, the number of relay nodes carrying the packet is unknown, which makes it more difficult to develop a Markov chain to analytically study the packet delivery performance.

Secondly, we study the packet delivery delay performance in 3D MANETs. A Markov chain theoretical frame is developed to depict packet delivery process under two-hop relay algorithm with packet redundancy. Under the Markov chain theoretical
framework, the analytical expression was derived for mean packet delivery delay. Besides that, the corresponding relative standard deviation was further derived. We provide simulation results to validate the theoretical models on the packet delivery delay and corresponding relative standard deviation not only under independent and identically distributed (i.i.d.) mobility model, but also under the random walk and random waypoint mobility models. Extensive simulation and numerical results with different parameters are further provided to do performance analysis and show the packet delivery performance in 3D MANET is different from that in 2D MANET.

Thirdly, we study the throughput capacity in 3D MANETs. We first construct two absorbing Markov chain theoretical frameworks to depict the packet distributing process at source and the packet receiving process at destination. Based on these two Markov chain theoretical frameworks, an analytical expression for the throughput capacity is further derived. We provide extensive simulation and numerical results to validate our theoretical models and to show our findings.

Finally, we introduce our future works. In this thesis, we adopt unicast for packet dispatching, one interesting future direction is to further explore the performance of 3D MANETs under a more efficient packet dispatching way, e.g. broadcast. We developed Markov chain-based theoretical frameworks to explore packet delivery performance in cell-partitioned 3D MANETs, it will be an interesting direction to study how to evaluate the performance under our theoretical frameworks in other network scenarios, such as delay tolerant networks (DTNs) and ALOHA networks. We focus on two-hop relay 3D MANETs, another interesting direction is to further extend the developed theoretical models to analyze packet delivery performance in multi-hop relay 3D MANETs. It is also interesting to explore the network performance with the consideration of constraints of nodes buffer size and packet loss in our future research.

審 査 結 果 の 要 旨

This thesis studied the fundamental packet delivery performances of 3D Mobile Ad Hoc Networks (3D MANETs) in terms of the packet delivery probability, packet delivery delay and throughput capacity. For 3D MANETs based on a generalized two-hop relay routing algorithm with /-cast packet redundancy technique, the thesis proposed a powerful Markov chain-based theoretical framework to analytically study their packet delivery probability, packet delivery delay and throughput capacity and to explore the difference of these performance metrics between 3D MAENTs and 2D ones. 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 3D 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 Works

Chapter 3 Preliminaries

Chapter 4 Packet Delivery Probability Study in 3D MANETs

Chapter 5 Packet Delivery Delay Study in 3D MANETs

Chapter 6 Throughput Capacity Study in 3D MANETs

Chapter 7 Conclusion

Appendix A

・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

MANETs with /-cast packet redundancy in terms of their packet delivery probability, delivery delay and throughput capacity, which are critical performance metrics and serve as the instruction guideline for the design and optimization of future 3D MANETs. Available studies on packet delivery delay/throughput capacity performances in 3D MANETs mainly focus on deriving the asymptotic results in special ad hoc networks, where nodes are statically distributed in such networks. These asymptotic results only illustrate how the performances vary with network size, whereas they cannot reveal the really achievable performances of 3D MANETs. Moreover, the theoretical analysis in these available studies also cannot be straightforward extended to the scenario of highly dynamic 3D MANETs. Different from these studies, this thesis establishes a complete theoretical framework based on the Markov chain theory to study the really achievable packet delivery delay/throughput capacity performances in such 3D MANETs. It is expected that such a study will significantly enhance the ability of future 3D MANETs to support various applications with different quality of service (QoS) requirements. Available works on packet delivery probability study in MANETs mainly focus on two-dimensional network scenario. Different from these

works, this thesis conducts study on the packet delivery probability based on the Markov chain theory in 3D 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 fundamental performance study in this thesis will be helpful for supporting various applications in future 3D MANETs, like the information exchanges in battlefield communication, emergency communications among the rescuers in disaster relief, real-time monitoring, etc. 2. The novel theoretical frameworks developed in this thesis could also provide precious insights for the study of packet delivery probability, delivery delay and throughput capacity performances in other 3D MAENT scenarios as well.