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Efficient QoS-Oriented Routing in Wireless Multi-Hop Networks Based on Natural Computation

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Preface

Nature might provide the most direct inspiration of all by letting us build devices that effect direct information processing. Inspired from nature, researchers from all over the world are doing outstanding work in applying the mechanics in this field to other fields. In this circumstance, we have done some valuable work, which includes using natural methods or schemes to design robust and secure wireless multihop networks.

During the course of writing this book, many people have supported, instructed and helped me. This work would not appear without their generous help.

First and foremost, I am extremely grateful to my PhD advisor, Prof. Guangzeng Feng, for always being there with his encouraging words and guiding me through the course of this research work. His deep and broad knowledge in communications, his never-ending enthusiasm for new and interesting ideas, and his complete dedication to his research work have been, and will always be, an example and inspiration for me.

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In the course of my research, I have had the benefit of interacting with some friends in Nanjing University of Posts and Telecommunciations and I would like to thank Lingyun Jiang, Hongliang Fu, Meiyan Ju, Xuelan Zhou, Fayong Zhao, Guangwen Li, Ming Lu, Jie yang, and Kaiqi Zhou for their

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This book has only been possible due to the encouragement, support and love of my parents. Their strength and sacrifice has gone a long way in keeping me focused on my work, and withstanding the trials and tribulations of my research. Special thanks go to Mr. Bo Wang for his encouragement without which this work will not be possible.

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Abstract

Wireless multi-hop networks have emerged as a new information-transmission paradigm based on collaborative efforts of multiple self-organized mobile nodes. Without the support from any fixed infrastructure, this type of network provides an extremely flexible method for establishing communications in situations where geographical or terrestrial constraints demand totally distributed network system. While the inherent characteristics of a wireless multi-hop network make it useful for many applications, they also bring in a lot of research challenges. One of the important issues is QoS routing, since conventional routing protocols adopted for traditional networks are not directly applicable to wireless multi-hop networks.

QoS routing plays an important role for providing QoS in wireless multi-hop networks. The goals of QoS routing are in general twofold: selecting routes with satisfied QoS requirement(s), and achieving global efficiency in resource utilization while processing the possible congestion self-adaptively. QoS routing is critical to the development of any real application of wireless multi-hop networks.

Natural computation is a field of research that is concerned with both the use of biology as inspiration for solving computational problems and the use of the natural world itself to solve problems. Inspired from ant colony, annealing process and fisheye technology, we proposed some new algorithms to solve QoS routing problem in wireless multi-hop networks. This book is organized as follows:

1. Chapter 1 outlines the recent advances in natural computation. This area is amazing and important and novel methods and approaches are

constantly emerging.

2. Chapter 2 gives a profound overview on wireless multi-hop networks, especially on routing in wireless multi-hop networks.

3. A special wireless multi-hop networks have drawn much attention from academic and industrial societies. In Chapter 3, state-of-art data forwarding methods in opportunistic networks are profoundly reviewed. Opportunistic networks is one of the most exciting evolutions of the legacy Mobile Ad hoc Networking (MANET) paradigm, in which the assumption of complete paths between data senders and receivers is not required all the time. Opportunistic networks enable users communication in disconnected environments, in which island of connected devices appear, disappear, and reconfigure dynamically. As one key and principal problem in any networking, data forwarding and routing play an important role in improving network performance. As present routing protocols are mostly based on one primary assumption that end to end complete route should exist while data need to be transported between source-destination node pair, these protocols do not fit for opportunistic networks. New data forwarding and routing methods and protocols should be proposed for emerging opportunistic networks in order to meet the extensive pervasive networking need from the industry society. Furthermore, in the end of this Chapter, new directions and trends in this area that are worth being studied further are pointed out.

4. Ant based routing protocols for MANETs have been widely explored, but most of them are essentially of single-path which tend to have heavy burden on the hosts along the shortest path from source to destination. The robustness of these protocols is comparatively not good which is further weakened by the positive feedback mechanism of ant. Node-disjoint multi-path routing is more robust and can support QoS better than single-path routing in MANETs. In Chapter 4 we combine swarm intelligence and node-disjoint multi-path routing to solve the problem mentioned above. A novel approach named Ant colony based Multi-path Routing (AMR) is proposed. AMR establishes and utilizes multiple routes of node-disjoint paths to send data packets concurrently and adopts pheromone to disperse communication traffic, thus it can adapt to the dynamic changes of the network and support QoS better. The simulation results show that the proposed approach outperforms

other pertinent algorithms.

5. In Chapter 5, we present an ant colony based multi-path routing protocol—ALMR for ad hoc networks to solve the routing problem effectively. In conclusion, it has the following features: a) It is on-demand routing protocol. b) It establishes and utilizes multiple paths for data session, thus routing robustness which is very necessary in computer networks especially mobile ad hoc networks can be obtained. c) It adopts probability routing tactics using pheromone to disperse communication traffic. Therefore, the new scheme is assure to provide QoS guarantee and improves the performance of the network. Simulation results indicate that it is a very attractive approach for ad hoc network that need to provide QoS guarantee.

6. Searching for the feasible route that can satisfy more than one QoS parameters simultaneously in wireless mobile ad hoc networks is an NP complete problem. Existing methods proposed for wired networks cannot solve it effectively. In Chapter 6, a novel algorithm based on SA (SA_RA) is proposed. It performs well especially when MANETs is not very large in scale and is combinatorially stable and it has computation complexity of $O(kL_m t(n))$, which is proportional to the iteration degree k, the length of the longest Markov Chain L_m, and polynomial function of the problem scale $t(n)$, respectively. Therefore, SA _ RA is a very attractive approach for multi-constrained QoS routing in MANETs.

7. Searching for the optimal route that can satisfy more than one QoS parameters simultaneously in wireless mesh networks is an NP complete problem. Existing methods proposed for wired networks cannot be used directly under these circumstances. SA based method is a powerful stochastic optimization method in searching for global optimal solutions, but it is time-consuming. In Chapter 7, a novel multi-constrained routing method named MFA_RS using mean field annealing is proposed. Mean field annealing, which adopts saddle point approximation, uses a set of deterministic equations to replace the stochastic process in SA, thus it is more efficient than SA. Numeric results have shown that MFA_RS can find the comparable solutions more quickly than the SA based methods and it is a promising multi-constraints QoS routing algorithm for wireless mesh networks.

8. In Chapter 8, an enhanced FSR named CO-FSR was proposed. CO-

FSR synthetically considers the state of MAC and network layer synthetically, adopts cross-layer technology to balance network traffic while supporting QoS better and achieving better network performance. In CO-FSR, the node that has worse traffic load state will not be selected to forward data packets even though it is on the shortest (that is, the number of hops is the smallest) path between source-destination pair. Simulation results shows that CO-FSR can decrease average end-to-end delay and increase throughput especially when the network has more offered load. CO-FSR inherits the merit of FSR such as simple, efficient and scalable etc while taking into account cross-layer optimization. Thus CO-FSR proves to be a more efficient solution to the routing problem in large mobile ad hoc networks.

9. Service-oriented online social networks (SOSNs) are emerging ubiquitous platforms for numerous services where service consumers require the selection of trustworthy service providers who are unknown to them before invoking service with the help of other intermediate participants. Under this circumstance, evaluation of the trust level of the service provider along the social trust paths from the service consumer to the service provider is required and to this end, selection of the optimal social trust path (OSTP) that can yield the most trustworthy evaluation result is pre-requisite. While existing single-trust-value methods can provide good but simple information to service consumers, more trust information, such as social intimacy degree between participants and the role impact factor of intermediate participants, should be considered to represent the trust level of a service provider more comprehensively. When more trust information is considered, OSTP selection will become an NP-complete problem. In Chapter 9, we propose PIMCQA_OSTP, Path Integral Monte Carlo Quantum Annealing based OSTP selection algorithm for complex SOSNs. PIMCQA_OSTP serves as the very first quantum inspired OSTP selection algorithm in complex SOSNs. Due to that quantum mechanics works with wave functions that can sample different regions of phase space equally well, and quantum systems can tunnel through classically impenetrable potential barriers between energy valleys, PIMCQA_OSTP shows its outstanding search ability and outperform existing methods. Results of experiments on a real dataset of online social networks verify that PIMCQA_OSTP is a promising tool and is especially fit for complex SOSNs.

10. Trust system plays a more and more important role in giving nodes incentives to cooperate in packet forwarding especially for wireless ad hoc networks. However, most existing works in this field either lack rigorous analysis of cost of their methods or have analysis in unrealistic models, which will clearly damage their effectiveness in real applications. In Chapter 10, based on previous work we proposed FROST (FRiendship and Ordered Semirings based Trust system) for wireless ad hoc networks. FROST introduce notion of friendship to reduce the trust table size and overhead while building and maintaining the trust system in large scale networks. Moreover, FROST use a more effective decaying model to enable the trust system to be more adaptive to the changing environment. Rigorous analysis and in-depth simulation show FROST has a good performance and can quantitatively measure reputation and defend trust system against malicious attacks.

11. In online social networks, it is crucial for a service consumer to find the most trustworthy path to a target service provider from numerous social trust paths between them. The selection of the most trustworthy path (namely, optimal social trust path (OSTP)) with multiple end-to-end quality of trust (QoT) constraints has been proved to be NP-Complete. Heuristic algorithms with polynomial and pseudo-polynomial-time complexities are often used to deal with this challenging problem. However, existing solutions cannot guarantee the efficiency of searching, that is, they can hardly avoid obtaining partial optimal solutions during searching process. Quantum annealing uses delocalization and tunneling to avoid falling into local minima without sacrificing execution time. It has been proved a promising way to many optimization problems in recently published literatures. In Chapter 11, for the first time, QA based OSTP algorithm (QA_OSTP) is applied to the selection of the most trustworthy path. The experiment results show that QA based algorithm has better performance than its heuristic opponents do.

12. In wireless sensor networks (WSNs) it is crucial for a truster node to find the trustworthiest trustee node in order to securing and benefiting the whole networks. This requires the evaluation of the trustworthiness of the trustee node along a certain social trust path from the truster node to the trustee node. Between the trustee and truster nodes pair there may be many social trust paths in large scale WSNs. Research in trust in WSNs has focused

mainly on trust management which directly merges trust between two nodes and recommendation from third party node without difference. In Chapter 12, unlike previous work in this field, in order to reflect the real-world scenarios better, we regard them as two independent different Quality of Trust (QoT) attributes both of which follow different aggregation rules and conduct the optimal social trust path (OSTP) selection with these two end-to-end QoT constraints in large scale WSNs. It has been proved this challenging OSTP problem is NP-Complete. Heuristic algorithms with polynomial and pseudo-polynomial-time complexities are often used to deal with this challenging problem. However, existing solutions cannot guarantee the efficiency of searching, that is, they can hardly avoid obtaining partial optimal solutions during searching process. Quantum annealing uses delocalization and tunneling to avoid falling into local minima without sacrifying execution time. It has been proved to be a promising way to many optimization problems in recently published literatures. In this Chapter, for the first time, QA based OSTP selection algorithms (QA_OSTP) is applied to the extraction of the optimal social trust path in large scale WSNs. We conduct the experiments on the Enron email dataset platform and the experiment results show that QA based algorithms outperforms its heuristic opponents.

13. With increasing popularity of smartphone-based mobile social networks (SMSNs), it is important for a service consumer to find trustworthy service providers throughout the whole networks. For this purpose, finding the optimal social trust path (OSTP) subject to multiple influence factors constraints (such as trust, recommendation roles and social relationships) between the consumer and provider pair that yields the largest trust value is required. Unfortunately, there usually exist numerous social trust paths between the consumer and the provider and the multi-constrained OSTP (MOSTP) selection has been proved to be NP-Complete. Moreover, since smartphone is battery-powered and energy-constrained, the selection algorithms should be energy efficient to extend the network life as long as possible. Till now, few research works has been done in this area for this new type of social networks. In Chapter 13, for the first time, quantum annealing (QA) based MOSTP selection algorithms, QA_MOSTP is applied to MOSTP selection in SMSNs. QA uses delocalization and tunneling to avoid falling into

local minima without sacrificing execution time and energy. It has been proved to be a promising way to many optimization problems in recently published literatures. We demonstrate that QA_MOSTP has better performance than existing heuristic algorithms in terms of utility of the selected social trust path, execution time and energy consumption.

In Chapter 14 and 15, we concludes this book with a summary and future research directions.

目　录

Chapter 1　Advances in Natural Computation …… 1
1.1　Swarm intelligence …… 2
1.2　Simulated annealing …… 3
1.3　Mean field annealing …… 5
1.4　Quantum annealing …… 7

Chapter 2　Overview of Wireless Multi-hop Networks …… 10
2.1　Classification of wireless multi-hop networks …… 10
2.2　QoS Routing (QoSR) in wireless multi-hop networks …… 14
2.3　Online social networks—a special form of wireless multi-hop networks and related works …… 28

Chapter 3　Data Forwarding in Opportunistic Networks …… 35
3.1　Introduction of opportunistic networks …… 35
3.2　The retrogression of routing in opportunistic networks …… 36
3.3　Data forwarding in opportunistic networks …… 37
3.4　Conclusions …… 50

Chapter 4　Swarm Intelligence Based Node-disjoint Multi-path Routing Protocol for Mobile Ad Hoc Networks …… 55
4.1　Introduction …… 55
4.2　AMR description …… 56
4.3　Simulation and performance analysis …… 63
4.4　Conclusions …… 65

Chapter 5 Ant Colony Based Multi-path QoS Routing Protocol for MANETs ····· 68
5.1 Overview of ant based routing protocols in MANETs ····· 68
5.2 Outline of ALMR ····· 69
5.3 Protocol description ····· 69
5.4 Simulation and performance analysis ····· 76
5.5 Conclusions ····· 80

Chapter 6 Multi-constrained QoS Routing Based on Simulated Annealing in MANETs ····· 83
6.1 Introduction ····· 83
6.2 Related work ····· 85
6.3 Introduction to simulated annealing ····· 89
6.4 Scheme description ····· 91
6.5 Conclusions ····· 98

Chapter 7 Mean Field Annealing Based Multi-constraints Path Selection in Wireless Mesh Networks ····· 101
7.1 Introduction ····· 101
7.2 Related work ····· 102
7.3 Proposed algorithm ····· 103
7.4 Scheme description ····· 108
7.5 Performance evaluation ····· 110
7.6 Conclusions ····· 114

Chapter 8 CO-FSR: Cross-layer Optimized Fisheye State Routing for Ad Hoc Networks ····· 117
8.1 Introduction ····· 117
8.2 FSR and its drawback ····· 118
8.3 Enhancements regarding FSR ····· 121
8.4 Simulation and analysis ····· 122
8.5 Conclusions ····· 125

Chapter 9 Optimal Social Trust Path Selection: Toward Representing the Trust Level of Service Providers More Comprehensively ····· 127
9.1 Introduction ····· 127
9.2 Related works ····· 129
9.3 Formulation of the problem ····· 134
9.4 Algorithm description ····· 136
9.5 Experimental results ····· 144
9.6 Conclusions ····· 148

Chapter 10 Can Friendship Be Counted on for Securing Wireless Ad Hoc Networks? ····· 152
10.1 Introduction ····· 152
10.2 Related work ····· 153
10.3 Core design of novel trust system ····· 154
10.4 Process of merging trust semiring, decaying model and friendship model ····· 158
10.5 Attacks and analyses ····· 158
10.6 Performance analysis ····· 161
10.7 Conclusions ····· 165

Chapter 11 The Most Trustworthy Path Selection in Online Social Networks ····· 168
11.1 Introduction ····· 168
11.2 Related work ····· 169
11.3 Algorithm description ····· 172
11.4 Experimental results ····· 181
11.5 Conclusions ····· 184

Chapter 12 Trustworthiest Trustee Node Selection in Large Scale Wireless Sensor Networks ····· 188
12.1 Introduction ····· 188
12.2 Related works ····· 189
12.3 Algorithm description ····· 190
12.4 Experimental results ····· 196

12.5 Conclusions ····· 201

Chapter 13 Energy Efficient Multi-constrained Optimal Social Trust Path Selection in Smartphone-based Mobile Social Networks ····· 204

13.1 Introduction ····· 204

13.2 Related works ····· 206

13.3 Algorithm description ····· 210

13.4 Experimental results ····· 218

13.5 Conclusions ····· 223

Chapter 14 Concluding Remarks ····· 227

Chapter 15 Future Directions ····· 234

Chapter 1 Advances in Natural Computation

Natural computation (computation) is the study of large, complex, computational systems that use ideas and get inspiration from natural systems, including biological, ecological and physical systems. It is an emerging interdisciplinary area in which a range of techniques and methods are studied for dealing with large, complex, and dynamic problems.

From a computational view, natural computation is the process of applying ideas from nature to develop computational methods, or using natural materials (e. g. , molecules) to perform computation process.

Natural computation is a field of research that testimonies against the specialization of disciplines in science. It shows, with its three main areas of investigation, that knowledge from various fields of research are necessary for a better understanding of life, for the study and simulation of natural systems and processes, and for the proposal of novel computation paradigms. Physicists, chemists, engineers, biologists, computer scientists, among others, all have to act together or at least share ideas and knowledge in order to make Natural computation feasible.

Most of the issues natural computation deals with are based on highly simplified versions of the mechanisms and processes present in the corresponding natural phenomena. The reasons for such simplifications and abstractions are manifold. First of all, most simplifications are necessary to make the computation with a large number of entities tractable. Also, it can be advantageous to highlight the minimal features necessary to enable some particular aspects of a system to be reproduced and to observe some emergent properties. Which level is most appropriate for the investigation and