WIFI, WIMAX, AND LTE
MULTI-HOP MESH
NETWORKS
The Information and Communication Technology (ICT) book series focuses on creating useful connections between advanced communication theories, practical designs, and end-user applications in various next generation networks and broadband access systems, including fiber, cable, satellite, and wireless. The ICT book series examines the difficulties of applying various advanced communication technologies to practical systems such as WiFi, WiMax, B3G, etc., and considers how technologies are designed in conjunction with standards, theories, and applications.

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WiFi, WiMAX, and LTE Multi-hop Mesh Networks: Basic Communication Protocols and Application Areas
Hung-Yu Wei, Jarogniew Rykowski, and Sudhir Dixit
WIFI, WIMAX, AND LTE MULTI-HOP MESH NETWORKS

Basic Communication Protocols and Application Areas

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FOREWORD

Increasing complexity of communication networks is a growing challenge for network designers, network operators, and network users. This raises the question of how this increased complexity can be reasonably managed without adding even more complexity, while also reducing or completely eliminating the cost of network operations and management. Therefore, the self-organizing characteristic of networks, whether in access, metro, core, or end-to-end, is being hailed as the next holy grail of (and a potentially disruptive technology in) networking and communication. Imagine wireless nodes (an internet of people, things, devices, and services) being able to connect with each other autonomously and self-organize based on their battery power, bandwidth needs, security requirements, and billing costs, among other requirements, with or without an entity in control. Indeed, it is going to change the game by opening up lots of new possibilities both technologically and commercially. Wireless mesh networking (WMN) technology enables the wireless entities to connect autonomously and reconfigure in the face of changing radio environment. WMN is rapidly evolving and reaching the mainstream, made possible by several standards that have been developed, and vendors and service providers building to those standards. WMNs can range from mobile ad-hoc networks (MANETS) to infrastructure-based stationary networks and can even be multi-hop. The three predominant mesh technologies that have been standardized and deployed are IEEE WLAN (aka Wi-Fi), WiMAX, and LTE. From the commercial perspective, WMNs enable various business models, ranging from free to billable, depending on whether or not a service provider is involved.

This book provides an excellent overview of wireless mesh networks in a manner that is easy for a nonexpert to understand, yet technical to the extent that the reader can appreciate the why, what, and how of mesh networking and the strengths and weaknesses of the dominant mesh networking standards: Wi-Fi, WiMAX, and LTE. What is unique about this book is that the authors take a very logical top-down approach. They first spend a good deal of time defining/explaining the topic, such as describing the compelling application areas driving the need for mesh networking, then they describe the various technical challenges emanating from those potential use cases, followed by a detailed technical overview of the various types of wireless mesh networks, their evolution to support IEEE WLAN to 4G technologies of WiMAX and LTE and beyond 4G (such as the LTE-Advanced). Since understanding the
technologies alone is not sufficient to develop a complete system, the authors also discuss the architectural and deployment issues of WMNs in great detail. This is the first book of its kind that has been written in a style best suited to those who wish to get a broad overview of WMNs, while avoiding the mathematics, formulas, and deep technical details. I am glad to find that the authors have not hesitated to bring out the technical and business challenges that WMNs face, which open up new vistas to research. I have enjoyed reading the manuscript, and I am sure you will enjoy the book, too!

Prith Banerjee

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Notwithstanding its infancy, wireless mesh networking (WMN) is a hot and growing field. Wireless mesh networks began in the military, but have since become of great interest for commercial use in the last decade, both in local area networks and metropolitan area networks. The attractiveness of mesh networks comes from their ability to interconnect either mobile or fixed devices with radio interfaces, to share information dynamically, or simply to extend range through multi-hopping. This enables easy use and reliability through alternate connectivity paths between source and destination nodes. Mesh networks are of immense interest throughout the world, and there is no reason to believe that this trend will diminish, as we live in a world where wireless continues to increase in popularity in all kinds of devices and access networks. This is primarily due to the need for devices to connect wirelessly in the immediate neighborhood and users wanting connectivity from anywhere anytime, whether mobile or stationary. Furthermore, the vision of a hyperconnected world will certainly strengthen the importance of wireless mesh networks in the future. The trends in location- and context-based social networking, wireless content and service delivery, sensor networks, vehicle area networks, and enterprises going wireless and mobile will only boost the role of mesh networks in the future. In the early days of WMNs, there were indeed exaggerated claims about their capabilities and applicabilities to all types of scenarios, which are natural of any new technology going through the hype cycle; but recently, such networks are finding true applications when they are carefully designed and deployed for specific scenarios and use cases.

While the consumers, solution developers, and networking engineers are typically not interested in the intricate details of technology, they are certainly interested in issues they might end up dealing with and the solutions to those issues. Nonetheless, in networking today, some knowledge of technology is essential to arriving at the correct networking architecture and choosing the correct equipment and software; otherwise, the goal of attaining the desired performance may remain unfulfilled. In this book, we provide broad coverage of wireless mesh networks in a manner that is easy to understand, yet technical. The book is intended for those who wish to learn about mesh networking from a practical point of view, but feel intimidated by the deep technical details found in the standards documents and/or textbooks. We explain the motivation behind WMNs, their evolution from IEEE WLAN to WiMAX to long term evolution (LTE) and to LTE-Advanced, and what lies ahead in the future.
Throughout the book, we have kept the use of mathematics and formulas to a minimum, and wherever we have had to use them we have made sure that the equations are explained qualitatively and the flow of the material remains seamless. Wherever and whenever appropriate, we have given ample examples of user scenarios, deployable architectures, and real-world implementations using commercially available equipment.

It is impossible to cover in detail a broad topic such as WMN in a single book. Therefore, rather than cover every topic in detail, we have presented the key concepts, architectures, and dominant wireless technologies, as well as discussed the performance issues in general and some of the real-world implementations in more specific terms. The book is organized in seven independent parts to allow the reader to skip the parts with which he or she may already be familiar (Fig. P.1). The first chapter introduces the reader to the subject of mesh networking and describes the drivers behind this important technology.

![Figure P.1. Organization of the book.](image-url)
The second and third chapters address the architectural and business/economics aspects of mesh networking. These chapters also cover some key application areas of mesh networking. Chapter 4 briefly describes the application of mesh concepts to IEEE 802.11 (WiFi) Wireless LAN, where it all began and is probably the most researched and written about. Chapter 5 covers the topic of mesh networking in IEEE 802.16 (WiMAX) radio access networks. Chapter 6 presents mesh and relay networking in LTE and LTE-Advanced radio access networks standardized by the International Telecommunication Union. Both IEEE 802.16 and LTE/LTE-A wireless standards have been defined and positioned as 4G radio technologies. Finally, in Chapter 7, we summarize the book and discuss the future directions in wireless mesh networks.

We thank Dr. Russell Hsing of Telcordia, ICT Book Series Editor, John Wiley and Sons, and Dr. Simone Taylor of John Wiley and Sons for their patience with us (with several missed deadlines) while we worked on the manuscript. Finally, we have made every attempt to be accurate and factual in the book, but it would be surprising if there were no errors, which would be solely ours. Please send any questions, comments, or corrections directly to us.

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