Preface

As children, many of us were glued to the science fiction stories in comic books or television shows. Arguably, computer-generated imagery (CGI) in the recent sci-fi shows or movies have improved hugely as compared to the 1980s. Along with that, in the last few decades, sensing and computing technologies have progressed by leaps and bounds. Today, we have sensors around us almost everywhere—be inside a car, in our house, or pretty much anywhere else. Computing devices, on the other hand, are getting smaller and smaller in size. Those awesome gadgets, such as smart watches and smart glasses, from the sci-fi stories are no more just elements of fantasy, but are reality now! In other words, the terms "pervasive computing," "ubiquitous computing," and "wearable computers" were perhaps never more justified as they are today.

Together with advances in computing technologies, the need for communication among the devices, especially in wireless mode, is also rising. Our familiar Internet model has worked great so far. But what if some of the fundamental assumptions of the Internet model do not hold true? Moreover, when would such situations arise? And most importantly, would we still be able to communicate in such scenarios? The Delay-Tolerant Networking (DTN) architecture was proposed in the last decade to mitigate such situations where communication based on the Internet model fail. Ever since its inception, Delay-Tolerant Networks (DTNs) and its variants, such as Opportunistic Mobile Networks (OMNs), have hogged the limelight in the relevant research community to a large extent. In this book, we would talk about some of the fundamental aspects of DTNs and OMNs, their various applications, and breakthroughs made in this domain in the recent years.

Why Another Book on OMNs?

About 2 years back, we began toying with the idea of writing a book on OMNs. Our motivation and objective were rather simple. We wanted to bring the latest developments in OMNs to the readers in a concise manner. For example, as we

shall see in the second part of this book, in contrast to the previously existing network communication models, human beings and their behaviors (such as movement patterns) are being increasingly intertwined with OMNs and related areas. Moreover, while cooperation in OMNs is a well-studied subject, we would observe in Part III of the book that an OMN by itself may move to equilibrium even in the absence of any incentive. In general, we wanted to talk about two specific topics—human aspects together with networking, and emerging forms of cooperation—among others in the context of OMNs.

However, we did not want to come up with yet another "reference book" on this subject. On one hand, our aim was not to make the treatment too shallow so that the reader misses the big picture. On the other hand, it should not be so much detailed that a novice reader shies away. Thus, in a way, this book is a quest for such a "just approach." Moreover, a narrow focus only on OMNs may not be a well-justified approach. There are various other closely related areas (for example, participatory sensing) that have emerged almost concurrently with OMNs. Much like one should be familiar with current affairs, it is desirable that a reader is equipped with such cross-disciplinary knowledge, which can lead toward further evolution and novel applications of OMNs. Furthermore, since network simulation is a quintessential tool for students and researchers alike, we wanted to have a specific focus on this aspect alongside the main matter. The present book, *Opportunistic Mobile Networks: Advances and Applications*, is a humble outcome of the above detailed thought process.

How to Use This Book?

This book can be used in different ways for different purposes.

As a Textbook

This can be used as a textbook for an introductory course on OMNs or an advanced course on communication networks that include DTNs/OMNs. Part I of the book is especially suitable for this purpose. Other parts of the book can be used to complement a similar course on OMNs with intermediate depth. This includes, but not limited to, post-disaster mobility and communication models, and heterogeneous networks. The remainder of the book would be suitable for a little advanced study. Although this is not supposed to be a book on Psychology, readers from that domain hoping to device online mechanisms for emotion detection might find a portion of this book interesting. In fact, the relevant bibliography would point to further resources in that area. Moreover, as we shall discuss below, this book is organized in a manner that both teachers and students would find it useful.

As a Reference Book

This book covers topics on some of the recent advances in OMNs as well as wireless sensor and ad hoc networks. Parts II–IV, in particular, are crafted to increase the appetite of a curious researcher. We hope that the huge volume of references presented herein would act as pointers for further advanced studies. In fact, several chapters of this book include discussions on some advanced topics, such as graph-based representation of DTNs, network equilibrium of cooperative and exploitative strategies, heterogeneous routing, and effects of emotions on communications. We hope that a reader with research mindset would find such content useful.

Who Is This Book For?

This book is intended to cater to the taste of a diverse audience including students, instructors, researchers, and practitioners. In general, this book is for anyone who wishes to learn about the recent advances in OMNs from a theoretical, as well as practical, point of view.

For Students

This book has been written with special care for the students. In particular, they would find Part I of this book particularly useful, where we present the general characteristics of OMNs, a detailed overview of contemporary routing protocols, and a chapter on simulating OMNs. Once comfortable, we encourage them to explore the remainder of this book. We have presented ample *illustrations* in this book to clearly convey the concerned ideas. Moreover, we have been careful to present relevant *examples* inside the chapters wherever appropriate. Such examples are a mean to better illustrate the underlying concepts. At the end of each chapter, there is a list of *review terms*. Much like the flash cards, we hope that these review terms would be helpful to quickly recollect the key concepts. Of course, there are *exercises* at the end of the chapters. Additionally, there are also accompanying *programming exercises* working on which would help in mastering the different techniques of network simulation.

Although we have tried to keep the language and flow of this book as simple as possible (but no more simpler, as Einstein once suggested), a previous exposure on the following topics would be helpful:

- Familiarity with wireless networks and basic concepts of mobile ad hoc networks.
- Familiarity with Java for working on the programming exercises.

For Instructors

Instructors would find this book useful to teach both undergraduate and post-graduate students. The book can be used to teach a course specifically on OMNs or as a part of a broader networking course covering OMNs. Part I of this book presents introductory concepts, which would be useful for the first-time students of this subject. The remaining parts of the book deal with slightly advanced topics that can be taught subsequently. Several examples and exercises are included in this book together with number of numerical problems that would be helpful for examination and evaluation purpose.

For Researchers

Researchers working in the domain of OMNs or other related areas would find this book a useful companion. This book not only present an exposure of a spectrum of contemporary research areas, but also discuss some of the specific problems in greater depth. Moreover, the book has a little cross-disciplinary flavor where we discuss certain aspects from artificial intelligence and psychology. A researcher might find those topics interesting. Moreover, this book contains around 300 bibliographic references to the current literature, which one might find useful.

For Practitioners

We hope that to a certain extent at least this book would be useful to practitioners. In particular, the final chapter of this book presents a tour of the existing technical specifications (requests for comments or RFCs) related to OMNs. The latter are essential if one wishes to develop real-life applications. Moreover, we also survey a sample of existing patents, which could be useful and motivating for future innovative ideas.

Organization of This Book

This book is divided into four parts as discussed below:

Part I: Introduction

The first part of this book presents a general introduction on the subject matter. Chapter 1 looks back at the origins of DTNs and its subsequent evolution over time giving rise to OMNs, Pocket Switched Networks (PSNs), and Mission-Oriented Opportunistic Networks (MOONs). The characteristics of DTNs are contrasted with existing conventional networks. This chapter, subsequently, presents a flavor of different research areas in DTNs. However, this is rather the tip of the iceberg, and some of these topics are discussed in greater depth in the remainder of this book.

Chapter 2 presents an overview of the contemporary routing protocols for DTNs and OMNs. This chapter also introduces the different performance evaluation metrics, which are essential to measure the performance efficiency of any networking scenario. Based on these metrics, some general insights into the broad class of routing protocols are provided. This chapter also presents a discussion on real-life traces that are increasingly being used in network simulations. Finally, this chapter concludes with a review of some of the existing applications of DTNs.

A quick introduction to the Opportunistic Network Environment (ONE) simulator is presented in Chap. 3. Specifically, this chapter guides the reader on setting up a simulation project using NetBeans and use it for application debugging. Subsequently, it describes how real-life traces can be incorporated into simulations. A key highlight of this chapter is a detailed discussion on development of a new routing protocol. We present a simple example with detailed code walk-through and insightful instructions. This chapter also introduces the reader to version controlling, which is essential in any real-life software development. In particular, basic usage of Git, a well-known distributed version control software, is discussed here. The latter portion of this chapter discusses unit testing of the protocols developed with the network simulator, and some of the best practices that one can follow while performing simulations.

Part II: Human Aspects in Opportunistic Mobile Networks

The second part of this book deals with an interesting topic—human aspects in the content of communication networks. Chapter 4 presents a quick tour of different forms of wireless sensor networks that have evolved in the recent past. Subsequently, their applications in disaster monitoring is discussed. In this context, we also discuss about some of the popular mobility models, as well as mechanisms of communication, in the aftermath of disasters. This chapter, then, presents an overview of agent-based systems, their applications, and typical representations of intelligence. This chapter concludes with a discussion of the effects of intelligence-induced mobility in a MOON formed in a post-disaster scenario.

Continuing the same thread, Chap. 5 deals with another fundamental aspect of human beings—emotion. This chapter begins with an overview of different theories

and computational models of human emotions that has been proposed in Psychology and related domains. Next, different contemporary techniques of emotion detection and their applications are discussed. Various innovative techniques for quantifying emotions, for example, using smartphones and social media, are discussed. This chapter, and the second part of this book, concludes with a discussion on the effects of emotions on communication aspects in MOONs by considering a previously described computational model of emotion.

Part III: Cooperation in Opportunistic Mobile Networks

In distributed networks, communication involves more than a source node creating a message and a destination node receiving it. The intermediate nodes in such networks play a crucial role in relaying messages from one to another along a potential shortest path. It is, therefore, of utmost importance that the nodes cooperate among themselves for efficient operations. The third part of this book addresses these issues.

Chapter 6 introduces the reader to classical and evolutionary game theory. Game theory has been successfully used to define a collective set of strategies among a group of rationally behaving nodes. Subsequently, its application to different types of networks is presented. In particular, this chapter discusses about a particular type of game known as the Rock-Scissors-Paper (RSP) game. In the latter portion of this chapter, a set of strategies for cooperation (or lack thereof) among the nodes based on the RSP game are discussed. Mathematical representation of the game formulation is presented. This chapter concludes with an analysis of the cooperative strategies and a discussion on their relationship with one another.

Chapter 7 discusses several schemes of internode cooperation proposed for DTNs/OMNs. In particular, we look at different approaches for inducing cooperation based on incentives, which involve providing credits to (or updating reputation scores) of nodes in an OMN depending upon their message replication behaviors. Subsequently, we also look at a few game theoretic schemes for cooperation. Additionally, some of the approaches that do not fall in either of the previous two categories are explored. The latter portion of this chapter presents a detailed discussion on DISCUSS, a distributed cooperation enforcement scheme for OMNs. This is followed by an in-depth look at its operation together with its theoretical characterization. Finally, this chapter closes with a quick study of feasibility and efficiency of DISCUSS in practice.

Part IV: Advanced Topics

The final part of this book deals with relatively advanced topics. In contrast to the remainder of the book, where network homogeneity was assumed, Chap. 8 presents a detailed discussion on the origins of heterogeneity in a network and its impacts. Subsequently, aspects of heterogeneity that are seen in the context of DTNs are discussed. In particular, heterogeneity arising due to diverse contact patterns among the nodes is also considered. This chapter then describes different ways of representing a DTN with a graph—a typical approach in computer networks. However, unlike the traditional graph theoretic approaches, DTNs require a special treatment. Using the concept of time-varying graphs, the notion of communication index is presented in this chapter. Finally, different ways of mitigating the adverse effects of heterogeneity are discussed here.

Chapter 9 presents a comprehensive look at the current reality of OMNs. In particular, it looks at a sample of quantified volume of research efforts on DTNs/OMNs in the recent years. This is followed by a discussion on RFCs, their categories, and overview of some of the RFCs related to our area of interest. A review of a sample of related inventions and corresponding patents is also presented. This chapter then outlines some of the promising avenues and directions along which OMNs can evolve in the future. This chapter ends with a discussion on a set of prospective projective topics that an interested reader can undertake.

Finally, Chap. 10 concludes the book. Throughout this book, several topics related to OMNs and closely allied areas are discussed. This final chapter presents all such discussions in perspective and looks at the big picture emerging out of it.

Organization of the Chapters

The chapters in this book are organized in the following way. A chapter begins with a general *introduction* on the larger set of topics to be discussed in the remainder. This introduction also presents an overview of the organization of the corresponding chapter. Subsequently, concerned subject matters are discussed. In general, the chapters in Parts II and III usually begin with simple aspects; deeper analysis of related problems are presented in the latter sections. Toward the end, we present *summary* of the chapters where the previous discussions are put in context. Followed by this, a set of *review terms* are presented, which curates the key terminologies used in a chapter. Next, a set of *exercises* are presented. We present here both numerical as well as descriptive type of problems, which should be useful to evaluate one's learning. Finally, a chapter ends with a set of *programming exercises*, where we list a variety of problems to be solved using the ONE simulator. We very much encourage the reader to attempt these problems, especially if he/she is a beginner to network simulations.

Conventions Used in This Book

The following convention is used in this book. Mathematical notations are displayed in slightly italicized text, for example, $S = (l, \theta, \Delta t_f, \Delta t_p)$. Vectors are denoted with bold faces, for example, **e**.

File names or other strings are displayed in fixed width teletype fonts, for example, `File > New Project`. Directories are indicated with a front-slash at the end of their names, such as `test/`. Commands, class names, and other (inline) code inside the text are displayed in small fixed width teletype fonts such as `StationaryMovement`. Source code listings are displayed inside the boxes with line numbers shown outside, for example:

Listing 1: The getMessagesWithCopiesLeft() method

```
115 protected List<Message> getMessagesWithCopiesLeft() {
116    List<Message> list = new ArrayList<Message>();
117
118    for (Message m : getMessageCollection()) {
119       Integer nrofCopies = ↩
              (Integer)m.getProperty(MSG_COUNT_PROPERTY);
120       assert nrofCopies != null : "SnW message " + m + " didn't ↩
              have " +
121          "nrof copies property!";
122       if (nrofCopies > 1) {
123          list.add(m);
124       }
125    }
126
127    return list;
128 }
```

In listing of Java codes, the keywords are displayed in blue and string constants in purple, whereas class and method names are depicted with bold faces. In some cases, the line numbers are omitted if not relevant, for example, while displaying the contents of the simulation settings files as shown below:

```
Scenario.simulateConnections = true

## Movement model settings
# KAIST movement trace
Group.movementModel = ExternalMovement
ExternalMovement.file = my_scenarios/KAIST_92n_movement_trace.txt
```

Additionally, listing of commands executed in a terminal, and their output, are also shown inside a box without line numbers. The terminal prompt is indicated with a $ symbol, as shown below.

```
$ git commit -m "Adding source files"
$
```

Buttons (in software screens) are shown in an oval box with the text inside, for example, Next. Note that images and code snippets are available in color in the electronic version of the book. Insights or additional information on the concerned topics are presented inside a gray box as shown below.

> Due to intermittent connectivity, contemporary global information about the OMNs is often not available to the nodes. Therefore, while routing, a node typically attempts to make an optimal message forwarding decision based on locally available information.

Supplementary Resources

This book comes with the following supplementary resources:

- **Solutions Manual**: This contains solutions to most of the exercises provided at the end of each chapter.
- **Source Code**: Solutions to selected programming exercises are presented in this book, which are to be used together with the ONE simulator.

The solutions manual can be obtained from website of the publisher, Springer. Readers can access the following GitHub repository to download the above-mentioned source code: https://github.com/barun-saha/one-simulator

http://www.springer.com/978-3-319-29029-4

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