# OPNET IoT Simulation

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華中科技大學出版社
Huazhong University of Science and Technology Press

Springer

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ISBN 978-981-32-9169-0 ISBN 978-981-32-9170-6 (eBook)
https://doi.org/10.1007/978-981-32-9170-6

Jointly published with Huazhong University of Science and Technology Press
The print edition is not for sale in China. Customers from China please order the print book from: Huazhong University of Science and Technology Press.



This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

# Foreword

The Internet of Things (IoT) is a revolutionary development of the information industry following computers, the Internet, and mobile communications. The long and diverse IoT industrial chain reaches into almost all walks of life. In recent years, huge market demand has driven rare development opportunities and created space for broad applications of the IoT. Although some successful demonstration applications have emerged, many technical challenges still need to be solved. Before the large-scale deployment of the IoT, the relevant theories and algorithms must be evaluated and verified, requiring a professional the IoT simulation platform.

The authors have compiled many years of research into this book. As a reference for *OPNET IoT Simulation*, this book is divided into 11 chapters covering basic knowledge of the IoT and multiple OPNET simulation models. This book not only introduces the classic algorithms, but also includes the authors' latest research work. The main topics are the basic network routing algorithms, green Internet of Things, smart Internet of Things, broadband Internet of Things, semi-physical simulations, narrowband Internet of Things, and wireless network caching. In addition, the models introduced are accompanied by source code which can be downloaded and freely used by IoT researchers. In summary, this book is innovative and significant.

November 2018

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# Preface

The rapid development of wireless communications, embedded systems, micro-electro-mechanical systems, and super-large-scale integration makes the design, development, and realization of new "microminiaturized," "intelligentized," and "networked" sensors possible. This lays the foundation for an Internet of Things (IoT) era. In combination with the development of cloud computing, big data, and new generation communication and network technologies, the continuous evolution of the IoT will greatly influence every aspect of people's lives in the near future.

The IoT evolves on the basis of sensor networks, extending to core networks to realize more intelligent applications. Thus, the sensor network is the foundation or key element. In recent years, the IoT has developed rapidly and some exemplary applications have been realized. Nevertheless, there are some technical problems still to be solved by researchers. With increasing amounts of terminal equipment, it is extremely difficult to deploy large-scale sensor networks for practical applications over the long term. In many cases, researchers have the ability to deploy real sensor node networks. However, the quantity of useable nodes is small and has a limited battery life, which cannot be brought into full play in long-lived, large-scale sensor networks. Therefore, it is difficult to check the required algorithms and protocols in real environments. Before deploying IoT applications at the large scale, the relevant theories and algorithms must be assessed and verified.

To address this problem, network simulation has become a vital component of IoT development. It resolves many difficulties for researchers building large-scale sensor networks with their associated high deployment requirements and costs. To meet the challenges of mass deployment, a large-scale sensor network simulation platform is urgently needed.

The IoT encompasses many complex network and communication systems. Thus, the OPNET Modeler, a network simulation software, is an excellent choice. Almost all of the latest network communication protocols can be realized in simulation models using OPNET. Beyond the standard protocols and algorithms, the construction of the enormous simulation systems appropriate for large-scale sensor networks is difficult. To aid researchers overcome this difficulty, the OPNET

Modeler-based IoT simulation model source code, *IOT_Simulation*, developed by the authors, is offered for researchers to download, study, and use.

This book covers various aspects of the IoT, including human-centric IoT, green IoT, narrowband IoT, smart IoT, and semi-physical simulation. IoT simulations and cloud computing are seamlessly connected with each other allowing "IoT–cloud integration" and various smart IoT applications to be realized. This book provides a comprehensive tutorial for IT enterprise staff and informatics/communications researchers to personalize their network applications, as well as being a valuable textbook for undergraduate and postgraduate students.

This book contains eleven chapters. Chapter 1 describes the development, history, and evolution of the IoT and its integration with the new technologies of mobile Internet, cloud computing, big data, software-defined networks, and 5G. In addition, the necessity for IoT simulations is presented. Chapter 2 introduces basic OPNET simulation knowledge, including common functions and a rudimentary packet switch process. Chapter 3 introduces the basic IoT simulation model using OPNET. The network, node, result collection, energy, and animation models are built in this chapter. Chapter 3 is the core of this book, and the subsequent chapters are mostly based on the models described in this chapter. Chapter 4 introduces OPNET model debugging. Problems which may be encountered by readers and their corresponding solutions are elucidated. Chapter 5 contains the implementation and simulation of algorithms for geographical routing, mobile multimedia geographical routing, directed diffusion routing, and Zigbee network layer routing. Chapter 6 introduces green IoT simulation and presents two cooperative communication models, REER, and KCN. Chapter 7 presents smart IoT simulation and mobile agents. Chapter 8 introduces broadband IoT technology and describes multi-path routing and the IoT backbone model. Chapter 9 contains wireless semi-physical simulation. Chapter 10 covers the development, construction, and examples of narrowband cellular network simulation. Chapter 11 introduces model building, structure, and analysis for wireless network caching simulation.

The contents of the book are collated from the authors' research over several years. During its compilation, the work and publications of many experts and scholars from the relevant technical literature have been used and referenced. Our sincere and deepest thanks are extended to them.

Due to the limitations of our knowledge, there may be flaws and errors in the book. Your suggestions and comments would be appreciated.

Wuhan, China — Min Chen
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Ljubljana, Slovenia — Iztok Humar

**Acknowledgements** Prof. Chen would like to acknowledge the source code and courseware support from the Embedded and Pervasive Computing (EPIC) Lab, School of Computer Science and Technology, Huazhong, and University of Science and Technology, Wuhan, China (https://www.aiwac.net/epic/OPNET/opnet.htm).

Dr. Humar would like to acknowledge the financial support from the Slovenian Research Agency (research core funding No. P2-0246—Algorithms and optimization procedures in telecommunications).

# Contents

# Abbreviations

| | |
|---|---|
| 1G-RFID-Sys | First-generation RFID systems |
| 3GPP | 3rd Generation Partnership Project |
| 5G | Fifth generation of mobile communication |
| AC | Access class |
| ACB | Access class barring |
| ACK | Acknowledgment |
| AIWAC | Affective interaction through wearable computing and cloud |
| AODV | Ad hoc On-Demand Distance Vector |
| AP | Access point |
| API | Application programming interface |
| APS | Application support sub-layer |
| BAN | Body area network |
| BCC | Body channel communication |
| BI | Beacon interval |
| BO | Beacon order |
| BPF | Berkeley Packet Filter |
| BSN | Body sensor network |
| BST-MIP | Balanced minimum spanning tree multi-agent itinerary planning |
| CAP | Contention access period |
| CBA | Commercial building automation |
| CC | Cooperative caching |
| CCN | Content-centric networking |
| CDB | Choose data broadcast |
| CFP | Contention free period |
| C-MBAN | Cloud-assisted medical body area network |
| CN | Cooperative node |
| CP | Cyclic prefix |
| CPS | Cyber-physical system |
| CS | Contents cache/content store |
| CSMA/CA | Carrier-sense multiple access/collision avoidance |

| | |
|---|---|
| D2D | Device to device |
| datapk | Data packet |
| DBN | Data broadcast node |
| DCF | Device configuration file |
| DD | Directional diffusion |
| DDoS | Distributed denial of service |
| DGR | Directional geographical routing |
| DREAM | Distance Routing Effect Algorithm for Mobility |
| DSDV | Destination-Sequenced Distance Vector |
| DSR | Dynamic Source Routing |
| DSSS | Direct-sequence spread spectrum |
| DTN | Delay-tolerant network |
| EAB | Extended access barring |
| ECG | Electrocardiography |
| EEG | Electroencephalography |
| EMA | External model access |
| EMG | Electromyography |
| eNodeB | Evolved Node B |
| EPC | Evolved packet core |
| EPCDS | EPC discovery service |
| EPCIS | EPC information service |
| ETE | End to end |
| FB | Function block |
| FEC | Forward error correction |
| FFD | Full-function devices |
| FIB | Forwarding information base |
| FIFO | First input first output |
| FSM | Finite-state machine |
| FTP | File Transfer Protocol |
| GA | Genetic algorithm |
| GA-MIP | Genetic multi-agent itinerary planning |
| GCF | Global closest first |
| GLS | Guided local search |
| GPS | Global Positioning System |
| GPSR | Greedy perimeter stateless routing |
| GPSR_E | Energy-based greedy perimeter stateless routing |
| HA | Home automation |
| HB | Header block |
| HMRP | Hybrid MANET Routing Protocol |
| HP | Hewlett-Packard |
| H-SPREAD | Hybrid multi-path scheme for secure and reliable data collection |
| ICI | Interface control information |
| ICT | Information and communication technology |
| IDC | International Data Corporation |
| IEEE | International Institute of Electrical and Electronics Engineering |

| | |
|---|---|
| IEMA | Itinerary energy minimum algorithm |
| IEMF | Itinerary energy minimum for first-source-selection |
| IETF | Internet Engineering Task Force |
| IFS | Inter-frame space |
| intpk | Interest packet |
| IoT | Internet of Things |
| IP | Internet Protocol |
| ISM | Industrial, Scientific, and Medical |
| KCN | K-cooperative nodes |
| KP | Kernel procedure |
| LAN | Local area network |
| LAR | Location-aided routing |
| LBS | Location-based service |
| LCF | Local closest first |
| LEACH | Low-Energy Adaptive Clustering Hierarchy |
| LFU | Least frequently used |
| LPWA | Low-power wide area |
| LRU | Least recently used |
| LTE | Long-Term Evolution |
| M2M | Machine to machine |
| MA | Mobile agent |
| MAC | Medium access control |
| MADD | Mobile agent-based directed diffusion |
| MBAN | Medical body area network |
| MBS | Macrocell base station |
| MCS | Modulation and coding scheme |
| MEMS | Micro-electro-mechanical systems |
| MGR | Multimedia geographic routing |
| MIB-NB | Master information block-narrow band |
| MIMO | Multiple input multiple output |
| MIP | Multi-agent itinerary planning |
| MMN | Mobile multimedia sensor node |
| MMR | Mobile multimedia routing |
| MMSN | Mobile multimedia sensor network |
| MS | Mobile station |
| MST | Minimum spanning tree |
| MTC | Machine-type communication |
| NB-IoT | Narrowband Internet of Things |
| NDN | Named data networking |
| NFC | Near-field communication |
| NPBCH | Narrowband physical broadcast channel |
| NPDCCH | Narrowband physical downlink control channel |
| NPDSCH | Narrowband physical downlink sharing channel |
| NPRACH | Narrowband physical random access channel |
| NPSS | Narrowband master sync signal |

| | |
|---|---|
| NPUSCH | Narrowband physical uplink shared channel |
| NRS | Narrowband reference signal |
| NSSS | Narrowband subsidiary master sync signal |
| ODB | Omniscient debugger |
| OFDM | Orthogonal frequency-division modulation |
| OFDMA | Orthogonal frequency-division multiple access |
| ONS | Object naming service |
| OS | Operating system |
| OSI | Open System Interconnection |
| PAN | Personal area network |
| PF | Potential forwarder |
| PHHC | Personal, home, and hospital care |
| PIT | Pending Interest Table |
| PRACH | Physical random access channel |
| PS | Personal server |
| PUCCH | Physical uplink control channel |
| PWDGR | Pair-wise directional geographical routing |
| QoE | Quality of Experience |
| RACH | Random access channel |
| RADB | Random access with differentiated barring |
| REER | Reliable energy-efficient routing |
| RF | Radio frequency |
| RFD | Reduced-function devices |
| RFID | Radio-frequency identification |
| RN | Reference node |
| SBS | Small cell base station |
| SC-FDMA | Single-carrier frequency-division multiple access |
| SCMR | Secure cluster-based multipath routing |
| SD | Superframe duration |
| SDGR | Spline-trajectory-based directional geographical multipath routing scheme |
| SD-IoT | Software-defined Internet of Things |
| SDN | Software-defined network |
| SDN-CPS | Software-defined cyber-physical systems |
| SE | Smart energy |
| SIB | System information block |
| SIP | Single-agent itinerary planning |
| SITL | System in the loop |
| SLA | Service-level agreement |
| SO | Superframe order |
| SOF | Sensor-based open flow/sensor open flow |
| SPIN | Sensor protocol for information via negotiation |
| SRS | Sounding reference signal |
| STD | State transition diagram |
| TA | Telecom applications |

| | |
|---|---|
| TBS | Transmission block size |
| TDMA | Time-division multiple access |
| TLR | Terminode local routing |
| TRR | Terminode remote routing |
| UDP | User Datagram Protocol |
| UE | User equipment |
| UWB | Ultra-wideband |
| VC | Visual C++ |
| VC6 | Visual C++ 6.0 |
| VCL | Visit central location |
| VM | Virtual machine |
| WLAN | Wireless local area network |
| WMSN | Wireless multimedia sensor network |
| WPAN | Wireless personal area network |
| WSA | Wireless sensor applications |
| WSN | Wireless sensor network |
| ZDO | ZigBee Device Object |