

OPNET IoT Simulation

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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.

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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