Middleware
for Network Eccentric and
Mobile Applications

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Editors

Middleware for Network Eccentric and Mobile Applications

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To the memory of Kimmo Raatikainen.

Preface

During the past decade, we have observed impressive scientific, technological and experimental advances in the area of mobile ad hoc networks (MANETs). Although this emerging network technology is considered one of the main enabler for future mobile applications, today we are lacking appropriate middleware abstractions that adequately address the requirement of such challenging environments. Yet, middleware is a critical component needed to leverage the development of a wide range of applications for MANETS. Such applications range from so-called mobile and ubiquitous applications to mobile peer-to-peer applications.

The challenges of building middleware for mobile environments are considerable. In particular, middleware solutions must abandon the strong assumption that there exists some underlying networking infrastructure upon which they can rely for communication. In some sense, this new class of emerging applications, and thus its supporting middleware, are not only mobile but also *network eccentric*, meaning they no longer rely on a network infrastructure at their core. In this context, the diversity of networking constraints and application requirements promotes the development of specialized middleware solutions, which are then hard to re-use in different contexts. Furthermore, in order to build successful middleware for mobile ad hoc networks, one requires complementary expertise in the area of distributed systems, networks, algorithms, programming languages, software engineering, and application development.

The challenges we just sketched are exactly those addressed in the context of the ESF MiNEMA (Middleware for Network Eccentric and Mobile Applications) programme, which brings together European research groups from different communities working on middleware for mobile environments. Along that line, this book precisely emerged from the idea to have MINEMA experts compile recent results on middleware for ad hoc networks in a single and consistent volume. For this reason, the book provides a comprehensive introduction to the main fundamental problems, technologies, paradigms, and services that developers of middleware for mobile environments need to know to be successful.

Content

This book offers a coherent and comprehensive set of tutorials on the main topics of relevance for the construction of middleware for mobile environments. Contributions have been carefully selected and revised to provide a broad coverage of MANETs, from networking aspects to application-level aspects. The book structure has been heavily inspired by the contents of the very successfully thematic schools organized by the ESF MiNEMA programme.

Presentation

Each chapter is written in a self-contained manner and starts with the identification of the problem being addressed, followed by a brief discussion of the related work. Each chapter then proceeds to describe illustrative instances of how the issue has been addressed in the literature.

The book is planned to serve as a textbook for advanced courses in mobile ad hoc networking at the graduate level. It is assumed that the reader has some introductory knowledge on existing networking technology and principles and wants to learn more about the specific problems posed by mobile ad hoc networks and the current state of the art in the field.

Organisation

The book is organised in a bottom-up manner and is divided in four main parts, including basic networking and programming issues, communication models, middleware issues, and high-level issues that are specific to a certain class of mobile ad hoc applications. The content of each of these parts and of their respective chapters is sketched hereafter.

Networking and Programming Issues. This part exposes the reader to a set of fundamental issues related to mobile ad hoc networks that the programmer of middleware and applications needs to be aware of. These include the need to make software that is energy-aware, the constraints that exist when programming for mobile devices, how the mobility patters of the devices can be modeled and, finally, what routing algorithms are available to ensure network connectivity. Namely:

- In Chap. 1, R. Mini and A. Loureiro address the need to consider energy consumption at every stage of the design and operation of mobile devices. They discuss the main energy-aware techniques that can be applied to the design of applications, algorithms and protocols for mobile devices, with emphasis on wireless sensor networks.

- Besides general purpose devices like PDAs and laptops, ad hoc networks are also expected to serve specialised devices, like sensors. These specialised devices impose severe restrictions on developers, making robust programming quite challenging. In Chap. 2, L. Lopes, F. Martins, and J. Barros, survey the current state of the art in programming languages and runtime systems for specialised devices that make up wireless sensor networks.
- Node motion may adversely impact the performance of mobile ad hoc networks by breaking routes and disconnecting nodes. In Chap. 3, M. Musolesi and C. Mascolo present a state-of-the-art survey on the mobility models commonly used in networking and systems research.
- Not surprisingly, packet routing was one of the first problems addressed in the scope of ad hoc routing. It is also one of the most well-studied issues in this domain. Chapter 4 by F. Araújo and H. Miranda surveys the main existing routing algorithms under different network and node assumptions, including the important case where nodes are aware of their own location and can use this information to route packets.

Communication Models. Depending on the way mobile devices are deployed and used, different interaction patterns are established among them. A communication model captures what is common to a representative set of interaction patterns. Thus, these models make the bridge between networking issues and middleware-specific issues. The second part of the book gathers chapters presenting key communication models used in ad hoc networks.

- In Chap. 5, J. Aspnes and E. Ruppert introduce a theoretical model for a collection (or population) of tiny mobile agents that interact with one another to carry out a computation. Their chapter surveys results that describe what can be computed in various versions of the population protocol model.
- Opportunistic networking relies on the idea of exploiting the mobility of nodes to provide connectivity in scenarios where the source and destination nodes might never be connected to the same network at the same time. Routing issues specific to opportunistic networking are discussed in Chap. 6 by M. Conti, J. Crowcroft, S. Giordano, J. Crowcroft, P. Hui, H. Nguyen, and A. Passarella.
- Chapter 7 describes an emerging network architecture, known as mesh network, that is characterised by the partial coverage of the network with infrastructure support. That is, a mesh network can be considered as a mix between a network-centric architecture and a network-eccentric architecture. This type of networks is discussed in Chap. 7 by J. Ishmael and N. Race.

Middleware Issues. The third part covers different problems that typically solved ate middleware level, such as efficient broadcast, structured message dissemination, event dissemination and subscription, distributed coordination, security, and adaptation. Namely:

- R. Friedman, A.-M. Kermarrec, H. Miranda and L. Rodrigues address in Chap. 8 the use of gossip-based protocols in mobile ad hoc networks. Gossip-

based protocols have the advantage of requiring little or no structure to operate, making them particularly suitable for dynamic systems such as wireless self-organizing networks.

- In Chap. 9, M. Allani, B. Garbinato and F. Pedone address the problem of structured dissemination of data, which is usually solved via some application layer multicast. In particular, the authors show how it is possible to efficiently disseminate information without forcing nodes to have global knowledge of their networking environment, typically by relying on some form of overlay creation and maintenance.
- Chapter 10 by R. Baldoni, L. Querzoni, S. Tarkoma, and A. Virgillito addresses the issue of achieving scalable information dissemination using the publish/subscribe paradigm. This paradigm is of particular interest for mobile ad hoc networks, as it offers both anonymity and asynchrony to communicating nodes.
- Chapter 11 addresses the implementation of tuple spaces, an abstraction that supports data sharing and coordination among components of a distributed system. P. Costa, L. Mottola, A. Murphy, and G. Picco concisely present the state-of-the-art concerning middleware platforms based on the tuple space abstraction and expressly designed for wireless scenarios.
- Mobile device applications can be highly security- or privacy-sensitive, which is often difficult to ensure due to the inherent limitations of mobile device platforms. In Chap. 12, B. De Win, T. Goovaerts, W. Joosen, P. Philippaerts, F. Piessens, and Y. Younan elaborate on possible threats and applicable security solutions for mobile devices.
- A fundamental characteristic of mobile systems is the variability of their deployment and execution environments. In this context, dynamic adaptation is an essential technique when it comes to ensure that these systems continually provide the required level of service, in spite of continuous changes. In Chap. 13, P. Grace investigates the software techniques for performing adaptation, as well as the adaptive middleware technologies that have been used to develop dynamic mobile applications.

Applicative Issues. The last part of the book focuses on aspects that are specific to some concrete application areas. In particular, we gather here chapters that discuss issues that are relevant to build context-aware applications, the problem of self-configuration, cyber foraging, and specific issues in the application area of vehicular networking.

- The part begins with Chap. 14, where P. Eugster, B. Garbinato, and A. Holzer address the issue of building context-aware applications, i.e., applications that can explicitly learn about a part of their deployment and execution context (individual or social), and act accordingly. The authors focus in particular on the problem of making context information available to the programmer and propose a categorization of middleware solutions to this problem.
- Entering an ad hoc network requires some negotiation, for example to ensure that each device will own a unique address. Ideally, the negotiation

should be performed without user intervention, in what is usually called self-configuration. The problems raised when trying to achieve self-configuration are addressed by J. Manner in Chap. 15.

- Chapter 16 addresses cyber foraging, the process of opportunistically using resources available in the surroundings. J. Porras, O. Riva, and M. Kristensen give an overview of the cyber foraging process, with a special focus on the challenges that arise in every step of the process, and offer an overview of some existing prototype systems that support cyber foraging.
- Finally, Chap. 17, by A. Senart, M. Bouroche, V. Cahill and S. Weber, discusses recent results on vehicular networks and applications. These networks pose a number of specific challenges, due to the high speed and predefined movement pattern, as well as to the real-time communication requirements that are essential to safety applications.

In summary, the present book provides a unique collection of tutorials, which will allow graduate students in computer science to get familiar with state-of-the-art researches in mobile ad hoc networks and applications, typically on their road to doctoral studies.

It is noteworthy that this book was made possible not only thanks to the dedication and expertise of our contributing authors, many from the ESF MiNEMA programme, but also thanks the excellent work done by our reviewers; we wish to thank them here. Their effort resulted in a book that is an invaluable tool for researchers and developers working this emerging domain.

September 2008 *B. Garbinato, H. Miranda, L. Rodrigues*

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Acronyms

AACS	Arithmetic Attribute Constraint Summary
ACM	Association for Computing Machinery
AEMD	Adaptive Algorithm for Efficient Message Diffusion
AODV	Ad Hoc On-Demand Distance Vector Routing Protocol
AOP	Aspect-Oriented Programming
API	Application Programming Interface
ARP	Address Resolution Protocols
ASLR	Address Space Layout Randomization
BTP	Banana Tree Protocol
CAR	Context Aware Routing
CCTV	Closed-Circuit Television
CLDC	Connected Limited Device Configuration
CORBA	Common Object Request Broker Architecture
CSMA	Carrier Sense Multiple Access
CUWiN	Champaign-Urbana Community Wireless Network
CWMN	Community Wireless Mesh Networking
DHCP	Dynamic Host Configuration Protocol
DHT	Distributed Hash Table
DNS	Domain Name Service
DSDV	Destination Sequence Distance Vector
DSR	Dynamic Source Routing
DT	Delaunay triangulation
DTM	Distributed Token Machine
DTN	Delay Tolerant Network
DYMO	Dynamic MANET On-demand Routing Protocol
GASR	Gambling Algorithm for Scalable Resource-Aware Streaming
GEDIR	GEographical DIstance Routing
GENA	Generic Event Notification Architecture
GPS	Global Positioning System
GPCR	Greedy Perimeter Coordinator Routing
GPRS	General Packet Radio Service

GPSR	Greedy Perimeter Stateless Routing
HiBOp	History Based Opportunistic Routing
HMTP	Host Multicast Tree Protocol
IEEE	Institute of Electrical and Electronics Engineers, Inc.
IETF	Internet Engineering Task Force
IIOP	Internet Inter-ORB Protocol
IP	Internet Protocol
ISO	International Organization for Standardization
LAN	Local Area Network
MAC	Medium Access Control
MAN	Metropolitan Area Network
MANET	Mobile Ad Hoc Network
MAODV	Multicast AODV
MIDP	Mobile Information Device Profile
MCL	Mesh Connectivity Layer
MFR	Most Forward within Radius
MIT	Massachusetts Institute of Technology
MMS	Multimedia Messaging Service
MTU	Maximum Transmission Unit
MUP	Multi-Radio Unification
NC	Nearest Closer Algorithm
ODMRP	On-Demand Multicast Routing Protocol
OLSR	Optimized Link State Routing Protocol
OWL	Web Ontology Language
OSPF	Open Shortest Path First
PADIS	Power-Aware data DIStribution algorithm
P2P	Peer to Peer
PDA	Personal Digital Assistant
Propicman	Probabilistic Routing Protocol for Intermittently Connected Mobile Ad hoc Network
PROPHET	Probabilistic ROuting Protocol using History of Encounters and Transitivity
QoS	Quality of Service
RDG	Restricted Delaunay Graph
RF	Radio Frequency
RFID	Radio Frequency Identification
RFC	Request for Comments
RIP	Routing Information Protocol
RMI	Remote Method Invocation
RMX	Reliable Multicast proXy
RNG	Relative Neighborhood Graph
RPC	Remore Procedure Call
RTP	Real-Time Transport Protocol
RTT	Round-Trip Time
SACS	String Attribute Constraint Summary

SETI	Search for Extra-Terrestrial Intelligence
SDP	Session Description Protocol
SDP	Service Discovery Protocol
SIG	Special Interest Group
SLP	Service Location Protocol
SMS	Short Message Service
SNR	Signal-to-Noise Ratio
SOAP	Simple Object Access Protocol
SOC	Service-Oriented Computing
SPIN	Sensor Protocols for Information via Negotiation
SQL	Structured Query Language
SRE	Security-Related Events
SSDO	Simple Service Discovery Protocol
STAG	Subnet Topology-Aware Grouping
STRAW	Street Random Waypoint
SxC	Security-by-Contract
TAG	Topology-Aware Grouping
TBCP	Tree Building Control Protocol
TBF	Trajectory Based Forwarding
TEDD	Trajectory and Energy-based Data Dissemination
TCP	Transmission Control Protocol
TIFF	Tagged Image File Format
TOMA	Two-tier Overlay Multicast Architecture
UDG	Unit Disk Graph
UDP	User Datagram Protocol
UPnP	Universal Plug and Play
URL	Uniform Resource Locator
UUID	Universally Unique Identifiers
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VITP	Vehicle Information Transfer Protocol
VANET	Vehicular Ad Hoc Network
VCP	Vehicular Communication Platform
WAN	Wide Area Network
WLAN	Wireless Local Area Network
WCETT	Weighted Cumulative Expected Transmission Time
WEP	Wired Equivalent Privacy
WiMAX	Worldwide Interoperability for Microwave Access
WMN	Wireless Mesh Network
WPA	Wi-Fi Protected Access
WSDL	Web Services Description Language
WSN	Wireless Sensor Network
XML	eXtended Markup Language
XSDF	eXtensible Service Discovery Framework