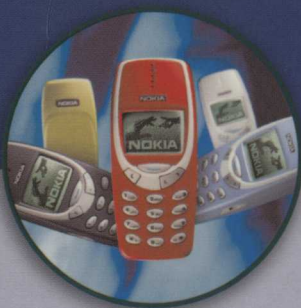


Ad Hoc Mobile Wireless Networks

Protocols and Systems



Age of Pervasive Mobile Networking and Computing

Samsung v. Four Batons
IPR2025-00496
Exhibit 1011

C - K T o h

Ad Hoc Mobile Wireless Networks

Protocols and Systems

C-K Toh



The authoritative guide to the state-of-the-art in ad hoc wireless networking

"Ad hoc" wireless networks eliminate the complexities of infrastructure setup and administration, enabling devices to create and join networks "on the fly"—anywhere, anytime, for virtually any application. The field is rapidly coming of age, reflecting powerful advances in protocols, systems, and real-world implementation experience. In ***Ad Hoc Mobile Wireless Networks***, one of the field's world leading researchers brings together these advances in a single consolidated and comprehensive archive. C-K Toh covers all this, and more:

- *Key challenges: device heterogeneity, diverse traffic profiles, mobility, and power conservation*
- *Routing protocols for ad hoc networks, including Associativity-Based Routing (ABR) and other IETF MANET protocols*
- *Real-world implementation issues—including a complete prototype implementation*
- *Ad hoc wireless network performance: results obtained from the latest field trials*
- *Leading approaches to service discovery*
- *Addressing TCP over an ad hoc wireless network environment*
- *Support for multicast communications*
- *The role of Bluetooth and WAP*

Ad Hoc Mobile Wireless Networks introduces detailed application scenarios ranging from home and car to office and battlefield. C-K Toh also introduces several of the field's leading projects, from Motorola's PIANO platform to UC Berkeley's "Smart Dust." Whether you're a researcher, scientist, implementer, consultant, technical manager, CTO, or student, you won't find a more authoritative and comprehensive guide to the new state-of-the-art in ad hoc networking.

ABOUT THE AUTHOR

C-K Toh chairs the IEEE Technical Subcommittee on Ad Hoc Mobile Wireless Networks, and is Director of the Ad Hoc Wireless Networking Consortium. He serves as an editor for IEEE Journal on Selected Areas in Communications, IEEE Network, Journal on Communications & Networks (JCN), and Personal Technologies Journal. As a senior member of IEEE and a fellow of the Cambridge Philosophical Society, he has consulted for numerous organizations, including Hughes, Nortel, and TRW. C. K. holds a Ph.D. degree from the University of Cambridge and is a Chartered Electrical Engineer.

PRENTICE HALL
Upper Saddle River, NJ 07458

www.phptr.com

Exhibit 1011

Page 02 of 27

ISBN 0-13-007817-4



9 780130 078179

90000



Toh

Ad Hoc Mobile Wireless Networks

TK5103.2
.T63
2002

AD HOC MOBILE WIRELESS NETWORKS: PROTOCOLS AND SYSTEMS

C.-K. TOH, PH.D.

PH
PTR

Prentice Hall PTR
Upper Saddle River, New Jersey 07548
www.phptr.com

ISBN 0-13-007817-4



9 780130 078179

9 0000



+K5103.2
.T63
2002
Library of Congress Cataloging-in-Publication Data

Toh, C.-K. (Chai-Keong)

Ad hoc mobile wireless networks: protocols and systems / C.-K. Toh.

p. cm.

Includes index.

ISBN 0-13-007817-4

1. Wireless communications systems. I. Title.

TK5103.2 T64 2002

384.3--dc21

2001036953

CIP

Editorial/Production Supervision: *Nick Radhuber*

Acquisitions Editor: *Bernard Goodwin*

Editorial Assistant: *Michelle Vincente*

Marketing Manager: *Dan DePasquale*

Manufacturing Buyer: *Alexis Heydt-Long*

Cover Design: *Talar Boorujy*

Cover Design Direction: *Jerry Votta*



© 2002 by Prentice Hall PTR
Prentice-Hall, Inc.
Upper Saddle River, NJ 07458

Prentice Hall books are widely used by corporations and government agencies for training, marketing, and resale.

The publisher offers discounts on this book when ordered in bulk quantities. For more information, contact Corporate Sales Department, phone: 800-382-3419; fax: 201-236-7141; email: corpsales@prenhall.com. Or write: Corporate Sales Department, Prentice Hall PTR, One Lake Street, Upper Saddle River, NJ 07458.

Product and company names mentioned herein are the trademarks or registered trademarks of their respective owners.

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission in writing from the publisher.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN 0-13-007817-4

Pearson Education LTD.

Pearson Education Australia PTY, Limited

Pearson Education Singapore, Pte. Ltd

Pearson Education North Asia Ltd

Pearson Education Canada, Ltd.

Pearson Educación de México, S.A. de C.V.

Pearson Education—Japan

Pearson Education Malaysia, Pte. Ltd

Pearson Education, Upper Saddle River, New Jersey

DEDICATION

So many changes have occurred in my life over the past few years. I moved from Asia to Europe and subsequently to America. I also realized just how much one could do if one is determined and motivated. Besides having a passion for technology, I have a great appreciation of life. Only by striking a balance can one truly enjoy the meaning of our existence. I would like to dedicate this book to:

My Parents

My Sister

My parents not only gave me life, but also the opportunity of a superb education. Without their support and love, this book would not have been written.

CONTENTS

	iii
ABOUT THE AUTHOR	xv
PREFACE	xvii
ACKNOWLEDGMENTS	xix
QUOTES & WORDS OF WISDOM	xx
1 INTRODUCTION TO WIRELESS NETWORKS	1
1.1 Evolution of Mobile Cellular Networks	2
1.1.1 First-Generation Mobile Systems	2
1.1.2 Second-Generation Mobile Systems	2
1.1.3 2.5G Mobile Systems	3
1.1.4 Third-Generation Mobile Systems	4
1.2 Global System for Mobile Communications (GSM)	5

1.3	General Packet Radio Service (GPRS)	6
1.4	Personal Communications Services (PCSs)	7
1.5	Wireless LANs (WLANS)	8
1.6	Universal Mobile Telecommunications System (UMTS)	9
1.7	IMT2000	10
1.8	IS-95, cdmaOne and cdma2000 Evolution	11
1.9	Organization of this Book	12
2	ORIGINS OF AD HOC: PACKET RADIO NETWORKS	13
2.1	Introduction	13
2.2	Technical Challenges	15
2.3	Architecture of PRNETs	15
2.4	Components of Packet Radios	16
2.5	Routing in PRNETs	17
2.5.1	Point-to-Point Routing	17
2.5.2	Broadcast Routing	17
2.5.3	Packet Forwarding	18
2.5.4	Impact of Mobility	18
2.6	Route Calculation	19
2.6.1	Principles of Packet Forwarding	21
2.7	Pacing Techniques	22
2.8	Media Access in PRNETs	23
2.9	Flow Acknowledgments in PRNETs	24
2.10	Conclusions	25
3	AD HOC WIRELESS NETWORKS	27
3.1	What Is an Ad Hoc Network?	27
3.2	Heterogeneity in Mobile Devices	28
3.3	Wireless Sensor Networks	30
3.4	Traffic Profiles	31
3.5	Types of Ad Hoc Mobile Communications	32
3.6	Types of Mobile Host Movements	33
3.6.1	Movements by Nodes in a Route	33

3.6.2	Movements by Subnet-Bridging Nodes	33
3.6.3	Concurrent Node Movements	34
3.7	Challenges Facing Ad Hoc Mobile Networks	34
3.7.1	Spectrum Allocation and Purchase	34
3.7.2	Media Access	35
3.7.3	Routing	35
3.7.4	Multicasting	36
3.7.5	Energy Efficiency	36
3.7.6	TCP Performance	36
3.7.7	Service Location, Provision, and Access	37
3.7.8	Security & Privacy	37
3.8	Conclusions	37
4	AD HOC WIRELESS MEDIA ACCESS PROTOCOLS	39
4.1	Introduction	39
4.1.1	Synchronous MAC Protocols	40
4.1.2	Asynchronous MAC Protocols	40
4.2	Problems in Ad Hoc Channel Access	40
4.2.1	Hidden Terminal Problem	40
4.2.2	Shortcomings of the RTS-CTS Solution	42
4.2.3	Exposed Node Problem	42
4.3	Receiver-Initiated MAC Protocols	45
4.4	Sender-Initiated MAC Protocols	45
4.5	Existing Ad Hoc MAC Protocols	47
4.5.1	Multiple Access with Collision Avoidance (MACA)	47
4.5.2	MACA-BI (By Invitation)	49
4.5.3	Power-Aware Multi-Access Protocol with Signaling (PA-MAS)	51
4.5.4	Dual Busy Tone Multiple Access (DBTMA)	52
4.6	MARCH: Media Access with Reduced Handshake	53
4.7	Conclusions	56
5	OVERVIEW OF AD HOC ROUTING PROTOCOLS	57

5.1	Table-Driven Approaches	58
5.2	Destination Sequenced Distance Vector (DSDV)	58
5.3	Wireless Routing Protocol (WRP)	59
5.4	Cluster Switch Gateway Routing (CSGR)	60
5.5	Source-Initiated On-Demand Approaches	62
5.6	Ad Hoc On-Demand Distance Vector Routing (AODV)	62
5.7	Dynamic Source Routing (DSR)	64
5.8	Temporally Ordered Routing Algorithm (TORA)	66
5.9	Signal Stability Routing (SSR)	68
5.10	Location-Aided Routing (LAR)	69
5.10.1	Shortcomings of LAR	70
5.11	Power-Aware Routing (PAR)	70
5.12	Zone Routing Protocol (ZRP)	71
5.13	Source Tree Adaptive Routing (STAR)	73
5.14	Relative Distance Microdiversity Routing (RDMAR)	75
5.15	Conclusions	77
6	ASSOCIATIVITY-BASED LONG-LIVED ROUTING	79
6.1	A New Routing Paradigm	79
6.2	Associativity-Based Long-Lived Routing	80
6.2.1	New Routing Metrics	83
6.2.2	Route Selection Rules	84
6.3	ABR Protocol Description	84
6.3.1	Route Discovery Phase	84
6.3.2	Route Reconstruction (RRC) Phase	86
6.3.3	Alternate Routes	90
6.3.4	Route Deletion Phase	91
6.3.5	ABR Headers and Tables	91
6.3.6	ABR Protocol Summary	94
6.4	Conclusions	94
7	IMPLEMENTATION OF AD HOC MOBILE NETWORKS	97

7.1	Introduction	97
7.2	ABR Protocol Implementation in Linux	98
7.2.1	System Components	98
7.2.2	Software Layering Architecture	99
7.2.3	Implementing ABR Packet Headers and Beacons	101
7.2.4	Implementing ABR Outflow and Inflow	102
7.2.5	Implementing ABR Routing Functions	102
7.3	Experimentation and Protocol Performance	108
7.3.1	Control Packet Overhead	108
7.3.2	Route Discovery Time	108
7.3.3	End-to-End Delay	110
7.3.4	Data Throughput	112
7.3.5	Effects of Beacons on Battery Life	112
7.4	Important Deductions	114
7.5	Conclusions	116
8	COMMUNICATION PERFORMANCE OF AD HOC NETWORKS	117
8.1	Introduction	117
8.1.1	ABR Beacons	118
8.2	Performance Parameters of Interest	119
8.3	Route Discovery (RD) Time	119
8.3.1	Impact of Beacons Interval on RD Time	120
8.3.2	Impact of Route Length on RD Time	120
8.4	End-to-End Delay (EED) Performance	122
8.4.1	Impact of Packet Size on EED	122
8.4.2	Impact of Beacons Interval on EED	123
8.4.3	Impact of Route Length on EED	123
8.5	Communication Throughput Performance	127
8.5.1	Impact of Packet Size on Throughput	127
8.5.2	Impact of Beacons Interval on Throughput	129
8.5.3	Impact of Route Length on Throughput	132
8.6	Packet Loss Performance	132
8.6.1	Impact of Packet Size on Packet Loss	132

8.6.2	Impact of Beacons Interval on Packet Loss	136
8.6.3	Impact of Route Length on Packet Loss	136
8.7	Route Reconfiguration/Repair Time	136
8.8	TCP/IP-Based Applications	137
8.8.1	Running TELNET over Ad Hoc	138
8.8.2	Running FTP over Ad Hoc	139
8.8.3	Running HTTP over Ad Hoc	140
8.9	Conclusions	141
9	ENERGY CONSERVATION: POWER LIFE ISSUES	143
9.1	Introduction	143
9.2	Power Management	144
9.2.1	Smart Batteries and Battery Characteristics	144
9.3	Advances in Device Power Management	147
9.3.1	Advance Power Management (APM)	147
9.3.2	Advance Configuration and Power Interface (ACPI)	148
9.4	Advances in Protocol Power Management	152
9.4.1	Power Conservation at the Data-Link Layer	152
9.4.2	Power Conservation at the Network Layer	154
9.4.3	Power Conservation at the Transport Layer	155
9.5	Power Conservation by Mobile Applications	155
9.6	Periodic Beacons On Battery Life	158
9.7	Standalone Beacons	159
9.7.1	At High-Frequency (HF) Beacons	160
9.7.2	At Low-Frequency (LF) Beacons	163
9.7.3	Comparing HF and LF Standalone Beacons	163
9.8	HF Beacons with Neighboring Nodes	164
9.8.1	With One Neighbor	164
9.8.2	With Two Neighbors	164
9.9	Comparison of HF Beacons with and without Neighbors	164
9.9.1	With One Neighbor	166
9.9.2	With Two Neighbors	167
9.10	LF Beacons with Neighboring Nodes	167

9.10.1 With One Neighbor	167
9.10.2 With Two Neighbors	168
9.11 Comparison of LF Beaconing with and without Neighbors	169
9.12 Deductions	172
9.13 Conclusions	174
10 AD HOC WIRELESS MULTICAST ROUTING	175
10.1 Multicasting in Wired Networks	175
10.1.1 IP Multicast Architecture	176
10.1.2 Multicast Tunnels and the MBone	176
10.1.3 Multicast Routing Algorithms	177
10.2 Multicast Routing in Mobile Ad Hoc Networks	178
10.3 Existing Ad Hoc Multicast Routing Protocols	181
10.3.1 Classification	181
10.3.2 DVMRP with Wireless Extension	181
10.3.3 AODV Multicast	184
10.3.4 Multicast Mesh: CAMP	186
10.3.5 Group-Based: ODMRP	187
10.3.6 Location-Based Multicast: LBM	191
10.4 ABAM: Associativity-Based Ad Hoc Multicast	192
10.4.1 Multicast Tree Formation	193
10.4.2 Handling Host Membership Dynamics (Join/Leave)	196
10.4.3 Dynamics Associated with Node Mobility	199
10.4.4 Deletion of Multicast Tree	204
10.4.5 ABAM Tree Reconfiguration	205
10.4.6 Complexity of ABAM	205
10.5 Comparisons of Multicast Routing Protocols	206
10.5.1 Protocol Differences	207
10.5.2 Operation and Performance Differences	208
10.5.3 Comparing Protocol Overhead	210
10.5.4 Time and Communication Complexity	211
10.6 Conclusions	212

11 TCP OVER AD HOC	215
11.1 Introduction to TCP	215
11.1.1 TCP Flow Control	216
11.1.2 TCP Congestion Control	217
11.1.3 Some Issues with TCP	218
11.2 Versions of TCP	219
11.2.1 TCP Reno	219
11.2.2 TCP Tahoe	219
11.2.3 TCP Vegas	220
11.2.4 TCP SACK	221
11.3 Problems Facing TCP in Wireless Last-Hop	222
11.3.1 Indirect TCP	222
11.3.2 TCP Snoop	223
11.4 Problems Facing TCP in Wireless Ad Hoc	223
11.5 Approaches to TCP over Ad Hoc	224
11.5.1 TCP Feedback (TCP-F)	224
11.5.2 TCP-BuS	225
11.6 Conclusion	228
 12 INTERNET & AD HOC SERVICE DISCOVERY	 229
12.1 Resource Discovery in the Internet	229
12.2 Service Location Protocol (SLP) Architecture	230
12.2.1 User Agent	230
12.2.2 Directory Agent	230
12.2.3 Service Agent	231
12.3 SLPv2 Packet Format	232
12.4 Jini	233
12.5 Salutation Protocol	234
12.6 Simple Service Discovery Protocol (SSDP)	236
12.7 Service Discovery for Ad Hoc	237
12.7.1 Limitations of Existing Schemes	237
12.8 Ad Hoc Service Location Architectures	237
12.8.1 Service Co-Ordinator Based Architecture	237

12.8.2 Distributed Query-Based Architecture	238
12.8.3 Hybrid Service Location Architecture	240
12.9 Conclusions	242
13 BLUETOOTH TECHNOLOGY	243
13.1 Bluetooth Specifications	244
13.2 Bluetooth Architectures	245
13.2.1 Bluetooth Piconet	245
13.2.2 Bluetooth Scatternet	245
13.3 Bluetooth Protocols	246
13.4 Bluetooth Service Discovery	249
13.5 Bluetooth MAC	250
13.6 Bluetooth Packet Structure	251
13.7 Bluetooth Audio	251
13.8 Bluetooth Addressing	253
13.9 Bluetooth Limitations	253
13.10 Bluetooth Implementation	254
13.11 Conclusions	255
14 WIRELESS APPLICATION PROTOCOL (WAP)	257
14.1 The WAP Forum	258
14.2 The WAP Service Model	259
14.3 The WAP Protocol Architecture	260
14.4 The WWW Programming Model	262
14.5 The WAP Programming Model	263
14.6 Conclusions	264
15 AD HOC NOMADIC MOBILE APPLICATIONS	266
15.1 In the Office	266
15.2 While Traveling	268
15.3 Arriving Home	268
15.4 In the Car	269
15.5 Shopping Malls	270
15.6 The Modern Battlefield	270

15.7 Car-to-Car Mobile Communications	271
15.8 Mobile Collaborative Applications	273
15.9 Location/Context Based Mobile Services	274
15.10 Conclusions	276
16 CONCLUSIONS AND THE FUTURE	277
16.1 Pervasive Computing	277
16.2 Motorola <i>PIANO</i> Project	278
16.3 UC Berkeley Sensor Networks: Smart Dust	279
16.4 EPFL Terminodes/Large-Scale Networks	281
16.5 802.15 PANs and 802.16 Wireless MANs	282
16.6 Ad Hoc Everywhere?	283
GLOSSARY OF TERMS	285
REFERENCES	289
INDEX	299

INTRODUCTION TO WIRELESS NETWORKS

Wireless communications have become very pervasive. The number of mobile phones and wireless Internet users has increased significantly in recent years. Traditionally, first-generation wireless networks were targeted primarily at voice and data communications occurring at low data rates.

Recently, we have seen the evolution of second- and third-generation wireless systems that incorporate the features provided by broadband. In addition to supporting *mobility*, broadband also aims to support *multimedia traffic*, with quality of service (QoS) assurance. We have also seen the presence of different air interface technologies, and the need for interoperability has increasingly been recognized by the research community.

Wireless networks include local, metropolitan, wide, and global areas. In this chapter, we will cover the evolution of such networks, their basic principles of

operation, and their architectures.

1.1 Evolution of Mobile Cellular Networks

1.1.1 First-Generation Mobile Systems

The first generation of analog cellular systems included the Advanced Mobile Telephone System (AMPS) [1] which was made available in 1983. A total of 40MHz of spectrum was allocated from the 800MHz band by the Federal Communications Commission (FCC) for AMPS. It was first deployed in Chicago, with a service area of 2100 square miles [2]. AMPS offered 832 channels, with a data rate of 10 kbps. Although omnidirectional antennas were used in the earlier AMPS implementation, it was realized that using directional antennas would yield better cell reuse. In fact, the smallest reuse factor that would fulfill the 18db signal-to-interference ratio (SIR) using 120-degree directional antennas was found to be 7. Hence, a 7-cell reuse pattern was adopted for AMPS. Transmissions from the base stations to mobiles occur over the *forward channel* using frequencies between 869-894 MHz. The *reverse channel* is used for transmissions from mobiles to base station, using frequencies between 824-849 MHz.

In Europe, TACS (Total Access Communications System) was introduced with 1000 channels and a data rate of 8 kbps. AMPS and TACS use the frequency modulation (FM) technique for radio transmission. Traffic is multiplexed onto an FDMA (frequency division multiple access) system. In Scandinavian countries, the Nordic Mobile Telephone is used.

1.1.2 Second-Generation Mobile Systems

Compared to first-generation systems, second-generation (2G) systems use digital multiple access technology, such as TDMA (time division multiple access) and CDMA (code division multiple access). Global System for Mobile Communications, or GSM [3], uses TDMA technology to support multiple users.

Examples of second-generation systems are GSM, Cordless Telephone (CT2), Personal Access Communications Systems (PACS), and Digital European Cordless Telephone (DECT [4]). A new design was introduced into the mobile switching center of second-generation systems. In particular, the use of base station controllers (BSCs) lightens the load placed on the MSC (mobile switching center) found in first-generation systems. This design allows the interface between the MSC and BSC to be standardized. Hence, considerable attention was devoted to *interoperability* and *standardization* in second-generation systems so that carriers

could employ different manufacturers for the MSC and BSCs.

In addition to enhancements in MSC design, the mobile-assisted handoff mechanism was introduced. By sensing signals received from adjacent base stations, a mobile unit can trigger a handoff by performing explicit signalling with the network.

Second generation protocols use digital encoding and include GSM, D-AMPS (TDMA) and CDMA (IS-95). 2G networks are in current use around the world. The protocols behind 2G networks support voice and some limited data communications, such as Fax and short messaging service (SMS), and most 2G protocols offer different levels of encryption, and security. While first-generation systems support primarily voice traffic, second-generation systems support voice, paging, data, and fax services.

1.1.3 2.5G Mobile Systems

The move into the 2.5G world will begin with General Packet Radio Service (GPRS). GPRS is a radio technology for GSM networks that adds packet-switching protocols, shorter setup time for ISP connections, and the possibility to charge by the amount of data sent, rather than connection time. Packet switching is a technique whereby the information (voice or data) to be sent is broken up into packets, of at most a few Kbytes each, which are then routed by the network between different destinations based on addressing data within each packet. Use of network resources is optimized as the resources are needed only during the handling of each packet.

The next generation of data heading towards third generation and personal multimedia environments builds on GPRS and is known as Enhanced Data rate for GSM Evolution (EDGE). EDGE will also be a significant contributor in 2.5G. It will allow GSM operators to use existing GSM radio bands to offer wireless multimedia IP-based services and applications at theoretical maximum speeds of 384 kbps with a bit-rate of 48 kbps per timeslot and up to 69.2 kbps per timeslot in good radio conditions. EDGE will let operators function without a 3G license and compete with 3G networks offering similar data services. Implementing EDGE will be relatively painless and will require relatively small changes to network hardware and software as it uses the same TDMA (Time Division Multiple Access) frame structure, logic channel and 200 kHz carrier bandwidth as today's GSM networks. As EDGE progresses to coexistence with 3G WCDMA, data rates of up to ATM-like speeds of 2 Mbps could be available.

GPRS will support flexible data transmission rates as well as continuous connection to the network. GPRS is the most significant step towards 3G.

1.1.4 Third-Generation Mobile Systems

Third-generation mobile systems are faced with several challenging technical issues, such as the provision of seamless services across both wired and wireless networks and universal mobility. In Europe, there are three evolving networks under investigation: (a) UMTS (Universal Mobile Telecommunications Systems), (b) MBS (Mobile Broadband Systems), and (c) WLAN (Wireless Local Area Networks).

The use of hierarchical cell structures is proposed for IMT2000. The overlaying of cell structures allows different rates of mobility to be serviced and handled by different cells. Advanced multiple access techniques are also being investigated, and two promising proposals have evolved, one based on wideband CDMA and another that uses a hybrid TDMA/CDMA/FDMA approach.

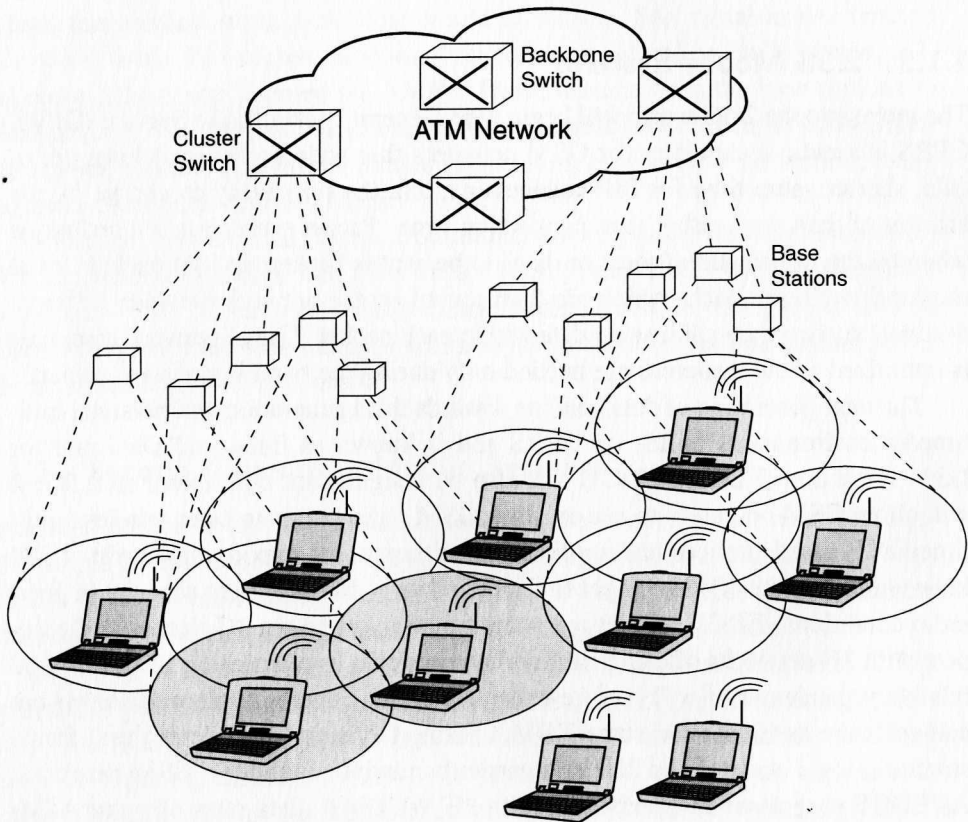


Figure 1.1. The architecture of a cellular wireless network based on ATM.

1.2 Global System for Mobile Communications (GSM)

GSM is commonly referred to as the second-generation mobile cellular system. GSM has its own set of communication protocols, interfaces, and functional entities. It is capable of supporting roaming, and carrying speech and data traffic.

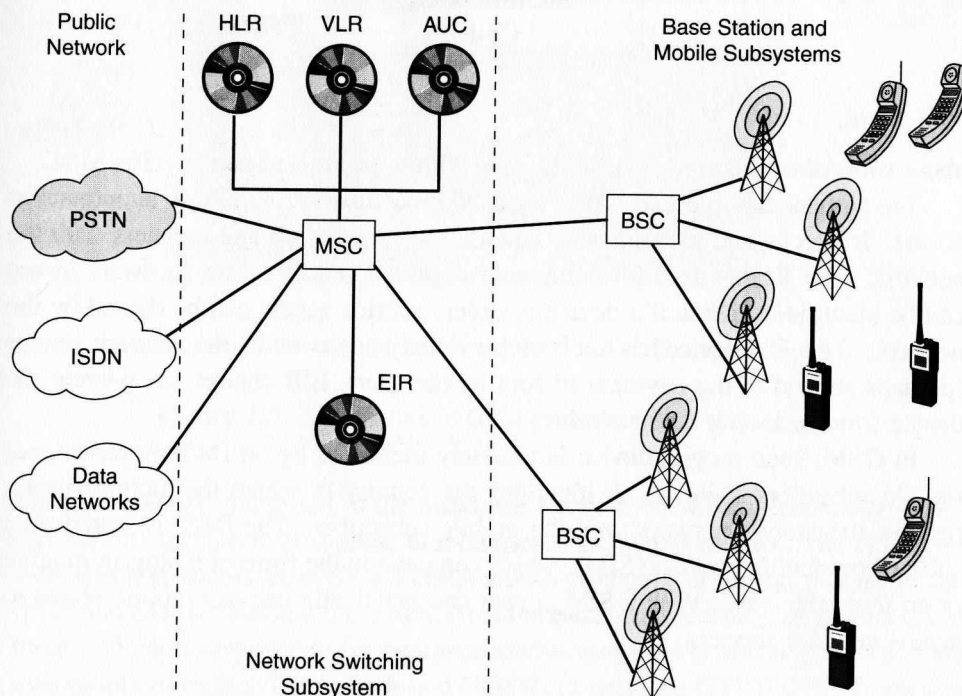


Figure 1.2. The network architecture of GSM.

The GSM network architecture (see Figure 1.2) comprises several base transceiver stations (BTS), which are clustered and connected to a base station controller (BSC). Several BSCs are then connected to an MSC. The MSC has access to several databases, including the visiting location register (VLR), home location register (HLR), and equipment identity register (EIR). It is responsible for establishing, managing, and clearing connections, as well as routing calls to the proper radio cell. It supports call rerouting at times of mobility. A gateway MSC provides an interface to the public telephone network.

The HLR provides identity information about a GSM user, its home subscription base, and service profiles. It also keeps track of mobile users registered within its home area that may have roamed to other areas. The VLR stores information

Table 1.1. The IMSI in GSM

Mobile Country Code
Mobile Network Code
Mobile Subscriber Identification Code

about subscribers visiting a particular area within the control of a specific MSC.

The authentication center (AC) is used to protect subscribers from unauthorized access. It checks and authenticates when a user powers up and registers with the network. The EIR is used for equipment registration so that the hardware in use can be identified. Hence if a device is stolen, service access can be denied by the network. Also, if a device has not been previously approved by the network vendor (perhaps subject to the payment of fees by the user), EIR checks can prevent the device from accessing the network.

In GSM, each mobile device is uniquely identified by an IMSI (international mobile subscriber identity). It identifies the country in which the mobile system resides, the mobile network, and the mobile subscriber. The IMSI is stored on a subscriber identity module (SIM), which can exist in the form of a plug-in module or an insertable card. With a SIM, a user can practically use any mobile phone to access network services.

1.3 General Packet Radio Service (GPRS)

The GSM general packet radio service (GPRS) is a data overlay over the voice-based GSM cellular network. It consists of a packet wireless access network and an IP-based backbone. GPRS is designed to transmit small amounts of frequently sent data or large amounts of infrequently sent data. GPRS has been seen as an evolution toward UMTS (Universal Mobile Telecommunications Systems). Users can access IP services via GPRS/GSM networks.

GPRS services include both point-to-point and point-to-multipoint communications. The network architecture of GPRS is shown in Figure 1.3. Gateway GSN (GGSN) nodes provide interworking functions with external packet-switched networks. A serving GPRS support node (SGSN), on the other hand, keeps track of an individual mobile station's location and provides security and access control. As shown in Figure 1.3, base stations (BSSs) are connected to SGSNs, which

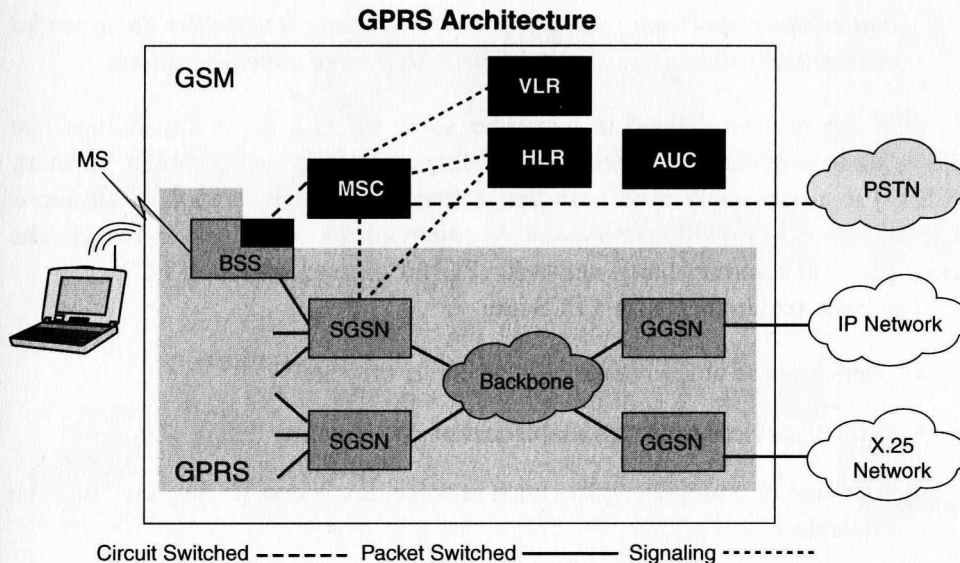


Figure 1.3. Architecture of GSM general packet radio service.

are subsequently connected to the backbone network. SGSNs interact with MSCs and various databases to support mobility management functions. The BSSs provide wireless access through a TDMA MAC protocol. Both the mobile station (MS) and SGSNs execute the SMDCP (Subnetwork-Dependent Convergence Protocol), which is responsible for compression/decompression and segmentation and reassembly of traffic. The SGSNs and GGSNs execute the GTP (GPRS Tunneling Protocol), which allows the forwarding of packets between an external public data networks (PDN) and mobile unit (MU). It also allows multiprotocol packets to be tunneled through the GPRS backbone.

1.4 Personal Communications Services (PCSs)

The FCC defines PCS [5] as “Radio communications that encompass mobile and ancillary fixed communication that provides services to individuals and business and can be integrated with a variety of competing networks.” However, the Telecommunications Industry Association (TIA) has a different definition for PCS:

A mobile radio voice and data service for the provision of unit-to-unit communications, which can have the capability of public switched telephone network access, and which is based on microcellular or other technologies

that enhance spectrum capacity to the point where it will offer the potential of essentially ubiquitous and unlimited, untethered communications.

PCS can also be defined in a broader sense [6] as a set of capabilities that allows some combination of *personal* mobility and *service* management. In short, PCS [7] is a commonly used term that defines the next generation of advanced wireless networks providing *personalized* communication services. In Europe, the term “personal communication networks (PCNs)” is used instead of PCS.

The basic requirements for a PCS are:

- Users must be able to make calls wherever they are
- Offered services must be reliable and of good quality
- Provision of multiple services such as voice, fax, video, paging, etc., must be available.

Unlike AMPS, PCS is aimed at the personal consumer industry for mass consumption. The FCC’s view of PCS is one where the public switched telephone network (PSTN) is connected to a variety of other networks, such as CATV (cable television), AMPS cellular systems, etc.

1.5 Wireless LANs (WLANS)

Wireless LAN technology has evolved to extend to existing wired networks. Local area networks (LANs) are mostly based on Ethernet media access technology that consists of an interconnection of hosts and routers. LANs are restricted by distance. They are commonly found in offices and inside buildings. Interconnection using wires can be expensive when it comes to relocating servers, printers, and hosts.

Now, more wireless LANs (WLANS) are being deployed in offices. Most WLANS are compatible with Ethernet, and hence, there is no need for protocol conversion. The IEEE has standardized 802.11 protocols to support WLANS media access. A radio base station can be installed in a network to serve multiple wireless hosts over 100-200 m. A host (for example, a laptop) can be wirelessly enabled by installing a wireless adapter and the appropriate communication driver. A user can perform all network-related functions as long as he or she is within the coverage area of the radio base station. This gives the user the capability to perform work beyond his or her office space.

As shown in Figure 1.4, several overlapping radio cells can be used to provide wireless connectivity over a desired region. If a wireless host migrates from one

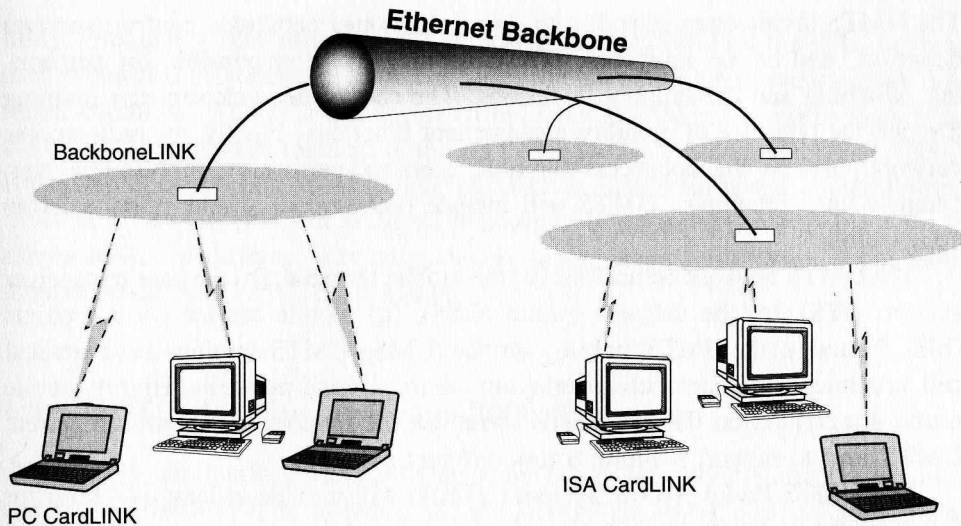


Figure 1.4. A WLAN with an Ethernet wired backbone.

radio cell to another within the same subnet, then there is no handoff. It is basically bridging, since the host's packet will eventually be broadcast onto the same Ethernet backbone.

WLANs support existing TCP/IP-based applications. There has been considerable debate in the past as to the low throughput WLANs provide compared to high-speed wired networks. It was not long ago that switched Ethernet technology [8] evolved, bringing the communication throughput of Ethernet into the gigabit range.

The desire to support higher throughput and ad hoc mobile communications has prompted the ETSI (European Communications Standard Institute) to produce a standard for high-performance Radio LAN (HIPERLAN), at 20Mbps throughput with a self-organizing and distributed control network architecture. HIPERLAN II is a wireless ATM system operating at the 17GHz band.

1.6 Universal Mobile Telecommunications System (UMTS)

The Universal Mobile Telecommunications System (UMTS) is commonly referred to as a third-generation system. It is targeted to be deployed in 2002. UMTS employs an ATM-based switching network architecture and aims to provide services for both *mobile* and *fixed* subscribers by common call-processing procedures.

The UMTS architecture is split into *core* (switching) networks, *control* (service) networks, and *access* networks. The core network is responsible for performing switching and transmission functions. The control network supports roaming through the presence of mobility management functions. Finally, the radio access network provides channel access to mobile users and performs radio resource management and signalling. UMTS will include both terrestrial and global satellite components.

The UMTS network comprises: (a) the mobile terminal, (b) the base transceiver station (BTS), (c) the cell site switch (CSS), (d) mobile service control points (MSCP), and (e) the UMTS mobility service (UMS). UMTS employs a hierarchical cell structure, with macrocells overlaying microcells and picocells. Highly mobile traffic is operated on the macrocells to reduce the number of handoffs required. UMTS aims to support roaming across different networks.

The UMTS Radio Access System (UTRA) will provide at least 144 kbps for full-mobility applications, 384 kbps for limited-mobility applications, and 2.048 Mbps for low-mobility applications. UMTS terminals will be multiband and multimode so that they can work with different standards.

UMTS is also designed to offer data rate on-demand. The network will react to a user's needs, based on his/her profile and current resource availability in the network. UMTS supports the virtual home environment (VHE) concept, where a personal mobile user will continue to experience a consistent set of services even if he/she roams from his/her home network to other UMTS operators. VHE supports a consistent working environment regardless of a user's location or mode of access. UMTS will also support adaptation of requirements due to different data rate availability under different environments, so that users can continue to use their communication services.

To support universal roaming and global coverage, UMTS will include both terrestrial and satellite systems. It will enable roaming with other networks, such as GSM. UMTS will provide a flexible broadband access technology that supports both IP and non-IP traffic in a variety of modes, such as packet, circuit-switched, and virtual circuit.

1.7 IMT2000

The ITU (International Telecommunications Union) has introduced a new framework of standards by the name IMT2000, which is a federation of systems for third-generation mobile telecommunications. IMT2000 aims to provide: (a) high-speed access, (b) support for broadband multimedia services, and (c) universal mo-

bility. Frequency spectrum has been allocated for IMT2000 by the ITU. Several multiple-access protocols based on code division have been proposed by many different countries. The ITU has approved the CDMA2000 radio access system as the CDMA multicarrier member of the IMT2000 family of standards. CDMA2000 is capable of supporting IS-41 and GSM-MAP to ensure backward compatibility. IS-41 is a network protocol standard that supports interoperator roaming [2]. It allows MSCs of different service providers to exchange information about their subscribers to other MSCs on-demand.

1.8 IS-95, cdmaOne and cdma2000 Evolution

The IS-95 [9] air interface was standardized by TIA in July 1993. Networks that utilize IS-95 CDMA [10] air interface and the ANSI-41 network protocol are known as cdmaOne networks. IS-95 networks use one or more 1.25 MHz carriers and operate within the 800 and 1900 MHz frequency bands.

Following the launch of the first cdmaOne network in Hong Kong in 1995, the number of cdmaOne subscribers has grown into millions. cdmaOne networks provide soft handoffs and higher capacity than traditional AMPS networks, with data rates up to 14.4 kbps. CdmaOne is based on IS-95A technology. IS-95B improves this technology further by providing higher data rates for packet- and circuit-switched CDMA data, with data rates up to 115 kbps.

This evolution continues with cdma2000, which is the third generation version of IS-95. This new standard is developed to support third generation services as defined by ITU. cdma2000 is divided into two parts, namely: (a) IS-2000/cdma200 1X, and (b) IS-2000A/cdma2000 3X. cdma2000 1X standard delivers twice the voice capacity of cdmaOne with a data rate of 144 kbps. The term 1X, as derived from 1XRTT (radio transmission technology), is used to signify that the standard carrier on the air interface is 1.25 MHz, which is similar to IS-95A and IS-95B. In cdma2000 3x, the term 3X, derived from 3XRTT, is used to signify three times 1.25 MHz, i.e., 3.75 MHz. cdma2000 3X offers greater capacity than 1X with data rates up to 2 Mbps while retaining backward compatibility with earlier 1X and cdmaOne deployments.

Lately, 3GPP (Third Generation Partnership Project) [11] is formed to defined standards for third generation all-IP networks. It is also responsible for the production of globally applicable technical specifications and reports for a 3G mobile system based on evolved GSM core networks and the radio access technologies that they support (i.e., Universal Terrestrial Radio Access (UTRA) both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes).

1.9 Organization of this Book

This book is organized in a manner that allows a gradual progression of the subject toward more advanced topics. Chapter 2 discusses the origin of ad hoc networks, in particular, the DARPA packet radio networks. Chapter 3 presents a current version of ad hoc networks and related challenges. Since there are no static base stations present in ad hoc wireless networks, centralized access control becomes a problem. Chapter 4 presents current channel access protocols and discusses some emerging protocols. Chapter 5 provides an overview of current ad hoc mobile routing protocols, discussing their principles, features, and operation. Chapter 6 presents a new era of routing known as longevity, or associativity-based routing. This protocol is a major deviation from traditional routing protocols, which use shortest path as the main routing metric. Chapter 7 provides a narration of the implementation of an ad hoc wireless network using a new routing protocol and current-off-the-shelf (COS) hardware. It also provides a discussion of the experimental results obtained via campus field trials. Chapter 8 continues with a discussion of the communication performance of ad hoc wireless networks so that readers can understand the capabilities of such networks and what potential applications can be supported.

The advancement in CPU technology has way surpassed that of battery technology. Hence, Chapter 9 discusses how device power life can affect communication performance and protocol design for ad hoc wireless networks. Multicasting has been widely used to support multiparty communications and conferencing. Chapter 10 provides insight on how ad hoc mobile multicasting can be achieved and presents a survey of current multicasting protocols. It also reveals how associativity or longevity can be applied to ad hoc multicasting.

Since the Internet Protocol (IP) provides unreliable datagram delivery, transmission control protocol has been introduced to provide reliable delivery of information over the internet. Chapter 11 discusses the problems associated with TCP in an ad hoc wireless network environment. Ad hoc networks should provide services to users. Chapter 12 presents existing service discovery protocols that will allow an ad hoc mobile host to discover services present in the network and to access such services.

Commercial realization of ad hoc networks has taken the form of Bluetooth. Chapter 13, therefore, presents a case study of this technology. Prior to the arrival of Bluetooth, the Wireless Access Protocol (WAP) was a popular technology since it enabled a cellular network to support data in addition to voice traffic. Chapter 14, therefore, provides a discussion of WAP. Many people have been wondering about the potential applications of ad hoc networking; Chapter 15 addresses this issue. A conclusion is finally presented in Chapter 16.