IMPLEMENTATION OF GEOCAST-ENHANCED AODVBIS ROUTING PROTOCOL IN MANET

OOI CHIA CHING

UNIVERSITI TEKNOLOGI MALAYSIA

IMPLEMENTATION OF GEOCAST-ENHANCED AODVBIS ROUTING PROTOCOL IN MANET

OOI CHIA CHING

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

OCTOBER 2005

To my dearest parents, siblings and friends
for their love and support to make the journey

ACKNOWLEDGEMENT

I would like to take this opportunity to extend my sincere gratitude and appreciation to many people who made this thesis possible. Special thanks are due to my supervisor, Associate Professor Dr. Norsheila binti Fisal for her invaluable guidance, suggestions and full support in all aspects during the research.

Mega thanks go to the Faculty of Electrical Engineering of Universiti Teknologi Malaysia for the full support in this project. Thanks are also due to UTM-PTP for the research funding.

I would like to express my sincere thanks to Associate Professor Liza binti Abdul Latiff and Mr. Adel Ali as well, for their assistance in conducting the numerous experiments during the research.

Finally, special thanks to all my friends for their unwavering support, concerns and encouragement.

ABSTRACT

Mobile Ad Hoc Network (MANET) has attracted extensive research interests over the past several years. However, far less effort has been done on the real implementation of MANET. This thesis explains the development and implementation of MANET test bed based on geocast-enhanced Ad-hoc On-Demand Distance Vector-bis (AODVbis) routing protocol. The MANET test bed consists of laptops, desktops and PDAs. Each of them was equipped with wireless network cards and configured to run in ad hoc mode. Linux and Familiar OS were chosen as their operating platform due to the open-source nature, which allows free access to the OS kernel especially the network protocol stack. AODVbis is an improved design of AODV routing protocol featuring path accumulation. The AODVbis routing module has been developed by using C language and executed at kernel level. To enhance the AODVbis routing protocol, a geocast-enhancement module has been coded and integrated into AODVbis so that location information can be utilized during the route discovery based on geocast instead of broadcast. A GPS-free location tracking program was installed in each node to obtain the distance value required during route discovery. The results obtained from the verification of AODVbis module shows that the AODVbis is more powerful than AODV especially in route dissemination. With the integration of geocast-enhancement module into AODVbis, the forwarding zone is restricted during route discovery. Consequently, the number of broadcast is significantly reduced especially in a dense network. In general, the geocast-enhanced AODVbis routing protocol has been implemented and verified successfully in the MANET test bed. The experimental results have shown that the average packet delivery ratio is high (more than 90%) while both the average minimum end-to-end delay and average route reconstruction time for a 2-hop communications are reasonably low and within milliseconds.

ABSTRAK

Mobile Ad Hoc Network (MANET) telah menarik perhatian para penyelidik sejak beberapa tahun yang lalu. Namun demikian, kerja penyelidikan melalui implementasi MANET adalah amat terhad. Tesis ini menerangkan proses pembinaan dan implementasi ujikaji MANET yang berdasarkan protokol laluan yang dikenali sebagai geocast-enhanced Ad-hoc On-Demand Distance Vector-bis (AODVbis). Ujikaji MANET ini merangkumi laptop, desktop dan PDA. Semua nod telah dipasang dengan kad rangkaian wayarles dan berfungsi dalam mod ad-hoc. Linux dan Familiar OS telah dipilih sebagai platform operasi sebab kedua-dua OS ini merupakan sumber terbuka. Ia membenarkan akses bebas ke OS kernel terutamanya susunan protokol rangkaian. Protokol AODVbis adalah protokol laluan AODV yang diperkayakan dengan akumulasi laluan. Modul AODVbis ini telah direka dengan menggunakan aturcara C dan dijalankan pada peringkat kernel. Untuk memperkayakan protokol laluan AODVbis, modul geocast telah direka dan digabungkan dengan AODVbis agar maklumat lokasi boleh digunakan semasa pencarian laluan melalui teknik geocast dan bukannya broadcast. Satu program mengesan lokasi nod yang tidak bergantung kepada sistem GPS telah dipasang dalam semua nod untuk mendapatkan nilai jarak antara nod semasa pencarian laluan. Hasil eksperimen telah menunjukkan bahawa AODVbis adalah protokol laluan yang lebih berkesan terutamanya dalam penyebaran laluan kalau dibandingkan dengan AODV. Dengan integrasi modul geocast dengan AODVbis, zon hantaran telah dihadkan semasa pencarian laluan. Oleh itu, jumlah broadcast telah dikurangkan secara mendadak terutamanya dalam rangkaian yang padat. Secara umumnya, protokol laluan geocast-enhanced AODVbis telah berjaya diuji dalam ujikaji MANET. Hasil eksperimen telah menunjukkan bahawa purata nisbah hantaran paket adalah tinggi manakala purata penangguhan hujung-ke-hujung dan purata masa yang diambil untuk mambina laluan dua hop adalah rendah dan dalam lingkungan milisaat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABR	Associativity-based routing
AODV	Ad-hoc On-demand Distance Vector
AP	Access Point
APL	Accumulated Path List
APN	Accumulated Path Node
ARM	Advanced RISC Machines
ARP	Address Resolution Protocol
BBS	Bulletin Board Systems
BSD	Berkeley Software Distribution
CPU	Central Processing Unit
DARPA	Defense Advanced Research Projects Agency
DRAM	Dynamic Random Access Memory
DSN	Destination Sequence Number
DSR	Dynamic Source Routing
FTP	File Transfer Protocol
GCC	GNU Compiler Collection
GNOME	GNU Network Object Model Environment
GPE	GPE Palmtop Environment
GPL	General Public License
GPS	Global Positioning System
GRUB	GRand Unified Boot-loader
GUI	Graphical User Interface
I-D	Internet Draft
I/O	Input/Output
IETF	Internet Engineering Task Force
IP	Internet Protocol

ISM	Industrial, Scientific and Military
JFFS2	Journalling Flash File System2
KDE	K Desktop Environment
KRT	Kernel Route Table
LAN	Local Area Network
LAR	Location Aided Routing
LILO	LInux Loader
LKM	Loadable Kernel Module
MAC	Medium Access Control
MANET	Mobile Ad-hoc Network
MaRS	Maryland Routing Simulator
MPR	Multi-point Relay
NIST	National Institute of Standards and Technology
OLSR	Optimized Link State Routing protocol
OPIE	Open Palmtop Integrated Environment
OS	Operating System
OSI	Open System Interconnect
OSPF	Open Shortest Path First
PA	Path Accumulation
PAN	Personal Area Network
PC	Personal Computer
PCMCIA	Personal Computer Memory Card International Association
PDA	Personal Digital Assistant
PR Net	Packet Radio Network
RAM	Random Access Memory
RERR	Route Error
RFC	Request For Comments
RISC	Reduced Instruction Set Computer
RREP	Route Reply
RREP-ACK	Route Reply Acknowledgment
RREQ	Route Request
RSSI	Received Signal Strength Indicator
RTT	Round Trip Time
SCTP	Stream Control Transmission Protocol

SSID	Service Set Identifier
TBRPF	Topology Based Reverse Path Forwarding routing protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TLB	Translation Look-aside Buffer
TTL	Time-To-Live
UDP	User Datagram Protocol
USB	Universal Serial Bus
WG	Working Group
Wi-Fi	Wireless-Fidelity
ZRP	Zone Routing Protocol

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1 Background and Motivation

Recent advances in wireless communication technology and portable computing devices such as wireless handhelds, Personal Digital Assistants (PDAs) and other mobile information terminals are driving a revolutionary change in our information society towards the era of mobile communications. Mobile users can utilize several electronic platforms simultaneously through which they can access all the necessary information whenever and wherever required [1]. The nature of ubiquitous devices makes wireless networks the easiest solution for their interconnection and, as a consequence, the wireless arena has been experiencing rapid growth in the past decade. Not only are the mobile devices getting smaller, cheaper, more convenient, and more powerful, they also run more applications and network services, thus fueling the explosive growth of mobile computing equipment market. The ever increasing demand for the Internet access anytime anywhere has generated vast interest and intensive works in developing and improving wireless and mobile network protocols for portable computing devices.

Today, the widely deployed network type is based on a centralized approach that requires a network point of access, commonly called the Access Point (AP), to serves as a gateway between the mobile device and the Internet. While infrastructure-based networks provide a great way for mobile devices to gain network services, it takes time and potentially high cost to set up the necessary

infrastructure [2]. Because of the limitation of radio range, radio must be within the vicinity of an AP to be connected. This is undesirable due to the cost of time especially in the marketing world. Additionally, it is important to note that, in the cases of natural catastrophe, war, or geographic isolation, communication infrastructure may be broken down or overloaded; thus, the network connectivity may not be always attainable [3]. In the situations where required networking connections are not available in a given geographic area, providing the needed connectivity and network services becomes a real challenge. Ad hoc technologies have emerged to solve this problem.

Mobile Ad-hoc Network (MANET) is a collection of mobile computing devices that communicate via wireless links, without the aid of infrastructures such as base-station [4]. Its topology is dynamic and nodes are free to join or leave arbitrarily. Traditionally, ad hoc technology has only been exploited in tactical networks to improve battlefield communications. Early ad hoc networking applications can be traced back to the Packet Radio Network (PR Net) project of Defense Advanced Research Projects Agency (DARPA) in 1972, which was primarily inspired by the efficiency of the packet switching technology, such as bandwidth sharing and store-and-forward routing, and its possible application in mobile wireless environment [5]. In the middle of 1990, with the introduction of new enabling technologies such as IEEE 802.11 and Bluetooth, commercial radio technologies have begun to appear on the market [5]. Lately, the wireless research community became aware of the great commercial potential and advantages of MANET outside the military arena due to the wide diversity of the potential MANET applications, ranging from the instantaneous conference in classroom to vehicular services [1].

Due to the characteristics of MANET, an adaptive and distributed routing protocol is necessary to provide a communication platform that is solid and dynamic in the face of widely fluctuating wireless channel characteristics and node mobility. Many existing proposed routing protocols have been evaluated and compared on the basis of simulation results [6, 7, 8, 9, 10]. In reality, connectivity and performance in MANETs can be affected by several factors, such as the limitations of Operating

System (OS) protocol stack and slow buffer allocation, and simulations cannot account for all of them [11].

1.2 Problem Statement

Traditional routing protocol designed for use in wired environment can no longer be applied to wireless and mobile network. Designing of routing protocol in a wireless environment with high mobility is not trivial. Many considerations are required prior to protocol development. The challenges in designing routing protocols for wireless networks include [12]:

a) **Redundant routes** - In wired networks, only one or a small number of routers are used to connect two networks. In wireless network, there may be several gateway nodes due to the wireless channel properties. Using the traditional routing protocol will cause generation of redundant paths and waste of bandwidth, computation and storage.
b) **Periodic routing updates** – Cost of sending routing updates is much greater in a wireless network than in a wired network due to the limitation of bandwidth and energy.
c) **Node mobility** - Wireless network links continuously change due to node mobility and environmental conditions. Convergence to stable routes may be too slow to produce useful information if routing updates are not sent often enough. But if too often, it is a waste of channel bandwidth and device power. Thus, an adaptive routing protocol is necessary.

When routing updates are large and periodic updates are often, high control message overhead is required and thus wastes the bandwidth. Routes may not be energy-efficient. Dynamic topology imposed by mobility may prevent routing protocol convergence as in traditional routing. Hence, to conserve the power consumption, the followings parameters should be taken into consideration when developing a routing protocol [1]:

- Route relaying load
- Battery life in route selection

- Reduction in the frequency of sending control messages
- Optimization of size of control headers
- Efficient route reconfiguration

Secondly, most of the current research works use simulation to investigate the performance issues and evaluate the practicality of realizing a MANET. However, even the most detailed simulation models available do not model various limitations of a real wireless network. These include the limitations of the interface hardware, such as limited buffer space, limitations due to OS protocol stack implementation and slow processor such as slow memory buffer allocation, or various random sources of errors in the wireless physical layer [13]. Simulation often makes many assumptions that are restricted to the expertise level of the researcher.

Apart from that, several research works have pointed out problems that could not be detected by preceding simulation studies. One of them is the gray zone communication problem for IEEE 802.11b based MANET [14]. In such zones, it is possible to receive broadcasts but it is unlikely to successfully send or receive unicast messages. This problem leads to invalid routing table entries for protocols that establish their routes using HELLO messages. Therefore, it made real test bed implementation an important step before developed protocols can be promoted to standards. Constructing a real system is not a trivial task since it is typically expensive and remains limited in terms of working scenarios, mobility models and so on. Hardware and software acquisition need to be done carefully to select the appropriate mobile computing devices and operating platform.

Currently, the MANET routing protocols being proposed in Internet Engineering Task Force (IETF) MANET Working Group (WG) Charter are Ad Hoc on-demand Distance Vector (AODV) [15], Dynamic Source Routing protocol (DSR) [16], Optimized Link State Routing protocol (OLSR) [17] and Topology Based Reverse Path Forwarding protocol (TBRPF) [18]. Performance comparisons have been made among these protocols based on simulation works [6, 7, 8, 9, 10]. In addition to its reactive nature that suits the resource-limited mobile computing devices, AODV has been proved to be in the favorable manner with good performance in most of the simulation works such as those in [19] and [20]. Therefore, AODV has been widely used in the implementation works such as in

UoB-JAdhoc, which is a Java-based AODV implementation by University of Bremen [21] and AODV-UCSB, which is the AODV implementation done by University of California, Santa Barbara [22].

In AODV [15] and AODVbis [23], route request message is broadcast to all reachable neighbors, which will do the same until the desired route is found. Frequent broadcast of route request messages will cause network congestion and degrade the performance of routing protocol. On the other hand, conventional multicast requires the organization of group membership before the data or control message can be distributed [24]. Geocasting algorithm is therefore an interesting alternative to conventional multicast. It defines forwarding and multicast zones based on the geographical location of the nodes [25].

1.3 Research Objectives

The objectives of the research work are to develop an enhanced MANET routing protocol and to verify its operation in a real MANET test bed. The proposed enhanced MANET routing protocol should be able to produce wider route dissemination, reduce the processing delay and routing overhead, and utilize the location information of nodes.

The existing AODVbis routing protocol will be developed and further extended to utilize the position information of nodes for routing purpose. Both the algorithm designs involved in coding the AODVbis routing module and the proposal of the geocast enhancement feature are our original ideas. This geocast-enhanced AODVbis routing protocol should be capable of reducing the routing overhead caused by frequent broadcast of control message in the MANET.

1.4 Scope of Work

The scope of this research work includes the development of MANET test bed consisting of laptops, desktops and PDAs; each of them works on Linux-based operating platform. The AODVbis routing module is developed and coded to run at the kernel space instead of user memory to reduce kernel-to-user crossing delay. The impact of the Path Accumulation feature on the route dissemination in the MANET is studied. The second part of the work involves the coding of the geocast module, which is to be integrated with the AODVbis routing module. This involves the linking of the geocast-enhanced AODVbis routing module with the location information produced by the location monitoring tool, which is installed in each node in the test bed. Once the geocast-enhanced routing protocol is developed, it is verified in the real MANET test bed through several experiments.

1.5 Research Approach

The development process can be broken into six phases. During the first phase, hardware and software required for MANET testbed setup are identified. Hardware includes laptops, desktops and PDAs, equipped with wireless cards or USB adapters, while software means OS, the development tools and the necessary drivers. Linux-based OS is chosen due to its open-source nature, availability and familiarity. Wireless adapters must be able to work with Linux kernel. Lastly, Linux kernel module programming skill is acquired with the aid of [26].

While setting up the MANET test bed, wireless cards and adapters are installed in every participating node in the test bed. Patches for incompatible drivers of wireless adapter are also installed to make sure that the wireless devices works properly in each kernel version of Linux being used. The interoperability among different type of wireless devices is tested as well. A MANET testbed is developed based on the freely available kernel-AODV implementation by National Institute of Standards and Technology (NIST) in United States. Multihop communication is verified to evaluate the practicality of realizing a MANET.

Prior to the designing and coding stage, different types of ad hoc routing protocols are analyzed. Both the AODV and AODVbis routing protocols are reviewed and compared. Next, the state diagrams of AODVbis operation are constructed for each module. The routing module is developed as a loadable kernel module at kernel space to avoid the costly kernel-to-user crossing for store-and-forward and to improve efficiency [27]. No recompilation is required. Since the routing module is operated in kernel space, communication with the user space is done via the Linux /proc file system. Any information especially the routing table can be read by calling the /proc file. Coding is done by C language on Linux-based platform.

The proposed routing module is installed in each participating node in the testbed. MAC-Kill tool is acquired and installed so that testing and debugging can be done within close physical distance among nodes. The GPS-free location detection feature has also been installed in each MANET node so that geocast enhancement in AODVbis can be deployed in the testbed. The geocast-enhanced AODVbis routing module is then verified in the real MANET test bed.

1.6 Significance of Research Work

Implementing a routing protocol in a real test bed is very important to validate its design. Coming up with a clean implementation not only helps better understanding of the protocol nuances, but also allows extensions to explore the protocol design space.

The utilization of node position information in the proposed geocast-enhanced AODVbis routing protocol aids to decrease the number of broadcast message generated in the MANET during the route discovery. Without the use of location information, AODVbis control messages are broadcasted to all neighbors in the network, which could possibly lead to broadcast storm. The geocast enhancement feature is capable to reduce the overall network traffic and the possibility of the occurrence of the broadcast storm.

1.7 Thesis Layout

The content of the thesis is organized as follows. Chapter two describes the generic characteristics of MANET and survey of current routing protocols designed for the highly dynamic MANET. Not all protocols are mentioned here, but rather those protocols that are intuitively relevant for our case of network.

Chapter three depicts the setup and configurations of MANET testbed, by pointing out some relevant topics such as the development platform including hardware and software, the interaction between user and kernel space of the OS in question and the functional representation of the whole work.

The test bed is set up to run the AODVbis routing module. The details of the development of AODVbis routing module are presented in chapter four while chapter five portrays the different test scenarios and the results obtained during the implementation and the verification of the developed routing module in the MANET test bed.

Chapter six elaborates the development and verification of the geocast-enhanced AODVbis routing module with the aid of the log messages generated by participating node in the test bed and finally, chapter seven presents the conclusions of the thesis and identifies some areas for future work.

REFERENCES

1. Imrich Chlamtac, Marco Conti, and Jennifer J. –N. Liu. Mobile Ad-hoc Networking: Imperatives and Challenges. *Elsevier Ad Hoc Networks Journal.* 2003. Vol. 1(1): 13-64.
2. Qi Xue and Aura Ganz. Adaptive Routing in Ubiquitous Mobile Access Networks. *Proceedings of IEEE VTC.* 6-9 October, 2003. Orlando, Florida: IEEE. 2003. 3070-6074.
3. N. Milanovic, M. Malek, A. Davidson, V. Milutinovic. Routing and Security in Mobile Ad hoc Network. *IEEE Computer Journal.* 2004. 37(2): 61-65.
4. Jun-Zhao Sun. Mobile Ad Hoc Networking: An Essential Technology for Pervasive Computing. *Proceedings of IEEE ICII 2001*. 29 Oct.-1 Nov 2001. Beijing: IEEE. 2001. 316-321.
5. Farid Dowla. Mobile Ad Hoc Networks. In: *Handbook of RF and Wireless Technologies*. Elsevier, 2004.
6. D. Kotz, C. Newport, R. S. Gray, J. Liu, Y. Yuan, C. Elliott. Experimental Evaluation of Wireless Simulation Assumptions. *Proceedings of 7th ACM Internaltional Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems.* Oct. 2004. Italy: ACM. 2004. 78-81.
7. S. R. Das, R. Castaneda, and J. Yan. Simulation Based Performance Evaluation of Mobile Ad-hoc Network Routing Protocols. *Mobile Networks and Applications, Kluwer.* 2000. 5(3):179-189.
8. S. R. Das, C. Perkins, and E. M. Royer. Performance Comparison of Two On-demand Routing Protocols for Ad hoc Networks. *Proceedings of IEEE INFOCOM 2000.* 26-30 March, 2000. Israel: IEEE. 2000. 3-12.
9. D. A. Maltz, J. Broch, J. Jetcheva, and D. B. Johnson. The Effects of On-demand Behavior in Routing Protocols for Multi-hop Wireless Ad hoc Networks. *IEEE Journal on Selected Areas in Communications Special Issue on Mobile and Wireless Networks.* 1999. 17(8): 1439-1453.

10. E. M. Royer and C.-K. Toh. A Review of Current Routing Protocols for Ad hoc Mobile Wireless Networks. *IEEE Personal Communications.* 1999. 6(2):46-55.
11. Kwan-Wu Chin, John Judge, Aidan Williams and Roger Kermode. Implementation Experience with MANET Routing Protocols. *ACM SIGCOMM Computer Communications Review*. 2002. 32(5): 49-59.
12. J. Wu. An Extended Dynamic Source Routing Scheme in Ad Hoc Wireless Networks. *Proceedings of HICSS 2002.* 7-10 Jan., 2002. Hawaii: IEEE. 2002.
13. Saman Desilva, and Samir R. Das. Experimental Evaluation of a Wireless Ad Hoc Network. Oct., 2000. *Proceedings of the 9th IC3N.* Las Vegas. 2000.
14. H. Lungren, E. Nordstrom and C. Tschudin. Coping with Communication Gray Zones in IEEE 802.11b Based Ad hoc Networks. *Proceedings of 5th ACM International Workshop on Wireless Mobile Multimedia.* Georgia: ACM. 2002. 49-55.
15. C. E. Perkins and E. M. Royer. Ad-hoc On Demand Distance Vector (AODV) Routing. *Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications.* Feb. 1999. New Orleans: IEEE. 1999. 90-100.
16. David B. Johnson, David A. Maltz, and J. Broch. Lessons from A Full-scale Multihop Wireless Ad hoc Network Testbed. *IEEE Personal Communications.* 2001. 8(1): 8-15.
17. T. Clausen and P. Jacquet. Optimized Link State Routing Protocol (OLSR). *RFC 3626 of IETF MANET WG.* October, 2003.
18. R. Ogier, M. Lewis and F. Templin. Topology-Dissemination Based on Reverse-Path Forwarding (TBRPF). *RFC 3684 of IETF MANET WG.* February, 2004.
19. J. Broch, D. A. Maltz, D. B. Johnson, Y. C. Hu, J. Jetcheva. A Performance Comparison of Multi-hop Wireless Ad hoc Network Routing Protocol. *Proceedings of ACM/IEEE International Conference on MobiCom'98.* October 1998. Dallas: ACM/IEEE. 1998. 85-97.
20. P. Johanson, T. Larsson, N. Hedman, B. Mielczarek and M. Degermark. Scenario-based Performance Analysis of Routing Protocols for Mobile Ad-hoc Networks. *Proceedings of ACM/IEEE International Conference on MobiCom'99.* August, 1999. Seattle: ACM/IEEE. 195-206. 1999.

21. K. Kuladinithi, A. Udugama, N.A. Fikouras, A. Timm-Giel, C. Görg, Experimental Evaluation of AODV Implementations. *Proceedings of CEWIT 2004.* Oct 2004. New York. 2004.

22. Ian D. Chakeres, Elizabeth M. Belding-Royer. AODV Routing Protocol Implementation Design. *Proceedings of 24th ICDCSW 2004.* 23-24 March, 2004. Tokyo: IEEE. 2004. 698-703.

23. C. E. Perkins, E. M. Royer, and Ian D. Chakeres. Ad hoc On Demand Distance Vector-bis (AODVbis) routing. *Internet Draft of IETF MANET WG.* Oct. 2003.

24. Sang Ho Bae, Sung-Ju Lee, and Mario Gerla. Multicast Protocol Implementation and Validation in an Ad hoc Network Testbed. *Proceedings of IEEE ICC 2001*. June, 2001. Helsinki, Finland: IEEE. 2001. 3196-3200.

25. Young-Bae Ko and N.H. Vaidya. Location-Aided Routing (LAR) in Mobile Ad Hoc Networks. *ACM/Baltzer Wireless Networks Journal.* 2000. 6(4):307-321.

26. Peter Jay Salzman and Ori Pomerantz, *The Linux Kernel Module Programming Guide*. 2003-04-04 ver 2.4.0. Copyright © 2001 Peter Jay Salzman. 2003.

27. Vikas Kawadia, Yongguang Zhang, and Binita Gupta. System Services for Ad-Hoc Routing: Architecture, Implementation and Experiences. *Proceedings of The First International Conference on MobiSys'03*. May, 2003. California. 2003.

28. I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci. Wireless Sensor Networks: a survey. *Elsevier Computer Networks Journal*. 2002. 38(4): 393-422.

29. Jie Wu and Ivan Stojmenovic. Ad Hoc Networks. *Journal of IEEE Computer Society*. 2004. 29-31.

30. Tatsuaki Osafune, Kazuya Monden, Shoji Fukuzawa, and Susumu Matsui. Performance Measurement of Mobile Ad Hoc Network for Application to Internet-ITS. *Proceedings of the 2004 International SAINT'04.* Jan., 2004. Tokyo: IEEE. 2004. 25-30.

31. D. M. Blough, G. Resta, P. Santi. A Statistical Analysis of The Long-run Node Spatial Distribution in Mobile Ad hoc Networks. *Proceedings of the 5th ACM MSWIM'02.* Sep. 2002. Atlanta: ACM. 2002. 30-37.

32. Jon Klstad, and Andreas Lundin. Ad-hoc Routing. *Term Paper of CS4274 NUS.* 2003.

33. Zygmunt J. Haas and Marc R. Pearlman. The Zone Routing Protocol (ZRP) for Ad Hoc Networks. *Internet Draft of IETF MANET Working Group*. June, 1999.

34. Hari Rangarajan and J. J. Garcia-Luna-Aceves. Achieving Loop-Free Incremental Routing in Ad Hoc Networks. *Proc. of the 9th ISCC'04.* July 2004. Alexandria, Egypt: IEEE. 2004.

35. Hari Rangarajan and J.J. Garcia-Luna-Aceves. Path Verification for Robust, Instantaneous Loop-Free Routing in Ad hoc Networks, *Proceedings of the 2005 WCNC 2005.* March 2005. New Orleans: IEEE. 2005.

36. J. P. Macker and M. S. Corson. Mobile Ad Hoc Networking and the IETF. *ACM Mobile Computing and Communications Review*, 1999. 3(2).

37. Ian D. Chakeres, and Luke Klein-Berndt. AODVjr, AODV Simplified. *Mobile Computing and Communications Review*, 2002. 6(3): 1-2.

38. Charles Perkins. Convergence in Ad hoc Networking Protocol. *The IASTED International Conference on WNET 2004*. July, 2004.

39. H. Lundgren, D. Lundberg, J. Nielsen, E. Nordstrom and C. F. Tschudin. A Large-scale Testbed for Reproducible Ad Hoc Protocol Evaluations. *Proceedings of IEEE WCNC'02.* March 2002.

40. David A. Maltz, Josh Broch, and David B. Johnson. Experiences Designing and Building a Multi-hop Wireless Ad Hoc Network Testbed. *CMU Technical Report CMU-CS-99-116.* 1999.

41. C.-K. Toh, Minar Delwar and Donald Allen. Evaluating the Communication Performance of an Ad Hoc Wireless Network. *IEEE Transactions on Wireless Communications.* 2002. 1(3): 402-414.

42. T.H. Clausen, G. Hansen, L. Christensen and G. Behrmann. The Optimized Link State Routing Protocol, Evaluation through Experiments and Simulation. *Proceedings of IEEE Symposium on Wireless Personal Mobile Communications.* Sep., 2001.

43. Yongguang Zhang, Wei Li. An Integrated Environment for Testing Mobile Ad-hoc Networks. *Proceedings of the 3rd ACM international symposium on Mobile ad hoc networking & computing.* June, 2002. Lausane: ACM. 2002.

44. C. E. Perkins, E. M. Royer, and S. R. Das. Ad-hoc On Demand Distance Vector (AODV) routing. *RFC 3561 of IETFMANET WG.* July 2003.

45. A. Ali, L. A. Latiff, N. Fisal. GPS-Free Indoor Location Tracking in Mobile Ad hoc Network (MANET) using RSSI. *Proceedings of RFM 2004.* Aug., 2004.