

**PERFORMANCE EVALUATION OF IPSec
IMPLEMENTATION IN IPV4 AND IPV6
NETWORKS**

**A Thesis submitted to the Graduate School in fulfillment
of the requirements for the degree of
Master of Science (Information Technology)
Universiti Utara Malaysia**

**By
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ABSTRACT

The fast proliferation and advancement of the Internet technology nowadays have led to an alarming increase of security issues of the whole network operation. The insecure nature of Internet today that based on Internet Protocol version 4 (IPv4) has a number of security problems. This scenario has driven for the development of many security protocols and one of them is Internet Protocol Security (IPSec). As a replacement for IPv4, Internet Protocol version 6 (IPv6) has a new security feature beside of its other new features. IPv6 implemented with security architecture which is called IPSec. The implementation of IPSec in IPv6 is mandated. Meanwhile for IPv4, IPSec is optional. This research aims to implement IPSec, to test, and then to perform the network performance evaluation in order to analyze and assess the impact of the IPSec implementation over IPv6 network as compared to IPv4 network. The tests have been done using network performance tools, namely Netperf and ICMP programs. In order to accomplish the performance evaluation, an IPv6 testbed which is called 6iNet has been developed at Universiti Utara Malaysia (UUM). This testbed has been developed as a platform to perform the related tests and tasks. The methodology used in this research is adopted from the IPv6 project of National Institute of Standard and Technology (NIST). This methodology has been modified to suite on LAN academic network and related tasks. The deployment of IPv6 testbed can be utilized to spearhead the implementation of operational IPv6 network in UUM in the future. From this study, we hope that the results of the experiments will give us the opportunity to understand the IPv6 architecture before any real implementation can take place. In addition, we hope that 6iNet will become a platform for various works over IPv6 in UUM.

ABSTRAK

Perkembangan yang pantas dalam teknologi Internet hari ini telah membawa kepada amaran terhadap isu-isu keselamatan bagi keseluruhan operasi rangkaian. Internet hari ini yang berasaskan Internet Protocol version 4 (IPv4) yang secara semulajadinya adalah tidak selamat, mempunyai masalah dari segi keselamatan. Senario ini telah membawa kepada pembangunan protokol-protokol keselamatan dan salah satu daripadanya ialah Internet Protocol Security (IPSec). Internet Protocol version 6 (IPv6), sebagai pengganti kepada IPv4 mempunyai satu ciri baru keselamatan di samping ciri-ciri barunya yang lain. Keselamatan dalam IPv6 adalah berasaskan ciri bina dalam dan IPSec adalah mandatori. Sementara itu, IPSec adalah sesuatu perkhidmatan pilihan di dalam IPv4. Tujuan penyelidikan ini adalah untuk melaksanakan IPSec, melakukan pengujian, dan kemudiannya mempersembahkan penilaian pelaksanaan IPSec agar kesan pelaksanaan IPSec ke atas rangkaian IPv6 berbanding rangkaian IPv4 dapat dianalisis dan ditaksirkan. Ujian-ujian tersebut telah dijalankan dengan menggunakan peralatan pelaksanaan rangkaian iaitu Netperf dan program ICMP. Bagi menyempurnakan penilaian pelaksanaan tersebut, satu medan uji IPv6 yang dipanggil "Sintok IPv6 Network" atau secara ringkasnya, 6iNet telah dibangunkan di Universiti Utara Malaysia sebagai platform untuk menjalankan ujian-ujian yang berkaitan dengan penyelidikan ini. Beberapa ujian yang berkaitan juga telah dijalankan untuk membuktikan bahawa medan uji IPv6 tersebut beroperasi dengan betul. Metodologi yang digunakan di dalam penyelidikan ini pula diadaptasi dari projek IPv6 daripada National Institute of Standard and Technology (NIST). Metodologi ini juga telah diubahsuai agar bersesuaian dengan rangkaian akademik LAN dan penyelidikan ini. Pembangunan 6iNet ini didapati boleh digunakan sebagai teraju kepada pelaksanaan rangkaian IPv6 yang beroperasi di UUM pada masa hadapan. Justeru, melalui penyelidikan ini, diharapkan dapat memberi lebih banyak peluang untuk memahami teknologi dan masalah-masalah dalam IPv6 sebelum pelaksanaannya yang sebenar mengambil alih. Medan uji IPv6 ini juga diharapkan akan menjadi satu platform bagi pelbagai penyelidikan yang seterusnya ke atas IPv6 di UUM.

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Abbreviations

6iNet	Sintok IPv6 Network
6INIT	IPv6 Initiative
6WINIT	IPv6 Wireless Internet Initiative
AH	Authentication Header
APIs	Application Programming Interfaces
ARPANET	Advanced Research Projects Agency Network
ATM	Asynchronous Transfer Mode
Avg	Average
BSD	Berkeley Software Distribution
CC	Computer Centre
CET	Cisco Encryption Technology
CSRG	Computer Systems Research Group
DHCP	Dynamic host configuration protocol
DNS	Domain name system
DoS	Denial of Service
DSTM	Dual Stack Transition Mechanism
ESP	Encapsulating Security Protocol
FIT	Faculty of Information Technology
FreeS/WAN	Free Software for Secure Wide Area Network

GTK	GIMP Tool Kit
GUI	Graphical User Interface
HP	Hewlett Packard
HTML	Hypertext Markup Language
ICMP	Internet Control Message Protocol
ICMPV6	Internet Control Message Protocol version Six
ICV	Integrity Check Value
IETF	Internet Engineering Task Force
IKE	Internet Key Exchange
IOS	Internetwork Operating System
IP	Internet Protocol
IPng	Next Generation Internet Protocol
IPSec	Internet Protocol Security
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ISAKMP	Internet Security Association and Key Management Protocol
ISATAP	Intra-site Automatic Tunnel Addressing Protocol
ISLAN	Integrated Sintok Local Area Network
ISP	Internet Service Provider
L2TP	Layer 2 Tunneling Protocol

LAN	Local Area Network
MANIS	Malaysian Advanced Network Integrated System
Max	Maximum
Mbps	Mega bits per second
Mdev	Mean Deviation
MIMOS	The Malaysian Institute of Microelectronic Systems
Min	Minimum
MS	Milliseconds
MSC	Multimedia Super Corridor
NAT	Network Address Translation
NAT-PT	Network Address Translation-Protocol Translation
NGTrans	Next Generation Transition
NIC	Network Interface Card
NIST	National Institute of Standards and Technology
NRENs	National Research and Education Networks
OS	Operating System
PC	Personal Computer
QoS	Quality of Service
RFC	Request For Comment
RTT	Round Trip Time

SA	Security Association
SAD	Security Association Database
SPD	Security Policy Database
SPI	Security Parameter Index
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol/Internet protocol
UDP	User Datagram Protocol
UPM	Universiti Putra Malaysia
USM	Universiti Sains Malaysia
US	United State
USAGI	Universal Playground for IPv6
UTM	University Teknologi Malaysia
UTP	Unshielded Twisted Pair
UUM	Universiti Utara Malaysia
VPN	Virtual Private Network
WIDE	Widely Integrated Distributed Environment
WWW	World Wide Web

Chapter 1

INTRODUCTION

Internet Protocol version six (IPv6) is the new Internet Protocol (IP) designed by the Internet Engineering Task Force (IETF) to replace the current version, Internet Protocol version four (IPv4) which was developed almost three decades ago. IPv4 is the most dominant communication protocol used in the Internet and network today. Originally, IPv4 was proven to be robust and used in trusted closed environment. IPv4 didn't require any security mechanisms for protecting host or network elements from external attacks or attacks to the host from each other [36]. Although IPv4 is well designed, data communication and Internet technology has expanded. IPv4 has some deficiencies that make it inappropriate for the current Internet. Now, IPv4 becomes the most popular protocol that is used with all of its inherited flexibility and insecure characteristic as it was originally developed.

In order to overcome these deficiencies, IPv6 was proposed. IPv6 contains numerous features that make it attractive especially from the security standpoint. This is due to the feature of IPv6 mandates the use of the security architecture for the IP, known as Internet Protocol Security (IPSec). IPSec has been defined as an integral part of IPv6. IPv6 has been designed in its way to satisfy the growing and expanded need for the network security. In IPv4 implementation, IPSec is an optional component. As a result,

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References

- [1] 6WINIT. IPv6 Wireless Internet Initiative. *Electronics and Computer Science, University of Southampton*, 2004. [Online]. Available: <http://www.6winit.org/>. [Accessed: Aug. 27, 2004].
- [2] S. Ariga, M. Minami, H. Esaki, and J. Murai. "Performance evaluation of data transmission using IPSec over IPv6 networks". Technical report, Inet Japan, 2000. [Online]. Available: <http://www.isoc.org/inet2000/>. [Accessed: Dec. 26, 2004].
- [3] Engineering Research Centers Association. "Attachment 6-4:Glossary". *Internet Article*, 2000. [Online]. Available: <http://www.erc-assoc.org/manual/>. [Accessed: June 12, 2004].
- [4] T. Aurish and C. Karg. "Securing the network: Comparing IP security implementations with respect to the Internet Protocol 6". *In the proceeding of Research and Technology Symposium (7th ICCRTS)*, 2002.
- [5] R. Blum. *Network Performance Open Source Toolkit*. Wiley Publishing, Inc., Indianapolis, Indiana, 2003.
- [6] F. Budd and D. Gray. "Security-A focus on IPSec". Technical report, WiTel Communications, 2002. White Paper.

- [7] E. Carmes. "The transition to IPv6". *ISOC Member Briefing Number 6: IPv6 Series*, 2002.
- [8] S. T. Chopra and R. P. Canale. "Numerical methods for engineers". McGraw-Hill, international edition edition, 1998.
- [9] Cisco. Configuring IPsec network security. Technical report, Cisco System, Inc., 2003.
- [10] European Commission. The 6net Project. *Information Society Technologies Programme of the European Commission*, 2003. [Online]. Available: <http://www.ipv6.ac.uk/docs/020327-networkshop-cisco.ppt>. [Accessed: Sept. 25, 2004].
- [11] Hewlett-Packard Company. *Netperf: A Network Performance Benchmark Revision 2.0*. Hewlett-Packard Company, 2 edition, February 1995.
- [12] Microsoft Corporation. Internet Protocol version 6. *Microsoft Research*, 2005. [Online]. Available: <http://research.microsoft.com/msripv6/>. [Accessed: April. 14, 2005].
- [13] N. Doraswamy and D. Harkins. *IPsec: The New Security Standard for the Internet, Intranets, and Virtual Private Network*. Prentice Hall, Inc., New Jersey 07458, second edition, 2003.
- [14] H. Feyrer. "The future of the Internet". *Internet Article*, May 2001. [Online]. Available: <http://www.onlamp.com/>. [Accessed: Jan 12, 2005].
- [15] B. Fink. IPv6 Backbone (6bone). *Internet Official Site*, 1997. [Online]. Available: <http://www.ietf.org/html.charters/OLD/6bone-charter.html>. [Accessed: June. 15, 2004].

- [16] R. L. Fink. "IPv6: What and where it is". *The Internet Protocol Journal of Cisco System*, Volume 2(Issue 1), March 1999.
- [17] M. E. Fiuczynski, V. K. Lam, and B. N. Bershad. "The design and implementation of an IPv6/IPv4 address and protocol translator". *In proceeding of USENIX Annual Technical Conference*, June 1998.
- [18] B. A. Forouzan. *Data Communication and Networking*. Mc Graw Hill, Singapore, 2 edition, 2000.
- [19] FreeS/WAN.org. "Linux FreeS/WAN". *Webpage, FreeS/WAN.org*, 2003. [Online]. Available: <http://www.freeswan.org/index.html>. [Accessed: June 25, 2004].
- [20] R. Glenn, J. Wack, and H. Fang. "Project: IPv6 technology". Technical report, National Institute of Standards and Technology, 1996.
- [21] J. He and M. Sato. *Advances in Computing Science-Asian 2000*. Springer, January 2001.
- [22] R. Hinden. "IPng implementations". *Internet Article*, August 2002. [Online]. Available: <http://playground.sun.com/pub/ipng/html/ipngimplementations.html>. [Accessed: Sept. 12, 2004].
- [23] Internet Engineering Task Force (IETF). 6Bone. *IETF IPng*, 2003. [Online]. Available: <http://www.6bone.net>. [Accessed: June. 25, 2004].
- [24] Cisco System Inc. IPsec. Technical report, Cisco System, Inc., 1998.
- [25] Linux Online inc. "What is Linux". *Linux Web Page*, 2005. [Online]. Available: <http://linux.org/>. [Accessed: June 25, 2004].
- [26] Red Hat Inc. "Red Hat". Technical report, Red Hat Inc., 2006. [Online]. Available: <http://www.redhat.com/>. [Accessed: Jan. 12, 2004].

- [27] Ixiacom. "Internet Protocol version 6 (IPv6) conformance and performance testing". Technical report, Ixiacom, January 2004. White Papers and guide.
- [28] R. Jones. "Welcome to the Netperf Homepage". Technical report, Netperf.org, 2005. [Online]. Available: <http://www.netperf.org/netperf/NetperfPage.html>. [Accessed: March. 15, 2005].
- [29] S. Kent and R. Atkinson. IP Authentication Header (AH). RFC 2402, November 1998.
- [30] S. Kent and R. Atkinson. IP Encapsulating Security Payload (ESP). RFC 2406, November 1998.
- [31] S. Kent and R. Atkinson. Security Architecture for the Internet Protocol. RFC 2401, November 1998.
- [32] G. C. Kessler. "IPv6: The Next Generation Internet Protocol". *In Handbook on Local Area Network*, August 1997.
- [33] G. Labouret. "IPSec: a technical overview". Technical report, Herve' Schauer Consultants, June 2000.
- [34] U. Lamping, R. Sharpe, and E. Warnicke. "Introduction: What is Ethereal". *Ethereal User's Guide*, 2005. [Online]. Available: <http://www.ethereal.com/>. [Accessed: June. 20, 2005].
- [35] Z. Li and J. Tian. "The next generation Internet Protocol and its test". *IEEE Journal*, pages 210–211, 2001.
- [36] F. Majstor. "Does IPv6 protocol solve all security problems of IPv4?". Technical report, Cisco System, 2003.
- [37] P. S. Mann. "*Statistic*". John Wiley And Son Inc, 5th ed edition, 2004.

- [38] R. Molva. "Internet security architecture". *Computers Network Journal*, (31):787-804, 2004.
- [39] G. A. A. Murshed and D. Komosny. "Comparison of IPv4 and IPv6". *Internet Article*, August 2004.
- [40] Courtesy of Cisco Enterprise Marketing. "IPv6 at a glance". Technical report, Cisco System, Inc., 2004.
- [41] Indiana Department of Education. "Definition of Terms". *Internet Article*, January 2005. [Online]. Available: <http://www.doe.state.in.us/asap/definitions.html>. [Accessed: Jan. 12, 2007].
- [42] University of Southampton, University College London, and Lancaster University. IPv6 Trials on UK Academic Networks : Bermuda 2. *United Kingdom Universities os Southampton, UCL and Lancaster*, 2004. [Online]. Available: <http://www.ipv6.ac.uk/bermuda2/>. [Accessed: Sept. 17, 2004].
- [43] A. D. Orebaugh. *Ethereal Packet Sniffing*. 1932266828. Syngress Publishing, Inc., Rockland, MA, 1st edition, February 2004.
- [44] S. Peterson. "extension of a network scanning tool with IPv6 features (IPv6)". Master's thesis, Faculty of Applied Science, Montefiore Electricity Institute, University of Liege, 2001-2002.
- [45] PC Pitstop. PC Pitstop Ping Test. *Internet Web Page*, 2006. [Online]. Available at <http://pcpitstop.com/internet/pinger.asp>.
- [46] J. Postel. Internet Protocol. RFC 791, September 1981.
- [47] I. Raicu. "An empirical analysis og internet protocol version 6 (IPv6)". Master's thesis, Graduate School of Wayne State University, 2002.

- [48] Research and Education Networks. The IPv6 forum. *North American IPv6 Task Force*, 1999. [Online]. Available: <http://www.ipv6forum.com>. [Accessed: Sept. 25, 2005].
- [49] S. Roa. "IPv6: An answer to build future network for the information society". *In the proceeding of Next Generation Networks Workshop*, 2000. [Online]. Available: <http://www.6init.or/presentation.html>. [Accessed: June. 25, 2004].
- [50] B. Robinson. Migrating to IPv6. *Internet Article*, 2006. [Online]. Available: <http://www.fcw.com>. [Accessed: Sept, 26, 2004].
- [51] Cisco IOS Learning Services. The ABCs of IP version 6. Technical report, Cisco Systems, Inc., 2000.
- [52] G. R. Sinniah. "The development of IPv6 technology in Malaysia: issues and solutions". *In the proceeding of APAN 2003 Fukuoka Conference*, 2003.
- [53] Sourceforge.net. IPSec-Tools. *IPSec-Tools Project Page*, November 2005. [Online]. Available: <http://ipsec-tools.sourceforge.net/>. [Accessed: June. 13, 2005].
- [54] L. Taylor. "Understanding IPSec". *Intranet Journal*, June 2002. [Online]. Available: <http://www.intranetjournal.com/articles/>. [Accessed: May 26, 2005].
- [55] TechTarget.com. "Performance". *General Computing Terms*, 2001. [Online]. Available: <http://whatis.techtarget.com/definition>. [Accessed: Jan. 2, 2006].
- [56] TechTarget.com. "Throughput". *General Computing Terms*, 2001. [Online]. Available: <http://whatis.techtarget.com/definition>. [Accessed: Jan. 2, 2006].
- [57] I. Tengwall. "Security in IPv4, IPv6 and IPSEC". Master's thesis, Department of Computer Engineering, Chalmers University of Technology, February 1997.
- [58] J. Thomas and A.J. Elbirt. "Understanding internet protocol security". *Internet Article*, 2005.

- [59] H. Tom. "Testbed". Technical report, DLI UIUC Glossary, 1198. [Online]. Available: <http://dli.grainger.uiuc.edu/glossary.htm>. [Accessed: June 5, 2004].
- [60] USAGI. USAGI (Universal Playground for IPv6) Linux IPv6 Development Project. *Internet Web Page*, 2005. [Online]. Available: <http://www.linux-ipv6.org>. [Accessed: Jan. 25, 2004].
- [61] M. H. Warfield. "Security implications of IPv6". *Internet Security System. Inc.*, 2003.
- [62] Wikipedia. "IPv4". *Internet Free Encyclopedia*, 2005. [Online]. Available: <http://en.wikipedia.org/wiki/>. [Accessed: Aug. 18, 2005].
- [63] Wikipedia. "Ethereal". *Internet Free Encyclopedia*, 2006. [Online]. Available: <http://en.wikipedia.org/wiki/>. [Accessed: Aug. 18, 2005].