

**CHARACTERIZATION OF INTERNET TRAFFIC IN UUM  
WIRELESS NETWORKS**

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# CHARACTERIZATION OF INTERNET TRAFFIC IN UUM WIRELESS NETWORKS

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## **ABSTRACT**

The development in communication technology and the propagation of mobile devices, lightweight, with built-in, high-speed radio access in wireless are making wireless access to the Internet the popular situation rather than a wire line. Whereas, the growth of the wireless network with additional mobile devices in the UUM and increasing number of users led to slow wireless connection. Therefore, understanding the behavior of traffic analysis helps us to develop, manage WLAN technology, and deploy. It help us to apply our workload analysis results to issues in wireless network deployment, such as capacity planning, and potential network optimizations, such as algorithms for load balancing across multiple Access Points (APs) in a wireless network. The trace composes of two parts: firstly, one that connects to the core switch in computer center which is connected with the distribution switches that link the Access Point (APs) with the wireless network at campus, and secondly, another one for the measurement of bulk data transfers and interactive data exchange between two nodes in UUM library, which had been initiated at that time. This thesis investigates the performance network and users' behavior in UUM wireless network.

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## LIST OF ABBREVIATION

AAA	Authentication, Authorization and Accounting Administrations.
AM	Amplitude Modulation.
ASK	Amplitude Shift Keying.
ASN	Access Service Network.
ASP	Application Service Provider.
AWGN	Additive White Gaussian Noise.
BER	Bit Error Rate.
BPSK	Binary Phase Shift Keying.
BS	Base Station.
DA	Destination Address
CC	Convolution Code.
CEPT	European Conference of Postal and Telecommunications.
CMIP	Common Management Information Protocol
CSN	Connectivity Service Network.
DAA	Detect and Avoid.
DKG	Dewan Kuliah Gugusan.
DL	Downlink.
DNS	Domain Name System.
DoS	Denial of Service.
DPSK	Differential Phase Shift Keying.
DPP	Dewan Penginapan Pelajar.
DPP YAB	Dewan Penginapan Pelajar Yagasan Al-Buqhari.
DSL	Digital Subscriber Line.
DSSS	Direct sequence Spread Spectrum.
DUR	Downlink to Uplink Ratio.
ECC	Electronic Communications Committee.
FCC	Federal Communications Commission.
FDM	Frequency Division Multiplexing.
FDMA	Frequency Division Multiple Access.
EDC	Executive Development Center.
FEC	Forward Error Correction.

FFT	Fast Fourier Transform.
FHSS	Frequency-hopping spread spectrum.
FTAM	File Transfer and Access Management Protocol
FTM	File Transfer Protocol
FTM	Fakulti Teknologi Maklumat
FM	Frequency Modulation.
FPAU	Fakulti Pengajian Antarabangsa dan Undang-Undang.
FSK	Frequency Shift Keying.
GW	Gateway.
HAP	High Altitude Platform.
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronic Engineers.
IFFT	Inverse Fast Fourier Transform.
IMS	IP Multimedia Subsystem.
IP	Internet Protocol.
ISI	Inter Symbol Interference.
ISP	Internet service provider.
ITU	International Telecommunication Union.
LAN	Local Area Network.
LOS	Line of Sight.
LTE	Long Term Evaluation.
MAC	Media Access Control.
MB-OFDM	Multiband OFDM.
Mbps	Mega bit per second.
MBWA	Mobile Broadband Wireless Access.
MFSK	Multiple Frequency Shift Keying.
MGF	Moment Generating Function.
MPSK	Multilevel Phase Shift Keying.
MS	Mobile Station.
MTRNG	Mersenne Twister Random Number Generator.
NLOS	None-Line of Sight.
NS	Network Simulator.
NSP	Network Service Provider.
NWG	Network Group.

OECD	Organization for Economic Co-operation and Development.
OFDM	Orthogonal Frequency Division Multiplexing.
OFDMA	Orthogonal Frequency Division Multiple Access.
PAPR	Peak-to-Average Power Ratio.
PE	Probability of Error.
PHY	Physical layer.
PK	Pusat Komputer.
PSD	Power Spectral Density.
PSK	Phase Shift Keying.
PSTN	Public Switched Telephone Network.
PUSC	Partially Used Sub-Carrier.
QAM	Quadrature Amplitude Modulation.
QoS	Quality of Service.
QPSK	Quadrature Phase Shift Keying
RA	Receiver Address
RNG	Random Number Generator.
RS	Reed-Solomon.
RSNA	Robust Security Network Association
SMTP	Simple Mail Transfer Protocol
SNR	Signal to Noise Ratio.
SS	Subscriber station.
STA	Station
TDMA	Time Division Multiple Access.
TA	Transmitter Address.
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UP	Uplink.
Wi-Fi	Wireless Fidelity.
WiMAX	Worldwide Interoperability for Microwave Access.
WLAN	Wireless Local Area Network.
WMAN	Wireless Metropolitan Area Network.

# **CHAPTER ONE**

## **INTRODUCTION**

In this chapter, wireless characterization is discussed in order to improve communication performance. This chapter highlights the concepts of Wi-Fi in term of standards and protocols. The attempt is to improve wireless services by study the characterization of UUM wireless network. The research problem, objectives and research questions together with significance of the study are included in this chapter.

### **1.1 BACKGROUND**

The development in communication technology and the widespread use of Mobile devices that are lightweight, compact, high speed radio access in wireless technology are increasingly popularizing wireless access to the Internet. WLAN runs on IEEE 802.11 technology and are catering to connectivity in various places such as, universities, companies, corporation, and even in public places such as shopping malls, airports, lounges, and libraries, etc.; in other words, where personnel spend a considerable amount of time outside of work and home. In Malaysia, most of connections to the networks depend on wireless network and most of these rely on free frequency 2.4 and 5GHZ. The environment in this is study on the University Utara Malaysia (UUM). A few areas of information technology are developing so rapidly as that of the current Wireless - LAN (WLAN). Always, new Wireless – Standards are adopted by the demands for ever increasing data throughout and greater range [1, 2]. In 2005, there are ten completely new wireless technologies [3]. The needs for security requirements, so far doesn't indicate the signs of existence, and it is well known that wireless networking's update occurs most of the time and this includes the telecommunications field which in turn has many classifications or

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## REFERENCES

- [1] D. M. Anurag Kumar, Joy Kuri, *Wireless networking 2009*.
- [2] J. Feng, *Wireless networks*, 2011.
- [3] Alberto Escudero P. Sebastian Buettrich, "*Basic Wireless Infrastructure and Topologies*," 2009.
- [4] Y. Miyahara, "Next-generation wireless technologies trends for ultra low energy," in *Low Power Electronics and Design (ISLPED) 2011 International Symposium on*, 2011, pp. 345-345.
- [5] M. Ciampa, *CWNA Guide to Wireless LANS. Networking*. Thomson Publish, 2006.
- [6] A. Kumar, *et al.*, *Wireless networking*: Morgan Kaufmann, 2008.
- [7] R. Price, *Fundamentals of wireless networking*: McGraw-Hill, Inc., 2006.
- [8] D. Schwab and R. Bunt, "Characterising the use of a campus wireless network," in *INFOCOM 2004. Twenty-third Annual Joint Conference of the IEEE Computer and Communications Societies*, 2004, pp. 862-870 vol.2.
- [9] D. Kotz and K. Essien, "Analysis of a campus-wide wireless network," *Wireless Networks*, vol. 11, pp. 115-133, 2005.
- [10] D. Hucaby and S. McQuerry, *Cisco field manual: catalyst switch configuration*: Cisco Systems, 2003.
- [11] T. Cooklev, "Wireless Communication Standards: A Study of IEEE 802.11, 802.15, and 802.16," *IEEE*, 2004.
- [12] A. Durrezi and M. Denko, "Advances in wireless networks," *Mobile Information Systems*, vol. 5, pp. 1-3, 2009.
- [13] T. Cornelsen, "*WiFi- implementation Fundamentals and piloting*," *PHD Thesis, Computer science University for Applied Science of Regensburg*, 2010.
- [14] W. Gardner, "Spectral correlation of modulated signals: Part I--analog modulation," *Communications, IEEE Transactions on*, vol. 35, pp. 584-594, 1987.
- [15] V. K. Garg, *Wireless communications and networking*: Morgan Kaufmann, 2007.
- [16] P. Rengaraju, *et al.*, "Measuring and Analyzing WiMAX Security and QoS in Testbed Experiments," in *Communications (ICC), 2011 IEEE International Conference on*, 2011, pp. 1-5.
- [17] M. Hassan and R. Jain, *High performance TCP/IP networking*: Pearson Prentice Hall, 2004.

- [18] E. Kartsakli, *et al.*, "Multiuser MAC Protocols for 802.11n Wireless Networks," in *Communications, 2009. ICC '09. IEEE International Conference on*, 2009, pp. 1-5.
- [19] Y. Kawasumi, "Deployment of WiFi for rural communities in Japan and ITU's initiative for pilot projects," in *Enterprise Networking and Computing in Healthcare Industry, 2004. HEALTHCOM 2004. Proceedings. 6th International Workshop on*, 2004, pp. 200-207.
- [20] A. A. Khan and N. Zaman, "Comparative analysis of broadband wireless access from Wi-Fi to WiMax," in *Applied Sciences and Technology (IBCAST), 2009 6th International Bhurban Conference on*, 2009, pp. 8-14.
- [21] B. S. C. Choi and M. Gerla, "Wireless Interrupt: Inter-Device Signaling in Next Generation Wireless Networks," in *INFOCOM IEEE Conference on Computer Communications Workshops*, 2010, 2010, pp. 1-5.
- [22] Y. M. Li and J. H. Jhang-Li, "Integration of WiMAX and WiFi Services: Bandwidth Sharing and Channel Collaboration," *Scopus*, 2010.
- [23] K. G. Paterson, "Generalized Reed-Muller codes and power control in OFDM modulation," *Information Theory, IEEE Transactions on*, vol. 46, pp. 104-120, 2000.
- [24] F. Ohrtman, *WiMAX handbook*: McGraw-Hill, 2005.
- [25] Z. Zeyu, *et al.*, "ONU Placement in Fiber-Wireless (FiWi) Networks Considering Peer-to-Peer Communications," in *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*, 2009, pp. 1-7.
- [26] S. Ahson and M. Ilyas, *The WiMAX handbook*: CRC Press, 2008.
- [27] J. G. Andrews, *et al.*, *Fundamentals of WiMAX: understanding broadband wireless networking*: Prentice Hall PTR, 2007.
- [28] M. A. Dye, *et al.*, *Network Fundamentals: CCNA Exploration Companion Guide*: Cisco Press, 2007.
- [29] H. Zimmermann, "OSI reference model--The ISO model of architecture for open systems interconnection," *Communications, IEEE Transactions on*, vol. 28, pp. 425-432, 1980.
- [30] L. L. Peterson and B. S. Davie, *Computer networks: a systems approach*: Morgan Kaufmann, 2003.
- [31] J. F. Kurose and K. W. Ross, *Computer networking*: Pearson/Addison Wesley, 2010
- [32] G. S. Poo and B. P. Chai, "ISO FTAM protocol performance," *Computer Communications*, vol. 14, pp. 413-422, 1991.
- [33] R. Lai, *et al.*, *On using PROTEAN to verify ISO FTAM protocol*: Springer, 1991.
- [34] S. Radicati, *Electronic mail: an introduction to the X-400 message handling standards*: McGraw-Hill, Inc., 1992.

- [35] U. Warrier, *et al.*, "Common management information services and protocols for the internet (CMOT and CMIP)," *RFC1189*, 1990.
- [36] J. Postel and J. Reynolds, "Rfc 959: File transfer protocol (ftp)," *InterNet Network Working Group*, 1985.
- [37] A. Tang, *et al.*, "Transport layer," *Wiley Encyclopedia of Computer Science and Engineering*, 2009.
- [38] L. Parziale, *et al.*, *TCP/IP Tutorial and Technical Overview*: IBM International Technical Support Organization, 2006.
- [39] J. F. Kurose and K. W. Ross, *Computer networking*: Pearson/Addison Wesley, 2011.
- [40] M. Gast, *802.11 wireless networks: the definitive guide*: O'Reilly Media, 2005.
- [41] S. Frankel, *et al.*, "Establishing wireless robust security networks: a guide to IEEE 802.11 i," *National Institute of Standards and Technology*, 2007.
- [42] D. Skordoulis, *et al.*, "IEEE 802.11 n MAC frame aggregation mechanisms for next-generation high-throughput WLANs," *Wireless Communications, IEEE*, vol. 15, pp. 40-47, 2008.
- [43] R. Blum, *Network Performance Open Source Toolkit Using Netperf, tcptrace, NISTnet, and SSFNet*: John Wiley & Sons, Inc., 2003.
- [44] J. Yeo, *et al.*, "A framework for wireless LAN monitoring and its applications," in *WiSe '04 Proceedings of the 3rd ACM workshop on Wireless security*, 2004, pp. 70-79.
- [45] J. Yeo, "Measuring traffic on the wireless medium: Experience and pitfalls," DTIC Document2002.
- [46] P. Orosz and T. Skopko, "Software-Based Packet Capturing with High Precision Timestamping for Linux," in *Systems and Networks Communications (ICSNC), 2010 Fifth International Conference on*, 2010, pp. 381-386.
- [47] T. Kalibera, *et al.*, "Automated benchmarking and analysis tool," in *'06 Proceedings of the 1st international conference on Performance evaluation methodologies and tools*, 2006, p. 5.
- [48] S. S. Kolahi, *et al.*, "Performance Monitoring of Various Network Traffic Generators," in *Computer Modelling and Simulation (UKSim), 2011 UkSim 13th International Conference on*, 2011, pp. 501-506.
- [49] H. Asai, *et al.*, "Towards characterization of wireless traffic in coexisting 802.11 a/g and 802.11 n network," in *CoNEXT '10 Student Workshop Proceedings of the ACM CoNEXT Student Workshop*, 2010, p. 1.
- [50] A. Balachandran, *et al.*, "Characterizing user behavior and network performance in a public wireless LAN," in *SIGMETRICS '02 Proceedings of the 2002 ACM SIGMETRICS international conference on Measurement and modeling of computer systems*, 2002, pp. 195-205.

- [51] A. Gember, *et al.*, "A Comparative Study of Handheld and Non-handheld Traffic in Campus Wi-Fi Networks Passive and Active Measurement." vol. 6579, N. Spring and G. Riley, Eds., ed: Springer Berlin / Heidelberg, 2011, pp. 173-183.
- [52] D. Tang and M. Baker, "Analysis of a local-area wireless network," in *MobiCom '00 Proceedings of the 6th annual international conference on Mobile computing and networking*, 2000, pp. 1-10.
- [53] D. Kotz and K. Essien, "Characterizing usage of a campus-wide wireless network," Technical Report TR2002-423, Dartmouth College, March 2002, pp. 107-118.
- [54] R. Hutchins and E. W. Zegura, "Measurements from a campus wireless network," in *Communications, 2002. ICC 2002. IEEE International Conference on*, 2002, pp. 3161-3167 vol.5.
- [55] T. Henderson, *et al.*, "The changing usage of a mature campus-wide wireless network," in *MobiCom '04 Proceedings of the 10th annual international conference on Mobile computing and networking*, 2004, pp. 187-201.
- [56] M. Balazinska and P. Castro, "Characterizing mobility and network usage in a corporate wireless local-area network," in *MobiSys '03 Proceedings of the 1st international conference on Mobile systems, applications and services*, 2003, pp. 303-316.
- [57] H. Wei-jen and A. Helmy, "On Modeling User Associations in Wireless LAN Traces on University Campuses," in *Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks, 2006 4th International Symposium on*, 2006, pp. 1-9.
- [58] E. Zola, *et al.*, *User behaviour in a WLAN campus: a real case study*, 2009.
- [59] D. Niyato and E. Hossain, "Wireless broadband access: Wimax and beyond-integration of wimax and wifi: Optimal pricing for bandwidth sharing," *Communications Magazine, IEEE*, vol. 45, pp. 140-146, 2007.
- [60] I. L. M. S. Committee, "Wireless LAN medium access control (MAC) and physical layer (PHY) specifications," *IEEE Standard*, vol. 802, p. 999, 1999.
- [61] M. L. Gress and L. Johnson, *Deploying and troubleshooting Cisco wireless LAN controllers*: Cisco Systems, 2009.
- [62] D. Phillips, "Computer music and the linux operating system: A report from the front," *Computer Music Journal*, vol. 27, pp. 27-42, 2003.
- [63] A. M. I. McHoes and I. M. Flynn, *Understanding operating systems*: Course Technology Ptr, 2010.
- [64] M. Welsh and S. S. Consultants, *Linux Installation and Getting Started*: Specialized Systems Consultants, 1998.
- [65] M. Garrels, *Introduction to Linux*: Fultus Publishing, 2010.
- [66] A. Petersson, "Operating systems," 2000.

- [67] C. L. Van Jacobon, and Steven McCanne. (1997). *tcpdump, manual page*. Available: <http://www.tcpdump.org>
- [68] A. Orebaugh, *et al.*, *Wireshark & Ethereal network protocol analyzer toolkit*: Syngress Media Inc, 2007.
- [69] P. Herman. (2000, 4/3/2012). *tcpstat* , *manual page*. Available: <http://frenchfries.net/paul/tcpstat/>
- [70] K. C. Rick Jones, Dave Shield. (1996). *Netperf. Manual Page*. Available: <http://www.netperf.org>
- [71] U. Lamping, "Wireshark Developer's Guide," 2004.
- [72] G. Combs, "Wireshark-network protocol analyzer," *Version 0.99*, vol. 5, 1998.
- [73] V. Y. Hnatyshin and A. F. Lobo, "Undergraduate data communications and networking projects using opnet and wireshark software," in *SIGCSE '08 Proceedings of the 39th SIGCSE technical symposium on Computer science education*, 2008, pp. 241-245.
- [74] CALIN. (2009). *Wireshark's most useful display filters*. Available: <http://www.firstdigest.com/2009/05/wiresharks-most-useful-display-filters/>
- [75] P. K. Janert, *Gnuplot in action: understanding data with graphs*: Manning Publications Co., 2009.