Malawi J. Sci. & Technol., 2009, 9(1):1-4
ISSN: 1019-7079 print

EXPERIMENTAL PERFORMANCE ANALYSIS OF WIRELESS LINKS FOR HEALTHCARE APPLICATIONS

H.S.H. Gombachika*[1], TA. Chadza[1], M.Mkoloma[1], M.Mafuta[1], R. Bakolo[1]
[1]Department of Electrical Engineering Malawi-Polytechnic, University of Malawi, P/Bag 303, Chichiri, Malawi.
Malawi J. Sci. & Technol., 2009, 9(1):1-4

ABSTRACT

Wireless networking is currently being deployed for various applications. However, the application of wireless networking in healthcare remains a challenge mainly because of security and reliability concerns. This paper presents experimental results of performance analysis of a wireless network for healthcare application in the City of Blantyre. The results show that the use of wireless networking in healthcare application will be limited by packet loss, delay and jitter when the number of hops involved in the transmission of information is large. Nevertheless, deployment of wireless networking for healthcare applications is viable when the number of hops a packet has to transverse is small.

Key words and phrases: Wireless networking, Healthcare applications, Telemedicine, E-health

1. INTRODUCTION

Recently, wireless networking has become an essential part of modern telecommunications and is increasingly being deployed for various applications including campus-wide networks, municipal community networks and healthcare applications. Varshney (2006) argues that the current and emerging wireless technologies could improve the overall quality of service for patients in both cities and rural areas. He argues further that these technologies could reduce the stress and strain on healthcare providers while enhancing peoples productivity, retention and quality of life, and reduce the overall cost of healthcare services in the long-term.

The characteristics and requirements of mobile telemedicine include long sessions for consultation, multi-location coordination, pervasive and ubiquitous access to patient data and information and ability to transmit significant data due to images, video and medical information (Varshney, 2006). However, Soomro and Cavalcanti (2007) argue that although some medical applications have quality of service (QoS) requirements similar to common multimedia applications, there is a significant difference in QoS for applications considered life critical. Specifically, Varshney (2006) points that networking requirements include dependable and reliable network architectures, universal access to wireless networks, real-time support for information upload, download and discussions, support for significant quality of service and continued access for long sessions. The additional requirements include security and privacy, mobile devices that can work with minimal input requirements and voice activation. Therefore the process of applying wireless networking in healthcare remains a challenge mainly because of security and reliability concerns. Nevertheless, healthcare can benefit significantly from wireless networking technologies provided that the technologies address the concerns raised in medical field. Furthermore, deployment of wireless networking technologies for healthcare applications will depend on the performance of the network in terms of bandwidth, delay, packet loss and jitter.

Some researchers have experimented with wireless networks mainly to characterise the behaviour of wireless networks and to assess the reliability of wireless links. Yeo and others (2004) used sniffers to observe traffic characteristics from the wireless point view. They claim that traffic measurements from wireless point of view are crucial when analysing the full picture of 802.11 wireless networks because this approach provides rich information on the wireless medium, which enables inferences being made on MAC and physical layer performance. This work, however, was limited to academic networks, and whether similar results could be obtained in networks for healthcare applications remains an open area.

Kotz and Esien (2003) analysed campus-wide wireless networks. They collected data on traffic, users, and protocols using syslog, snmp and sniffers (tcpdump). The results showed that traffic generated from residential halls dominated traffic from other places and that the traffic was dominated by web protocols. Similarly, this work, however, was limited to academic networks, and whether similar results could be obtained in networks for healthcare applications remains an open area.

Souryal and others (2006) assessed link quality in an indoor environment and investigated the relationship between packet loss and link distance, SNR and time. The results confirmed earlier results that link distance is not indicative of the link quality, as there was low correlation between link distance and packet loss. Furthermore, the results showed that the SNR reported by the radio is indicative of the link quality in low-interference environment, however, as the interference increases; SNR reported by the cards becomes less reliable predictors of link quality. They recognised that the accuracy of the results of their work was, however, affected by delay imposed by measurement window and the period of the

*Corresponding author: H.S.H. Gombachika, Department of Electrical Engineering Malawi-Polytechnic, University of Malawi, P/Bag 303, Chichiri, Malawi, Email: hgombachika@poly.ac.mw

broadcast beacon. Furthermore, the paper assumed that bit errors are independent. In wireless links, however, bit errors and consequently packet losses are bursty.

Korhonen and Wang (2005) noted that link and transport layer protocols depend on checksums to detect errors in packets and discard any packet that contains errors. Obviously, large packets are more likely to be discarded than small packets. On the other hand, small packets size leads to high proportional overhead. Having said that, the researchers argued that packet-size optimisation is not necessary in high bit rate WLAN, for example, IEEE 8202.11b and they concluded that it is beneficial only when bit rate is low. However, the question on whether packet-size optimisation is not necessary in terms of packet delay and jitter remains open.

More recently, Soomro and Cavalcanti (2007) provided an overview of Wireless network technologies that have the potential to support medical applications. The paper identified four categories of Healthcare applications based on quality of services requirements as Medical IT, real-time non-critical applications, real-time critical applications and remote control applications.

These reviews on wireless networking reveal several issues. Firstly, utilisation of wireless networking for healthcare application has to address the reliability and security concerns and that the deployment of various healthcare applications must be matched with the performance of real wireless networks. Furthermore, unique characteristics associated with wireless networking have not been fully utilised. Finally, there are no pilot test-beds to experiment with various healthcare applications. This paper presents results of an experimental performance study of end-to-end wireless links for healthcare applications in the City of Blantyre. The contribution of this paper is that it has experimentally established the limitation of wireless networks in supporting some healthcare applications. The remainder of the paper is arranged as follows: Section 2 describes the experimental methodology followed in the study; Section 3 presents and discusses the results of the study, while section 4 concludes the paper.

2. EXPERIMENTAL METHODOLOGY

In general, the performance of communication systems can be evaluated through analytical methods, computer simulation and experiments. The analytical methods use mathematical notations and equations to describe the system and give clear insights into relationships between system parameters and performance. Analytical methods, however, may not be possible where the mathematics is intractable. Computer simulation is a technique that involves designing a model of the actual or theoretical communication systems, executing the model on a digital computer and analysing the results. Although this approach provides insight into the performance of a system and can be used to predict how the actual system is going to perform, its accuracy depends on the accuracy of the model. Finally, experiment approach involves building the actual network or test-bed and evaluating the performance based on measurements obtained from the model. This approach is more accurate and credible (Tranter and Kosbar, 1994). In this work, we used the experiment approach and this section describes the experimental network set-up and experiments conducted.

2.1. *Experiment Set-up*

The experiments were conducted on a pilot network in the city of Blantyre linking six (6) nodes resulting in five (5) links as shown in Figure 1.

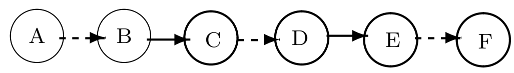

Fig. 1.— Experiment conceptual diagram

The nodes consisted of Metrix I wireless radios acting as routers configured as access points (AP) and client modes and layer 2 switches. The characteristics of the links are summarized in Table 1.

TABLE 1
Summary of the characteristics of the links

Link		Type	Max. speed (Mbps)	Distance (km)
1	**A-B**	Wireless	5.5	3.14
2	**B-C**	Wired	100	N/A
3	**C-D**	Wireless	5.5	6.35
4	**D-E**	Wired	100	N/A
5	**E-F**	Wireless	5.5	0.76

The performance of the network was measured in terms of packet loss, delay and jitter measured against packet size. Packet loss was measured as a ratio of the number of packets lost to the total number of packets sent and it indicates the reliability of the link. Packet delay on the other hand, was measured as the round-trip delay and it indicates congestion at a router (Chen 2006). Packet jitter was measured as a standard deviation of the packet delay and it indicates the stability of the network. These performance metrics are indicators of the network quality and reliability consequently the networks ability to support healthcare applications. According to Soomro and Cavalcanti (2007), packet loss should be less 1% for healthcare application in general and less 0.0001% for healthcare applications considered life critical such as cardiac signal monitoring.

2.2. *Data Collection and Analysis*

Data used in the study was collected using LINUX-based software tool called *mtr*. *Mtr* is a combination of two network diagnostic tools, namely, *traceroute* and *ping*. Traceroute establishes the route that a packet takes from source to destination while ping measures the packet round-trip delay, jitter and loss from source to destination. Therefore, using *mtr*, 32 experiments were carried out. Each experiment involved serially sending 1000 packets from source (Node A) to destination (Node F) and collecting data on packet loss, average delay and jitter expressed as a standard deviation of the packet delay. The experiments were repeated for two packet sizes (64 and 1024 bytes). Then the averages for packet loss, delay and jitter for each link were calculated. Furthermore, for each link, the difference in performance averages for the two packet sizes were statistically tested.

3. RESULTS AND DISCUSSION

In this study we experimentally assessed the performance of the wireless network in terms of packet loss, delay and jitter in order to evaluate its viability for healthcare applications.

3.1. *Packet Loss*

Firstly, we assessed the performance of the pilot wireless network in terms of packet loss (%) with packet size as a parameter. Table 2 shows the results of the network performance in terms of packet loss expressed as a percentage for the two packet sizes (64 and 1024 bytes). The results show that in general for both packet sizes, packet loss increases as the number of nodes increases. This implies that networks where packets have to hop through many nodes may not be able to support some healthcare applications because of packet loss limitation. In other words, the wireless links become less reliable as the number of hops the packet has to transverse becomes large. According to Soomro and Cavalcanti (2007), packet loss should be less 1% for healthcare application in general and less 0.0001% for healthcare applications considered life critical such as cardiac signal monitoring.

TABLE 2
PACKET LOSS FOR TWO PACKET SIZES (64 AND 1024 BYTES)

Link		**Packet Loss (%)**		
		64 bytes	1024 bytes	t-test (t,p)
1	A-B	0.92	0.60	2.347, 0.022
2	B-C	1.04	0.55	2.106, 0.039
3	C-D	2.45	2.13	0.565, 0.574
4	D-E	2.32	2.12	0.373, 0.711
5	E-F	2.97	3.57	-0.968, 0.337

Furthermore, the results show that there is a difference in packet loss between the two packet sizes (64 and 1024 bytes). However, the difference is statistically significant when the mean packet loss is small: links 1 and 2, $t(62) = 2.347$, $p < 0.05$ and $t(62) = 2.106$, $p < 0.05$, respectively; and the difference is not statistically significant when the packet loss is large: links 3,4 and 5, $t(62) = 0.565$, $p < 0.05$, $t(62) = 0.373$, $p < 0.05$ and $t(62) = -0.968$, $p < 0.05$, respectively. This means that the packet size has an effect on the performance of the network in terms of packet loss when the packet loss is small. However, the effect of packet size on performance is insignificant when the packet loss is large. Nevertheless, according to Korhonen and Wang (2005), packet size optimization is not necessary when bit-rate is high, for example, IEEE 802.11b.

3.2. *Packet Delay*

Secondly, we assessed the performance of the pilot wireless network in terms of packet delay with packet size as a parameter. Table 3 shows the results of the network performance in terms of packet delay for the two packet sizes (64 and 1024 bytes). The results show that for both packet sizes, the packet delay increases as the number of nodes increases, implying that networks may not be able to support real-time interactive healthcare applications when packets have to hop through many nodes.

TABLE 3
PACKET DELAY FOR TWO PACKET SIZES (64 AND 1024 BYTES)

Link		**Packet Delay (ms)**		
		64 bytes	1024 bytes	t-test (t,p)
1	A-B	8.13	12.92	-14.458, 0.0
2	B-C	8.99	13.97	-14.648, 0.0
3	C-D	20.80	30.60	-6.899, 0.0
4	D-E	22.54	32.07	-6.419, 0.0
5	E-F	29.95	77.40	-2.601, 0.012

The results further show that large packets experience longer average delays than small packets and that the differences in average delays are all statistically significant $t(62) = -14.458$, $p < 0.05$, $t(62) = -14.648$, $p < 0.05$, $t(62) = -14.458$, $p < 0.05$, $t(62) = -6.419$, $p < 0.05$ and $t(62) = -2.601$, $p < 0.05$ for links, 1,2,3,4 and 5, respectively. This means that packet size has a significant effect on the performance of a network in terms of packet delay. Large sized packets experience larger delay than small sized packets. However, although Korhonen and Wang (2005) claimed that packet-size optimization is not necessary in terms of packet loss, it could be interesting to investigate experimentally whether packet-size optimization would be necessary in terms of packet delay.

TABLE 4
PACKET JITTER FOR TWO PACKET SIZES (64 AND 1024 BYTES)

Link		**Packet Delay (ms)**		
		64 bytes	**1024 bytes**	**t-test (t,p)**
1	A-B	5.04	6.48	-4.211, 0.0
2	B-C	5.05	6.43	-4.183, 0.0
3	C-D	32.33	34.84	-0.746, 0.459
4	D-E	35.36	34.95	0.121, 0.904
5	E-F	46.83	259.59	-1.758, 0.084

3.3. *Packet Jitter*

Thirdly, we assessed the performance of the pilot wireless network in terms of packet jitter with packet-size as a parameter. Table 4 shows the results of the network performance in terms of packet jitter for the two packet sizes (64 and 1024 bytes). The results show that for both packet sizes, the packet jitter increases as the number of nodes increases. Similarly, this implies that networks may not be able to support real-time interactive healthcare applications when packets have to hop through many nodes. In other words, as the number of hops increases, the links become less stable.

TABLE 5
Correlation analysis between packet jitter, delay and loss

Correlation Analysis (r,df,p)			
	Packet Loss	**Packet Delay**	**Packet Jitter**
Packet Loss	1.0,0,*	0.27,317,0.0	0.13,317,0.02
Packet Delay	0.27,317,0.0	1.0,0,*	0.97,317,0.0
Packet Jitter	0.13,317,0.02	0.97,317,0.0	1.0,0,*

Furthermore, the results show that there is a difference in packet jitter between the two packet sizes (64 and 1024 bytes). In addition, the difference is statistically significant when the mean packet jitter is small: links 1 and 2, $t(62) = -4.211$, $p < 0.05$ and $t(62) = -4.183$, $p < 0.05$, respectively. However, the differences in mean jitter are not statistically significant when the packet jitter is large: links 3,4 and 5, $t(62) = -0.746$, $p < 0.05$, and $t(62) = -1.758$, $p < 0.05$, respectively. This means that the packet size has an effect on the performance of the network in terms of packet jitter when the average packet jitter is small. However, the effect on performance is not statistically significant when the packet jitter is large.

3.4. *Relationship between Packet Jitter, Delay and Loss.*

Finally, we conducted a correlation analysis between packet jitter, delay and loss and Table 5 shows the correlation analysis results. The results show that the correlation between packet loss on one hand and packet delay and jitter on the other are weak $r(317) = 0.27$, $p < 0.05$ and $r(317) = 0.13$, $p < 0.05$ respectively while there is a strong correlation between packet delay and jitter $r(317) = 0.97$, $p < 0.05$. Although there is a strong correlation between packet delay and jitter, it will be interesting to investigate why there is such a strong correlation.

4. CONCLUSIONS

This paper has presented experimental results of performance analysis of a wireless network for healthcare application in the City of Blantyre. The results have shown that the use of wireless networking in healthcare application could be limited by packet loss, delay and jitter when the number of links involved in transmission of information is large. However, wireless networking is viable when the number of hops the packet has to transverse is small. These experiments were conducted on a pilot wireless network which was not heavily loaded. It could be interested to analyse the network when its fully operational in order to take into account the impact of loading on the performance metrics.

ACKNOWLEDGEMENT

The authors would like to thank the Aeronomy and Radio Propagation Laboratory (ARPL) at the International Centre for Theoretical Physics (ICTP), Trieste, Italy for providing equipment deployed in the pilot wireless network in the City of Blantyre.

REFERENCES

[1]Chen, M. (2006). A General Framework for Flow Control in Wireless Networks. PhD Thesis, University of California, Berkeley. Retrieved on 30th March 2007 from http://www.eecs.berkeley.edu/Pubs/TechRpts /2006/EECS-2006-194.html

[2]Korhonen, J. and Wang, Y. (2005). Effect of Packet Size on Loss Rate and Delay in Wireless Links. 2005 IEEE Wireless Communications and Network Conference (WCNC-05). (pp 1608-1613).

[3]Kotz, D. and Esien, K. (2002). Analysis of a Campus-wide Wireless Network. Proceedings of the 8th annual international conference on Mobile computing and networking. pp 107-118. viewed on 25th December 2006, www.cs.dartmouth.edu/ dfk/papers/kotz: campus.pdf

[4]Soomro, A. and Cavalcanti, D. (2007). Opportunities and Challenges in Using WPAN and WLAN Technologies in Medical Environments. IEEE Communication Magazine, 45(2), pp 114-122.

[5]Souryal, M.R., Berndt, L.K., Miller, L.E., and Moayeri, N. (2006) Link Assessment in an Indoor 802.11 Network. IEEE 2006 Wireless Communications and Networking Conference Proceedings, 3 (pp 1402-1407).

[6]Tranter, W.H.; Kosbar, K.L. (1994). Simulation of communication systems. IEEE Communications Magazine, 32 (7) pp.26-35.

[7]Varshney, U. (2006). Using Wireless technologies in Healthcare International. Journal of Mobile Communications, 4 (3) pp. 354-368.

[8]Yeo, J. Youssef, M. and Agrawala, A. (2004). Characterising the IEEE 802.11 Traffic: The Wireless Side.Technical Report University of Maryland.