Universiti Malaysia PAHANG

RESEARCH REPORT UMP GRANT
Laporan Prestasi Skim Geran UMP

Final	X	Progress		*Progress Period :* _____	*√ Please tick*

PROJECT DETAILS *(Keterangan Projek)*

A	**Grant No**	RDU1703293
	Faculty/CoE	IBM CoE
	Project Title	PERFORMANCE IMPROVEMENT IN END-TO-END BANDWIDTH ESTIMATION TOOL IN WIRELESS LOCAL AREA NETWORK (WLAN)
	Project Leader	IMRAN EDZEREIQ BIN KAMARUDIN
	Project Member	1. ZAFRIL RIZAL BIN M AZMI 2. MUHAMAD IDAHAM BIN UMAR ONG 3. ABBAS SALIIMI BIN LOKMAN 4. MOHAMED ARIFF BIN AMEEDEEN

PROJECT ACHIEVEMENT *(Pencapaian Projek)*

B

ACHIEVEMENT PERCENTAGE				
Project progress according to milestones achieved up to this period	**0 - 25%**	**26 - 50%**	**51 - 75%**	**76 - 100%**
Percentage (please state %)				85%

EXPENDITURE *(Perbelanjaan)*

C

Budget Approved *Peruntukan diluluskan*	**Amount Spent** *Jumlah Perbelanjaan*	**Balance** *Baki*	**% of Amount Spent** *Peratusan Belanja*
RM 20,000	**RM 3,050**	**RM 16,950**	**16%**

RESEARCH OUTPUT *(Output Penyelidikan)*

D

NO OF PUBLICATION

KPI FOR NO OF PUBLICATION

	ISI	Scopus	Index Proceedings	Others
KPI		1		
Achievement		1		

The contribution of funder (UMP, MOHE, MOSTI, Industry etc.) as the fund provider must be acknowledged at all times in all forms of publications. Please state the grant number (RDU/UIC) and grant name.

Number of articles/ manuscripts/books *(Please attach the First Page of Publication)*	**ISI** 1. 2.	**Scopus** 1. 2.
Conference Proceeding *(Please attach the First*	**International**	**National**

Page of Publication)	1. 6th International Conference on Software Engineering & Computer Systems (ICSECS) – published in IOP Conference Series: Materials Science and Engineering	

HUMAN CAPITAL DEVELOPMENT

KPI FOR HUMAN CAPITAL DEVELOPMENT

	PhD Student	Master Student
KPI		1
Achievement		0

Human Capital Development	**Number**				**Others** (please specify)
	On-going		**Graduated**		
Citizen	Malaysian	Non Malaysian	Malaysian	Non Malaysian	
PhD Student					
Masters Student					
Undergraduate Student					
Total					

Name of Student: **ID Matric No:** **Faculty:** **Thesis title:** **Graduation Year:** *** enter for more space*	None

INTELECTUAL PROPERTIES

KPI FOR INTELECTUAL PROPERTIES

Patent, Copyright, Trademark,Industrial Design: _____

Patent, Copyright, Trademark, Industrial Design ect	Not applicable

OTHERS

KPI FOR OTHERS

Prototype, Technology,Collaborations etc: _____

Prototype, Technology, Collaborations etc	Not applicable

ASSET *(Aset)*

E

Bil	**Peralatan** *(Equipment)*	**Model**	**No Daftar Aset** *(Asset Tagging No)*	**Amount** (RM)	**Lokasi** *(Location)*
	None				

PRODUCT DESCRIPTION FOR UMP R&D DIRECTORY (SHORT & BRIEF) *Only for Final Report*	
F	Not Applicable
PRODUCT PICTURE FOR UMP R&D DIRECTORY *Only for Final Report*	
G	Not Applicable
SUMMARY OF RESEARCH FINDINGS (*Ringkasan Penemuan Projek Penyelidikan)*	
H	For this progress, we found that Rount Trip Time (RT) based available bandwidth estimation toolls were able to provide more consistence and accurate reading compare to non RT based tools. To prove this, RT based tools were put to multiple testing to benchmark with state of the art and well known non RT based tools. The result were positive for RT base available bandwidth tools.
PROBLEMS / CONSTRAINTS IF ANY *(Masalah/ Kekangan sekiranya ada)*	
I	

Date : 4/8/2020
Tarikh

Project Leader's Signature:
Tandatangan Ketua Projek

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COMMENTS, IF ANY/ ENDORSEMENT BY FACULTY (*Komen, sekiranya ada / Pengesahan oleh Fakulti)*

J **Recommend** / Not Recommend / KIV / Need Ammendment

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Name:
Nama:

Date:
Tarikh:

ASSOC. PROF. DR. MOHD NIZAM BIN MOHMAD KAHAR
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Signature:
Tandatangan:

** Dean/TDR/Director/Deputy Director

COMMENTS, IF ANY/ ENDORSEMENT BY RMC PNI (*Komen, sekiranya ada / Pengesahan oleh RMC PNI)*	
K	**Recommend / Not Recommend / KIV / Need Ammendment** .... **Name:** *Nama:* **Date:** *Tarikh:* **Signature:** *Tandatangan:*

Performance Improvement in End to End Bandwidth Estimation tool in Wireless Local Area Network (WLAN) – RDU1703293

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ABSTRACT (120 words)

In wireless mesh network environment, available bandwidth (ABW) estimation is important to provide feedback on the quality of network infrastructure to end user. Recent study shows the emerging of Round Trip (RT) based ABW tools where it eliminates the need of having a receiver end. However, these tools are not fully tested in various network environment and benchmark with existing widely used ABW tools. In this paper, we perform an extensive performance analysis study on RT based tools with other widely used ABW tools by looking at the accuracy and consistency. In term of accuracy and consistency, RT based tools excel in these conditions.

1. INTRODUCTION

ABW measurement techniques are divided into two types of probing, passive based and active based probing. Congestion situation, packet loss, and delay performance are used to estimate the ABW in passive based probing. For active based probing, it sends probe-packets over a network path to estimate the ABW. Due to efficiency and reliability of estimations, active probe is preferable. Active-based ABW tool is implemented by inducing traffic congestion from sender, where probe packets are sent at increasing rates. At the recipient end, the probe packets delay is measured to determine the time or point at which they start to increase in a consistent basis. The ABW is then measured at the probe packet rate utilized by looking at turning point of the packets.

2. RESEARCH METHODOLOGY

This section will describe the environment in executing this research. In general, this research is to evaluate existing RT ABW and non-RT ABW tools to look for accuracy and consistency. The testing and evaluation is done in two conditions: 1) Probe test traffic is generated from ABW server to Node A without external traffic 2) Probe test traffic is generated from ABW server to Node A

with external traffic from Traffic generator server to Node B. First test, ABW tools were tested by probing the network path where only traffic exists in the path was only from the tools itself. In the second test, external packets generated along the network path using TCP traffic, generated from traffic generator server, on top of the tools itself. This action causes both traffic to access the shared wireless channel and competing on the same path. Both conditions were then tested in three WMN environment 1) IEEE802.11b at maximum speed of 11Mbps across all link, 2) IEEE802.11g at maximum speed of 54Mbps across all link, 3) IEEE802.11ac at maximum speed of 100Mbps across all link.

Data collection and analysis in term of accuracy and consistency for each of the AWB Tool with the predetermine WLAN environment will be performed. Next the task producing feasibility and making sure all the strength and weakness is highlighted and benchmarked with the current practice of the industry.

Figure 1 describe the step by step process in conducting the research clearly and structured. Each research objective has been carefully aligned with the flow-chart. Objective must be achieved in certain stage of the process flow to proceed. Hopefully by successfully following the propose flow-chart, the research could complete without any hiccup.

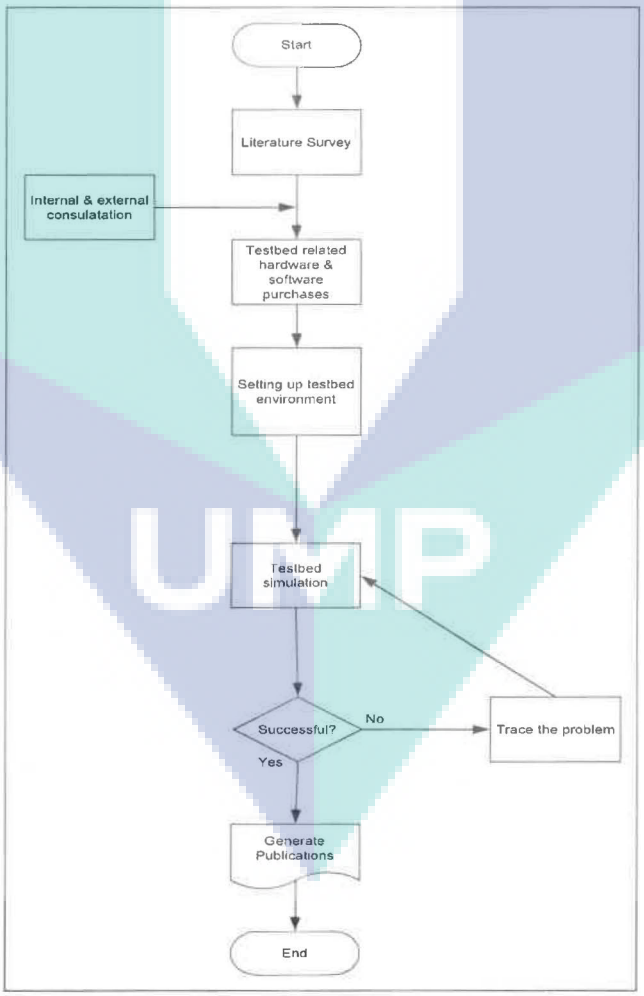

Fig. 1. Flow-chart for achieving the desired goal

3. LITERATURE REVIEW

Active probing is classified into two model; Probe Gap Model (PGM) and Probe Rate Model (PRM). In PGM, estimation of ABW is done based on the readings at the cross-traffic rate in the path. Previous capacity reading of the network path is required to develop tools using this technique. The probing technique works when the sender transmits a pair of packets to the receiver end, where the pair packets transmit close enough to each other in time for packets to queue at the bottleneck path. The change in packet spacing can be determine by receiver end to make an estimation of the amount of cross traffic during the measurement time in the bottleneck path and then compute the ABW as the difference between the bottleneck path capacity and the cross-traffic rate. Spruce and IGI are examples of tools utilizing this approach. For PRM, it estimates the ABW based on the probe rate results between the sender and receiver. Along the path, when the probe traffic is sent at a rate lower compare to the available bandwidth, the arrival rate at the receiver end will match with the sender rate. On the opposite, when the probe traffic is higher compare to the available bandwidth, it will result in queuing and delay of transmitting probing packets. Based on this and by identifying at the turning point, PRM measures the available bandwidth, where the probe sending and receiving rates match. TOPP, Pathload and NEXT are examples of ABW tools that utilized this approach.

The main limitation of active based probing tools is that it needs to be deployed on both the sender and receiver end. They need to be installed and run at both end along the network path. To overcome this limitation, recent research suggests that there is a need to deploy ABW tools at only one end, especially only at the sender, along the network path. This estimation of ABW is based on round-trip-time measurements with low intrusiveness in the network path and short convergence time to produce the estimation. RT-WBest is an example of tools utilizing this approach. It utilizes two-parts algorithm where at the first part, it uses the packet-pair dispersion technique to estimate path capacity. Once complete, at the second part, it sends a packet train to estimate available bandwidth.

4. FINDINGS

The testing is done in two conditions: 1) Probe test traffic is generated from ABW server to Node A without external traffic 2) Probe test traffic is generated from ABW server to Node A with external traffic from Traffic generator server to Node B. First test, ABW tools were tested by probing the network path where only traffic exists in the path was only from the tools itself. In the second test, external packets generated along the network path using TCP traffic, generated from traffic generator server, on top of the tools itself. This action causes both traffic to access the shared wireless channel and competing on the same path. Both conditions were then tested in three WMN environment 1) IEEE802.11b at maximum speed of 11Mbps across all link, 2) IEEE802.11g at maximum speed of 54Mbps across all link, 3) IEEE802.11ac at maximum speed of 100Mbps across all link.

For accuracy, Based on this, RT-WBest was the only tool able to measure and produce result close to theoretical reading within the acceptable range of bandwidth for each WLAN, both for with and without external traffic scenario. When compare with other well know ABW tools, only RT-WBEST and Pathload were able to provide acceptable result. In contrast, Spruce, IGI, Partchip and TOPP provided few readings outside of the acceptable range of bandwidth for each WLAN. The abw reading was easily affected when tested with external traffic. IGI suffers the most in our case, almost 70% of the result are outside of the acceptable bandwidth range. For

consistency, RT-Wbest provided the highest consistency in estimation reading across all scenario and WLAN. This finding is supported by the earlier accuracy result. It shows that by applying RT method, RT-WBest was able to provide a much consistent reading throughout the testing.

5. CONCLUSION

Contributing in knowledge of Information, Communication and Technology. This will serve as a guideline in selecting the best ABW tool, given the WLAN environment.

ACHIEVEMENT

i) Name of articles/ manuscripts/ books published

1. Performance analysis on round trip available bandwidth estimation tools for wireless mesh network.
   https://iopscience.iop.org/article/10.1088/1757-899X/769/1/012047

2. WORDKIDS : English Learning Application for Preschoolers (CITREX 2020)

Performance analysis on round trip available bandwidth estimation tools for wireless mesh network

IOP Conf. Series: Materials Science and Engineering **769** (2020) 012047 doi:10.1088/1757-899X/769/1/012047

Performance analysis on round trip available bandwidth estimation tools for wireless mesh network

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Abstract. In wireless mesh network environment, available bandwidth (ABW) estimation is important to provide feedback on the quality of network infrastructure to end user. Recent study shows the emerging of Round Trip (RT) based ABW tools where it eliminates the need of having a receiver end. However, these tools are not fully tested in various network environment and benchmark with existing widely used ABW tools. In this paper, we perform an extensive performance analysis study on RT based tools with other widely used ABW tools by looking at the accuracy and consistency. In term of accuracy and consistency, RT based tools excel in these conditions.

1. Introduction

With the rapid increase of network applications and services available, available bandwidth (ABW) estimation plays an important role to provide feedback on the quality of the network infrastructure to support those services. For example, streaming services rely heavily on the available bandwidth to adjust its stream bitrate base on the current ABW result to further improve the streaming session.

A typical mistake by user is assuming that the actual maximum bandwidth capacity supported by any network in the path is based on the wireless network standard itself. For example, wireless mesh network (WMN) for IEEE802.11ac, the maximum bandwidth supported is 100Mbps. However, theoretically it can only support up to 97.80 Mbps [1]. This assumption is wrong because we need to factor in other consideration such as what kind of traffic going through the network. As a result, this will most probably lead to underestimating the total bandwidth requirement on given path.

Bandwidth capacity refer to the maximum throughput that can be transmitted across a path. The ABW refer to the unused capacity at the same path. As shown in equation 1, at any given time, a network path is either in idle state or in transmitting packets state, the definition of the ABW is by looking at the average unused bandwidth over some interval T. Therefore,

$$Ai(t,T) = \frac{1}{T}\int_{i}^{T+t} \big(Ci - \lambda i(t)\big)dt \qquad (1)$$

Where Ai (t; T) is the ABW at path i at time t, Ci is the path's bandwidth capacity, and λi is its network traffic. The ABW along the path is the minimum ABW of all traversed links.

To estimate the ABW, each tool uses either one of this technique, passive or active. Both techniques require a sender and a receiver end to complete the probing cycle. All tools will not work when either one end at the sender or receiver of the end-to-end path malfunction. Recent studies [1-3] shows that by introducing Round Trip (RT), it helps to eliminate the decency of having the need of a receiver. In addition, RT based tools also provide lower intrusion and better convergence when tested. However,

this RT based tools were not tested extensively across different network settings such as varying different bandwidth. Furthermore, benchmarking testing was not done to compare with other widely used ABW tools such as Pathrate [4], Pathload [5] and IGI [6].

In this paper, we evaluate existing RT ABW and non RT ABW tools to look for accuracy and consistency. The evaluation is done by testing across different 802.11-based WMN, with various parameters such as physical data rate and by inducing external traffic in the path. Our work and contributions are highlighted as below:

- We select six ABW tools from RT and non RT probe type.
- We perform extensive testing in terms of different WMN physical rate and network conditions.
- We assess all tools base on accuracy and consistency. For accuracy, tools must be able to estimate ABW within the selected WMN bandwidth range. For consistency, tools must be able to provide the least fluctuation of over and underestimate the bandwidth.

2. Background

ABW measurement techniques are divided into two types of probing, passive based and active based probing. Congestion situation, packet loss, and delay performance are used to estimate the ABW in passive based probing. For active based probing, it sends probe-packets over a network path in order to estimate the ABW. Due to efficiency and reliability of estimations, active probe is preferable. Active-based ABW tool is implemented by inducing traffic congestion from sender, where probe packets are sent at increasing rates. At the recipient end, the probe packets delay is measured to determine the time or point at which they start to increase in a consistent basis. The ABW is then measured at the probe packet rate utilized by looking at turning point of the packets.

Active probing is classified into two model; Probe Gap Model (PGM) and Probe Rate Model (PRM). In PGM, estimation of ABW is done based on the readings at the cross-traffic rate in the path. Previous capacity reading of the network path is required to develop tools using this technique. The probing technique works when the sender transmits a pair of packets to the receiver end, where the pair packets transmit close enough to each other in time for packets to queue at the bottleneck path. The change in packet spacing can be determine by receiver end to make an estimation of the amount of cross traffic during the measurement time in the bottleneck path and then compute the ABW as the difference between the bottleneck path capacity and the cross-traffic rate. Spruce [7] and IGI [6,13] are examples of tools utilizing this approach. For PRM, it estimates the ABW based on the probe rate results between the sender and receiver. Along the path, when the probe traffic is sent at a rate lower compare to the available bandwidth, the arrival rate at the receiver end will match with the sender rate. On the opposite, when the probe traffic is higher compare to the available bandwidth, it will result in queuing and delay of transmitting probing packets. Based on this and by identifying at the turning point, PRM measures the available bandwidth, where the probe sending and receiving rates match. TOPP [8,14], Pathload [5,15] and NEXT [9] are examples of ABW tools that utilized this approach.

The main limitation of active based probing tools is that it needs to be deployed on both the sender and receiver end. They need to be installed and run at both end along the network path. To overcome this limitation, recent research [1-3] suggests that there is a need to deploy ABW tools at only one end, especially only at the sender, along the network path. This estimation of ABW is based on round-trip-time measurements with low intrusiveness in the network path and short convergence time to produce the estimation. RT-WBest is an example of tools utilizing this approach. It utilizes two-parts algorithm where at the first part, it uses the packet-pair dispersion technique to estimate path capacity. Once complete, at the second part, it sends a packet train to estimate available bandwidth.

3. Comparison of existing tools

In this section, we describe the testing environment setup and the validation methodology.

3.1 Tools and test environment.

We evaluate selected tools; RT-Best, Spruce, IGI, Pathchirp TOPP and Pathload in a testbed environment in Figure 1. Probe traffic for all tools is sent from ABW server to Node A. External traffic

is generated by the traffic generator to Node B. The servers are connected to the access point 1 (AP1) with a wired 100Mbps LAN. The nodes are connected to the access point 2 (AP2). Table 1 shows the detail specifications of each devices.

Table 1. Testing devices specifications

Device	Specifications
AWB & Traffic generator server	Intel Core i7 3.0 GHz CPUs, 4 GB RAM, Ubuntu 18.04
Node A & B	Intel Core i5 2.6 GHz CPUs, 4GB RAM, Ubuntu 18.04
Access Point 1 & 2	D-Link AC1200 DAP1665

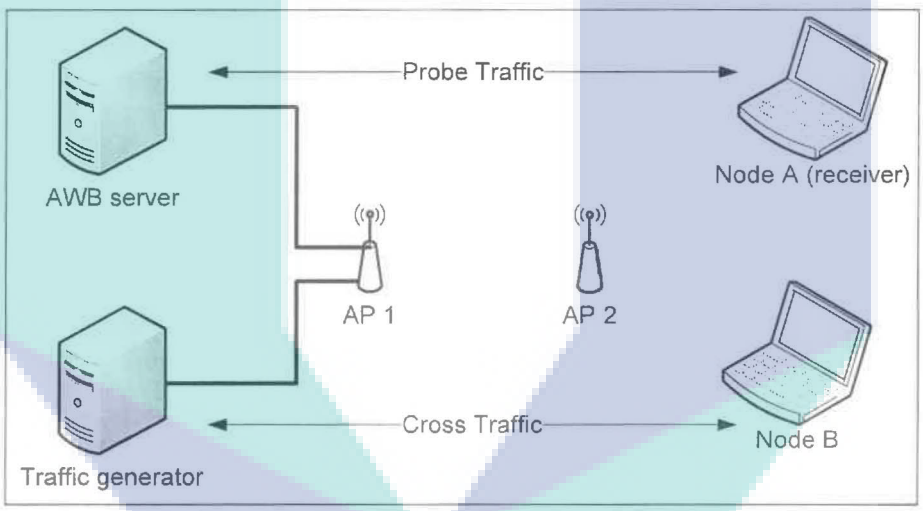

Figure 1: Experimental scenario

3.2 Testing method and evaluation

Probe traffic will be generated by the ABW server to Node A and then the Node A replies through the APs. To standardize the testing, we generate 150 packet pairs, with 70 as the length of the packet train, and 1500 bytes as the size of probe packet in IP layer [12]. Additional traffic will come from the Traffic generator server to the Node B, sharing the same path along both APs.

The testing is done in two conditions: 1) Probe test traffic is generated from ABW server to Node A without external traffic 2) Probe test traffic is generated from ABW server to Node A with external traffic from Traffic generator server to Node B. First test, ABW tools were tested by probing the network path where only traffic exists in the path was only from the tools itself. In the second test, external packets generated along the network path using TCP traffic, generated from traffic generator server, on top of the tools itself. This action causes both traffic to access the shared wireless channel and competing on the same path. Both conditions were then tested in three WMN environment 1) IEEE802.11b at maximum speed of 11Mbps across all link, 2) IEEE802.11g at maximum speed of 54Mbps across all link, 3) IEEE802.11ac at maximum speed of 100Mbps across all link.

For evaluation, each tool is tested for accuracy and consistency across the two types of network conditions, with three different network environments standard. In this test, we took 30 readings for each of the tools. The summary of all testing conducted as below:

- Probe test without external traffic: 1) IEEE 802.11b scenario at 11Mbps 2) IEEE 802.11g scenario at 54 Mbps 3) IEEE 802.11ac scenario at 100Mbps.
- Probe test with external traffic: 1) IEEE 802.11b scenario at 11Mbps 2) IEEE 802.11scenario at 54 Mbps 3) IEEE 802.11ac scenario at 100Mbps.

4. Experimental result

4.1 Accuracy

For accuracy, we take overestimation into consideration. Equation 2 shows the calculation for accuracy.

$$Accuracy[within\ range\ of\ selected\ WMN] = \frac{Number\ of\ times\ within\ range}{30} \times 100 \qquad [2]$$

For IEEE802.11b, 802.11g and 802.11ac, the theoretical value of the capacity throughout the network is 7.80 Mbps, 37.80 Mbps and 97.80 Mbps [10] respectively. Hence, in this testing, the benchmark accuracy reading of available bandwidth was set within each respective range. Only results that falls under this ranges will be considered as accurate in this testing. The measurement of RT-Best, Spruce, IGI, Pathchirp, TOPP and Pathload are shown in Figure 2 and 3 for IEEE 802.11b, Figure 4 and 5 for IEEE 802.11g and lastly Figure 6 and 7 for 802.11ac.

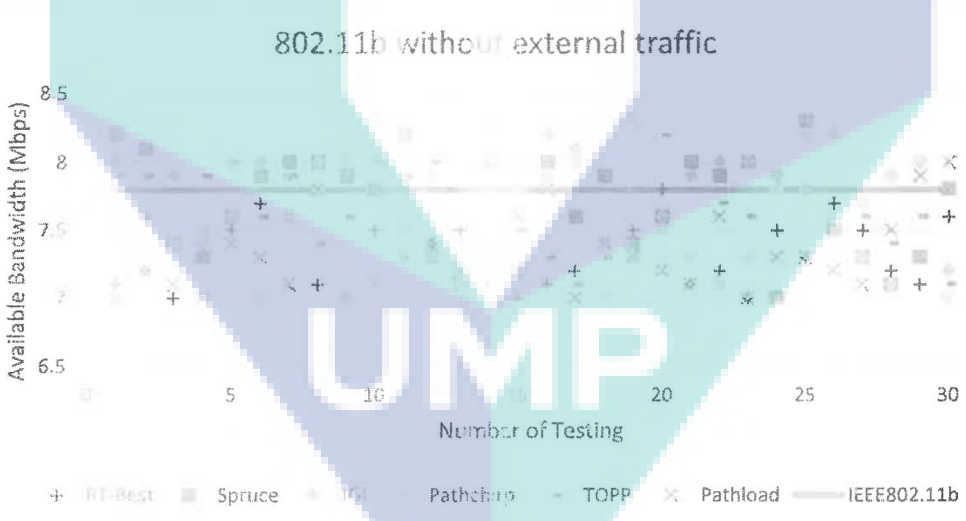

Figure 2: Estimation of ABW for IEEE 802.11b without external traffic

Based on this, RT-WBest was the only tool able to measure and produce result close to theoretical reading within the acceptable range of bandwidth for each WLAN, both for with and without external traffic scenario. When compare with other well know ABW tools, only RT-WBEST and Pathload were able to provide acceptable result. In contrast, Spruce, IGI, Partchip and TOPP provided few readings outside of the acceptable range of bandwidth for each WLAN. The abw reading was easily affected when tested with external traffic. IGI suffers the most in our case, almost 70% of the result are outside of the acceptable bandwidth range.

In summary when looking at the accuracy of each tools, RT-Wbest provide the most accurate result compare to the rest on all scenarios. It does not have significant impact during estimation like other tools, even when tested with external traffic.

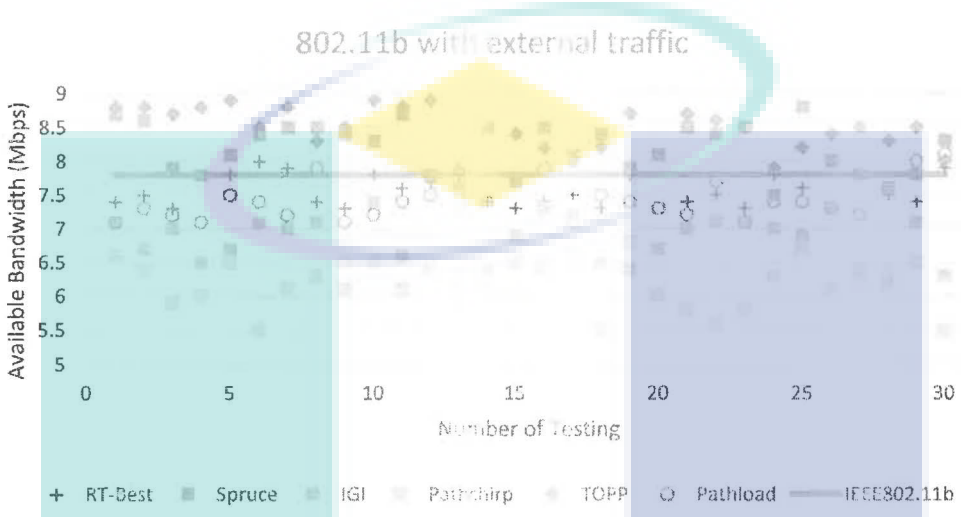

Figure 3: Estimation of ABW for IEEE 802.11b with external traffic

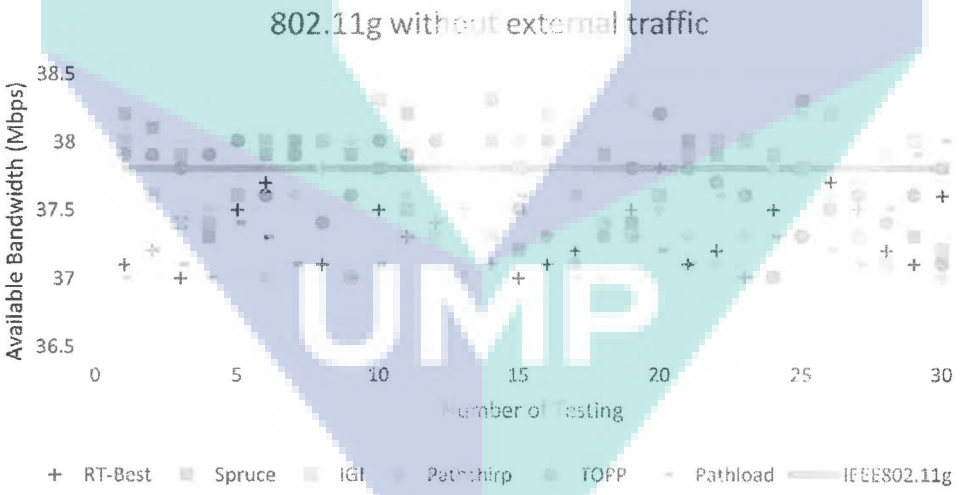

Figure 4: Estimation of ABW for IEEE 802.11g without external traffic

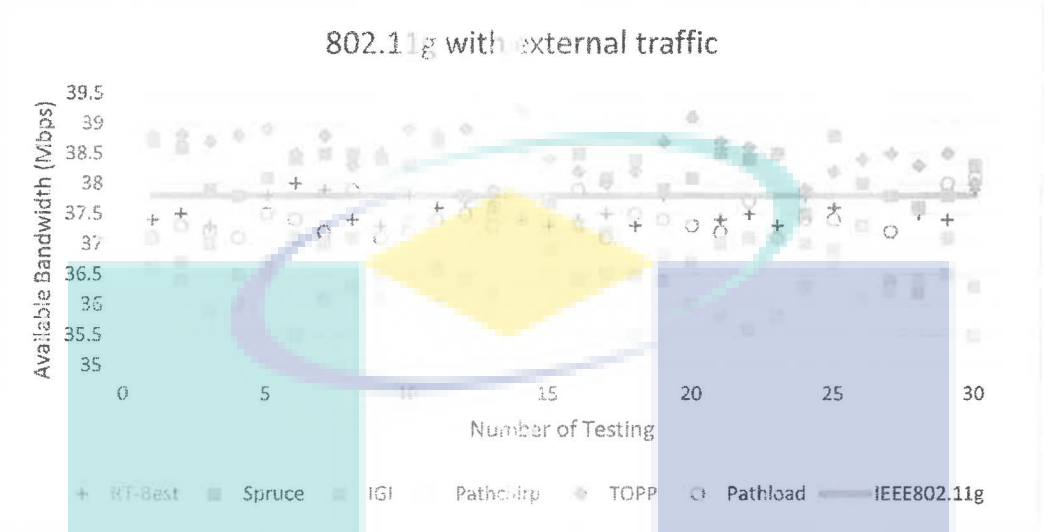

Figure 5: Estimation of ABW for IEEE 802.11g with external traffic

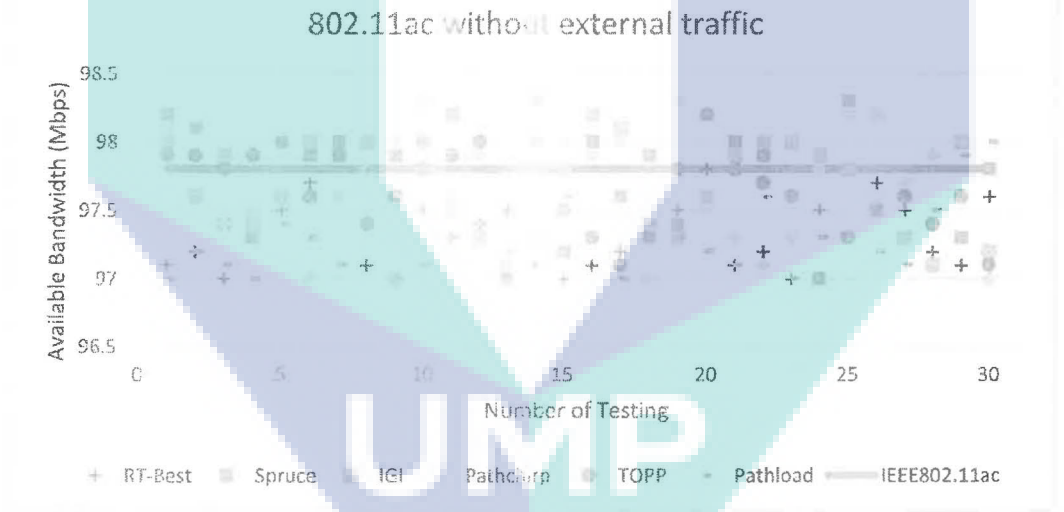

Figure 6: Estimation of ABW for IEEE 802.11ac without external traffic

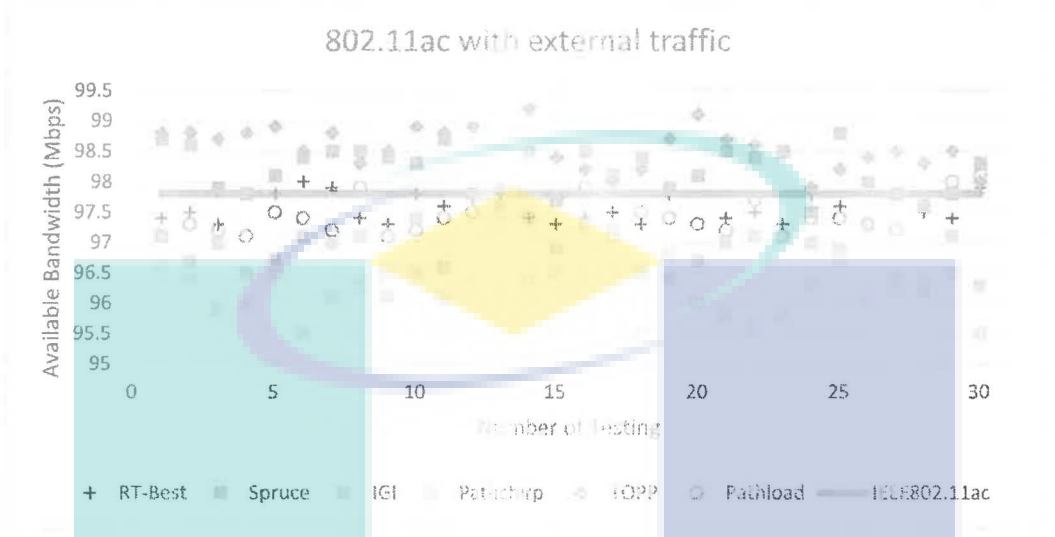

Figure 7: Estimation of ABW for IEEE 802.11ac with external traffic

4.2 Consistency

For consistency, we calculate the standard deviation for each tool base on equation 3. The lower the standard deviation value shows the accuracy of the tools in bandwidth estimation.

$$\sigma = \sqrt{\frac{\sum_{k-1}^{n}(X\,k - \mu)^2}{n}} \tag{3}$$

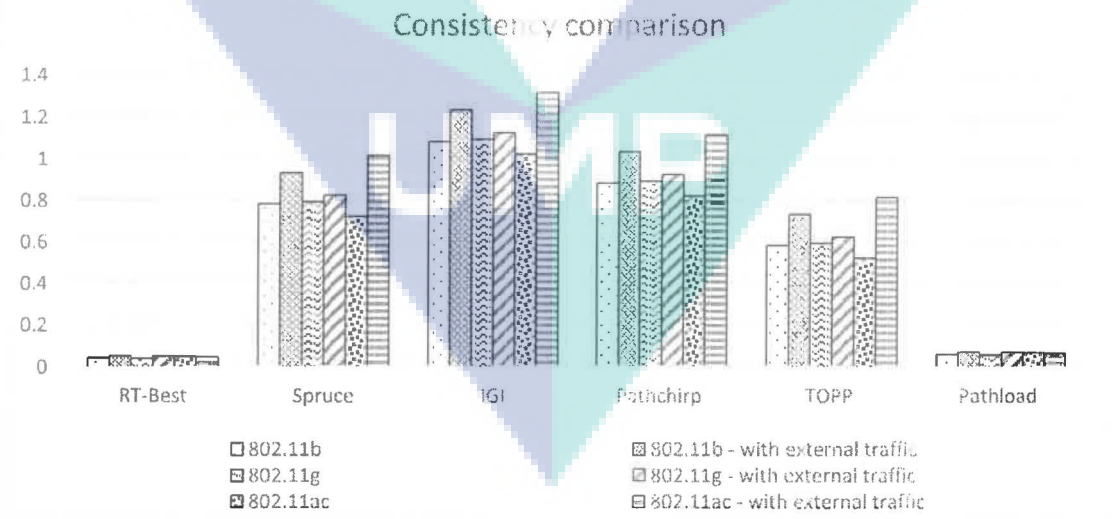

Figure 8: ABW tools consistency comparison

Figure 8 shows the standard deviation value for all tools in respective testing scenario. Based on our findings, RT-Wbest provided the highest consistency in estimation reading across all scenario and

[13] Kamarudin, I. E., Ameedeen, M. A., & Azmi, Z. R. M. (2015). Experimental Analysis on Available Bandwidth Estimation Tools for Wireless Mesh Network. In H. A. Sulaiman, M. A. Othman, M. F. I. Othman, Y. A. Rahim, & N. C. Pee (Eds.), *Advanced Computer and Communication Engineering Technology* (pp. 525–535). Cham: Springer International Publishing.

[14] S. Ekelin *et al.*, "Real-time measurement of end-to-end available band- width using Kalman filtering," in *Proc. 10th IEEE/IFIP Netw. Oper. Manag. Symp. (NOMS)*, Vancouver, BC, Canada, Apr. 2006, pp. 73–84.

[15] Zhong M, Hu P and Jadwiga I. Revisited: bandwidth estimation methods for mobile networks. In: Proceedings of the IEEE 15th international symposium on world of wire- less, mobile and multimedia networks (WoWMoM), Syd- ney, NSW, Australia, 16–19 June 2014. New York: IEEE.

WLAN. This finding is supported by the earlier accuracy result. It shows that by applying RT method, RT-WBest was able to provide a much consistent reading throughout the testing.

In summary, we conclude that RT- WABest provides more accurate results than Pathload, Spruce, IGI, TOPP and Pathchirp in all tested scenario. In contrast, IGI provided the least consistent reading among all, with similar result as the accuracy report.

5. Conclusion

In this paper, we performed a robust testing on six widely of ABW estimation tools; RT-WBest, Spruce, IGI, Partchip, TOPP and Pathload. All tools were tested in 802.11b, 802.11g and 802.11ac environment, with and without the existing of external traffic sharing the same path. In our testing, we look at the accuracy and consistency of each tools across the testing scenario.

The result shows that, no matter what the network condition, RT-Wbest provides more accurate and consistent reading in each evaluation case. It shows that by implementing RT, estimation of bandwidth can be further improved. IGI has the least accurate and consistent. In the future, we will implement more RT on existing ABW tools to improve their accuracy and consistency.

6. Acknowledgement

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7. References

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