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DETERMINATION OF OPTIMUM RETRANSMISSION LIMIT FOR ABU WIRELESS CAMPUS AREA NETWORK

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ABSTRACT

This research paper used an adaptive queuing model to determine an optimum acceptable retransmission limit of Wireless Campus Area Network which gave minimum packet loss rate. Data traffic was collected from the network using "Winbox" software monitoring tool for a period of 11 months from 31th January 2011 to 30th December 2012. The average arrival rate of 176.5 kilobits per second, average service rate of 746 kilobits per second and packet error rate of 0.76 were obtained. Like most researchers a buffer space of 50 was used in the analysis and graphs were plotted using Excel Spreadsheet. The optimum retransmission limit was found to be 10, which gave a minimum packet loss rate of 0.05. Above and below 10 retransmissions resulted in more packet loss.

SIGNIFICANCE: This paper established the optimum number of retransmissions a wireless queuing system could be subjected to with minimum loss. This limit is significant for the proper management of the wireless queuing system in order to control congestion and reduce overall loss rate.

KEYWORDS: M/M/1, WCAN, Packet, Retransmission limit, and Overall Loss rate.

1. INTRODUCTION

The aim of this research is to determine the optimum retransmission limit required to be able to control congestion Wireless Campus Area Network (WCAN) like Ahmadu Bello University. This is the motivation to embark on this study so as to achieve this limit.

A wireless network is a dynamic structured technology which provides convenience, unlimited mobility and support for multiservice applications for both fixed and mobile devices (Shakkottai *et al*, 2003). The WCAN links wireless nodes Campus Area Network (CAN) together via access points with wireless adapters.

A wireless network has well defined standard specifications which vary in accordance with the technology employed and common framework exists that characterizes the wireless network. In other words, the main concepts developed for the wireless system are based on International Telecommunication Union (ITU) standards, which give the network universal acceptance (Afolounso, 2008).

The dynamic topology of the WCAN makes it unpredictable (Zhao *et al*., 2008) and contributes to serious congestion and unnecessary delays of the system. With the wireless market becoming increasingly competitive, rapid deployment of innovative solutions for better quality of service and excellent performance become central for any successful adopted strategy on bandwidth, congestion and traffic loss management. To resolve these congestion and traffic loss problems so many researchers studied several techniques such as the fluid model to determine the retransmission limit, rate control model to determine packet data rate, scheduling model to control service and delivery mechanism, as well as combining some of these methods with a cross-layer design.

For instance, **Chih-Ming *et al*., (2010)** worked on "cross layer content-aware retry limit adaptation (CA-RLA)" to reduce error and packet loss of an IEEE802.11 wireless LAN. The CA-RLA model was used to set the retry limits of packets to correspond to their error propagation characteristics in order to prevent late arrival of packets for presentation and improve video quality as well. To do this, they protected video packets of different retry limits by monitoring the error rate of each packet to enable them determine its retry limit at the MAC layer. The number of retry limits determined the packet error protection, for example, packets of higher loss were assigned more retransmissions to reduce their delays. The waiting time before the next retransmission was also considered in their model to obtain the desired results. The limitation of this work was the lack of congestion monitoring and control mechanism in their CA-RLA cross layer design. Hence, there was no means to known when the retransmission limit was reached.

In their work to resolve the problem of ad-hoc network using cross-layer design, **Jhunu *et al*., (2012)** focused on obtaining information on link failure, route reliability and power conservation, forgetting that not only these affect the system's performance. They were able to predict the link quality on transmission rate adjustment by the application layer from the information received on signal strength at the physical layer and RTS/CTS packet exchange between transmitter and receiver. Though, reduction in congestion was achieved, but their difficulties were that they could not quantify by how much collision was reduced, as well as the performance enhancement of the model. The reason was that they could not determine the acceptable retransmission limit of the wireless system.

The research work of **Kwang-Chun *et al*., (2013)** compared the combined hybrid automatic repeat request (HARQ) with adaptive modulation and coding (AMC) schemes against the combined automatic repeat request (ARQ) with AMC. They discovered that the former combination gave better results on spectral efficiency, PER and end-to-end throughput. These results were achieved through cross-layer communication design which allowed individual protocol layers co-operate and share information of their retransmission schemes and parameters defining each service class. They also found that the AMC with HARQ combination was more suitable for real time service than AMC with ARQ combination. What this model failed to address was the effect of parameters optimization on the characteristics of each service class, and more important the model's optimum retransmission limit.

In view of the limitations encountered by most of the researches, our approach to resolve the unnecessary packet loss problem of the wireless queuing system was to determine an optimum retransmission limit that would give minimum

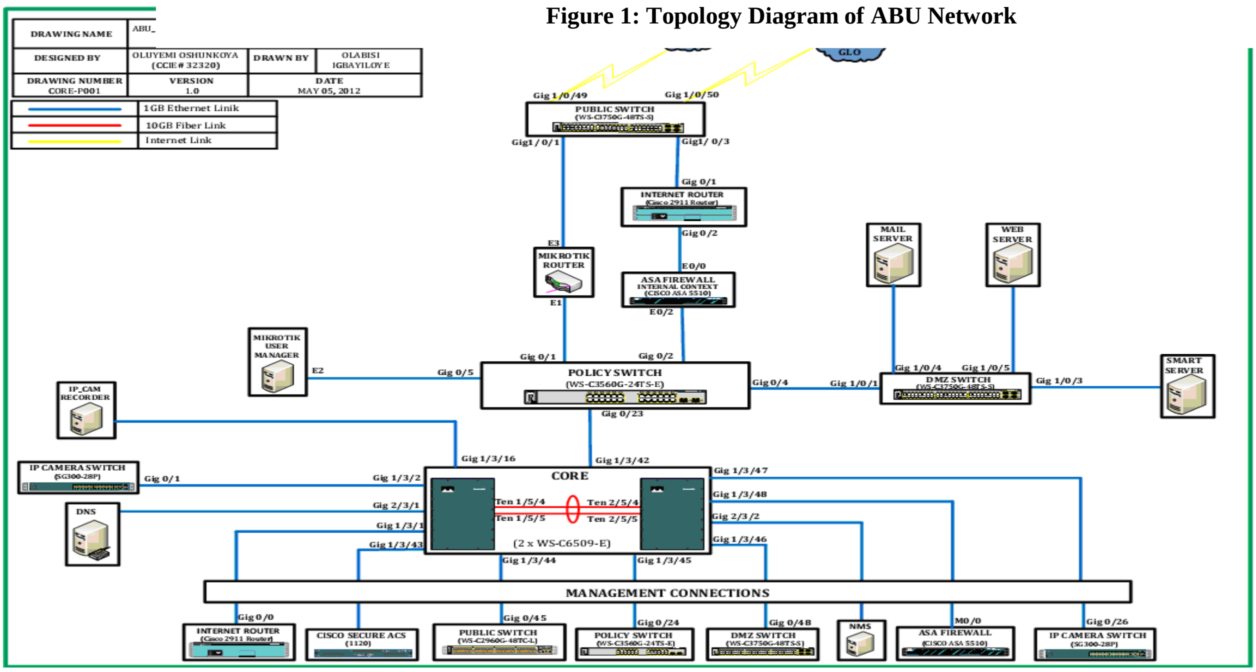

Figure 1: Topology Diagram of ABU Network

loss. An adaptive queuing model was used to determine this optimum retransmission limit. The

knowledge of this limit enables congestion monitoring and control in order to reduce loss and achieve improved performance of the wireless system.

1.1 Overview of University WCAN

Traffic data used in the analyses was collected from the university network shown in Figure 1. The main Mikro Tik wireless router between the VSAT station and internal university WCAN represented in Figure 2, served as a queuing system for traffic data captured over a period of 11 months.

During low traffic when there is no congestion at the router interface, packets on arrival are serviced and dispatched immediately. On one hand, during heavy load periods of traffic, congestion occurs because arrival rates are faster than outgoings. Packets queue for the service at the interface to avoid drop. Once the interface is free, they are serviced and delivered. If delivery fails, retransmissions are carried out until the limit is reached before a packet is discarded.

2. THEORETICAL FUNDAMENTALS

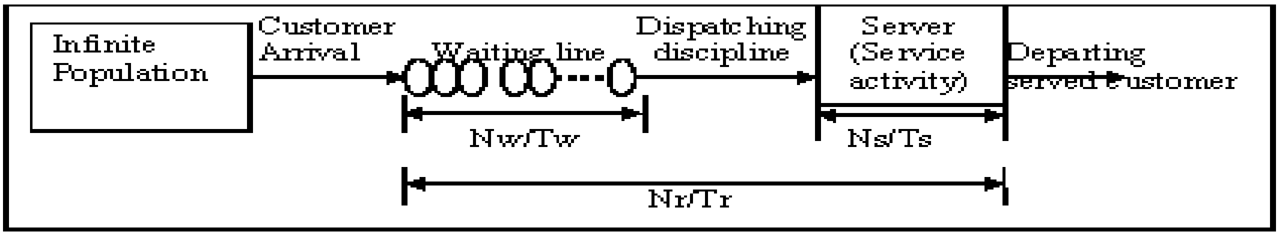

Figure 2: Poisson Process of Queuing System (Stallings, 2000)

2.1 M/M/1 Queuing Model

M/M/1 is Kendall's notation for a queuing model of three different components, namely, the input process, the service process and the number of servers handling these processes. The symbol M which is an abbreviation for Markovian represents both arrival and service times exponential distributions. Therefore, the model M/M/1 represents a single channel queuing system of Poisson arrival rate and exponential service time, where the population is unlimited and uses First-In First-Out (FIFO) queue discipline as shown in Figure 2 (Stallings, 2000).

M/M/1 is widely used in queuing analysis because it represents closely the behavior of a large number of queuing systems. It is also simple, fits well to real queuing situations and gives close results to those obtained by very good simulations. This model approximation is a good assumption for Poisson arrival process of real queuing systems which meet the following three conditions (Stalling, 2000):

(i) A system with a large number of users.

(ii) An individual user consuming only a small percentage of resources has little effect on the system's performance.

(iii) Decisions of users to access and use the system are completely independent of each other.

2.2 First-In-First-Out Queuing Mechanism

The First-In-First-Out (FIFO) scheme is a queue dispatch discipline where the first packet to arrive in the queue is the first one serviced and dispatched to the end system. In a FIFO system, priority is not observed and any packet can be dropped from any class once the queue is full. However, queue congestion management is accomplished by employing Random Early Detection (RED) mechanism at the end system which uses admission control to control queue congestion (Massoulie and Roberts, 2000).

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According to Stallings, (2000), FIFO is better than PQ, SFQ, WFQ and CBQ because:

(i) Its buffer is not partitioned and no data is lost.

(ii) It does not use the hashing function in queue assignment, which makes it faster and effective for large links that have little congestion and delay.

(iii) The unbalance resource allocation problem is prevented because FIFO has no priority attached to its packets in the queue.

Furthermore, FIFO discipline was implemented because of the following reasons:

(i) It works well with M/M/1 model to give better response time as opposed to algorithms using more than one queue

(ii) The scheme puts packets in an orderly self-arranged format that does not require sorting at the receiver end.

(iii)The algorithm is very simple and easy to implement and produce fast delivery of packets than other queuing disciplines.

2.3 Random Early Detection (RED) Mechanism

This mechanism is an effective queue management process for dropping packets before buffers overflow by monitoring the queue overflow preset threshold levels for congestion as shown in Figure 3. When a maximum preset level is within reach, implying congestion, RED drops a packet to slow down new arrivals from the sender. All packets are dropped when the maximum threshold is reached. RED does this using Early Congestion Notification (ECN) algorithm.

In order to avoid unnecessary packets drop and fully utilize the channel, the minimum threshold was set a bit high. Also, the gap between the maximum and minimum thresholds was made a bit large to prevent packets been unnecessarily dropped and transmitted at once.

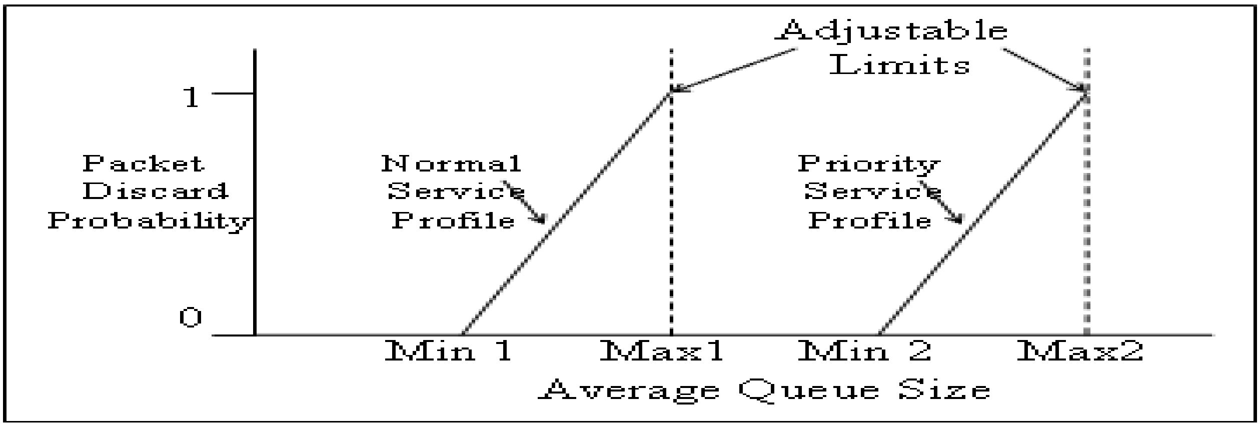

Figure 3: Two Service Levels of RED Packet Drop Probability (www.cisco.com, 7/13/13)

Unlike End-system now control, Network-based congestion control and Resource allocation control techniques, RED mechanism used in this work has the necessary congestion prevention policy and load shedding-level controlled scheme. By monitoring the levels for congestion status of the network it was possible to know when to slow, stop or resume transmission (Afolorunso, 2009). Also, RED with ECN algorithm works well with all types of networks by carrying out the following steps (Afolorunso, 2009):

1. Monitors the system in order to detect when and where congestion may occur.
2. Pass information to where action can be taken.
3. Drop delayed real-time packets which will be discarded at receiver anyway.

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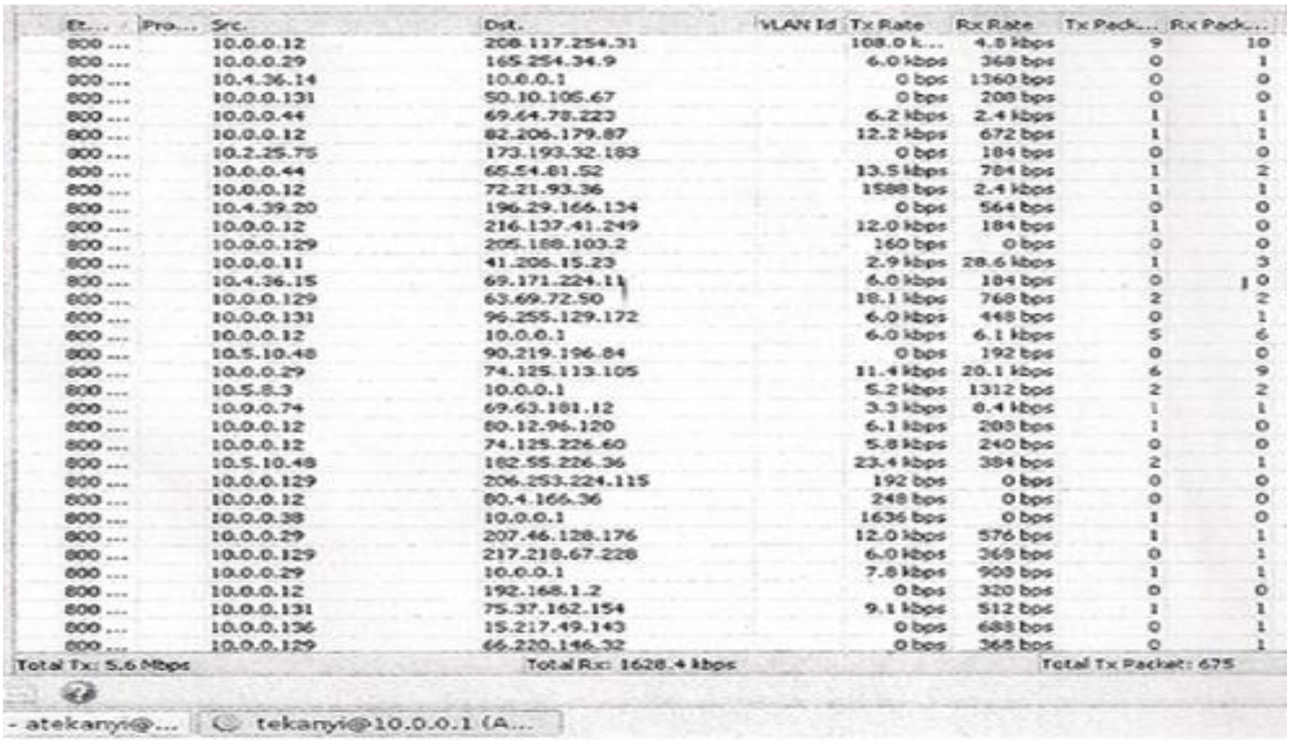
4. Adjust system operation to correct the problem.

3. MATERIALS AND METHODS

The methodology adopted to achieve the desired optimum acceptable retransmission limit for the university main wireless router was as follows:

(a) Implementation of M/M/1 Queuing Model using First-In-First-Out Queuing discipline and Random Early Detection (RED) Mechanism to control the queue.

(b) Carry out data collection and analysis to determine the minimum packet loss rate.



Et...	Pro...	Src.	Dst.	VLAN Id	Tx Rate	Rx Rate	Tx Pack...	Rx Pack...
800 ...		10.0.0.12	208.117.254.31		108.0 k...	4.8 kbps	9	10
800 ...		10.0.0.29	165.254.34.9		6.0 kbps	368 bps	0	1
800 ...		10.4.36.14	10.0.0.1		0 bps	1360 bps	0	0
800 ...		10.0.0.131	50.10.105.67		0 bps	208 bps	0	0
800 ...		10.0.0.44	69.64.78.223		6.2 kbps	2.4 kbps	1	1
800 ...		10.0.0.12	82.206.179.87		12.2 kbps	672 bps	1	1
800 ...		10.2.25.75	173.193.32.183		0 bps	184 bps	0	0
800 ...		10.0.0.44	65.54.81.52		13.5 kbps	784 bps	1	2
800 ...		10.0.0.12	72.21.93.36		1588 bps	2.4 kbps	1	1
800 ...		10.4.39.20	196.29.166.134		0 bps	564 bps	0	0
800 ...		10.0.0.12	216.137.41.249		12.0 kbps	184 bps	1	0
800 ...		10.0.0.129	205.188.103.2		160 bps	0 bps	0	0
800 ...		10.0.0.11	41.206.15.23		2.9 kbps	28.6 kbps	1	3
800 ...		10.4.36.15	69.171.224.11		6.0 kbps	184 bps	0	0
800 ...		10.0.0.129	63.69.72.50		18.1 kbps	768 bps	2	2
800 ...		10.0.0.131	96.255.129.172		6.0 kbps	448 bps	0	1
800 ...		10.0.0.12	10.0.0.1		6.0 kbps	6.1 kbps	5	6
800 ...		10.5.10.48	90.219.196.84		0 bps	192 bps	0	0
800 ...		10.0.0.29	74.125.113.105		11.4 kbps	20.1 kbps	6	9
800 ...		10.5.8.3	10.0.0.1		5.2 kbps	1312 bps	2	2
800 ...		10.0.0.74	69.63.181.12		3.3 kbps	8.4 kbps	1	1
800 ...		10.0.0.12	80.12.96.120		6.1 kbps	208 bps	1	0
800 ...		10.0.0.12	74.125.226.60		5.8 kbps	240 bps	0	0
800 ...		10.5.10.48	182.55.226.36		23.4 kbps	384 bps	2	1
800 ...		10.0.0.129	206.253.224.115		192 bps	0 bps	0	0
800 ...		10.0.0.12	80.4.166.36		248 bps	0 bps	0	0
800 ...		10.0.0.38	10.0.0.1		1636 bps	0 bps	1	0
800 ...		10.0.0.29	207.46.128.176		12.0 kbps	576 bps	1	1
800 ...		10.0.0.129	217.218.67.228		6.0 kbps	368 bps	0	1
800 ...		10.0.0.29	10.0.0.1		7.8 kbps	908 bps	1	1
800 ...		10.0.0.12	192.168.1.2		0 bps	320 bps	0	0
800 ...		10.0.0.131	75.37.162.154		9.1 kbps	512 bps	1	1
800 ...		10.0.0.136	15.217.49.143		0 bps	688 bps	0	1
800 ...		10.0.0.129	66.220.146.32		0 bps	368 bps	0	1

Total Tx: 5.6 Mbps Total Rx: 1628.4 kbps Total Tx Packet: 675

- atekanyi@... tekanyi@10.0.0.1 (A...

Figure 4: A Sample of Captured Traffic Data

3.1 Data Collection Process

Data on average arrival rate (λ) and average service rate (μ) were collected on the main wireless MikroTik router (at Senate Building) over a period of eleven months, from 31 January 2012 to 30 December 2012. This router shown in Figure 1 is linked to the VSAT satellite link feeding the university community with all necessary information. It is the router linking the university to the outside world and internally to various areas such as Main Samaru Campus, Congo Campus and Shika Teaching Hospital. The process of data collection was done on a daily basis from Mondays to Fridays only, excluding Saturdays and Sundays when the place would have been closed. At this MikroTik router, arriving packets in kilobits per second (kbps) and transmitted packets also in kbps

Table 1: Average Arrival/Service Rates

RATE (kbps)	TOTAL 3	TOTAL 4	GRAND TOTAL	AVERAGE (260 Days)	USED DATA
μ	133933.5	45117.8	179051.3	746.04708	746
λ	26138.2	16217.75	42355.95	176.48313	176.5

were captured from 9 am to 4 pm at an interval of two hours, that is, 9 am 11 am, 1 pm, 3 pm, respectively as shown in Figure 4 and represented in a table form as illustrated in Appendix 1. The two hours interval between 9 am and 4 pm were established as busy times of the day for data collection when the network is fully utilized. An average arrival rate (λ) and computed as represented in Appendix 2 and referred to as TOTAL 3 and TOTAL 4, respectively. Finally, the overall total traffic for the eleven months of data collection is represented by Table 1 and from which average arrival rate (λ kbps) and average service rate (μ kbps) are computed for the 240 days period.

3.2 Analysis of Packet Loss Rate

In a wireless network (Gu *et al.*, 2003), each packet may be lost either due to overflow and is dropped at the wireless access point with probability of P_D or due to channel errors and is dropped with probability of P_L. These losses lead to overall probability packet loss rate of the queuing system P_T. The relationship of the packet error rate (P_e), the channel (link) loss rate (P_L), and the retry limit (L_r) of packet retransmissions by the wireless access point is given by (Bobarshad and Shikh-Bahaei, 2009):

$$P_L = P_e^{(L_r+1)} \qquad (1)$$

Since the probability of the overall packet loss rate is the sum of the loss due to network buffer overflow and loss due to link error, consequently this overall packet loss rate is given by:

$$P_T = P_D + (1 - P_D)P_L$$
$$P_T = (P_D + P_L) - (P_D * P_L) \qquad (2)$$

Assuming both P_D and P_L are relatively very small, $(P_D * P_L)$ in equation (2) is negligible, hence, the overall packet loss rate is approximated as:

average service rate (μ) per day were computed from the 240 days traffic data contained in Appendix 1 and represented in Table 1.

T1 of Appendix 1 gives individual totals of traffic data from 31st January, 2012 to 15th July, 2012 and T2 are the totals of traffic data from 18th July, 2012 to 30th December, 2012. These totals are rearranged and their summations again

$$P_T = P_D + P_L \qquad (3)$$

The aim is to find the optimum value of the retry limit (L_r) so as to minimize the overall packet loss (P_T), by virtue of the fact that increasing L_r will decrease the packet link loss rate (P_L) and also increase the overflow packet loss rate (P_D) and satisfies equation (3).

The required condition for analysis is the stability of the system. The system can only attain its stability if the average arrival rate is less than average service rate (Kleinrock, 1988; Stallings, 2000). In other words, the system's utilization is less than unity.

Mathematically, the utilization (ρ) of the system is represented as:

$$\rho = \lambda / \mu < 1 \qquad (4)$$

where λ is the arrival rate and μ is the service rate of the queuing system.

This expression forms the basis of most analyses in queuing theory and it is an established condition because the system can only service what is within its capacity and nothing more. That is, utilization should be less than unity (Kleinrock, 1988; Stallings, 2000). That is, the system is only considered stable if the work offered per unit time is less than it can handle per unit time in order to prevent congestion and packet loss due to overflow.

Such packet loss rate due to overflow (Bobarshad and Shikh-Bahaei, 2009) is given as:

$$P_D = (1 - P_L)^{(B+1)} \qquad (5)$$

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where B is the network buffer space available to service the queue to prevent overflow.

Substituting equations (1) and (5) in equation (3) gives the overall packet loss rate (Bobarshad and Shikh-Bahaei, 2009) as:

$$P_T = (1-P_L)^{(B+1)} + P_e^{(L_r+1)} \tag{6}$$

4. RESULTS AND DISCUSSION

The key performance parameters such as the average arrival rate (λ), average service rate (μ) were used to determine packet error rate (P_e) of the wireless system. With the value of P_e available, equations (1), (6) and (3) were employed to obtain values of packet loss rate (P_D) due to network buffer overflow, packet loss rate (P_L) due to link errors and the overall packet loss rate (P_T). P_D and P_L defined optimum retry limit (L_{rOpt}) that gave the minimum overall P_T. The L_{rOpt} determined the acceptable operational maximum number of retransmissions a wireless access point could conduct on each packet before dropping it.

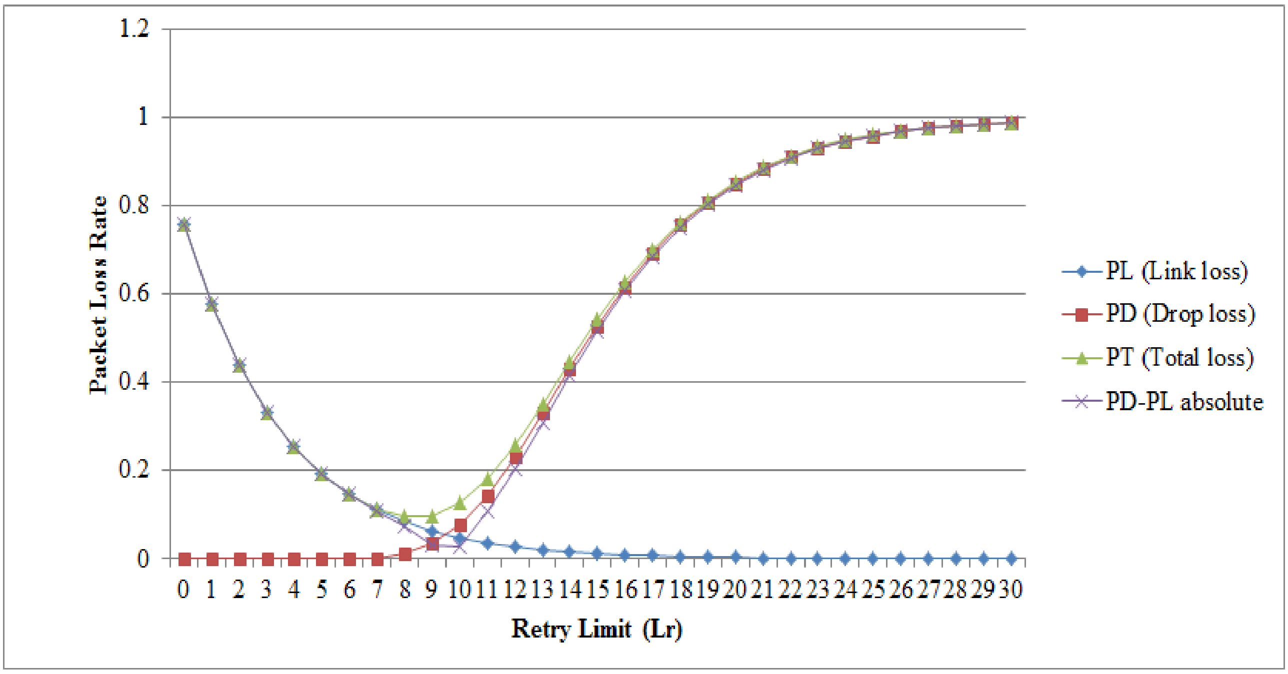
The L_{rOpt} parameter is very important because it is required to be able to manage and control the wireless queuing system such as the MikroTik wireless router access point linked to the VSAT satellite feeding the university community with information. Management and control of this router then leads to efficient and proper operation of the network to achieve the optimization and good quality of service required by users.

To determine the optimum retransmission limit (L_{rOpt}) that gives the best operational throughput of the wireless system, Microsoft Spreadsheet was used to obtain the results represented in Table 2. Different graphs of these respective loss rates were plotted against the increasing values of L_r as represented in Figure 5 to obtain L_{rOpt}. The value of L_{rOpt} is at the point of the intersection of P_D and P_L as in Li and Van der Schaar, (2004); Bobarshad and Shikh-Bahaei, (2009). A graph of $|P_D - P_L|$ against L_r also shows the variation of absolute values of the differences between P_D and P_L with an increase in L_r. This graph enables L_{rOpt} be obtained because at $|P_D - P_L| = 0$ L_{rOpt} corresponds to the state of the system when $P_L = P_D$. This is also the state when P_T is minimum at 0.05 because the queuing system is stable with very little or no congestion and has its highest throughput possible.) The packet loss rate 0.05 is obtained

Table 2: Values of Loss Rates

L_r	$P_L = P_e^{(L_r+1)}$	$P_D = (1-P_L)^{(B+1)}$	$P_T = P_D + P_L$	$\lvert P_D - P_L \rvert$	B
Retry Lim	PL (Link loss	PD (Drop loss	PT (Total loss	PD-PL absolu	Capacity
0	0.76	2.459E-32	0.76	0.76	50
1	0.5776	8.164E-20	0.5776	0.5776	50
2	0.438976	1.578E-13	0.438976	0.438976	50
3	0.3336218	1.023E-09	0.3336218	0.333621759	50
4	0.2535525	3.334E-07	0.2535529	0.253552204	50
5	0.1926999	1.815E-05	0.1927181	0.192681782	50
6	0.1464519	0.0003109	0.1467629	0.146141041	50
7	0.1113035	0.0024346	0.1137381	0.108868879	50
8	0.0845906	0.0110251	0.0956157	0.07356554	50
9	0.0642889	0.0337467	0.0980356	0.030542205	50
10	0.0488596	0.07771	0.1265696	0.028850478	50
11	0.0371333	0.1451695	0.1823028	0.108036241	50
12	0.0282213	0.2322398	0.2604611	0.20401851	50
13	0.0214482	0.33096	0.3524081	0.309511785	50
14	0.0163006	0.4324964	0.448797	0.416195775	50
15	0.0123885	0.529534	0.5419225	0.517145539	50
16	0.0094152	0.6172682	0.6266834	0.607852972	50
17	0.0071556	0.693332	0.7004876	0.686176402	50
18	0.0054382	0.7572158	0.762654	0.751777512	50
19	0.0041331	0.8095936	0.8137266	0.805460506	50
20	0.0031411	0.8517608	0.8549019	0.848619638	50
21	0.0023873	0.8852408	0.887628	0.882853507	50
22	0.0018143	0.9115452	0.9133595	0.909730891	50
23	0.0013789	0.9320476	0.9334265	0.930668745	50
24	0.0010479	0.9479312	0.9489791	0.946883226	50
25	0.0007964	0.9601799	0.9609763	0.959383422	50
26	0.0006053	0.9695925	0.9701978	0.968987219	50
27	0.00046	0.9768066	0.9772666	0.976346549	50
28	0.0003496	0.9823244	0.982674	0.981974808	50
29	0.0002657	0.9865384	0.9868041	0.986272712	50
30	0.0002019	0.9897529	0.9899548	0.989550967	50

Figure 5: Characteristic Curves of a Queuing System



from Figure 5 and it is the point on the vertical axis that corresponds to the point of intersection of P_D and P_L. It may as well be deduced from Figure 5 that when $P_L > P_D$, $L_r < L_{rOpt}$ and overall loss (P_T) of the system is dominated by link error loss (P_L), which decreases sharply with an increase in L_r. The reasons are that the number of retransmissions is within the acceptable limit. During this state of the queuing system, the link is less likely to encounter errors for packets to be dropped because of the less number of packets in the system. All new arrivals and retransmitted packets are all highly likely to be accepted and delivered by the wireless router. After the L_{rOpt} point, a decrease in P_L becomes very small and gradual as L_r continues to increase because retransmissions are less due to limited arrivals of new packets into the system as the network buffer approaches its full capacity. At saturation point when the network buffer has attained its full capacity, P_L remains constant at zero even when L_r continues to increase because there are no more new arriving packets into the channel that may encounter errors to be dropped. Since there are no new arrivals, it means that there are no packets to retransmit which may also encounter errors in the channel to be dropped too. These are reasons why P_L remains constant at zero when the network buffer space is saturated.

Contrarily, when $P_L < P_D$ and $L_r > L_{rOpt}$, system loss is mainly influenced by packet overflow loss. This increases with an increase in L_r as shown by P_D graph in Figure 5. P_D has very small gradual increase before the L_{rOpt} point is reached, a sharp increase thereafter and constantly held at unity at and after saturation of the system is attained. Also, the reasons are that before L_{rOpt} point, the wireless system has enough room in the buffer and hardly drops a packet. After this point, storage space decreases as the system approaches saturation. There is a constant maximum drop of packets at full capacity of network buffer onwards because there is no more room to accept new arrivals. Consequently, all new packets are dropped as they arrive. This is the reason why P_D remains constant at maximum when the network buffer space is saturated.

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5. CONCLUSION

The representations of Figure 5 clearly show that the overall packet loss rate of the wireless queuing system is influenced by the retransmission limit of the system. It is observed that the optimum retransmission limit of 10 only occurs at the point of intersection of the loss due to channel errors and the loss due to buffer overflow. This is the point when the system has very little or no congestion. It is the point when the queuing system attains its stability, experiences minimum loss (0.05, a point on the vertical axis corresponding to P_D and P_L) and delivers high throughput.

From zero value of retransmission limit to an optimum retransmission limit of 10, the overall packet loss rate decreases with an increase in the number of retransmissions because the overall loss rate is influenced only by packet loss rate due to errors in the link which decreases towards the optimum point. The packet loss rate due to buffer overflow has no effect on the overall packet loss rate before the optimum retransmission limit is reached.

Also, moving away from the optimum retransmission limit of 10 towards its large (infinite) values, more overall packet loss rate is observed which is constant at the saturation point of the network buffer. The reason is that before the full buffer capacity is reached at 30, the overall packet loss rate is caused only by the packet loss rate due to buffer overflow which increases to the saturation point and then remains constant and equal to overall packet loss rate because at this point the loss due to link errors has no effect on the overall packet loss rate.

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APPENDICES

Appendix 1: Arrival and Service Rates at the Public Router of Ahmadu Bello University WCAN Network and their totals, T1

Items	Mon	Tues	Wed	Thurs	Fri	Mon	Tues	Wed	Thurs	Fri	Mon	Tues	Wed	Thurs	Fri	T1
31 Jan - 18 Feb																
µkbps	204.2	232.8	105.4	1664.4	822.1	1007.7	1013.8	1005.6	1005.2	822.1	897.3	1005.8	905.3	966.4	98.2	11756.3
λkbps	7.1	13.1	21.9	100.3	93.8	103.4	79.4	99.5	81.8	93.8	6000	35.9	32	31.7	10.8	6804.5
21 Feb - 11 Mar																
µkbps	346.1	180.5	382.7	105.5	637.6	603.7	790.6	361.9	332.2	995.8	1002.2	1003.7	1007.2	1001.2	1009.4	9760.3
λkbps	23.3	7.4	21.6	24.7	46.7	25.7	45.2	16.1	15.9	86.3	61	72.4	91.9	58.2	56.4	652.8
14 Mar - 1 Apr																
µkbps	1005.1	1002.2	1004.9	1006.9	1004.3	1007.4	1002.7	1005.3	1009.9	1009.9	1002.7	1009.4	1005.2	1004.8	964.9	15045.6
λkbps	64.7	67.8	64.4	57.8	69.7	77.9	60.6	96.9	78.2	81.7	60.6	106.8	91.2	82.1	177	1237.4
4 Apr - 23 Apr																
µkbps	788.7	888.3	878.1	762.4	6200	6300	6400	6300	6200	3600	519.7	517	511.7	523.5	513.1	40902.5
λkbps	139.1	203.3	158.5	204.5	953	786	829.1	799.9	870.3	885.8	87.8	108.9	76.8	67.7	72.9	6243.6
26 Apr - 13 May																
µkbps	511	515.9	507.3	520.7	526	7900	6200	5900	6400	836.2	619.8	475.8	281.4	519.5	730.9	32444.5
λkbps	95.5	46.7	107.3	52.4	48.8	1965.1	1438.8	1456.7	1027.3	69	83.4	62.6	23.3	51.6	91.2	6619.7
16 May - 3 June																
µkbps	541.4	420.6	339.4	230.5	926	969	861.3	920	831.3	956.2	1003.4	1003.3	713.2	664.1	1009.8	11389.5
λkbps	50.3	29.5	37.7	46.8	96.3	162.6	95.1	125.9	74.1	48.5	81.4	72.6	86.8	111.8	104.2	1223.6
6 June - 24 June																
µkbps	13.2	3.8	2.8	798	5.2	1002.7	1007.2	1002.6	1001.4	1004.1	86.5	150.8	79.7	213.8	140.9	6512.7
λkbps	14.2	6.6	6.3	3.5	4.5	44.1	56.1	57.9	53.2	57.6	41.5	32.7	43.1	42.9	42.1	506.3
27 June - 15 July																
µkbps	206.8	201.7	240.5	155	138.8	420.2	694.8	632.3	656.2	900.1	526.3	175.9	391.3	263.1	519.1	6122.1
λkbps	42.5	58.5	67	38.8	40.4	306.8	304.7	306.7	319.1	273.6	173	161.7	207.7	469.3	80.5	2850.3

Appendix 1: Arrival and Service Rates at the Public Router of Ahmadu Bello University WCAN Network and their totals, T2

Items	Mon	Tues	Wed	Thurs	Fri	Mon	Tues	Wed	Thurs	Fri	Mon	Tues	Wed	Thurs	Fri	T2
18 July - 5 Aug																
µkbps	6000	20.4	69.4	4.7	36.5	999.2	1001.9	1039.1	969.3	1005.8	998.2	1020.8	1039.6	970.9	1010.1	16185.9
λkbps	1300	9.1	36.5	9.6	17.6	335.8	324.5	230.7	334.4	454.3	201	275.7	329.7	391.7	234.2	4484.8
8 Aug - 26 Aug																
µkbps	74.1	82.8	74.9	93.4	107.9	99.1	114.2	145.7	203	120.2	48.8	49.3	27.2	6.1	20.3	1267
λkbps	13.2	12.9	15.9	18.4	12.8	30.7	11.4	48.1	31.7	40.4	24.4	9.1	4.8	3.1	8.9	285.8
29 Aug - 16 Sept																
µkbps	444.1	465.7	295.9	463.3	503.4	189.4	148.5	147.7	134.3	207.3	157.1	196	189	171.6	225.4	3938.7
λkbps	177.6	179.6	308.8	332.4	277.6	49.9	27.9	90.4	39.8	69.5	37.4	47.3	64.3	36.8	81.4	1820.7
19 Sept - 7 Oct																
µkbps	257.9	261.1	264.8	208.3	226.7	265.4	261.2	264.5	250.7	255.1	337.1	472.4	491.7	397.1	410.1	4624.1
λkbps	104.9	96.2	52.6	145.9	61.3	88.7	67.9	73.8	57.3	83.4	38.5	82.8	37	38	43.8	1072.1
10 Oct - 28 Oct																
µkbps	508.6	478.8	352.7	370.6	296.4	324	379.8	360.8	236.2	267.1	172.6	160.5	114.9	254.8	161.2	4439
λkbps	35.4	50.4	42.7	42.5	47.1	40.9	131.7	59.7	122.7	124.5	42	29.4	34.6	31.6	27.4	862.6
31 Oct - 18 Nov																
µkbps	717.7	514.2	524.4	514.7	461	516	509	517.3	515.1	254.8	227.5	461.1	470.8	395.7	418.1	7017.4
λkbps	169.5	61.6	74.3	53.2	71.1	43	97.1	87.4	66.7	31.6	542	703.1	690	688.8	601.1	3980.5
21 Nov - 9 Dec																
µkbps	503.7	517.8	504.4	497.7	436.4	511.9	490.3	515.4	512.3	512.8	36.1	513.6	453.6	461	470.8	6937.8
λkbps	549.8	589.5	573.1	657.7	617.9	44	54.5	51.9	35.3	43.8	4.5	49.1	42.6	71.1	32.6	3417.4
12 Dec - 30 Dec																
µkbps	51	12.6	25.6	21.2	29.7	25.7	29.5	33.3	36.1	25.5	76.2	76.1	81.1	107.1	77.2	707.9
λkbps	49.1	1.75	39.6	3.2	7.9	4.7	4.2	10.3	4.5	4.5	54.3	11.8	50.8	25.1	21.7	293.45

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Appendix 2: Totals of arrival and Service Rates with Received and Transmitted Packets for the Public Router of ABU WCAN Network

Items	31Jan-18Feb	21Feb-11Mar	14Mar-1Apr	4Apr-23Apr	27Apr-13May	16May-3Jun	6Jun-24Jun	27Jun-15July	TOTAL3=SUM T1
µkbps	11756.3	9760.3	15045.6	40902.5	32444.5	11389.5	6512.7	6122.1	133933.5
λkbps	6804.5	652.8	1237.4	6243.6	6619.7	1223.6	506.3	2850.3	26138.2
Items	18July-5Aug	8Aug-26Aug	29Aug-16Sept	19Sept-7Oct	10Oct-28Oct	30Oct-18Nov	21Nov-9Dec	12Dec-30Dec	TOTAL4=SUM T2
µkbps	16185.9	1267	3938.7	4624.1	4439	7017.4	6937.8	707.9	45117.8
λkbps	4484.8	285.8	1820.7	1072.1	862.6	3980.9	3417.4	293.45	16217.75

Appendix 3: The Arrival and Service Rates values used in the Analysis

Table 1: Average Arrival and Service Rates

ITEM	TOTAL 3	TOTAL 4	GD TOTAL	AVERAGE	USED DATA
µkbps	133933.5	45117.8	179051.3	746.04708	746
λkbps	26138.2	16217.75	42355.95	176.48313	176.5