AN INVESTIGATION ON TCP SACK CONGESTION CONTROL ON UNIVERSITY OF NIGERIA LIONET HOTSPOT

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Abstract—With the increasing awareness of mobility cloud computing via-a-vis wireless networks, there is an indication that Flow-Aware Wireless LAN (FA-WLAN) will play an important role in future internetworks supporting clouding, virtualization, Smart grids, and 4G LTEs. Congestion management in FA-WLAN considering existing network transport protocols such as TCP and UDP have limitations when fitting into these new technologies as increased heterogeneity and mobility will generate issues and concerns in managing congestion issues. With respect to realistic loads, TCP-SACK cannot handle traffic congestion in a Flow Aware-WLAN for scalable Internet traffic. This work conducted a pilot study in University of Nigeria Nsukka using three sets of APs to carry out measurements and analysed the behaviour of data frame size in traditional TCP- SACK. We used ethereal wireshack in a real time scenario for the data collection. Also, we considered IEEE 802.11 based wireless LAN where the access points is used to connect a fixed number of users to the Web or to a shared file system.The results of our investigation showed that in FA-WLANs, TCP-SACK will scale poorly in this new era of high performance computing (HPC), hence a novel congestion control scheme which will harvest packet size distributions is proposed, layer4 DMF.

Keywords: FA-WLAN, Wireless, Congestion, TCP, SACK, Ethereal, HPC.

1. INTRODUCTION

Mobility computing in the context of hotspot networks goes with its associated transport layer challenges. The 802.11a/b/g is the de facto standard for wireless local area networks (WLANs). Which aim at providing wireless connectivity to the Internet, representing a valid alternative to classical Ethernet LANs. Communication in wireless network is quite susceptible to mobility, nodes capacity and power consumption level [1]. These might contributes to the major problem of TCP performance degradation where there are highly potential of packet loss and packet reordering [1].

In particular, it turns out that, due to the extremely high overhead encompassed by the 802.11 TCP protocol which lacks robust explicit duplexing mechanism, this will have an extremely negative effect on packet size distribution metrics. Also, we analyze the impact of the TCP congestion mechanism on frame size window distribution. However, evidence is provided that, under a careful tuning of design of an efficient algorithm as well as setting of some AP parameters, TCP delayed ACK technique scan help in reducing the mean session delay which could affect packet size distribution, thereby enhancing effective throughput.

The paper is organized as follows. Section 2 reports on related works as well as a broad description of a contextual network scenario of the 802.11 MAC protocol. The methodology involving the UNN measurement testbed for TCP SACK frame size distribution analysis for persistent TCP connections is presented in Section 3. The analysis of the limitations of generic TCP SACK is presented in Section 4. Section 5 concludes the paper.

2. RELATED WORKS

The author in [2] carried out an exhaustive investigation into the effects of data frame size distribution on WLANs without understudying the congestion effects of TCP mechanisms. For HTTP traffic in the context of persistent connections, the work in [3] analysed the network performance of an 802.11-based WLAN in the presence of realistic workloads. A derivation of estimates for the TCP throughput in the context of competing persistent connections, for both standard TCP and generalized delayed ACK techniques was presented. This leads to their development of a queuing model.

The work in [4], presented a simulation study on WLANs for http services using OPNET IT Guru. A collective sample of literature on wireless traffic measurement and Internet protocol performance over wireless networks was studied in [5], [6], [7], and [8]. We observed that several studies have utilized measurements from production wireless networks to compute traffic models [10], [11], [12], [13], [14]. The primary focus of these studies has been to either investigate transport and application layer performance through the analysis of traffic captured on the wireline portion of the network, or utilizes SNMP and syslog information from access points to model mobility and association patterns. The effect of congestion on the performance of the various protocol layers has been studied extensively using either simulations or analytical methods. Cen et al. Propose algorithms for distinguishing congestion from wireless network losses [15]. The algorithms provide a basis for optimizing TCP parameters such as back-off intervals and congestion window sizes. Several methods for the optimization of the 802.11 protocol in congested environments have been suggested [16], [17], [18].

The above studies do not offer an experimental evaluation of link-layer performance in heavily utilized and congested wireless networks particularly for TCP SACK vis-a-vis frame size distribution. This research opines that by gaining a deep understanding of the real-world performance of the TCP SACK under congestion scenario, a novel algorithm can now be considered to address packet size distribution in host spot scenarios.

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2.1 Contextual Network Scenario

Consider a hotspot WLAN where an access point (AP) provides access to Web or a shared file system to *(n…..N+1)* hosts. At any instant of time, a host is downloading (or, receiving) at most one file via an AP. This file transfer is controlled using TCP SACK. After the completion of a file transfer, a host waits for a random amount of time before initiating another file transfer request. The size of the requested files in successive requests is assumed to be independent and identically distributed. The TCP controlled Data traffic flows in the downlink direction (from the AP to the hosts) while the TCP Acknowledgement traffic flows from the hosts to the AP. The AP and various node s use the IEEE 802.11 MAC protocol for transmission of their data (TCP DATA packets in case of AP and TCP ACK packets in case of nodes).

This work seeks to show the weakness of existing TCP SACK for real time mission critical applications in a flow-Aware hotspot scenario.

Hence, an important issue to address is the impact of congestion via the 802.11 MAC and the closed-loop nature of TCP SACK. This is accomplished in this paper, where we estimate the frame size distribution by TCP SACK in UNN lionet network for concurrent and persistent connections. A natural step in the wireless frame size distribution is to understand the effect of congestion control mechanism on the network.

3. RESEARCH METHODOLOGY

The experimental approach presents a congestion measurement based on TCP SACK vis-à-vis data frame sizes with characterization of a real life testbed in University of Nigeria Nsukka (UNN Lionet). This work will first characterize the lionet WLAN environment for high density user data access with a good experimental technique to derive our evidence which now gave rise to real plots for analysis purposes

3.1 Description of Experimental Environments

This section discussed UNN Lionet wireless network architecture, the congestion monitoring framework and a set of monitoring challenges for heavily utilized wireless networks. The traffic scenarios comprise of heavy database access, email access, file transfers, etc. Fig. 3.1 shows a Sniffer test terminal (in Room A) with the WifiCard for selective TCP SACK filtering of the designated metrics.

Fig.3.1: A Sniffer test terminal (in Room A) with the WifiCard

Fig. 3.2 shows a fixed data center for mobility Computing (FA-WLANS) (Source UNN data center, 2012). In this network, the traffic is typically based on TCP SACK. Several applications and services are hosted from this environment which the end users can access.

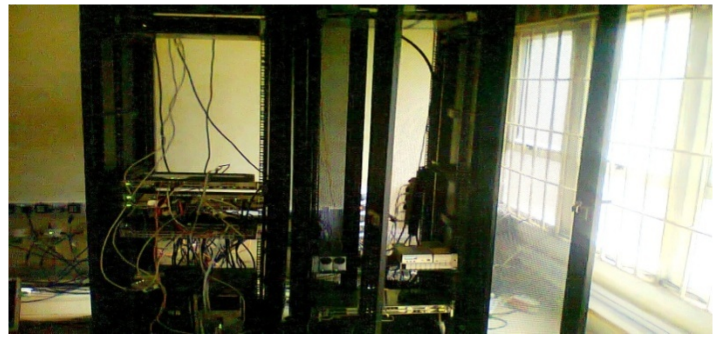

Fig.3.2: A Fixed Data center for Mobility Computing (FA-WLANS) (Source UNN data center, 2012)

3.1.1 Lionet Wireless Access Point Environment

In this research we structured the wireless network to comprised of 3 Airspace Access Points (Linksys APs) distributed on three adjacent doors cover a vicinity of about 200m for our investigations. Each AP supported the IEEE 802.11a, IEEE 802.11b and IEEE 802.11n protocol standards; however, in this experiment, we assumed the operation of the IEEE 802.11 generic FA-WLAN for the three standards as depicted by the setup in Fig. 3.1.

Fig. 3.3 show the placement of the 3 APs in the rooms where we conducted our measurement and collection data frame during the day and late evening sessions, respectively.

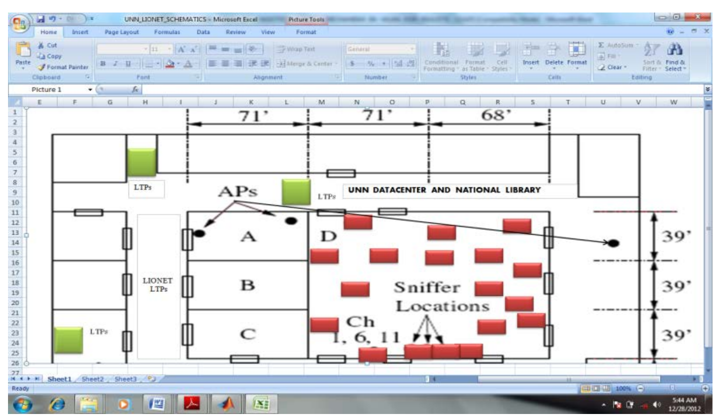

Fig. 3.3: Sniffer locations For Frame Captures.

Fig.3.4 shows the floor Plan of UNN Lionet indicating the positions of the access points. The access points connects to a dynamic hosts configuration server (DHCP) which allocates the respective IP addresses to client machines after a challenge handshake authentication from the network server. In order to optimize network performance, the Airspace APs are designed to support dynamic channel assignment, client load balancing, and transmission power control. The dynamic channel assignment and power transmission controls were

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enabled. Dynamic channel assignment refers to the technique that switches the AP's operating channel, depending on parameters such as traffic load and the number of users associated with the AP. Client load balancing refers to the technique that controls per-AP user associations via their service set identifiers (SSIDs). The transmission power control regulates the power at which an AP transmits a frame. In our observation, the technical details about these three optimizations are proprietary. Also, the access points were observed to switch channels dynamically to balance the number of users and traffic volume on the three channels.

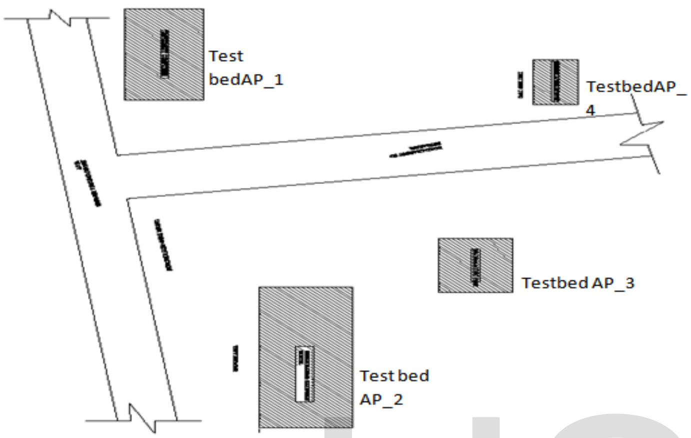


Fig.3.4: Structural diagram of the entire network AP placement

Basically, in heavily utilized FA-WLAN, the wireless portion of the network is a major performance bottleneck. Understanding the behavior of the wireless portion of such networks is critical to ensure their robust operation. This understanding will help us to optimize network performance in our future work.

A quantitative approach was used in carrying out congestion management study using link layer information collected from an operational, medium-scale, and heavily utilized IEEE 802.11 wireless network deployed in our testbed. This work then considered the use of trace file data set define highly congested, moderately congested, and uncongested network states in the context of TCP SACK scheme. This formed the basis for the proposed layer 4DMF which will be compared with other existing congestion control schemes as part of our future work.

3.2 Data Collection Methodology

With the network sniffer, wireshack, measurements were taken on the network described above on each test bed. The attributes (settings) of the access points (Linksys) were first configured and the network sniffer was used to measure the TCP frame sizes, throughput, delay, signal strength, the MAC address, the access point types, the speed, the noise level, vendor etc.

The method used to collect data from the MAC layer is called *vicinity sniffing* [19]. The vicinity sniffing framework consisted of three *sniffers*, Dell Inspiron laptops. Each sniffer was equipped with a Wifi-802.11n radio with WLAN cards. The radios were configured to capture packets in a special operating mode called the *RFMon* mode. The RFMon mode enables the capture of regular data frames as well as IEEE 802.11 management frames. In addition, the RFMon mode records information for each captured packet. This information includes the send rate, the channel used for packet transmission, the signal to- noise ratio (SNR) of the received packet, frame number, number of bytes on channel, number of bytes captured and some prism monitor header information which included whether the frame were a wireless LAN management frame or not. Because the Airespace access points were expected to switch between the 802.11 channels 1, 6, and 11, each sniffer was configured to sniff on one of the three different channels for the duration of each session. The packets were captured using the sniffer utility E*thereal wireshack*. The snap-length of the captured packets was set to 250 bytes in order to capture only the RFMon, MAC, IP and TCP/UDP headers. The data capturing process was conducted using a placement configuration during the day only.

i. Day sessions: The day sessions done between 09:30am and 4:00pm on August 24.08, 2012. The day sessions were split into 1 to 3 parallel tracks and each track was held in one of the several meeting rooms shown in Fig. 3.1. The parallel session tracks were held at three intervals
During the day: 09:30 am to 11:30am, 12:30am to 2:30 pm, and from 2:30pm to 4:00pm. This work chose to place the three sniffers in one of the busiest and largest meeting rooms close to MTN ICT center while picking packets from lionet network. The placement of the three sniffers is shown in Fig. 3.4. Data was collected during the day sessions

3.3 Analysis Data Sets

Wireless network data collected from the Lionet network was arranged into a day session. A trace file of captured real live wireless traffic from UNN wireless Network (LIONET) was used in the analysis considering the congestion scenarios. Wireshark Network Analyzer (Etheral) was used on the various sniffer machines and the traffic data collected. Our collection framework recorded a total of 1.6 million data frames, 1.05 million acknowledgment frames, 40,000 RTS frames, and 17,490 CTS frames during the day and the plenary sessions cumulatively. However, a total of 100000 frames were captured for analysis by progressively analyzing the selected frame captures. The trends of individual frame size types as well as the trend of management and non-management (mostly data) frames were discerned. The use of the RTS.CTS mechanism is generally turned off by default on wireless devices and its use is optional. The data indicates that the use of the RTS.CTS mechanism for channel access by users was average on Table 3.1:

Table 3.1: Trace files Data Set

Data Set	Day	Channel	Time
Day	August 24, 2012	1	09:30am to 1:30am
	August 24, 2012	6	12:30am to 2:30pm
	August 24, 2012	11	02:30pm to 4:00pm.

However, our sniffer machines satisfy the above requirements. Fig. 3.5 depicts the congestion traffic captured with ethereal Wireshack from varying IP sources as allocated by the DHCP server. Fig. 3.6 depicts the congestion traffic captured with Etheral Wireshack under TCP-SACK and its variants. Fig. 3.7 depicts the Average packets transmitted under congestion scenario. Fig. 3.8 depicts the congestion traffic captured with Etheral Wireshack from varying TCP services. Fig. 3.9 shows the TCP services statistics. Fig. 3.10 shows the congestion traffic captured with Etheral Wireshack from varying TCP Ack feedback packet drop scenario while Fig. 3.11 shows the summary congestion traffic statistics captured with Etheral Wireshack under varying TCP services.

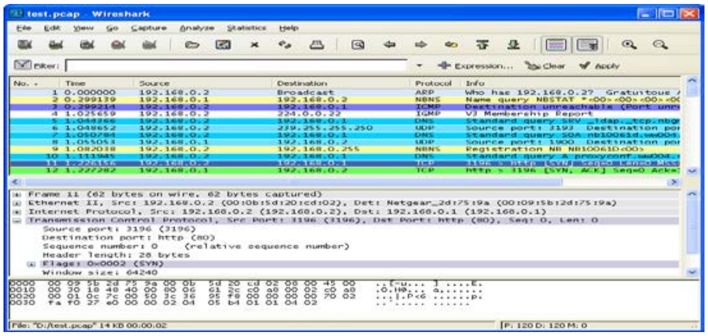


Fig.3.5: Wireshark captured packet with TCP variants

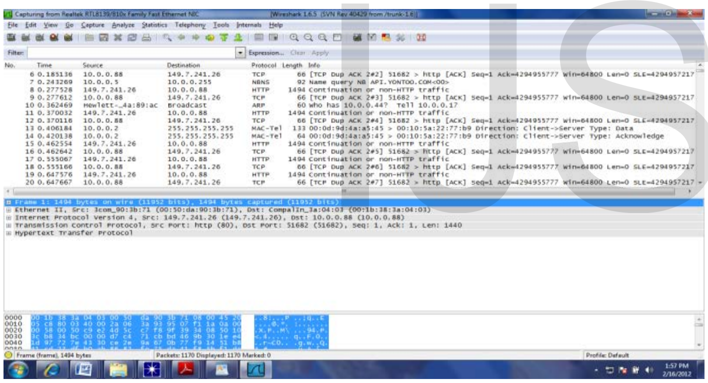


Fig.3.6: Congestion traffic captured with Etheral Wireshack under TCP-TRONVS.

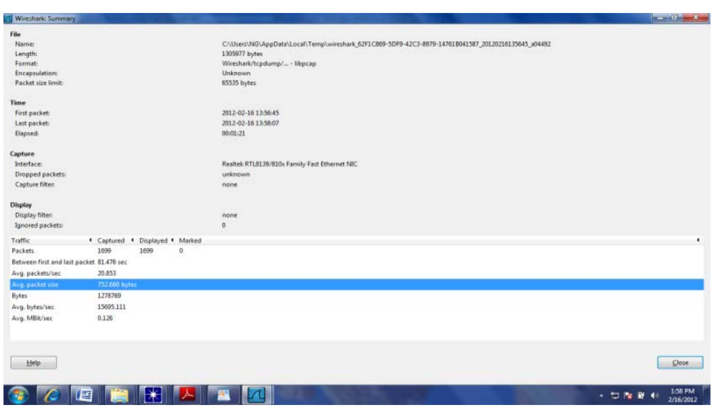


Fig.3.7: Average packets transmitted under congestion scenario

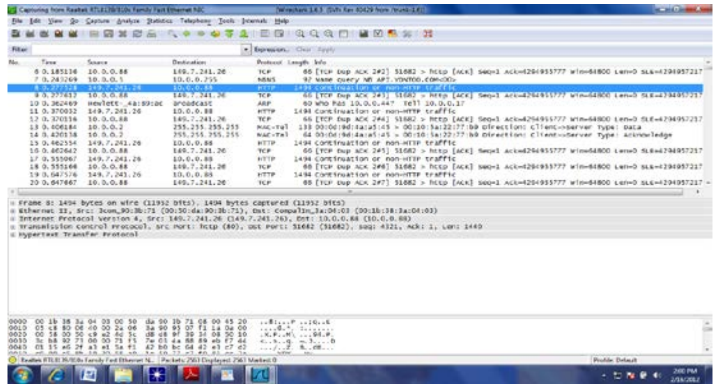


Fig.3.8: Congestion traffic captured with Etheral Wireshack from varying TCP services

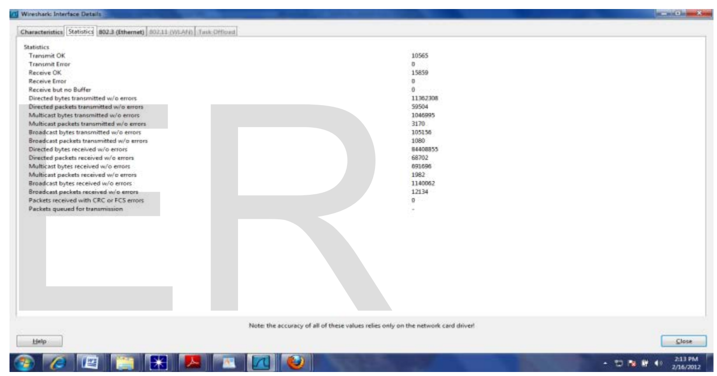


Fig.3.9: TCP services statistics

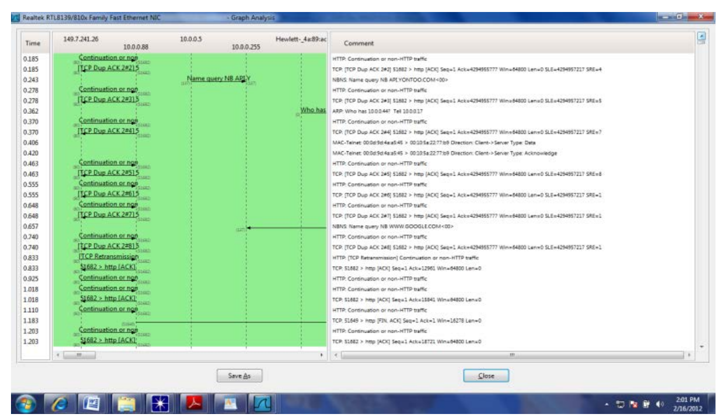


Fig.3.10: Congestion traffic captured with Etheral Wireshack from varying TCP Ack feedback packet drop scenario

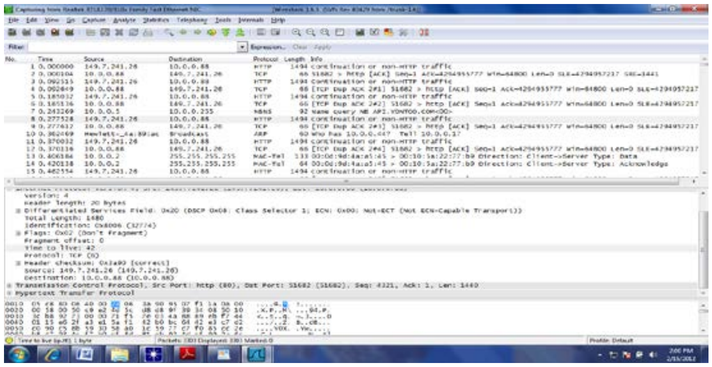


Fig.3.11: Summary congestion traffic statistics captured with Etheral Wireshack under varying TCP services.

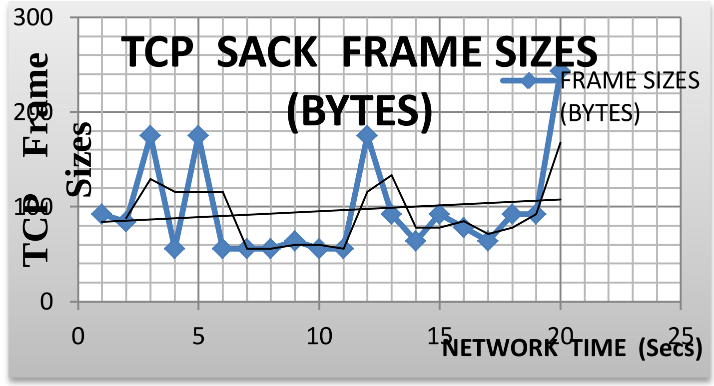


Fig.3.13: Congestion TCP SACK Frame size behaviour (bytes)

During the day sessions between 09:30am and 4:00pm, frame propagation under congestion periods as a result of much traffic enabled the capturing of TCP frames at various tracks. Fig.s 3.5 to Fig. 3.11 shows the responses of the combinations of selected frames sizes from the trace file of the scenario data set whose metrics are shown for captures 1, capture 6, capture 13, capture 23, capture 36, capture *N.*
However, this work only focused on TCP SACK traffic captures 1, capture 6, capture 13, capture 23 and capture 36. The metric selected for our study included frame sizes, throughout, latency, sources and destination.

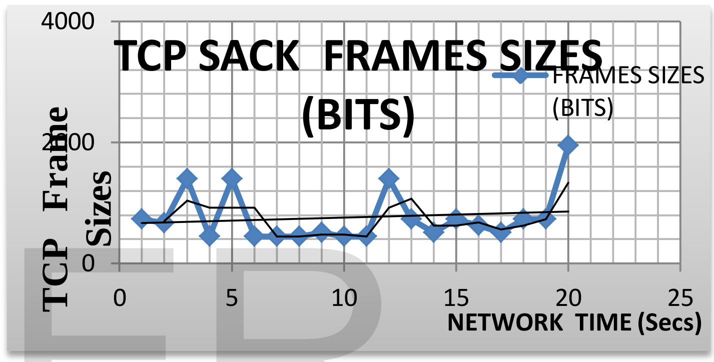
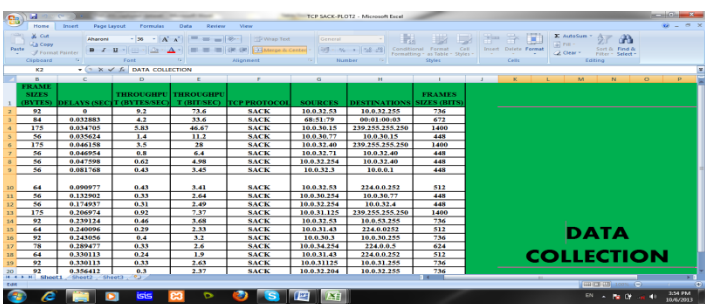


Fig.3.14: Congestion TCP SACK Frame size behaviour (bits)

4. ANALYSIS OF TCP SACK METRICS

Fig. 3.12 shows an ethereal data collection snapshot showing various parameters such as frame sizes (Bytes/Bits), delays (Secs), throughputs (Bytes/Bits), TCP SACK protocols, sources, destinations.



	FRAME SIZES (BYTES)	DELAYS (SEC	THROUGHPUT (BYTES/SEC)	THROUGHPUT (BIT/SEC)	TCP PROTOCOL	SOURCES	DESTINATIONS	FRAMES SIZES (BITS)
2	92	0	9.2	73.6	SACK	10.0.32.53	10.0.32.255	736
3	84	0.032883	4.2	33.6	SACK	68:51:79	00:01:00:03	672
4	175	0.034705	5.83	46.67	SACK	10.0.30.15	239.255.255.250	1400
5	56	0.035624	1.4	11.2	SACK	10.0.30.77	10.0.30.15	448
6	175	0.046158	3.5	28	SACK	10.0.32.40	239.255.255.250	1400
7	56	0.046954	0.8	6.4	SACK	10.0.32.71	10.0.32.40	448
8	56	0.047598	0.62	4.98	SACK	10.0.32.254	10.0.32.40	448
9	56	0.081768	0.43	3.45	SACK	10.0.32.3	10.0.0.1	448
10	64	0.090977	0.43	3.41	SACK	10.0.32.53	224.0.0.252	512
11	56	0.132902	0.33	2.64	SACK	10.0.30.254	10.0.30.77	448
12	56	0.174937	0.31	2.49	SACK	10.0.32.254	10.0.32.4	448
13	175	0.206974	0.92	7.37	SACK	10.0.31.125	239.255.255.250	1400
14	92	0.239124	0.46	3.68	SACK	10.0.32.53	10.0.53.255	736
15	64	0.240096	0.29	2.33	SACK	10.0.31.43	224.0.0252	512
16	92	0.243056	0.4	3.2	SACK	10.0.30.3	10.0.30.255	736
17	78	0.289477	0.33	2.6	SACK	10.0.34.254	224.0.0.5	624
18	64	0.330113	0.24	1.9	SACK	10.0.31.43	224.0.0.252	512
19	92	0.330113	0.33	2.63	SACK	10.0.31125	10.0.31.255	736
20	92	0.356412	0.3	2.37	SACK	10.0.32.204	10.0.32.255	736

DATA COLLECTION

Fig. 3.12: A Snapshot of Etheral Wireshack Capture Datasets

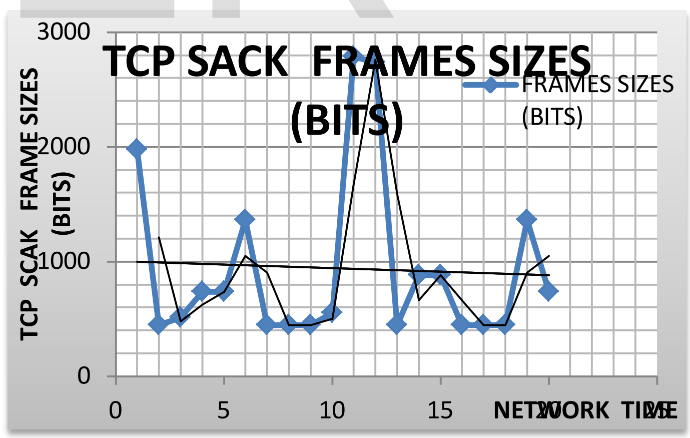


Fig. 3.16: Congestion TCP SACK Throughput behaviour (Bytes/secs)

In Fig 3.13 and Fig. 3.14, congestion analysis in context was based on frame size distributions. As shown in the trends, the frame sizes follow an odd sequence as result of TCP SACK mechanism leading to intermittent packet drops. In Fig. 3.15 and 3.16, the TCP SACK easily gets saturated and once this occurs, a gradual decrease in the throughput response follows suite with time particularly with corresponding increase in the number of users on the network. This is also the case with Fig 3.21. Fig. 3.18 and Fig. 3.19 show a similarity response with Fig. 3.15 and Fig. 3.16.

Fig. 3.17 and Fig. 3.20 show the delay transitions under the influence of TCP SACK congestion. The delay gradually builds from an initial gradient to a maximum of about 1second before switching on the users to the network.

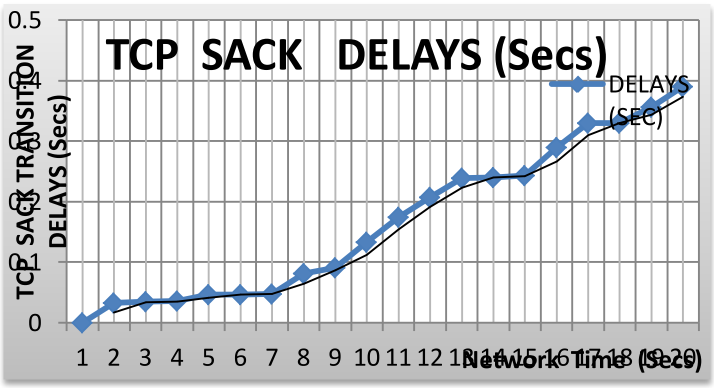


Fig. 3.17: TCP SACK delay transition plot

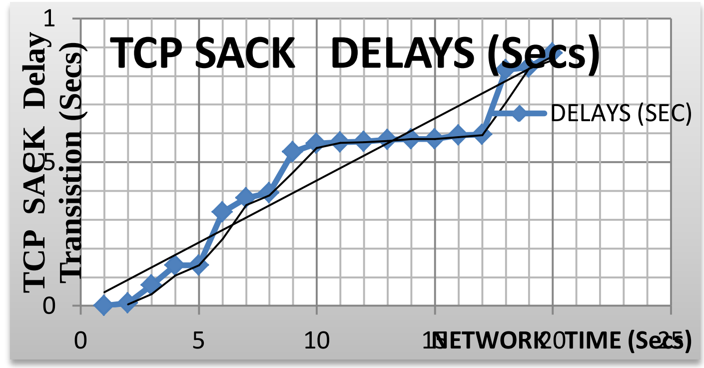


Fig. 3.20: TCP SACK Delay transition behaviour (Secs)

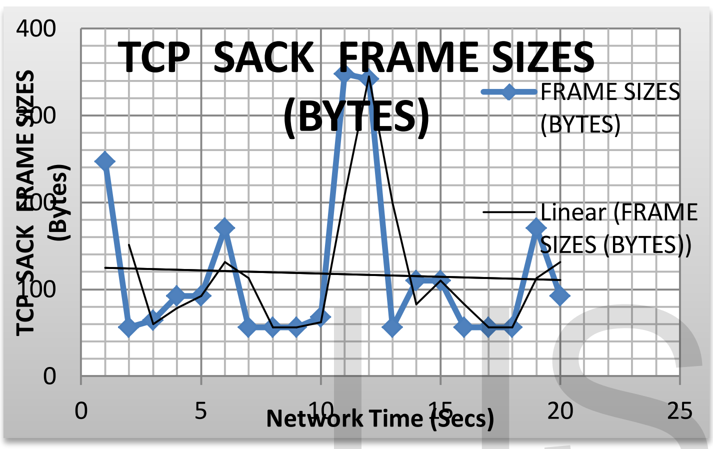


Fig.3.18: Congestion TCP SACK Frame Size behaviour (Bytes)

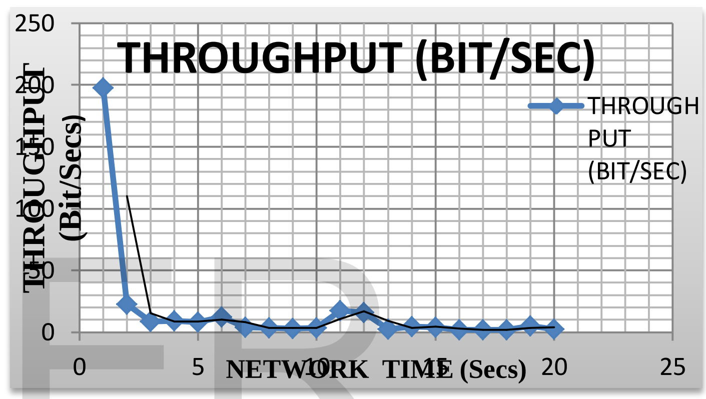


Fig.3.21: Congestion TCP SACK Throughput behaviour (Bits/Secs)

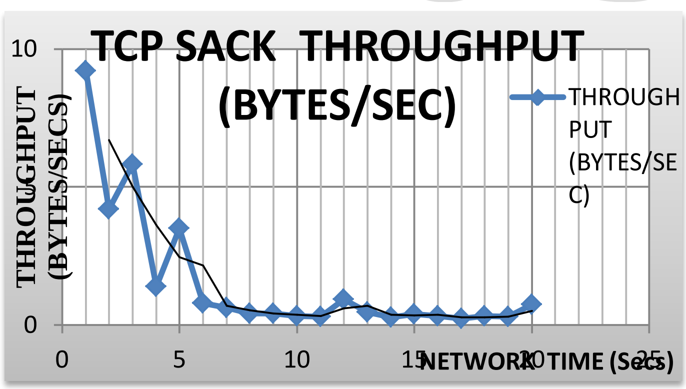


Fig.3.19: Congestion TCP SACK behaviour (Bits) for capture 23

An analysis of the data from the plots of Fig. 3.13 to Fig. 3.21 now led to the following main observations:

- The throughput metrics in TCP SACK scheme is largely unacceptable for FA-WLAN as packet drops at peak times very common.
- The delay time based on TCP SACK is too large for a network intensive service provisioning.
- The use of RTS.CTS by a few nodes in a heavily congested environment (frame size context) prevents those nodes from gaining fair access to the channel.
- The number of frame transmissions at 11Mbps is low while that of 54Mbps are high for all congestion levels. Current rate-adaptation implementations make scarce use of the 2 Mbps and 5.5 Mbps data rates irrespective of the level of congestion.
- At high congestion levels, the time to successfully transmit a large frame sent at 54Mbps is *lower* than for a small frame sent at 11 Mbps.
- At high congestion levels, the delay time consumed by frames transmitted at 54Mbps is only about half the time consumed by frames transmitted at 11Mbps. Yet the number of bytes transmitted at 54Mbps is approximately 300% more than at 11Mbps.
-

These observations offer important insight into the operation and performance of congested wireless networks. The plots in Fig.s 3.22, 3.23 and 3.24 also present an insight into congestion classification.

4.1 Congestion Classification

This work through the observed trends in the ethereal traffic plots and data set captured, classified FA-WLAN into three classes: uncongested, moderately congested, and highly congested. In context, on the wireless network case study, an uncongested channel is a channel that experiences less than 30% utilization form the capture framed. When the throughput and goodput of the network shows a gradual increase from 30% utilization to 84%, the network is moderately congested (medium throughput). A network is stated to be highly congested when the channel utilization is greater than the 90% threshold ie very low throughput with large packet drops.

4.2 Effects of Congestion

The aggregate effects of effect of the different congestion levels on network characteristics, behavior of the RTS-CTS mechanism, and reception of frames of different frame sizes transmitted at different rates, and acceptance delays for data packets is very large for TCP SACK. These characteristics offer a basis for understanding the operation of the IEEE 802.11 MAC protocol in heavily congested networks. In our experiments to better understand the effects of congestion, we categorize data frames capture into 10 different categories. The categories are defined as a combination of (1) the four possible data rates: 1, 5.5, 11, and 54Mbps, and (2) the four different frame size classes: small, medium, large and extra-large. The frames are split into the four size classes so that the effect of congestion on different sized frames can be derived separately. The four size classes are defined as follows:

i. **Small (S)**: frame sizes between 1-400 bytes
ii. **Medium (M)**: frame sizes between 401-800 bytes
iii. **Large (L)**: frame sizes between 801-1200 bytes
iv. **Extra-large (XL)**: frame sizes greater than 1200 bytes

The behavior of the small size class is representative of short control frames and data frames generated by voice and audio applications. The medium, large, and extra-large size class represents the frames generated by file transfer applications, SSH, HTTP, and multimedia video applications. Fig. 3.22, Fig. 3.23 and Fig. 3.24 depict these behaviors.

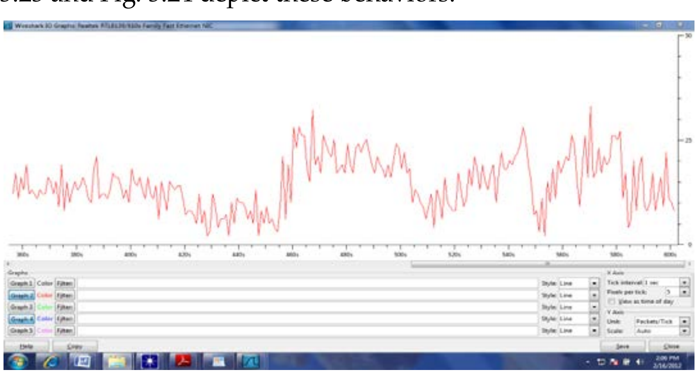


Fig.3.22: Congestion response with frame sizes between 401-800 bytes {Medium (M)}

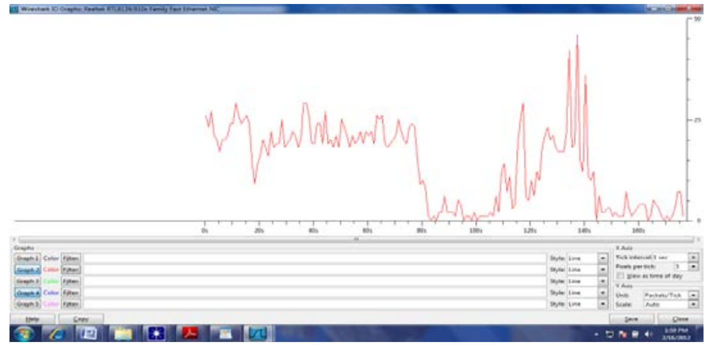


Fig.3.22: Congestion response with frame sizes between 801-1200 bytes {Large (L)}

Fig.3.24: Congestion response with frame sizes greater than 1200 bytes (Extra-large (XL))

4.3 Channel Utilization, And Throughput Qos

Channel utilization for a set period of time is computed on a real time scale. In this study, we configured the graph plotter in the server to show the channel utilization of TCP SCK as shown in Fig. 3.25 and Fig. 3.26. This work observed that the timing interval is an appropriate granularity for a good analysis. The utilization of a network channel per second is computed by adding (1) the time utilized by the transmission of all data, management, and control frames recorded by the sniffers, and (2) the total number of delay components such as the Distributed Inter-frame Spacing (DIFS) and Short Inter-frame Spacing (SIFS) during the same second. These delays form a part of the channel utilization computation because, during this period, the medium remains unshared between the stations in the network. The communication channel is unshared when no other station in the vicinity of the station that holds the channel can transmit frames for the specified delay time. Congestion was observed at different time tracks as the frame data set kept increasing with time. For TCP SACK, the channel utilization effects as depicted in Fig.s 3.25 and Fig. 3.26 is not reliable for a FA-WLAN.

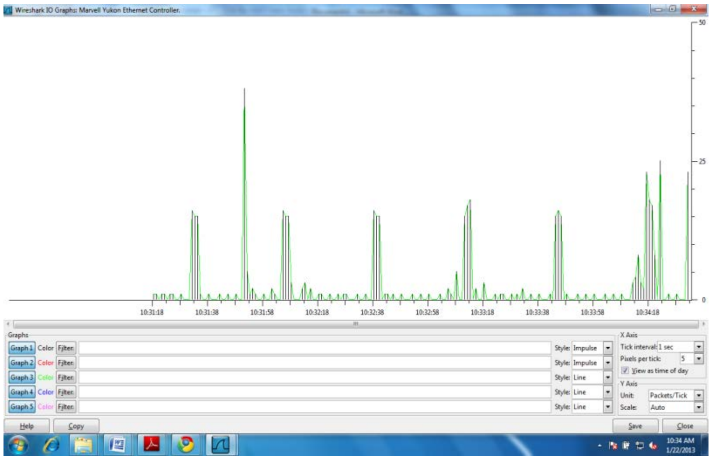


Fig. 3.25: TCP SACK Utilization response for capture 23

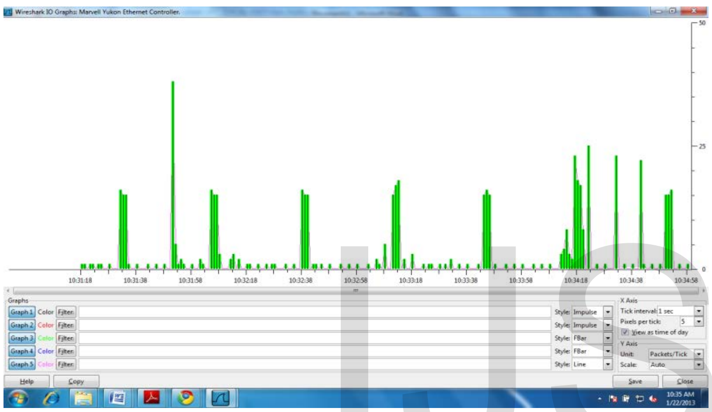


Fig.3.25: TCP SACK Utilization response for capture 6

5. DISCUSSION

Based on the observed congestion trends from the study, TCP frame dataset under congestion experiences large data drops, poor throughput while building large queuing lengths in the testbed environment. Under TCP SACK variant, congestion control under realistic loads is really difficult. Also, the quality of service will not be optimized in any intelligent network that uses TCP SACK. Finally, with TCP SACK, optimization of resources in WLAN setups will be expensive and resource consuming.

6. CONCLUSION AND FUTURE DIRECTIONS

In investigation on TCP SACK control scheme as well as the analysis of congestion effects on frame size distribution is crucial for the robust operation of efficient networks. An improved congestion control scheme will enhance a reliable user experience on FA-WLANs. To this end, this paper has presented an analysis of a large-scale hotspot wireless network deployed at the University of Nigeria Lionet Hotspot environment. Specially, we have investigated the effect of congestion on frame size distribution, delay, congestion classification and TCP utilization. It is shown that TCP SACK as well as other TCP variants will need to be remodified to address complex network scenarios.

Future work will show how a proposed layer4 –DMF algorithm can improve the overall performance of FA-WLAN in context. A validation criterion will be used to justify our proposal.

REFERENCES

[1] Haniza N., Zulkiflee M., Abdul S.Shibghatullah, Shahrin S., " Congestive Loss in Wireless Ad hoc Network Network Performance Analysis" In *World of Computer Science and Information Technology Journal (WCSIT) ISSN: 2221-0741 Vol. 1, No. 6, 269-273, 2011.*

[2] Aneke Ogochukwu Joseph, "Effects of data frame size distribution on WLAN"M.Sc thesis, UNN, 2009.

[3] Salam A. Najim, Ibrahiem M. M. El Emary, and Samir M. Saied, "Performance Evaluation of Wireless IEEE 802.11b used for E-Learning Classroom Network" IAENG International Journal of Computer Science, 34:1, IJCS. August 2007.

[4] Daniele Miorandi, Arzad A. Kherani, Eitan Altman, " A queuing model for HTTP traffic over IEEE 802.11 WLANs" Elsevier Computer Networks50 (2006) 63–79

[5] B. Bennington and C. Bartel, "Wireless Andrew: Experience Building a High Speed, Campus-WideWireless Data Network", Proceedings of ACM MOBICOM, Budapest, Hungary, pp. 55-65, September, 1997.

[6] T. Hansen, P. Yalamanchili and H-W. Braun, "Wireless Measurement and Analysis on HPWREN", Proceedings of Passive and Active Measurement Workshop, For Collins, Co, pp. 222-229, March 2002.

[7] A. Balachandran, G. Voelker, P. Bahl, and P. Rangan, "Characterizing User Behavior and Network Performance in a Public Wireless LAN", Proceedings of ACM SIGMETRICS, Marina Del Rey, CA, pp. 195- 205, June 2002.

[8] H. Singh and P. Singh, "Energy Consumption of TCP Reno, TCP NewReno, and SACK in Multihop Wireless Networks", Proceedings of ACM SIGMETRICS, Marina Del Rey, CA, pp.206-216, June 2002.

[9] D. Tang and M. Baker, "Analysis of a Metropolitan- Area Wireless Network", Proceedings of ACM MOBICOM, Seattle, WA, pp. 13 23, August 1999.

[10] A. Balachandran, G. M. Voelker, P. Bahl, and P. V. Rangan. Characterizing User Behavior and Network Performance in a Public Wireless LAN. In *Proceedings of ACM SIGMETRICS*, pages 195.205, Marina Del Rey, CA, June 2002.

[11] T. Henderson, D. Kotz, and I. Abyzov. The Changing Use of a Mature Campus-wide Wireless Network. In *Proceedings of ACM MOBICOM*, Philadelphia, PA, September 2004.

[12] D. Kotz and K. Essien. Analysis of a Campus-wide Wireless Network. In *Proceedings of ACM MOBICOM*, Atlanta, GA, September, 2002.

[13] X. Meng, S. Wong, Y. Yuan, and S. Lu. Characterizing Flows in LargeWireless Data Networks. In *Proceedings of ACM MOBICOM*, Philadelphia, PA, September 2004.

[14] D. Schwab and R. Bunt. Characterizing the Use of a Campus Wireless Network. In *Proceedings of IEEE INFOCOM*, Hong Kong, March 2004.

[15] S. Cen, P. C. Cosman, and G. M. Voelker. End-to-end Differenti-

ISSN 2229-5518

ation of Congestion and Wireless Losses. ACM/IEEE Transactions on Networking, 11(5):703–717, October 2003.

[16] E. Modiano. An Adaptive Algorithm for Optimizing the Packet Size Used inWireless ARQ Protocols. *Wireless Networks*, 5(4):279.286, July 1999.

[17] Y. Tay and K. Chua. A Capacity Analysis for the IEEE 802.11 MAC Protocol. *Wireless Networks*, 7(2):159.171 March 2001.

[18] M. Torrent-Morenoe, D. Jiang, and H. Hartenstein. Broadcast Reception Rates and Effects of Priority Access in 802.11 Based Vehicular Ad hoc Networks. In *Proceedings of ACM VANET*, Philadelphia, PA, October 2001.

[19] A. Jardosh, K. Ramachandran, K. Almeroth, and E. Belding-Royer. "Understanding Link-Layer Behavior in Highly Congested IEEE 802.11b Wireless Networks". In *Proceedings of ACM SIGCOMM Workshop E-WIND*, Philadelphia, PA, August 2005.