# Capacity Analysis of Internet Protocol Television (IPTV) over IEEE 802.11ac Wireless Local Area Networks (WLANs)

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**Abstract**

Internet Protocol Television (IPTV) has emerged as a personal entertainment source for home users. Streaming IPTV content over a wireless medium with good Quality of Service (QoS) can be a challenging task as IPTV content requires more bandwidth and Wireless Local Area Networks (WLANs) are susceptible to packet loss, delay and jitter. This research presents the capacity of IPTV using User Datagram Protocol (UDP) and TCP Friendly Rate Control (TFRC) over IEEE 802.11ac WLANs in good and bad network conditions. Experimental results show that in good network conditions, UDP and TFRC could accommodate a maximum of 78 and 75 Standard Definition Television (SDTV) users, respectively. In contrast, 15 and 11 High-Definition Television (HDTV) users were supported by UDP and TFRC, respectively. Performance of UDP and TFRC was identical in bad network conditions and same number of SDTV and HDTV users were supported by TFRC and UDP. With background Transmission Control Protocol (TCP) traffic, both UDP and TFRC can support nearly the same number of SDTV users. It was found that TFRC can co-exist fairly with TCP by giving more throughput to TCP unlike UDP.

***Keywords: IPTV, TCP, TFRC, UDP, Capacity.***

## 1. Introduction

With the advent of multimedia applications, users can now enjoy on demand High Definition (HD) content on their mobile devices [12]. Multimedia content can be the collection of various media sources like text, images, graphics, audio and video [11]. YouTube and Netflix are popular multimedia platforms providing audio and video content [22]. Internet Protocol Television (IPTV), another multimedia application, has grown rapidly in recent years [1] [3] [17]. Users can watch SDTV or HDTV content and have video telephonic conversations through IPTV using their WLANs. WLANs have also grown rapidly over the past few years and are commonly available in public places like cafes, libraries, train stations and airports. Since 1999, the Institute of Electrical and Electronics Engineers (IEEE) has introduced many wireless standards including the latest, widely used IEEE 802.11ac standard having features like beamforming and Multiple Input Multiple Output (MIMO) which makes it capable of achieving high data rate of gigabits per second [27]. However, providing good QoS to wireless IPTV users is difficult as WLANs are prone to packet loss, jitter and delay. To provide good QoS to IPTV users, various studies in existing literature suggest the threshold values of 50 ms, 200 ms and 1% for jitter, delay and packet loss, respectively [6][23]. Capacity of IPTV is defined as the maximum number of IPTV users supported by the WLAN until the threshold values of delay, jitter and packet loss are violated [23]. Determination of capacity of IPTV over WLANs was important as it helps network engineers and administrators to deploy IPTV services more efficiently.

IPTV is a multimedia application which uses User Datagram Protocol (UDP) at the transport layer. Delay and packet loss can affect QoS of IPTV. UDP is suitable for delay sensitive applications as it provides less delay, but absence of congestion control mechanism increases packet loss. Therefore, TCP Friendly Rate Control (TFRC) was proposed for streaming applications to resolve congestion less mechanism of UDP [9][23]. Few studies have determined IPTV capacity using UDP and TFRC over IEEE 802.11n WLANs [4] [22]. However, which protocol (UDP or TFRC) supports higher number of IPTV users over IEEE 802.11ac WLANs is still unknown. Therefore, the first aim of this research was to analyze capacity of IPTV using UDP and TFRC over IEEE 802.11ac WLANs in good and bad network conditions.

Many studies suggest that 80% of network traffic is delay insensitive non-real time traffic (e.g. web browsing, file transfer etc.) based on the widely used Transmission Control Protocol (TCP) [22] [23]. TCP is different from UDP as it is connection oriented with a network congestion avoidance mechanism, therefore, it was important to

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analyze capacity of IPTV in the presence of simultaneous TCP traffic in the network [19]. The second aim of this research was to analyze the capacity of IPTV in good and bad network condition using UDP and TFRC over IEEE 802.11ac WLANs in the presence of concurrent TCP traffic determining which protocol (UDP or TFRC) provides more IPTV capacity in the presence of the TCP traffic. Moreover, the impact of UDP and TFRC on the throughput achieved by TCP was also analyzed in this research.

Quantitative experimental research methodology was used to carry out this research. Experiments were performed in lab environment at Whitireia Community Polytechnic, Auckland, New Zealand. Distributed Internet Traffic Generator (D-ITG) was used to generate UDP, TFRC and TCP traffic and data was stored in the form of log files containing values for delay, jitter, throughput and packet loss. Packet size for IPTV traffic was 1328 bytes [5][16]. Data rate requirements for IPTV (SDTV and HDTV) were based on MPEG-4 encoding scheme.

The main contributions of this research are: (i) To analyze the capacity of IPTV over IEEE 802.11ac WLANs, (ii) To determine which protocol (UDP or TFRC) gives more capacity of IPTV over IEEE 802.11ac WLANs, (iii) To evaluate the impact of background TCP traffic on capacity of IPTV over IEEE 802.11ac WLANs.

The remainder of this paper is arranged as follows: Section 2 presents the related work. Section 3 includes research methodology explaining the equipment used in the experiments and the experimental set up. Section 4 presents the results and the discussion based on these results. Section 5 concludes this article followed by references.

## 2. Related Work

IPTV is widely adopted by many home users who prefer on demand content over traditional TV set up and therefore, multimedia traffic generated by IPTV is growing rapidly. IPTV traffic can be either Standard Definition Television (SDTV) or High-Definition Television (HDTV). In order to maintain good QoS, data rate requirement for SDTV and HDTV is 2.36 Mbps and 15.92 Mbps, respectively [6][10] [13][22][23].

### 2.1 IPTV Capacity over WLANs

In [4], authors performed experiments to test the performance of IPTV over IEEE 802.11n. It was found that IEEE 802.11n WLAN could support 17 SDTV users. In addition, delay, jitter and packet loss were not consistent for all users. Interference from other networks was not considered in this research. In [15], authors proposed an algorithm determining which type of wireless technology can be used to meet the QoS standards of IPTV. The authors performed experiments using IEEE 802.11a, IEEE 802.11g and IEEE 802.11n and found that IEEE 802.11n and IEEE 802.11g could support 3 and 2 HDTV users, respectively. Similarly, IEEE 802.11a could only support 1 HDTV user. In [23], authors analyzed combined capacity of Voice over IP (VoIP) and IPTV over IEEE 802.11n, in experiments performed in NS-2 simulator. The authors found that UDP and TFRC support maximum of 4 and 5 HDTV users, respectively.

### 2.2 Factors Affecting IPTV Capacity over WLANs

In [22], authors stated that Access Point (AP) is major entity that restricts the bandwidth. The buffer size of AP is limited which leads to packet loss once it is full [26]. In [30], authors stated that bandwidth is the major challenge in WLANs as it is limited. Services like Video on-Demand (VoD) uses unicast transport for communication between user device and VoD servers creating a huge amount of traffic. If the available bandwidth is less than required, the QoS will suffer to a great extent [2]. Another issue is Zap time which is the time between a user pressing the button on the remote to change channel until the first view of the new channel displays on the screen [3][18][28].

Authors in [23] studied the IEEE 802.11n parameters and obtained the optimal values for Queue size, Block Acknowledgement (ACK), Transmission Opportunity (TXOP) and frame aggregation size. The authors found that optimal frame aggregation size is 4 times packet size. With 4 times frame aggregation size, maximum number of HDTV and SDTV users supported by WLAN are 4 and 17, respectively. These experiments were performed in NS- 2 simulator and therefore, the real-world results may vary. Experiments performed in [22] showed that the use of transport layer protocol can impact the capacity of IPTV. Authors found that TFRC for combined IPTV and VoIP can increase network capacity. In addition, IPTV and VoIP traffic generated using TFRC can co-exist with TCP in the same network. In [22], authors also found that by using TFRC instead of UDP the capacity increased by 25% for HDTV and 35% for SDTV. With TCP traffic present in the network, UDP capacity decreased by 25% for HDTV and 24% for SDTV while TFRC capacity decreased by 20% for HDTV and 13% for SDTV.

### 2.3 Solutions to Increase IPTV Capacity over WLANs

Many solutions have been proposed in the literature to overcome the issues faced in wireless IPTV services. To optimize bandwidth utilization, efficient networking schemes should be used. To minimize bandwidth usage over the network, better caching mechanism such as caching video content nearest to the user should be implemented [30]. Improved video coding and routing can help deploy VoD and IPTV services efficiently. In [22][23], authors showed that optimal AP parameters can help increase the capacity of IPTV users over IEEE 802.11n WLANs. 4 times frame aggregation is optimal to maximize the number of IPTV users present in the WLAN. In [24], authors found that TFRC protocol helps to increase capacity of VoIP and IPTV over wireless networks. TFRC provides 167.4% more throughput to TCP compared to UDP.

### 2.4 Research Gap

Many studies have been conducted over IEEE 802.11n WLANs to analyze the capacity of IPTV. However, no study has been carried out to analyze capacity of IPTV over IEEE 802.11ac WLANs. IEEE 802.11ac was introduced with many improvements like MIMO, beamforming, increased channel width and data rates of gigabit per second [27]. In addition, it is yet to be analyzed whether TFRC instead of UDP can enhance the capacity of IPTV over IEEE 802.11ac WLANs and which protocol (UDP or TFRC) co-exists fairly with TCP in the same network. This research is focused to fill this research gap by analyzing capacity of IPTV provided by IEEE 802.11ac WLANs using standalone UDP and TFRC and with simultaneous TCP traffic.

## 3. Research Methodology

Quantitative experimental research methodology was used in this research. This section explains in detail the experimental setup and the hardware and software used to perform the experiments.

### 3.1 Hardware and Software Used

A dual band Linksys router with model number WRT1200AC was used to perform experiments. This router can be enabled with both 2.4GHz and 5GHz frequencies at the same time. It has two external antennas and supports 2*2 MIMO [14]. Asus FX753VD-GC084T laptop was configured as the server to receive traffic from the client. This laptop is equipped with Intel Core i7-7700 CPU clocked at 2.8GHz and Intel Dual band Wireless-AC 7265 wireless adapter which supports 2*2 MIMO. Toshiba satellite L850-I2011 laptop was configured as client to send traffic to the server. D-ITG was used to generate UDP, TFRC and TCP traffic from client to server [8]. inSSider tool was used to check for interfering networks and measure the Received Signal Strength Indicator (RSSI) at different points [25].

### 3.2 Experimental Setup

The experiments were conducted in indoor environment at Whitireia Community Polytechnic, Auckland, New Zealand. IPTV traffic was generated from client to server over IEEE 802.11ac WLAN. Client machine was connected to the Linksys WRT1200AC router through ethernet port whereas the server machine was connected to the router through IEEE 802.11ac WLAN. Both machines were running the virtual Ubuntu 18.04 LTS operating system using VMware Workstation 15 pro. D-ITG tool was compiled and installed on both server and client machines. Data was stored in the form of log files containing values for delay, packet loss, jitter and throughput. Packet size for IPTV traffic was 1328 bytes [5][16]. IPTV capacity analysis was conducted for both SDTV and HDTV using MPEG-4 encoding scheme. Data rate requirements for SDTV and HDTV using MPEG-4 encoding scheme are shown in table 1 [22][23]. Multiple readings of delay, jitter, throughput and packet loss were taken at various times throughout the experiments. The average of all readings is presented in the results. Experimental setup is shown in figure 1.

Table 1: Data Rate Requirements for IPTV

| Type of IPTV | Frames Per Second | Resolution | Compression Scheme | Required Data Rate (Mbps) |
|---|---|---|---|---|
| SDTV | 24 | 640*480 | MPEG-4 | 2.36 |
| HDTV | 24 | 1920*1080 | MPEG-4 | 15.92 |

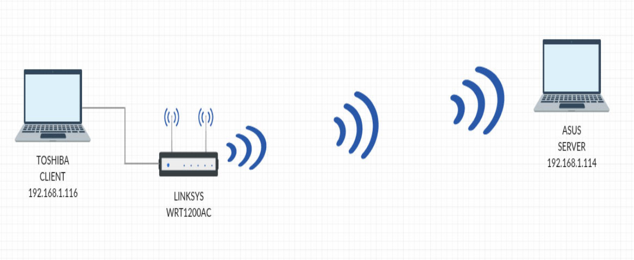

Figure 1: Experimental Setup

Figure 2 shows the experimental test bed. Experiments were performed at two different points: A (0.4m) and B (11.6m). Point A represents good network condition being closest to the router and point B represents bad network condition being far from the router.

## 4. Results and Discussion

In this section, the results of the experiments are presented.

### Result 1: RSSI and Capacity of IPTV using UDP and TFRC

The first step was to measure the RSSI value at point A and point B using the inSSider tool. RSSI is the measurement of the strength of the signal. The value of RSSI helps determine whether the strength of signal is strong enough to ensure a good wireless connection. Network condition can be perceived based on the RSSI value which is measured in dBm. The higher the RSSI value, the better the channel conditions and vice versa [29].

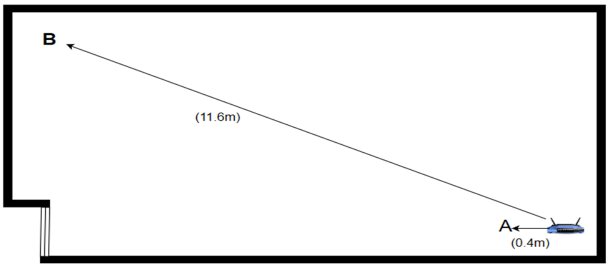

Figure 2: Experimental Test Bed

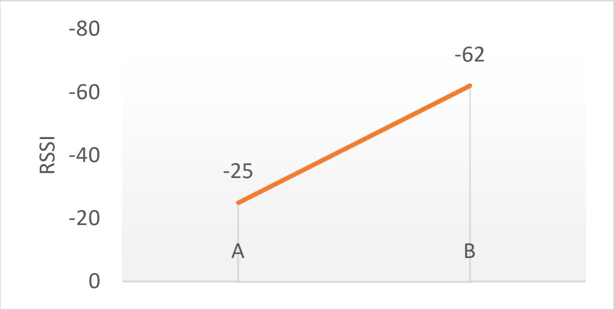

Figure 3: RSSI value in good and bad network conditions

Figure 3 shows RSSI value at point A and point B. The best RSSI was received at point A (0.4m) which was -25 dBm. As the distance between router and the laptop was increased, the value of RSSI decreased. At point B (11.6m), the value of RSSI was recorded -62 dBm. All the experiments were conducted at -25 dBm and -62 dBm RSSI using UDP, TFRC and TCP protocols. To evaluate the capacity of IPTV, default threshold values for delay, jitter and packet loss were 200ms, 50ms and 1% respectively. The main objective was to analyze maximum number of IPTV (SDTV and HDTV) users supported by IEEE 802.11ac WLANs using UDP and TFRC protocol. SDTV is a traditional television system which supports resolution of 640*480 and requires 2.36 Mbps data rate using MPEG-4 encoding scheme. SDTV supports aspect ratio of 4:3 [21][23]. Figure 4 shows the capacity of SDTV users with UDP and TFRC protocol in good and bad network conditions. In good network conditions, UDP could support maximum of 78 SDTV users. Table 2 shows delay and packet loss for UDP and TFRC. Delay, jitter and packet loss for UDP was 4.6ms, 0.10ms and 0.22%, respectively with an average throughput of 194.9 Mbps. As the 79th SDTV user was added to the IEEE 802.11ac WLAN, overall packet loss was 0.38%, but packet loss rose above the 1% threshold value for some users and throughput for those users dropped below the required value of 2.36 Mbps, decreasing the average throughput to 182 Mbps. On the other hand, TFRC could support a maximum of 75 SDTV users with an average throughput of 190.3 Mbps. With 75 SDTV users, average delay, jitter and packet loss for TFRC was 5.6ms, 0.3ms and 0.09% respectively. As the 76th user entered the IEEE 802.11ac WLAN, the average packet loss was 0.43% but went above the 1% threshold value for one SDTV user. It can be observed that in good network conditions, UDP provided more capacity of SDTV users than TFRC as there is no congestion control mechanism in UDP. Therefore, UDP throws all the packets in the network without sensing the network condition. Hence, UDP was able to achieve more throughput and SDTV users than TFRC.

Table 2: Delay and Packet loss for UDP and TFRC

| RSSI | IPTV | UDP | | | TFRC | | |
|---|---|---|---|---|---|---|---|
| | | Users | Delay (ms) | Packet Loss (%) | Users | Delay (ms) | Packet Loss (%) |
| -25 | SDTV | 78 | 4.6 | 0.22 | 75 | 5.6 | 0.09 |
| -25 | HDTV | 15 | 4.4 | 0.10 | 11 | 5.5 | 0.24 |
| -62 | SDTV | 50 | 8.4 | 0.82 | 50 | 5.8 | 0.06 |
| -62 | HDTV | 7 | 4.7 | 0.20 | 7 | 27.7 | 0.19 |

As the network conditions worsened, the maximum number of SDTV users supported by UDP and TFRC dropped to 50. The packet loss for UDP and TFRC was 0.82% and 0.06%, respectively. The 51st SDTV user increased packet loss for UDP and TFRC to 7.41% and 1.08%, respectively. It can be observed that UDP had less delay and more packet loss compared to TFRC. UDP sends data without realizing network conditions, whereas TFRC has a congestion control mechanism and adjusts its data rate based on the network conditions to avoid delay and packet loss [9][23]. HDTV is a modern television system which supports resolution of 1920*1080 and requires 15.92 Mbps of data rate using MPEG-4 encoding scheme. Compared to SDTV, HDTV can show videos with more detail, sharpness, and better color. HDTV supports aspect ratio of 16:9 which is wider than SDTV [21][23]. Figure 5 shows the capacity of HDTV users with UDP and TFRC. It can be observed that in good network conditions, UDP could support a maximum of 15 HDTV users with an average throughput of 266.7 Mbps. The average packet loss with 15 users was 0.10%. The 16th HDTV user increased packet loss to 1.53%, reducing average throughput to 256 Mbps. In contrast, TFRC could support maximum of 11 HDTV users with 0.09% packet loss. The 12th user increased the packet loss to 1.07%. The main reason behind fewer users compared to UDP is the congestion control mechanism of TFRC.

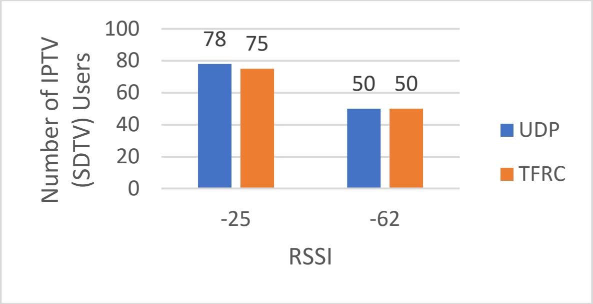

Figure 4: Capacity of SDTV with UDP and TFRC

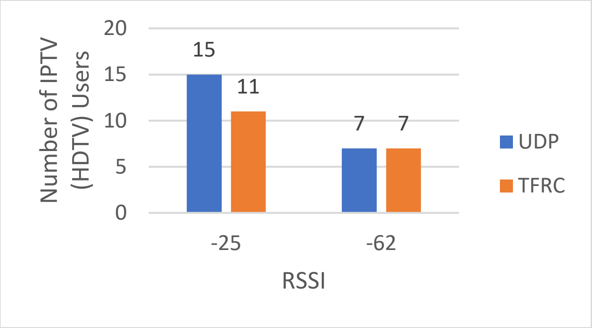

Figure 5: Capacity of HDTV with UDP and TFRC

HDTV requires more data rate which requires a greater number of packets to be pushed through the network. As the queue congestion at the wireless Access Point (AP) occurs, TFRC adjusts its data rate to avoid packet loss and delay [23]. Hence, fewer users were supported by TFRC compared to UDP. As the network conditions worsened, the number of HDTV users supported by UDP and TFRC dropped to 7. As the 8th user entered the network, packet loss for UDP and TFRC increased to 37.41% and 35.12%, respectively. This increase in packet loss brought the average throughput to 115.9 Mbps and 107 Mbps for UDP and TFRC respectively.

### Result 2: Capacity of IPTV with background TCP traffic

This section presents the capacity of IPTV (SDTV and HDTV) in the presence of background TCP traffic. The main objective was to analyze which protocol (UDP or TFRC) gives more capacity of IPTV in the presence of background TCP traffic and to analyze the impact of UDP and TFRC on background TCP traffic. Figure 6 shows the average throughput of simultaneous UDP and TCP and the capacity of SDTV users in the presence of background TCP traffic. In good network conditions, UDP could support a maximum of 71 SDTV users with average throughput of 185.3 Mbps and 0.23% packet loss with background TCP traffic. As soon as the 72nd user entered the IEEE 802.11ac WLAN, packet loss increased to 1.08%, violating the packet loss threshold of 1%. Similarly, for HDTV users the maximum capacity with UDP reduced to 11 users in the presence of background TCP traffic as shown in table 3. The 12th user increased the packet loss to 1.73% and reduced the average throughput to 162.3 Mbps.

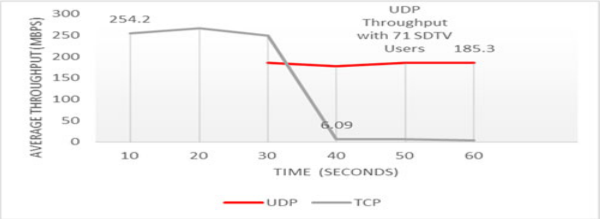

Figure 6: Average throughput of simultaneous UDP and TCP

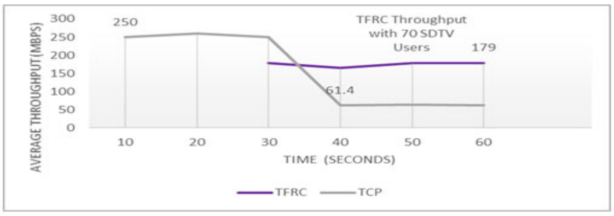

Figure 7: Average throughput of simultaneous TFRC and TCP

On the other hand, TFRC could support maximum of 70 SDTV users in the presence of background TCP traffic in good channel conditions as shown in figure 7. Average throughput of TFRC was 179 Mbps with 0.66% packet loss. The 72nd user increased the packet loss to 1.59%. As HDTV requires more data rate, the maximum number HDTV users supported by TFRC reduced to 10 users. The 11th user increased the packet loss to 1.50% which reduced the average throughput to 156.3 Mbps. It can be observed from figure 6 that average throughput achieved by standalone TCP was 254.2 Mbps. As soon as 71 UDP flows entered the IEEE 802.11ac WLAN, TCP throughput dropped to 6.09 Mbps. Studies suggest that UDP does not co-exist fairly with TCP in the same network. UDP takes the TCP share of bandwidth and keeps pushing packets into the network. Since TCP provides both a flow control and congestion control mechanism, TCP reduces its window size to avoid packet loss and delay [9][23]. Similarly, as soon as 70 TFRC flows entered the IEEE 802.11ac WLAN, throughput of TCP dropped to 61.4 Mbps. TFRC gets feedback from receiver side in the form of loss event rate and uses this feedback to measure the round-trip time. TFRC uses TCP throughput equation to adjust its data rate to co-exist fairly with TCP [20]. There is a decrease of 97.6% and 75.4% in TCP throughput with UDP and TFRC, respectively. These results show that TFRC gave more throughput to TCP compared to UDP. Table 3 shows that with simultaneous UDP-TCP (SDTV), the decrease in capacity was 8.97% compared to TFRC-TCP (SDTV), where it was 6.66%. Similarly, with simultaneous UDP-TCP (HDTV), the decrease in capacity was 26.66%, but it was only 9.09% with TFRC-TCP (HDTV). It clearly shows that in both scenarios TFRC-TCP (SDTV and HDTV) has less decrease in capacity compared to UDP-TCP (SDTV and HDTV).

**Table 3:** Capacity of IPTV using UDP and TFRC with background TCP Traffic

| Type of IPTV | Combined traffic flows | Average Throughput (Mbps) | With TCP capacity | Without TCP capacity | Capacity Decrease (%) |
|---|---|---|---|---|---|
| SDTV | UDP-TCP | UDP: 185.3<br>TCP: 6.09 | 71 | 78 | 8.97 |
| SDTV | TFRC-TCP | TFRC: 179.4<br>TCP: 61.4 | 70 | 75 | 6.66 |
| HDTV | UDP-TCP | UDP: 177.4<br>TCP: 38.3 | 11 | 15 | 26.66 |
| HDTV | TFRC-TCP | TFRC: 165.4<br>TCP: 63.5 | 10 | 11 | 9.09 |

## 5. Conclusions

In this research, capacity of IPTV (SDTV and HDTV) was determined over IEEE 802.11ac WLAN. The results obtained from experiments show that UDP could support a greater number of SDTV and HDTV users compared to TFRC in good network conditions. Congestion control mechanism of TFRC adjusts its data rate to avoid delay and packet loss, therefore, TFRC supports less number of SDTV and HDTV users compared to UDP over IEEE 802.11ac WLANs. However, in bad network conditions, the performance of UDP and TFRC was identical as both UDP and TFRC supported the same number of SDTV and HDTV users. It can be observed from the results that UDP did not co-exist fairly with background TCP traffic present in the same network. As soon as UDP flows were initiated, throughput of TCP dropped to 6.09 Mbps. In contrast, TFRC co-existed fairly with TCP traffic as there was less decrease in throughput of TCP when TFRC flows were initiated in the network. It was analyzed that not only TFRC co-existed fairly with TCP, but there was also less drop in IPTV capacity with background TCP traffic compared to UDP.

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