Computing, Performance and Communication Systems (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/cpcs.2022.060203
ISSN 2371-8889 Vol. 6 Num. 2

Research on Wireless Local Area Network Planning from the Perspective of Capacity Optimization

Quanhui Wang[a,*], Yuejun Zhang[b], Yufei Zheng[c], Yaorong Yu[d], Yongquan Wang[e]

Shanxi Branch of Inner Mongolia Power Investment Energy Co., Ltd., Taiyuan, Shanxi, 030000, China

[a]17735161832@189.cn, [b]17735161822@189.cn, [c]15894890613@139.com, [d]15333091539@wo.cn, [e]15847580900@139.com

[*]Corresponding author

Keywords: Wireless Local Area Network, Capacity Planning, Wireless Communication Link, Channel Bandwidth, Wireless Access Point

Abstract: Wireless local area network planning use to be only focusing on coverage to ensure that the signal quality of all coverage areas meets the requirements. However, with the rapid growth of user equipment that supporting more complex and bandwidth-demanding applications, capacity in wireless local area network planning has become an equally important goal as coverage. This study is focusing on wireless local area network capacity planning affected by application throughput requirements, high-speed IEEE 802.11 standards, and user equipment performance. The measurements and performance evaluation are based on IEEE 802.11ac and IEEE 802.11n standards.

1. Instruction

Traditional WLAN (Wireless Local Access Network) planning aims to ensure SINR (Signal to Interference plus Noise Ratio) and RSSI (Received Signal Strength Indicator) for all target areas meet the coverage requirements. However, there is an increasingly growth in the number of mobile devices such as smartphones, tablets, and high-performance notebook computers which are capable of supporting applications with more complex functions and demand higher network bandwidth, along with the large-scale deployment of high-speed WLAN technology, network capacity has become an indicator as important as coverage in current and future WLAN planning[1-4]. This paper discusses the capacity-centric network planning and performance evaluation based on IEEE 802.11n and IEEE 802.11ac high-speed WLAN technologies under 40MHz and 80MHz channel bandwidth.

2. General Procedures of WLAN Planning

Generally, WLAN planning consists of four procedures from environmental survey, frequency channel allocation to WAP (Wireless Access Point) deployment and optimization, as shown in Figure 1.

(1) WLAN communication requirements need to be determined based on the survey results of

the users and the communication environment in the target area.

(2) Ascertaining the available WLAN frequency bands and channels according to the IEEE 802.11 standard and the communication environment of the target area.

(3) Determine the WLAN coverage to ensure that the network capacity, SINR and RSSI should meet the requirement, while considering throughput and the number and type of UE (User Equipment).

(4) Deployment and optimization of the WAPs should be according to the frequency channel allocation, vendor's suggestion and engineer's experience.

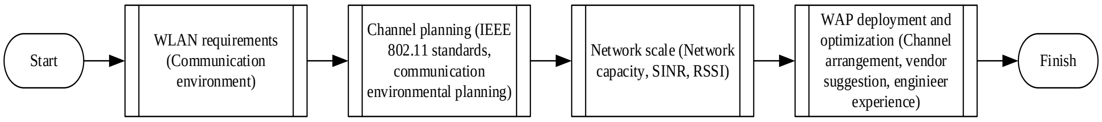

Figure 1: General procedures of WLAN planning

The communication environment survey includes collecting various data such as the number, type, performance and density of UEs in target area, and the throughput requirements of applications, etc. Accordingly, to formulate proper QoS (Quality of Service) and IP network security indicators for the target area in advance. In addition, successful WLAN planning also requires a full investigation on the scale of the target coverage area, communication environment type (Indoor, Outdoor or Mobile), structure of the target building (Single-floor or multi-floor), and the current communication infrastructure (LAN, Internet), etc.

3. Frequency Channel Allocation for 2.4GHz and 5GHz bands

This section discusses frequency channel allocation in 2.4GHz and 5GHz frequency bands. IEEE 802.11 standard defines fourteen frequency channels in 2.4GHz frequency band. The bandwidth of a single frequency channel is 22MHz, the effective bandwidth within the channel is 20MHz, and the remaining 2MHz gap serves as a guard band to allow the signal sufficient attenuation occurs at the band edges to provide isolation. The availability of these frequency channels varies in different countries and regions. For instance, there are thirteen channels, from 1 to 13, allowed to be used in China, while in the case of United States, there are eleven channels, from 1 to 11. As Figure 2 shows, only 3 non-overlapping channels exist at the same time in 2.4GHz frequency band such as channels 1, 6 and 11, and most of the remaining channels overlap with each other. Therefore, the limited bandwidth and channel overlap of 2.4GHz frequency band lead to that relatively less channels are available simultaneously, which is not suitable for application in areas with high UE density.

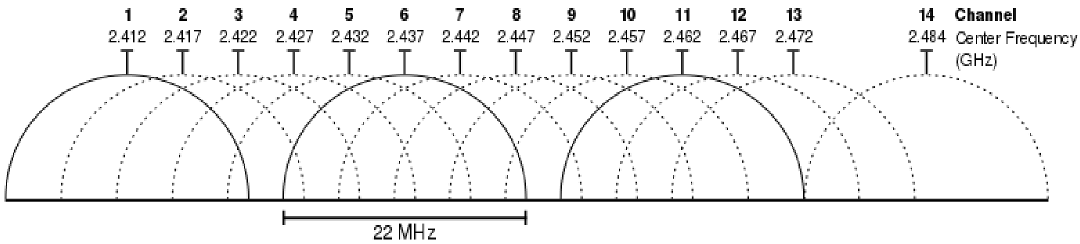

Figure 2: IEEE 802.11b/g channel allocation in 2.4GHz band

Aside from 2.4GHz frequency band, dozens of channels have been added from IEEE 802.11a to 802.11ax standards to enable more simultaneously non-overlapping channels in 5GHz frequency band, with 20MHz, 40MHz, 80MHz and 160MHz bandwidth. Thirteen 5GHz channels are used in China initially, later the 32 and 68 channel are added in 2013 [5], and then the 169 channel in 2017 [6]. Currently, there are sixteen channels are available in 5 GHz frequency bands in China (Table 1).

Table 1: Available channels for IEEE E 802.11 in the 5 GHz band (China)

Channel Index	Frequency Range	Channel Index	Frequency Range
32	5 150-5170MHz	64	5310–5330MHz
36	5170–5190MHz	68	5330-5350MHz
40	5190–5210MHz	149	5735–5755MHz
44	5210–5230MHz	153	5755–5775MHz
48	5230–5250MHz	157	5775–5795MHz
52	5250–5270MHz	161	5795–5815MHz
56	5270–5290MHz	165	5815–5835MHz
60	5290–5310MHz	169	5835-5850MHz

Interference avoidance is one of the key issues in channel planning. There are two types of channel interference in WLAN wireless environment: CCC (Co-Channel Contention) and ACI (Adjacent Channel Interference). CCC is also called CCI (Co-Channel Interference), which refers to mutual interference caused by two or more WAPs working on the same frequency channel. Unlike other RF (Radio Frequency) interference, WLAN allows multiple UEs to compete for the same wireless channel on same frequency through CDMA/CA (Carrier Sensing Multiple Access with Collision Avoidance), therefore CCC is a key factor in WLAN capacity planning [7-9]. However, increasing the number of WAPs on the same frequency tends to have the opposite effect, by complicating UE contention then resulting the decrease of throughput. ACI means that two or more WAPs working on adjacent frequency channels interfere with each other. This type of interference is also one of the factors that need to be considered in WLAN planning.

4. Capacity Planning of WLAN

The goal of traditional coverage-based WLAN planning is to ensure that SINR and RSSI in whole coverage areas meet the requirements. However, with the rapid growth of various mobile devices that support high-throughput applications, coverage alone cannot meet the ever-increasing demand for network services, and capacity has become an equally important WLAN planning indicator as coverage. Network capacity planning of WLAN can be conducted by adjusting the number of required WAPs based on the usage of radio link shared by UEs. It depends on the throughput of the application and the performance of the UE itself. For example, an application process with a throughput of 2Mbps generated by a notebook computer with a TCP throughput of 100Mbps occupies 2% of the wireless channel. The following three examples are to illustrate the calculation of the radio link usage and the determination of the number of WAPs to meet the throughput and UE performance requirements.

(1) Sixty notebook computers which support 2x2 MIMO (Multi-Input Multi-Output), 2SS (Service Set), 300Mbps data transmission rate (Table 2) and TCP throughput of 150Mbps (50% of the data transmission rate) with 40MHz channel bandwidth. A general video application usually generates 2Mbps throughput [10-11], so the average wireless link usage of each computer is 1.33% (2/150), and the total usage of the wireless link for sixty notebook computers is 79.8%. Usually, the channel saturation of a WAP is about 80%, thus the ratio of the channel usage of sixty notebook computers to the channel saturation of the WAP is 0.998, so one WAP is needed for the current capacity requirement.

Table 2: Data transmission rate (Mbps) of IEEE 802.11ac standard

MCS	Modulation and Code Rate	40MHz 1SS	40MHz 2SS	80MHz 2SS	80MHz 2SS
5	64QAM 2/3	120	240	260	520
6	64QAM 3/4	135	270	292.5	585
7	64QAM 5/6	150	300	325	650
8	256QAM 3/4	180	360	390	780
9	256QAM 5/6	200	400	433.3	866.7

(2) In addition to former example, adding forty tablets which support 1x1 SISO (Single-Input Single-Output), 1SS, 135Mbps data transmission rate (Table 2), TCP throughput of 67.5Mbps. The wireless link usage of each tablet is 2.96% (2/67.5), the overall usage of the wireless link for forty tablets is 118.4%, plus the usage of former example 93.1% results in 198.2% as total. Also considering the usual channel saturation of WAPs as 80 %, then the ratio of the total wireless link usage of 198.2% for sixty notebook computers and forty tablets to the channel saturation of 80 % is 2.48, so three WAPs are needed to satisfy the capacity requirements.

(3) Add thirty smartphones to the second example, which support 2x2 MIMO, 2SS, 300Mbps data transmission rate (Table 2), and TCP throughput of 150Mbps. While the throughput of the application increases to 4Mbps, the wireless link usage per smartphone is 2.67% (4/150), and the overall utilization of the wireless link for thirty smartphones is 80.1%, plus the usage of the first and second example as 160.2% and 37.2% respectively for a total of 477.5% usage. Also considering that the usual channel saturation of WAP is still 80%, the ratio of the total wireless link usage of 477.5 % to the channel saturation of 80% for sixty notebook computers, forty tablet and thirty smartphones is 5.97, so six WAPs are required to meet the capacity requirement.

Above examples also presents that the calculation of the number of WAPs required for application throughput and UE performance in different scenarios.

5. Setup of the Test Scenario

The real-life WLAN usage environment involves different IEEE 802.11 standards and UEs. The test network established in this study includes a WAP (ASUS TUF AX5400) which supports IEEE 802.11n/ac and six different UEs, by using the inSSider and iPerf software to evaluate the performance of channel throughput, as shown in Figure 3.

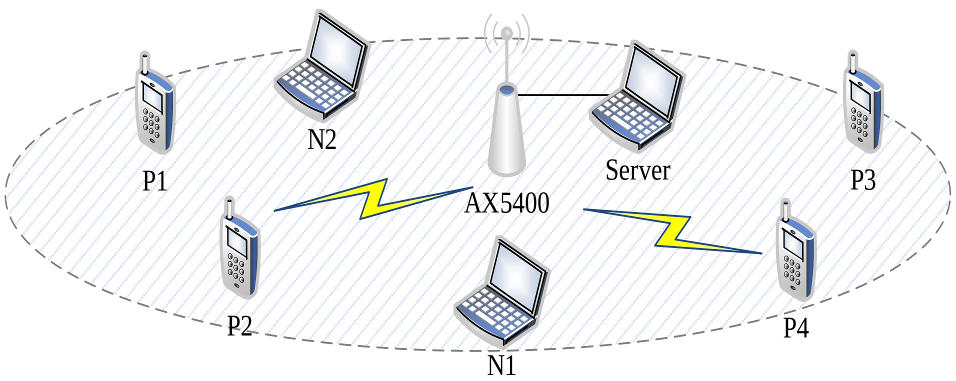

Figure 3: Network Scenario for Test

Among the network scenario, the performance of four smartphones and two notebook computers is shown in Table 3.

Table 3: UE performance for testing

UE Type	Wi -Fi Version	MIMO	Channel Bandwidth
P1	802.11a/b/g/n/ac	2x2	40MHz/80MHz
P2	802.11a/b/g/n/ac	2x2	40MHz/80MHz
P3	802.11a/b/g/n/ac	1x1	40MHz/80MHz
P4	802.11a/b/g/n/ac	1x1	40MHz/80MHz
N1	802.11a/b/g/n/ac	2x2	40MHz/80MHz
N2	802.11a/b/g/n/ac	1x1	40MHz/80MHz

The server provides the basic configuration of the WAP with all necessary data inputs for the wireless network, such as channel, channel bandwidth, frequency band, signal strength, etc., through a wired connection.

6. Analysis of Theoretical Throughput and Measured Throughput

To determine the impact of IEEE 802.11n/ac high-speed WLAN standard and UE performance on network throughput, detailed measurements were performed with the test network. Here, only the uplink TCP throughput is considered, and the measured results are compared with the theoretical throughput.

6.1 Calculation of Theoretical Throughput

This section calculates the throughput in five scenarios based on the performance and number of different UEs, the results are shown in Figure 4.

(1) Throughput of a single UE (Smartphone P1)

The performance of smartphone P1 is MCS 7, 64QAM 5/6, 2x2 MIMO, 40MHz channel bandwidth, 300Mbps data transmission rate (Table 2), assuming that the theoretical TCP throughput is 150Mbps. Since the smartphone P1 alone uses the wireless network provided by the WAP, the throughput is considered as 150Mbps.

(2) Throughput of a single UE (Smartphone P2)

Smartphone P2 has the same performance as P1 and uses the wireless network provided by the WAP alone, so the throughput is also considered as 150Mbps here.

(3) Throughput of two UEs (Smartphone P1 and P2)

Assuming two UEs share the channel equally, that is, each smartphone accounts for 50% of the total channel capacity, the TCP throughput of P1 and P2 are both considered as 75Mbps, and the total throughput is cumulated as 150Mbps. Since the performance of the two UEs is the same, the total throughput is the same as the scenarios with only one UE.

(4) Throughput of two UEs (Smartphone P2 and P3)

The performance of smartphone P3 is MCS 7, 64QAM 5/6, 1x1 SISO, 40MHz channel bandwidth, 150Mbps data transmission rate (Table 2), TCP throughput of 70Mbps. Assuming that two UEs share the channel on average, that is, each smartphone occupies 50% of the total channel capacity, the throughput of P2 is considered as 75Mbps, and the throughput of P3 is considered as 35Mbps, the total throughput is cumulated as 110Mbps. Which means, the total throughput of 1x1 and 2x2 MIMO respectively supported UEs is less than the total throughput of two 2x2 MIMO supported UEs (Scenario 3).

(5) Three UEs (Smartphone P1, P2 and P3)

Assuming that all three smartphones share the channel equally, i.e., each mobile phone occupies one third of the total channel capacity, the throughput of both P1 and P2 is considered as 50Mbps each, while the throughput of P3 is about 23Mbps (70/3), therefore, the total throughput is 123Mbps after adding up. Which means, the total throughput of the three UEs that support 1x1 and 2x2 MIMO is less than the total throughput of the two 2x2 MIMO supported UEs (Scenario 3), and larger than the total throughput of 1x1 and 2x2 MIMO supported UEs (Scenario 4).

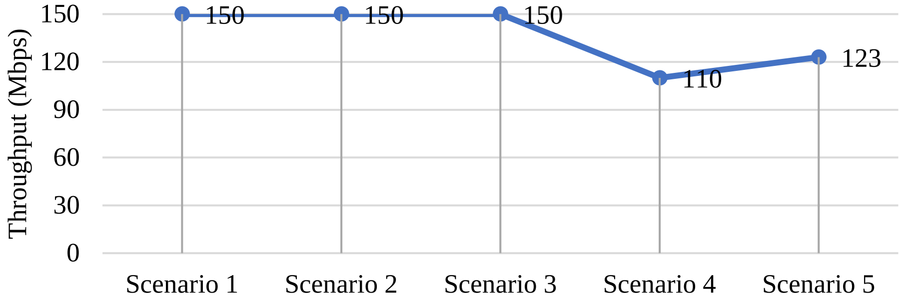

Figure 4: Measured throughput based on performance and number of different UEs.

Obviously, UE with lower performance will cause the channel throughput to drop according to Figure 4. In addition, by linearly sharing the channel based on the UE performance, the overall channel usage can be improved, thereby bringing higher throughput.

6.2 Measurement of Actual Throughput

This section evaluates the performance of wireless channel throughput based on the measurement results of following five different scenarios.

(1) Throughput of one UE with 40MHz channel bandwidth in Dual-Band (2.4GHz and 5GHz) and Single-Band (5GHz) mode. Equipment used: Server (Gigabit network adapter), UE (P1 2x2 MIMO, P2 2x2 MIMO, N1 2x2 MIMO), WAP (ASUS TUF AX5400). The measurement results in this scenario are shown in Figure 5.

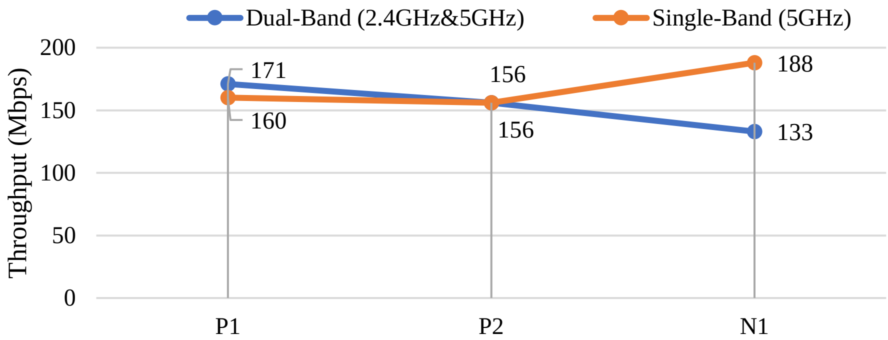

Figure 5: Throughput of single UE in Dual-Band and Single-Band mode.

From the results in Figure 5, it can be seen that for the two smartphones P1 and P2 that only operate in the 5GHz band, there is no effect on the throughput whether the WAP operates in Single-Band or Dual-Band mode; but for notebook computer N1, WAP operating on 5 GHz Single-Band provide much higher throughput than 2.4GHz and 5GHz Dual-Band mode because of the higher channel overlap and CCC interference in 2.4GHz band. Due to the basic control overhead of TCP transmission, the measured TCP throughput of P1 is 53.3% (160/300) of its data transmission rate, while the TCP throughput of P2 is 52% (156/300) of its data transmission rate, both are within the usual range of 40% to 60%.

(2) Throughput of a single UE when the TCP transmission window size is set to 1MB through iPerf. Equipment used: Server (Gigabit network adapter), UE (P1 2x2 MIMO, P2 2x2 MIMO),

WAP (ASUS TUF AX5400). The measurement results in this scenario are shown in Figure 6.

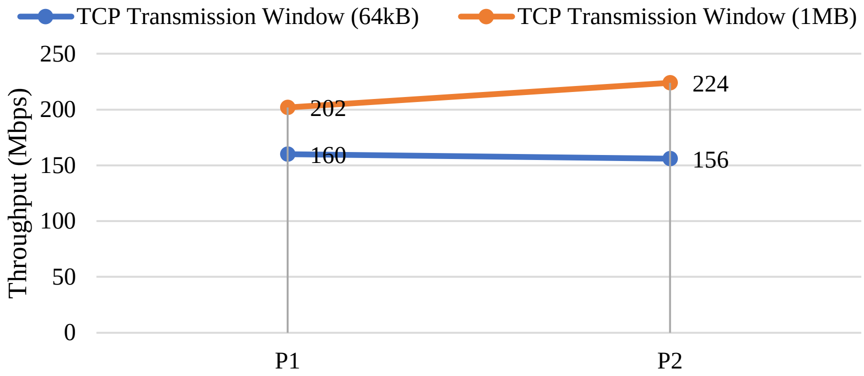

Figure 6: Throughput of single UE with 64kB and 1MB TCP Transmission Window

The measurements in Figure 6 show that a TCP transmission window of 1MB is more capable of supporting higher throughput than the default TCP window size of 64kB. This is because the default window is too small to make full use of the end-to-end wireless link capacity. After sending 64kB of data, the sending process must wait for the receiver's TCP sliding window to update before sending more data to the wireless link.

(3) Single and multiple UEs with 40MHz channel bandwidth. Equipment used: Server (Gigabit network adapter), UE (P1 2x2 MIMO, P2 2x2 MIMO, N2 2x2 MIMO Dual-Band network adapter), WAP (ASUS TUF AX5400). The measurement results in this scenario are shown in Figure 7.

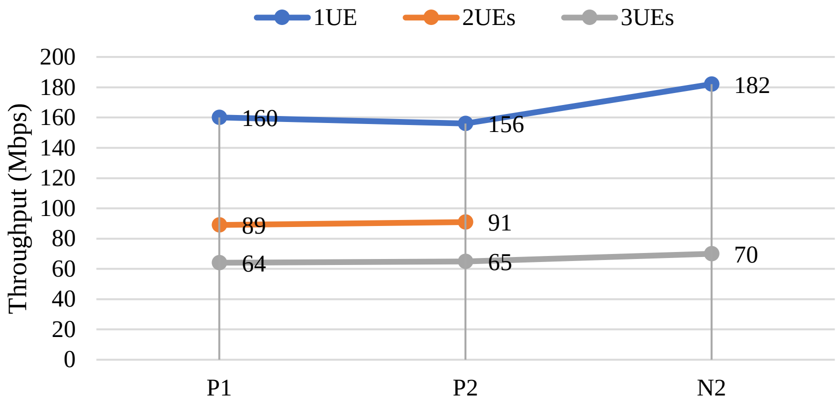

Figure 7: Throughput of single and multiple UEs with 40MHz channel bandwidth

From the measurement results shown in Figure 7, it can be observed that in the case of using two smartphones P1 and P2, the total throughput is 180Mbps (89+91), which is higher than that of a single smartphone P1 (160Mbps) or P2 (156Mbps). The total throughput of three UEs (P1, P2 and N2), 199Mbps, is higher than the total throughput of two UEs, 180Mbps. This is because in a relatively high-bandwidth, high-latency wireless environment, TCP transmission is usually limited by the amount of data in transit state. More TCP connections can be established by using two or more UEs simultaneously, since the communication delay acts on each UE individually, multiple TCP connections can play a role in increasing the total throughput of the whole wireless network. The measured total TCP throughput of both P1 and P2, 180Mbps, is 60% (180/300) of the total data transmission rate, which is also within the normal range of 40 %~60%.

(4) Throughput of single and multiple UEs with 40MHz and 80MHz channel bandwidths. Equipment used: Server (Gigabit network adapter), UE (P1 2x2 MIMO, P2 2x2 MIMO), WAP (ASUS TUF AX5400). The measurement results in this scenario are shown in Figure 8.

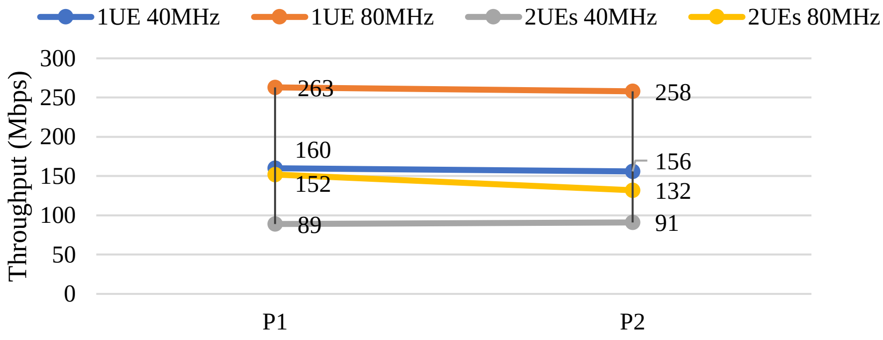

Figure 8: Throughput of single and multiple UEs with 40MHz and 80Mhz channel bandwidth

As can be seen from the results shown in Figure 8, although the throughput increases significantly when using wider channel bandwidth, doubling the channel bandwidth does not result in twice the throughput. By comparing the data transmission rates for 40MHz channel bandwidths (MCS 7) and 80MHz (MCS 9) (Table 2), it can be observed that for UEs with the same performance, the data transmission rate of 80MHz channel bandwidth is twice that of 40MHz. Table 4 shows that the data transmission rate of the four different UEs with 80MHz channel bandwidth is 189% averagely higher than 40MHz.

Table 4: Data transmission rate and throughput statistics of different UEs

UE Type	Data Transmission Rate		Throughput	
	40MHz Channel Bandwidth	80MHz Channel Bandwidth	40MHz Channel Bandwidth	80MHz Channel Bandwidth
P1	300Mbps	866Mbps	160Mbps	263Mbps
P2	300Mbps	866Mbps	156Mbps	258Mbps
P3	150Mbps	433Mbps	72Mbps	220Mbps
N1	300Mbps	866Mbps	133Mbps	229Mbps

Measurement result of single UE in Figure 8 shows that the throughput when the channel bandwidth is 80MHz is 65% higher than that when the channel bandwidth is 40MHz. In addition, when two UEs share the wireless link, the measurement results show that the throughput when the channel bandwidth is 80MHz is increased by about 58% compared with that when the channel bandwidth is 40MHz. Due to the control plane overhead of WLAN, the TCP throughput of a single UE when the channel bandwidth is 80MHz is about 30% of the data transmission rate (P1: 263/866, P2: 258/866); when P1 and P2 use 80MHz channel together, the measured total throughput of 284Mbps (152+132) is 32.8% (284/866) of the data transmission rate, which is slightly higher than that of using a single UE, 30%, but the measurement results in both cases are lower than the usual range of 40%~60%, thus, it can be seen that the wireless link usage when the channel bandwidth is 80MHz is decreased compared to 40MHz, therefore the range of 40%~60% is not suitable for the 80MHz channel bandwidth.

Figure 9 compares the calculated theoretical throughput with the measured throughput when the channel bandwidth is 40MHz. It shows the reasonability of assuming the TCP throughput is 50% of the data transmission rate under the 40MHz channel bandwidth.

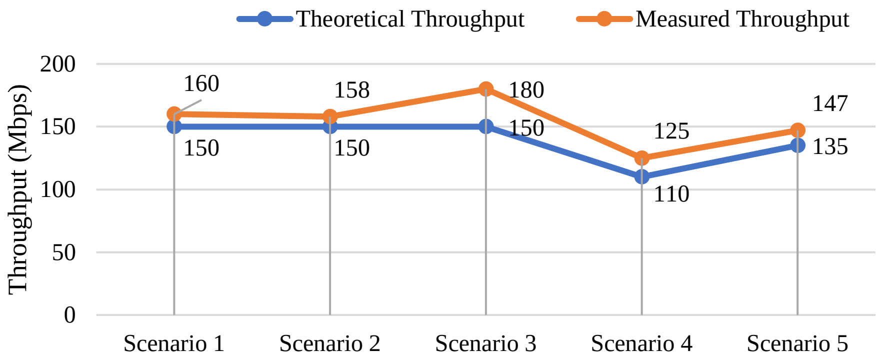

Figure 9: Comparison of theoretical throughput and measured throughput with 40MHz channel bandwidth

7. Conclusion

This paper studies on WLAN capacity planning and performance evaluation, focusing on the impact of application throughput requirements, IEEE 802.11 standards, and UE performance. Traditional WLAN planning is driven by coverage with the goal of meeting the SINR and RSSI requirements within the target area. With the rapid development of high-bandwidth applications and high-performance UEs in recent years, capacity has become a key indicator in WLAN planning to meet user requirements. For capacity-centric WLAN planning, the number of required WAPs needs to be determined according to the usage of the shared wireless link. The computational results in this paper show that applications with higher throughput require more WAPs, while UEs with better performance require fewer WAPs. The measurement results show that the WAP operating in Single-Band or Dual-Band mode has no impact on the throughput performance of UEs operating only in 5GHz band, however, UEs that can operate in both modes reaches better performance when operate in 5GHz band only (Figure 5). In addition, 1MB TCP transmission window provides higher throughput than 64kB (Figure 6), because the default 64kB window is too small to fully utilize the end-to-end wireless link capacity. The measurements also show that the total throughput of two UEs working simultaneously is higher than that of a single UE, while the throughput of three UEs working simultaneously is higher than that of two UEs (Figure 7). Because with high-bandwidth wireless links, TCP transmissions are generally limited by the amount of data in transit state. Multiple TCP connections can be established while two or more UEs are used at the same time. Since the wireless link delay acts independently on the TCP connections of each UE, more TCP connections can lead to the throughput increasing of the whole wireless network. In addition, although the wireless link throughput increases significantly when using wider channels, it cannot achieve the same scale increase as the channel bandwidth. Comparing the data transmission rate of 40MHz channel bandwidth (MCS 7) and 80MHz (MCS 9), for UEs with the same performance, the data transmission rate when the channel bandwidth is 80MHz is 189% higher than that when the channel bandwidth is 40MHz. The measurement results show that the throughput of a single UE when the channel bandwidth is 80MHz increases by 65% compared with that when the channel bandwidth is 40MHz; and when two UEs work on a shared wireless link simultaneously, the throughput when channel bandwidth is 80MHz increased by 58% over 40MHz.

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