Throughput analysis method of uplink competitive transmissions under actual environment using smartphones

Kenji Kita\textsuperscript{1a)}, Tsubasa Ito\textsuperscript{1}, Masato Uchida\textsuperscript{2}, Hiroyasu Ishikawa\textsuperscript{3}, and Hideyuki Shinonaga\textsuperscript{1,2}

\textsuperscript{1} Faculty of Science and Engineering, Toyo University, 2100 Kujirai, Kawagoe, Saitama 350–8585, Japan
\textsuperscript{2} Graduate School of Science and Engineering, Toyo University, 2100 Kujirai, Kawagoe, Saitama 350–8585, Japan
\textsuperscript{3} College of Engineering, Nihon University, 1 Nakagawara, Tamuramachi, Koriyama, Fukushima 963–8642, Japan

\textsuperscript{a)} kita@toyo.jp

Abstract: With the spread of smartphones, connections to the same access point have increased, but the method of evaluating the throughput characteristics of smartphones has not been established. Therefore, in this paper, we propose a method for evaluating the throughput characteristics of smartphones in an actual environment and evaluation index. Furthermore, as an example using the proposed method, we analyzed the throughput characteristics during single device and two devices competitive transmission and confirmed the effectiveness of the proposed method.

Keywords: throughput analysis method, smartphone, actual environment experiment

Classification: Network System

References

1 Introduction

Among many smartphones, the global share of Android and iOS devices is over 96% in May 2017 [1]. Opportunities to communicate using public free Wi-Fi are also increasing. However, despite such situations, analysis methods and evaluation indexes of smartphone throughput characteristics have not been established. Therefore, the authors propose those and introduce experimental results.

2 Throughput analysis method

Fig. 1(a) shows the measurement system. iPerf for Android [2] and iPerf3 for iPhone [3] are installed in each device. This can set a transmission data amount of User Datagram Protocol (UDP) packets per unit time at transmitting devices (called the preset UDP transmission speed in this paper) and also send packets by Transmission Control Protocol (TCP). Packets are transmitted from the smartphone to Rx Personal Computer (PC) on which Ubuntu 14.04 [4] is installed via the Access Point (AP). In the wireless section, the Capture PCs connected with AirPcap Nx [5] capture the packets. In order to avoid capture mistakes, those are captured and complemented in two sets of the Capture PCs. The AP and the smartphone were separated by 7 m, and placed 0.9 m above the floor. The smartphone was stood with the back facing the AP. Furthermore, the authors propose an evaluation index, the effective transmission speed rate which is the throughput ratio to the preset UDP transmission speed. This index can indicate the packet transmission capability of each device. In order to observe these characteristics, 3-D charts are prepared, and for more detailed analysis, these can be studied by obtaining a regression line from two-dimensional charts. From these characteristics, we can analyze the throughput characteristics during single device transmission and competitive transmission. In this paper, as an example of those evaluation by the proposed method, analysis results at UDP uplink communication during single device and two devices competitive transmission are shown.

3 Analysis example at single device transmission

3.1 Experimental system

Experiments were conducted at a laboratory of Toyo university. Radio wave absorbents were attached to prevent interference as much as possible. We employed ARROWS NX F-05F as the Android device, the Operating System (OS) was version 5.02, iPerf for Android was version 2.06, and employed iPhone 6, the iOS was version 9.3.4, iPerf3 for iPhone was version 3.0.9. In this study, IEEE 802.11g mode is adapted, and the throughput is defined as the data transmission amount per the measurement time.

3.2 Contention window size of Android and iOS device

Figs. 1(b) and (c) show the occupied duration calculated from captured data in the wireless section for 180 seconds at the preset UDP transmission speed 30 Mbit/s. Fig. 1(b) shows the contention window size of the Android is 15, because 16 discrete distributions are observed, and 9 micro seconds of these interval time except for the first is consistent with the slot time. Fig. 1(c) similarly shows that of the iOS is 31. These results indicate those devices have different contention window size, and were the same even if other devices and UDP packet transmission software were used.

3.3 Throughput characteristics of Android and iOS device

Throughputs were calculated by the average value of three times for 30 seconds. Firstly, the theoretical maximum throughput [6] was calculated by the contention window size, the Android is 30.5 Mbit/s, the iOS is 25.8 Mbit/s. Since beacon signals and packet retransmissions occur in actual measurements, the upper limit becomes smaller than the maximum. Figs. 1(d) and (e) show the throughput characteristics, 28.2 Mbit/s for the Android and 22.5 Mbit/s for the iOS are the upper limit. We consider the difference in the contention window size is one of the factors for this difference.
4 Analysis example at two devices competitive transmissions

Throughput characteristics during competitive transmissions are analyzed. One RxPC was added to the system in Fig. 1(a), and the UDP packets were simultaneously transmitted from those devices to the AP.

4.1 Throughput characteristics of Android, iOS and system

Figs. 2(a) to (c) respectively show the throughput characteristics of the Android, iOS and the system. The preset UDP transmission speeds were selected by combining arbitrary speeds from 2 Mbit/s to 21 Mbit/s. In Fig. 2(a), the Android throughput increases with the preset UDP transmission speed of the Android regardless of that of the iOS. Whereas, the iOS throughput in Fig. 2(b) decreases as that of the Android and the iOS increase. In Fig. 2(c), the system throughput increases as that of two devices increase, however it is saturated. Throughput characteristics are discussed in detail using two-dimensional charts, Figs. 2(d) to (f). The vertical axes indicate respectively the Android, the iOS and the system throughput, while the horizontal axes are respectively the preset UDP transmission speed of the iOS and Android, and that of each device is plotted as a parameter.

Fig. 2(d) shows the Android throughputs are constant values and equal to that of the Android even if that of the iOS increases. Although that of the Android 21 Mbit/s was measured several times, the throughputs were not stable. As a feature at measurement, packet retransmission was more frequent than other. Therefore, we speculate the Android device used by these experiments had some factors making the system unstable. Whereas, Fig. 2(e) shows although the iOS throughputs are similar tendency when that of the iOS is small, it is limited as that of the Android increases, and the iOS throughput and that of the Android have a negative correlation. The correlation coefficient enclosed by the dotted line is $-0.995$ (significance level $p < 0.01$), and according to Guilford’s Rule of Thumb [7], there is a very strong negative correlation. Furthermore, the regression line is as follows.

$$y = -0.642x + 20.8 \ (2 \leq x \leq 21).$$  \ (1)

iOS throughput upper limits exist on this equation in this range. Then, Fig. 2(f) shows the system throughput upper limit is 26.9 Mbit/s. When the combination of that of the iOS 21 Mbit/s or 16 Mbit/s and that of the Android 21 Mbit/s, the system throughput is low. As described in Fig. 2(d), we assume unstable behavior at that of Android 21 Mbit/s is influenced, the system throughput upper limit may be a little larger. And, although the system throughput linearly appears for the preset UDP transmission speed, linearity is disturbed as the sum of that increases.

Then, the effect of the contention window size is discussed. The theoretical value of the transmission probability is calculated using the contention window size 16 of Android and 32 of iOS. For simplicity, the expansion of the contention window size at collision occurrence is not considered. In the case of first time competitive transmission, when the iOS generates numbers 16 to 31, the Android can inevitably transmit a packet. If it generates numbers 0 to 15, the transmission probability at that time is $1/2$, and when those devices generate the same number, the contention window size expands and the same calculation will proceed. The transmission probability of the Android at the first time is as follows.
Eventually, that of the Android and iOS respectively converged to 75.79% and 24.21%. Therefore, the transmission probability ratio of the iOS to the Android is

\[
\frac{1}{2} + \frac{1}{2} \times \left\{1 - \left(\frac{1}{16} \times \frac{1}{16} \times 16\right)\right\} \times \frac{1}{2} = 73.4375[\%]
\]

Eventually, that of the Android and iOS respectively converged to 75.79% and 24.21%. Therefore, the transmission probability ratio of the iOS to the Android is
31.93%. Fig. 2(g) shows the throughput ratio of the iOS to that of the Android calculated from the measured values when the transmission rates of the two devices are the same. The vertical axis indicates iOS throughput ratio to the Android throughput, while the horizontal axis is the preset UDP transmission speed. When the preset UDP transmission speed is 21 Mbit/s, the throughput ratio becomes 43%, which shows it approaches the theoretical value of 31.93%. The deviation of about 10% is expected to become asymptotically closer if the preset UDP transmission speed is further increased. Finally, UDP video communications such as LINE and Skype require at most about 2 Mbit/s. If the number of devices is small, these applications will not be affected. However, when many devices with different OSs are connected, the throughput may be degraded depending on the device.

4.2 Effective transmission speed rate of Android, iOS and system

We define the effective transmission speed rate which is the throughput ratio to the preset UDP transmission speed. Fig. 3(a) to (c) respectively show that of the Android and iOS, and the system throughput. Fig. 3(a) shows that of the Android is almost 100% irrespective of the preset UDP transmission speed of the iOS until that of the Android 16 Mbit/s. Fig. 3(b) shows when the sum of the preset UDP transmission speed exceeds a certain value, the effective transmission speed rate decreases. That of the system throughput in Fig. 3(c) has also similar tendency. For detailed analysis in Fig. 3(c), the two-dimensional chart Fig. 3(d) was used. Fig. 3(d) shows when the sum of that exceeds 23 Mbit/s, the effective transmission speed rate decreases. The correlation coefficient between the sum of that and effective transmission speed rate of the system throughput enclosed by the dotted
line is $-0.953$ (significance level $p < 0.01$), and according to Guilford’s Rule of Thumb, there is a very strong negative correlation. Furthermore, the regression line is as follows.

$$y = -2.0465x + 144.2 \ (23 \leq x \leq 42).$$  \hspace{1cm} (3)

It means the effective transmission speed rate decreases approximately 2% each the sum of that increases by 1 Mbit/s. From the above results, throughput characteristics were evaluated from a different perspective.

5 Conclusion

The authors proposed the throughput analysis method for smartphones and the evaluation index of the effective transmission speed rate, and showed two analysis examples. The results showed that the contention window size differed depending on the devices, and the detailed analysis could be performed by the regression line. From these results, the effectiveness of the proposed method was confirmed. In the future, we will analyze combinations of various terminals, OSs, wireless LAN standards and TCP, and compare the results of computer simulation.