Users' Reaction to Network Quality during Web Browsing on Smartphones

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***Abstract*—Understanding the Quality of Experience (QoE) of users is important for network and service providers. Many researches of QoE have been reported where subjective analysis, e.g. in the form of Mean Opinion Score (MOS), for audio/video applications and data services are performed. These studies mainly focus on how users feel while using such applications. In this paper, we focus on how users behave and react to communication network quality. We analyze the telecom traffic of smartphones passively monitored from 3G mobile network and show the effect of network quality on the users' web behavior. In particular, we investigate user behavior as a series of multiple actions in a flow of web browsing. We show that the observed results coincide with the MOS obtained through subjective analysis: The condition of network quality where the users' web behavior changes matches with the condition where the MOS starts to degrade. In addition, the obtained results illustrate that the users perform various reactive actions depending on the perceived network quality. Specifically, users generate more web traffic and transactions when the qualities of the network are both good and poor.**

Keywords—web behavior; QoE; network quality; mobile traffic; passive monitoring

I. Introduction

Smartphones are getting increasingly popular in the global market and the users are enjoying variety of applications over wireless and mobile networks. As the contents of the Internet become more developed and richer, quality of communication network plays a key role in determining the perceived experience of users. Therefore, an important issue for network service providers is to maintain the service quality not only to avoid congestion and overloads, but also to provide sufficient quality to maximize satisfaction of the users. Traditionally, Quality of Service (QoS), such as packet loss rate, latency, jitter, throughput etc., is monitored by the network service providers [1]. Although these QoS parameters are still important, they are not sufficient to understand what the users are actually experiencing. As a result, investigating the Quality of Experience (QoE) [2] of users while using various applications is becoming increasingly important [3]-[5].

Many researches of QoE have been reported where various analysis for audio/video applications and data/web services are performed. For example, [6] and [7] analyze the QoE of video streaming application, while [8]-[14] all report the QoE for data services such as data downloading and web browsing. Specifically, [8] analyzes QoE for file downloads and web browsing and show that time perception of users during web browsing is more complex than that during simple file downloads. Reference [9] illustrates the relationship between acceptability and QoE for interactive data services, while [10] investigates the memory effects i.e. the effects of temporal changes and dynamics of service quality on user's satisfaction. References [11] and [12] discuss about models and functions to relate and map QoS with QoE.

Meanwhile, a popular method to assess users' QoE is the subjective analysis of specific applications. Here, users perform some experiments, e.g. in a test-bed environment, and are asked whether the experiences were pleasant or not, typically in the form of Mean Opinion Score (MOS). The strength of this approach is its preciseness to fully understand what the users require and feel. However, the drawbacks are their time and cost consuming load and this could be a problem when large-scale analyses are preferred for statistical purposes. In addition, it is also important for network service providers to understand the behavior and reactions of users in real environments on a regular basis. For these purposes, passive approach is effective and efficient since vast volume of data and large number of users could be analyzed without interfering the services of actual users. Likewise, [13] and [14] adopts passive methods to analyze web QoE from monitored traffic.

Accordingly, this paper analyzes the behavior and reaction of users to network quality during web browsing on smartphones. Similar to [13] and [14], we utilize the passive approach to analyze the behavior of users in real environments where the traffic of web and HTTP, which accounts for a large proportion of the Internet, are monitored and analyzed. In addition, since web browsing is a flow experience [4], we analyze users' web behavior as a series of multiple actions. In order to do so, a method to convert passively monitored traffic, in units of packets and TCP/HTTP sessions, into units of user's actions is introduced. The main contributions of this paper are two folds. Firstly, we show that the observed behavior of users' web usage coincides with the MOS obtained through independent subjective analysis: The condition of the network quality where the users' web behavior changes matches with the condition where the MOS starts to degrades. We assume

978-0-9836283-9-2

that this obtained feature is evidence which supports our passive method to analyze user's web behavior. Secondly, we illustrate various reactions of the users depending on the perceived network quality. Specifically, the users generate more web traffic and transactions when the qualities of the network are both good and poor. We also analyze the abandon behavior of users depending on the network quality.

Rest of the paper is organized as follows. Section II explains the method to analyze the user's web behavior using the passively monitored traffic. In Section III, we compare the observed results with the subjective analysis of web QoE and show that the both results coincide with each other. Section IV illustrates the various reactive actions of the users depending on the perceived network quality during mobile web browsing. Finally, we conclude our paper in Section V.

II. Analysis of Users' Web Behavior by Passive Monitoring of Telecom Traffic

In this section, we describe the methods and features introduced in this paper to analyze users' web behavior depending on the network quality. Particularly, we aim to analyze the flow experience of web browsing as a series of multiple user actions. In addition, we evaluate an adequate setting for the parameters introduced by our method.

A. Conversion of Passive Traffic into Units of User Actions: Transactions and Flows

There are several methods to monitor traffic and/or the behaviors of users using various applications. For example, [6] uses agent-based approach where analytical plug-ins are installed in media players, and the user's behavior and perceived quality are directly monitored at the user terminals. These approaches are effective since accurate and precise information of the users and data transmission could be monitored. There are also some active methods to monitor the quality of the network [15].

In this paper, we utilize the passive approach in order to analyze the behavior of users in real environments. Similar to [13] and [14], the advantage of the passive approach is its effectiveness and efficiency: Vast volume of data and large number of users could be analyzed, on a regular basis, without interfering the services of actual users. The drawback, however, is that the actual timings of data reception and transmission and precise values of perceived qualities cannot be monitored, since traffic is monitored at intermediate nodes of the network. In addition, there is a notable difficulty for passive monitoring of web browsing. As the contents become richer and more developed, even a single web page consists of multiple objects, and thus multiple TCP/HTTP sessions are generated to transport such data. In a passive monitoring environment, however, it is difficult to understand the full structure of a webpage. More specifically, dependent and interdependent relationships between the multiple objects, i.e. multiple sessions, cannot be fully analyzed without detailed and thorough Deep Packet Inspection (DPI). Meanwhile, the aim of this paper is to analyze user's behavior of web browsing as a series of multiple user actions, and not just multiple sessions. Therefore, we introduce a method to convert

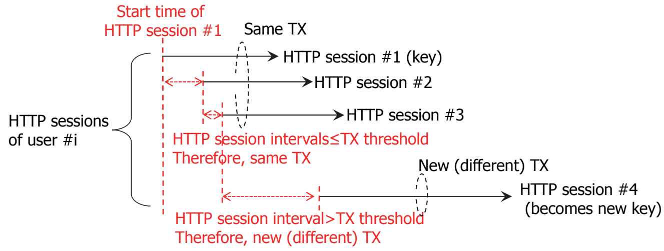


Fig. 1. Definition of Transaction.

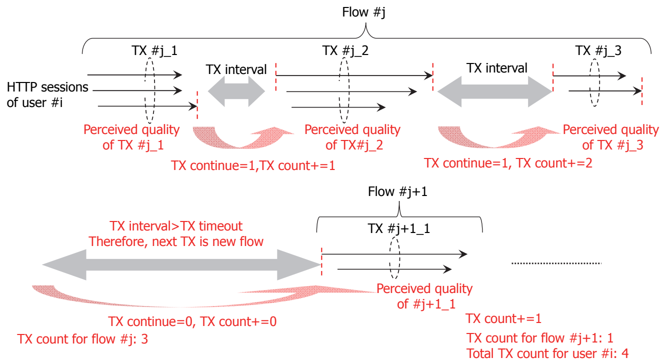


Fig. 2. Definition of Flow.

passively monitored traffic, in units of packets and TCP/HTTP sessions, into units of user's actions.

Fig. 1 and Fig. 2 illustrate the methods used in this paper. Firstly, passively monitored packets are summarized into TCP sessions using the 5-tuple informations of the TCP/IP header [16]. Next, TCP data for port number 80 are recognized as HTTP sessions, and various information regarding HTTP are analyzed [17]. Specifically, timings and data volumes for requests and responses are analyzed and recorded. Secondly, analyzed HTTP sessions are summarized into units of user actions, defined as Transactions (TXs) hereafter. TX corresponds to a "single" web page requested and browsed by the users. Although TXs are not perfect representation of actual webpages, they are simple, feasible and scalable method to analyze vast volume of passively monitored traffic since no complex DPI is required.

Fig. 1 illustrates the method to summarize multiple HTTP session into TXs. As shown in the figure, only the timing information of HTTP sessions is used for simplification of analysis. In addition, since recent web sites are constructed with multiple objects which are possibly stored in multiple servers, only the source information, i.e. user ID, is used when summarizing HTTP sessions into user TXs. The summarization methods are as follows. Firstly, we introduce a threshold value for TX summarization, noted as TX threshold. Next, HTTP sessions, from the same user, destined for the same and/or different servers are all summarized into the same TX when their intervals of session occurrence are within the predefined TX threshold. Time intervals are calculated as the elapsed time between the start times of two consecutive HTTP sessions. HTTP sessions having the intervals that exceed TX threshold are summarized as new and different TX where the next first subsequent HTTP session is recognized as the new

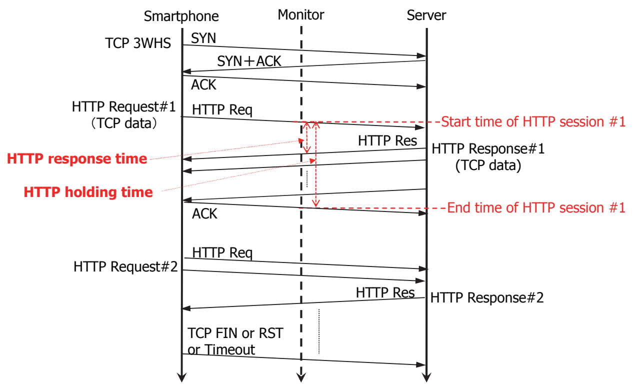


Fig. 3. TCP and HTTP sequence and features of network quality.

key. The verification of the value of TX threshold is discussed in the later section.

In addition to TX, we introduce another unit of user action defined as Flow. Fig. 2 shows an image of Flow in conjunction with TXs and HTTP sessions. Flow corresponds to a series of multiple user actions, i.e. TXs, during browsing. Flow consists of one or more TXs and they are recognized as the same Flow when their time intervals are within a predefined value of TX timeout. Here, TX interval is calculated as the time between the end time of the current TX, which is the lattermost end time of the HTTP session consisting a TX, and the start time of the next TX. When TX interval exceeds TX timeout, the next first TX is recognized as the first TX of the next Flow. Using TX and Flow, user's reaction to network quality during web browsing is analyzed.

Fig. 3 illustrates the features of the network quality, in terms of waiting times, analyzed in this paper. HTTP response time is defined as the time interval or the delay between the start times of a HTTP request and response. It corresponds to the response delay for the first packet or data to arrive at the user terminal since the request of such data. In addition, HTTP holding time is defined as the time interval or the delay between the start time of a HTTP request and the end time of a HTTP response. The end time of a response is defined as the time when the ACK packet for the last data consisting a response is monitored. The holding time corresponds to the delay between the last packet or data to be successfully downloaded at the user terminal since the request of such data. Note that both features of time illustrated in Fig. 3 are not perfectly similar to those perceived by the users, since traffic is passively monitored at intermediate network nodes. Thorough evaluations of the monitored qualities are discussed in the later sections. Using the defined HTTP response and holding times, perceived qualities for each TX are calculated. Specifically, the statistical values, e.g. the mean, of both time features, of HTTP sessions consisting one TX, are calculated for each TX. Furthermore, using their summarized size, download throughputs for TXs are also calculated.

Meanwhile, we also introduce features regarding user's behavior. Firstly, TX continue is introduced to analyze the flow behavior. It is defined as a flag value to represent the continual behavior in web browsing. That is, the value is set at 1 when the time interval of the next TX is within the TX timeout i.e. when the current and the consecutive TXs are in the same Flow. Likewise, TX continue is set as 0 when the time interval of the consecutive TX exceeds TX timeout. Furthermore, we monitor the counts of TX in one Flow. The total count of TX, of multiple Flows, for a unique user is also analyzed.

B. Parameter Settings for Analysis

In this subsection, we investigate the effect of the two parameters, TX threshold and TX timeout, introduced in our analysis and illustrate the reasons for the adopted values. The idea is to set TX threshold smaller and set TX timeout larger than the user think time, respectively, so that these parameters do not negatively affect the analysis of user behavior.

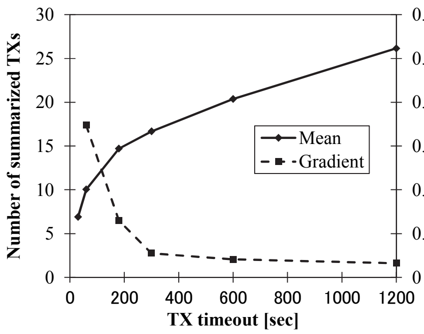
In this paper, we analyze telecom traffic of smartphones passively monitored from 3G mobile network. The analyzed data consisted of 6 days of traffic where more than 16 million HTTP sessions from over 3,000 users are monitored. Only the traffic for web browsing and HTTP is analyzed to focus on the analysis of user's web behavior. Table I shows the basic properties of the analyzed TXs and Flows when TX threshold and TX timeout are set as 3 and 600 [sec], respectively. The reason for choosing these values is discussed in the following. The data in the table is shown as a brief reference to illustrate the properties of the analyzed traffic.

Two panels of Fig. 4 show the effect of TX timeout on the mean number of TXs summarized as one Flow, when TX thresholds are set at 1 and 3 [sec], respectively. The gradients are also shown in the graphs. As shown in the figure, the mean number of TXs in one Flow increases as TX timeout increases. This is quite natural since larger TX timeout means more TXs could be summarized. Meanwhile, the values for TX threshold=1 [sec] are larger than those for TX threshold=3 [sec], since smaller threshold splits TXs into multiple and smaller parts even when the duration of sessions are the same. An interesting point to be noted is that the trend of increase, or the gradient, is larger and non-linear when TX threshold<600 [sec] for both cases. Meanwhile, Fig. 5 shows the effect of TX threshold on the mean number of HTTP sessions summarized as one TX when TX timeout is fixed at 600 [sec]. The result is similar to Fig. 4 where the mean number of HTTP sessions increases as TX threshold increases. In addition, the gradients also show a non-linear trend. These non-linear trends shown in both graphs indicate the time dependency of HTTP session and TX occurrences. We assume that there are two different causes.

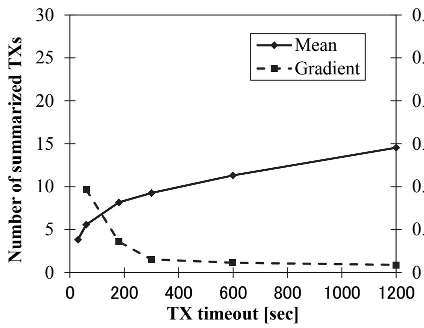
Firstly, as reported in [14], a webpage generally consists of a base file and embedded files. The base file is the first webpage requested by the user, e.g. after the web-click, whereas the embedded files are those consecutively requested and retrieved, somewhat automatically, by the browser after the base file. In other words, the occurrences of HTTP sessions and TXs for embedded files are triggered by the reception of base files. This could cause the time dependency properties of summarized TXs and HTTP sessions. Another reason is the effect of user think time when summarizing TX and Flow. Note that the user think time is the time interval between browsing of webpages. Since users are generally expected to continue browsing for a while once they started, the occurrence

TABLE I. BASIC PROPERTIES OF ANALYZED TXS AND FLOWS.

Type	Property	Mean	Standard deviation
Transaction	Download size [kBytes]	112	572
	Duration [sec]	6.06	17.0
	# of HTTP sessions	11.8	22.0
Flow	Download size [kBytes]	1,266	5,014
	Duration [sec]	375.7	947.4
	# of Transactions	11.3	30.1



(a) TX threshold = 1 [sec].



(b) TX threshold = 3 [sec].

Fig. 4. Effect of TX timeout: Number of summarized TXs in one Flow.

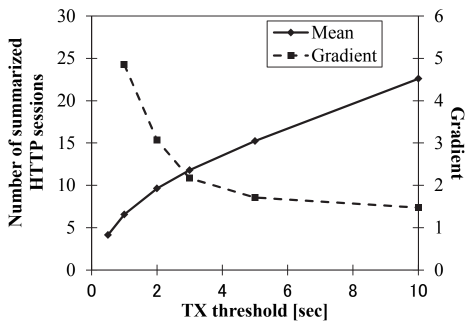


Fig. 5. Effect of TX threshold: Number of summarized HTTP sessions in one TX.

of webpages, thus TXs, get concentrated and bursty. On the other hand, when the users stop browsing, it should take a while, longer than the user think time, for the users to return and start browsing again. Consequently, the number of TXs summarized in one Flow could get correlated when TX timeout is set smaller than the user think time.

Overall, a desirable setting for TX threshold and timeout is to eliminate the effect of these correlations and time dependency. Therefore, from the obtained results and evaluations, we hereafter set TX threshold and TX timeout as 3 and 600 [sec], respectively. Although, this setting might not be perfect, we assume that it is an adequate value to decrease, if not eliminate, the correlations and time dependencies. In addition, these values are similar with the user think times and time intervals between base files analyzed in [14], which indirectly supports our evaluation.

III. REACTIONS OF USERS DURING WEB BROWSING: CONTINUOUS BEHAVIOR

In this section, we analyze the reactions of users during web browsing in terms of continuous behavior. Specifically, the continue ratios of users during web browsing in relation to various perceived qualities are analyzed.

A. Verification of Observed Results with Subjective Analysis

In this subsection, we verify the validity of our method to analyze user's behavior and reactions. Specifically, we compare the observed results of user behavior with the subjective analysis of web QoE. As a measure of user behavior, we analyze the continue ratio of TX in correlation with the network quality. Our assumption is that users react and change their behavior when experiencing different network qualities, especially during poor conditions.

Fig. 6 shows the continue ratio of TX against download throughput. Each point on the graph is calculated by analyzing TXs having the same bin of throughput. The bin, however, is summarized until when the number of logs in the summarized bin exceeds a preset value to maintain statistical significance. The bin and the preset value are set at 10 [kbps] and 1000 logs, respectively. Hereafter we use the same set of values unless stated otherwise. The continue ratio is calculated as the number of TXs having TX continue=1 to the total number of TXs, including TX continue=0.

As shown in the figure, the values of the continue ratio are always below 1.0 even when the throughput is high. This is not surprising since the users might stop browsing depending on the context and/or the conditions other than the network quality. Meanwhile, the continue ratio starts to decrease as the throughput decreases. This is also reasonable since the degradation of the throughput results in the increase of download times of webpages, thus resulting in the increase of dis-satisfaction. In these situations, some users starts to stop browsing resulting in the decrease of the continue ratio. Note that, however, the continue ratio sometimes increase when the throughput is below 50 [kbps]. Although this seems somewhat strange, the cause for the increase is described in the later section.

Fig. 7 illustrates the results of subjective analysis of web QoE, in form of MOS, when the download throughput is varied. The experiments were performed in a test-bed environment where users were asked to perform some tasks, e.g. searching a designated restaurant, using web browsers on smartphones. During the experiment, throughput was varied using a network emulator and after each trial, the users were asked to answer their level of satisfaction as a 5-point scale. The number of participants was 106. The plots represent the actual measured values of MOS. In addition, we also show results from other

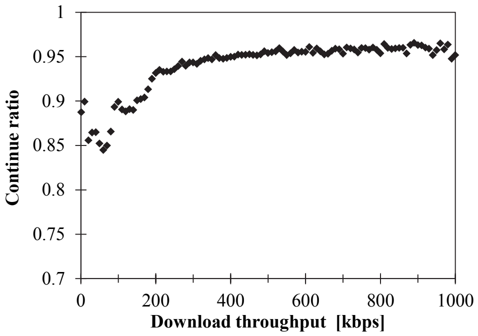


Fig. 6. Ratio of TX continue against download throughput.

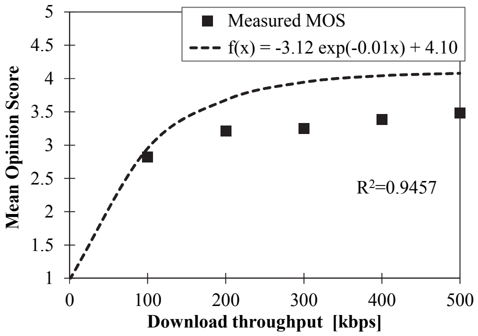


Fig. 7. MOS of web QoE against download throughput.

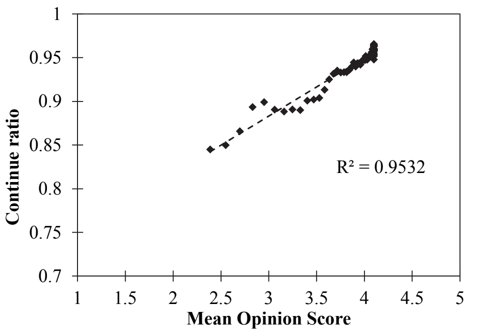


Fig. 8. Correlation between continue ratio and MOS.

study [8] which are numerically calculated using the exponential equation shown in the legend of the dotted line.

As shown in the figure, the measured MOS starts to degrade as the throughput decreases. The degradation is notable when the throughput becomes smaller than 200 [kbps]. Although specific values are not exactly the same due to different conditions of the experiment, the observed properties are similar to past studies such as [8] and [9], where MOS or user's acceptance against throughput, respectively, degrades steeply when below 200-300 [kbps]. Furthermore, the coefficient of determination, R^2, between the measured MOS and the calculated values derived from [8] becomes 0.9457. This shows that the two results are highly correlated and thus similar to each other.

Comparing the results of Fig. 6 and Fig. 7, a distinguishing feature to be noted is that the point of throughput where both the continue ratio and MOS starts to degrade matches. To evaluate this property in more detail, we analyzed their correlation. Fig. 8 shows the correlation between the continue ratio and MOS. Since only five plots are available for the measured MOS, we instead used the calculated values of MOS using the fitted equation of [8] shown in Fig. 7. In addition, to focus on the relationship of the decreasing trend, the values obtained when throughput is below 50 [kbps] were omitted from the evaluation.

As the figure shows, there is a strong correlation between the continue ratio and MOS, where the coefficient of determination becomes very high with 0.9532. We assume that this is evidence that supports our passive method to analyze web behavior of users, where the continue ratio of TX could be used, for example, as a substitution of MOS for web QoE. Meanwhile, the results also indicate that, for the data sets and conditions analyzed in this paper, throughput around 200 [kbps] is a threshold point of user's satisfaction or tolerance. This, however, could vary depending on various conditions such as age, place of use etc. [3]. Therefore, an important insight obtained from the results is that the users react and change their web behavior when experiencing poor throughput, especially when, or just before, the perceived quality exceeds their level of tolerance.

B. Continue Ratio against Waiting Times

As reported in [4], throughput is not a direct psychological stimulus to users and waiting times, or perceived delay, are also important features of network quality. Accordingly, we analyze the effects of these waiting times on the continue ratio. Fig. 9 and Fig. 10 illustrate the continue ratio of TX against mean response time and mean holding time, respectively. The bin and the preset value of bin summarization are set at 0.1 [sec] and 1,000 logs, respectively. Hereafter we use the same set of values unless stated otherwise. The x-axes of both graphs are shown as log scale.

As shown in the results, the properties of continue ratio differ depending on the type of the waiting time. Fig. 10 shows that the continue ratio starts to decrease as the mean holding time increases, especially when it exceeds 20 [sec]. When the holding time is below 20 [sec], however, there seem to be no correlation with the continue ratio. More rather the continue ratio seems to slightly increase when the holding time is between 0.1 [sec] to 10 [sec]. We assume the reasons for these features as follows. Since holding time is the total duration of download, the types and the context of the contents could have large impact on user's behavior. For example, webpages with many image files having larger file sizes could result in large holding times. In addition, some part of the contents, e.g. texts of a webpage, might be shown on the browser before all the contents are shown or downloaded. In these situations, users might expect larger waiting times as were reported in [3] and [8]. This results in more tolerance towards larger delay, meaning that the continue ratio does not decrease until the holding time becomes relatively large. When the holding time get very large i.e. over 20 [sec], however, the continue ratio starts to decrease showing that users change their behavior. The obtained results coincide with other studies such as [8] and [11], where the MOS start to degrade when the download time exceeds 15-20 [sec], meaning that the users get dis-satisfied when the delay gets too large. Meanwhile, the increase of the

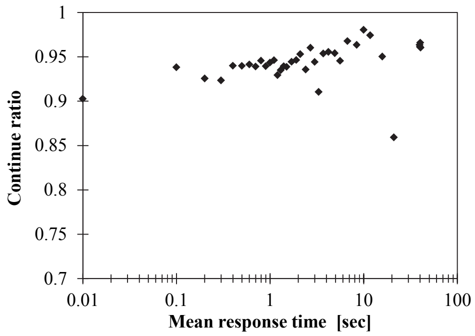


Fig. 9. Continue ratio of TX against mean response time.

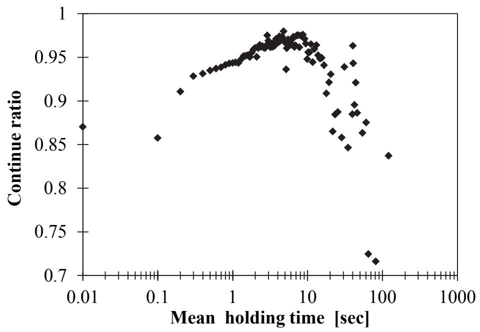


Fig. 10. Continue ratio of TX against mean holding time.

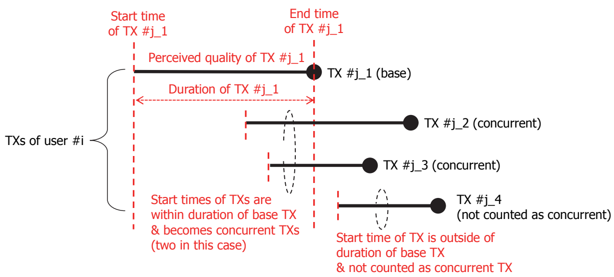


Fig. 11. Definition of concurrent TX.

continue ratio when the holding time is between 0.1 [sec] to 10 [sec] might suggest a sign of some willingness of users to continue browsing, e.g. when just started browsing. There might also be different causes for this property and more thorough evaluation remains for future works.

As for the response time, Fig. 9 shows that there is no strong correlation with continue ratio. This might contradict with our intuition since the increases of response time means larger delay for the users. So, a natural assumption is that it should lead to a change of user behavior, namely decrease of continue ratio due to dissatisfaction of the users. However, the obtained results show a different character and we evaluate the reason for this as follows. Since response time is the delay between the request of a data and the start of its download, the actual download time after the response time varies depending on the types of contents and their file sizes. For example, logs with small response times might have large holding time, or vice versa. The users, however, behave and react to the perceived delay which is recognized, for example, as the partial display of text and image files on the browser. Therefore, since total perceived delay is a combination of response and actual download times, small, or large, response time does not necessarily end up with user satisfaction, or dis-satisfaction. Consequently, this results in the uncorrelated relationship between the response time and the continue ratio.

IV. Reactions of Users during Web Browsing: Concurrent and Abandon Behavior

In this section, we analyze the reactions of users during web browsing in terms of concurrent and abandon behavior. Specifically, the number and the total download size of concurrently generated TXs during web browsing in relation to various perceived qualities are analyzed. We also analyze the abandon ratio in terms of TCP resets and timeouts. Concurrent behavior represents the active reactions of users, whereas the abandon behavior represents the inactive or passive reactions.

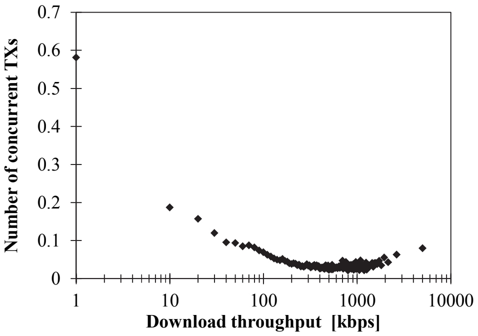
A. Analyzed Features

Fig. 11 shows an image of concurrent TXs when multiple TXs are generated. As shown in the figure, a TX is classified as a concurrent TX when its start time is within the duration time of a base TX. This duration is calculated as the time interval between its start time and end time, which are the start time of the first HTTP session and the end time of the last HTTP session summarized as one TX, respectively. In the example shown in Fig. 11, the number of concurrent TXs associated with a base TX #j_1 is 2. We analyze this number of concurrent TXs and their total download size in relation with the perceived quality of TX, #j_1 in this case. In this way, TXs are classified as concurrent and their features are sequentially analyzed. The aim of concurrent TX is to quantify the reactions of users, in form of the increase of traffic and transactions, during browsing of a webpage. Note that concurrent TX could be a new webpage requested by a new window or a new tab, or a re-load of a webpage. For example, [18]-[20] reported that users utilize multiple windows and generate new tabs during web browsing. All these actions by users could be regarded as concurrent behavior. However, we do not intend to distinguish them from each other, since our focus is to analyze the properties of concurrent TXs depending on the perceived network quality.

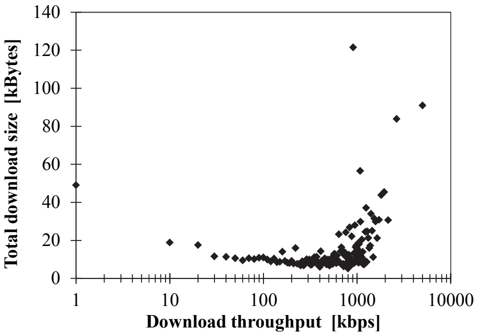
Another analyzed feature is the abandon behavior during web browsing. We quantify the user's abandon behavior as the occurrence ratio of TCP timeouts and resets (TCP RST). As shown in Fig. 3, there are several types of termination for a TCP connection; FINs, RSTs and timeouts. In this paper, we calculate the two ratios of abandon behavior as the proportion of TCP connections that terminated with RST or timeout to the total number of TCP connections summarized as one TX.

B. Obtained Results: Conccurent TXs against Download Throughput

The two panels of Fig. 12 show the number and the total download size of concurrent TXs against download throughput. Similar to the continue ratio, each plot on the graphs is calculated by analyzing TXs having the same bin of throughput. The bin is summarized until when the number of logs, in the summarized bin, exceeds a preset value to maintain statistical significance. Since multiple logs, i.e. different TXs with

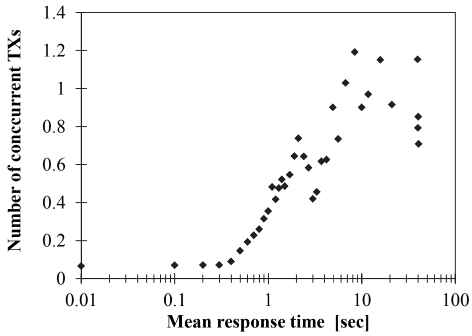


(a) Number of concurrent TXs.

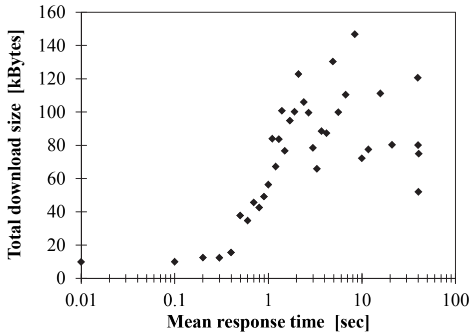


(b) Total download size of concurrent TXs.

Fig. 12. Conccurent TX against download throughput.



(a) Number of concurrent TXs.



(b) Total download size of concurrent TXs.

Fig. 13. Conccurent TX against mean response time.

TABLE II. INCREASE RATIO OF TRAFFIC DEPENDING ON THROUGHPUT

	Quality of download throughput	Increase ratio
# of conccurent TXs	Low (<10[kbps])	18.5
	High (≥2,500 [kbps])	2.3
Total download size	Low (<10[kbps])	4.0
	High (≥2,500 [kbps])	7.1

various values, are collected in one bin, we calculate their mean as the representative value for such bin. The x-axes of both graphs are shown as log scale.

From the results, we observe that the number of concurrent TXs is always below 1.0, which shows that concurrent TXs are not always generated. This is natural since users do not always generate concurrent TXs. A distinguishing feature, however, is that there is a clear trend of increase in the number of concurrent TXs as the throughput decreases. The total download size shows similar feature as well. The obtained results show that users are reacting to the poor quality and change their behavior by generating new and concurrent TXs. Meanwhile, the number and the total download size of concurrent TXs also increase as the throughput increase. This shows that users are reacting to the good quality also. The obtained results therefore suggest that higher throughput causes smooth browsing and encourages users to browse more.

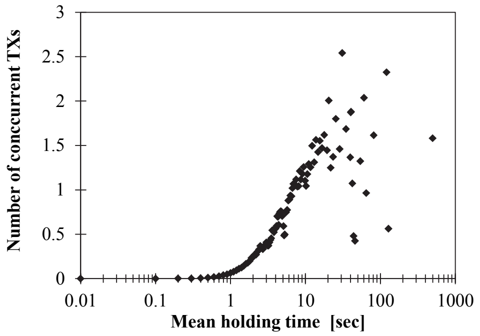
Overall, the obtained results show that the users generate more traffic and TXs when the throughput is both good and poor. However, the properties of the increase differ. Table II shows the increase ratios of traffic. Here, the mean values calculated using the properties of 200-1,000 [kbps] are used as the denominator. As shown in the table, when throughput is high, the increase trend for the download size is larger than that for the number of concurrent TXs. On the other hand, when throughput is low, the increase trend for the number of concurrent TXs is larger than that for the total download size. We assume that this increase of traffic during low throughput is the cause for the increase of continue ratio shown in the previous section.

Consequently, the results indicate that effects of user reactions on the network performance differ. When throughput is high, the volume of traffic increases meaning that effect on the capacity of the network and links is more evident, whereas when throughput is low, the number of TXs thus TCP/HTTP sessions increases resulting in the increase of requests for servers and gateways.

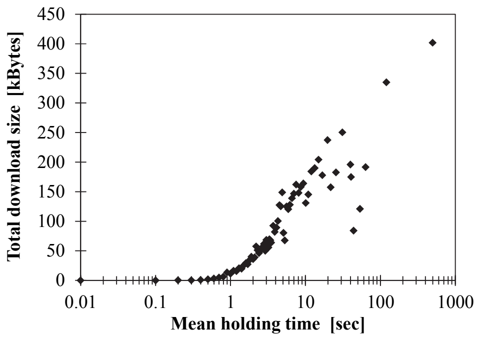
C. Obtained Results: Conccurent TXs against Waiting Times

The two panels of Fig. 13 and Fig. 14 show the number and the total download size of concurrent TXs against mean response time and mean holding time, respectively. As shown in the figures, both properties increase as the times increase. These are also some signs showing that users react to the poor quality and change their behavior by generating more traffic, possibly new clicks or tabs. There are differences, however, when both times are small, i.e. during good quality. Unlike throughput, there seem to be no increase of traffic. To evaluate the cause for the differences, we also analyzed the properties when the number of concurrent TX>0, i.e. only when concurrent TX were actually generated.

Fig. 15 and Fig. 16 illustrate the number of concurrent TXs against both times when concurrent TX>0. The results for the



(a) Number of concurrent TXs.



(b) Total download size of concurrent TXs.

Fig. 14. Conccurent TX against mean holding time.

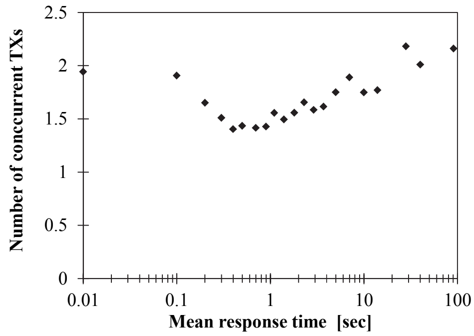


Fig. 15. Conccurent TX against mean response time when number of concurrent TX>0.

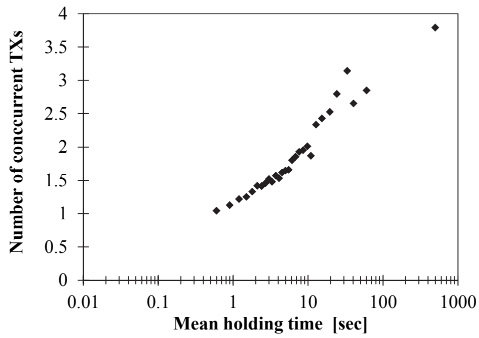


Fig. 16. Conccurent TX against mean holding time when number of concurrent TX>0.

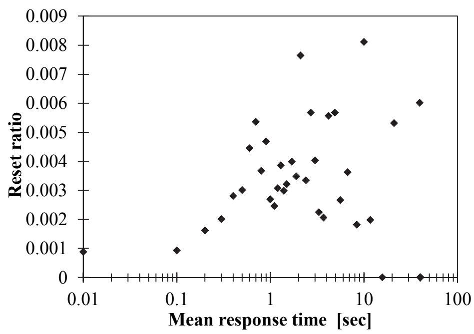


Fig. 17. Reset ratio against mean response time.

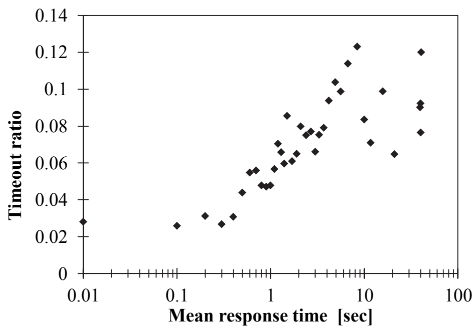


Fig. 18. Timeout ratio against mean response time.

total download size are not shown due to limited space. From the figures, the number of concurrent TXs increases when the mean response times are both good and poor. Meanwhile, the number only increases for the mean holding time when the quality is poor i.e. the values are large. We assume the cause as follows. Firstly, holding time is the duration of download itself, so when it is small, actual duration of the data transfer is also small. In this case, there is literally not enough time to generate a lot of concurrent TXs. On the other hand, when holding time increase, the chance or the time to generate one or more concurrent TX increases. The monotonic increasing trend of Fig. 16 supports this assumption. Meanwhile, since mean response time is the delay until the start of the download of contents, the total duration after this delay could vary. So, there could be enough time for users to generate many concurrent TXs.

Looking at the properties of Fig. 13 and Fig. 15, the results show that the proportion of logs with concurrent TX=0 is large when the response time is small. This means that not everyone, in fact only a small portion of users, generates concurrent TXs even when the response time is small and the quality is good. This is reasonable since some users might be satisfied with the situation and the users do not always get encouraged by the smoothness of browsing.

D. Obtained Results: Abandon Behavior

In this subsection, the abandon behavior of users is analyzed. Fig. 17 and Fig. 18 show the reset ratio and the timeout ratio against the mean response time, respectively. As shown in the results, although there seems to be some points of increase, correlation against the mean response time is not so strong. There could be several reasons for this. For example, as was described in the previous subsection, the actual duration of download is not included in the response time, thus the problems which could cause resets might not be apparent in this feature. Another reason is that, as reported in [22] and [23], TCP RSTs could occur due to various causes other than the quality of the network, such as the types of the OS, the browsers or the applications used. Therefore, the increases of the response time might not be a key factor in some cases, causing the weak relationship with the reset ratio. Meanwhile, the timeout ratio increases as the mean response time increases. This is reasonable since longer response time means no response or reaction from the server and when this delay is too long, timeouts of TCP connections are caused. Note that timeouts could be assumed as inactive reactions by users where they do nothing or do not take any further actions while waiting for the data to be downloaded.

Overall, analyzing these inactive and abandon behaviors by the users in addition to the active behavior of concurrent TXs enable us to evaluate the reactions of the users more thoroughly depending on the network quality.

V. Conclusion

This paper analyzed the behavior and reaction of users to network quality during web browsing on smartphones. Telecom traffic of smartphones passively monitored from 3G mobile network was analyzed to investigate user behavior as a series of multiple actions in a flow of web browsing. We introduced a method to convert passively monitored traffic, in units of packets and TCP/HTTP sessions, into units of user's actions. We showed that the observed behavior of users' web usage coincides with the MOS obtained through independent subjective analysis: The condition of throughput where the users' continuous behavior changes matches with the condition where the MOS starts to degrades. In addition, the obtained results illustrated that the users perform various reactions depending on the perceived network quality. Specifically, users generate more web traffic and transactions when the qualities of the network are both good and poor. We also showed the abandon behavior of users when the network quality is poor.

The obtained results indicate some insights that could be utilized for network planning and analysis of users' QoE. For example, using the correlation between the continue ratio and download throughput, users' QoE could be estimated from the point of throughput where users' behavior changes. Although subjective analysis of users for various applications is still important, the passive analysis approach could be performed as a preliminary survey prior to the thorough investigations of users. In addition, the trend or the sensitivity of traffic increase depending on the throughput could be utilized, for example, to analyze the impact of traffic control during congestion. The obtained results suggest that too much restriction on the user's throughput could cause somewhat paradoxical increase of traffic due to user's active reactions.

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