Computer Science and Artificial Intelligence Laboratory

Technical Report

MIT-CSAIL-TR-2011-028 May 3, 2011

Comparison of User Traffic Characteristics on Mobile-Access versus Fixed-Access Networks

Mikko V. J. Heikkinen and Arthur W. Berger

massachusetts institute of technology, cambridge, ma 02139 usa — www.csail.mit.edu

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Mikko V. J. Heikkinen
Aalto University School of Electrical Engineering
Helsinki Institute for Information Technology HIIT
Massachusetts Institute of Technology
mikko.heikkinen@aalto.fi

Arthur W. Berger
Massachusetts Institute of Technology
Akamai Technologies
awberger@mit.edu

Abstract

We compare Web traffic characteristics of mobile- versus fixed-access end-hosts, where herein the term "mobile" refers to access via cell towers, using for example the 3G/UMTS standard, and the term "fixed" includes Wi-Fi access.

It is well-known that connection speeds are in general slower over mobile-access networks, and also that often there is higher packet loss. We were curious whether this leads mobile-access users to have smaller connections.

We examined the distribution of the number of bytes-per-connection, and packet loss from a sampling of logs from servers of Akamai Technologies. We obtained 149 million connections, across 57 countries. The mean bytes-per-connection was typically larger for fixed-access: for two-thirds of the countries, it was at least one-third larger. Regarding distributions, we found that the difference between the bytes-per-connection for mobile- versus fixed-access, as well as the packet loss, was statistically significant for each of the countries; however the visual difference in plots is typically small. For some countries, mobile-access had the larger connections. As expected, mobile-access often had higher loss than fixed-access, but the reverse pertained for some countries. Typically packet loss increased during the busy period of the day, when mobile-access had a larger increase. Comparing our results from 2010 to those from 2009 of the same time period, we found that connections have become a bit smaller.

1. INTRODUCTION

We are interested in comparing Web traffic characteristics of mobile- versus fixed-access end-hosts, where herein the term "mobile" refers to access via cell towers, using for example the 3G/UMTS standard, and the term "fixed" includes Wi-Fi access. Whereas prior work has compared the applications used by mobile- and fixed-access devices [1], here we are interested in the network level, and comparing the size of connections (i.e., number of bytes per connection) for mobile versus fixed devices that are accessing the Web.

It is well-known that connection speeds are in general slower over mobile-access networks [2]. Also, as reported herein, often, though not always, there is higher packet loss on mobile-access networks, see Sec. 4.2. We are curious whether this leads users to have smaller connections, or would they persevere, so to speak, through the more adverse network conditions.

From a sampling of logs from July 2010 from servers of Akamai Technologies, we examine the distribution of the number of bytes-per-connection, and packet loss. We found that the difference in the distributions for mobile- versus for fixed-access for both the bytes-per-connection and for packet loss was statistically significant (based on the Kolmogorov-Smirnov test) for each of the countries. However, the difference is typically (but not always) small, when one views plots of the distributions. For some countries, the mobile-access has the larger connections, and in some countries mobile-access has lower packet loss.

In a scatter plot of per-country mean connection size versus mean packet loss, there is a statistically significant trend of smaller connection size with higher packet loss for both fixed- and-mobile access, though there is great variability. China and Russia stand out as having relatively high fixed-access packet loss but also relatively large connections.

We also found per-connection packet loss being often greater than the overall access-network packet loss, indicating smaller connections having higher loss. Often, but not always, mobile-access had higher loss than fixed-access. Typically, but again not in all cases, packet loss increased during the busy period of the day.

Comparing our results from 2010 to those from 2009 of the same time period, we found that connections have become a bit smaller.

The data for this study was collected prior to the deployment of 4G/LTE, and thus forms a baseline for comparison for when 4G/LTE is broadly in use.

The contributions of this study are:

1. The first reported comparison of mobile- versus

fixed-access connection-size and packet-loss

2. The comparison of the daily demand distribution for bytes and packet loss, for mobile- and fixed-access

3. Results spanning 57 countries

This paper is structured as follows: Sec. 2 reviews background and related work. Sec. 3 describes our data set. Sec. 4 contains our results. Sec. 5 summarizes and discusses our results.

2. BACKGROUND AND RELATED WORK

Mobile broadband has become a significant factor in the Internet communications market: Cisco [3] forecast that global mobile IP data traffic will double every year through 2014. Comscore [4] estimated that the number of US mobile phone subscribers with unlimited data plans increased 31% over a one-year period. Informa [5] estimated that there would be globally 450 million mobile broadband subscribers in 2010 and 670 million in 2011. Nielsen [6] estimated that "smartphones" have penetrated one quarter of the US population, and expected smartphones to overtake feature phones in the US market by the end of 2011. Pew Research Center [7] surveyed a 25% increase in the number of adult Americans using Internet with their mobile phones; in its other report [8] it noted saturation in home broadband adoption. Validas [9] found the number of its US panelists adopting mobile broadband increased 26%, and the average number of bytes transferred per panelist increased 51% over a period of a year.

As another illustrative example of the popularity of mobile broadband, when the Apple iPhone was introduced in South Korea, the sudden increase in the number of mobile-access connections markedly decreased the overall (mobile- plus fixed-access) average connection speed in the country, as a typical mobile-access data connection is slower than a fixed-access one [10].

Several analysts have claimed that mobile broadband is unprofitable and flat rate pricing is unsustainable in the long run, because traffic grows faster than revenue. Blennerud [11] argued that profitability of mobile broadband can be maintained, i.e. revenue and traffic remain coupled, by attracting "normal" subscribers who do not generate excessive amount of traffic, and by applying traffic management methods.

Collecting data directly from end-users, employing usage monitoring systems, measuring at network nodes, and measuring at network servers are the main methods for analyzing the usage of mobile services [12]. Each of the methods results in different coverage and granularity in data one is able to collect.

Akamai [2] quarterly reports connection speeds for both fixed- and mobile-access. Sandvine [1] reported traffic profiles for both fixed- and mobile-access. Complementing these two studies we are aware of that have done a side-by-side comparison of mobile- and fixed-access traffic, the present work also makes such a comparison, though in contrast to the prior work, we examine different attributes: the number of bytes per connection and packet loss. Using a dataset from the Akamai content distribution servers, our study is global in scope and presents results for over 50 different countries.

In addition to the two previous side-by-side fixed- and mobile-access traffic comparisons at the network level, at least two studies have compared fixed- and mobile-access traffic at the application level: Hossfeld et al. [13] compared the performance of a peer-to-peer file sharing application in both fixed- and mobile-access networks, whereas Svoboda [14] compared the session lengths of online gamers in fixed- and mobile-access networks. Furthermore, Kalden & Ekström [15] compared (non-side-by-side) the results of their analysis of GPRS mobile-access traffic to studies of fixed-access traffic by other researchers.

Several efforts have been made to gather and assess traffic datasets from fixed- and mobile-access networks for consumers. We introduce some: Benko et al. [16] and Ivanovich et al. [17] did extensive measurements in GPRS mobile-access networks. Plissonneau et al. [18] detected peer-to-peer traffic in the access network of a French DSL operator. Cho et al. [19, 20] analyzed the traffic generated by Japanese residential DSL and fiber users. Dischinger et al. [21] analyzed the traffic data they collected from major cable and DSL providers in Europe and North America. Siekkinen et al. [22] investigated the performance limitations of ADSL users. Afanasyev et al. [23] compared traffic from static, laptop, and handset users of a large urban Wi-Fi network. Heikkinen et al. [24] and Riikonen & Kivi [25] analyzed the majority of traffic in Finnish mobile-access networks. Bauer et al. [26] are collecting data from US broadband access networks. Maier et al. [27] analyzed traffic data from the access network of a large European DSL operator, in [28] they analyzed traffic generated by mobile devices connecting to the access network via Wi-Fi. Pietrzyk et al. [29] compared statistical classification of ADSL traffic to deep packet inspection. Romirer-Maierhofer et al. [30] studied round trip times in a 3G network. Ofcom [31] compared UK fixed-access providers by distributing to their customers routers modified to measure traffic.

The issue of fixed-mobile substitution is relevant to our study, albeit we cannot make any definitive claims on the topic based on our data. We would need to be able to identify individual users and the services they use to make such claims. What we can do is to use our measures as a pointer towards preliminary observations on the topic.

Multiple definitions for substitution and complementariness of commodities exist in the literature. We omit the formal algebraic definition. Most informal definitions are similar to Wetzstein's [32]:

> "Two commodities are substitutes if one commodity may, as a result of a price change, replace the other. Examples are two brands of cola or gasoline. Two commodities are complements if one commodity is consumed with another good. Examples of complements are pancakes and syrup, gasoline and automobiles, and a baseball bat and ball."

The question whether mobile handsets have substituted fixed telephones has been studied extensively. Vogelsang [33] surveyed fixed-mobile substitution studies. He noticed three main methods used to conduct the studies: 1) diffusion models, 2) subscription cross-elasticities in a single country or multiple countries, and 3) cross-elasticities for fixed-line call demand. He found that "the price data in cross-country studies are often not meaningful or are insufficient in that they only provide single prices out of a non-linear or bundled tariff schedule." He concluded that the relative price decline of mobile services compared to fixed services, together with network effects, explain substitution of fixed phones with mobile phones in wealthy countries.

Ward and Woroch [34] used a US household panel containing demographic and billing information to estimate cross-elasticities of demand for fixed and mobile services, and found moderate substitution between the two.

Bohlin et al. [35] investigated the inter-generation effects in the diffusion process of mobile technology generations. They found evidence that increases in urbanization, GDP per capita, and penetration of the Internet positively influenced the adoption process of new technology generations. They hypothesized that "third-generation mobile will substitute for fixed broadband at a later time, if it crosses a certain performance/price level threshold." They observed that behavior in Finland, where the number of fixed broadband connections is declining and the number of mobile broadband connections is increasing [36].

The substitutability of fixed broadband with mobile broadband has been studied qualitatively. Lehr and Chapin [37] noted persistent differences between wired and wireless networks in terms of capacity, topology, reliability, and mobility. They foresaw no convergence to a common architecture within the wireless network domain.

Lehr [38] expected both fixed and mobile broadband to expand the range of services they offer, but the peak and sustainable average data rate of mobile broadband services to continue to lag behind those of fixed broadband services. He noted the growth of Machine-to-Machine (M2M) communications using mobile broadband connections to the Internet, such as credit card payments with mobile terminals, and remote controlling of facilities. Power and form factor constraints limit the usability of mobile devices using mobile broadband, but increasing value of mobility contributes to the growth of them. He concluded that mobile broadband complements fixed broadband access, but mobile broadband facilitates the creation of new Internet services and enhances the scale and scope economies in provisioning of Internet services.

We are not aware of any quantitative studies on fixed-mobile broadband substitution.

3. DATA SET

We used data from log files of Akamai Technologies. Although the data had been logged for other purposes, it contained information that enabled a comparison of mobile- and fixed-access on a per country basis. Data consisted of a global sub-sampling of TCP connections between clients and Akamai servers. The measurements included the number of bytes per connection and the number of duplicate packets sent (which we use as an estimate of packet loss), and the Unix time. For the present analysis we used logs from the week of July 25 through 31, 2010. We also did a comparison on data from the same time period in 2009.

Autonomous Systems (ASs) of mobile Internet service providers had been identified, as part of the work for Akamai's Quarterly State of Internet Report [2]. Some of such ASs were known a priori to the investigators, some were identified by their name, and some by contacting them. Additional mobile ASs were found by using the discriminator of the ASs having a relatively low average connection speed. From the pool of such ASs, further inquiries were made. Results on the average connection speed, grouped by access type and country, are presented in [2] and not repeated here. Given countries in which mobile ASs had been identified, a sampling of fixed-access ASs were also selected to provide a comparison. ASs that contained both mobile- and fixed-access were excluded.

TCP connections in the log files were selected where the client IP address was in one of the selected mobile or fixed ASs. We used the Akamai geo-location service EdgeScape [39] to identify the country in which the client IP was located. We obtained 149 million connections, across 57 countries, where we excluded countries for which the dataset contained less than 1,000 mobile or fixed connections. The median number of mobile-access connections per-country was 48,000, and for fixed-access was 650,000.

As we were interested in comparing the mobile and fixed daily demand, we again used EdgeScape to obtain the latitude and longitude of the client of IP, from which we obtained the local time zone relative to GMT. This enabled daily demand plots where hour "0" corresponds to midnight for the given client.

4. RESULTS

4.1 Number of Bytes per Connection

4.1.1 Summary Statistics

Table 1 shows the median, 3rd quartile, and mean of the number of KiloBytes-per-connection, partitioned by 57 countries and by fixed- versus mobile-access. The rows are arranged in increasing order of the mean number of KBytes-per-connection for fixed-access. Note that the mean is larger than the 3rd quartile as the distribution of KBytes-per-connection tends to have a small percentage of large connections.

There is clear variation across countries. The median for fixed-access and for mobile-access varies from 1 to 9 KBbytes-per-connection; the 3rd quartile varies from 6 to 25 for fixed-access, and 7 to 27 for mobile-access; and the mean varies from 38 to 152 for fixed-access, and 19 to 178 for mobile-access.

There is also variation between fixed-access versus mobile-access. For 65% of the countries, the mean bytes-per-connection was at least one-third larger for fixed-access. For most of the countries (∼75% based on the 3rd quartile), the fixed-access connections have more KBytes than mobile-access; and thus there is a minority where the reverse pertains. As an example, in the USA, the 3rd quartile of KBytes-per-connection for fixed-access is larger than mobile-access, being respectively 16 and 12; while in the South Korea the order is reversed, having values 6 and 27, respectively. In the USA, mean is again greater for fixed-access, 152 versus 44 KBytes-per-connection, while in France the corresponding values are 102 and 178.

4.1.2 Distributions

We also examined the cumulative distribution function (CDF) of KBytes-per-connection for fixed-access and mobile-access. Using the non-parametric Kolmogorov-Smirnov test, we found that the null hypothesis that the two sample distributions (fixed- and mobile-access) come from the same population distribution is rejected with high confidence, for all of the countries, typically with p-values much less than 0.01.

Although the two sample distributions are statistically distinct, for many of the countries the visual difference in the plot is rather slight. Though, for a minority of countries, the difference is dramatic. The following Figures 1-4 are a sampling of four countries.

For each country, we show two plots: a CDF with a linear scale on the axes, and a complementary distribution function with logarithmic scales. The former is use-

Table 1: KiloBytes-per-Connection Statistics

	Median		3rd Quartile		Mean	
Country	Fixed	Mobile	Fixed	Mobile	Fixed	Mobile
Indonesia	9	9	21	19	38	29
Uruguay	7	7	17	16	38	53
Nicaragua	6	7	20	21	41	46
Argentina	5	7	13	16	42	32
Peru	8	8	19	19	45	27
Egypt	7	7	19	16	46	45
Venezuela	8	7	18	17	47	39
Sri Lanka	6	6	18	16	47	45
Bolivia	9	7	22	17	49	43
El Salvador	5	7	18	20	50	44
Pakistan	6	5	19	17	52	59
Croatia	8	5	18	9	55	19
Malaysia	8	7	20	18	55	43
Israel	5	6	16	17	57	49
Greece	7	6	19	15	59	41
Paraguay	6	6	19	17	59	44
Colombia	8	6	19	14	59	52
Slovenia	8	5	20	9	60	38
Italy	8	8	18	17	60	44
Thailand	6	6	18	14	62	31
Slovakia	7	7	18	17	62	71
Chile	7	7	19	17	64	43
Czech Republic	7	7	18	17	67	43
Australia	4	4	13	11	68	37
Morocco	8	7	20	18	70	50
Hungary	7	6	19	16	71	47
South Africa	4	4	12	12	72	123
Kuwait	5	7	18	20	72	153
Puerto Rico	7	5	18	17	74	72
Lithuania	8	7	19	18	77	64
Brazil	4	5	19	20	78	58
Mexico	6	7	18	21	79	36
Romania	7	9	25	24	80	40
Spain	4	5	16	16	80	49
Singapore	4	6	16	15	82	46
New Zealand	5	5	16	16	83	40
Hong Kong	5	6	18	14	87	65
Portugal	6	6	20	19	88	53
Poland	6	5	17	16	91	56
Taiwan	3	4	13	12	91	77
Ireland	6	6	20	17	92	101
Belgium	6	6	19	15	95	93
Ukraine	4	3	19	14	96	70
France	7	7	21	18	102	178
Austria	6	6	18	15	104	54
United Kingdom	6	6	18	16	104	69
Estonia	6	6	18	17	107	56
Norway	6	5	16	13	111	38
Canada	6	5	18	11	113	38
Germany	6	5	19	12	122	71
Switzerland	5	5	17	11	123	54
Russia	4	3	21	16	125	92
Moldova	6	5	18	19	129	54
China	2	1	19	7	130	64
Netherlands	3	4	14	11	135	79
South Korea	1	8	6	27	135	131
USA	4	5	16	12	152	44

ful for seeing the bulk 90% of the connections, and the latter for the minority of large-size connections, which impact the means reported in Table 1.

For the USA and France, the distributions given fixed-access versus mobile-access are rather similar, at least for the bulk of the connections. The medians are essentially the same. By the 3rd quartile (75% quantile) the difference is more noticeable. An interesting contrast between the USA and France is that in the former the distribution given fixed-access connections has a heavier tail, whereas in the latter the mobile-access connections do, up to 10 MBytes. For example, in the USA, 0.7% of the fixed-access connections are at least 1 MBytes, which is greater than the 0.4% of mobile-access connections. In France, again 0.7% of the fixed-access connections are at least 1 MByte, whereas 2.9% of the mobile-access connections are. For connections of 100 MBytes or more, fixed-access dominates (though of course the percentage of connections is quite small).

In contrast to the USA and France, China and South Korea are two of the minority of countries in Table 1 where the difference in distributions is visually quite evident even for the non-tail portion. Also, as a contrast between South Korea and China, in the former the mobile-access connections are larger (in the sense of the CDF), and in the latter the reverse pertains, even up to connections of 10 MBytes. For example, in South Korea, 22% of the mobile-access connections are greater than 40 KBytes, while fewer (8%) of fixed-access are. In China, 8% of the mobile-access connections are greater than 40 KBytes, whereas more (15%) of fixed-access are.

4.2 Packet Loss

Packet loss on the connection is one of the performance measures of the quality of service provided by the network operator. We were curious how packet loss compared on fixed-access versus mobile-access networks.

Note that this comparison of mobile- and fixed-access packet loss is for clients accessing web content from Akamai servers. The Akamai server is typically in the same AS as the client, in which case the loss, when it occurs, is within client's AS. And if the server is not in the same AS, then in all likelihood it is in a nearby upstream AS. Thus, in general, the loss percentages reported herein will be lower as compared with when the client accesses web content directly from an origin site, as then the path is longer, with greater opportunity for experiencing congestion.

For each connection, we compute the percent of packets sent from the server to the client that are duplicate packets, which we use as an estimate of lost packets.

Table 2 reports the 3rd quartile and mean per-connection percent packet loss, partitioned by country and by fixed-access versus mobile-access connections. The median per-connection packet loss was 0.0% in all cases, except for Indonesia where on mobile-access it was 2.7%. Note that the mean per-connection packet loss gives equal weight to large and small connections. Thus, Table 2 also reports the overall, or access-network, packet loss, defined as the total number of duplicate packets, summed across the set of connections, divided by the total number of packets sent. The rows are ordered in increasing value of fixed-access minus mobile-access mean per-connection packet loss. Countries where this difference is positive, the last 16 rows of the table, had higher packet loss on the fixed-access connections.

Note that the mean per-connection packet loss is more often greater than the overall access-network packet loss, which indicates that smaller connections tend to have higher loss.

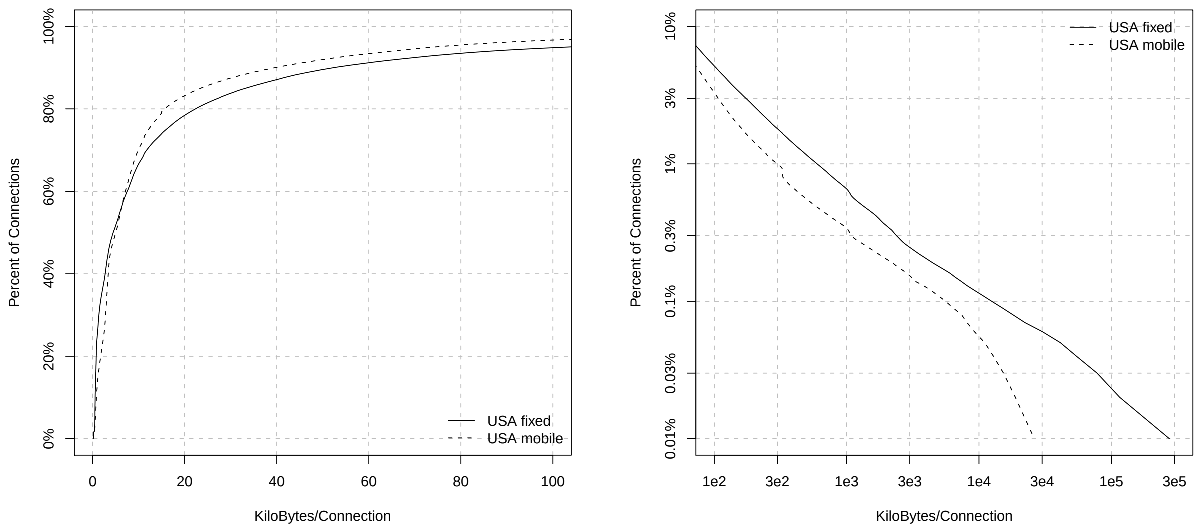
4.3 Dependence of Connection Size on Packet Loss

We wanted to examine the heuristic notion that higher packet loss leads to smaller connection sizes. From Table 2 and Table 1, we have the average network packet loss and mean connection size, respectively, per country. Figure 5 displays a scatter plot of these values and a fitted linear regression line. Since the few countries with the upper-end packet loss can be considered atypical, Figure 6 shows the subset of countries whose mean packet loss is no more than 3%. (The countries with the highest packet loss are Romania, Indonesia, and Bolivia.) Both plots are truly scattered; though, by eye one can sense a downward trend, i.e. smaller mean connection size with higher packet loss, for both fixed- and mobile-access. The regression lines are included not because a linear model is a good fit, but to indicate the downward trend. The statistical test on the regression lines having zero slope is rejected with high confidence, 99.8% for mobile-access in Figure 6, and the others with higher confidence.

Although the data supports the notion that higher packet loss leads to smaller connection size, one's viewpoint of the strength of the trend (-20 KBytes-per-percentage-packet-loss for mobile in Figure 6) is obviously colored by one's prior expectation. Regardless, the plots also clearly show the great variability. Of particular note are the two countries whose fixed-access has high packet loss of at least 4% and relatively high mean connection size of at least 125 KBytes: China and Russia (see Tables 1 and 2).

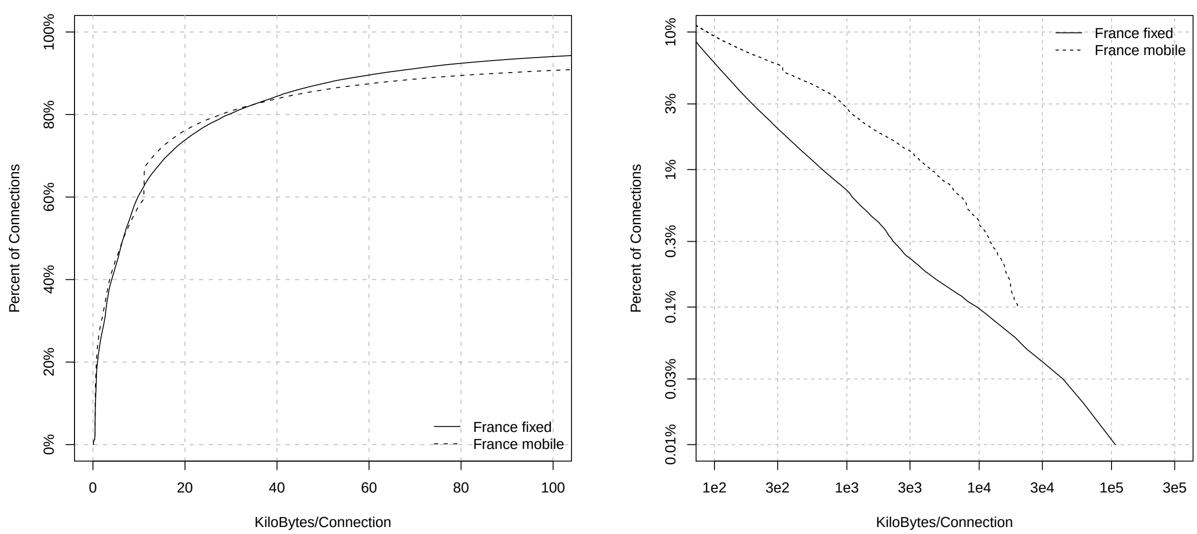
4.4 Daily Traffic Pattern

We compared the mobile- and fixed-access daily demand. Figure 7 shows the fraction of Bytes sent in each of the 24 hours of a day, on fixed-access and on mobile-access networks across all countries. Figures for



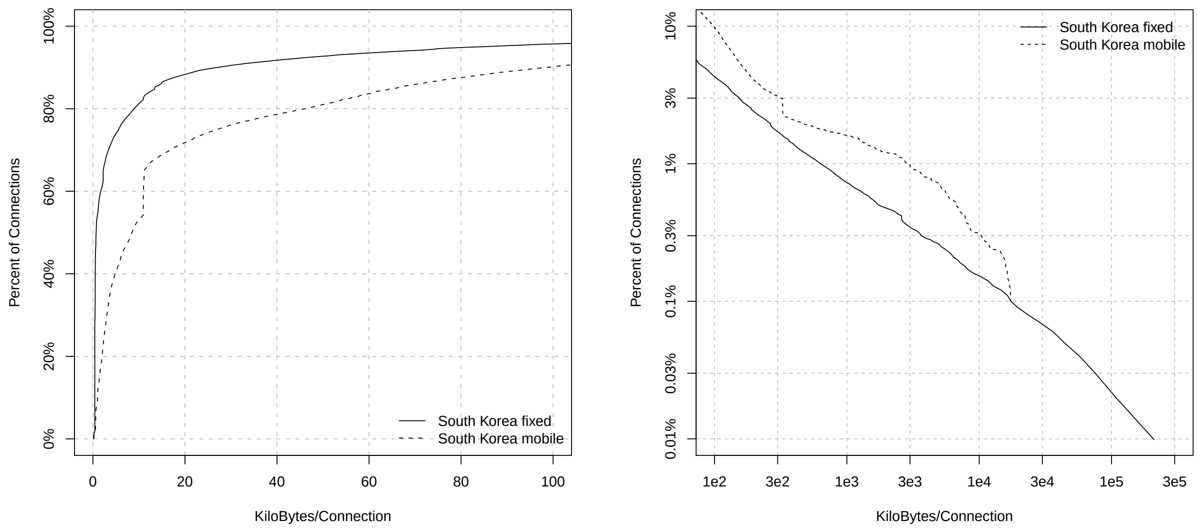
(a) Distribution for size of connections (b) Complementary distribution for size of connections

Figure 1: USA



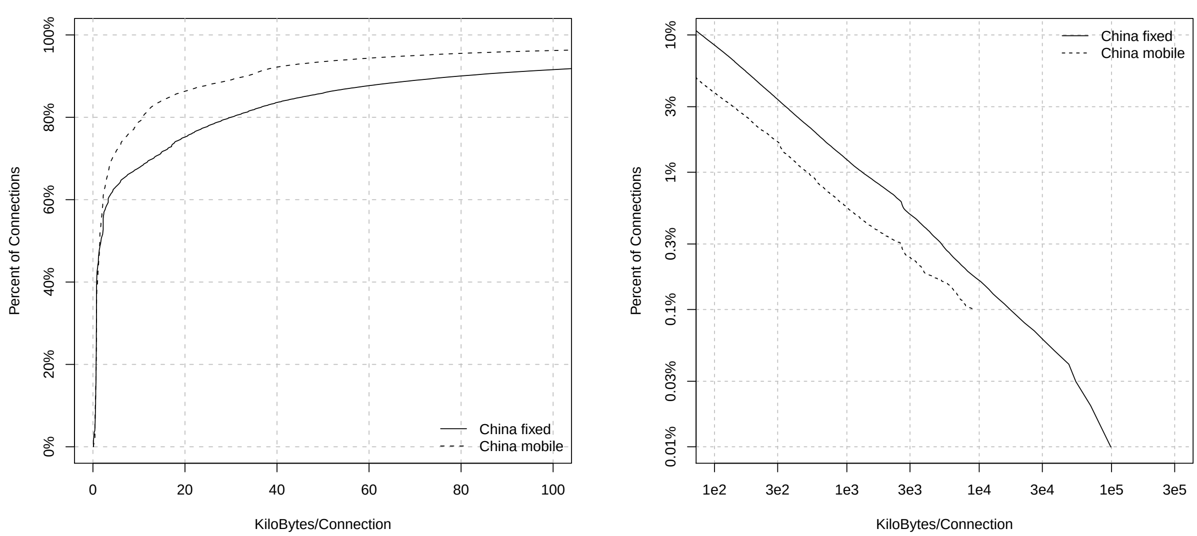
(a) Distribution for size of connections (b) Complementary distribution for size of connections

Figure 2: France



(a) Distribution for size of connections (b) Complementary distribution for size of connections

Figure 3: South Korea



(a) Distribution for size of connections (b) Complementary distribution for size of connections

Figure 4: China

Table 2: Percent Packet Loss Statistics

Country	Per-Connection Packet Loss 3rd Quartile Fixed	Per-Connection Packet Loss 3rd Quartile Mobile	Per-Connection Packet Loss Mean Fixed	Per-Connection Packet Loss Mean Mobile	Access-Network Mean Packet Loss Fixed	Access-Network Mean Packet Loss Mobile
Romania	0.0	20.0	1.4	10.7	0.8	10.1
Argentina	0.0	12.5	1.8	8.0	2.1	6.9
Peru	0.0	9.1	2.0	5.8	2.0	5.1
Czech Republic	0.0	3.7	1.3	4.5	1.0	3.2
Egypt	8.0	15.4	5.7	8.8	5.1	6.4
Chile	0.0	6.7	2.0	5.1	1.4	2.7
Moldova	0.0	0.0	1.1	3.7	0.4	4.7
Colombia	0.0	3.8	2.3	4.8	1.9	2.2
Poland	0.0	2.9	1.8	4.2	1.1	1.9
Morocco	0.0	6.7	3.2	5.4	2.1	3.0
Portugal	0.0	2.1	1.6	3.7	0.8	3.4
Estonia	0.0	2.6	1.6	3.7	1.0	2.1
Ukraine	0.0	0.0	1.6	3.6	1.2	2.7
Hungary	0.0	1.3	1.8	3.7	1.0	2.0
Brazil	0.0	2.8	2.3	4.1	1.6	2.4
Croatia	0.0	0.0	1.4	3.1	1.0	3.8
Norway	0.0	0.0	1.5	3.2	0.5	3.1
Belgium	0.0	0.0	1.4	3.1	0.7	0.8
Spain	0.0	0.0	1.6	3.3	0.9	1.8
Lithuania	0.0	0.0	1.6	3.3	1.1	2.0
Venezuela	1.0	3.8	3.6	5.0	2.9	3.7
Greece	0.0	0.0	1.5	2.9	1.0	2.1
France	0.0	0.0	1.5	2.9	0.9	0.6
Puerto Rico	0.0	1.7	3.0	4.3	1.6	4.2
Italy	0.0	1.3	2.6	3.9	1.5	2.0
Israel	0.0	0.0	2.1	3.3	1.6	6.8
New Zealand	0.0	0.0	2.6	3.6	1.5	2.9
Ireland	0.0	0.0	2.5	3.3	0.9	1.0
Slovakia	0.0	0.0	2.1	2.9	1.6	1.3
Russia	0.0	2.0	4.0	4.7	5.2	2.9
South Korea	0.0	0.0	0.7	1.4	0.4	0.6
Austria	0.0	0.0	1.4	2.0	0.6	0.9
Canada	0.0	0.0	1.3	1.9	0.6	1.1
Taiwan	0.0	0.0	2.1	2.6	1.5	1.0
Hong Kong	0.0	0.0	1.9	2.4	1.1	1.1
Pakistan	3.0	3.4	4.8	5.2	4.2	3.5
Germany	0.0	0.0	1.2	1.6	0.5	4.2
Uruguay	0.0	0.0	2.9	3.3	2.4	2.3
Australia	0.0	0.0	2.5	2.9	1.3	1.6
Mexico	0.0	0.0	2.6	2.8	1.3	2.4
USA	0.0	0.0	1.9	1.9	0.9	1.4
Sri Lanka	2.1	0.0	3.5	3.1	3.2	3.3
Switzerland	0.0	0.0	1.5	1.0	0.6	0.6
Singapore	0.0	0.0	3.8	3.2	4.8	2.6
Netherlands	0.0	0.0	1.2	0.6	0.5	0.2
Slovenia	0.0	0.0	1.7	0.8	1.1	0.8
Indonesia	17.2	16.7	10.0	9.1	11.4	7.2
United Kingdom	0.0	0.0	2.8	1.7	0.9	1.0
Paraguay	5.7	2.6	5.4	4.0	5.0	3.6
Nicaragua	4.7	0.0	5.0	3.5	9.4	2.6
El Salvador	5.7	0.0	5.1	3.1	5.5	2.6
Kuwait	0.0	0.0	3.0	0.7	2.3	0.2
South Africa	0.0	0.0	3.4	1.0	3.5	0.6
Malaysia	9.1	0.0	6.0	3.5	6.5	4.2
Thailand	2.0	0.0	3.9	0.3	3.3	0.5
China	6.2	0.0	7.4	3.8	4.0	3.5
Bolivia	25.0	7.7	13.3	5.1	12.8	4.4

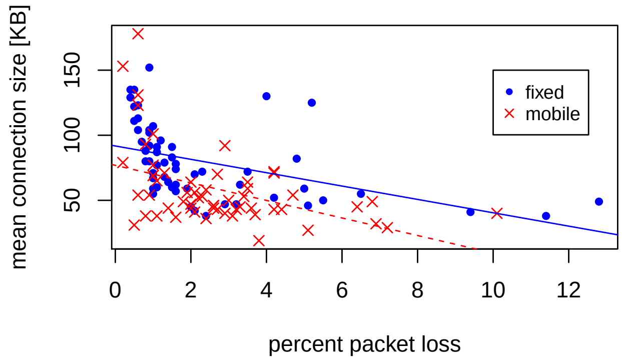


Figure 5: Mean connection size versus packet loss, per country

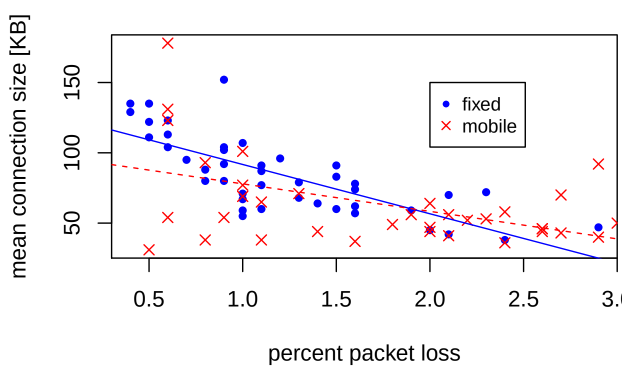


Figure 6: Mean connection size versus packet loss, per country, for the subset of countries whose mean packet loss is no more than 3%

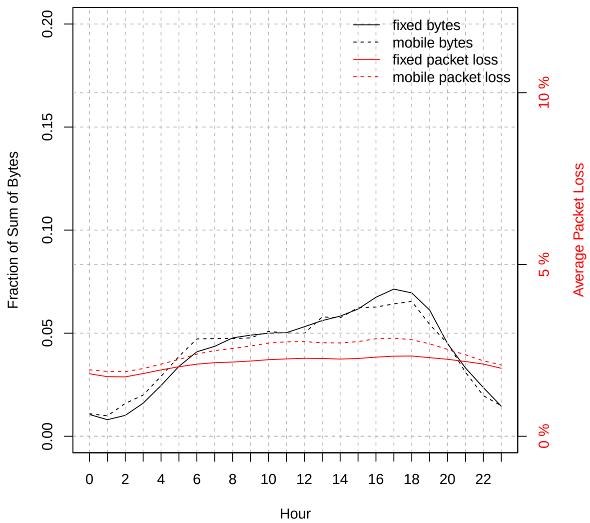


Figure 7: Daily distribution for size of connections and packet loss, all countries

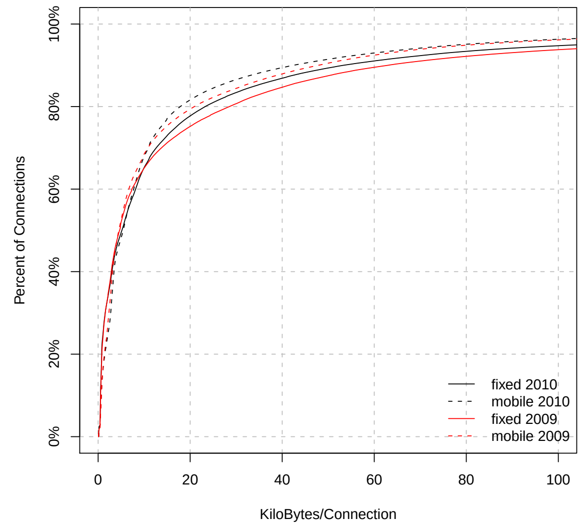


Figure 8: Distribution for size of connections, all countries, 2009 versus 2010

some individual countries are in Appendix A. We determined the latitude and longitude of the client address, from which we obtained the local time zone relative to GMT, see Sec. 3, and thus we could bin the traffic such that the hour "0" corresponds to midnight for the given client. Also shown on the plots is the mean per-connection packet loss in the respective hour.

In Figure 7 the daily demand pattern for fixed- and mobile-access are very much alike—fixed has a slightly higher afternoon peak, and mobile-access has a bit higher proportion the post-midnight early-morning hours. Packet loss on mobile-access is higher than on fixed-access and has a larger increase during the heavy traffic period of the day.

As one would expect, the packet loss for both mobile- and fixed-access increases during the busy period of the day. If one considered the regression of the per-hour packet loss on the per-hour fraction of Bytes sent, then the hypothesis of zero slope would be rejected with extremely high confidence (p-value less than 1e-6) for both mobile- and fixed-access. The correlation of packet loss with the fraction of Bytes sent is 0.94 for mobile-access and 0.95 for fixed-access.

4.5 Comparison with July 2009

We were interested in whether the KBytes-per-connection has changed over time, particularly for mobile-access. We compared the July 2010 data with July 2009. For the July 2009 data, we again computed the cumulative distribution function of KBytes-per-connection, for given country and given access type. Then for each country for which we had sufficient data from July 2009, which was 53 out of the 57 countries, and for each access type, we applied the Kolmogorov-Smirnov test to the sample CDFs from 2009 and from 2010. For 47 of the 53 countries, the sample CDFs are from distinct distributions with 99% confidence or greater, for both fixed and mobile access.

Rather than showing the analogue of Table 1, we show the difference. For the 47 countries with statistically distinct distributions, Table 3 shows the 3rd quartile, and mean, from the July 2010 CDF minus that from July 2009, for given access type, and where the rows are sorted by the last column. Negative values in the table indicate that the 3rd quartile, or the mean, from 2010 is smaller than that from 2009, which would suggest smaller connections in 2010.

Figure 8 shows the CDF of bytes-per-connection from all countries, Figure 9 from the USA. To the extent that the CDF for July 2010 data lies above that for July 2009 data, for given access type, indicates that connections have become a bit smaller.

5. CONCLUSIONS

We examined the distribution of the number of bytes-per-connection, and packet loss from a sampling of logs from servers of Akamai Technologies.

Regarding to the original question of whether the more adverse conditions on mobile-access networks leads to shorter connections, the rough, first-order answer is "yes"; though, a fuller answer is much more nuanced. One caution to keep in mind is that the statistical anal-

Table 3: Difference in KiloBytes-per-Connection July 2010 versus July 2009

	KiloBytes-per-Connection			
	3rd Quartile from 2010 minus 3rd Quartile from 2009		Mean from 2010 minus Mean from 2009	
Country	Fixed	Mobile	Fixed	Mobile
Kuwait	-3	-92	-26	-691
Puerto Rico	-6	0	-2	-217
Moldova	-2	-2	58	-130
Morocco	-2	-7	-47	-96
Paraguay	-5	-2	-1	-66
China	-8	-15	-3	-64
Pakistan	0	-2	-25	-61
Sri Lanka	-4	-4	-4	-55
Mexico	-3	-4	-6	-50
Poland	-5	-6	-51	-50
Brazil	-4	-6	-38	-49
Russia	-4	-6	-82	-49
Argentina	1	-4	-15	-38
Estonia	-1	0	-21	-37
Taiwan	-2	-7	-10	-30
New Zealand	-4	-4	7	-24
Uruguay	-5	-6	-29	-23
Czech Republic	-3	-3	-45	-19
Norway	-4	-4	20	-16
Croatia	-7	-13	-13	-14
Venezuela	-4	-1	-44	-14
Hong Kong	1	-4	-13	-10
Hungary	-1	-5	-76	-10
Israel	2	-2	-9	-10
Australia	-3	-5	9	-9
Indonesia	0	-3	4	-9
Italy	-4	-6	-11	-7
Greece	-5	-5	-18	-4
Canada	-5	-2	0	-3
Switzerland	-3	-10	-26	-1
USA	-3	0	48	5
Egypt	-1	5	-25	6
Chile	0	-1	-5	8
Netherlands	-8	-6	-30	9
Thailand	0	4	-10	9
Lithuania	-3	-3	-72	11
Bolivia	1	-4	-84	12
Slovenia	-3	-11	-5	12
Austria	-2	-1	3	14
Slovakia	-2	-3	-21	17
Germany	-5	-4	-18	25
United Kingdom	-2	-1	17	26
Ukraine	1	3	-79	38
Ireland	-4	-1	16	48
Belgium	-3	-6	10	55
South Africa	-1	4	-17	62
France	0	-6	-13	82

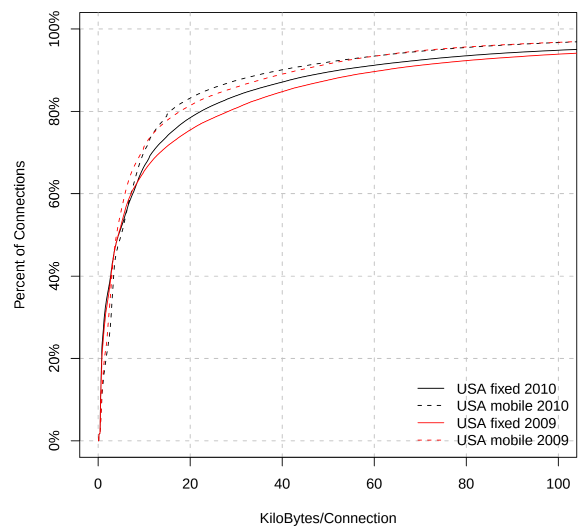


Figure 9: Distribution for size of connections, USA, 2009 versus 2010

ysis of the present study does not prove a causal relationship. Tables 1 and 2 do show that on a per-country basis, packet loss is higher and the mean connection size is smaller on mobile-access for most countries; but there are noted exceptions. From the viewpoint of distributions, we found that the difference between the bytes-per-connection for mobile-access versus fixed-access, as well as the packet-loss distributions, was statistically significant, for all countries we analysed. However, when plotted, the visual difference is typically small. Also, for some countries, the mobile-access had the larger connections.

In a scatter plot of per-country mean connection size versus mean packet loss, there is a statistically significant trend of smaller connections having higher packet loss for both mobile- and fixed-access, though there is great variability. Aggregating across counties, we found that the daily demand variation is about the same for mobile- and fixed-access, and for both, the packet loss does increase during the busy period of the day, though the increase of mobile-access is greater, suggesting greater sensitivity to the increased demand, that is a greater likelihood of constrained capacity. Though, as reported in Appendix A, some countries have little to no daily variation in packet loss. We also found per-connection packet loss for both fixed- and mobile-access is often greater than the overall access-network packet loss, indicating smaller connections having higher loss.

Self-selection explains partially why mobile-access connections are typically smaller than fixed-access connections. Users may prefer not to stream long video clips, engage in large downloads, or do other high volume transactions over mobile-access connections. Prevalence of high-speed mobile-access connections could lead to more traffic over mobile-access. In other words, a complementary effect would occur, where higher speed of mobile-access would enable more large-volume transactions.

Comparing our results from 2010 to those from 2009 of the same time period, we found that connections have become a bit smaller over time. The high packet loss evident in some access networks may lead to smaller connections as users decide to discontinue use as they perceive their experience unsatisfactorily. Also, as newer web browser versions open more connections in hope of sustaining higher download speeds [40], the size of connections tends to decrease over time.

Acknowledgments

During this work, MH was a Visiting Student at MIT CSAIL. MH's work was supported by FICNIA and TEKES. We would like to thank Steven Bauer, David Clark, Rubén García, Tuomo Komulainen, William Lehr, Antti Riikonen, Jesse Sowell, and Stephen Woodrow for their assistance and comments. Any opinions expressed, and any errors are solely the responsibility of the authors.

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APPENDIX

A. DAILY TRAFFIC PATTERNS

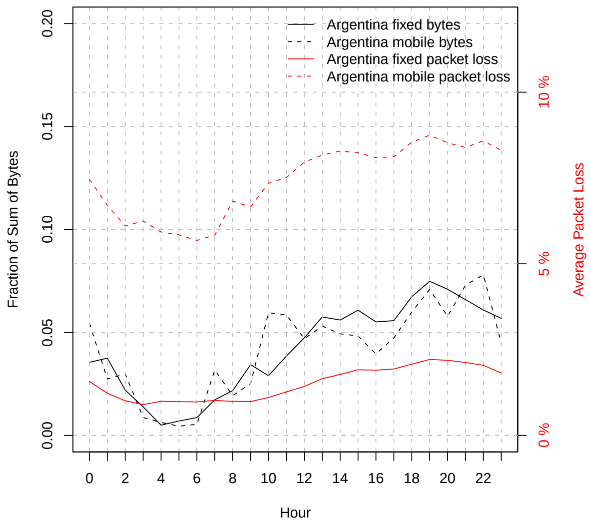


Figure 10: Daily distribution for size of connections and packet loss, Argentina

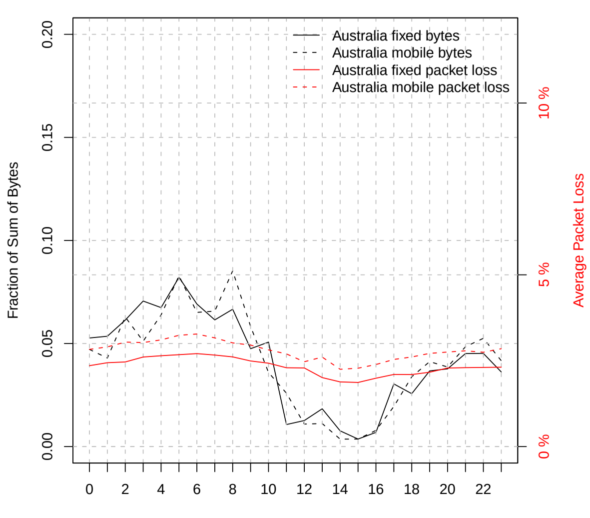


Figure 11: Daily distribution for size of connections and packet loss, Australia

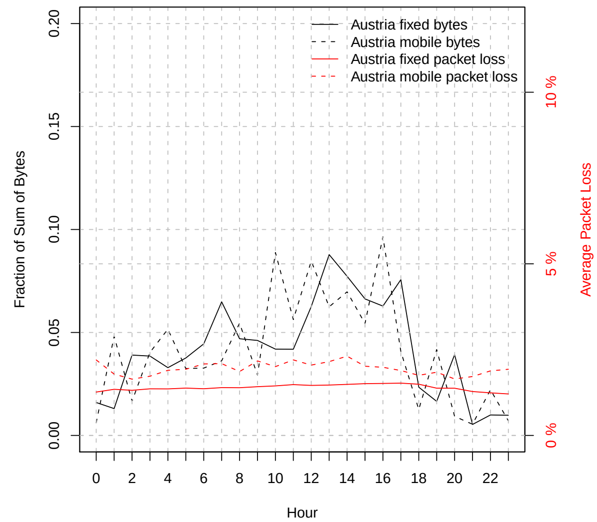


Figure 12: Daily distribution for size of connections and packet loss, Austria

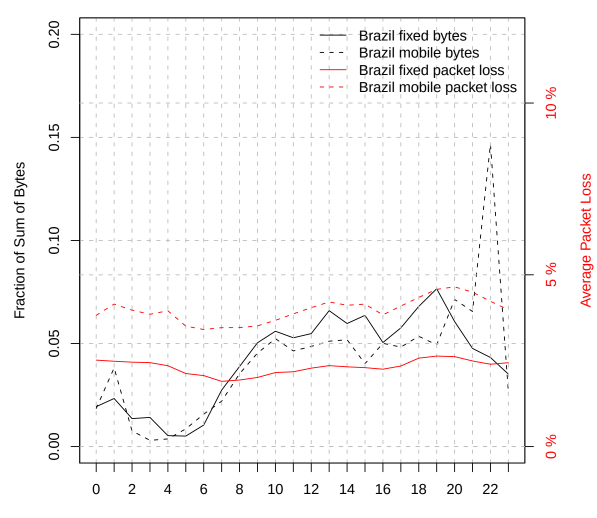


Figure 13: Daily distribution for size of connections and packet loss, Brazil

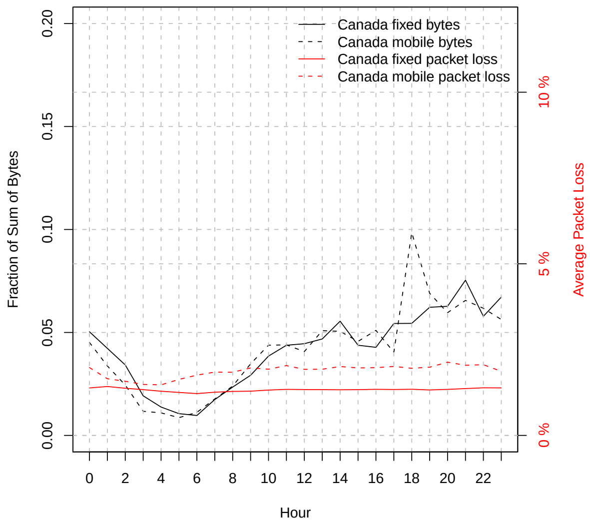


Figure 14: Daily distribution for size of connections and packet loss, Canada

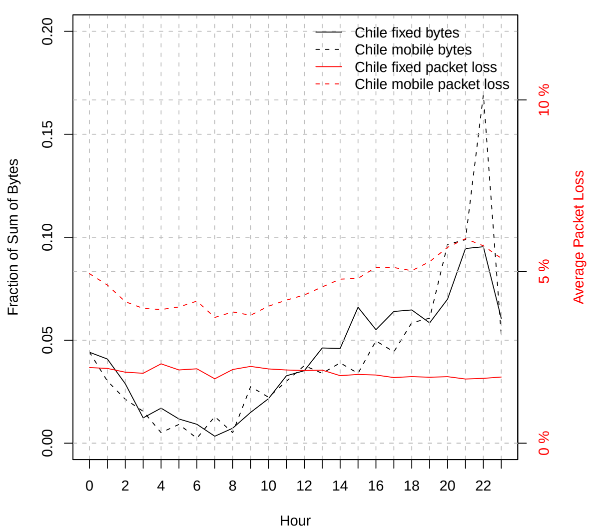


Figure 15: Daily distribution for size of connections and packet loss, Chile

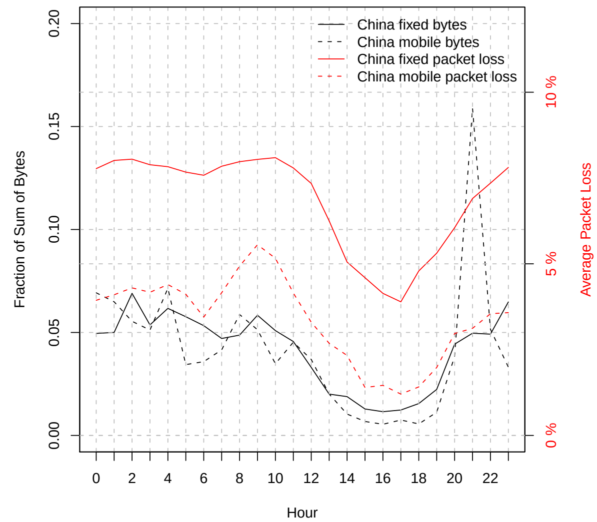


Figure 16: Daily distribution for size of connections and packet loss, China

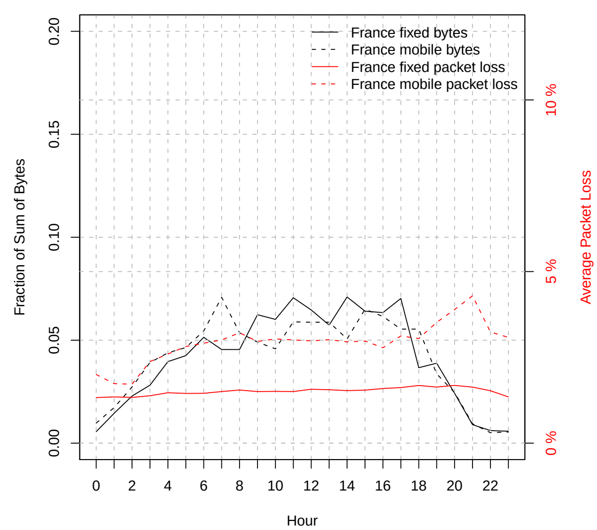


Figure 17: Daily distribution for size of connections and packet loss, France

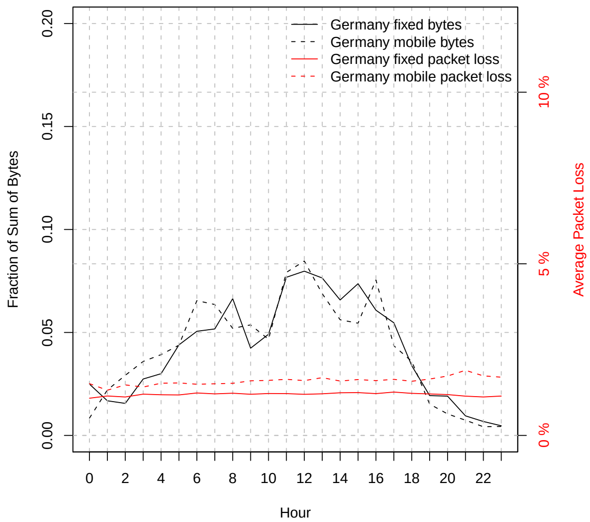


Figure 18: Daily distribution for size of connections and packet loss, Germany

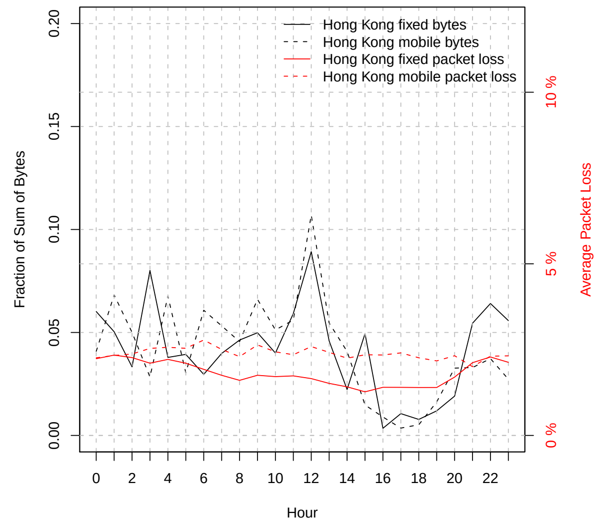


Figure 20: Daily distribution for size of connections and packet loss, Hong Kong

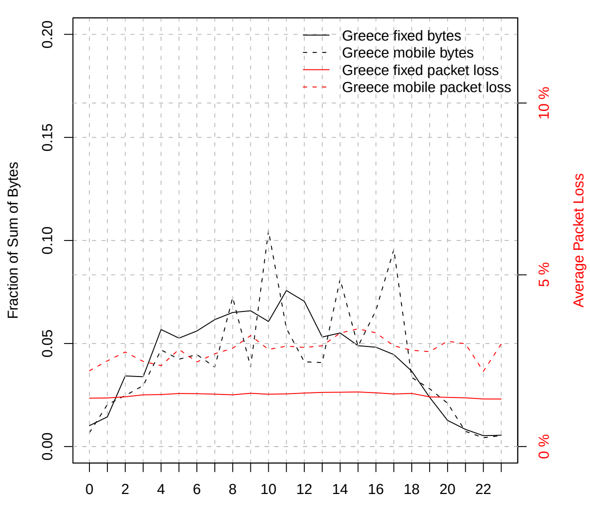


Figure 19: Daily distribution for size of connections and packet loss, Greece

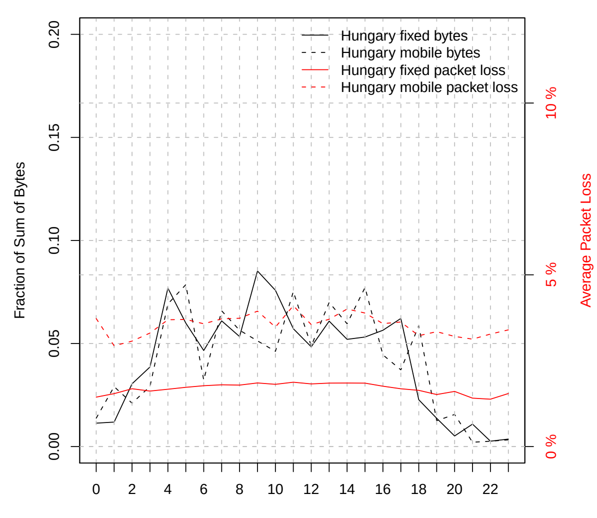
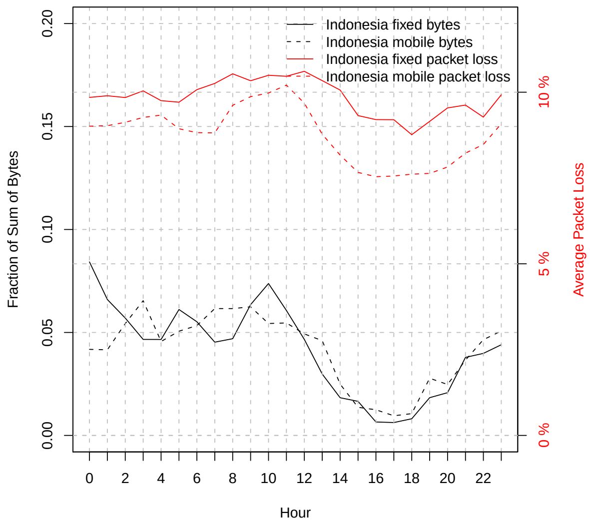


Figure 21: Daily distribution for size of connections and packet loss, Hungary



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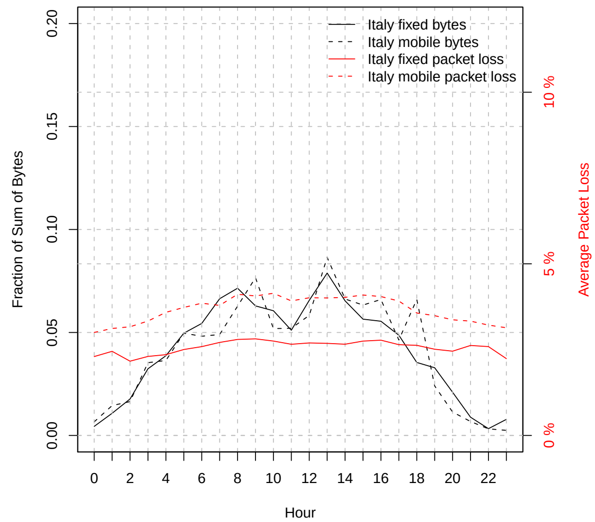

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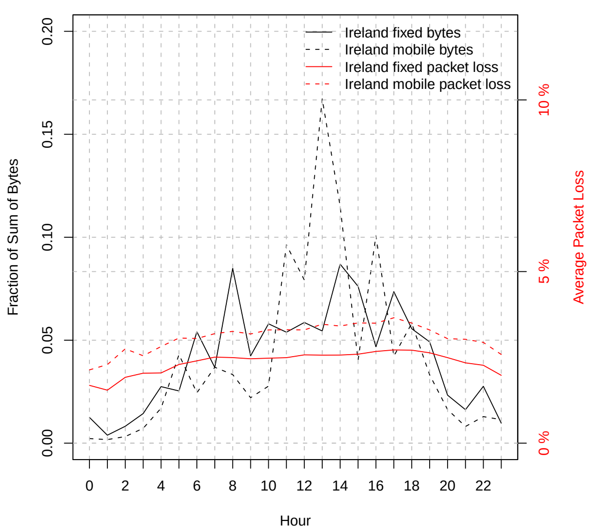

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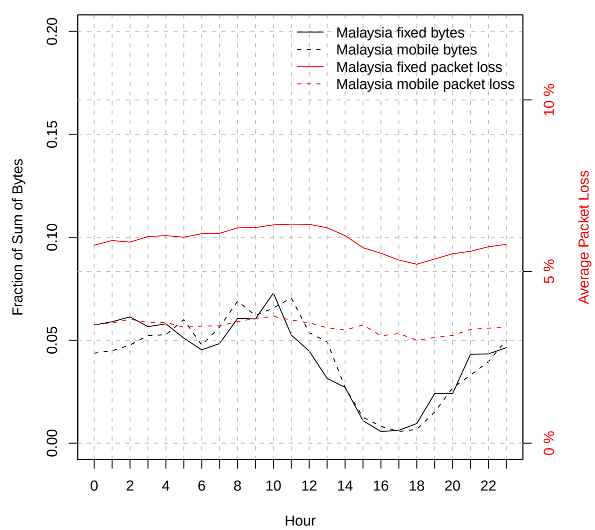

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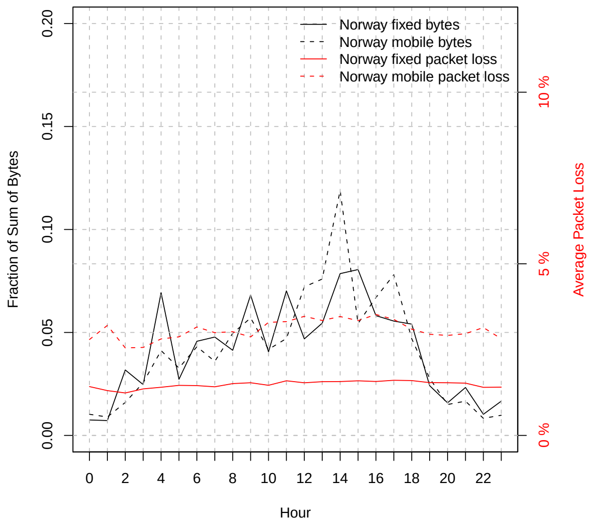

Figure 26: Daily distribution for size of connections and packet loss, Norway

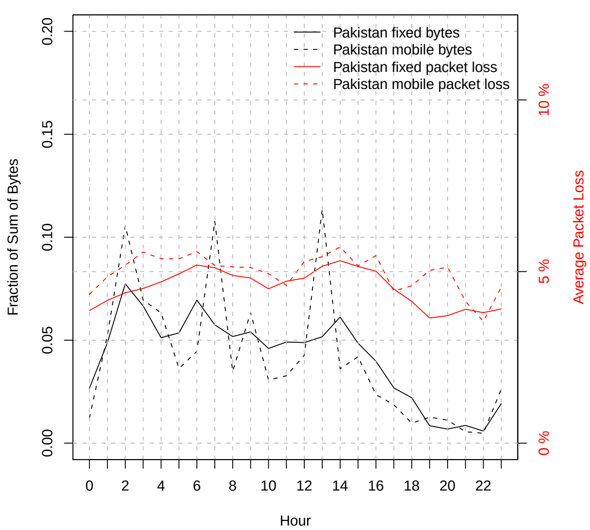

Figure 27: Daily distribution for size of connections and packet loss, Pakistan

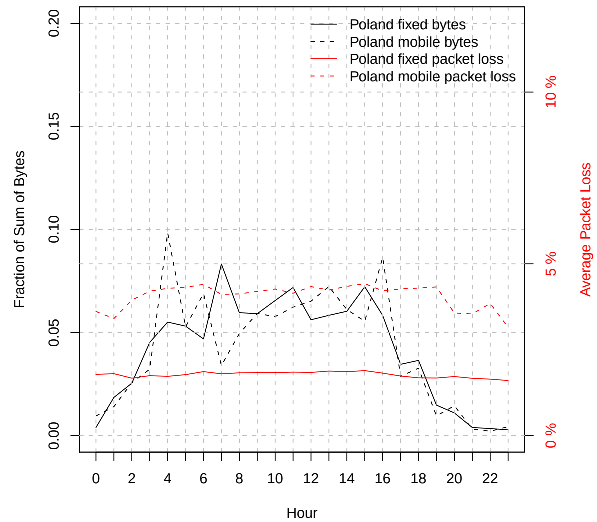

Figure 28: Daily distribution for size of connections and packet loss, Poland

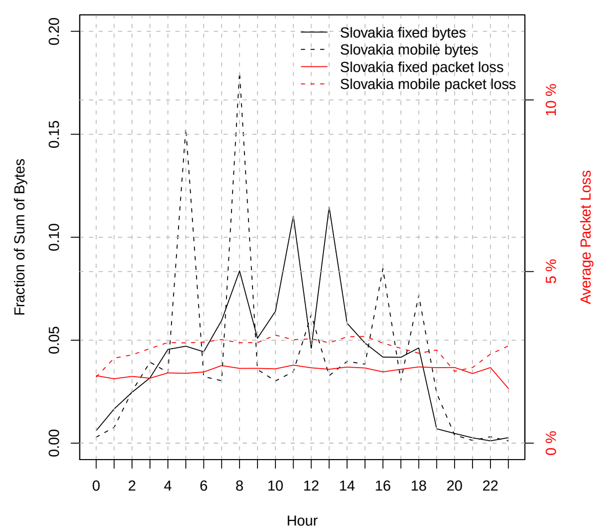

Figure 29: Daily distribution for size of connections and packet loss, Slovakia

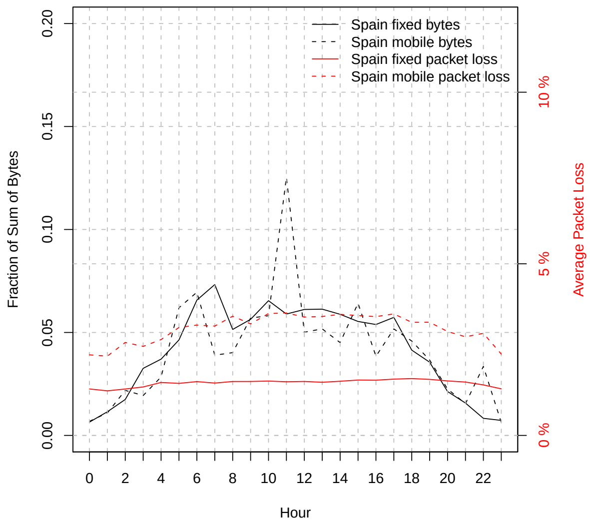

Figure 30: Daily distribution for size of connections and packet loss, Spain

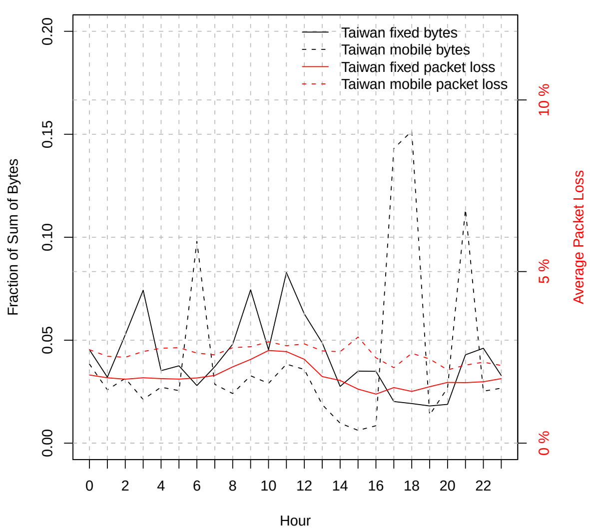

Figure 31: Daily distribution for size of connections and packet loss, Taiwan

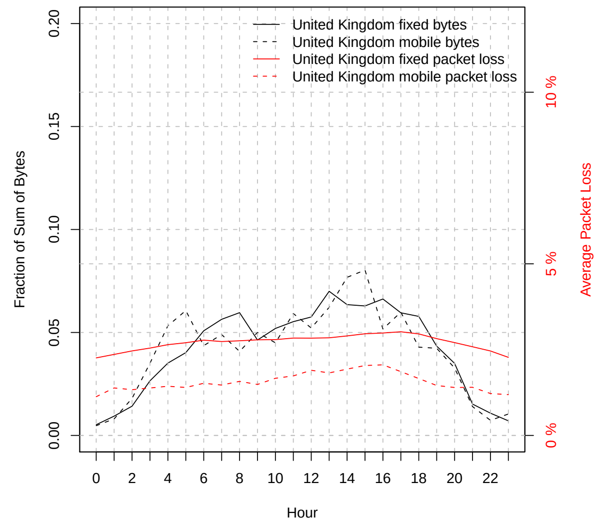

Figure 32: Daily distribution for size of connections and packet loss, United Kingdom

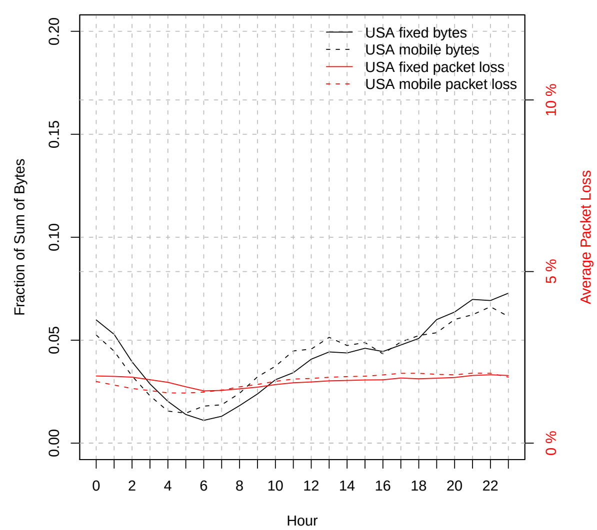

Figure 33: Daily distribution for size of connections and packet loss, USA

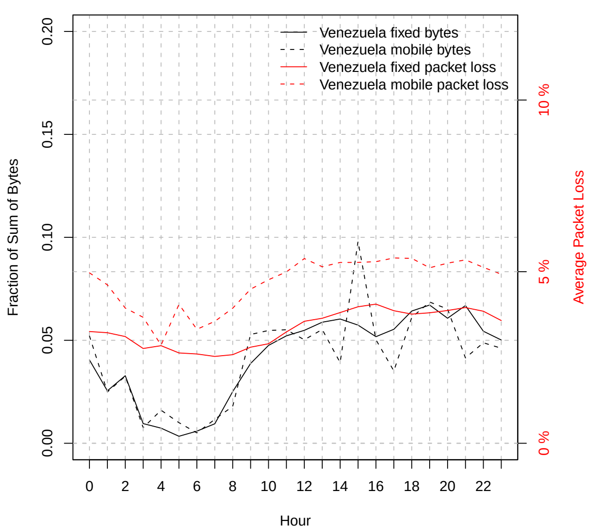

Figure 34: Daily distribution for size of connections and packet loss, Venezuela