# When the Rich Get Richer: A Case Study of Traffic Demand Response to Service-Plan Upgrades

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## Abstract

We present an analysis of usage patterns of Comcast subscribers whose service was increased from one high service tier to another. This study focuses on changes in usage behavior of two groups of users in the same city, a control group (105 Mbps tier link) and a treatment group (250 Mbps tier link). Members of the treatment group were randomly selected from the control group to receive 250 Mbps without their knowledge.

Previous work has shown that users who are already maximizing their usage on a given access link will continue to do so when they are migrated to a higher service tier. We study how users who are already on service plans with high downstream throughput respond when they are moved to a higher service tier without their knowledge. We find that subscribers who are already using most of their available capacity do not use significantly more capacity when they are moved to a higher service tier; in contrast, 50% of the subscribers who have low traffic demand increase their 95 percentile peak usage by 10% on upgrading the service plan. We also show that the median daily usage increases by 20% during off-peak hours.

## 1 Introduction

With the large impact of broadband Internet on our daily lives, and its rapid increase in bandwidth-intensive services, policy makers and service providers (ISPs) are perplexed with the question: how much bandwidth do people actually need? For lower service tiers, traffic demand increases with upgrades in service plans. However, with the growing consumption of high quality video content, coupled with a recent boom in Internet-enabled consumer goods (IoTs), subscribers who are currently satisfied with higher service plans may not continue to be so.

Previous work studying the complex relationship between demand and capacity has shown that users who are already maximizing their usage on a given access link will continue to do so when they are migrated to a higher service tier. The focus of our work is to study the traffic demand of subscribers who are already on service plans with high downstream throughput capacity, and their response to an undisclosed service plan upgrade as part of a randomized controlled trial (RCT). Our dataset offers the unique opportunity to explore the impact on traffic demand while mitigating the cognitive bias of the service tier upgrade by withholding that information from subscribers. To the best of our knowledge, this is the first such comparative study of usage behavior in a controlled experiment to study responses to service upgrades.

Our study is based on Comcast's analytic data collected from home gateways for their residential broadband customers in Salt Lake City, Utah. This data consists of byte transfers collected continuously every 15 minutes from two types of users; control: users that pay and use a high capacity access link (105 Mbps), and treatment: users that pay for 105 Mbps but are actually offered a much higher capacity access link (250 Mbps) without their knowledge. This decision was specifically anticipated to enable researchers to investigate the question: *does increase in capacity change traffic demand*?

We evaluate three months of traffic demand for more than 20,000 individual subscribers, 2,200 of whom had access to a 2.5-fold increased service capacity. Our analysis shows that while the aggregate and mean daily usage did not change significantly due to the upgrade, we observe a daily 20% increase during the off-peak hours, when subscribers are not expected to fully utilize the link. [1] Subscribers who are already using most of their available capacity in 105 Mbps, do not use significantly more capacity when they are moved to a higher tier. In contrast, subscribers with a low traffic demand increase their daily 95 percentile peak usage by 10%. Finally, we observed that more than than 99% of the users do not even use the increased service tier consistently for 15 minutes at any time in the three months of data we study.

Following the Federal Communications Commission (FCC) recent interest in adopting usage (traffic demand) as one of the broadband benchmarks, we discuss the possible implications of our observations on traffic demand for both policy makers, who determine broadband deployment policies for the US based on consumer demands, as well as ISPs such as Comcast, who plan broadband deployment and capacity upgrades based on trends in aggregate usage behaviors. We conclude that both policy makers and ISPs may have different perspectives of the same observation, and motivate the need

[1] SG: confirm this by taking the ratio of avg or median usage per time-slot in treatment and control.

to further study traffic demand as a broadband benchmark metric.

The rest of the paper is organized as follows. In § 2 we overview some previous studies of traffic demand and service capacity. Then, in § 3, we offer details about our data, sanitization, and characterization. We then proceed by describing our evaluation criteria and analyze traffic demand in response to a service tier upgrade in § 4. [2] Lastly, we comment on the differing perspectives of traffic demand in § 5, and summarize our findings in § 6.

## 2 Background and Related Work

Traditionally, broadband performance analysis has attracted the attention of the measurement community. However with increasing availability of high bandwidth Internet services and FCC's recent interest in exploring traffic demand as a broadband benchmark [5], the focus has moved to evaluating the complex interplay between broadband demand and availability.

Our work build upon earlier analysis of the relationship between traffic demand and service capacity by Bischof *et al.* [1]. In this prior work, natural experiments were used hypothesize and infer causal relationships between the traffic demand[3] and factors such as service capacity, performance, and price. They showed that demand increases with capacity, but "follows a law of diminishing returns", *i.e.*increases in capacity for an already high tier causes a lower increase in demand, than if the upgrade would have occurred for a lower tier. Our work complements their study via a large-scale controlled experiment and examines in particular a high service tier (105 Mbps) that has not been studied before. Our dataset mitigates the affect of price, performance, and other potential biases (such as regional [**?**, **?**], capped usage [**?**], and "geek-effect" [1]) by limiting the dataset to a large number of users selected randomly from the same service tier and location.

Zheleva *et al.*present a case study of the affect of an Internet service upgrade, from 256 kbps satellite to 2 Mbps terrestrial wireless, in rural Zambia. This work observed that the stark change in traffic demand three months after the upgrade caused a performance bottleneck. Our work focuses on higher service tier subscribers, who are presumably not bottlenecked, and studies changes in traffic demand without informing users of the upgrade.

Other efforts such as [**?**] study the characteristics of residential DSL broadband, and report the contributions of the most popular web applications to the total usage. The bi-annual Sandvine reports [**?**, **?**] provide an overview of overall Internet traffic demand from fixed lines and mobile carriers as well as an updated analysis of the most popular Internet applications. They showed that video accounts for 63% of traffic usage overall, and traffic demand peaks during the peak evening hours, possibly due to increasing video content consumption. Our work does not concern with the applications responsible for most traffic, but only with the peak period during which an individual subscriber's traffic demand is high.

## 3 Data Source and Characterization

We follow the popular statistical convention of experimental designers to refer to the service upgrade as *factor*, the group of users without the upgrade as *control* and the upgraded users as *treatment* [2]. Our dataset consists of network usage byte counters reported by Comcast residential broadband gateways every 15 minutes from October 1, 2014 to December 29, 2014. There are two sets of broadband service tiers that were used to collect this data: *control* set, consisting of 18,322[4] households with a 105 Mbps access link, and the *treatment* set, consisting of 2,200[5] households that were paying for a 105 Mbps access link, yet were receiving 250 Mbps instead. Subscribers in the *treatment* set were selected randomly and were not told that their access bandwidth has been increased.

**Data Description:** Each dataset contains the following relevant fields: Device ID, sample period time, service class, service direction, anonymized IP address, and the bytes transferred in the 15 minute sample slot, as described in table 1.

| Field | Description |
|---|---|
| Device_number | Arbitrarily assigned household identifier |
| end_time | 15 minute sample period end time |
| cmts_inet | Anonymous IP identifier |
| service_direction | {downstream, upstream} |
| octets_passed | Byte count in 15 minutes sample period |

**Table 1:** *Field descriptions for Comcast's* control *and* treatment *datasets*

**Data Sanitization:** Our initial analysis of the data from more than 22,000 households[6] showed that not all gateways were reporting their traffic counters every 15 minutes. 32% of the *treatment* set, and 72% of the *control* set gateway devices were responsive for less than 80% of the time periods over the three months. For the analysis in § 4, we present our results based on the accepted group of subscribers, that contributed to the dataset more that 80% during their lifetime.

**Data Characterization:** Our sanitized dataset consisted of 4,845 subscribers in the *control* group and 1,519 subscribers in the *treatment*. The mean traffic usage per subscriber was **XXX** bytes for the *control* group and **XXX** bytes for the *treatment* every 15 minutes. We interpret the traffic transferred over uplink or downlink in 15 minutes in terms of the average traffic demand (data rate) by averaging it over the measurement period to effectively compare demand with the service capacity.

Figure 1 shows the average subscriber traffic demand (data rate) for both groups. The Service Level Agreement with Comcast was 105 Mbps (upgraded to 250 Mbps) and is not

[2]SG: We do this by studying spacio-temporal usage patterns in terms of peak utilization, prime-time ratio, asymmetry, and prevalence.

[3]referred to as user demand, or usage in their work

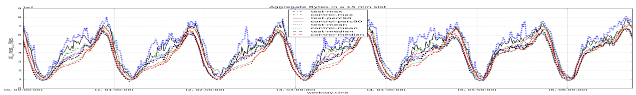
[4]SG: confirm

[5]SG: confirm

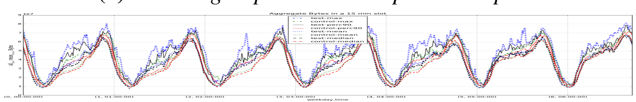
[6]SG: confirm exact number instead

| Dataset | users | Bytes (up) | Bytes (dw) | Average (up) | Average (dw) | 95% (up) | 95% (dw) | Util. (up) | Util. (dw) |
|---|---|---|---|---|---|---|---|---|---|
| *control*[7] | | | | | | | | | |
| *treatment*[8] | | | | | | | | | |
| *control* | | | | | | | | | |
| *treatment* | | | | | | | | | |

**Table 2:** *Data characteristics for datasets before and after sanitization. Average traffic demand (kbps) is the average data rate per subscriber calculated by averaging the bytes transferred over the 15 minute time period. The 95 percentile demand only averages the traffic data rate per subscriber for the top 95% usage. Utilization (util.) is the ratio of 95%ile traffic demand to the service tier capacity that the subscribers pay for: 105 Mbps.*



**(a)** *Control group with 105 Mbps service plan*



**(b)** *Treatment group with 250 Mbps service upgrade*

**Figure 1:** *PLACEHOLDER: Average traffic demand per subscriber (kbps) over time*

shown in the figure due to the difference in scale. Table 2 shows that the 95 percentile utilization, calculated as the ratio of the mean 95 percentile traffic demand to the service capacity, is **YYY** averaged over the *control* group and **YYY** for the treatment group. In comparison, the mean traffic demand is extremely similar, **ZZZ** for the *control* group and **ZZZ** for the *treatment*.

## 4 Empirical Analysis

The nature of the randomized controlled experiment used to collect the dataset of high service tier users allows us to evaluate the effect of a *factor*, the service plan upgrade, as a treatment applied to a control group. This served a two-fold purpose in avoiding biases that previous studies on usage and capacity suffer from: (a) *Behavioral change bias:* offering users with high capacity a further increase without their knowledge avoids the risk of behavioral changes that may occur when one purposefully buys a higher bandwidth connection; and (b) *Dissatisfied user bias:* we study high capacity tier users in a *control* group, that are are not utilizing their access link completely, and thereby mitigate the effect of traffic biases that occur because subscribers' previous capacity was insufficient for their usage. Studying datasets with these biases will always show a positive correlation between usage and capacity, which we avoid by examining a single high capacity tier with an unannounced upgrade.

We start by evaluating traffic demand. We calculate demand by averaging the bytes transferred in uplink or downlink direction over the sample period (15 minutes). This allows us to capture both the average per subscriber demand at any time in a day, and the aggregate demand at the ISP over a longer period, such as a day or a week.

**Temporal Trends.** We aggregate the traffic demand over multiple households during the same sample period, and present daily or weekly description (mean, median, and 95th percentiles) as a time series.

**Spacial Trends.** We aggregate the traffic demand of a single subscriber over its lifetime to measure their aggregated traffic demand, and present description of aggregated subscribers (mean, median, and 95th percentiles).

| Parameter | Definition | Who defined |
|---|---|---|
| Demand per Subs. | $\frac{\text{aggregate data usage in time slot}}{\text{number of contributing subscribers}}$ | Authors |
| Prime Time[9] | 7:00 PM - 11:00 PM | FCC |
| Prime Time | 8:00 PM - 12:00 AM | Authors |
| Prime Time Ratio | $\frac{\text{avg usage in peak (prime-time) hour}}{\text{avg usage in off-peak hour}}$ | Sandvine |
| Peak Period | Time of demand 95% of max | Sandvine |
| Peak Ratio | $\frac{\text{95\%-ile of max daily traffic demand}}{\text{mean of daily traffic demand}}$ | Authors |

**Table 3:** *Evaluation Criteria*

**Evaluation Criteria.** We describe daily traffic demand, prime-time ratio, and peak usage as criteria to evaluate general trends and changes in traffic demand (table 3). We interpret the behavior of the datasets both separately as well as comparatively as (1) general inferences drawn from analyzing the dataset, and (2) comparative inferences drawn from observing changes in user behavior due to the upgrade in access link bandwidth. We report on the results for uplink traffic demand where applicable. Lastly, we also evaluate the prevalence of the small number of subscribers who actively exceeded the service tier bandwidth they were paying for (105 Mbps) after the unannounced service tier upgrade to 250 Mbps.

### 4.1 Traffic Demand Per Subscriber

Internet usage throughout a day follows diurnal sleep-patterns, and researchers have shown that such patterns are in fact correlated with GDP, Internet allocations, as well as electrical consumption of a region [6]. This makes the study of usage behavior extremely relevant to the governmental bodies responsible for development, such as the FCC, when considering policy decisions.

To characterize diurnal user behavior as observed at the ISP, we first calculate usage per subscriber (table 3), and then plot the median and 95%-ile of total usage over a week for both *treatment* and *control* sets (figure 3).

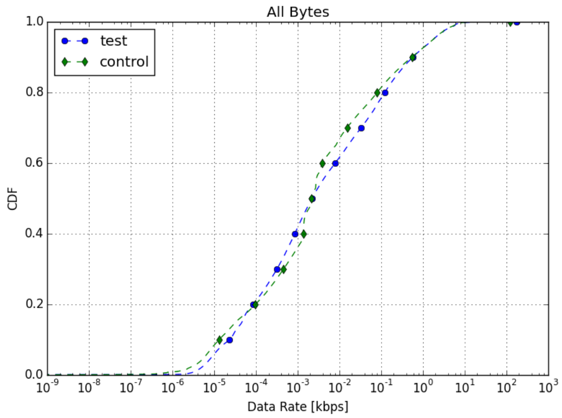



**Figure 2:** *CDF of data rate per time slot for all devices (agg view of data): Overall not much change due to capacity increase. Median data rate  2bps for 3 months x thousands of devices!*

A comparison of the aggregate traffic demand distribution of all devices and sample periods shows that the *treatment* has no significant affect on the mean traffic demand. Figure 2 shows that the median utilization of subscribers throughout the dataset is 50 kbps[10].

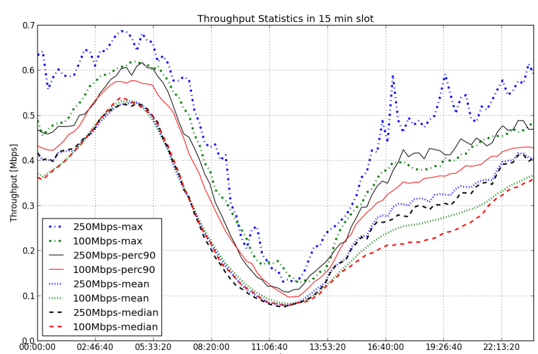



**Figure 3:** *agg (days) over means (devices): aggregate has no trough, peaks in the evening hours*

Figure 3 shows the aggregate data rate for a day. We observe that the rise to the peak prime time hour usage on weekdays is not plateaued like the pattern observed on weekends (and holidays). A generic (median) weekday aggregate usage consists of a rise in usage that starts early in the morning that builds up to the prime-time period, peaks, and then falls sharply. We do not observe a trough in mid afternoon (between 2:00 PM – 6:00 PM), as is usually the case for overall usage observed at US Fixed access providers [7].

[10] SG: confirm

We observed that the median traffic demand during 7:00 PM – 7:00 AM is **XXX** for both *treatment* and *control*. However, during off peak daytime (work) hours, between 7:00 AM – 7:00 PM, the *treatment* group has a median of **XXX** , 20% higher than the *control* set.

## 4.2 Prime-Time Ratio

The daily diurnal nature of usage patterns across many households naturally requires the provider to design networks capable of handling load at the peak times in a day. Such peak times are usually observed during evening hours, and the data transferred at this time is called peak usage. The FCC defines **Prime Time** as the local time from 7:00 PM to 11:00 PM [3], when many households heavily consume real-time entertainment traffic (video), seen as primarily responsible for high usage during these hours. Latency and performance are adversely affected during prime-time, causing bottlenecks at home, the last mile, in transit, or at the content server. For example, the Sandvine Global Internet Phenomena Report [11] showed that devices in the same household selected Netflix's own CDN (OpenConnect) during off-peak hours, and third party CDNs (with differing performance) during prime-time. This may happen because Netflix OpenConnect is over-utilized during prime time [7].

To measure the concentration of network usage during prime time, Sandvine defined the **Prime-Time ratio** as the "absolute levels of network traffic during an average peak period hour with an average off-peak hour". Based on the FCC definition of prime-time hours (7p-11p), we measure the daily prime-time ratio of the *control* group and compare it to the *treatment*. Prime-time ratio is definded by dividing the the average traffic data rate during an average prime-time hour, by the off-peak average traffic rate.

Prompted by the monotonically increasing trend of usage behavior during daytime hours on weekdays (figure 3) we calculated the prime-time ratio for each four hour period throughout the day to find the evening hours with the largest ratio. In our dataset, the prime time ratio peaks at 8:00 PM – 12:00 AM, rather than FCC's definition of 7:00 PM – 11:00 PM. This discrepancy could be limited only to the high tier households in our dataset, but we deem that unlikely. Another reason could be that prime time is delayed globally with the rise in real time entertainment's contribution to traffic.

We use our updated definition of Prime Time (table 3) to calculate and plot the Prime Time ratio per day for the *treatment* and *control* groups in figure 4. A comparison shows that the *treatment* set's prime time ratio is unexpectedly 10% lower than the *control* group. This supports our initial observation [§ 4.1] that showed that the usage during peak evening hours is similar across both groups, but the usage in off peak hours is higher in the *treatment*.

[11] The Sandvine Reports [7, 8]are released bi-annually and contain a detailed analysis of aggregate Internet usage. They are also referred to in the FCC reports [3–5]

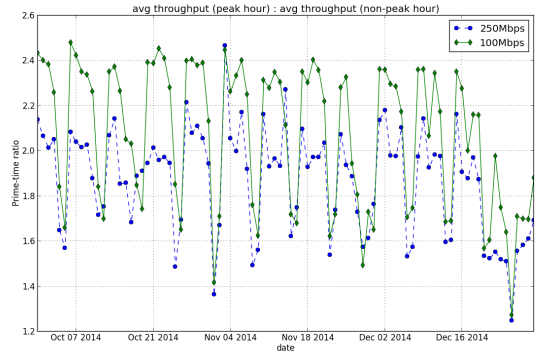
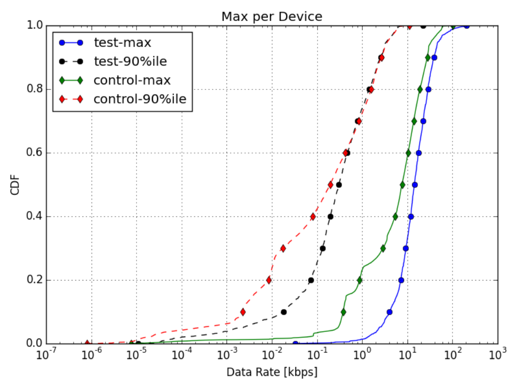
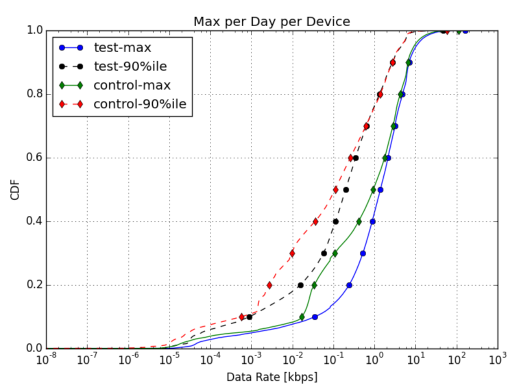



**Figure 4:** *Prime Time ratio showing weekly pattern + differences during holiday periods (Thanksgiving, Christmas)*

## 4.3 Peak Traffic Demand




**(a)** *CDF of max per device: test set has higher (max) average data rate below 10 kbps. 30% of devices in the control set have a max data rate of 2 kbps while 30% of test set has a max data rate of 10 kbps. (sanity check numbers, redo plot)*




**(b)** *CDF of max per device daily*

**Figure 5:** *Peak Utilization: The maximum data rate varies for test and control set for low data rates, and this variation is present daily.*

Based on the measurement methodology, we study the highest utilization seen by a household both in its lifetime, and on each day. Our aim is to examine the peak usage per household, and study if the behavior changes due to an upgrade.

Figure 5a provides a distribution of the highest average data rate a household achieves. To avoid outliers, we also plot the 90%-ile of the max data rate achieved by households in both *treatment*and *control*sets. We see that a median household is expected to achieve the highest data rate of between 1 – 10 Mbps over its lifetime. This is much lower than the access link capacity, indicating that the median device has a utilization ratio (avg data rate:capacity) under 0.1 in our dataset. The number of households that increased their peak utilization beyond the *control*set's 105 Mbps capacity were negligible.

Surprisingly, we see that 30% of the households from the *treatment*set have a low peak utilization (under 0.1 Mbps), while 40% of the *control*set households are under 0.1 Mbps. Thus, the absolute peak utilization does not increase when compared to the access link capacity, but there is certainly an increase in peak utilization of devices that had a low requirement, due to the change in capacity.

To investigate this further, we also study the *peak utilization per device on a daily basis*. Figure 5b shows that for 30% of the devices, the maximum data rate in the *treatment*set is consistently higher than the *control*set, albeit no where near the actual access link capacity.

This is similar to the behavior observed in figure 3, showing that the peak usage during prime-time is unaffected, but lower utilization throughout the day is higher for the test set. We speculate that there could be two possible reasons for this increase in utilization: (1) short term downloads and/or web browsing achieves a slightly better data rate on a small time scale, or (2) real-time video quality is slightly higher, but not enough to completely saturate the access link capacity. Unfortunately, we miss these short lived, or consistent, events due to a 15 minute time slot granularity and only looking at byte counters.

**Peak Ratio:** The Sandvine Reports show that although the mean usage has remained stable for the past few years, usage during peak-times has increased drastically [7]. To measure this growth, they introduce the concept of peak period, measured when the network is within 95% of its highest point. Although, these reports present a good view into aggregate usage patterns over a month, they neglect to analyze usage characteristics individually. Inspired by their definition, we measure the disparity between the 90 percentile of the peak and median usage of each household within a day, and call this the *Peak-Ratio*. In section 4.3 we show that the peak ratio can be used to divide users in the same tier based on their usage behavior.

To further characterize and compare the deviation of data rate for the *control*and *treatment*set, we examine *peak-ratio* as defined above. Figure 6 shows that the median peak-ratio for each device in the *treatment*set is much larger than that of the *control*set. **replace much larger with the exact number or percentage** . SG: Taken together with our observations of a lower prime-time ratio of the *treatment*set (section 4.2)

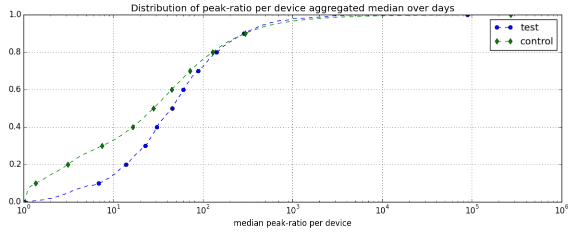



**Figure 6:** *Median peak ratio per device showing that test set has higher daily ratio (50 times by median). Thus ISPs should condition their networks to 50 times the median usage for each user added in the worst case scenario.*

this implies that there are households in the *treatment*set that achieve a peak-ratio > 1, but not during the prime-time hour. We believe that these households might actually be small businesses or work-at-home users that peak during daytime hours instead of evening hours.

The median peak-ratio per device itself shows a large range, from 1 to 10e6 (figure 6), and the maximum peak-ratio per device was an order higher. Clearly there are some households that have a very even usage throughout the day (low peak ratio), and others that are extremely aggressive only at certain times (high peak ratio).

## 4.4 Prevalence

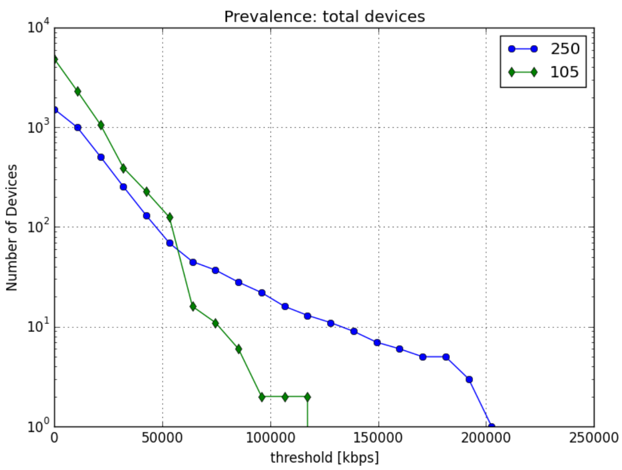



**Figure 7:** *User prevalence as threshold increases.*

Only 11 users beyone 10000 Kbps.

# 5 Discussion

We take this opportunity to reflect on the interpretation of the disparity of peak utilization per device, as shown in figure 5a. The FCC has the responsibility to increase the availability and deployment of broadband throughout the US (with the broadband threshold benchmark defined as 25 Mbps in downlink and 3 Mbps in uplink). Their progress report states that: given the option, users will adopt a higher tier bandwidth [], thereby meriting the high investment. However, a survey conducted by NCTA showed that the largest deterrent to broadband adoption is that users do not *need* broadband (the second largest is the cost). The conflicting view of the ISP is that the cost of deployment in an unchartered area is too high, unless a significant number of households *need* it. Thus, both parties are asking the same question: do people *need* a higher capacity, i.e., what is their *utilization* as compared to the capacity?

Previous research shows that the utilization will increase as the capacity of the access link increases [], and also that utilization and capacity follow a law of diminishing returns [1]. However, such studies have been biased by studying users that actually required a higher capacity for their usage. It is inevitable that such a correlation would exist for such households, whose utilization is bottlenecked by the ISP.

In this work, we ask a more fundamental question: *how much does the user behavior change with increasing capacity*. Specifically, when the capacity is already very high and the user has not opted for an increase, does their utilization still vary with capacity? Both the FCC and the ISPs have a different perspective of the utilization:

The ISP may interpret this as no change in peak usage, as the prime-time usage remained the same based on aggregated usage, even in prime-time. Thus, we believe that given the opportunity, the provider will not invest to offer a higher access link unless it in a region showing such low demand unless it is guaranteed profit, or is forced into deployment by an external agency.

In contrast, the consumer (and therefore the FCC) might be convinced that individually the usage behavior of a household is affected by the increase in access link capacity, especially for households with a lower utilization. We believe that this is the perspective the FCC takes when considering deployment and adoption of broadband services.

**The FCC perspective:** *Utilization as adoption* of a higher capacity link when available (but not under the constraints of a much higher cost). The answer to this question is important to the FCC to encourage further deployment of high tier links throughout the US. Essentially, if *any* change is observed in link utilization due to the upgrade in our dataset, the FCC may interpret that as *adoption* to the higher available tier.

**The ISP perspective:** *Utilization as a capacity bottleneck*, i.e., if the ISP can show that the *maximum utilization* of a household does not vary with increasing capacity, it will prove there is not enough demand to offer a higher tier. The ISP needs the answer to this question for future capacity planning, and the cost-analysis for the investment of new technology in any area. For example, Google Fiber is now expanding to Salt Lake City, from where we received our dataset. The analysis of change in user behavior with capacity will estimate the number of users that actually *need* the higher capacity service offered by Google.

# 6 Conclusion

For heavy hitters, the highest using 50 percent of the users, the 95th percentile utilization over a three-month period did not change when the speed tier increases. But for lighter subscribers, the 50 percent with a lower peak demand, the 95th percentile peak usage increases substantially.

Overall data rate and average utilization are similar Heavy users who utilize most of the link capacity do not increase their demand Average peak ratio doesnt rise for majority of subscribers Prime time seems to be 8p-12a for both control group and treatment This suggests that (1) the series are similar and (2) the ISP is not the bottleneck for heavy users.

For time slots with low data rate over 15 min, peak demand per subscriber is higher in the test set Median data rate per subscriber during off-peak hours also increases There are a few outliers that have very high demands (high utilization) that increase in the treatment.

This suggests that increasing ISP capacity (tier) affects demand for very high speed tiers, even though the link is not fully utilized by the affected subscribers.

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