eXploring Xfinity
A first look at provider-enabled community networks

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Abstract. Several broadband providers have been offering community WiFi as an additional service for existing customers and paid subscribers. These community networks provide Internet connectivity on the go for mobile devices and a path to offload cellular traffic. Rather than deploying new infrastructure or relying on the resources of an organized community, these provider-enabled community WiFi services leverage the existing hardware and connections of their customers. The past few years have seen a significant growth in their popularity and coverage and some municipalities and institutions have started to considered them as the basis for public Internet access.

In this paper, we present the first characterization of one such service – the Xfinity Community WiFi network. Taking the perspectives of the home-router owner and the public hotspot user, we characterize the performance and availability of this service in urban and suburban settings, at different times, between September, 2014 and 2015. Our results highlight the challenges of providing these services in urban environments considering the tensions between coverage and interference, large obstructions and high population densities. Through a series of controlled experiments, we measure the impact to hosting customers, finding that in certain cases, the use of the public hotspot can degrade host network throughput by up-to 67% under high traffic on the public hotspot.

1 Introduction

The impressive growth in the number of mobile devices and our dependance on them and the services they support have created a high demand for Internet connectivity on the go. Several large network providers including Comcast, Time Warner, British Telecom (UK), and Orange (France) have started addressing such demand by deploying millions of WiFi hotspots around the globe, as a free service to existing customers or as an additional source of revenue.

Rather than deploying new infrastructure or relying on the resources of an organized community [8], these provider-enabled community WiFi services leverage the existing hardware and connections of their customers for coverage. In these networks, residential and commercial customers' access points broadcast an additional public hotspot SSID to bootstrap coverage of the community WiFi network. Despite their rapid growth and extensive media coverage, we lack an understanding of the effective value of these community network service for consumers, and the impact - if any - of their use on the residential customers they rely upon.

In this paper, we present the first characterization of a provider-enabled community WiFi network, focusing on the Xfinity Community WiFi. Xfinity WiFi is the largest of such networks available in the U.S. with over 10 million devices in July 2015 [24]. Taking the perspectives of both the home router owner and the public hotspot user, we characterize the coverage, availability, and performance of this service under various geographic and temporal contexts, over three weeks in 2014 and six weeks in 2015. We performed controlled experiments to measure the impact of concurrent access of both the home network and the public Xfinity WiFi hotspot. Our results highlight the challenges of providing these community WiFi services in urban and suburban settings considering the tensions between coverage and interference in high population densities.

Key findings. First, we found significant growth in the Xfinity WiFi network in all areas measured during the period of our study. Much of this growth was in the number of from access points starting to broadcast in the 5 GHz band, particular in our urban environment where 45% of access points use 5GHz (compared to only 15% in the measured suburban one). Second, despite the higher number of Xfinity WiFi access points, we found it challenging connecting to these access points for Internet connectivity. After examining the signal strength and interference in each environment, we found much lower signal strength and higher interference levels in our urban setting measurements, compared with the suburban ones, which partially explain the observed differences in connectivity and performance. Last, we found significant performance degradation of the hosting customer's home network with throughput reaching to half of the maximum attainable throughput for 4 Mbps traffic on public WiFi. This appear to be caused not by the additional traffic on the link, but rather because of the competition with the hosted public WiFi hotspot network for same radio device and spectrum.

2 Community Wifi Networks

There has been a growing interest in providing public WiFi access from the private sector, civil organizations and end users. As a notable example, the Electronic Frontier Foundation is one of the many sponsors of the Open Wireless Movement [13], aimed at creating a network of volunteer-supported free and open wireless Internet. Several router manufacturers are equipping routers with additional "Guest" WiFi access point, allowing public access while isolating public from home traffic. As another example, FON offers access to a virtually global WiFi network of "foneros" that support guest users in exchange for free roaming and/or revenue from paid users [15].

Several municipalities around the world, sometimes in cooperation with the private sector, have also begun providing free or fee-based access to city-wide wireless networks. Chicago is coming up with the Chicago Tech Plan to build a model for cities and technology for smart communities [22]. Other examples include early efforts such as the MIT RoofNet [4] and MadMesh [9], and the Google's public Wifi in Palo Alto, CA.

Recently, Internet service providers such as AT&T, Comcast, Time Warner, British Telecom (UK) and Orange (France) have also started to offer public WiFi hotspots for their existing customers. In the case of AT&T, for example, both existing cellular and broadband customers have access to a nationwide network of WiFi hotspots, labeled `attwifi`, located at AT&T retail locations, as well as partnered businesses.

2.1 Xfinity WiFi - A Provider-Enabled Community WiFi

On June 10th, 2013, Comcast announced its plans to create millions of WiFi AP available to its customers through a neighborhood hotspot initiative [10]. The company started to enable a second *xfinitywifi* SSID broadcast in their existing customer gateways to act as a publicly accessible hotspot. The uniqueness of this model comes from its customer-supported-and-provider-enabled approach, what we call *provider-enabled community WiFi*, that allowed Comcast to bootstrap hotspot coverage by leveraging the provided routers of existing commercial and residential customers.

Since then the service has grown to include over 10 million public hotspots in the US [24]. All Comcast users with XFINITY Internet Performance tier and above can connect to these hotspots for free[1], while non-Comcast customers can purchase an XFINITY WiFi Access Pass with different hourly, daily and weekly durations [11].

3 Characterization of Xfinity WiFi Network

To understand the challenges of providing community WiFi services in urban environments, we conducted a series of experiments in Chicago's central business district (*The Loop*) and in Evanston, one of its northern suburbs. We designed our experiments to capture the experience of public users, taking measurements from public areas surrounding Xfinity WiFi access points. In the following paragraphs, we use results from a series of such experiments conducted over the course of a year to discuss (i) the coverage of Xfinity WiFi, (ii) its availability as a usable Internet connection, and (iii) its performance to users. Motivated by the comparable poor connectivity and performance we observed in urban Chicago, we investigate possible causes including radio interference and signal strengths of deployed access points.

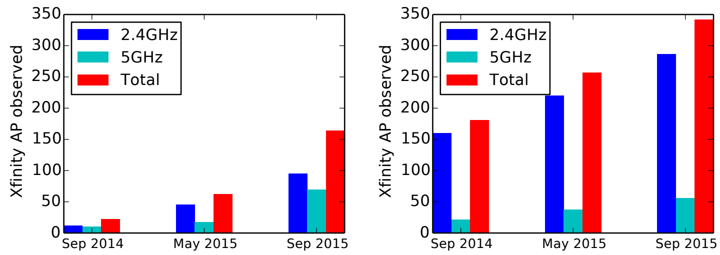
3.1 Data and Methodology

We measured the coverage, availability and performance of Xfinity WiFi using an instrumented Samsung Galaxy S4 to continuously scan for available APs, recording their signal strength, BSSIDs and channel, along with the device's current GPS location. When an available `xfinitywifi` SSID was found, the tool attempts to connect to the one with the strongest received signal strength (RSSI), and upon successful association and authentication, conducts network performance measurements using the Network Diagnostic Tool (NDT) [18] [2].

We conducted our experiments in two geographic areas, one in the high-density urban environment of Chicago, IL and one in a mix of residential and low-density commercial in Evanston, IL. Each area covers a similar surface – 4x4 block area (0.13 sq. mi) and a 6x4 block area (0.15 sq. mi) in Evanston and Chicago respectively. We

[1] Before connecting, a Comcast user must be authenticated through an HTML form with their subscription credentials.

[2] While NDT results on network properties have been questioned, we believe that the gathered measurements should be consistent for comparisons between settings, and, 2.4GHz and 5GHz bands [7].



(a) Chicago (b) Evanston

Fig. 1: Growth of Xfinity: Significant deployment of Xfinity WiFi APs in both areas, with more deployments using 5GHz radio bands in urban Chicago compared to suburban Evanston.

took our measurements at three separate times between 2014 and 2015: in September 2014, April 2015 and September 2015. In each instance, we canvassed each area, walking the same path in 2 hour intervals both in the morning and evenings to capture peak and non-peak hours. Unless otherwise specified, the results presented for availability and network performance come from the September 2015 dataset.

3.2 Deployment and Coverage

We measured the growth in deployed Xfinity WiFi access points in both locations between September 2014 and September 2015, noticing a significant growth in both areas in the number of observed access points. We found that while Evanston gained more overall access points, Chicago saw a much larger relative increase. Between September 2014 and 2015, the number of Xfinity WiFi hotspots in urban Chicago has increased more than 7 times (from 22 to 164); during the same period, the number of hotspots in suburban Evanston has nearly doubled (from 181 to 342). Despite the large growth, we still observed twice as many access points in Evanston than in Chicago in our final measurement.

Aside from the overall growth in the number of access points, we observed a higher proportion of new 5GHz band deployments over the year. Similar to the results from total access points, we observed a larger overall growth in the 5 GHz band in Evanston than Chicago, yet a much higher growth rate of 5GHz hotspots in Chicago (around 45%) compared with suburban Evanston (15%). Deploying hotspots using 5GHz radio band in urban environments may be driven by the assumption of lower radio interference.[3]

Geographic coverage is determined by dividing each measured area into a grid of cells - each cell an area of of 0.001 degree latitude by 0.001 degree longitude - and searching for the presence of Xfinity WiFi access points in each. In September 2015,

[3] http://www.extremetech.com/computing/179344-how-to-boost-your-wifi-speed-by-choosing-the-right-channel

Table 1: Xfinity WiFi APs statistics for urban Chicago and suburban Evanston, taken in September 2015.

Location	5GHz				2GHz			
	All	Xfinity	Attempted	Connected	All	Xfinity	Attempted	Connected
Chicago (urban)	3840	71	49	8 (16%)	3688	97	75	10 (13%)
Evanston (suburban)	442	56	39	13 (33%)	2316	286	150	66 (44%)

we found access points in over 70% of areas in downtown Chicago, and over 90% of areas in Evanston.

3.3 Availability

The utility of community WiFi networks depends not only on the presence of an access point, but in the ability of clients to successfully connect to them. There are many reasons why a client could see the service SSID but be unable to connect to it, such as low signal strength. In this section, we discuss results from our measurements of service availability which we define as the percentage of Xfinity WiFi access points that one can successfully connect to during an experiment.

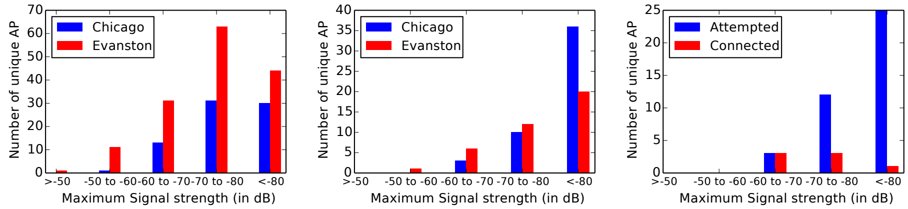
Overall, despite the extensive coverage and high density of the Xfinity WiFi hotspot network, we found the service to be typically unavailable with our measurement device unable to connect to the large majority of access points – 36% in Evanston and 87% in downtown Chicago. Table 1 summarizes these findings, organized by measurement location and radio band.

We find that the Xfinity WiFi in Evanston displayed much higher availability compared to downtown Chicago. Of 146 APs we attempted connection with in Chicago, we were only able to connect with 10 (13%) 2.4 GHz and 8 (16%) 5 GHz hotspots. In Evanston, we successfully connected to a significantly higher fraction of access points – 66 (44%) 2.4 GHz and 13 (33%) 5 GHz networks.

There can be many external factors which explain the poor connectivity in urban areas. We investigated how signal properties of these access points affected our availability results, looking at the RSSI of devices we issued connect requests to. Figures 2a and 2b display the distribution of maximum signal strengths observed for the set of Xfinity WiFi access points found in each radio band.

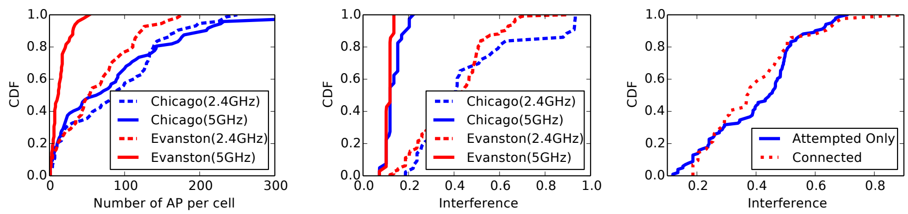
We noted a higher presence of Xfinity WiFi hotspots with strong signal strength (broadcast RSSI) in suburban Evanston than in urban Chicago, which partially helps explain the higher service availability observed in Evanston. The impact of low signal strength on availability is clearly illustrated in Figure 2c, which shows the number of successful connections compared to the total attempts for 5 GHz access points in Chicago at different signal strengths. The steep drop off of successful attempts with decreasing signal strength – including the 4% success rate of 5 GHz APs with RSSI less than 80 – explains much of the low availability seen in this setting.

Investigating Wireless Properties After observing the low availability of Xfinity WiFi access points in urban Chicago, we further investigated whether interference on



(a) 2.4GHz (b) 5GHz (c) Chicago 5GHz

Fig. 2: Signal Strength in two areas. Chicago has poor wireless signal strength compared to suburban Evanston. APs with low signal strength suffer from very low connectivity rates.



(a) Density of APs (b) Interference (c) Evanston (2.4GHz)

Fig. 3: Interference and Density of APs in two areas: Urban Chicago has slightly higher radio interference due to high density of wireless APs in both radio bands. 5GHz networks have significantly less interference compared to 2.4GHz band. However, we find small impact of interference on connectivity.

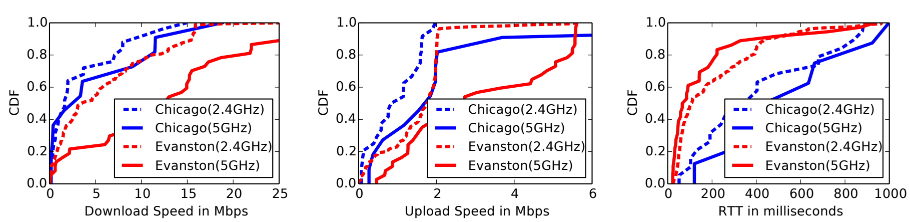
Xfinity WiFi radio channel was contributing to the lack of connectivity. During our September 2015 measurements we employed an instrumented Linux laptop equipped with an Atheros AR9820 802.11a/b/g/n chipset to measure interference on different WiFi channels by capturing channel busy time (CBT). CBT represents a more accurate picture of the radio channel than medium utilization as it also accounts for channel noise and packet collisions [2]. We continuously recorded the CBT from NIC registers exposed in Atheros radio. To normalize each CBT, we further calculated the Interference Factor (IF) for each channel, defined as the ratio of the observed busy time over the time spent on the channel [1].

A large source of interference for wireless 802.11 hotspots comes from other nearby access points. We found that the density of wireless access points in urban Chicago is significantly higher compared to our suburban setting. At median, we observed around 70 of 2.4 GHz and 90 of 5 GHz wireless APs per cell in Chicago compared to around 50 of 2.4 GHz and 5 of 5 GHz wireless APs per cell in Evanston as shown in Figure 3a. The density of 2.4GHz network is similar in both areas we measured, as well as, similar radio interference for 2.4 GHz. However, with an order of magnitude more 5 GHz radio networks in urban Chicago, we observed a very small but a clear separation in the interference graph of 5GHz for the two areas (Figure 3b). We found that interference in the 5 GHz radio band is much lower in both areas than the 2.4GHz band with a median interference of 0.05 (compared to 0.4 for 2.4 GHz), for instance, in our urban environment.

Figure 3c illustrates the comparison of minimum channel interference observed for connected and attempted only access points, in the 2.4 GHz band in Evanston. In the median case, we see a difference of around 0.1 between the interference value for the access points we were able to connect and those we were not. For 5 GHz networks, which showed very low interference values, we did not noticed a significant impact of interference on connectivity.

3.4 Network Performance

We present the performance of Xfinity WiFi hotspots in both areas across download speed, upload speed and RTT, collected using NDT. We observed significant difference in network performance in between areas and radio bands, as well as a large variation in performance of such networks within each area. The results are shown in Figure 4.



(a) Download Speed (b) Upload Speed (c) RTT

Fig. 4: Network performance measured at Xfinity WiFi hotspots by radio band and environment. Xfinity WiFi hotspots show lower performance in downtown Chicago across all metrics. 5 GHz band radios also performed better in both locations.

We find a large performance differential between the two radio bands, with 5 GHz bands exhibiting higher throughput in both areas. Surprisingly though, these 5 GHz bands showed higher latencies in Chicago than 2.4 GHz bands. We believe this is likely due to the poor signal strength properties observed in Chicago rather than indicative of general performance. Sundaresan et al. [23] found similar performance results for home networks.

4 Cross Traffic Interference

Comcast is leveraging its customer's gateway routers as public hotspots for their *neighborhood xfinitywifi* service. To understand the impact of such sharing on customers' performance, we conducted controlled experiments for the case when both networks use same router with single radio band (and hence, share same radio channel). We generated cross traffic on a node connected to Xfinity WiFi network and measured the network performance on another node connected to home network. Since we started our study, Comcast has been moving toward double band routers now offering three new devices, two of them supporting dual band radio. However, one of these routers is currently only available in selected markets while the other one is provided only to customers with high-end Internet plans [12].

4.1 Methodology

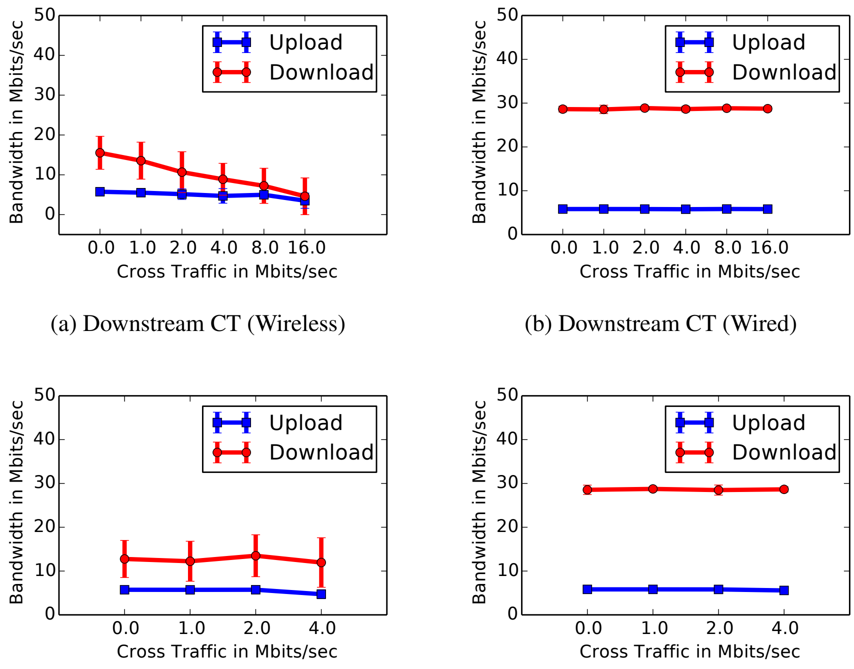
We conducted our experiments over a continuous 24-hour period to account for time-of-day patterns. Each set of tests consisted of injecting different amounts of downstream or upstream cross traffic (one direction at time) at different rates. We run experiments with downstream cross traffic at 0, 1, 2, 4, 8 and 16 Mbps and and upstream cross traffic at 0, 1, 2 and 4 Mbps. Both upper bound limits were set based on our initial experiments. All experiments were run under controlled settings, with only one home device connecting to these gateways. We collected our measurements using a single Xfinity customer's ARRIS TG862 Gateway [5] which was actively broadcasting *xfinitywifi* SSID, in a home with a 25Mbps subscription. Based on preliminary measurements, we believe that our key observations would apply to other single-radio-band devices and broadband subscriptions.

Cross traffic was generated on a separate node connected to the *xfinity-network* broadcasted from the same router. Upstream cross traffic was generated by running iPerf [16] utility to send upstream UDP packets at specific rates. Downstream traffic generation was generated using a python server hosted in university network that sent UDP packets at the requested rate to the *xfinity-network* node. These two processes of performance measurement on *home-network* and traffic generation on *xfinity-network* were coordinated and automated using a configuration/coordination server in our lab. We took all performance measurements using NDT [18] on a node connected to the *home-network*. [4] We took three measurements of download/upload rate and selected the maximum to handle small temporal variations.

4.2 Experimental Results

Figures 5a and 5c show the mean of the observed bandwidths along with the standard deviation for cross traffic. We observed significant performance degradation of the *home-network* WiFi due to cross traffic from *xfinity-network*. The impact of downstream

[4] We refer to the public hotspot WiFi network as the *xfinity-network* and customer's personal network as the *home-network*.



(a) Downstream CT (Wireless)

(b) Downstream CT (Wired)

(c) Upstream CT (Wireless)

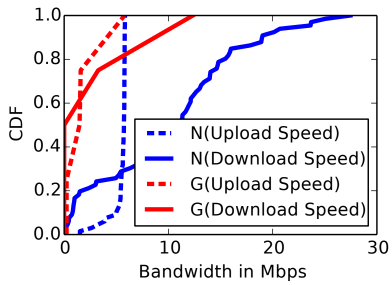
(d) Upstream CT (Wired)

Fig. 5: Cross Traffic Impact of Public Hotspot on Hosting router's Personal Network. As the public and hosting WiFi share same radio spectrum, we observe significant performance degradation of hosting network.

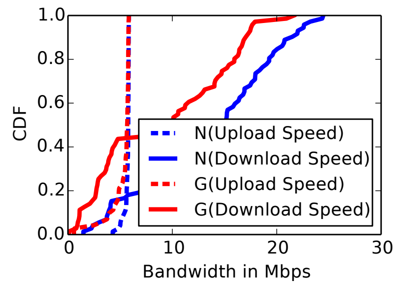
cross traffic is significant starting at low values; for 2 Mbps cross traffic on *xfinity-network*, we observe the download speed of *home-network* drop from 15 Mbps to 10 Mbps, and drop by half (7.5 Mbps) for a cross traffic of 4 Mbps. Figure 5a illustrates this trend in decreasing performance as cross traffic is increased, with reduction in throughput as high as 67% for 16 Mbps traffic on public WiFi.

As the upstream cross traffic is limited at 4 Mbps, it caused less wireless interference and has lower impact on download speed. The maximum upload speed we observed on the public hotspot was around 2 Mbps, and the impact on download speed and upload speed is not noticeable before 4 Mbps upstream cross traffic as seen in Figure 5c. Hence, we don't observe any significant impact of upstream traffic from public hotspot network on the hosting network.

To isolate the cause of cross traffic interference, we performed the same series of experiments with the measurement node in *home-network* connected via Ethernet to the router in place of the wireless interface. Figure 5b and Figure 5d show the home network performance for downstream and upstream cross traffic, respectively, for a client connected over the wired interface. The figures show that download and upload measured bandwidths of *home-network* remain constant for all values of cross



(a) Downstream Cross Traffic (10Mbps)



(b) Upstream Cross Traffic (2Mbps)

Fig. 6: Performance impact due to WiFi incompatibility of connected public hotspot user device. A public user with WiFi 802.11g device brings down the performance of 802.11n device in home network.

traffic on *xfinity-network*, for both downstream and upstream cross traffic. With no cross traffic interference over the wired interface, we conclude that interference due to *xfinity-network* cross traffic originates solely from the two WiFi competing for same radio (device and spectrum) resulting in significant radio interferences with increase in network traffic.

4.3 WiFi Compatibility Issues

The performance of the home-router owner could be impacted by a public hotspot user connecting with an old WiFi standard device. To evaluate the potential impact of this issue, we run experiments connecting a 802.11n device and a 802.11g device, one at a time, to *xfinity-network* and measuring the performance of a home user using a 802.11n device. We run our experiments using NDT, and during off-peak hours (2am-6am). Figures 6a and 6b present our results. We observed many NDT timeouts while measuring the impact of downstream cross traffic with the 802.11g device that lead to fewer data points. The 802.11g device has, as we expected, a significant impact on the home network and brings down the overall WiFi performance by a significance margin.

5 Related Work

Several projects have measured the performance characteristics of wireless networks, including Kotz et al. [17] study of campus-wide network and Aguayo et al. [4] report on link level characteristics of a rooftop based mesh network. Farshad et al. [14] used mobile crowdsourcing to characterize the Edinburgh WiFi. More closely to our work, Sathiaseelan et al. [21] focused on the technical and social context of providing Internet access by sharing existing broadband subscribers' connections deploying PAWs in medium-sized British city. Mota et al. [19] recently evaluated the feasibility of offloading cellular data traffic through WiFi hotspots provided by the government and private WiFi access points in Paris. Robinson et al. [20] and Afanasyev et al. [3] studied the coverage properties of the Google WiFi mesh network around Mountain View, CA. Brik et al. [9] focused on a Mad Mesh network with 250 Mesh Access Points. Braem et al. [6] analyzed the end-to-end quality of Internet access in community networks. By contrast, our work focuses on characterizing a provider-enabled WiFi network in urban and suburban settings and from the perspectives of both the public user and the host network owner.

6 Conclusion

We presented the first characterization of the coverage, availability and performance of provider-enabled community networks. We focused our study on Comcast' Xfinity WiFi network - the largest community WiFi network in US, with more than ten million devices in July 2015. We analyzed the performance of this service under various geographic and temporal contexts, and from the perspectives of both the home router owner and the public hotspot user. We found that the connectivity and performance of these services in urban environment can be impacted by high signal attenuation from densely populated physical objects and radio interference from crowded wireless APs. Our results show a significant degradation on the performance of the hosting customer's home network with reductions in throughput as high as 67% due to wireless interference. This preliminary study was focused on a single service in two limited geographic areas - downtown Chicago and Evanston, IL and we would like to expand this as part of our future work. We believe, however, that our findings and analysis should be applicable to other community WiFi networks and comparable urban and suburban environments.

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