STARRY™

# FCC Progress Report II
# December 6, 2017

Federal Communications Commission
Experimental Licensing Branch
MS 1300E1
445 12th Street SW
Washington, DC 20554

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# I. Introduction

In February 2017, Starry, Inc. ("Starry") filed a Progress Report with the Federal Communications Commission ("FCC" or "Commission") updating the Commission on Starry's progress in developing, deploying and testing its fixed 5G wireless broadband access network. This second Progress Report contains additional information related to Starry's deployment efforts in the markets in which it holds experimental test authority licenses.

# II. Background: Company Overview

Over the last decade, the Commission has recognized that ubiquitous, reliable internet is a critical part of our nation's infrastructure and a building block for economic growth. As such, the Commission has initiated proceedings and implemented policies that encourage the expansion of broadband access across geographies and demographics. It has never been more clear: having reliable, affordable broadband access can make a marked difference in the lives of families across the country, enabling access to job opportunities for adults and educational tools for children. However, the reality remains that access to fast, reliable and affordable internet access is not universal and the digital divide – across urban and rural communities – is real and continues to hamstring families and communities.

At Starry, we believe that emerging "5G" technologies – fixed wireless, in particular – offers an opportunity to use previously untapped millimeter wave spectrum to deploy next generation wireless access technologies that have the potential to not just narrow the digital divide, but close it all together.

Starry is a Boston- and New York-based technology company that is using millimeter waves to re-imagine last-mile broadband access as an alternative to fixed-wireline broadband. Starry has developed and deployed proprietary fixed 5G wireless technology that utilizes millimeter wave spectrum to connect consumers to affordable, high speed, gigabit-capable wireless broadband. Starry's ability to provide wireless last-mile connectivity, at a nearly two-kilometer range from our base stations, without the need for direct line-of-sight, offers a major advantage over traditional fixed-wireline providers, enabling Starry to offer broadband access at a fraction of the cost of current providers.

Starry was founded in late 2014 as "Project Decibel" by a team of talented hardware, software and RF engineers who began work on developing millimeter wave technology that could deliver reliable, gigabit-capable connections in dense urban environments. Starry has created and built a full-stack technology consisting of a network-node ("Starry Beam"), a home receiver ("Starry Point") suitable for single family homes or multiple-dwellings ("MDUs"), and an in-home, touchscreen Wi-Fi access hub ("Starry Station"). In 2016, Starry sought and was granted by the FCC experimental market test authority licenses for the 37.0 to 38.6 GHz bands in 18 markets.

Starry has performed extensive tests to characterize the performance of these bands, to test weather, foliage, and seasonality impacts in both urban and suburban environments. In the late summer of 2016, Starry launched a closed beta in the Boston area and more recently, expanded its deployment in Boston, passing more than 240,000 homes in the metropolitan area. Starry is now testing various business models for last mile broadband in buildings and neighborhoods across several urban areas.

Starry is requesting renewal of its experimental license across most of the markets in which it is currently testing or has plans to, and is seeking to add a number of smaller-sized markets in order to continue testing performance of these bands across a diversity of markets that range in population density, demographics and topography.

As required by the grant of this license, Starry has prepared this second progress report which provides the Commission with a window into our learnings over the past 18 months.

## III. Background: Starry's Technology Approach

Starry's technical architecture includes three key components: Starry Beam, the network- node, which communicates using millimeter wave spectrum to Starry Point, the at-premise transceiver, which communicates to Starry Station, the in-home WiFi hub. In addition to these network building blocks, Starry is also developing low cost relay systems to add coverage in extreme non-line-of-sight conditions.

Starry Beam utilizes an active phased array for Point-to-Multipoint consumer internet access. By taking the innovative approach of utilizing available 802.11ac baseband technology

in our infrastructure, Starry is able to marry these two technological approaches to create a highly efficient and extremely low-cost internet delivery system using millimeter waves. This is a hybrid approach to beamforming which is especially efficient and practical for millimeter waves due to the small sizes of antennas.

Designed and developed in-house, Starry's full-stack technology approach enables the company to have transparency into the performance and stability of the Starry internet service, from node to home, ensuring a better overall quality of customer care.

Starry's key technology innovations include:

- Innovative approach to baseband radios in infrastructure: utilization of 802.11ac radios with 5 Gbps per beam sector with MU-MIMO (15-20 Gbps per site) covering approximately 2 km in near-line-of-sight conditions and 1 km in non-line-of-sight conditions.
- Ability to transition to 802.11ax which will enable ~45-50 Gbps per site.
- Deployment of active phased array for consumer internet.
- Hybrid multi-beamformed Rx & Tx.
- Starry Beams cover 120-degree sectors with an effective range of nearly 2 km, after taking into account rain fade, foliage and reflections. Free space range in line-of-sight conditions is approximately 10 km.

Starry's second generation technology, Gen 2, for the base station and at-premise transceiver, which is currently in development and production for Q2 2018, will dramatically decrease the cost of both pieces of equipment and increase capacity, further driving down passing costs and increasing the efficiency of Starry's total technology stack. Our Gen 2 consumer side equipment incorporates Starry's own Active Electronically Steered (Phased) Array ("AESA") and transceiver ICs. Our Gen 2 base station equipment incorporates 802.11ax technology with OFDMA & additional MU-MIMO functionality, further building throughput.

Additionally, new design iterations for Starry's Gen 2 transceivers for single family homes and MDUs shrink the form factor of our equipment, making it easier to deploy and more community-friendly for challenging sites, such as historic districts. Starry is also readying an

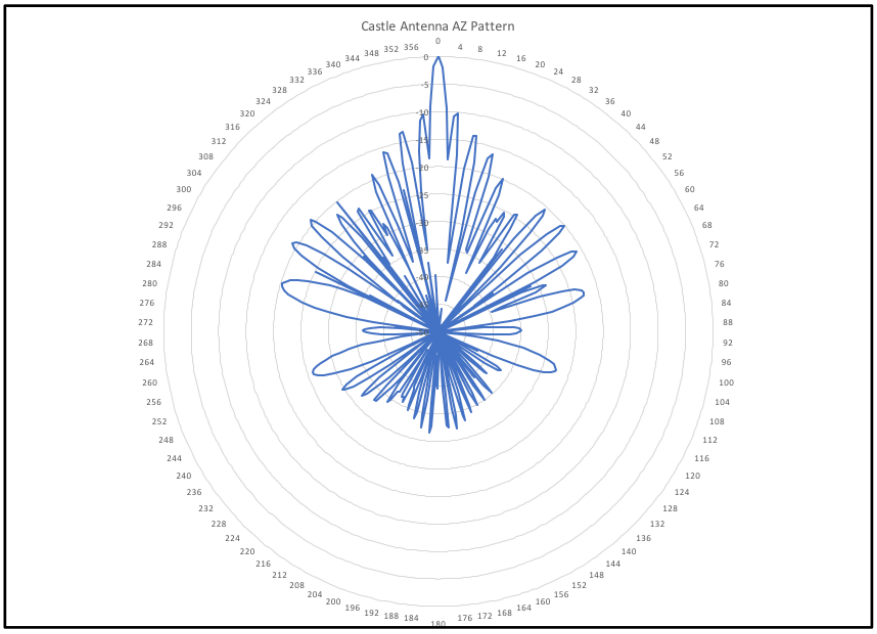
intermediate-range base station called Relay, which has an even smaller visual impact than the zoning-friendly, 18” x 18” design of our full range base station.

The ability to drive down the cost of both the base station and the consumer-premise equipment (“CPE”) is a critical factor in Starry’s success and makes the deployment of 5G networks not just an aspiration, but a reality. Today, the cost of building a fixed-wireline network is approximately $2,000 per home passed. At today’s current economics, taking into account the relatively low-volume of equipment we currently manufacture, Starry’s passing costs are approximately $20 per home passed. With the advances in our Gen 2 technology, we are confident that we can lower the passing costs to below $12 per home passed in 2018.

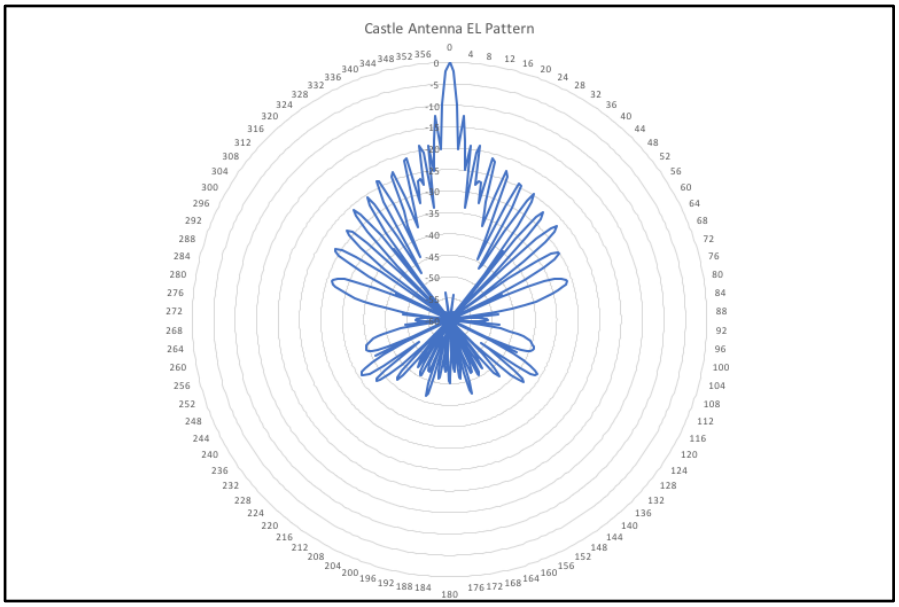
Today, each Starry Beam can serve approximately 1,000 subscribers. Each deployed site typically contains 3 to 4 base stations (each its own sector); in aggregate, each site today can serve between 3,000 and 4,000 subscribers with approximately 20 Gbps of capacity. We expect that that capacity will increase in our Gen 2 technology to approximately 40 Gbps per site with the use of advanced .11ax standards. We expect CPE costs to decline rapidly to even more attractive levels in 2018, enabling a robust business case in both multi-family and single-family residences with as little as 4% to 5% market penetration.

The FCC’s experimental market test authority license has allowed Starry to test and better understand market dynamics for new access networks, from gaining valuable technical data on how millimeter wave bands behave in a variety of environments and weather conditions, to better understanding the barriers to deployment for siting network equipment. Additionally, Starry has gained valuable experience and insight into barriers to deployment in MDU’s as well as market reaction to pricing and speed plan offers. Continuing to develop a better understanding of these dynamics and what strategies are most successful at enabling 5G fixed networks will lay the groundwork for future network providers to emerge and provide a diversity of options for consumers.

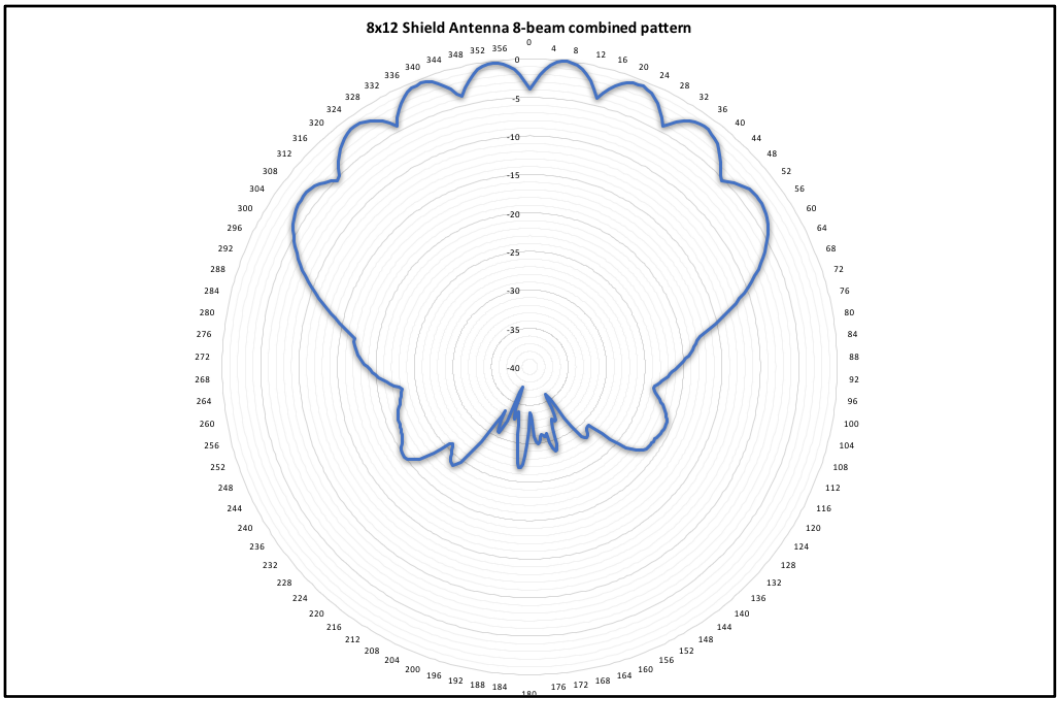
## IV. Starry: Field Tests & Results




*Above: End Point Antenna Pattern in Azimuth (degrees)*

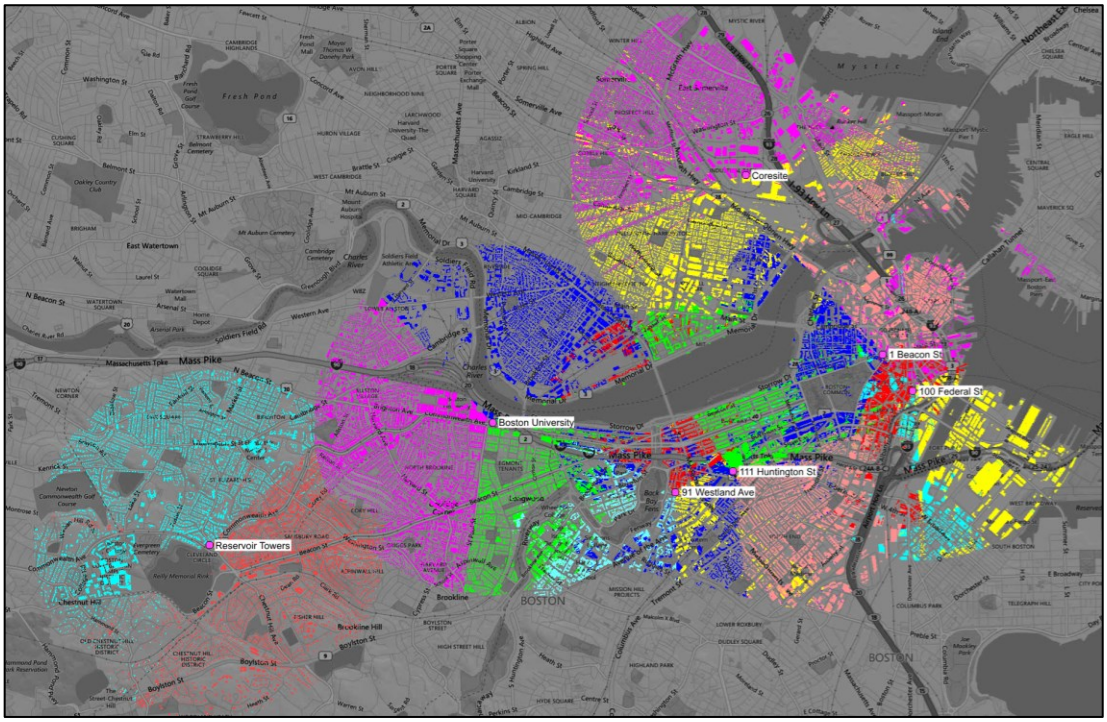



*Above: End Point Antenna Pattern for Elevation (degrees)*




*Above: Effective Antenna Gain of Base Station Sector (Starry Beam) in Azimuth, composite of all MIMO beams*

## Resulting Coverage for Seven Physical Base Station Sites in Boston Using the Above Base Station Antenna Patterns




*<u>Above</u>: Colors above indicate individual areas served by a single base station. Colors indicate area has coverage.*

## V. Starry Path Loss Models

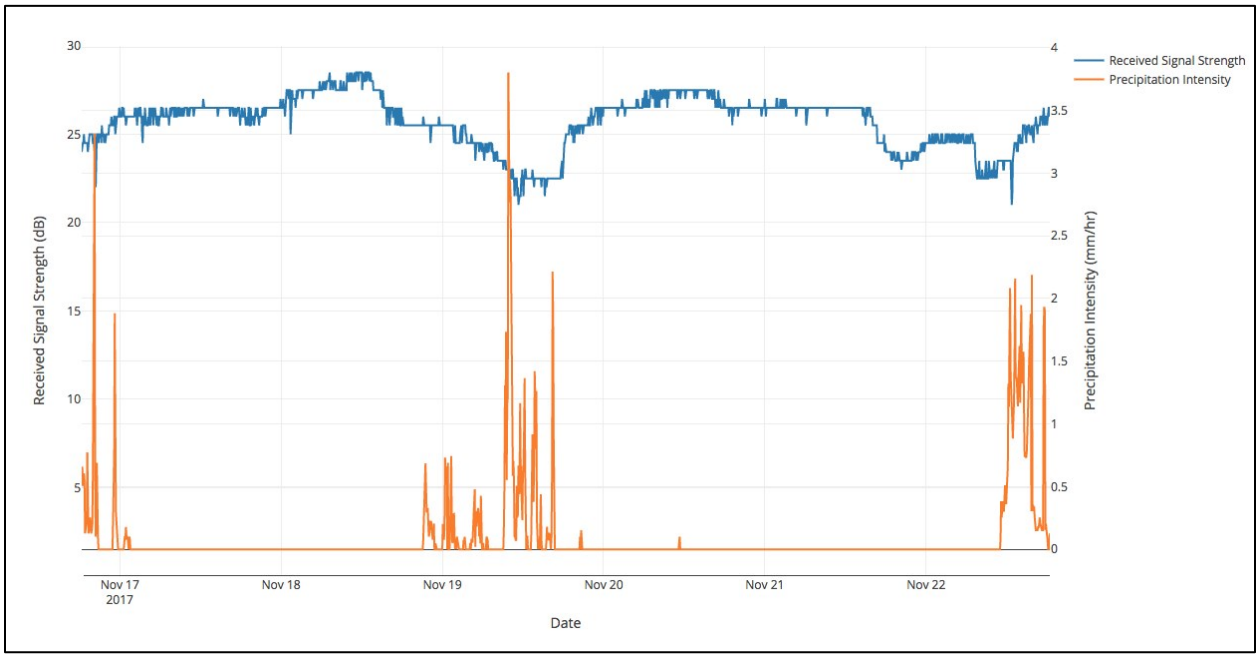



*Chart above: Observed effect of significant localized storm precipitation on 1.2 km link in Boston, Mass., November 17-22, 2017.*

### Sample Link Budget (from Hub to End Point):

| Parameter | Typical | Unit |
|---|---|---|
| **Transmit EiRP (average over Az)** | +56 | dBm |
| **Receiver Sensitivity (256 QAM as example, 5/6 LDPC, 1700 Mbps PHY rate/2SS)** | -60 | dBm |
| **Rx Antenna Gain** | 30 | dB |
| **System Gain** | 146 | dB |
| **Path Loss (1000m)** | 124 | dB |
| **Margin** | 22 | dB |

## VI. Network Deployment: Opportunities & Obstacles

In building its network, Starry has gained valuable insight into the opportunities and obstacles presented at the municipal level for siting and deployment of new wireless equipment. Starry typically deploys its base stations on vertical assets – either managed rooftops or towers – that are 100 feet or higher in elevation. A key factor in speeding the deployment of network equipment is size. Starry purpose-built its base stations and transceivers to be compact in size in order to reduce barriers to siting that often plague larger equipment installations. By shrinking the size of our base stations to 18 inches with no additional cabinet or external equipment, Starry believes it will be able to reduce the friction often encountered during the municipal permitting process. Additionally, by developing a variety of form factors for the Starry transceiver and making it small, compact and highly concealable, Starry has also reduced time to deployment for the at-premise equipment. The design of our hardware is a critical part of enabling a rapid and easily scalable deployment strategy.

A delay in any part of the chain of deployment increases costs at every step in the process. And even with the most thought-out planning process, siting and deployment delays are inevitable.

Even though Starry understands the risks and obstacles of wireless network deployments and has worked to minimize the impact of its deployment, Starry's deployment process is still a lengthy exercise in risk management to minimize delays. Starry's process begins with site identification. It sounds simple enough, but because of the insidious impact of unexpected and unforeseen delays, it forces Starry to evaluate and analyze over a dozen potential deployment sites in order to yield one functional site that has been pre-determined to have the least amount of "delay risk" associated with it. Once the site is identified, then the process of negotiating a lease begins, which can take several weeks or months, depending on the type of site and owner. Once a lease agreement is in place, then plans for pulling or leasing fiber and electricity to the site are put into place, and the appropriate applications for permits and review (local and federal) are submitted, a process that can take several months. This entire process involves the work and time of company project managers, lawyers and

operations staff. And even if all moves according to plan, the process still requires weeks, if not months of diligence.

In infrastructure deployment, there is one certain truth: time is money. In Starry's experience, each day that a project runs behind schedule, the cost of personnel, materials and loss of potential revenue increases. Those costs are compounded the longer the delay. Unexpected delays can also wreak havoc on deployment timelines and equipment supply chain. An unexpected delay in this process of 30 days can translate to a delay of 45 days or more for our business, due to this domino effect. And for every month that a site deployment is delayed, it costs our company thousands of dollars in site rental fees and other related costs. Multiply that over multiple sites in multiple cities and delay costs can become a significant financial drag, an added "tax" on companies, not to mention a detriment to our customers who must wait longer for service. This is why Starry invests in a tremendous amount of contingency planning upfront to head off unexpected delays, which itself carries substantial costs. We understand that this is a cost of doing business in infrastructure deployment, but those resources ideally would be invested in technology development, not diverted to risk managing site acquisition and deployment.

For example, in Washington, DC, Cleveland, Seattle and New Jersey (metro NYC), the permitting process was estimated at 30 days by the local municipality. However, the reality is that the permitting process took 60-90 days, 2-3 times longer than anticipated in each of these markets. The permits were for standard issue items such as electrical and basic construction and there were no defects or issues with the permits filed. The length of delay was arbitrary and not related to Starry; the permits were simply delayed due to internal municipal processes. For example, in Washington, DC five different permitting bodies were required to review Starry's permit application, some multiple times. In Seattle, the municipality mandated a new requirement for construction drawings that our local vendor had never encountered previously, even though the tower location was already pre-zoned and had similar wireless equipment present.

## VII. Market Deployment Status: Boston

In late summer 2016, Starry launched a closed beta in the Boston area to test service to consumer households. Starry's initial beta targeted areas where the population density is a minimum of 1,000 homes per square mile. Starry's initial beta sought to build on and further confirm the results of the experimental data gathered in the previous months. Since our launch, we have tested a variety of weather and foliage conditions in a variety of neighborhoods throughout Boston and Cambridge. In addition, Starry's network was stress tested against the winds and rain of Hurricane Jose in September 2017 and performed well without interruption in service to consumers.

Presently, the Starry Boston installation provides coverage in portions of Back Bay, Beacon Hill, the North End, Charlestown, Cambridge and Somerville, Massachusetts, passing approximately 240,000 homes. Consumers in Boston are offered a monthly, no-contract, no installation fee, no data cap plan of 200 Mbps down/up for a flat rate of $50 per month, all inclusive of equipment and other fees. Starry's penetration rate across all deployed neighborhoods in Boston is 18%. In certain MDUs, Starry's penetration rate exceeds 50%. Starry has experienced the most success in buildings and areas where there was previously only one choice in internet providers and in early days is targeting areas where there is no competitive choice for broadband.

In the homes that Starry serves, three critical data points have emerged:

- **Consumers are increasingly craving affordable broadband-only services.** Our customers are generally considered "cord-cutters" – consumers who have chosen to forgo traditional television/internet/phone bundles for broadband-only access. Often, when presented with only one choice in provider, these consumers will pay for a "triple play" package because it is the only way for them to access premium broadband speeds at reasonable prices. Yet, they only utilize the broadband portion of the triple play, choosing to cobble together a variety of over-the-top ("OTT") video services for their consumption.
- **Data consumption is rapidly increasing with the advent of OTT 4K video, the size and sophistication of software upgrades for connected devices and the**

**number of WiFi-connected devices currently present in the home.** To date, 20% of Starry subscribers consume between 530 gigabytes to 1.4 terabytes of data per month. The median Starry subscriber consumes in excess of 350 gigabytes per month. Based on this data, shown in more detail below, we reasonably anticipate that data consumption will continue to rise at a fast pace.

- **Even though Starry has built a gigabit-capable broadband network to consumers, we have not observed a demand for gigabit broadband for individual premises.** With speeds of 200 mbps symmetrical, we have found that most households are more than well-served at this level. We will continue to test and experiment with additional speed tiers in new markets, but our initial observation is that gigabit service is not at the forefront of consumer demands.

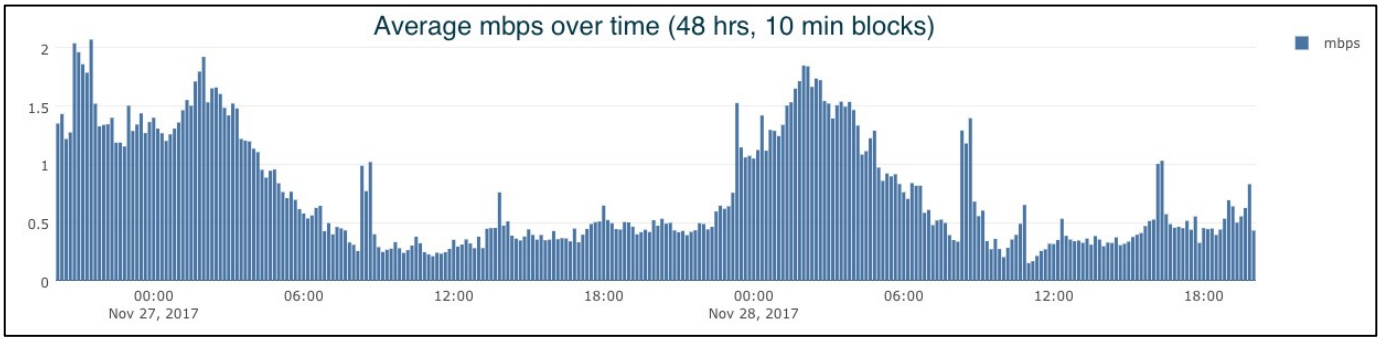



*Chart Above: Average Individual usage rates (Megabits per second for a 10-minute interval of a random sample of 200 Starry Internet users from November 27-28, 2017. Time zone is GMT.*

Starry is also testing consumer-oriented home installation processes. Starry's installation and customer care process is uniquely designed with the customer in mind. From enabling the customer to pick their own installation service time, to customer installers who communicate specific arrival times and don foot booties before they enter the home, showing respect for the customer is at the core of Starry's care approach. Starry has also tested on-the-spot installations within buildings, installing service immediately upon an in-person sign up.

Additionally, Starry installers, once on the premise, perform WiFi performance tests throughout the home to ensure reliable whole-home coverage and work with the customer to connect and test all their WiFi-connected devices before completing the install process. Starry's white-glove approach aims to reduce the customer frustration and friction often associated

with a typical service call. In Boston, Starry has a 98.5% 5-Star Rating (highest possible) for all installations. Starry continues to refine and improve its customer installation process with a goal of maintaining 100% satisfaction across all of its customers.

## VIII. MDU Market: Challenges and Opportunities

As Starry expands its test deployment in Boston and other cities, we are learning firsthand of the challenges and opportunities presented by a marketplace that has long been dominated by one incumbent provider. Overwhelmingly, it has been our experience that both individual consumers and property owners/managers crave competitive choice in broadband. However, their efforts to gain choice are often hamstrung by practices employed by incumbent providers. Today, exclusive marketing agreements between broadband providers and MDU building owners and managers in practice act like exclusive access agreements (that are prohibited by the FCC) and they significantly hinder the ability for new entrants to provide broadband service to residents of MDUs, to detriment of residents.

From our experiences in the field, building owners and managers enter exclusive marketing agreements often in tandem with revenue sharing schemes or a "door fee" arrangement with the only service provider available in their area. While marketing exclusivity agreements do not explicitly bar other broadband providers from providing service within a building, the overly restrictive language and threatening tone leaves building owners and managers with the impression that they will face litigation for simply allowing their residents a choice in internet providers. MDUs working to provide Starry Internet service have received cease and desist letters from incumbent providers that overstate the legal restrictions in the marketing agreements, attempting to enforce them like exclusive access agreements. Unfortunately, these scare tactics are typical for the market. We have found that 100 percent of MDUs with 75 or more rental units have exclusive marketing agreements and/or revenue sharing or door fee agreements in place with an incumbent internet access provider. In our experience, exclusive marketing agreements do not provide MDU residents with any clear benefits. However, they do discourage and create massive barriers to competition.

Starry is fortunate to be a well-capitalized startup with an experienced sales and operations team in place. While exclusive marketing agreements have posed significant challenges to expanding our deployment, our teams have found creative ways to work with MDU owners and managers to allay their fears of retribution from incumbents and provide their residents with a competitive broadband alternative. And while Starry is fortunate to be able to address these challenges head on, often with the vocal support of motivated consumers who want a choice in internet provider, they cost the company deployment time and financial resources. Unfortunately, in some cases, our teams cannot overcome the challenges posed by these agreements and a building may go unserved.

## IX. Market Deployment Status: Additional Markets

Starry is in the process of expanding its footprint beyond the Boston market. Prior to the end of Q1 of 2018, Starry will establish a beta presence in 16 additional markets including Los Angeles; New York; Houston; Denver; Seattle; Dallas; Cleveland; San Francisco; Washington, DC; Philadelphia; Miami; Minneapolis; Detroit; Atlanta; Indianapolis; and Chicago.

Key goals of the beta in each of these markets is to understand in more detail the impacts of regional weather and foliage variations and urban and suburban topography on service to both MDUs and single family homes. Augmenting our current data sets with new markets will provide a more robust understanding of how these bands perform in a variety of conditions outside of the Northeast. Additionally, Starry will also test new pricing models and speed plans to better understand consumer demand and usage. Starry will continue to target non-competitive areas where only a single provider is currently available to consumers.

# Market Status

*Updated November 30, 2017*

| Market | Status | Projected Closed Beta Launch |
|---|---|---|
| Los Angeles, CA | Base station installation construction near completion. First Beam in operation by end of November 2017. | December 2017 |
| Washington, DC | Base station installation construction commences December 2017, with Beam in operation by mid-December 2017. | Late December 2017 |
| Cleveland, OH | Base station installation construction commences at end of November 2017 with Beam in operation mid-December 2017. | Late December 2017 |
| Chicago, IL | Base station installation construction commences mid-December 2017, with completion by EOY. | January 2018 |
| New York Metro | Base station construction to commences in December 2017, with completion by EOY. | January 2018 |
| Houston, TX | Base station installation to commence before EOY. | January 2018 |
| Dallas, TX | Base station installation construction to commence in December with completion by January 2018. | January 2018 |
| Denver, CO | Base station installation construction to commence in December with beam in operation by EOY. | January 2018 |
| Seattle, WA | Base station installation construction to commence in December with beam in operation by EOY. | January 2018 |
| Detroit, MI | Base station installation construction to commence in December with beam in operation by EOY. | January 2018 |
| Atlanta, GA | Base station installation construction to commence in December with beam in operation by EOY. | January 2018 |
| Indianapolis | Base station installation construction to commence in December with beam in operation by January 2018. | January 2018 |
| San Francisco, CA | Base station installation construction projected to begin in January 2018, pending permitting process. | February/March 2018 |
| Philadelphia, PA | Base station installation construction projected to begin in January 2018, pending permitting process. | February/March 2018 |
| Miami, FL | Base station installation construction stalled due to hurricane activity. Construction projected for January 2018, pending permitting process. | February/March 2018 |
| Minneapolis, MN | Base station installation construction to commence late December, with beam in operation by January 2018. | January/February 2018 |

Additionally, Starry is requesting experimental test market authority for the following cities: Manchester, New Hampshire; Portland, Oregon; Sioux Falls, South Dakota; Phoenix, Arizona; and Memphis, Tennessee, to better understand market conditions across a variety of city sizes and demographics. Due to a variety of circumstances, Starry no longer requires market test authority for Leesburg, Virginia.

## Creating a 5G Technology Ecosystem

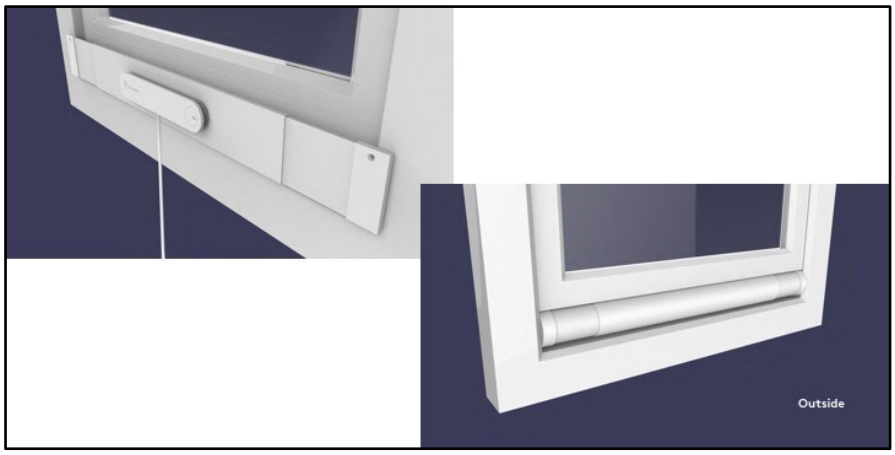
Starry recognizes that in order to accelerate broadband deployment using fixed 5G wireless networks, an ecosystem of service providers and hardware manufacturers must emerge in order to meet the demands of a capacity and bandwidth-hungry future. Today, 5G technology development is happening in silos with the mobile ecosystem controlling the direction and pace of innovation and product development. While the use cases of post-standard 5G remains under development, with mobile use cases still years away, the most practical near-term use is fixed wireless broadband access. However, the barriers to market entry are cost-prohibitive, particularly from a technology standpoint, and few companies are willing or able to challenge the incumbent structure.

Starry sees an opportunity to accelerate adoption and deployment of these broadband networks to meet the FCC's goals of expanding broadband deployment and access, by leveraging our pre-standard 5G technology using ubiquitous IEEE 802.11 protocols. Starry is investing in ways to make our access technology more widely available across a diverse set of hardware manufacturers and emerging network providers. By democratizing access to these 5G technologies, the costs of equipment and deployment of these new networks will be driven down dramatically, lowering the barriers to entry for new service providers, expanding the deployment of new access networks providing multitudes of benefits for consumers. Starry plans to make a more detailed announcement of its plans in Q1 of 2018.

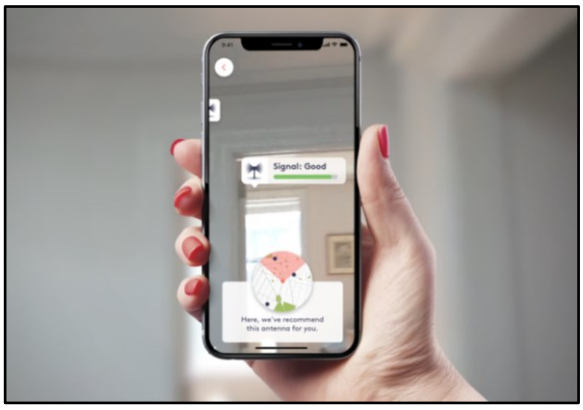
## Looking Ahead: 2018 and 2019

While Starry's work developing 5G technologies across a number of areas has been groundbreaking to date, we believe that the technology is still nascent and will benefit from additional innovation and testing. Starry has developed definitive plans to market-test the following broad areas over the next two years:

1. **The ability for subscribers to self-install low cost CPEs.** Below is an example of a low-profile window-mount device that can be self-installed. There are numerous challenges in accomplishing this objective. A critical challenge is the mechanism through which a customer can identify the availability of a quality network and have a rapid and satisfactory install experience. Starry is actively developing augmented reality techniques to help the consumer visualization of mmWave propagation and signal availability. An example of the technology we are building is below.




*Above: Starry Point for Single Family Units: Window-mount, Self-install CPE*




*Above: Screenshot of augmented reality application that helps consumers identify an available network for consumer self-install process.*

2. **To extend coverage in NLOS and *extreme* nLOS conditions, a multi-tier network is the most robust approach.** Starry is developing low-cost, mini-base stations or digital "Relays" that incorporate electrical steering and provide coverage extension for up to 600 meters in **NLSO and *extreme* nLOS** conditions.
3. **To maximize spectrum usage and efficiency, testing a variety of spectrum sharing techniques will ensure that mmWave spectrum is put to use.** Starry expects to continue to develop spectrum sharing techniques, and is prepared to work within the industry and federal community to help develop a consensus approach. Specifically, in a two-tier network, where both the front-haul and access network are operating in the same band, it presents a unique opportunity to observe future shareability. It also provides a test-bed for both federal and commercial users to perform actual tests in the field and develop concrete ideas around spectrum sharing using coordination, altitude and cognitive "smart radio" techniques.

## Conclusion

Millimeter wave spectrum offers enormous opportunity to expand broadband access and competition and Starry has proven, through its innovative technology approach, the ability to put these bands to work today to expand broadband access and competition. The opportunity to continue to test, characterize and provide service in these bands through the FCC's market test authority license provides valuable data and the validation necessary to continue our investment in developing the next generation of 5G communications technology and provides confidence in the market for further development and capital investment in building the 5G networks of the future.