TELECOM INFRA PROJECT

Path to Commercialization: From Technical Trial to Commercial Pilot

Execution Summary and Lessons Learned

mmWave Networks Project Group

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Table of Contents

1 Introduction 6
1.1 Overview of Worldwide mmWave Field and Lab Trials 7
1.2 Fixed Wireless Access: a Short Primer on Customer Perspective 7
2 Virtual Fiber Field Trials in Hungary 8
2.1 Setting the Scene 9
2.2 Field trial users' baseline data and expectations 10
2.3 Installation and Service Provisioning Plus Involved Challenges 11
2.4 Network Installation and Customer Activation Processes 13
2.4.1 Program Approach, Network Installation Processes, & Findings 13
2.4.2 Customer Activation Processes and Findings 17
2.5 KPI Report 21
2.5.1 KPI measurements and results 23
2.6 Weather Impact Analysis on 60 GHz mmWave Technology 25
2.6.1 One-Hour Sampling 25
2.6.2 Ten-Second Sampling 27
2.6.3 Raw Data Sampling 29
2.6.4 Conclusion 30
2.7 The Customer Perspective: Perceived Performance of the Tested Service 30
2.7.1 First Impressions After One Month of Using the Service 31
2.7.2 Results After > Six Months of Use: High Satisfaction Rate Throughout the Entire Field Trial 32
2.8 Qualitative Customer Research Reveals Areas for Improvement and Important Success Factors 33
2.8.1 Outdoor Unit Design 34
2.8.2 Easy Installation, Support, and Service 38
2.8.3 Indoor Connectivity – Smart Wi-Fi 40
2.8.4 Summary and Implications 41
3 Moving to Commercial Pilot – Some Practical Pointers 43
3.1 Planning, Availability Check, and Presales Consultancy 43
3.2 Distribution Node (DN) – Mounting and Installation 44
3.3 Customer Node (CN) and CPE – Indoor Positioning, Installation, and Cabling 45
4 Summary 45

Glossary

CE	consumer electronics
CN	customer node
CPE	customer premises equipment
DN	distribution node
FWA	fixed wireless access
ICMP	internet control message protocol
IPTV	internet protocol television
ISP	internet service provider
LOS	line-of-sight
QoS	quality of service
mmWave	millimeter wave
OTS	off the shelf
STB	set-top box
WTTH	wireless to the home
ZTO	zero-touch operations
ZTP	zero-touch provisioning

1 Introduction

To build a gigabit society, we need to be able to provide every household with high speed internet connectivity. This covers urban, suburban, and rural areas having many differing characteristics—and therefore challenges—to providing such connectivity. Meeting such challenges requires us to provide a measured, flexible response based on a smart toolset of possible solutions.

In this report we will show how fixed wireless access (FWA) using last mile, 60 GHz millimeter wave (mmWave) technology can help solve this connectivity ecosystem challenge while proving to be a valuable component of this smart toolset.

FWA serves this mission by accelerating the rollout speed. Moreover, 60 GHz mmWave provides a high-capacity, cost-effective solution in creating both a scalable distribution network as well as in connecting to customers' premises. Indoor connections (the way customers connect to the internet) at present would be provided using standard Wi-Fi.

In this best-practice report created by the mmWave Networks project group, we will focus on the required equipment, what we learned regarding customer site installation, and other findings from the Hungarian field trials of FWA/WTTH.

These include the following:

- Network installation and customer activation processes
- A weather impact analysis on 60 GHz mmWave technology
- Matters pertaining technical components installed at customers' premises
- Customers' perception of the installation process, overall tested service performance, and impacts on their internet behavior

This report concludes with some practical pointers as one Hungarian trial moves toward commercial pilot, in addition to a look at some trial findings and the move to commercial pilot. These could inspire additional inputs on the way to making mmWave WTTH or similar approaches a reality.

1.1 Overview of Worldwide mmWave Field and Lab Trials

The goal of the mmWave Networks project group is to address the constantly growing demand for bandwidth by delivering gigabits of capacity more quickly, easily, and cost-effectively as compared to fiber deployments.

Several mmWave lab and field trials have been conducted worldwide to test technical feasibility while gaining market and customer feedback. Fixed wireless access (FWA) and public Wi-Fi are key scenarios that have been tested.

Trial types and locations are depicted below:

Figure 1 – Global trial locations and types

The YES test in George Town, Penang (Malaysia) is particularly interesting. It is an early and successful trial in offering both a FWA high-speed broadband connection (aimed at business customers) in addition to free of charge public Wi-Fi. Here there was the obvious challenge of providing high-speed connectivity to a dense urban UNESCO World Heritage area, where performing civil engineering to install fiber is not an option. The findings from this setup are included herein and are of particular interest.

1.2 Fixed Wireless Access: a Short Primer on Customer Perspective

FWA can function using mmWave technology on a freely available 60 GHz frequency, permitting fast transfer of large data amounts. Using wireless to bridge the last mile, we used it to rapidly and flexibly supply households and small businesses with broadband—without any construction work such as digging or drilling.

Three layers have to be taken into account on the customer's side; these influence overall performance and the customer's perception of the service.

- Access points must be installed on streetlights or similar fixtures. Such distribution nodes (DN) deliver the signal to the house. To receive it, customers need a weatherproof outdoor antenna installed to serve as the customer node (CN). The CN must have a line-of-sight to the DN to enable access.
- The outdoor CN delivers the signal into the house via cabling that passes through an exterior wall. The cables provide power to the unit and relay the signal inside to the customer's Wi-Fi apparatus (CPE).
- The CPE provides the signal throughout the house via Wi-Fi.

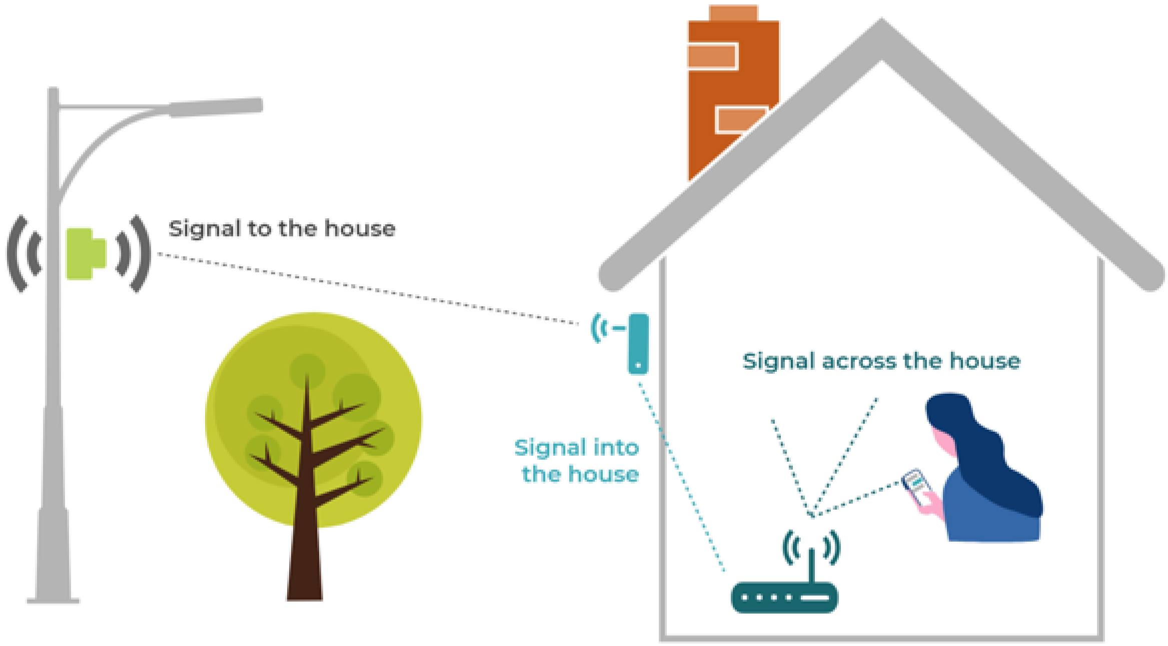


Figure 2 – Three steps to bring the signal to a customer

Due to similarities from a customer's perspective, to a large extent insights gained in user research are applicable and of value to other FWA technologies.

2 Virtual Fiber Field Trials in Hungary

Deutsche Telekom and a subsidiary, Magyar Telekom (MT)—the largest telecom provider in Hungary—ran trials in that country. In evaluating FWA with 60 GHz as a high-speed, fixed broadband connectivity solution, it used the technology to connect homes where broadband was only previously available through copper/DSL.

Deutsche Telekom's Virtual Fiber innovation project explores the use of mmWave technology to wirelessly deliver fiber-like gigabit experience to customers. It is a complementary deployment model to traditional fiber, helping make rapid and flexible network expansions possible. The Hungarian field trials validated its deployment methods, activated a network, and evaluated technical performance in a real-life environment.

This section provides details regarding the service installation and provisioning steps needed to provide the community, in addition to user research and customer feedback results. The latter mainly refers to Márkó, as that location provided a larger sample. It also proved to be the more challenging setting, as we encountered non-MT customers with greater internet proficiency who were also highly dissatisfied with their current internet service.

We will also discuss measurements taken to determine possible impact of weather on network performance. While based on Mikebuda data, it should be applicable to other locations.

In this section:

- Obtain relevant field trial background information
- Take a walk through the network installation and customer activation process
- Review the trial KPI results
- See how weather measurements might possibly impact network performance
- Evaluate perceived service performance and other user insights
- Review important success factors and assess areas for improvement

2.1 Setting the Scene

Two Hungarian field trials were conducted in the municipalities of Mikebuda and Márkó, aiming to prove technical feasibility and test customers' acceptance. Both locations being considered underserved, they were also chosen because fiber deployment would have required major construction work.

Located in western Hungary about 70 km outside of Budapest, rural Mikebuda has about 650 inhabitants. Its purchasing power is moderate and its infrastructure underdeveloped. About 50 Magyar Telekom-friendly customers tested the internet service and IPTV.

Relatively well off, Márkó is suburban in character and has 1200 inhabitants. It has a developed infrastructure but did not yet have a Magyar Telekom presence. Around 100 households, none of which had previously been Magyar Telekom customers, were connected to the tested internet service. Generally speaking, Márkó customers had been highly dissatisfied with their current ISP due to low speed and instability. Therefore, test users eagerly participated in the field trial.

Table 1 – Overview of Hungarian field trials

	Overview of Trials in Mikebuda & Márkó, Hungary
Partners	• Deutsche Telekom • Magyar Telekom • Facebook

Timing	• 06/2018 – 10/2019
Use Case /MVP	• FWA: high-speed internet up to 1 Gbit/s: 500 Mbits/up and down • Magyar Telekom IPTV included in Mikebuda only
Target audience	• Residential households (B2C) • Some small business customers
Installed equipment	• Outdoor antenna • Cabling into and inside houses • Indoor gateway (router)
Technical setting	• 350 nodes installed • Meshed network with fiber backhaul • 150 households connected to high-speed internet service
Installation	• Performed by third party • DIY installation looked into during focus group discussions
Next steps	• Transition to commercial pilot to start by December 2019

The trials investigated the technical feasibility, processes, and customers' general acceptance of the wireless technology and required CPEs, in addition to their satisfaction level pertaining the service.

In both locations, a free of charge, high-speed internet service was offered; it included IPTV service by MT in Mikebuda.

2.2 Field trial users' baseline data and expectations

Telephone interviews provided insights into the test users' demographics, their current Internet usage behavior and their expectations of the tested service.

Table 2 – User baseline data and expectations

	Mikebuda	**Márkó**
Participants	Approx. 50 MT-friendly users	Approx. 100 households, not MT customers
Participant makeup	53% female, 47% male average: 41.4 years old	52% female, 48% male average: 45.5 years
Household size	48% with four of more members, 38% with children	54% with four of more members, 55% with children (above Hungarian average)
Housing situation	Majority living in single houses (homeowners)	Mixed building structures, predominantly homeowner

Education of participants	52% high school graduates, 23% vocational school graduates (below Hungarian average)	32% university or college graduates (above Hungarian average)
Internet speed @home (legacy)	68% described download speed as 50 Mbps and below (mostly 6 – 10 Mbps range)	Internet service download speed ranges from 1 – 5 and 21 – 30 Mbps for 70% of participants
Current internet usage behavior	• Basic internet users • Using download	• More advanced users • No usage requiring high-speed internet on daily basis • > 90% stated social media use or searching/surfing the internet more than once a day • Only 47% used live streams on a daily basis • Children are the most frequent and relevant internet users
Reason for trial participation	• Interested in fast internet service and the technology • Enjoyed free of charge internet use during field trial	• Highly dissatisfied with current internet provider • Frustrated to not have other fixed line internet options • Interested in fast internet service and the technology • Enjoyed free of charge internet use during field trial
Expectations in tested service	• Improvements in speed and stability over legacy internet	• Very fast, reliable internet connection available throughout house • Stability as a need was mentioned but rated lower than speed

2.3 Installation and Service Provisioning Plus Involved Challenges

Installation and Service Provisioning

Onsite installations in customers´ homes were mainly done by a third party. Technicians reviewed the location to define exact CN placment and line of sight toward the DN. The picture below shows all parts required for one installation:

- Antenna mount
- Virtual fiber radio unit (CN)
- Router

- PoE injector
- Power supply
- STB (media receiver) – *Used in Mikebuda only*
- Additional cable ducts and Ethernet cables were needed for some customers

Except for the media receiver (an STB), all were pre-production engineering units; this is why they appear bulkier than market-ready production units. A more discreet CN is used in the current Márkó commercial deployment.

Figure 3 – Component Overview

The STB was used exclusively in Mikebuda; only there did we offer IPTV as part of the package.

A brief installation and provisioning process overview follows. Greater detail appears later in this section.

Running through a cable duct, an Ethernet cable and power line had first been led by a technician from inside the house to the previously defined, exterior CN mounting location. The CN was then mounted to the customer's home; these were mostly placed under eaves since this incurs the least façade marring. Next, the cables were connected to the CN and interior endpoint, then securely clamped in place. After the technician checked the Ethernet connection using a cable tester, all power converters were installed and the CPE (e.g., router) was placed where the customer designated.

The service was provisioned immediately after installation. After checking and scanning the MAC address/serial number of the CN, it was added to the network management system. The link from the customer home to the DN was live. Subsequently acustomized configuration was remotely downloaded from MT to the customer's router.

Upon connection verification, a unique sticker was placed on the router; this included MT's customer care phone number and the router ID number. In the event of an incident, the customer could call MT and easily identify themselves by way of the router ID number. The final step was to perform both a 2.4GHz and 5GHz Wi-Fi interface speed test.

Challenges

Both locations had some line-of-sight challenges. Site survey and network design was required to avoid placing nodes in locations having limited visibility to other nodes and subscriber households. Trees required trimming in some cases, which necessitated negotiations with a few customers. All in all the challenge was manageable, as evidenced by healthy performance of the resultant network. Revealing itself as an opportunity for further improvement, this raises vegetation management as being an ongoing issue for maintaining stable network operations.

In terms of availability, power interruption is a main challenge. On occasion, power outages affected sections of the municipality—including the poles from which nodes draw power. In other instances, subscribers unwittingly unplugged power to their externally mounted CN.

As for wireless connectivity at customer sites, at present there is not an affordable, gigabit-range wireless solution for indoor use. For now this is their primary roadblock to true gigabit range access. Additionally, customers may experience connectivity problems because of interior home issues, such as especially thick walls. A solution may be to provide a distributed infrastructure, either meshed or wired. Since most customers almost exclusively use their devices over Wi-Fi, their experience is determined by such factors.

2.4 Network Installation and Customer Activation Processes

As with any other current technology, the timeline for network deployment and customer activation depends on several variables: customer availability, weather conditions, resource availability, subcontractors' agreements, and planning. Through the Hungarian trials experiences we could stand to mature our process and may be able to provide valuable inputs for similar deployments going forward.

This section looks at the phases and respective activities required to improve overall customer experience and accelerate network deployment.

2.4.1 Program Approach, Network Installation Processes, & Findings

Best Practice Program Deployment Approach

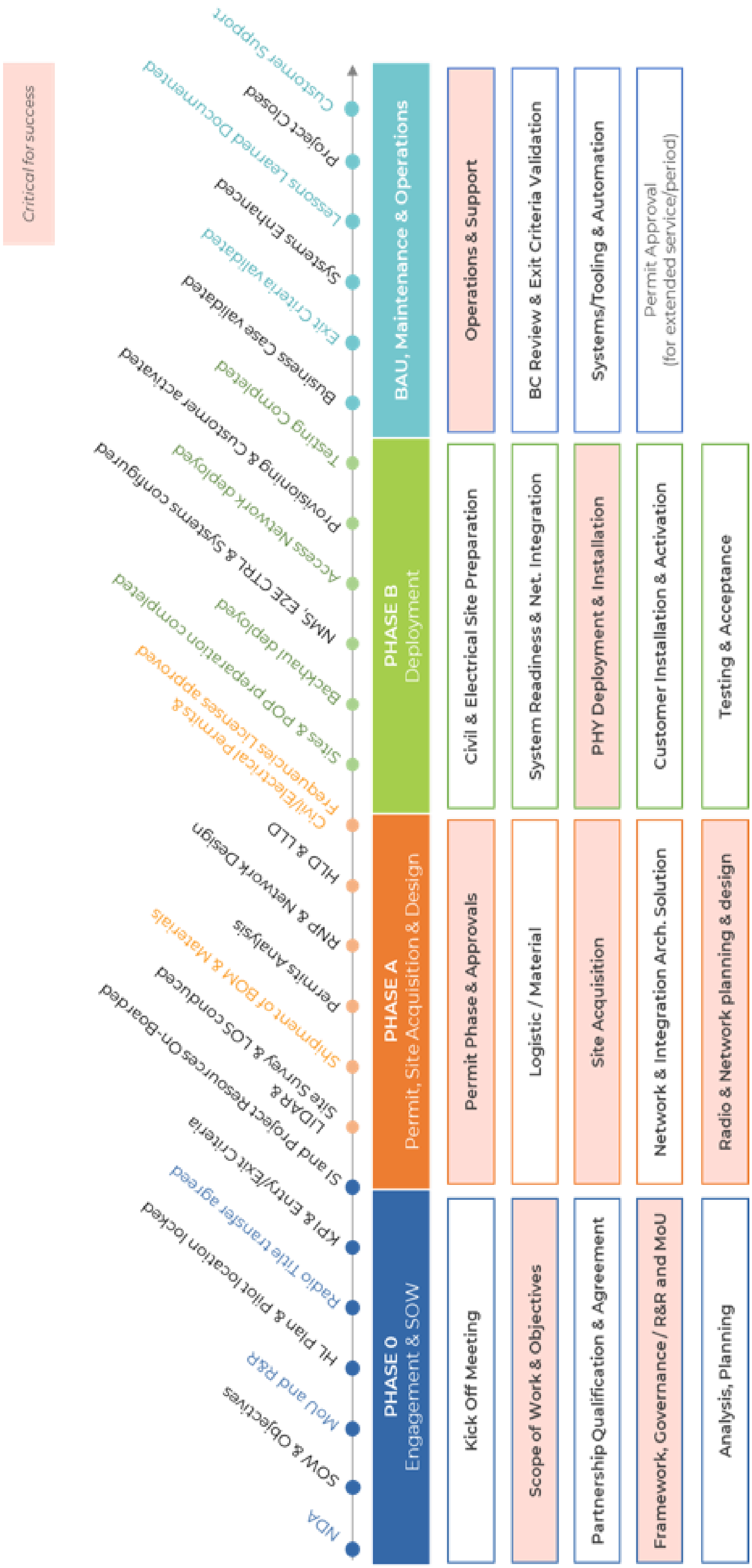
A comprehensive project plan is always dependent on local conditions and the country in which installation is to occur. Therefore this section does not consider dependencies between each activity. With the intent of minimizing risks and issues, instead the following approach provides a best practice example that highlights all required phases for a successful network deployment.

The overall program deployment has been divided into four main phases:

- Phase 0 – Engagement and SOW
- Phase A – Permit, Site Acquisition, and Design
- Phase B – Deployment

- Regular Operation – Maintenance and Operations

Table 3 – Process, phases, and milestones



Deployment findings from Mikebuda and improvements in Márkó

Along with process changes based on lessons learned in Mikebuda, improved tooling enabled us to accelerate installation in Márkó by about 50%. We required about the same amount of time to install the 38 distribution nodes (DN) on poles in Márkó as we did for the 23 DNs in Mikebuda.

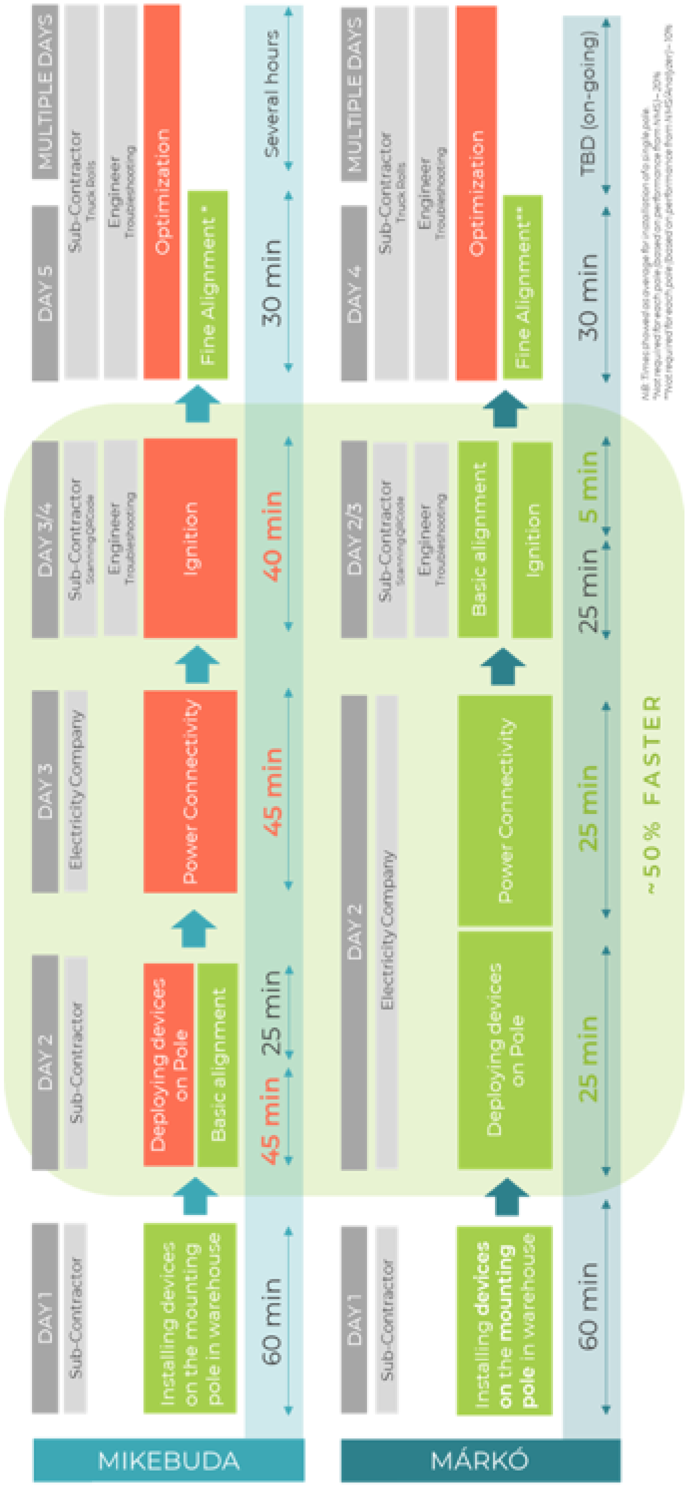


Chart 1 – Comparison of Network Installation Activities

Findings and measures used to save time

Time-Savings & Lessons Learned

20 mins saved	20 mins saved	20 mins saved
- **Concrete Pole** / faster install than wood pole. **(50%)** - **Sub-Contractor** with better deployment **experience** on street furniture. **(50%)**	- **20% of poles** in Márkó **didn't required double installation** to a 2nd Telecom pole by like in Mikebuda. **(55%)** - **Additional fuse panel** box (required because of local regulation) **preinstalled** in the mounting poles on DAY 1. **(30%)**	- **Bucket-Truck** rather than ladder. **(15%)** - Network **Topology programmed** in **NMS + SW Bugs solved. (75%)**

Potential Area of Improvement

Merge "Deployment devices on Pole" / "Power Connectivity" with Basic Alignment and Ignition

- Using the Terragraph Ignition mobile app permitted faster link ignition.
- Activities required to pole mount and power-up DNs on poles were scheduled to occur simultaneously using the same technician team.
- Using subcontractors with more experience in deploying on-street fixtures.
- The subcontractor used bucket trucks to connect power in Márkó, rather than a ladder as in Mikebuda.
- In Márkó, electrical contractors could install power together with the pole mount, so installation of separate junction boxes was not required. Contrast this with Mikebuda, where local regulations required installation of fuse panel boxes. A solution to accelerate deployment was the preinstallation of a junction box on a mounting pole in the warehouse.
- We did not use telecom poles in Márkó. But we did in Mikebuda, where we had to install a mount on each pole to house the power supply, then run a power cable across the street to the telecom poles where the Terragraph radios were located.
- It was easier to mount DNs on concrete poles rather than wooden ones. Márkó has 75% concrete poles, whereas Mikebuda only has wooden poles.

2.4.2 Customer Activation Processes and Findings

Herein we look at ways we optimized the customer activation process, then describe the hardware installation procedure followed by the service provisioning process. Table 4 shows the timing for each activity.

Findings and improvements

During the trial we were able to accelerate installation and customer activation by 55%. While we needed about 300 minutes for a single activation in Mikebuda, we were able to reduce that to 135 minutes in Márkó.

In addition, we improved the customer experience and reduced the overall timeline from eight (8) days to five (5) days by taking the following measures:

- We could reduce the required number of customer visits from four (4) to two (2) by:
  - ✓ Performing site surveys during sales activity rather than as a separate task
  - ✓ Completing the quick survey review during the installation phase
  - ✓ Testing hardware readiness in the warehouse rather than as a bespoke onsite activity
  - ✓ Making provisioning occur sooner after installation
- Better provisioning scripting tools helped avoid calls from onsite engineers to remote counterparts
- Using better subcontractors having greater experience and commitment for installation

Table 4 – Overview of activities and time needed to perform

Hardware Installation		Time (in mins)
1	Site survey	10
2a	Collection of material	10
2b	Preparation	15
3	Cabling	25
4a	External installation	30
4b	Internal installation	30
4c	Administration	10
	Total	**80**
Provisioning		
1	NMS configuration	10
2	Link activation	5
3	Router configuration	10
4	Tests	2.5
5	Customer documentation signature	5
6	Set up terminals, answer questions	10
7	Pictures	2.5
	Total Customer Activation time	45
8	Administration	10
	Total	**55**

Beyond these implemented trial improvements, costs could potentially be further reduced by permitting customer self-installation.

For more detail, please refer to [areas for improvements and important success factors](#).

Hardware installation procedure

The installation team conducts a site survey when it arrives at a customer's site. The installation team compares its findings with sales team intake data, discusses installation details with the customer, and agrees on a way forward.

Discussion details include router location, how cables will run from the CN to it (through the roof, attic, or a wall), and whether cable channels are needed. They assess the optimal CN location based on line-of-sight with the respective DN.

Next the team leader collects all requisite installation materials and completes required administrative tasks. The materials include the Terragraph radio, router, cables, power supply, antenna mount, and all ancillary hardware (e.g., screws, washers, cable holders). The leader enters serial numbers, MAC addresses, and any other component identification into an Excel spreadsheet template using a tablet device.

In tandem the other technicians prepare by unboxing and mounting the radios (and grommets), fixing connectors on one side of each cable, and getting the power supply and its connectors ready for installation.

The team then feeds the cable from the exterior CN location to the router inside the premises.

Table 5 – Images of site surveys




One team member sets up the internal network—including cabling, power supply, and router. Another fixes the antenna mount to the predetermined exterior location and mounts the CN, connects its cables, aligns the radio, and then installs the rain/bird protective casing.

Table 6 - Images of CN installation at customer location

After everything is installed, the team leader completes the Excel sheet with all requisite data and emails it to their competence center for further processing.

The team proceeds to the next address.

Provisioning

Being separate from the hardware installers, a follow-up technician visits to provision the customer's service and perform other related tasks. To this end the technician is forwarded the corresponding Excel data from the subcontractor's competence center—including the respective MAC address, the identity of the DN to which the CN is connected, and the CN's GPS coordinates. This data is used to establish the customer endpoint (site, node, and link) in the network management system.

Once the link is up, the technician requests router provisioning from an MT support engineer, who remotely provisions the service and configures the router. Next the technician runs speed tests on 2.4G/5G Wi-Fi and wired Ethernet interfaces, then photographs exterior portions of the setup for record control purposes.

The customer now signs off on the installation; if required, the techninican sets up the customer terminals and answers technical questions that may have arisen.

Here is an overview of the customer installation process timing, comparing the processes used in Mikebuda and Márkó:

Chart 2 – Customer Installation Process Comparison

2.5 KPI Report

We defined a few KPIs prior to the field test to assess its success or failure:

KPI #1 | Network Availability

Terragraph network availability at customer sites (up to CNs) should be at least at the 99.5% level of MT service availability.

- Testing using ICMP ping every 1 second
- Based on 7 or 14 days/period
- CNs are on (due to customer intervention this lets us exclude offline CNs from the calculation)
- Maintenance windows and power outages were excluded from the calculations

KPI #2 | Users Throughput

At least 95% of customers should have at least 25mbps simultaneous download capability. Bandwidth threshold was considered by measuring availability at the POP during the trial phase.

2.5.1 KPI measurements and results

Table 7 – KPI measurements and results

KPI #1 | Network Availability

✓ TG Network availability at the customer site (up to CNs) should at least be at the level of Magyar Telekom (MT) service availability 99.5 %

KPI	PERIOD	RESULTS	
DNs - 99.5 %	12th to 24th May	Mikebuda – 99.85% Márkó – 99.71%	PASSED

For more than 60 Days, DNs Network availability was meeting MT's KPI, in both Márkó and Mikebuda!

KPI	PERIOD	RESULTS	
CNs - 99.5 %	12th to 24th May	Mikebuda – 99.61% Márkó – 99.09%	PASSED

Test and results were affected by multiples issues in the MT Network, including power outages, MT Core Backhaul Issue, customers turning off CN's,and drops in the dashboard (due to lack of QoS). Despite these issues, the KPI was met.

KPI #2 | Users Throughput

✓ 95% Customers having – 25 Mbps DL to simultaneously

KPI	PERIOD	RESULTS
95% users | 25 Mbps DL to simultaneously	16th April to 3th May	PASSED

While we achieved MT's KPI as part of the testing, we stressed the network with speed up to 35 Mbps.
Results showed that we were able to achieve the KPI on most of the nodes but due to the lack of QoS, we saw drops in availability of the overall network as some links were getting bottlenecked.

KPI #1 | Comments regarding network availability results

Measured performance data show that network availability of the DNs was meeting the KPIs in both Márkó and Mikebuda for more the 60 days.

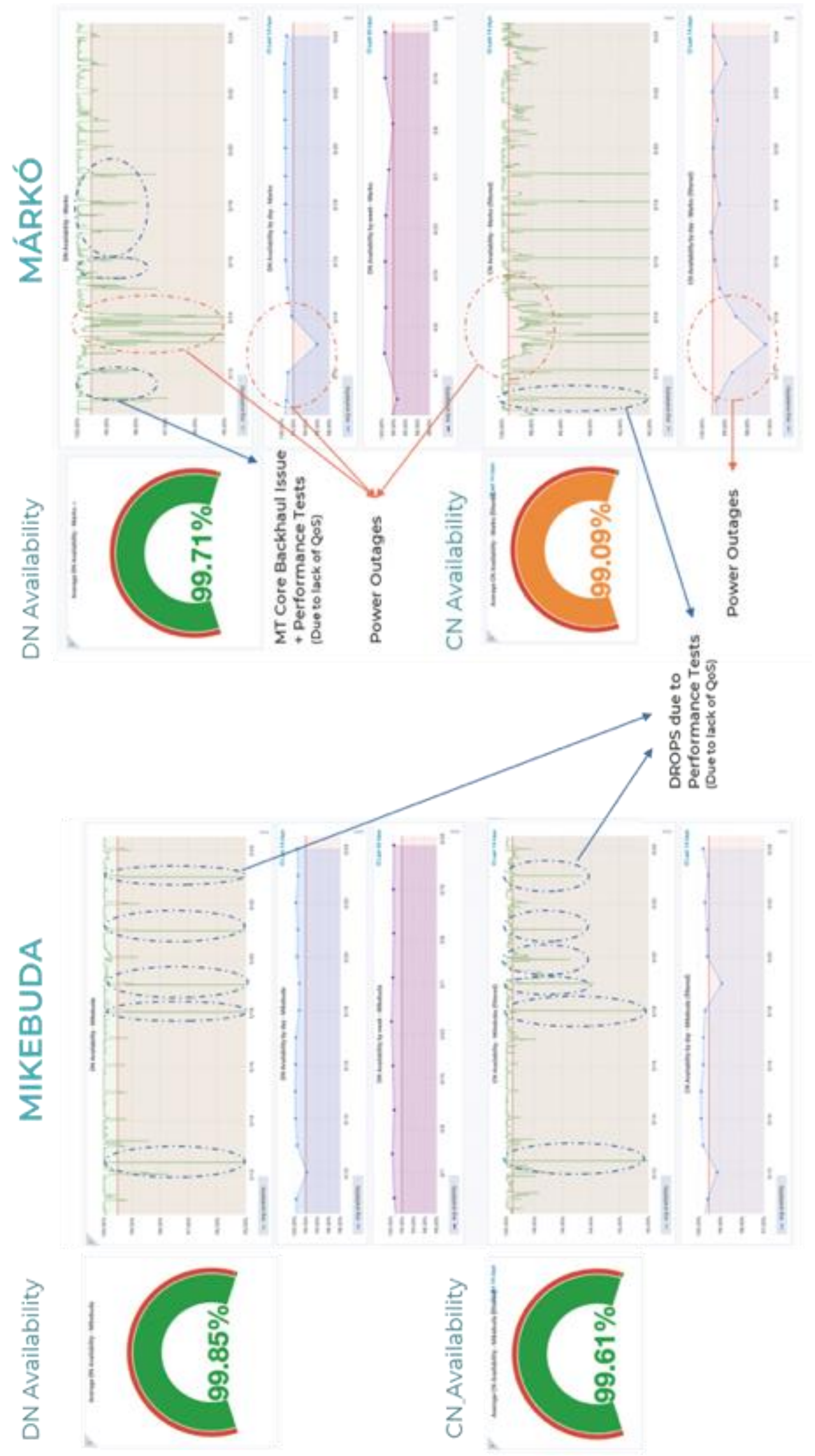


Figure 4 – DN and CN availability in Mikebuda and Márkó

However, test, analysis, and results were affected by multiple MT network issues. These included power outages, MT core backhaul issues, customers having taken their CN offline, and even drops in the dashboard due to quality of service (QoS) problems.

That said, the KPIs we had estbalished with were all met despite these issues.

KPI #2 | Comments pertaining user throughput results

While the KPI related to throughput of at least 95% of customers having simultaneous download capability of at least 25 Mbps was achieved, we also stressed the network with speeds up to 35 Mbps as part of our overall test. Results showed that we were able to achieve that on most of the nodes, but due to some quality of service problems we saw drops in overall network availability as some links became a bottleneck.

2.6 Weather Impact Analysis on 60 GHz mmWave Technology

We wanted to provide insight into a real network deployment (and not necessarily to conduct a marginal link test). To do this, in Mikebuda we performed an analysis on links with lengths ranging 90 – 100 meters (typical in that locale and in mmWave mesh networks in general) to assess the correlation between weather conditions and network performance. The link lengths are well within the link budget/available system gain for the equipment.

We collected weather station data (e.g., rainfall, snow intensity, temperature) and network availability data, then visualized used Grafana (an open source analytics and monitoring solution) to visualize disparate time sample levels. In addition to overall network availability, we also analyzed radio frequency data (including SNR, RSSI, MCS, and PER at a link level) during periods of rainfall and snowfall.

To help us identify any changes in network performance data during periods of high precipitation, we collected three levels of time sample data to analyze network performance data at various granularities:

- One hour sampling
- 10 seconds sampling
- Raw data

All data was gathered over a period of four months—from January to April 2019.

2.6.1 One-Hour Sampling

The first weather data with a precipitation level (<1mm) that could potentially impact RF quality of the Terragraph network occurred between January 18 – February 11 as highlighted in Figure 6.

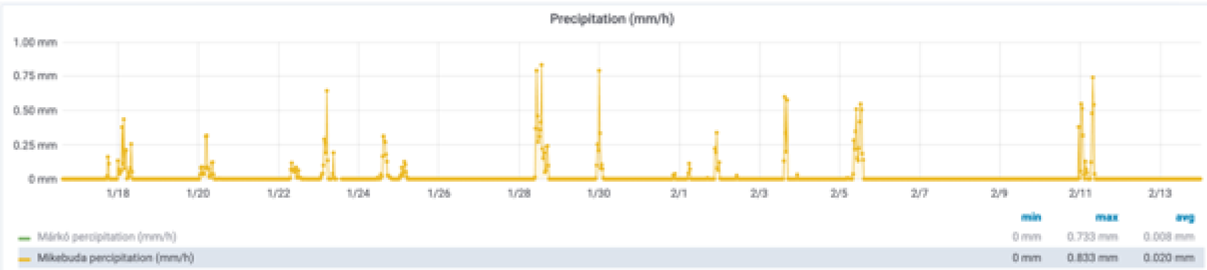


Figure 5 – Precipitation in Mikebuda

The respective rain and snow precipitation for this period is depicted below.

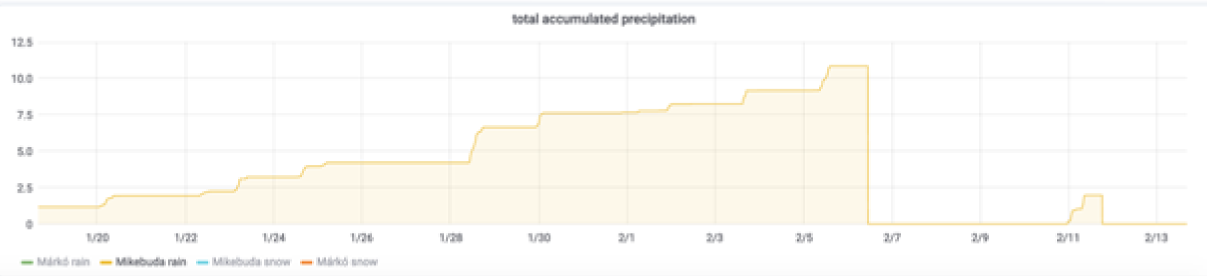


Figure 6 – Precipitation: rain

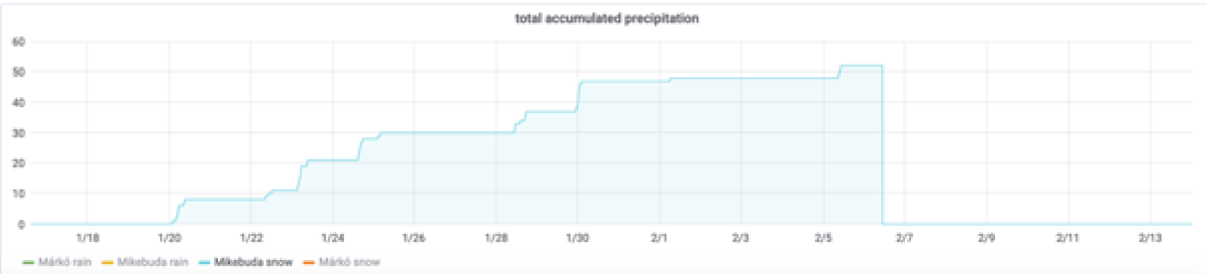


Figure 7 – Precipitation: snow

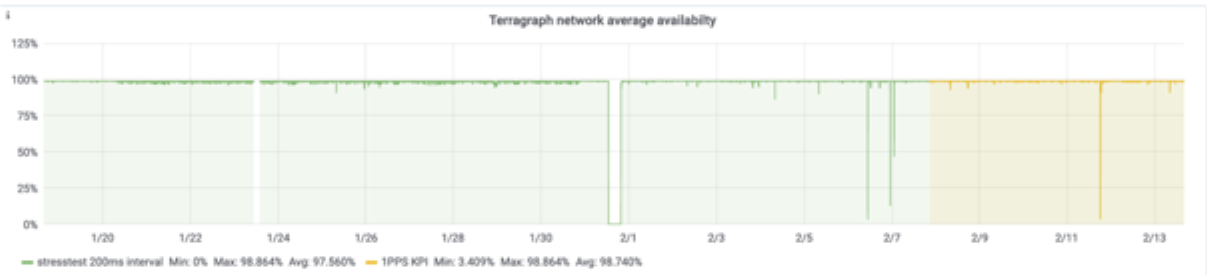


Figure 8 – Mikebuda network availability

The Grafana visualizations show no evidence of precipitation having a negative impact on Terragraph network availability in Mikebuda (**Error! Reference source not found.**). The only visible drops in availability are due to network-wide backhaul outages or planned maintenance.

To verify if weather conditions had any impact on RF links during the evaluation period, we also looked at metrics (e.g., SNR, MCS, TxPower) on a few links.

SNR, MCS, and TxPower one-hour sampling results

SNR, MCS, and TxPower values on any of the observed links did not show any conspicuous readings on days having the highest precipitation (compared to days with no precipitation). Link metrics analysis did not indicate precipitation as having any impact. At this stage there is no evidence that weather conditions such as rain/ snow have any significant impact on the Terragraph network.

2.6.2 Ten-Second Sampling

To gain definitive insight as to whether conditions such as snow and rain have any significant impact on a mmWave mesh network, for times of higher precipitation (>1mm/h) we analyzed Mikebuda RF data having a granularity of 10 seconds per data sample.

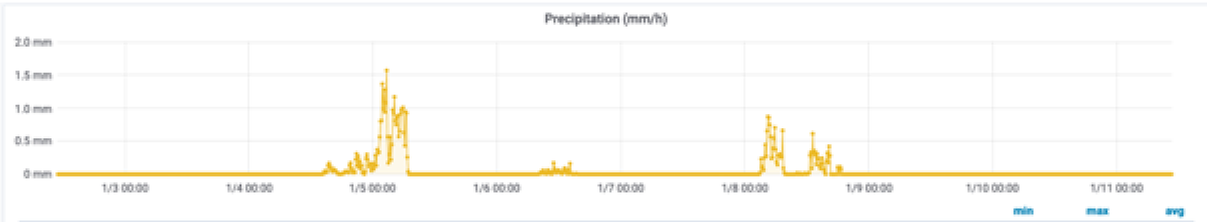


Figure 9 – Precipitation

Link-53.3-57.1

RF data collected between 2:00 pm (4/1/19) and 7:00am (5/1/19) at 10 seconds granularity.

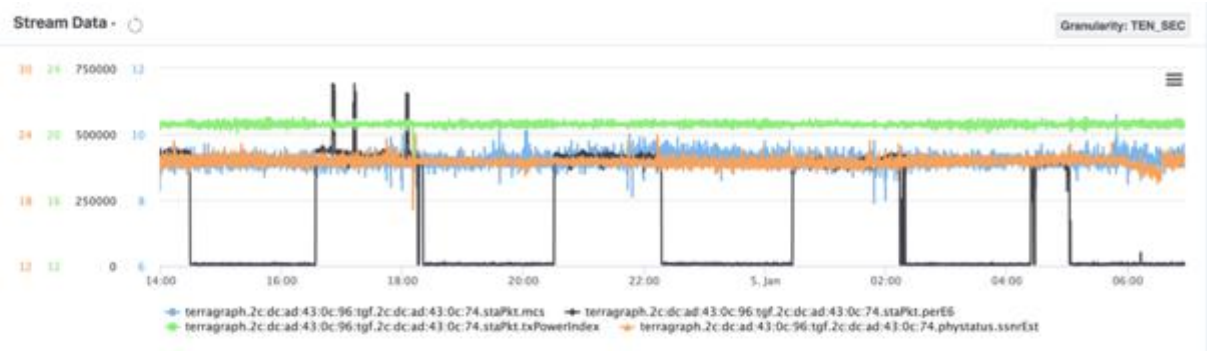


Figure 10 – Overview of RF Data

Figures 11 – 13 show the individual RF parameters on and around the time of high precipitation (between 12:00am on 4/1/19 and 6:00am on 5/1/19.

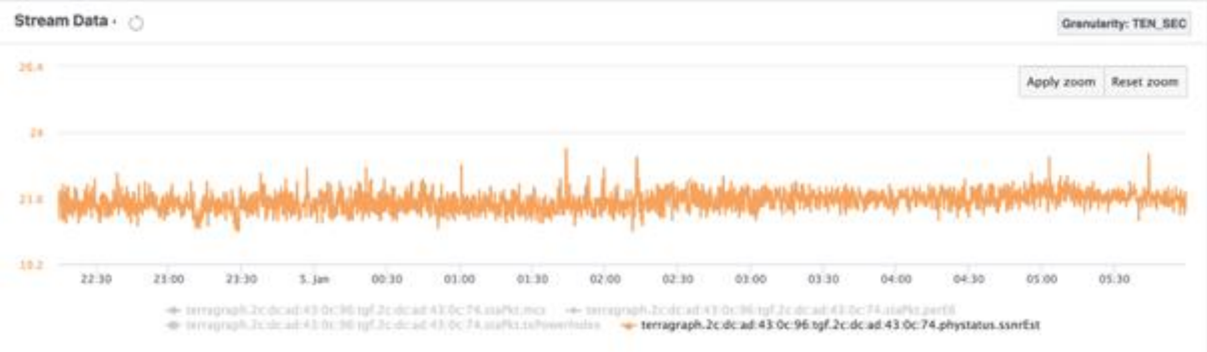


Figure 11 – SNR

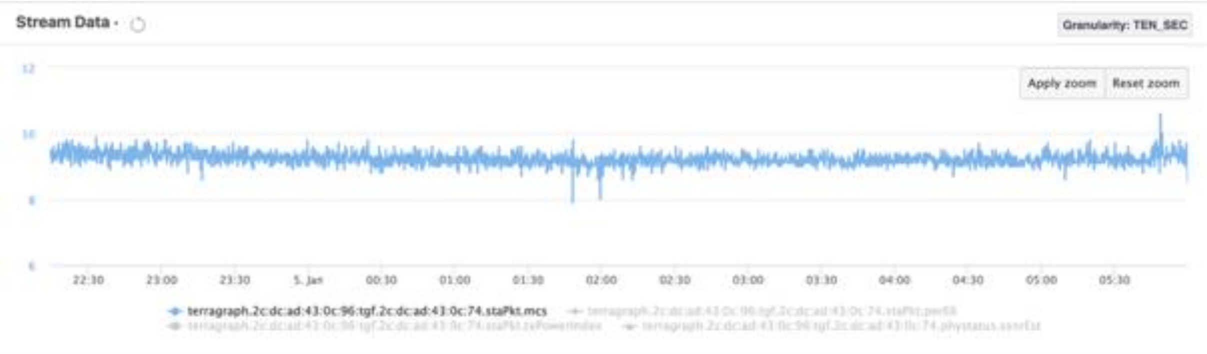


Figure 12 – MCS

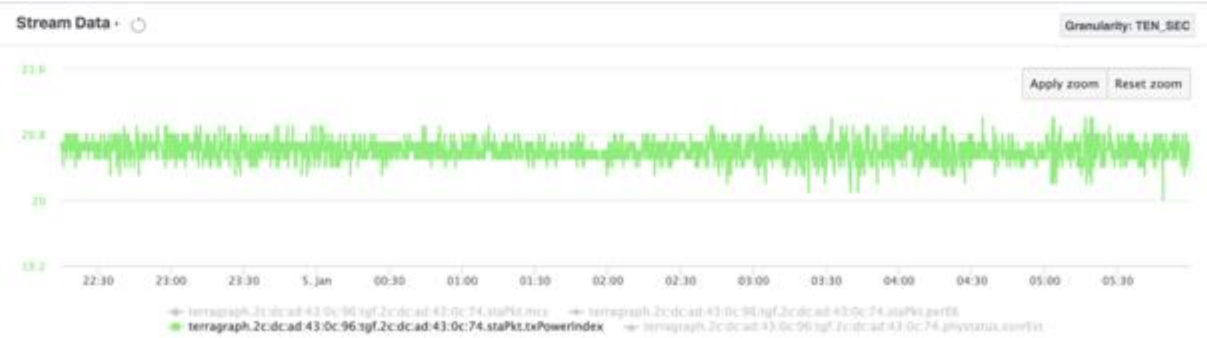


Figure 13 - Tx Power

10-second sampling results

Recorded values for parameters MCS, SNR, and TxPower during the period of high precipitation was not any different than the patterns observed during time of low or zero precipitation.

Having looked at a single link with a 10-second time sampling, the collected data does not reveal any indication that precipitation levels had any significant impact on RF link performance.

2.6.3 Raw Data Sampling

Diving further, from the raw data sampling we analyzed the behavior of two links during the highest recorded precipitation level.

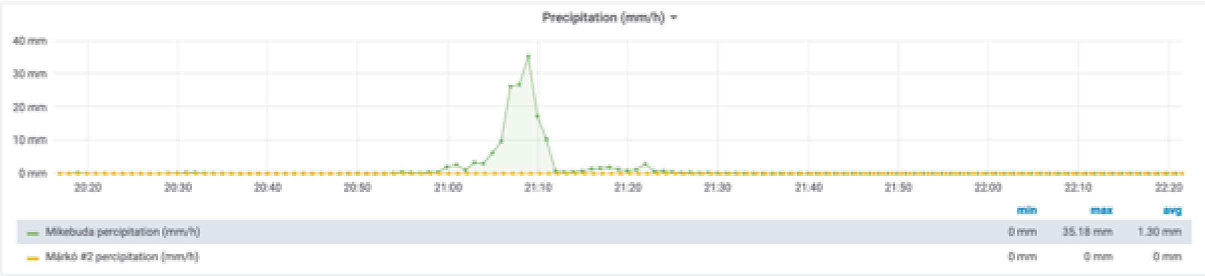


Figure 14 – Highest level of precipitation recorded during trial

The period having the highest level of precipitation (up to 40mm/h) recorded in Mikebuda was between 8:30 pm – 9:30 pm on April 8, 2019.

Link-15.1-16T.2

Figure 15 – Link-15.1-16T2 raw data

Link-1.1-Fiber_Hut_North

Figure 16 – Link-1.1-Fiber_Hut_North raw data

Raw data sampling results

As shown in Figures 14 – 16, during a high precipitation period none of the exhibited RF parameter data differed significantly when compared to periods of low or zero precipitation.

2.6.4 Conclusion

Based on the Mikebuda weather data and Grafana visualizations, there is no indication that precipitation levels have any significant impact on Terragraph network performance.

This may not be the case in a different network environment with high data transmission, or with weather conditions having a greater precipitation level compared to that seen in Mikebuda.

2.7 The Customer Perspective: Perceived Performance of the Tested Service

We sought to gain insights regarding customer satisfaction and acceptance rates, changes in usage behavior, and perceived issues during the field trial. Using a mix of qualitative and quantitative research methods, surveys were set up by Deutsche Telekom and Magyar Telekom, then executed by an external agency.

The following KPIs were measured regarding field trial customer perspectives:

- Reported change in internet usage behavior
- Satisfaction rate with tested internet service over time
- Acceptance rate
- Incidents of perceived issues over time
- Proportion: use of legacy internet vs. tested internet service

Quantitative online surveys were used to collect this KPI data. Additionally, we ran focus groups to gain a deeper, qualitative understanding of reasons behind customers' perception regarding:

- overall setting
- outdoor units or issues
- attitude toward a possible DIY installation procedure
- general feedback for further improvements

Table 6 provides an overview of the applied methodology and covered topics.

Table 8 – Applied methodology and covered topics

	1x Telephone Interview July 2018 – Dec 2018	3-4x Online Waves Oct 2018 – Aug 2019	Qualitative Phase Jan 2019 + May 2019
Method	Computer Aided Telephone Interviews (CATI) to catch testers demographics and spontaneous expectations	Self-completed online questionnaire to gain insights on perception, overall feedback, requirements	2 Focus-Group discussions (FGD) after 1st online wave + 3 FGD in May before the final online wave
Covered Topics	• Demographics • Current internet Usage • Expectations	• Satisfaction • Issues • Change in behaviour • Feedback on future packages	• Reasons behind their perception • Deep understanding of service & installation process • Hints towards improvements

Feedback has been very similar in both Hungarian locations. But because Márkó represents a bigger sample and its customers are more advanced, the following results refer only to Márkó.

2.7.1 First Impressions After One Month of Using the Service

- There was a distinct **'wow'-factor** regarding the connection **speed** coupled with a **high overall satisfaction rate—**even when a number of people were using the internet service at the same time

  > *"I expected a fast and stable internet, and I got a fast and stable service. It is just the icing on the cake that this internet is very fast."*

- Only occasional problems with **stability** were reported
- Users had **expected** a service which is also wireless inside the house
- The **installation process** was perceived to be smooth; the installation team was perceived as dedicated and proactive
- Respondents considered the **indoor cabling** to be the most **complicated part of the installation**

A few negative aspects were also mentioned:

- The design of the **external antenna (CN) is not aesthetically pleasing**
- Some participants **claimed** that the tested **service** was not **fast enough**
- Some reported a **lower Wi-Fi coverage in the house than before**

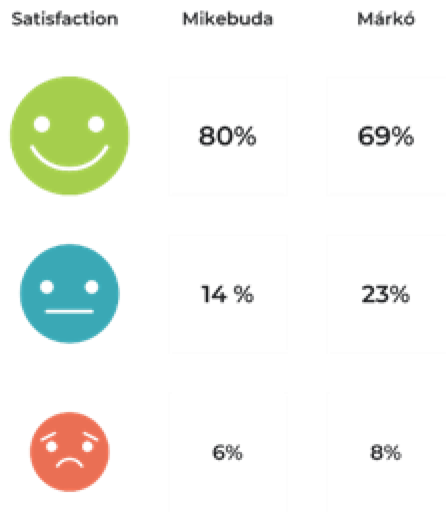
  > *"The Wi-Fi signal is weak, with a smaller range. Maybe there is too much iron and concrete in our house, but the signal is not available upstairs."*

- An **occasional loss of connection** was reported
- Some wished for the ability to **set up the router themselves**

The installation process was perceived as being extremely smooth. On average, the overall installation included four site visits and up to 300 minutes in total in Mikebuda, which was entirely acceptable. The process significantly improved over time and was performed much faster in Márkó, even with only two site visits.

2.7.2 Results After > Six Months of Use: High Satisfaction Rate Throughout the Entire Field Trial

Even after the initial excitement—the ‘wow’-factor—had passed and occasional technical issues had crept up, the satisfaction rate remained high throughout the entire trial. A 69% satisfaction rate was reported for Márkó and 80% for Mikebuda during the last wave. Speed was considered the most important factor.



Acceptance rate shows a promising value

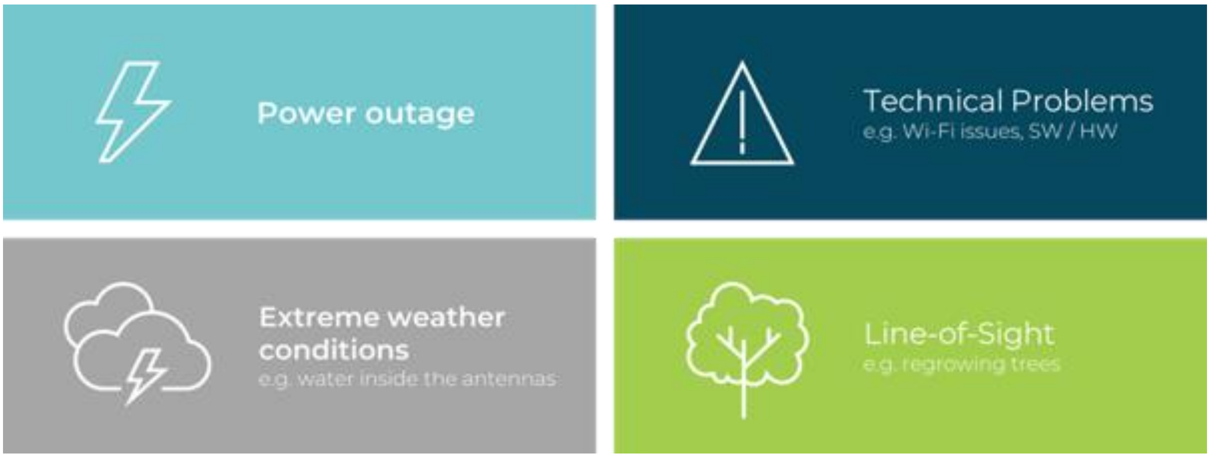
73% of respondents are willing to subscribe to the service after field trial completion. When taking price into account, the number of respondents willing to subscribe fell to 50%—still very promising.

Positive effect on reported internet use

Most respondents stated they used the tested service more often, with 88% reporting more intensive internet use—a significantly positive effect. The most popular reported activity was streaming movies and series. 65% of the participants said they streamed more often with the tested service. Before then, streaming had not been possible at the desired viewing quality. In addition, activities such as working from home and uploading bigger files to the cloud were performed more often.

Perceived issues and the reasons behind them

Even though satisfaction rates were high, issues were reported in the course of the trial. Topics such as “Internet was slow” and “Lost connection while using the internet” were reported by some participants.



There are several reasons for reported issues; not all were related to the tested technology. For example, power outages are not unknown in this region. This resulted in a small number of reported incidents where they caused dropped connections. Other reasons included technical problems caused by software releases, hardware issues resulting in node replacements, a few Wi-Fi issues, and LOS problems (e.g., growing trees).

For the most part, respondents were able to identify the reasons behind service issues. A diagnostic tool could help inform and instruct customers in the future. Despite these issues, the satisfaction rate—especially regarding perceived speed—was very high and promising.

Pointers regarding future service packages

During the last online wave, respondents were also asked to create preferred packages based on predefined elements, such as internet service speed, optional services such as streaming options, or antenna design and type. High-speed internet was most important and, in combination with IPTV, the most popular package. The majority expressed low interest in having fixed line telephony included, so it may be omitted.

Additional aspects mentioned by respondents:

- willingness to pay for a smart Wi-Fi device
- not open to paying for onsite advice
- majority would choose 1 Gbit/s as preferred speed

Note: During the focus group discussion, participants had considered lower requirements of 150 to 300 Mbit/s to be sufficient

2.8 Qualitative Customer Research Reveals Areas for Improvement and Important Success Factors

Qualitative focus group discussions investigated deeper aspects, such as the outdoor CN unit, the possibility of DIY installation, and other matters that could foster overall acceptance of the service. Participants provided many valuable insights into possible improvements.

Participants have evaluated virtual fiber from an end-to-end perspective. They do not distinguish between the three layers of data transmission: signal to the house, then into and throughout the building. This presents opportunities as well as risks. It makes clear that the technology in itself is not crucial to customers, but rather the resulting experience. It can therefore be concluded that the findings regarding customers' perspectives are applicable to other FWA technologies.

Based on these results we have grouped success factors that support a high acceptance rate into these three areas:

Figure 17 – Success factors

2.8.1 Outdoor Unit Design

Participants fully accepted the need for an outdoor antenna, even though they perceived the one provided during the test as lacking aesthetic appeal. Because of this, several prototypes—created by Deutsche Telekom as part of its Virtual Fiber project—were presented to the focus groups. Aspects such as design, size, antenna protection, and multi-functionality were discussed in this context. Flexible placement was also a topic, in the sense that outdoor units should be provided that can be placed in different locations, such as the façade, window, or roof.

An overview of the presented prototypes follows. These include indoor components, as were shown at the TIP summit in Amsterdam (November 2019).

Figure 18 – 2019 TIP Summit prototype presentation, Amsterdam

The most popular outdoor device turned out to be a simple unit that could be placed almost anywhere on the house. It was followed by the outdoor lighting and the house number models. The window-attached device appeared to be less relevant in this setting, as most respondents are owners living in single-family residences. However, they did mention it could provide a relevant solution for apartment building dwellers.

Table 9 – Customer feedback on CN device prototypes

Devices	Positive	Negative
Simple Unit 	Users found it easy to install, easy to remove, with no difficult drilling required. They also liked its small size, that it is discreet and could be placed almost anywhere to ensure best LOS.	That drilling is required could pose a problem with insulation (for example). Also, due to simple installation, there is also theft risk.
Outdoor Lighting 	Users generally liked the design and that it serves a second function beyond being an antenna.	That drilling is required could pose a problem with insulation (for example). It might also be a problem for the outdoor unit to function without switching on the light.
House Number 	Users again generally liked the design, that it serves a second function beyond being an antenna, and that it could replace a missing house number.	Its function as a house number defines where it needs to be placed and could cause LOS issues. The need for drilling also could pose a problem.
Window Unit 	Users liked that no drilling was required and that it was easy to install.	Users wondered about the durability of the ribbon cable that goes under the window frame, and also suggested that, for some, it could raise the question as to where to put the flowerpots.

Easy installation, support, and service at all customer journey stages

The need for an outdoor unit creates a new paradigm. In essence, two factors require consideration:

- **You have to choose a device and perhaps buy it**, depending on packaging of the offer. This implies more similarities with setting up other consumer electronic devices, such as satellite dishes, than the usual process of providing fixed-line connectivity.
- **You have to install the device**, i.e., attach it to the building, lead the cable inside, and properly align the device. The need to ensure LOS is a completely new aspect in this case, especially given that it does not exclusively refer to the visible electromagnetic spectrum.

For both points, communicating with the customer is essential. They must understand what needs to be done and be given a say in the procedure. This should include the option to self-install. Our experience clearly reveals: *Self-installation is not a consumer need, but a force.*

Focus group participants were asked to recall their residence installation process, its phases and main steps. Topics included finding the proper location for the outdoor unit and installing it, finding the best place for the Wi-Fi router, performing the indoor wiring, and how to cope with all of this.

A relevant share of testers stated they would feel comfortable doing the installation themselves.

"How capable and comfortable do you feel doing it yourself without the help of a professional?"

Figure 19 – Self installation: Márkó online wave results

Remark: Respondents were owners mainly living in multi-story or single-story homes. For this group, defining where to place devices did not require much discussion.

The following self-installation aspects need consideration in further developments:

- Installation should be part of the service, especially for less technology-inclined customers. Self-installation should be rewarded.
- The warranty needs to be guaranteed; fear of voiding it during self-installation was expressed.
- The most popular ways of receiving DIY how-to installation instructions are an app, a printed IKEA-style manual, or a YouTube video.
- Participants require personal contact information, such as a hotline, in case of problems.
- It is also crucial to offer easy-to-use tools to verify the equipment functions as required, so customers can make sure they did not receive faulty devices.
- Dedicated tools to perform the DIY installation should be provided.
- Keep required devices few in number.

From customers' perspective, DIY installation has two parts: outdoor unit followed by the cabling connection.

2.8.2 Easy Installation, Support, and Service

Where to place the outdoor unit

Placement and installation of the external antenna was not considered to be a large or complicated effort. Participants shared a few requirements:

- It should provide protection against weather and vandalism
- It should offer multi-functionality
- It should be flexible in its placement
- Little or no drilling should be required to install the outdoor unit
- The installation should be as simple as possible

The following placements were considered most likely to fulfil these expectations: under the roof beam, under the eave, or on the balcony railing.

How to install the outdoor unit

Respondents had seen the professionals selecting external antenna location by way of visual estimation, then using an instrument to assess the possible LOS connection. Participants asked for a mobile app that helps determine a viable location for the outdoor unit. It should also check the connection, providing feedback in the form of an LED signal from the mounted antenna to indicate connection status.

Given this, we created an app prototype that guides a customer through the process—from initial availability check through installation.

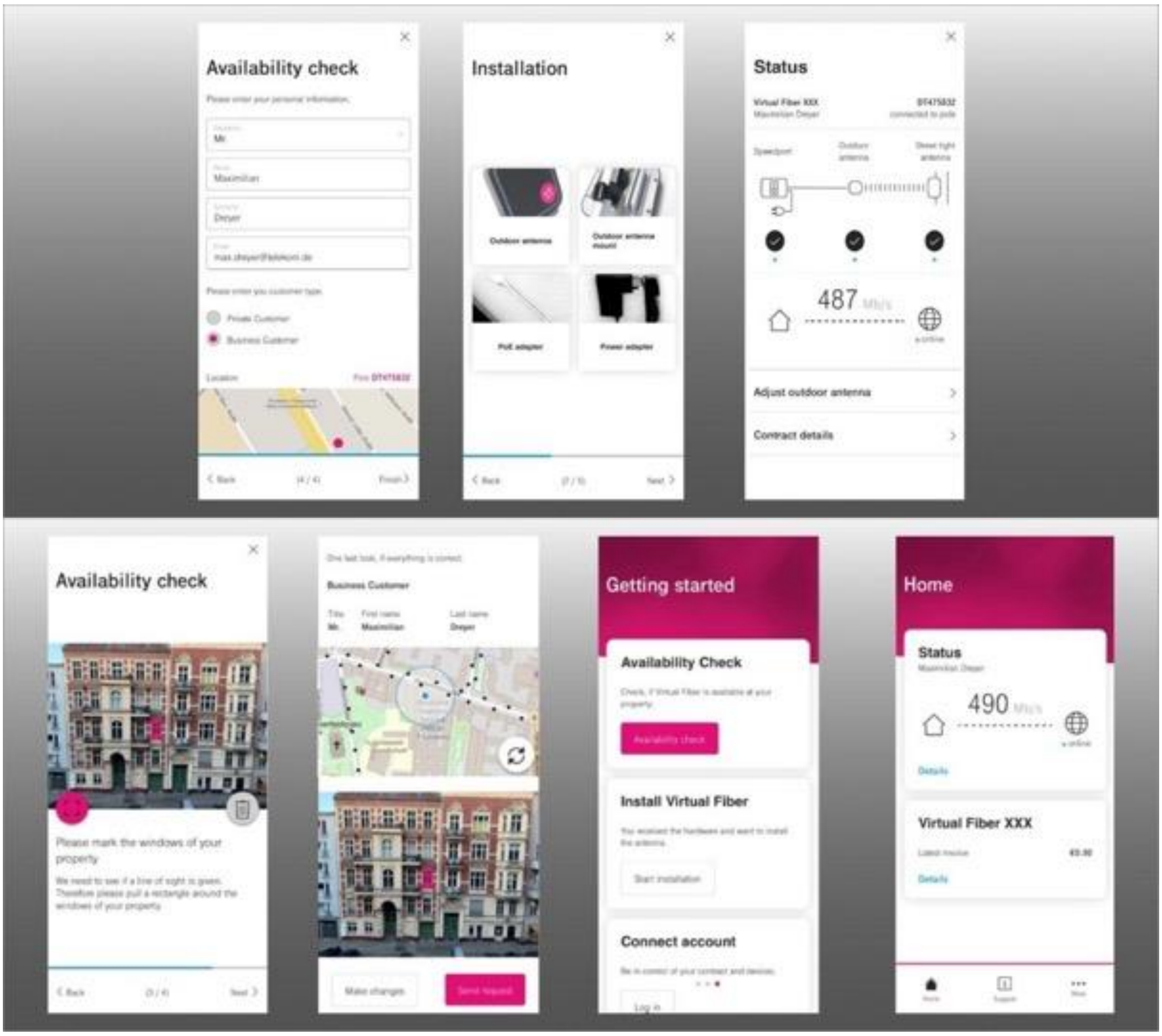


Figure 20 – Installation app prototype

The app would provide help in choosing a viable location for the outdoor unit, guide the customer through the installation procedure by way of a video, and give feedback pertaining antenna connection status.

Cabling

Participants perceived the inconvenience of running cabling to be a bigger issue than mounting the outdoor antenna. For example, they would not necessarily know if they had made a mistake or if the appliances were not fully functional prior to being connected.

Other perceived cabling issues mentioned by the participants:

- Connecting the outdoor antenna to the indoor unit could be difficult.
- The need for two cables to be connected to the inside of the house (in some cases even across the house) was criticized.
- Connecting the cables was described as complicated.

- The design and size of the indoor cables was called out.

Several aspects must be taken into account to make DIY cabling more convenient.

- The need for drilling should be reduced or avoided to forego damaging the wall the insulation.
- The number and length of required cables should be reduced.

Cable aesthetics should also be considered; consider offering them in different colors.

A best-practice approach that borrows pointers from similar CE installations is required to provide a user experience that satisfies—or even delights. This may require different measures for disparate situations; a mobile app may be a good way to provide instructions, but contact with a service representative is required when issues arise. A combination of channels will keep customers updated with all required information throughout the entire installation process.

As for the need to ensure LOS, two matters need to be considered.

- During installation, it is necessary to determine if sufficient LOS exists before placing the CN. An app could be a good way to provide this information.
- While this may not be an issue at every location, customers need remember that proper LOS must be maintained post-installation. Vegetation growth or other environmental changes may require them to intercede— by cutting back tree limbs, for example. Communication and system feedback (e.g., deteriorating connectivity due to LOS degradation) is called for.

2.8.3 Indoor Connectivity – Smart Wi-Fi

About 20% of the participants claimed their field test Wi-Fi signal was not covering all of the house compared to their legacy Wi-Fi. Advanced users missed setting up the Wi-Fi router themselves.

This issue is especially pertinent for two reasons:

- Given that it is WTTH—and will be marketed as such (as in Hungary under the Virtual Fiber name)—customers perceive the service as being completely wireless. Therefore they may attribute any indoor connectivity problems with the service, rather than correctly attributing them to their own Wi-Fi problems.
- The need for CN interconnection with the customer's Wi-Fi router influence where the latter is placed in the house. Because of this, a less optimal router location may be chosen that results in indoor Wi-Fi signal degradation.

A smart Wi-Fi solution—one that offers customers an easy way to create a meshed Wi-Fi network inside their home—should be offered along with the possibility of a DIY router set up.

2.8.4 Summary and Implications

This section compares results against the predefined KPIs. It also summarizes the detailed findings from the previous section and introduces implications.

Comparing the KPIs with field trial success yields promising results

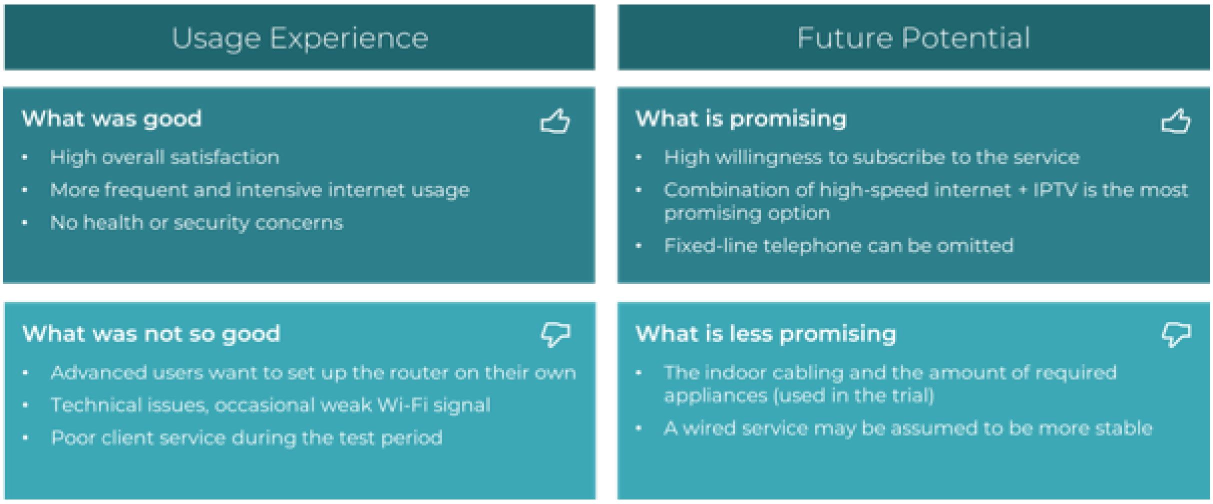


Figure 21 – Usage experience and future potential

- **Change in behavior –** In Márkó, 88% of participants reported significantly increased internet use (especially true for activities requiring high bandwidth), indicating a positive behavior change.
- **Satisfaction rate –** Achieving a total satisfaction rate >70%, this was high throughout the entire field trial.
- **Acceptance rate –** 73% of participants did not reject subscribing to the tested service. Connection speed is a major factor for customers. But while using the service, stability increased in importance for them.
- **Number of perceived issues –** Remained at the same level over time.
- **Proportion of usage –** 61% of participants used the tested service more frequently than their legacy internet.

Table 10 – Key findings and their implications

Success Factors	Findings	Implications
Antenna Design	• The need for using an outdoor antenna is fully accepted • Design makes the difference	• Offer multi-functional antennas • Flexible placement • Easy to mount and to install
DIY Installation	• Ability to perform a self-installation is cited quite often • Tools for instructions and status feedback are needed to support a self-installation	• Reduce complexity—in particular regarding cabling • Reduce the number of devices • Provide simple instructions via different channels, preferably a mobile app, YouTube video, and/or an IKEA-style manual • Provide feedback via LED signals on the devices • Reward self-installation and ensure full warranty
Wi-Fi Signal	• Issues regarding Wi-Fi signal and coverage	• Provide advice where to best place the Wi-Fi router inside • Offer a smart Wi-Fi solution, e.g., additional (or special?) Wi-Fi devices
Service and Support	• There is no one-fits-all solution • Under certain circumstances contact with a tech rep is required	• Offer a variety of communication channels, including a mobile app and sales or tech representatives, e.g., during pre-purchase decision making or for when issues occur • Educate a dedicated support team
Technology Agnostic	• Evaluation is done on an E2E perspective	• Consider diagnostic tools • Tools can be used for other FWA technologies as well

3 Moving to Commercial Pilot – Some Practical Pointers

Due to the very positive customer feedback, the Márkó field trial has morphed into a commercial pilot that is already well underway. Its goals are regain customers while offering a commercially feasible service using available technology.

A few challenges had to first be met:

- The trail equipment had to be replaced by commercially available units
- New contracts had to be collected

What follows are several pointers when using a similar WTTH/FWA approach.

3.1 Planning, Availability Check, and Presales Consultancy

When comtemplating moving from a field trial to a commercial rollout, items such as availability checks and other presales considerations become increasingly poignant.

Work done during the initial planning phase becomes highly relevant. Creating a meshed network requires collecting extensive real-world data to facilitate its modeling. This entails the following steps:

1. Build a 3D model based on a lidar scan or other environmental data.
2. Classify the data and detect objects that can either serve as a fixture for placing DNs or could a problem for LOS.
3. Filter relevant data for network nodes and check for LOS issues to build a candidate network graph.
4. Dimension and optimize the WTTH network.

The candidate network graph then needs to be checked against reality. This includes talking with local people and authorities to ensure fixture availability and DN power access. It is also necessary to check for LOS issues not apparent in the 3D model. For example, trees and other vegetation may have to be cut back; this can only be done after conferring with property owners and/or authorities.

Once all data is collected and processed, it forms the basis of an availability check. This may be made available to presales consultants, or even online for prospective customers.

A presales consultancy also helps in determining on the desired CN device, the connection into a customer’s premises, possible indoor connectivity, and overall packaging of the offer.

Given the nature of WTTH, many of these elements may be influenced by the LOS connection requirement vis-à-vis CN placement.

This underlines the fact that customers view the service end-to-end in a technologically agnostic way—such that service, support, and communication over a variety of channels are important components of any offering.

3.2 Distribution Node (DN) – Mounting and Installation

Moving toward the commercial pilot in Márkó, observations collected during the field trial enabled us to envision ideal DN designs. These devices should:

- Be compact, light, and affordable
- Adhere to standards and features (IPv6, mesh, routing)
- Hide complexity in relation to CPE and ISP
- Use OTS hardware with OTS software
- Use ZTP/ZTO to reduce required customer activity

Here we present what we call the *MT Hack*—a DN constructed from OTS components that:

- can provide 360° to customers
- offers room for additional 2x Wi-Fi sectors
- has a power consumption of about 50W – nominal consumption of about 20 – 25W
- runs with 230V, or from DC 24 – 57V
- is about 30 cm in height and weighs 4.9 kg

Figure 22 – New DN in Márkó

3.3 Customer Node (CN) and CPE – Indoor Positioning, Installation, and Cabling

The new CN used in the Márkó commercial pilot is also based on OTS components. It uses the same casing as the DN, it being a less obtrusive than the trial design, and also offers reduced complexity—a big step toward enabling DIY installation. Figure 22 shows this simplified CN and CPE setup for the commercial pilot.

Figure 23 – CN and CPE set for Márkó commercial pilot

Regarding the CN connection into a customer's house and internal components, we have learned that customers want integratation with their existing device ecosystem. Reduced complexity is also important here; fewer cables requiring connection from the outside aids in DIY installation.

4 Summary

Based on our field trial experiences and transition to a commercial pilot, we recommend the following improvements to increase customer satisfaction:

- CN equipment should be visible to establish and maintain LOS, but also be aesthetically appealing. Further work is needed in creating market-ready CN alternatives.
- Customers feel capable of performing DIY installations. This presents a cost reduction opportunity and, if done correctly, may increase their satisfaction. Specific opportunities to drive adoption include creation of tools, tutorial videos, and potentially an app that aids in DIY installation.
- Customers would benefit from the development of solutions to help them easily solve wireless indoor connectivity problems. These include signal loss due to residential construction and material composition, in addition to Wi-Fi router location due to CN placement. This is independent of the internet connection type used.

- Whatever solutions are developed should integrate with CE customers already own that provide modern connectivity benefits.
- Functional requirements depend on the service architecture. Creating a lean and intelligent service architecture is one way to create easy-to-use connectivity for customers.