ELIoT

Enhance Lighting for the Internet of Things

DELIVERABLE: 6.3 Fixed Wireless Access Demonstrator

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Abstract

This document reports on the ELIOT demonstrators for Fixed Wireless Access (FWA). A FWA use case was demonstrated using the Optical Wireless Communication (OWC) technology that was developed in the ELIoT project. Intension of this demonstrator was the demonstration of a gigabit-capable broadband access service with a Fixed Wireless Access concept.

Unfortunately, due to the COVID-19 pandemic, it was not possible to make the FWA demonstrator available to the general public. Hopefully this report can nevertheless provide a sufficient overview of the FWA demonstrator activity.

Index of terms

AES	Advanced Encryption Standard
CINR	Channel-to-Interference-and-Noise Ratio
CN	Client Node
CPE	Customer Premise Equipment
CPN	Customer Premises Network
DN	Distribution Node
DSL	Digital Subscriber Line
DTAG	Deutsche Telekom
ELIoT	Enhance Lighting for the Internet of Things
FTTH	Fiber To The Home
FWA	Fixed Wireless Access
HD	High Definition
HHI	Heinrich-Hertz-Institute
IETF	Internet Engineering Task Force
IR	Infra-Red
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LiFi	Light Fidelity
LoS	Line of Sight
MC	Media Converter
mmWave	millimeter wave
NIR	Near-Infrared
OWC	Optical Wireless Communication
PoE	Power over Ethernet
PtP	Point to Point
PU	Public
QoE	Quality of Experience
QoS	Quality of Service
RGW	Residential Gateway
Rx	Receiver
SNR	signal to noise ratio
Tx	Transmitter
VDSL	Very High Speed Digital Subscriber Line
VLC	Visible Light Communication
VOIP	Voice over Internet Protocol

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1 Motivation

Very high data rates and cost-efficient broadband access networks become indispensable to address changing market demands. Changing user behaviour and related expectations on broadband connectivity in residential and other diverse environments will lead to ever-increasing total traffic volumes [4]. In the gigabit society, gigabit-capable broadband access services must be provided to customers at low cost.

In principle, it is wildly accepted that optical fiber is the best choice for high speed fixed broadband access deployments. However, the installation of optical fibers is very expensive, and the deployment and planning process take a long time. The cost driver and primary determiner of the rollout speed is the final drop link, which comprises the network section between a flexibility point at the street level (e.g., street cabinet) and the customer location in the buildings including the in-house network. The final drop link accounts for a very large share of the total cost of a fiber-to-the-home (FTTH) installation. With a Fixed Wireless Access (FWA) network concept the last meters between customer location and street-level flexibility point are bridged via a wireless transmission technology, and therefore, FWA could overcome these barriers, resulting in potentially lower upfront investments compared to pure FTTH deployments. On the other hand, the operation of an active system compared to a pure passive fiber network imposes higher operational efforts. A FWA solution may be used as complementary solution to FTTH in order to enable a fast and cost-efficient deployment sharing existing street furniture sites, e.g., light poles, in the access network.

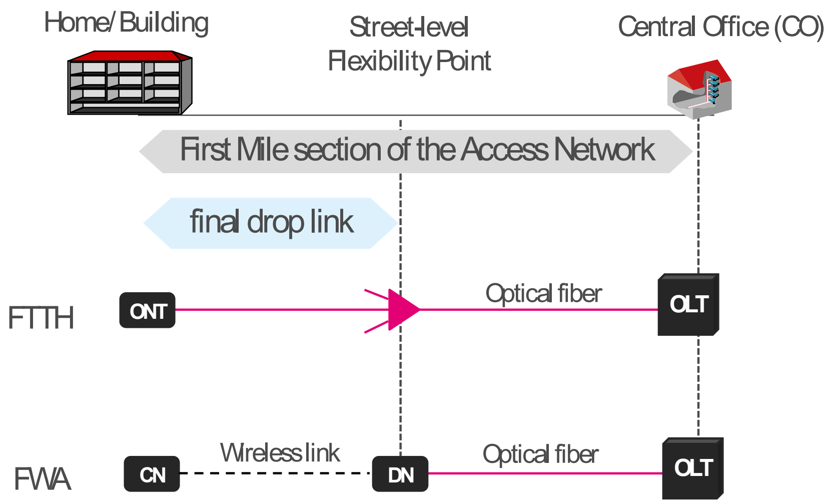

Figure 1 First Mile section of the Access Network

In principle, different technologies can be used for FWA deployments, e.g., 60 GHz mm-wave radio technology or Optical Wireless Communication (OWC) technology. The latter was the focus of the ELIoT project and the FWA demonstrator [1].

2 Scope of the demonstrator

A Fixed Wireless Access (FWA) use case was demonstrated using the Optical Wireless Communication (OWC) technology that was developed in the ELIoT project. Intension of this demonstrator was the demonstration of a gigabit-capable broadband access service with a Fixed Wireless Access concept.

The FWA demonstrator was integrated into an outdoor test bed to study the impact of different weather conditions on the quality of service and to estimate general system limitations. Further details on the demonstrator setup are described in Chapter 3.

Different tests were defined [5] and performed to evaluate system performance and quality of service, particularly with respect to the most important KPI of the FWA demonstrator, namely the ability of a transmission through window glass to enable indoor network termination equipment on the user side. The results of the test analysis were documented in the chapter 4 (Test results).

Table 1 describes the technical KPIs of the FWA demonstrator.

Table 1: Technical KPIs of the FWA demonstrator

Parameter	Value	Description
Throughput	1 Gbit/s	Minimum achievable Ethernet Throughput on the FWA link with respect to transmission through window glass
Latency	< 1 ms	Latency of the FWA link similar to FTTH
Frame loss	< 1 %	Frame loss of FWA link similar to FTTH
Reliability	Weather independent performance with respect to Throughput, Latency and Frame loss	High link performance independent of weather conditions

3 Demonstrator setup

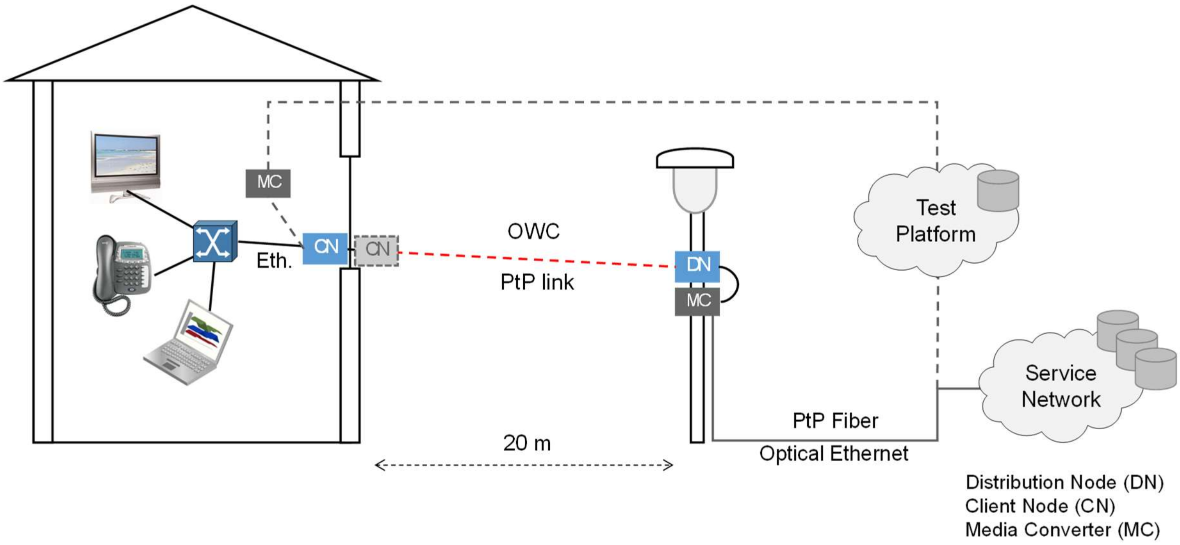

Figure 2 FWA Demonstrator setup

Figure 1 shows the FWA demonstrator setup. A point-to-point (PtP) Optical Wireless Communication (OWC) link was provided between an indoor subscriber site and a lamp pole in an outdoor test environment. The PtP link was established between the OWC distribution node (DN) that was mounted at the lamp pole and an OWC client node (CN) that was installed either outside (in front of the window) or inside the subscriber building (behind the window). The distance between distribution node and client node was about 20 meters. The distribution node was connected to a service network via optical fiber using a Media Converter (MC) that was needed to convert the transmission media from electrical to optical Gigabit Ethernet. The service network provided typical broadband access applications, e.g., high-speed Internet access, video streaming, video conferencing, etc. The client node was connected to customer premises network (CPN) via electrical Gigabit Ethernet link. In addition, the OWC system could also be connected to a measurement platform for measurement analysis.

In the following some features of the developed OWC link are listed:

- ITU-T Rec. G.9991 (G.VLC, prepared for IEEE P802.15.13)
- Low power near-infrared (NIR) LED at 850 nm → eye-safe
- AES 128 encryption possible
- Operating temperature -20°C to +60°C
- Capacity at distance:
  - 1.5+ Gbit/s at < 50 m
  - 1.4 Gbit/s at 50 m
  - 1.0 Gbit/s at 100 m

Figure 3 Distribution node (DN) mounted at the lamp pole in the outdoor test environment

Figure 3 shows some impressions of the distribution node (DN) that was mounted at the lamp pole in the outdoor test environment. In principle, the installation of the DN could be done relatively uncomplicated with a short installation time. However, the prototype required an additional housing cabinet for the power supply and the media converter that was needed to convert the transmission media from electrical to optical Gigabit Ethernet. The next solution release should integrate the power supply and the media converter into the DN device. Furthermore, the dimensions of the DN should be reduced for real deployments.

Figure 4 shows the client node (CN) installed inside the subscriber building (behind the window) in the first floor. The CN was mounted on a support pillar, with a distance of about 40 cm to the window. Similar to the DN, the form factor of the CN should be reduced, and, in addition, innovative mounting solutions must be developed enabling an easy and rapid installation in the window area.

Figure 4 OWC client node (CN) installed inside the building (behind the window).

Figure 5 Outdoor test environment with PtP OWC link between distribution node (DN) and client node (CN)

Figure 5 illustrates the PtP OWC link between distribution node (DN) and client node (CN) in the outdoor test environment (dashed red line). A manual alignment between DN and CN was necessary to establish the PtP link. Innovative solutions need to be developed to automate the alignment process (e.g., beamforming).

4 Test results

This chapter describes the test results of the ELIoT Fixed Wireless Access (FWA) demonstrator activity. During the demonstrator phase between August 2021 and June 2022, several qualitative and quantitative tests were carried out. The following tests were performed to analyse the system capabilities:

- Link Capacity and signal to noise ratio (SNR) with and without influence of window glass
- FWA system performance measurements
- Long-term performance measurements
- High Speed Broadband Access demonstration

Link Capacity and SNR with and without influence of window glass

Measurements were performed with and without window glass in the line-of-sight (LOS) of the OWC link. [2], [3]

With a free LOS between the two OWC terminals, a maximum gross data rate of 1.549 Gbit/s was measured, with an average electrical signal to noise ratio (SNR) of 35 dB. One by one, a single layer window glass was inserted in the LOS of the terminals. The effect of inserting the non-coated single laser glass was small, lowering the measured gross data rates to 1.496 Gbit/s for a single layer of glass and 1.452 Gbit/s for 2 layers of non-coated glass.

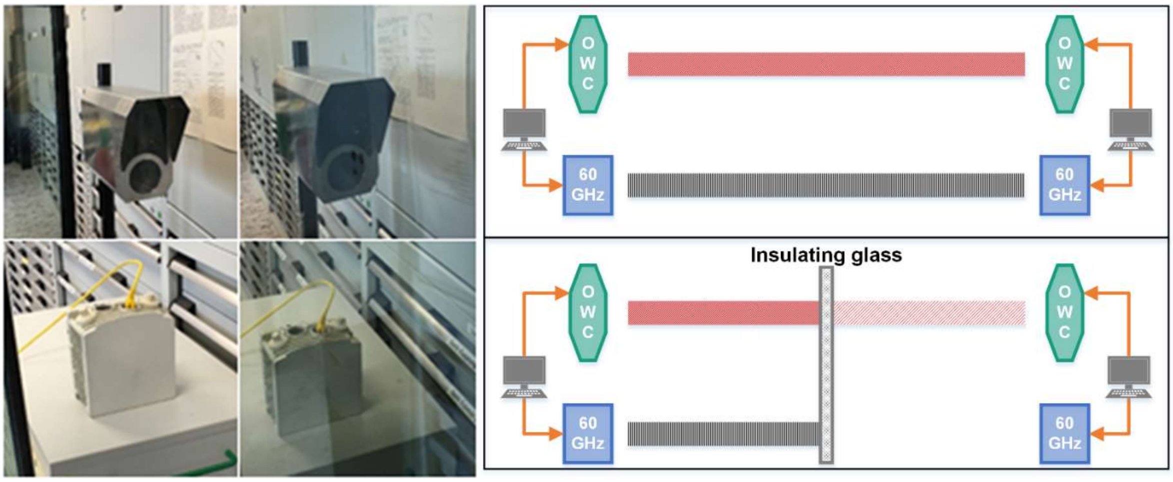

Figure 6: OWC link and 60 GHz link with a free LOS and a metal coated double insulation glass inserted in the LOS

Next to the influence of non-coated glass, measurements were performed inserting a metal-coated double insulation glass into the LOS between the two OWC links. As a comparison, the same insulation glass was also inserted in the LOS of a commercial 60 GHz millimeter wave (mmWave) link from Siklu [8]. Figure 6 shows the schematical test set-up with the OWC link in parallel to the 60 GHz mm-wave link.

The SNR of the OWC link and the channel-to-interference-and-noise ratio (CINR) of a commercial PtP 60 GHz mm-wave link was measured. Figure 7 shows the results of this system comparison. For the OWC link, the SNR is given per carrier while the 60 GHz link provides only an average value. Therefore, the CINR is a constant line. It can be observed that the average SNR drop of the optical link is 13 dB in the electrical domain when comparing free LOS transmission with the inserted insulation glass. This drop is attributed to the fact that light is partially reflected when passing through the heat insulation glass. The same experiment was also done with the 60 GHz link. With a free LOS between the two 60 GHz terminals the CINR is 27 dB but when the insulation glass is inserted into the LOS, the CINR drops to 0 dB and communication is interrupted. Heat insulation glass is coated with a thin metal layer, depleting the link margin of the 60 GHz link entirely. Even though the SNR of the OWC link was reduced, too, communication was possible at 600 Mbit/s.

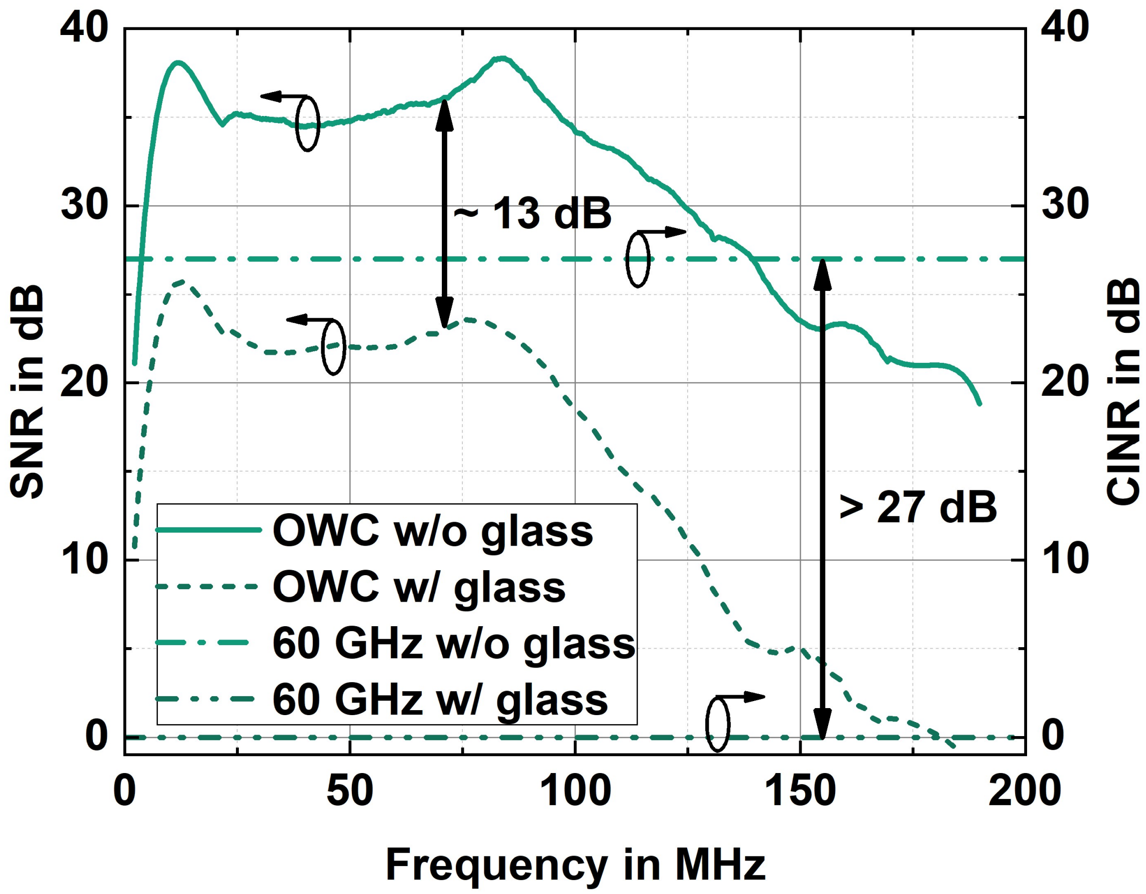

Figure 7: Measured SNR for the OWC link and CINR for a commercial 60 GHz link with and without the impairment of a coated double-insulation glass

FWA System Performance Measurements

The Layer-2 Ethernet performance of the FWA system was measured according to RFC 2544 (Benchmarking Methodology for Network Interconnect Devices) that defines several tests that may be used to describe the performance characteristics of network-interconnecting devices [6], [7].

The following table lists the performance parameters that have been evaluated.

Table 2: RFC related Terms and their Descriptions

Performance Parameter	Description
Throughput	"The maximum rate at which none of the offered frames are dropped by the device." (RFC-1242)
Latency	Total delay of a device or system. "For store and forward devices: The time interval starting when the last bit of the input frame reaches the input port and ending when the first bit of the output frame is seen on the output port. For bit forwarding devices: The time interval starting when the end of the first bit of the input frame reaches the input port and ending when the start of the first bit of the output frame is seen on the output port." (RFC-1242)
Frame Loss rate	"Percentage of frames that should have been forwarded by a network device under steady state (constant) load that were not forwarded due to lack of resources." (RFC-1242)

Throughput

According to RFC-1242 the Throughput is defined as "*The maximum rate at which none of the offered frames are dropped by the device*" [7]. However, regarding the frame loss, the FWA prototype implementation showed some weaknesses that needs to be improved with a next system release. For this reason, in deviation from the throughput definition, low single-digit percentage values of frame loss were also permitted for the throughput measurement.

Figure 9 and Figure 8 show the Throughput for different frame sizes and accepted frame loss ratios for downstream and upstream respectively. While the downstream throughput at 0% frame loss is only between 112 Mbit/s and 401 Mbit/s, at 5% frame loss almost the theoretical maximum Gigabit Ethernet bitrate (dashed red line) is reached. Note: The theoretical maximum Ethernet bitrate depends on the Ethernet frame size and increases with larger frame sizes.

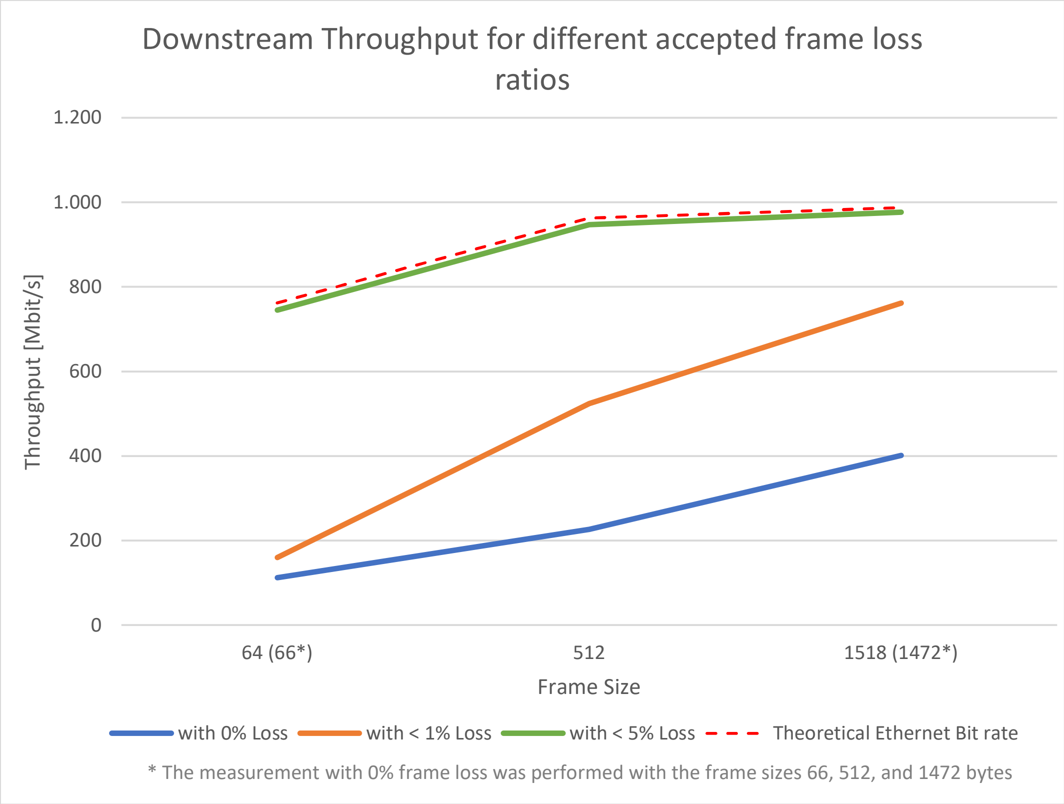

Figure 8 FWA system Downstream Throughput

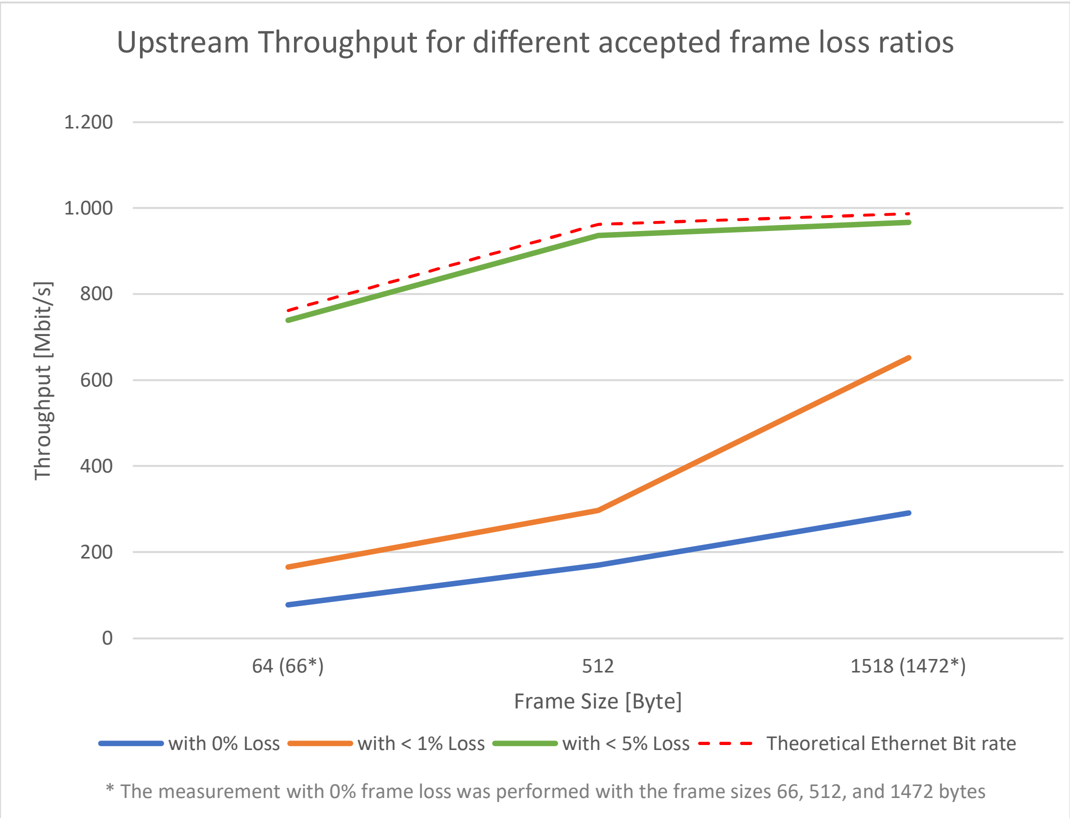

Figure 9 FWA system Upstream Throughput

While the upstream throughput at 0% frame loss is only between 78 Mbit/s and 291 Mbit/s, at 5% frame loss almost the theoretical maximum bitrate (dashed red line) is reached.

Figure 10 shows the Throughput of the OWC link as a percentage of the maximum Gigabit Ethernet bitrate at 5% accepted frame loss. In downstream direction, the throughput ranges between 97.0% and 98.4% of the maximum Gigabit Ethernet bitrate.

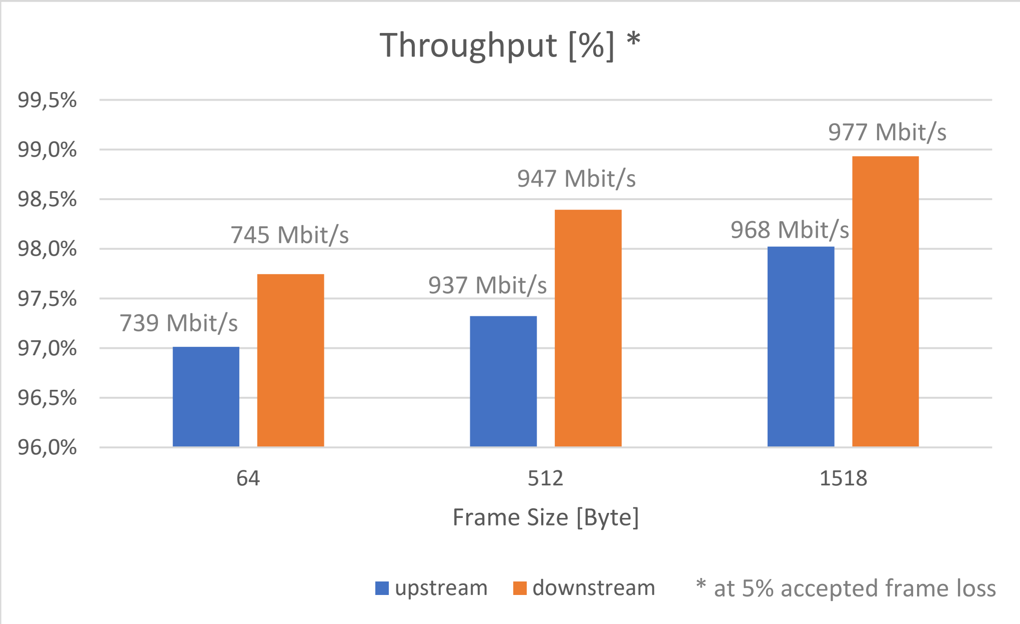

Figure 10 Throughput [%] at 5% accepted frame loss

Frame Loss

Figure 11 shows the downstream frame loss rate for different frame sizes. The frame loss rate is between 2.4% (64 Bytes) and 1.1% (1518 Bytes) and decreases with increasing frame size. In general, frame loss of less than 1% is considered "good" for audio or video streaming, while frame loss between 1% and 2.5% is considered "acceptable". The frame loss target value should be below 1%, which is not achieved by the first version of the FWA prototype implementation and needs to be improved with the next system release.

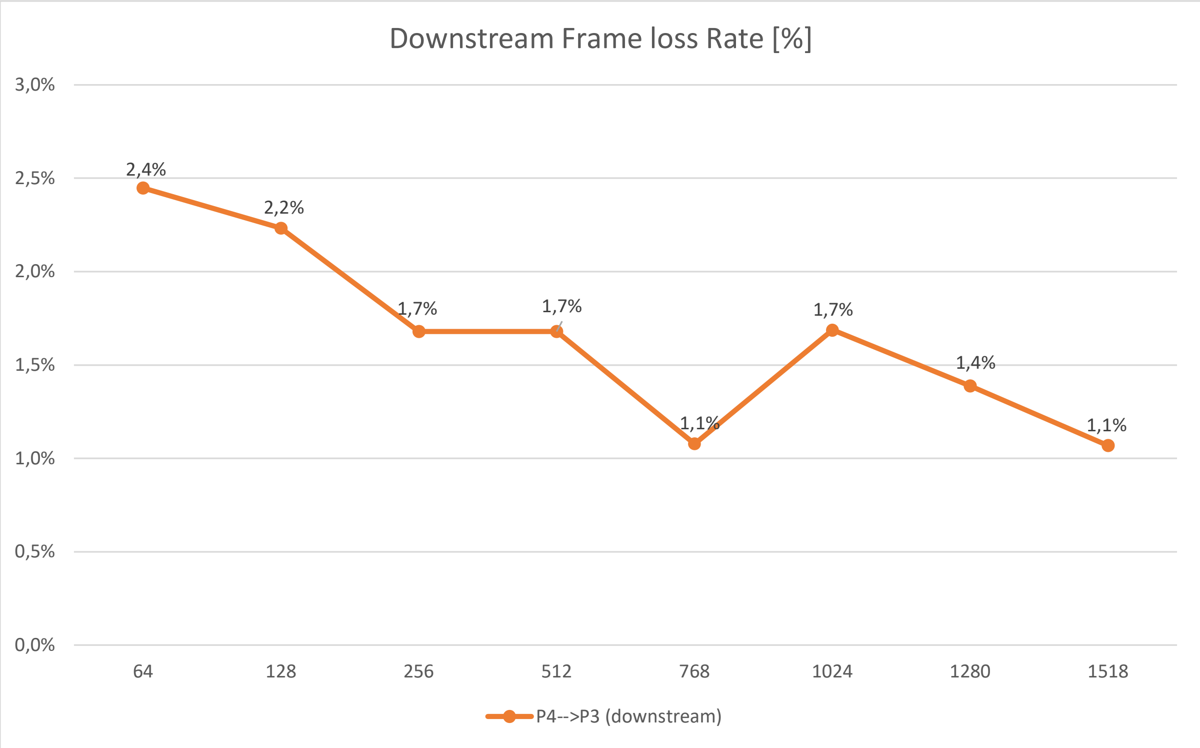

Figure 11 Downstream Frame Loss Rate

Latency

FTTH technologies (e.g., G-PON, PtP Ethernet) enable latency values below 1 ms in the access network. Such low latency values could not be determined with the FWA prototype implementation, which showed some weaknesses in terms of average latency, especially at small frame sizes.

Figure 12 shows the average latency of the PtP OWC link for both directions, up- and downstream. It makes clear that the average latency decreases as the frame size increases. An average latency of 18.6 ms in downstream and 17.1 ms in upstream was measured for a frame size of 64 bytes, whereas an average latency of 2.8 ms in downstream and 2.6 ms in upstream was measured for a frame size of 1518 bytes.

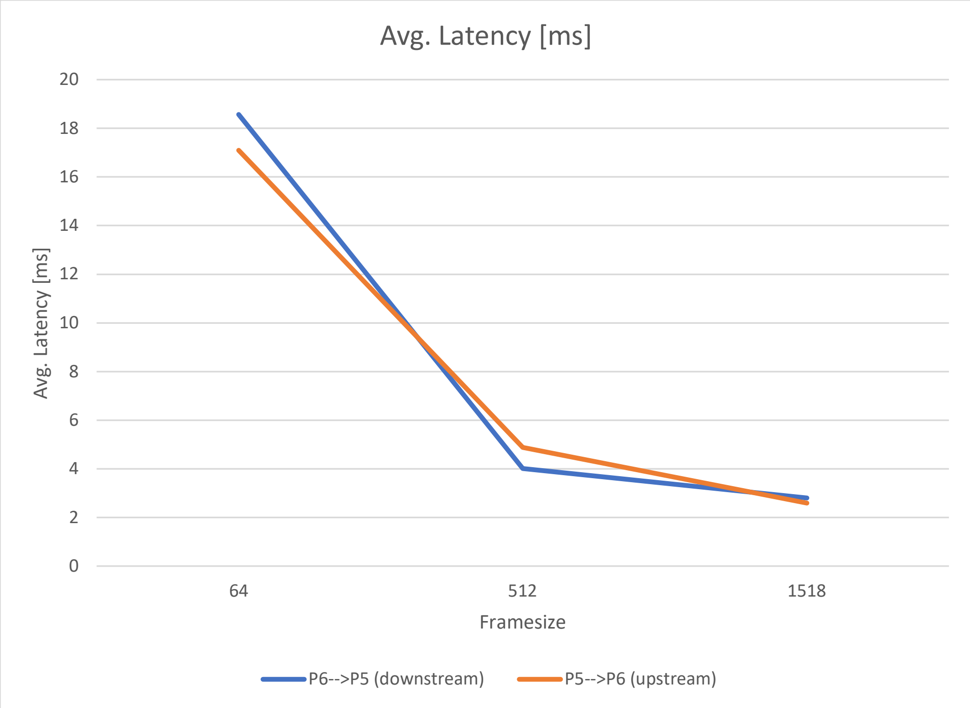

Figure 12 Avg. Latency for downstream and upstream

Performance Measurements Conclusions

The results of the L2 performance measurements show that the OWC technology is in principle able to support a gigabit-capable broadband access service with a Fixed Wireless Access concept. The prototype implementation supported Ethernet bitrates up to 976 Mbit/s. However, frame loss and latency need to be improved with the next system release.

Long-term Performance Measurements

To investigate the influence of the atmospheric conditions (weather conditions like rain, fog, sunlight) the FWA link parameters were monitored and logged for almost three weeks. The gross data rate as well as the SNR of the FWA link were logged every 10 seconds, to enable the performance evaluation of the optical link in changing atmospheric conditions. Next to the average gross data rates achievable, the minimum available data rate, the average SNR and also the availability of the optical link can be derived from the long-term evaluation.

Gross data rate and signal to noise ratio

During the three weeks of measurement, more than 150123000 data points were recorded. To enable an overall overview of the link performance, Figure 13 shows the SNR and Figure 14 the related gross data rate of the optical link. It can be observed that the overall performance of the optical link is good, whit an average data rate of 1319 Mbit/s. For the SNR, an average value of 34 dB could be observed, indicating low atmospheric influence and high signal strength. Few drops in the SNR and associated in the gross data rate can be observed. These very short time events, reducing the performance from the optical link for only a few minutes, can most likely be explained by the influence of sunlight. The decrease is appearing in the morning and can be seen on several days. However, the available data rate is not significantly reduced, which will also be demonstrated in the following subsection.

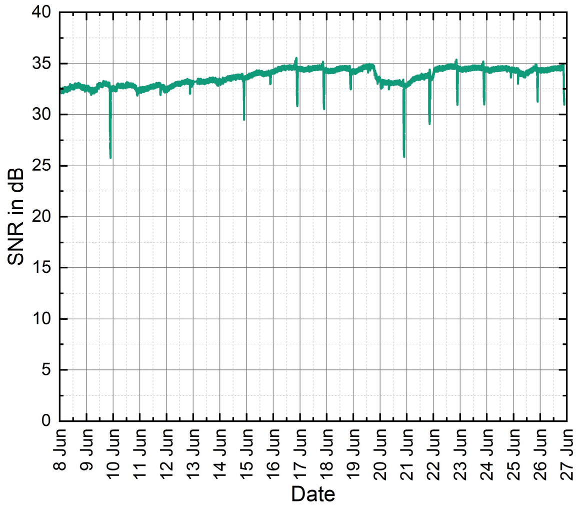

Figure 13 SNR of the optical link

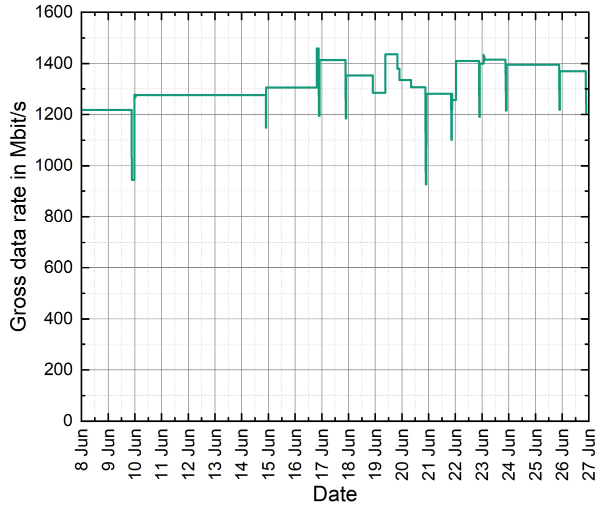

Figure 14 Gross data rate of the optical link

Minimum data rates and availability

The aforementioned measured values provide information about the behaviour of the link over time and related to the atmospherically conditions. However, the statistics of the connection are also important, as the availability, link interruptions and the probabilities for high data rates can be derived. The cumulative distribution function, depicted in Figure 15 and Figure 16, allows to identify the aforementioned parameters. As seen in the Figure 16, the x-axis of the graph shows a range between 900 and 1500 Mbit/s. The minimum data rate measured during the period was 925 Mbit/s. That is indicated by the orange dotted line. On the one hand that indicates that even with reduced system performance a gross rate of more than 900 Mbit/s can be achieved in the current setup. On the other hand, the data rate shows that there was no link interruption at all, as there was no data point recorded with a data rate of zero. The related SNR is depicted in Figure 15, indicating a minimum recorded SNR of 26.4 dB.

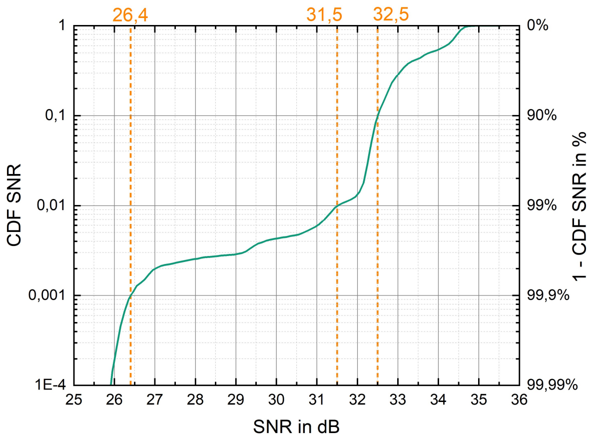

Figure 15 Cumulative distribution function SNR

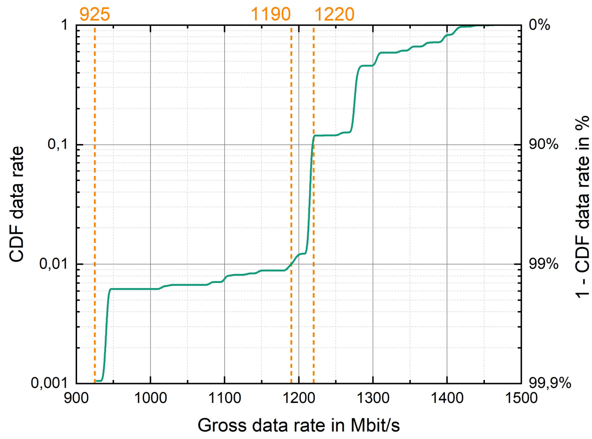

Figure 16 Cumulative distribution function Data rate

Conclusions from the Long-Term Measurement

During the long-term measurement, the optical wireless link was monitored continuously for almost three weeks. During this period of time there was no link interruption and thereby a very high availability was achieved. One reason could be the weather conditions, which did not represent a large challenge for the optical wireless link due to the high link budget. But in general, the rather short transmission distance < 50 m guarantees for a robust and uninterrupted connection. Severe weather conditions can cause up to several hundred decibel of attenuation per kilometre. However, when the transmission distance is short, the link budget and thereby the SNR is not depleted, despite very bad weather conditions. This makes the optical wireless technology a suitable alternative for fixed wireless access applications, realizing stable connectivity with high data rates.

High Speed Broadband Access demonstration

This section addresses some quality tests in the context of a high-speed broadband access service.

Up- and Download Speed test

Description: Measurement of the upload and download speed and the Ping time using a freely available broadband access speed test (http://kabelspeed.telekom-dienste.de/).

KPIs:

- Download speed near to 1 Gbit/s
- Upload speed near to 1 Gbit/s
- Ping time (Benchmark: DSL 40-50 ms, VDSL 15-20 ms, FTTH 5-10 ms)

Results:

- As shown in Figure 17, a very good upload and download speed with more than 910 Mbit/s was measured.

- Ping times between 16 ms and 39 ms were observed. This corresponds to values typically achieved with (V)DSL technologies.

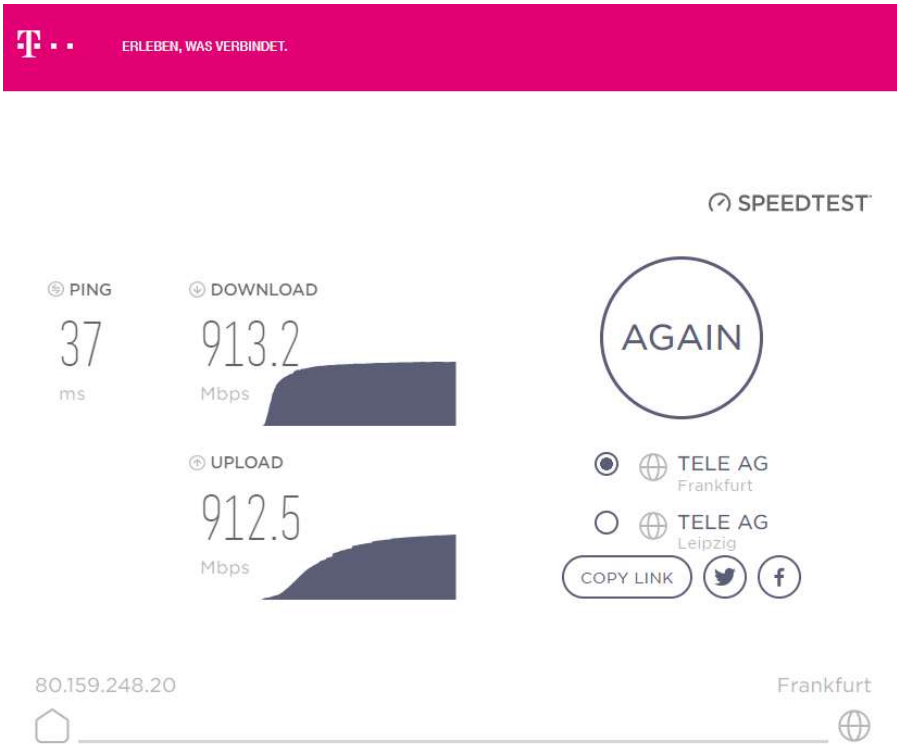

Figure 17 Result of the Internet access speed

Ultra HD Video Streaming

Description: Evaluation of the quality of experience (QoE) of a non-real time video by watching of an Ultra HD video streaming content that was streamed from a media-server in the Internet (YouTube).

KPIs:

- Audible audio artifacts (e.g., clicks due to lost or late samples), loss of audio track
- Video freeze, video artifacts

Results:

- Figure 18 shows the data rate of the Ultra HD video stream was above 44 Mbit/s.
- An uninterrupted and smooth streaming of the audio and video track was observed without perceptible audio or video artifacts.

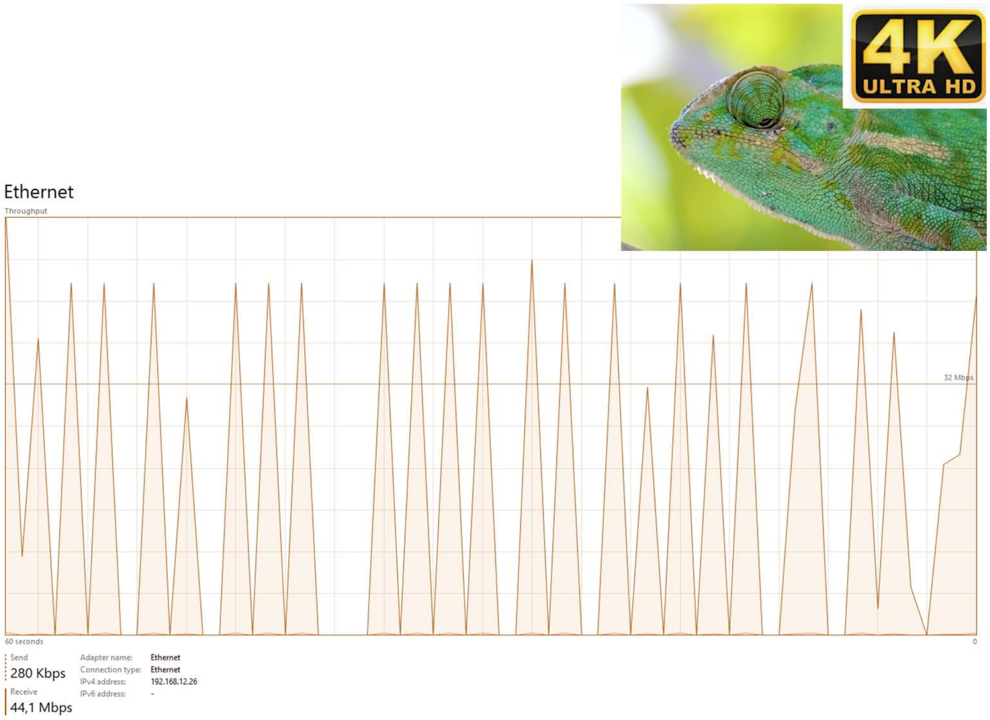

Figure 18 Ultra HD video streaming data rate

Teleconferencing (Work from Home)

Description: Establish a teleconferencing session (audio, video, data) using a professional conferencing application (MS Teams) with 2 or more participants; participants actively interact with each other.

KPI:

- E2E Audio/video latency/jitter
- Audible audio artifacts (clicks due to lost/late samples), loss of audio
- Video freeze, artifacts

Results:

- Uninterrupted audio and reasonably responsive data sharing was observed without perceptible audio or video artifacts or video freeze.

5 Conclusions

With the Fixed Wireless Access demonstrator, a gigabit-capable broadband access service was demonstrated using an Optical Wireless Communication (OWC) system developed by the project partner Heinrich-Hertz-Institut (HHI). The FWA demonstrator was integrated into an outdoor test bed to study the impact of different weather conditions on the quality of service and to estimate general system limitations.

The OWC components could be installed relatively uncomplicated with a short installation time. However, the form factor of the devices should be reduced, and innovative mounting solutions must be developed enabling an easy and rapid installation in the window area at the subscriber site. In addition, innovative solutions need to be developed to automate the alignment process between DN and CN (e.g., beamforming).

Different tests were performed to evaluate system performance and quality of service. The tests showed that the OWC technology is in principle able to support a gigabit-capable broadband access service with a Fixed Wireless Access concept. Data rates in the order of 1000 Mbit/s could be shown and typical broadband access applications could be demonstrated with satisfactory quality of experience. However, the FWA prototype system showed some weaknesses in terms of the performance parameters frame loss and latency. But further development in chip sets and OWC equipment are expected to increase the system performance. The FWA prototype system used half-duplex transmission, which is not ideal for high-quality broadband access products. It is recommended to consider a full-duplex transmission for the next system release.

During the long-term measurement, the optical wireless link was monitored continuously for almost three weeks. During this period there was no link interruption and thereby a very high availability was achieved. This makes the optical wireless technology a suitable alternative for fixed wireless access applications, realizing stable connectivity with high data rates.

A very important aspect of the demonstrator was the proof of concept in terms of the OWC transmission through window glass, which could be clearly proven. The FWA competing technology 60 GHz millimeter-wave (mmWave) does not support transmission through window glass, and therefore a network termination device must always be installed outdoors at the subscriber site, which drives up the installation costs. With the OWC technology the network termination device (client node) can be located indoor which is a significant unique selling point compared to the mmWave technology. Nevertheless, a combination of OWC and mmWave could make sense since both technologies have advantages and drawbacks regarding the environmental limitations and weather conditions. Together they offer increased performance in terms of capacity, stability, and reliability.

Unfortunately, due to the COVID-19 pandemic, it was not possible to make the FWA demonstrator available to the general public. With this report we can hopefully nevertheless give a sufficient overview of the FWA demonstrator activity.

References

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