Enhance Lighting for the Internet of Things

DELIVERABLE: D6.4

Consumer Demonstration

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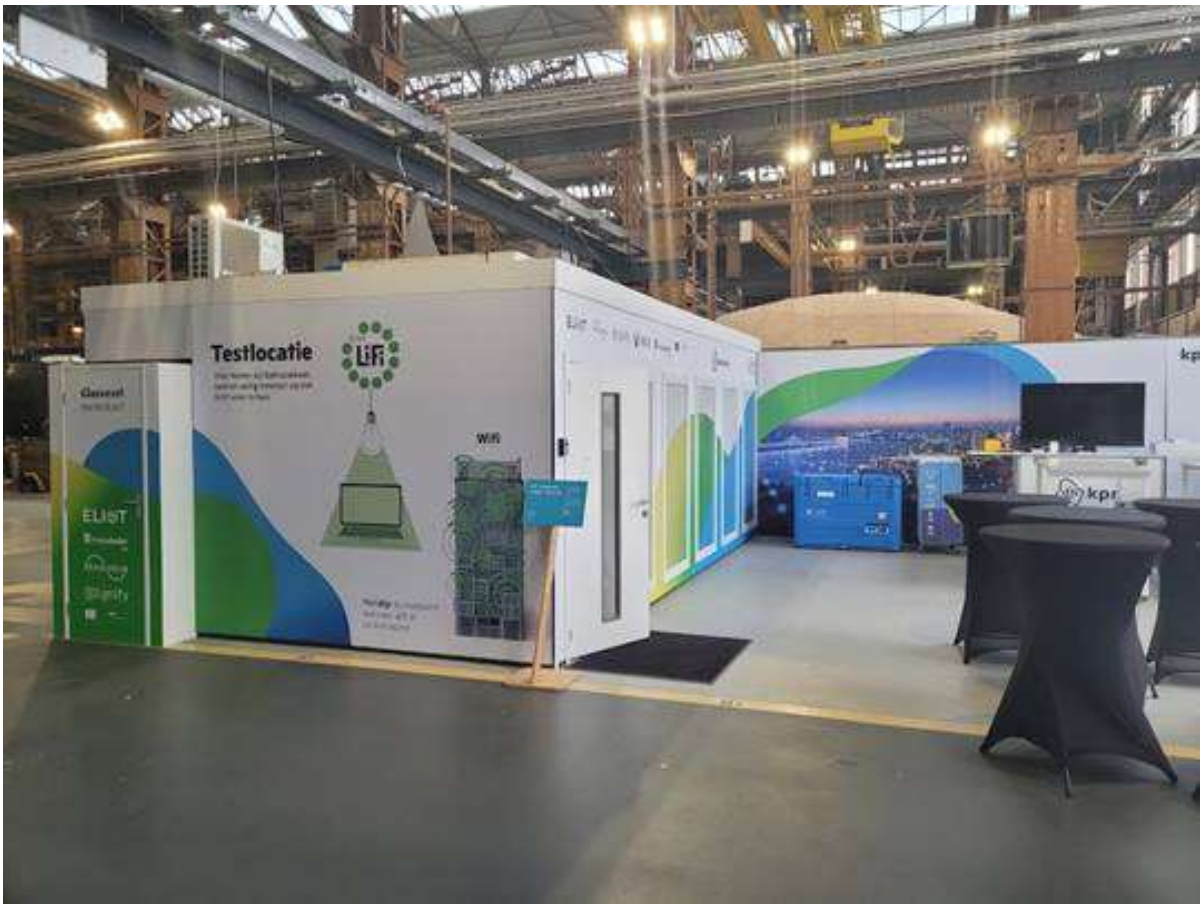
Li-Fi Consumer Demo

Performance, Results & Experience(s)



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1 Introduction

At KPN we believe in the power of connection. By connecting we make life more free, easy and more fun. We are passionate about offering secure, reliable and future-proof networks and services, enabling people to be connected anytime, anywhere, whilst at the same time creating a more prosperous and cleaner world.

We look at Li-Fi technology as a potentially additional enabler of connectivity for our biggest market, the consumer market. The household is located at the very edge of our network and it remains our biggest challenge to get the best connectivity to the consumer and devices in -home. It is standard for a household to have a Wi-Fi access point, often provided by the Internet Service Provider (ISP). Many times, however, the coverage and stability of a single Wi-Fi access point is not good enough for the whole house. ISP's like KPN struggle with Wi-Fi coverage and interference for many years, offering extra Wi-Fi tuning services. Li-Fi could be an attractive addition to a Wi-Fi only network solution within a residence.

The aim of the consumer demonstrator is to give an experience on how Li-Fi technology can be applied in an everyday life, residential environment, and thus to determine what value it currently has. But also, what the future holds.

In this demonstration we examined three main topics;

- Creation of a vertical handover between Li-Fi and Wi-Fi so that a MS Teams video call will continue when losing Li-Fi coverage.
- Evaluation of the performance of Li-Fi in a household environment.
- Examination of the user experience, retrieving feedback

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2 Main Learnings

Overall

- Our consumer demo has intrigued each visitor, yet Li-Fi is not at the stage where anyone expressed explicit interest in having this at home in its current form.
- Consumers find it difficult to compare the quality of networks in a demonstrator situation. Experiences are too short to be able to compare this properly. Also, consumers will only notice the difference when there is a major quality gap between Wi-Fi and Li-Fi. Li-Fi performs well, yet in practice one uses Wi-Fi initially as the device connects automatically to Wi-Fi. You immediately forget that there is Li-Fi coverage around you as the Wi-Fi performed really well in the consumer demonstration. As such there is no trigger to use the Li-Fi. Especially since you needed to find a dongle, put it into the device and then connect to Li-Fi. Thus; only when Wi-Fi underperforms, Li-Fi will be used. As long as Wi-Fi meets the requirements of the consumer, there is no demand for Li-Fi.
- The physical security offered by Li-Fi (As the infrared does not leave the room) is seen as a benefit by many of the visitors.

Technical

- Li-Fi can performance very stable and with high speeds. One observation has been that Li-Fi performance degrades when being used in combination with the PLC solution. For some reason, throughput halved when being used in combination.
- Horizontal handovers work flawlessly when all transceivers are connected to the same modem. When another modem is introduced, interference comes into play, causing the networks to crash. Signify has got a solution to solve this, yet this was not in scope of this project. As we do not expect that consumers would ever need two modems to cover their homes, further investigation into this topic was not executed.
- The coverage of the transceivers has been excellent. The way we set this up, one could walk throughout a large area of the room without losing connection.
- Connection quality remains stable even when the transceiver dongle is positioned at an angle to the transceiver in the building.
- Installation of the devices is straight forward. When installing the Li-Fi equipment on top of KPN's modem, we did experience issues regarding the DHCP / static IP settings. These should be kept in mind.
- When the signal is lost due to blocking, a connection is rebuilt within around 8 seconds. See the attachments for the measurement values
- Li-Fi in combination with the Ethernet over the Powerline solution of Maxliniear underperforms by a factor 2. Speeds achieved through this way were about half of what was reached without the Maxlineair in between. A reduction of bandwidth was expected, however not as large as we have experienced. Higher package loss was observed, yet a clear explanation cannot be given and needs more investigation.
- The Signify Dongle currently, only has an USB connection. Several business consumers have indicated that there should also be an option for a RJ45 plug. For some companies an unknown USB device is not allowed to be plugged in, due to security measures.
- Having Li-Fi coverage adds a significant amount of energy consumption, due to the fact that the equipment is always on. In further development of Li-Fi technology this needs to be taken into account by, for instance.
    - Giving the option to schedule on/off of coverage.
    - Incorporating functionality so that the needed hardware is limited.

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3 Consumer Demonstrator – Why & What?

Why we built the demonstrator

The aim of the consumer demonstrator is to give an experience on how Li-Fi technology can be applied in an everyday life, residential environment. In this demonstration we examined three main topics;

- Creation of a vertical handover between Li-Fi and Wi-Fi so that a MS teams call will continue when losing Li-Fi coverage.
- Evaluate the performance of Li-Fi in a household situations, in terms of speed and stability.
- Examine the user experience; what consumers experience and think of Li-Fi.

KPN facilitated the demonstrator in one of their prime demonstration locations: KPN's Innovation Playground situated at the harbor of Rotterdam. The demonstrator is located in a large old factory hall, housing multiple innovative ventures and start-ups. This location is being used for multiple purposes; Running technical tests, hosting partners and customers, organizing events on technology and innovation. Through using this accessible location, we have been able to give more exposure to Li-Fi technology. This demonstrator has been open (on invitation) to a select public to test out the performance of Li-Fi.

Figure 1: Location Consumer Demonstration – KPN Innovation Playground – Scheepsbouwweg 8 Rotterdam

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What we built;

With this demonstration, we show an actual deployment of Li-Fi. To do this we built a living room that has both Li-Fi and Wi-Fi coverage. We ensured we have Li-Fi connectivity in three different areas, so we could mimic an actual household. These areas are the following;

- Multimedia area with TV Cabinet
  - TV
  - Game Console
  - Interactive television decoder box
  - Coverage through the HHI Li-Fi Transceivers

- Desk / Couch
  - Laptop (nomadic device)
  - Coverage through Signify Trulifi

- Dining Area with kitchen table and chairs
  - Laptop (nomadic device)
  - Coverage Through Signify Trulifi

Figure 2: The three areas in the demonstrator

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The Li-Fi Transceivers were placed in such a way that there is full coverage of each area, and moreover, than one can walk from the table to the couch to the desk without losing coverage. As the beam of each transceiver is 120 degrees this was possible.

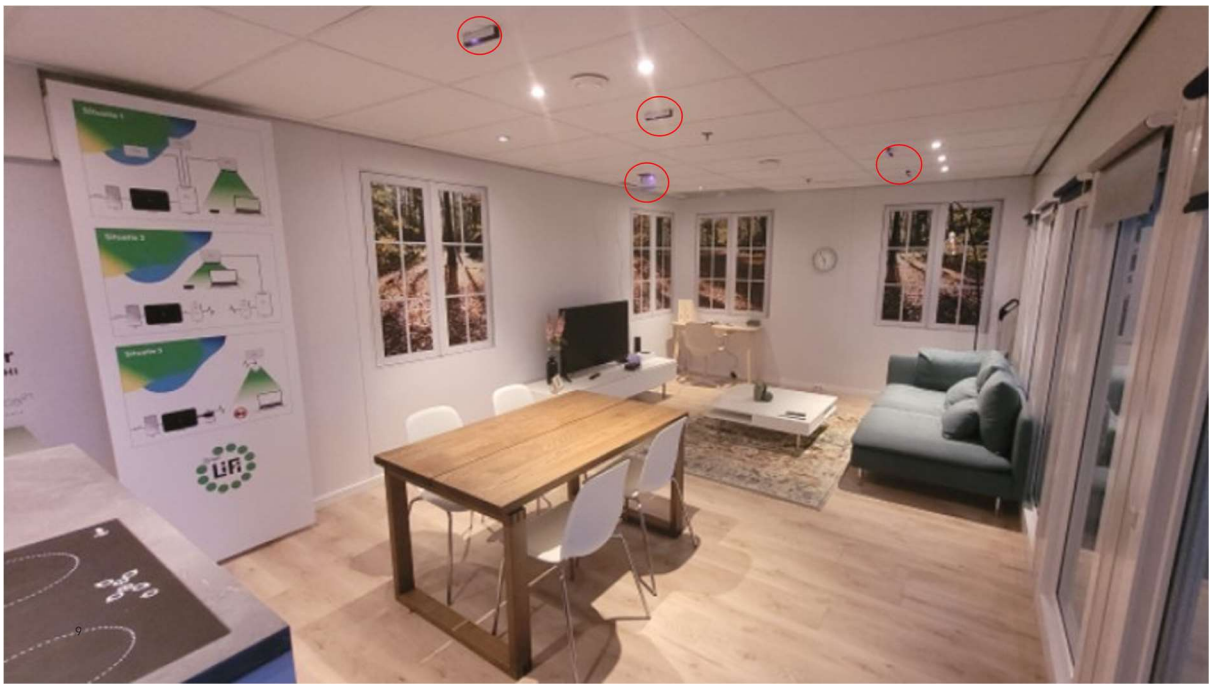

Figure 3: Layout of the Li-Fi Transceivers

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Network infrastructure & used equipment

In this location we have got a 500 Mbps fiber subscription from KPN. This is connected to our Linksys Modem through a Huawei Router (needed for other projects at this location, not necessary for the Li-Fi demonstration. From the ASUS Modem, we built three "pathways". The numbers in figure 4 correspond to the different areas in the demonstrator.

1. Multimedia area
2. The desk & the couch
3. The dinner table

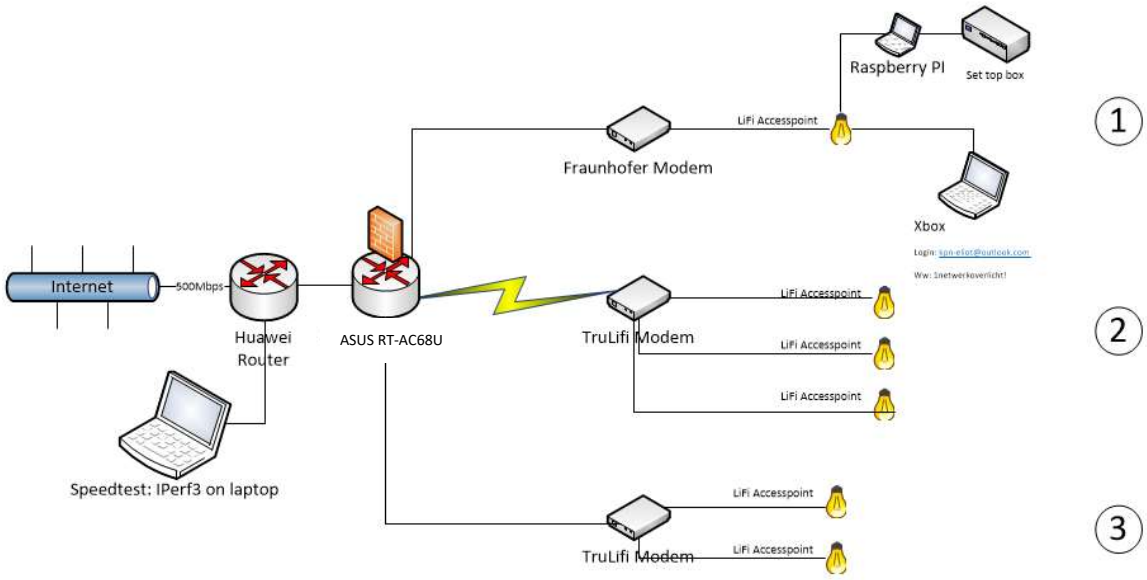

Figure 4: Overview of the LAN

Installed Li-Fi Hardware

For this demonstration, we installed the following Li-Fi hardware of our ELIOT partners;

- 1 x Signify Trulifi Modem Office 6002.2
- 3x Signify Trulifi USB Key 6002.1
- 5x Signify Trulifi Transceiver 6002.2
- 2 x HHI Li-Fi transceivers (Ceiling & Bottom unit)

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4 Development of the Vertical Handover between Wi-Fi & Li-Fi

It is very common for a household to have a Wi-Fi access point, often provided by the Internet Service Provider (ISP). Many times, however, the coverage and stability of a single Wi-Fi access point is not good enough for the whole house. ISP's like KPN struggle with Wi-Fi coverage and interference for many years, offering extra Wi-Fi tuning services. Li-Fi could be an attractive addition to a Wi-Fi only network solution within a residence. As we acknowledge that Wi-Fi will keep playing a big role in consumer homes, so this demonstration has a key focus area on combining Li-Fi and Wi-Fi to give a seamless user experience.

A poor Internet connection is very noticeable during a video conference call. Especially during the ongoing Covid-19 pandemic, within which people are expected to work remotely. A poor Internet connection during a conference call is one of the biggest dissatisfies. When using a bad Internet connection during a conference call people experience a drop-in frame rate, glitches and even disconnects. A conference call therefore is a very good way to experience the connection quality.

With the development of this handover, we aimed to conduct a Microsoft Teams call that experiences minimal interruption when Li-Fi or Wi-Fi is interrupted. So, when the Li-Fi is interrupted the call will continue Wi-Fi, and when Wi-Fi is interrupted, the call will continue Li-Fi.

For the creation & demonstration of the handover, we used the following hardware:

- 1x clean installed Windows 10 x64 devices with Wi-Fi
- 2x Raspberry Pi 4b with Raspbian Linux installed
- 1x managed Ethernet and Wi-Fi router (minimal 3 ethernet ports and 1 WAN).
- 1x TruLiFi 600x series Li-Fi (modem, optical frontend and usb dongle)

The Li-Fi-Wi-Fi handover is accomplished by using the open-source network service called ZeroTier-One version 1.8.6 ZeroTier – Global Area Networking. This network service is designed to create secure direct networks between different internet connected devices without the need of a VPN server and tunnel. See figure 5 for a clarification of the setup.

We used this technology to setup a local Zerotier network that can route all traffic over a single client gateway. ZeroTier creates a Virtual Network Adapter and supports the network traffic to be routed over multiple physical Network Adapters using different bonding protocols like Active Backup. This allows the creation of a seamless Li-Fi-Wi-Fi handover by bonding the Li-Fi and Wi-Fi adapter in the client device. *A description of how-to setup this handover is included in the demonstrator deliverables of D6.4.*

It is important to note that the technology for the handover can also be used on other networking technologies. If lacking a Li-Fi module other connections can be used to setup a handover i.e., a Wi-Fi and ethernet connection.

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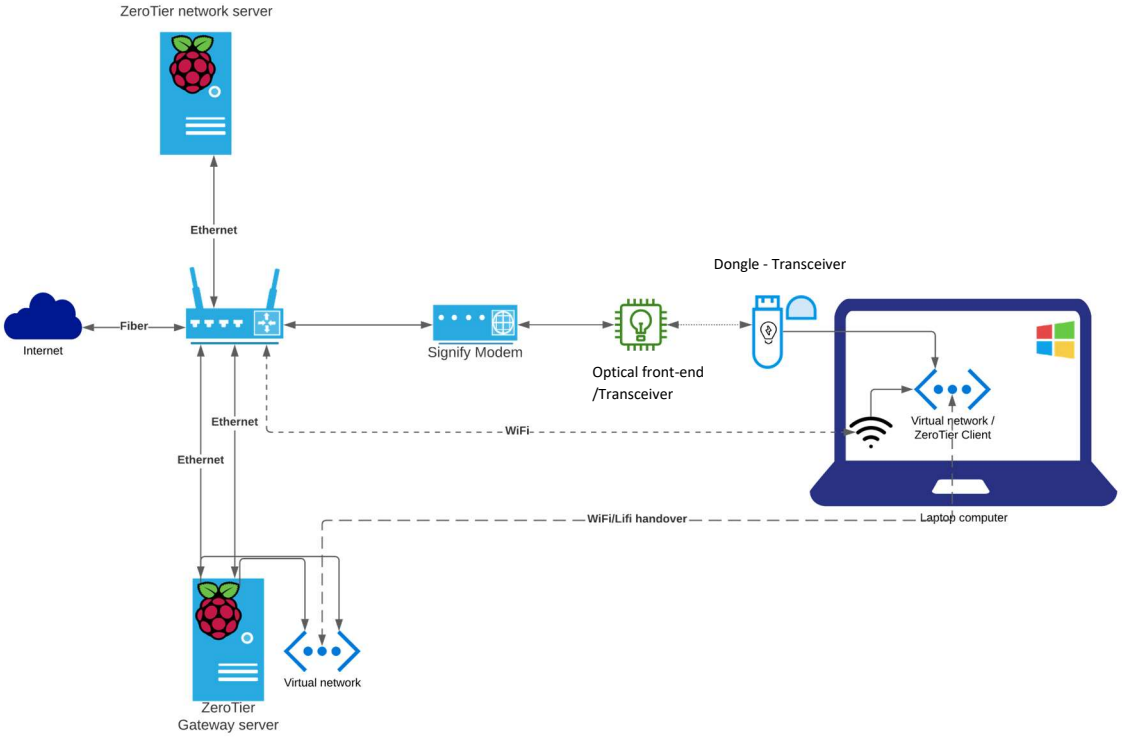

Figure 5. The setup of the hand-over.

Performance of the handover

The below figures show the performance of the handover. In Red you see the download Speed in KB/s through Li-Fi. In Green you see the Download speed in KB/s. In Blue you see the aggregation of both sources. At around 14:53:39 the Li-Fi transceiver is blocked, almost instantly, the Wi-Fi connection kicks, causing the MS Teams call to continue only with a minor hick-up in the video (not the sound). The handover performs equally well in both handover directions. *A video explanation and demonstration of this handover in practice will be made available on Youtube.*

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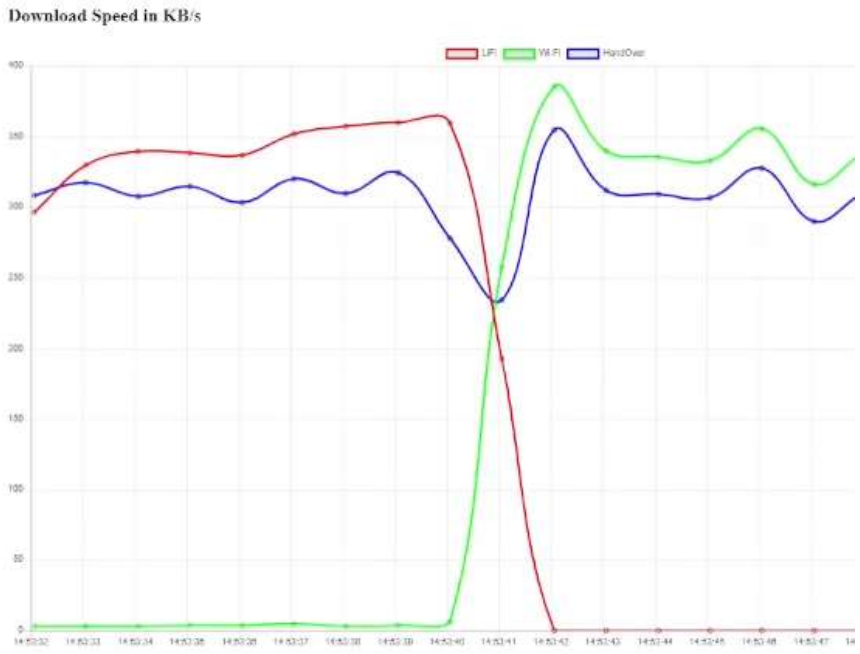

Figure 4. Handover from Li-Fi to Wi-Fi: Download Speed in KB/s during a MS teams call

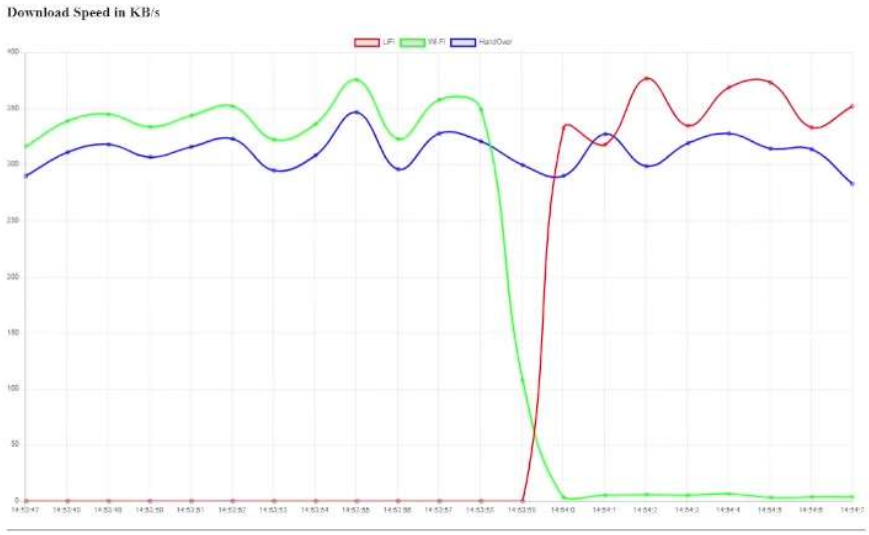

Figure 4. Handover from Wi-Fi to Li-Fi: Download Speed in KB/s during a MS teams call

The Upload speeds during the hand-over can be found in the attachments

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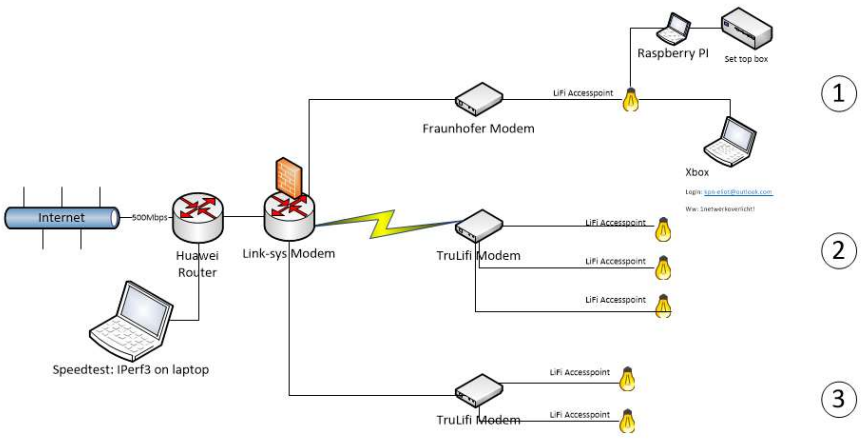
5 Performance of Li-Fi in the demonstrator

In this test case, we evaluate how the Li-Fi performs in the demonstration. As seen earlier; we have setup three pathways to do so:



Speed tests were conducted using the following:

- Raspberry PI 4 with Iperf3 installed
- UTP 6 Cable
- Dell Latitude 5480 laptop

The Raspberry Pi4 was setup as the receiving server, the laptop as the sending. The following results were observed; (all detailed measurements can be found in the attachments)

1. **The HHI equipment**
   During testing, we achieved a stable connection of up to 280 Mbps. The equipment needs some time to get up to speed. After around 15sec, this speed was reached.

2. **The TruLiFi in combination with ethernet over powerline by MaxLiniear**
   It was expected that the PLC solution would have influence, yet Li-Fi over the powerline performed less than expected. Where in situation 3 a stable 122 Mbps was reached, in situation 2 we only achieved around 68 Mbps throughput.

   Therefore, we measured the PLC throughput itself, in terms of bandwidth we found no limiting factor as this achieved 193Mbps. Looking further into the cause, we suspected that there would be package loss. However, when measuring the packet loss, we found a packet loss of around 9%. This on its own could not explain the 50% loss of throughput in the chain.

3. **TruLiFi connected through UTP**
   A throughput of 122 Mbps was measured. This is lower than the rated throughput of the equipment. It is good to note that the equipment is rated for around 200 Mbps, during several occasional speed tests on speedtest.net, these speeds were indeed achieved. All used equipment for the Iperf3 speed test had a (port) capacity of 1Gbps, so it is unclear why the 200 Mbps was not reached using this setup.

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6 Evaluation of the Consumer experience & feedback

In the demonstration room we have shown consumers all the applications and performance of Li-Fi. We were also planning to evaluate the user experience directly, but we have seen that the questionnaire was not fruitful. Therefore, we have observed what consumers shared while visiting the demonstration.

We started off with the following expectations.

- People will not experience a difference between a good Wi-Fi Connection and Li-Fi connection as both can reach a minimum of 200 Mbps throughput, which is plentiful for every activity.
- In places with bad Wi-Fi, people will see a great increase in speed and stability when using Li-Fi.

Throughout the year, around 150 people have visited the demonstration, most on invitation. Some on occasion when visiting neighboring companies and events. Therefore, most people who visited were already interested in the technology (since they came over).

Overall, the perception of Li-Fi to them is positive, yet none had a direct willingness to get this technology for their homes. From these visits it became very clear that only in cases where Wi-Fi is significantly unstable, Li-Fi would be a good backup. Often mentioned topics were:

- How Li-Fi works
- Li-Fi capabilities and how it relates to Wi-Fi (Stability, Speed, interference)
- Ease of installation
- Amount of hardware necessary
- Energy consumption and the need for additional devices

In short: customers are intrigued by the technology. Yet are not interested in having this at home currently considering they have no need for Li-Fi, it is costly, and it needs quite some effort to install.

In the demonstrator location, both Wi-Fi and Li-Fi connectivity was excellent. Therefore, consumers did not experience the difference firsthand. They could only think of a bad Wi-Fi coverage and acknowledge that in that case a Li-Fi solution would have helped. The consumer needs in terms of bandwidth are on average much lower than the performance given by Li-Fi and Wi-Fi, such that the difference is not noticed.

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7 Bonus; A short reflection in-home connectivity & Li-Fi

As KPN we want our customers to have the best network and the best experience. This responsibility includes the connectivity in home. Of course, this also the most difficult domain to manage as it is not completely in our hands. In order to optimize in-home connectivity, we already deploy many (Wi-Fi) Innovations such as Wi-Fi Mesh Satellites & a digital Wi-Fi Manager. Of course, we keep our eyes open for new solutions. This chapter is used to share some of our insights.

Current status

With the increase in smart home appliances and access points; the 2.4 GHz band is being widely used and thus is becoming more saturated. Zigbee, Bluetooth & Wi-Fi all use the 2.4 GHz band. All these different devices will influence the quality of Wi-Fi on the 2.4 GHz frequency. With the 5 GHz band, major capacity has already been added.

For our customer call agents, solving unstable Wi-Fi is a game of deduction as there can be so many causes of badly performing Wi-Fi; These include our agents requestion; what issues the client experience, what devices he/she uses, what modem he/she uses, what kind of house, the age of the house etc.

Wi-Fi is not perfect, KPN still experiences a large amount of customer calls relating to the stability and performance of Wi-Fi. At KPN we log our calls based on the reason for calling. Around 80% of calls are questions related to the installation of hardware. And around 15% is related to interruptions/usage/setup. Which means that a major cost factor is related to the installation and performance of equipment. Therefore, it is adamant that any newly introduced hardware is plug & play, with the least amount of support possible.

Looking further

Wi-Fi as a standard and as a technology has gone through multiple evolutions already. Currently Wi-Fi 6 is already reality. With Wi-Fi 6 we should expect less interference, higher speeds and less issues. When looking towards the future it is expected that Wi-Fi 6 will mainly gain traction at the premium side of the market.

Inherently, the 6 GHz frequency as used by Wi-Fi 6 has less reach and penetration capability than the 2.4 GHz & 5 GHz range. Therefore, we see expect that UTP cables, especially in new build wel isolated houses are crucial as a backbone to deliver a good Wi-Fi experience for every room of the house. This also means that Mesh satellites will be used more widely

When every room is equipped with an ethernet connection, an easier step would be to connect the luminaires to this network. Integration of the transceivers in regular lighting is an important step, next to the integration of the hardware and antenna's into widely used equipment. Currently Li-Fi needs too much equipment. Only when functionality can be included in the household modem, and the transceiver can be directly plugged into the modem then there will be more traction.

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Sustainability

Energy consumption and material use are becoming more and more important, for consumers, but also for ISP's like KPN. Energy & material usage is therefor on top of mind when considering new connectivity technology.

With the current state of technology, in households use one can expect that the Li-Fi Modem and PLC will always be on. Yet it will rarely be on full performance. Therefore, we measured the stand-by energy consumption, and the consumption when running a speed test (i.e.- full power).

Device	Without connection	Without Load – 1 dongle connected	With full Load – 1 dongle on speed test
Signify Modem (0 Spots)	41 kWh	-	-
Signify Modem (1 Spot)	81 kWh	84 kWh	89 kWh
Signify Modem (2 spots)	121 kWh	125 kWh	134 kWh
Signify Modem (3 spots)	160 kWh	165kWh	177 kWh
Maxlineair PLC	19 kWh	19 kWh	39 kWh
Signify Modem (1 spot) + PLC	100 kWh	100 kWh	129 kWh

Table 1. Estimated Yearly energy consumption of the Signify TruLiFi

	Consumption top unit	Consumption below unit	Consumption at full load
HHI Modem/transceiver	134 kWh	158 kWh	292 kWh

Table 2. Estimated Yearly energy consumption of the HHI equipment

To compare Li-Fi with Wi-Fi; The ASUS modem as used in this demonstrator uses 8.8 W in idle mode & 12 W when at full power through 5G Wi-Fi. Where Li-Fi uses a minimum of 9.2 W for having one transceiver on stand-by. At full load, this compares at 12 W for Wi-Fi to 10 W for Li-Fi.

Next to the energy consumption, Li-Fi coverage currently needs a significant amount of additional hardware, the dongle, the modem and the transceivers. Integrations of Li-Fi capabilities into existing hardware such as the modem or existing luminaires would therefore be a recommendation.

So, in the development of the technology, we see several recommendations:

- Include on/off option in transceivers
- Avoid the need for additional hardware, try to incorporate this as much as one can into the existing infrastructure: Modem/luminaries/devices

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8 Attachment

Full list of used equipment

- 1 x ASUS RT-AC68U
- 1 x Signify TruLi-Fi Modem Office 6002.2
- 6x Signify TruLi-Fi USB Key 6002.1
- 2 x HHI Li-Fi Tranceivers (Ceiling & Bottom)
- 2 x MaxLineair RD-HNPLC-DW920-01
- 2x switches : Netgear GS305 v3
- 1x Huawei switch
- Raspberry PI 4 with Iperf3 installed
- UTP 6 Cable

Signal blocking performance

Interference of signal causes 8 seconds connection break

4] 10.01-11.00 sec 10.9 MBytes 92.2 Mbits/sec

[4] 11.00-12.00 sec 12.0 MBytes 101 Mbits/sec

[4] 12.00-13.01 sec 8.88 MBytes 73.8 Mbits/sec

[4] 13.01-14.00 sec 384 KBytes 3.17 Mbits/sec

[4] 14.00-15.01 sec 0.00 Bytes 0.00 bits/sec

[4] 15.01-16.02 sec 0.00 Bytes 0.00 bits/sec

[4] 16.02-17.02 sec 0.00 Bytes 0.00 bits/sec

[4] 17.02-18.01 sec 0.00 Bytes 0.00 bits/sec

[4] 18.01-19.01 sec 0.00 Bytes 0.00 bits/sec

[4] 19.01-20.01 sec 0.00 Bytes 0.00 bits/sec

[4] 20.01-21.02 sec 0.00 Bytes 0.00 bits/sec

[4] 21.02-22.01 sec 0.00 Bytes 0.00 bits/sec

[4] 22.01-23.00 sec 2.88 MBytes 24.2 Mbits/sec

[4] 23.00-24.00 sec 9.88 MBytes 82.9 Mbits/sec

[4] 24.00-25.00 sec 11.4 MBytes 95.2 Mbits/sec

[4] 25.00-26.01 sec 11.6 MBytes 97.0 Mbits/sec

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Upload Performance of vertical handover

Handover from Wi-Fi to Li-Fi: Upload Speed in KB/s during a MS teams call

Handover from Wi-Fi to Li-Fi: Upload Speed in KB/s during a MS Teams scall

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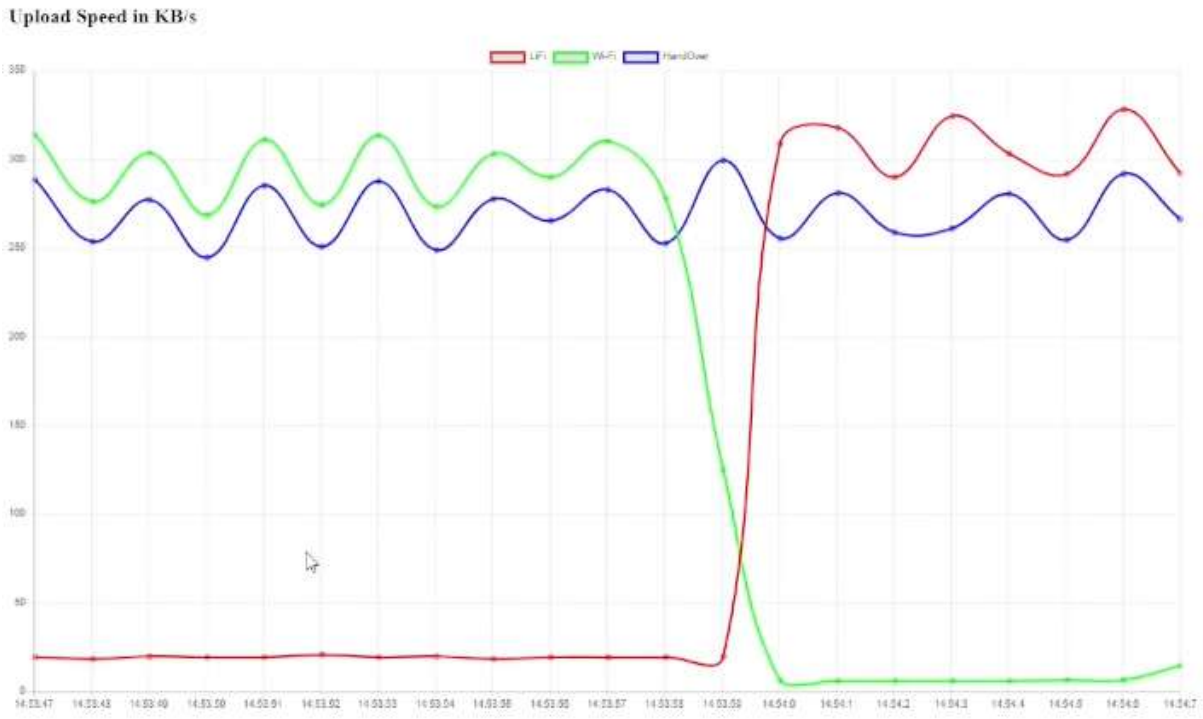

Li-Fi Throughput measurements

Situation 1
Connected directly to HHI transceiver via cat 6 cable

[4] local 192.168.1.237 port 1158 connected to 192.168.1.63 port 5201

[ID] Interval Transfer Bandwidth

[4] 0.00-1.01 sec 9.00 MBytes 75.0 Mbits/sec (omitted)

[4] 1.01-2.00 sec 11.5 MBytes 96.7 Mbits/sec (omitted)

[4] 2.00-3.01 sec 10.1 MBytes 84.2 Mbits/sec (omitted)

[4] 3.01-4.00 sec 10.5 MBytes 89.1 Mbits/sec (omitted)

[4] 4.00-5.01 sec 11.4 MBytes 94.9 Mbits/sec (omitted)

[4] 5.01-6.00 sec 12.0 MBytes 101 Mbits/sec (omitted)

[4] 6.00-7.00 sec 12.5 MBytes 105 Mbits/sec (omitted)

[4] 7.00-8.01 sec 13.4 MBytes 111 Mbits/sec (omitted)

[4] 8.01-9.00 sec 14.1 MBytes 120 Mbits/sec (omitted)

[4] 9.00-10.01 sec 14.1 MBytes 117 Mbits/sec (omitted)

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[4] 0.00-1.00 sec 11.8 MBytes 98.2 Mbits/sec

[4] 1.00-2.00 sec 12.5 MBytes 105 Mbits/sec

[4] 2.00-3.00 sec 12.1 MBytes 101 Mbits/sec

[4] 3.00-4.00 sec 13.0 MBytes 109 Mbits/sec

[4] 4.00-5.00 sec 15.4 MBytes 129 Mbits/sec

[4] 5.00-6.00 sec 17.8 MBytes 149 Mbits/sec

[4] 6.00-7.00 sec 19.6 MBytes 164 Mbits/sec

[4] 7.00-8.00 sec 21.9 MBytes 185 Mbits/sec

[4] 8.00-9.00 sec 24.2 MBytes 203 Mbits/sec

[4] 9.00-10.00 sec 25.4 MBytes 213 Mbits/sec

[4] 10.00-11.00 sec 27.8 MBytes 234 Mbits/sec

[4] 11.00-12.00 sec 28.8 MBytes 241 Mbits/sec

[4] 12.00-13.00 sec 31.2 MBytes 261 Mbits/sec

[4] 13.00-14.00 sec 32.8 MBytes 274 Mbits/sec

[4] 14.00-15.00 sec 33.0 MBytes 278 Mbits/sec

[4] 15.00-16.00 sec 34.2 MBytes 287 Mbits/sec

[4] 16.00-17.00 sec 34.8 MBytes 290 Mbits/sec

[4] 17.00-18.00 sec 33.5 MBytes 283 Mbits/sec

[4] 18.00-19.00 sec 34.2 MBytes 286 Mbits/sec

[4] 19.00-20.00 sec 35.1 MBytes 295 Mbits/sec

[4] 20.00-21.00 sec 35.0 MBytes 294 Mbits/sec

[4] 21.00-22.00 sec 33.4 MBytes 279 Mbits/sec

[4] 22.00-23.00 sec 34.4 MBytes 289 Mbits/sec

[4] 23.00-24.00 sec 33.8 MBytes 283 Mbits/sec

[4] 24.00-25.00 sec 32.9 MBytes 276 Mbits/sec

[4] 25.00-26.00 sec 32.5 MBytes 273 Mbits/sec

[4] 26.00-27.00 sec 34.2 MBytes 287 Mbits/sec

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[4] 27.00-28.00 sec 34.9 MBytes 293 Mbits/sec

[4] 28.00-29.00 sec 34.5 MBytes 289 Mbits/sec

[4] 29.00-30.00 sec 35.2 MBytes 296 Mbits/sec

[4] 30.00-31.00 sec 33.2 MBytes 279 Mbits/sec

[4] 31.00-32.00 sec 32.4 MBytes 272 Mbits/sec

[4] 32.00-33.00 sec 34.5 MBytes 290 Mbits/sec

[4] 33.00-34.00 sec 33.9 MBytes 284 Mbits/sec

[4] 34.00-35.00 sec 34.8 MBytes 292 Mbits/sec

[4] 35.00-36.00 sec 34.6 MBytes 291 Mbits/sec

[4] 36.00-37.00 sec 34.5 MBytes 289 Mbits/sec

[4] 37.00-38.00 sec 34.2 MBytes 287 Mbits/sec

[4] 38.00-39.00 sec 34.6 MBytes 291 Mbits/sec

[4] 39.00-40.00 sec 35.2 MBytes 295 Mbits/sec

[4] 40.00-41.00 sec 34.4 MBytes 289 Mbits/sec

[4] 41.00-42.00 sec 34.6 MBytes 290 Mbits/sec

[4] 42.00-43.00 sec 33.4 MBytes 280 Mbits/sec

[4] 43.00-44.00 sec 33.2 MBytes 279 Mbits/sec

[4] 44.00-45.00 sec 33.0 MBytes 277 Mbits/sec

[4] 45.00-46.00 sec 34.1 MBytes 287 Mbits/sec

[4] 46.00-47.00 sec 33.4 MBytes 280 Mbits/sec

[4] 47.00-48.00 sec 34.4 MBytes 288 Mbits/sec

[4] 48.00-49.00 sec 34.1 MBytes 286 Mbits/sec

[4] 49.00-50.00 sec 33.6 MBytes 282 Mbits/sec

[4] 50.00-51.00 sec 34.8 MBytes 292 Mbits/sec

[4] 51.00-52.00 sec 33.5 MBytes 280 Mbits/sec

[4] 52.00-53.00 sec 31.9 MBytes 268 Mbits/sec

[4] 53.00-54.00 sec 32.4 MBytes 271 Mbits/sec

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[4] 54.00-55.00 sec 33.2 MBytes 279 Mbits/sec

[4] 55.00-56.00 sec 33.2 MBytes 279 Mbits/sec

[4] 56.00-57.00 sec 34.5 MBytes 289 Mbits/sec

[4] 57.00-58.00 sec 33.4 MBytes 281 Mbits/sec

[4] 58.00-59.00 sec 34.6 MBytes 290 Mbits/sec

[4] 59.00-59.99 sec 34.4 MBytes 293 Mbits/sec

- -

[ID] Interval Transfer Bandwidth

[4] 0.00-59.99 sec 1.81 GBytes 260 Mbits/sec sender

[4] 0.00-59.99 sec 1.81 GBytes 260 Mbits/sec receiver

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Situation 2:
Positioned under the spot above the desk/couch

[4] local 192.168.1.232 port 30818 connected to 192.168.1.63 port 5201

[ID] Interval Transfer Bandwidth

[4] 0.00-1.00 sec 7.25 MBytes 60.8 Mbits/sec

[4] 1.00-2.00 sec 10.1 MBytes 84.8 Mbits/sec

[4] 2.00-3.01 sec 8.12 MBytes 67.5 Mbits/sec

[4] 3.01-4.00 sec 5.88 MBytes 49.8 Mbits/sec

[4] 4.00-5.00 sec 6.62 MBytes 55.4 Mbits/sec

[4] 5.00-6.00 sec 6.62 MBytes 55.7 Mbits/sec

[4] 6.00-7.01 sec 6.88 MBytes 57.4 Mbits/sec

[4] 7.01-8.01 sec 5.00 MBytes 41.9 Mbits/sec

[4] 8.01-9.01 sec 9.38 MBytes 78.7 Mbits/sec

[4] 9.01-10.00 sec 6.62 MBytes 55.9 Mbits/sec

[4] 10.00-11.01 sec 9.75 MBytes 81.4 Mbits/sec

[4] 11.01-12.02 sec 9.00 MBytes 74.6 Mbits/sec

[4] 12.02-13.01 sec 5.25 MBytes 44.5 Mbits/sec

[4] 13.01-14.00 sec 6.88 MBytes 57.9 Mbits/sec

[4] 14.00-15.00 sec 8.88 MBytes 74.3 Mbits/sec

[4] 15.00-16.00 sec 9.00 MBytes 75.6 Mbits/sec

[4] 16.00-17.01 sec 9.75 MBytes 81.5 Mbits/sec

[4] 17.01-18.01 sec 10.0 MBytes 83.6 Mbits/sec

[4] 18.01-19.00 sec 9.62 MBytes 81.3 Mbits/sec

[4] 19.00-20.01 sec 9.62 MBytes 80.5 Mbits/sec

[4] 20.01-21.00 sec 9.12 MBytes 76.9 Mbits/sec

[4] 21.00-22.00 sec 8.88 MBytes 74.5 Mbits/sec

[4] 22.00-23.00 sec 8.25 MBytes 69.2 Mbits/sec

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[4] 23.00-24.00 sec 6.00 MBytes 50.3 Mbits/sec

[4] 24.00-25.00 sec 6.62 MBytes 55.6 Mbits/sec

[4] 25.00-26.00 sec 7.00 MBytes 58.7 Mbits/sec

[4] 26.00-27.00 sec 8.25 MBytes 69.4 Mbits/sec

[4] 27.00-28.00 sec 6.50 MBytes 54.5 Mbits/sec

[4] 28.00-29.01 sec 9.75 MBytes 81.4 Mbits/sec

[4] 29.01-30.00 sec 8.62 MBytes 72.7 Mbits/sec

[4] 30.00-31.00 sec 9.38 MBytes 78.6 Mbits/sec

[4] 31.00-32.01 sec 9.38 MBytes 78.3 Mbits/sec

[4] 32.01-33.01 sec 9.38 MBytes 78.4 Mbits/sec

[4] 33.01-34.01 sec 8.75 MBytes 73.3 Mbits/sec

[4] 34.01-35.01 sec 6.50 MBytes 54.7 Mbits/sec

[4] 35.01-36.00 sec 7.62 MBytes 64.4 Mbits/sec

[4] 36.00-37.01 sec 10.1 MBytes 84.1 Mbits/sec

[4] 37.01-38.00 sec 7.38 MBytes 62.3 Mbits/sec

[4] 38.00-39.01 sec 6.88 MBytes 57.5 Mbits/sec

[4] 39.01-40.00 sec 9.38 MBytes 79.1 Mbits/sec

- -

[ID] Interval Transfer Bandwidth

[4] 0.00-40.00 sec 324 MBytes 67.9 Mbits/sec sender

[4] 0.00-40.00 sec 324 MBytes 67.9 Mbits/sec receiver

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Measuring speed of PLC connection coming into the Li-Fi Modem for situation 2

[4] local 192.168.1.237 port 30684 connected to 192.168.1.63 port 5201

[ID] Interval Transfer Bandwidth

[4] 0.00-1.01 sec 13.5 MBytes 113 Mbits/sec

[4] 1.01-2.00 sec 22.9 MBytes 193 Mbits/sec

[4] 2.00-3.01 sec 22.4 MBytes 187 Mbits/sec

[4] 3.01-4.01 sec 23.2 MBytes 195 Mbits/sec

[4] 4.01-5.00 sec 24.6 MBytes 207 Mbits/sec

[4] 5.00-6.00 sec 24.5 MBytes 206 Mbits/sec

[4] 6.00-7.00 sec 25.2 MBytes 212 Mbits/sec

[4] 7.00-8.00 sec 21.8 MBytes 182 Mbits/sec

[4] 8.00-9.00 sec 23.4 MBytes 196 Mbits/sec

[4] 9.00-10.00 sec 24.9 MBytes 209 Mbits/sec

[4] 10.00-11.00 sec 23.1 MBytes 194 Mbits/sec

[4] 11.00-12.00 sec 24.1 MBytes 202 Mbits/sec

[4] 12.00-13.00 sec 24.5 MBytes 206 Mbits/sec

[4] 13.00-14.00 sec 24.2 MBytes 204 Mbits/sec

[4] 14.00-15.00 sec 24.2 MBytes 203 Mbits/sec

[4] 15.00-16.00 sec 25.0 MBytes 209 Mbits/sec

[4] 16.00-17.00 sec 23.6 MBytes 199 Mbits/sec

[4] 17.00-18.01 sec 24.8 MBytes 207 Mbits/sec

[4] 18.01-19.01 sec 24.5 MBytes 206 Mbits/sec

[4] 19.01-20.01 sec 18.9 MBytes 158 Mbits/sec

[4] 20.01-21.00 sec 20.5 MBytes 173 Mbits/sec

[4] 21.00-22.01 sec 23.0 MBytes 192 Mbits/sec

[4] 22.01-23.00 sec 21.2 MBytes 179 Mbits/sec

[4] 23.00-24.00 sec 19.8 MBytes 166 Mbits/sec

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[4] 24.00-25.00 sec 20.0 MBytes 168 Mbits/sec

[4] 25.00-26.00 sec 23.8 MBytes 199 Mbits/sec

[4] 26.00-27.00 sec 24.9 MBytes 208 Mbits/sec

[4] 27.00-28.00 sec 23.4 MBytes 197 Mbits/sec

[4] 28.00-29.00 sec 24.0 MBytes 201 Mbits/sec

[4] 29.00-30.00 sec 24.2 MBytes 203 Mbits/sec

[4] 30.00-31.00 sec 22.2 MBytes 187 Mbits/sec

[4] 31.00-32.00 sec 23.6 MBytes 198 Mbits/sec

[4] 32.00-33.00 sec 23.1 MBytes 194 Mbits/sec

[4] 33.00-34.00 sec 22.2 MBytes 187 Mbits/sec

[4] 34.00-35.00 sec 22.9 MBytes 192 Mbits/sec

[4] 35.00-36.00 sec 24.5 MBytes 205 Mbits/sec

[4] 36.00-37.00 sec 24.2 MBytes 204 Mbits/sec

[4] 37.00-38.00 sec 24.5 MBytes 205 Mbits/sec

[4] 38.00-39.00 sec 23.6 MBytes 199 Mbits/sec

[4] 39.00-40.00 sec 23.4 MBytes 196 Mbits/sec

- -

[ID] Interval Transfer Bandwidth

[4] 0.00-40.00 sec 922 MBytes 193 Mbits/sec sender

[4] 0.00-40.00 sec 922 MBytes 193 Mbits/sec receiver

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 825651 (ELIOT)

Situation 2
UDP test - Experiencing a package loss of 9%

Connecting to host 192.168.1.63, port 5201

[4] local 192.168.1.186 port 53156 connected to 192.168.1.63 port 5201

[ID] Interval Transfer Bandwidth Total Datagrams

[4] 0.00-1.01 sec 8.81 MBytes 73.4 Mbits/sec 1128 (omitted)

[4] 1.01-2.00 sec 9.53 MBytes 80.5 Mbits/sec 1220 (omitted)

[4] 2.00-3.01 sec 9.52 MBytes 79.3 Mbits/sec 1219 (omitted)

[4] 3.01-4.01 sec 9.51 MBytes 79.8 Mbits/sec 1217 (omitted)

[4] 4.01-5.01 sec 9.58 MBytes 80.4 Mbits/sec 1226 (omitted)

[4] 5.01-6.00 sec 9.54 MBytes 80.5 Mbits/sec 1221 (omitted)

[4] 6.00-7.01 sec 9.54 MBytes 79.5 Mbits/sec 1221 (omitted)

[4] 7.01-8.01 sec 9.61 MBytes 80.7 Mbits/sec 1230 (omitted)

[4] 8.01-9.00 sec 9.45 MBytes 79.7 Mbits/sec 1209 (omitted)

[4] 9.00-10.01 sec 9.54 MBytes 79.6 Mbits/sec 1221 (omitted)

[4] 0.00-1.00 sec 9.57 MBytes 80.3 Mbits/sec 1225

[4] 1.00-2.00 sec 9.49 MBytes 79.6 Mbits/sec 1215

[4] 2.00-3.00 sec 9.55 MBytes 80.1 Mbits/sec 1223

[4] 3.00-4.00 sec 9.65 MBytes 81.0 Mbits/sec 1235

[4] 4.00-5.00 sec 9.48 MBytes 79.5 Mbits/sec 1213

[4] 5.00-6.01 sec 9.48 MBytes 78.4 Mbits/sec 1214

[4] 6.01-7.00 sec 9.59 MBytes 81.7 Mbits/sec 1228

[4] 7.00-8.00 sec 9.52 MBytes 79.9 Mbits/sec 1219

[4] 8.00-9.00 sec 9.54 MBytes 80.0 Mbits/sec 1221

[4] 9.00-10.00 sec 9.57 MBytes 80.5 Mbits/sec 1225

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[ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 825651 (ELIOT)

[4] 0.00-10.00 sec 95.5 MBytes 80.1 Mbits/sec 1.213 ms 1011/11316 (8.9%)

[4] Sent 11316 datagrams

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UDP test of PLC - Experiencing a package loss of 6%

[4] local 192.168.1.237 port 56003 connected to 192.168.1.63 port 5201

[ID] Interval Transfer Bandwidth Total Datagrams

[4] 0.00-1.00 sec 8.95 MBytes 75.0 Mbits/sec 1146 (omitted)

[4] 1.00-2.00 sec 9.46 MBytes 79.2 Mbits/sec 1211 (omitted)

[4] 2.00-3.01 sec 9.48 MBytes 79.1 Mbits/sec 1213 (omitted)

[4] 3.01-4.01 sec 9.59 MBytes 80.4 Mbits/sec 1227 (omitted)

[4] 4.01-5.01 sec 9.42 MBytes 79.1 Mbits/sec 1206 (omitted)

[4] 5.01-6.00 sec 9.66 MBytes 81.5 Mbits/sec 1236 (omitted)

[4] 6.00-7.00 sec 9.50 MBytes 79.5 Mbits/sec 1216 (omitted)

[4] 7.00-8.01 sec 9.44 MBytes 78.9 Mbits/sec 1208 (omitted)

[4] 8.01-9.01 sec 9.89 MBytes 83.0 Mbits/sec 1266 (omitted)

[4] 9.01-10.00 sec 9.31 MBytes 78.6 Mbits/sec 1192 (omitted)

[4] 0.00-1.00 sec 9.43 MBytes 78.6 Mbits/sec 1207

[4] 1.00-2.01 sec 9.55 MBytes 80.0 Mbits/sec 1222

[4] 2.01-3.00 sec 9.56 MBytes 80.6 Mbits/sec 1224

[4] 3.00-4.00 sec 9.55 MBytes 79.9 Mbits/sec 1223

[4] 4.00-5.00 sec 9.58 MBytes 80.3 Mbits/sec 1226

[4] 5.00-6.00 sec 9.45 MBytes 79.4 Mbits/sec 1210

[4] 6.00-7.00 sec 9.72 MBytes 81.6 Mbits/sec 1244

[4] 7.00-8.00 sec 9.55 MBytes 80.0 Mbits/sec 1222

[4] 8.00-9.00 sec 9.75 MBytes 81.8 Mbits/sec 1248

[4] 9.00-10.00 sec 9.25 MBytes 77.6 Mbits/sec 1184

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[ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams

[4] 0.00-10.00 sec 95.4 MBytes 80.0 Mbits/sec 2.088 ms 743/12210 (6.1%)

[4] Sent 12210 datagrams

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Situation 3
Connectivity of TruLi-Fi equipment above the diner table

[4] local 192.168.1.186 port 1548 connected to 192.168.1.63 port 5201

[ID] Interval Transfer Bandwidth

[4] 0.00-1.00 sec 11.5 MBytes 96.1 Mbits/sec

[4] 1.00-2.01 sec 13.2 MBytes 111 Mbits/sec

[4] 2.01-3.00 sec 14.5 MBytes 122 Mbits/sec

[4] 3.00-4.01 sec 14.6 MBytes 122 Mbits/sec

[4] 4.01-5.00 sec 14.6 MBytes 123 Mbits/sec

[4] 5.00-6.00 sec 14.5 MBytes 122 Mbits/sec

[4] 6.00-7.00 sec 15.1 MBytes 127 Mbits/sec

[4] 7.00-8.01 sec 15.2 MBytes 128 Mbits/sec

[4] 8.01-9.00 sec 15.1 MBytes 127 Mbits/sec

[4] 9.00-10.00 sec 14.9 MBytes 125 Mbits/sec

[4] 10.00-11.00 sec 14.6 MBytes 123 Mbits/sec

[4] 11.00-12.00 sec 14.8 MBytes 124 Mbits/sec

[4] 12.00-13.00 sec 14.2 MBytes 119 Mbits/sec

[4] 13.00-14.00 sec 14.8 MBytes 123 Mbits/sec

[4] 14.00-15.01 sec 14.8 MBytes 124 Mbits/sec

[4] 15.01-16.00 sec 14.8 MBytes 124 Mbits/sec

[4] 16.00-17.00 sec 14.5 MBytes 122 Mbits/sec

[4] 17.00-18.00 sec 14.4 MBytes 121 Mbits/sec

[4] 18.00-19.00 sec 14.6 MBytes 123 Mbits/sec

[4] 19.00-20.00 sec 14.8 MBytes 123 Mbits/sec

[4] 20.00-21.01 sec 14.4 MBytes 121 Mbits/sec

[4] 21.01-22.01 sec 14.6 MBytes 123 Mbits/sec

[4] 22.01-23.01 sec 14.9 MBytes 124 Mbits/sec

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 825651 (ELIOT)

[4] 23.01-24.01 sec 14.8 MBytes 124 Mbits/sec

[4] 24.01-25.00 sec 14.4 MBytes 121 Mbits/sec

[4] 25.00-26.00 sec 14.1 MBytes 118 Mbits/sec

[4] 26.00-27.00 sec 14.2 MBytes 120 Mbits/sec

[4] 27.00-28.00 sec 14.8 MBytes 123 Mbits/sec

[4] 28.00-29.01 sec 14.9 MBytes 124 Mbits/sec

[4] 29.01-30.00 sec 14.6 MBytes 123 Mbits/sec

[4] 30.00-31.00 sec 14.9 MBytes 125 Mbits/sec

[4] 31.00-32.01 sec 15.0 MBytes 125 Mbits/sec

[4] 32.01-33.00 sec 14.5 MBytes 122 Mbits/sec

[4] 33.00-34.00 sec 14.8 MBytes 124 Mbits/sec

[4] 34.00-35.00 sec 14.8 MBytes 124 Mbits/sec

[4] 35.00-36.01 sec 14.8 MBytes 124 Mbits/sec

[4] 36.01-37.00 sec 14.5 MBytes 122 Mbits/sec

[4] 37.00-38.01 sec 14.8 MBytes 123 Mbits/sec

[4] 38.01-39.00 sec 14.5 MBytes 122 Mbits/sec

[4] 39.00-40.00 sec 14.6 MBytes 122 Mbits/sec

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[ID] Interval Transfer Bandwidth

[4] 0.00-40.00 sec 582 MBytes 122 Mbits/sec sender

[4] 0.00-40.00 sec 582 MBytes 122 Mbits/sec receiver

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Observed power consumption

	Ceiling unit	Base/below unit	Full load (during speedtest)
HHI Modem/transceiver	15.3W	18W	~30W (base station) ~30W (ceiling unit)

Device	Without connection	Without Load – 1 dongle connected	With full Load – 1 dongle on speedtest
Signify Modem (0 Spots)	4,7W	-	-
Signify Modem (1 Spot)	9,2W	9,6W	10,2W
Signify Modem (2 spots)	13,8W	14,3W	15,3W
Signify Modem (3 spots)	18,3W	18,8W	20,2W
Maxlineair PLC	2,2W	2,2W	4,5W
Signify Modem (1 spot) + PLC	11,4W	11,8W	14,7W

This translates into a yearly consumption of;

Device	Without connection	Without Load – 1 dongle connected	With full Load – 1 dongle on speedtest
Signify Modem (0 Spots)	41,2 kWh	-	-
Signify Modem (1 Spot)	80,6 kWh	84,1 kWh	89,4 kWh
Signify Modem (2 spots)	120,9 kWh	125,3 kWh	134,0 kWh
Signify Modem (3 spots)	160,3 kWh	164,7 kWh	177,0 kWh
Maxlineair PLC	19,3 kWh	19,3 kWh	39,4 kWh
Signify Modem (1 spot) + PLC	99,9 kWh	103,4 kWh	128,8 kWh

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