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In-House Light Paths Network Architecture

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Short online lecture Sept 28, 2021; 17:15 -17:30. Will be made available later on YouTube

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Dedicated to: Victor (Vic) Hayes and

Cees Links [Wi-Fi], Jaap Haartsen [Bluetooth]

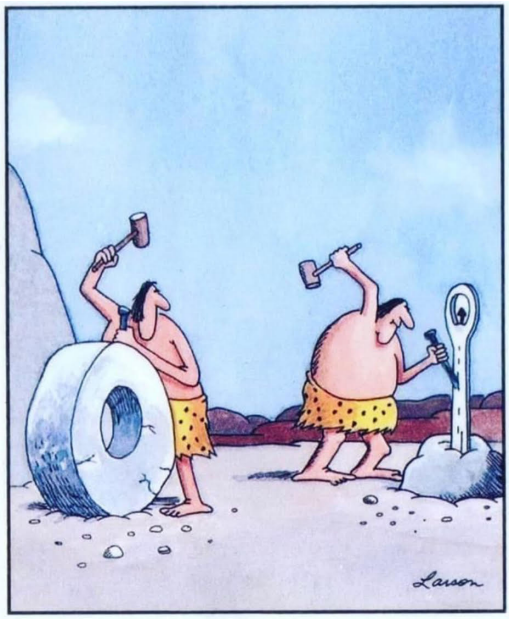

Fig. 1: Human inventions. It makes sense to look ahead what may come and what the infrastructure needs will be then.

Summary / Abstract

This lecture presents a new architecture for indoor interconnection of mobile user-devices: laptops, smartphone's, tablets; using a combination of plastic optic fiber (POF) cables in buildings and self healing smart mesh light paths in each room or office. In this way the devices can each be connected with 1 to 10 Gb/s symmetric IP links to each other and to FttH/FttB Wide Area Networks. This architecture is future proof (up-scalable) and can function as successor to in-house Wi-Fi or in-house 4G/5G, both of which are running into a number of limitations, and will need successors. In other words, the Ti-Fi architecture can be described as "Wi-Fi with Light".

What can be achieved is for instance communication between server farms, in cloud services of data centers, all the way to/from the mentioned user devices, almost completely with photon streams, instead of electrons. This agrees with the long time trend in digital infrastructures to replace electronics with photonics.

This new in-house digital infrastructure is tailored to requirements of the customer side which are driving the demand for connectivity all over the world. Wi-Fi 6, 4G, 5G and even 6G had to segment design & implementation into diverse specific environments like factories, vehicle traffic, medicine, stadiums. For the presented architecture we have a) extended the requirements to what hundreds of millions of people would like/ demand in environments b) restricted to **rooms** in homes and rooms in offices. This is in fact the mainstream growth area for mobile computer network use. In practice 80% of that use is '**nomadic**', meaning at a number of places/desks people use for instance internet access stationary (not moving) for a certain amount of time and then move to other **stationary** places in the building/ campus or go visit other companies, or go home, and sit down there with better online access.

The Ti-Fi architecture does employ Li-Fi components (bidirectional infrared light beams) but not vertical from the ceiling or beam steered, but **horizontal** above the heads of the users to/from Ti-Fi devices at the walls connected with POF cables through plastic tubes installed in buildings/homes for AC power cables.

At the user side a simple Ti-Fi omni-directional light beam/sensor device is connected with USB-C cable for power& signals to/from the user device. Enclosed in the room/office a mesh of light paths is set up by an App, with store & forward. In this way we make use of the fact that light beams can NOT penetrate walls. So there is no interference/electrosmog inside or outside the buildings. This mesh setup can be kept simple since only a limited amount of fixed positions (seats) are available in a room/office. The aim of this architecture is to make it robust and very low cost and DIY so implementation can take off into a volume market and at the same time unplugging the obstacles in the homes and offices for high speed network and ICT/ Cloud services use.

What is presented is in essence a kind of **T**-Ford (1908), the first affordable mass produced car, for our data highways. Hence, the name **T**i-Fi. Yes it is a construction that has all the attributes (DIY) of a disruptive technology and it can be made to evolve and excite other innovations in society.

In the lecture we focus also on the real driver for the huge growth in bandwidth demand: computer-computer communication is bursty, self-similar with fractal volume sizes of blocks that have to be transported. In fact this has all the attributes of traffic on a **BUS** (computer backplane). This explains the popularity of Ethernet–like (level-2)/USB protocols on (optic fiber cable) digital infrastructures and at the same time forecasts the upper bound of needed bandwidth capacity speeds: the speed inside the CPU's and GPUs and inside the backplanes of for instance the laptops must be extended in the building and long distance to the computers in de datacenters. Multi Gigabits/second streams for computers Apps that do not want to wait, but bombard the network with demands for data. An ancient saying applies here: "As within so without".

The Apple "Airport Base Station" (2001) was a big gamble of Steve Jobs, but it helped launch Wi-Fi into massive mainstream use. And it did wonders for Mac sales. Our guess is that Ti-Fi's will launch the sales of Li-Fi links and photonics OWC equipment in a number of positive ways.

2. Contents

5. The proposed “Ti-Fi Network Architecture”. 5.1 Rationale for choices of architecture components

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Fig. 2: Ask your children. They can tell you that this ‘70’s World’ of analog Radio, TV and Telephone is GONE. In combination with the “Shopwindow Problem” of supply side. If you ask a shopkeeper what the public wants to buy, he/she will show you what is in their shopwindow.

3. What are the problems: Stability, Coverage and Speed?

Short term remedies for WIFI congestion and instabilities are: boosters, mesh network boxes.

- On the **customer side**: simply put, after the vital resources of ‘Gas, Water, Electricity’, people expect well working Wi-Fi everywhere they are. But that is clearly not the case. It is not robust, not functioning all the time (especially at the edges of the radiation field), not in every room or office. And not secure against ‘onlookers’, who might misuse transmitted info.

- The indoor “digital infrastructure”, due to its success during Covid lockdown (Tele-working, Tele-school) is reaching its limitations. 4G, Wi-Fi is getting bad, jittery, due to density: too many people in the house (H2O frequency) absorb; edge oscillations when field is not strong enough.

- Spectrum congestion. See report and lecture of the NL frequency quality supervisor and regulator [2].

- Exponential growth in numbers of devices as well as demand for capacity (streaming video, bigger files).

- Speed (bits/s) also known as “bandwidth” = link capacity is not adequate anymore, however 4G, 5G and Wi-Fi speeds cannot be scaled up anymore, see next slide. In for instance USA and Germany the Fiber Optic cable wired and their connected wireless backbones are years behind NL, so they may not even have noticed yet, they will face a brick wall soon.

- For certain applications, like cloud computing, telemedicine and games, latency is getting longer, and what is worse: variable. This is negative too for Home Office transaction responsiveness.

- It is rather silly when Wide Area Network (WAN) connections are converging on 1 Gb/s or even 10/10 Gb/s to the premises, for instance with XGS-PON[9], while in house/indoors that sinks to for instance 10 Mb/s down/ 1up per laptop.

- In response to this "crowding" developers of network services had to resort to fragmentation into products for special applications & environments (i.e. 5G): factories, PANS, Internet of Things (IoT), vehicles, agriculture, stadiums, and emergency services (with slicing for priorities).

- Problem: Social-cultural obstacle: Most of the Supply side lives with the mindset of the successes of '70s: TV, Telephone, newspapers, see Fig.2.

4. Approach to solve the in-house Dilemmas

Optical Wireless Communication (OWC) as successor to Wi-Fi and G4, G5, G6 ...

4.1 Requirements

Disadvantages of Mobile Networks and WiFi : growing complexity, reflections, protocol overhead (handover, error correction)

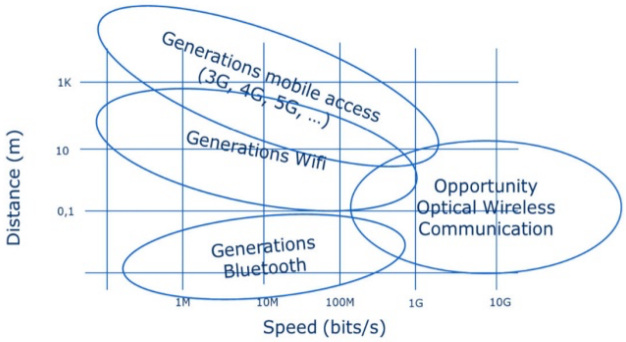


Fig. 3: Positioning "Optical Wireless Communication" in Speed vs. Distance

General overview. See figure 4 from [2] and [3]:

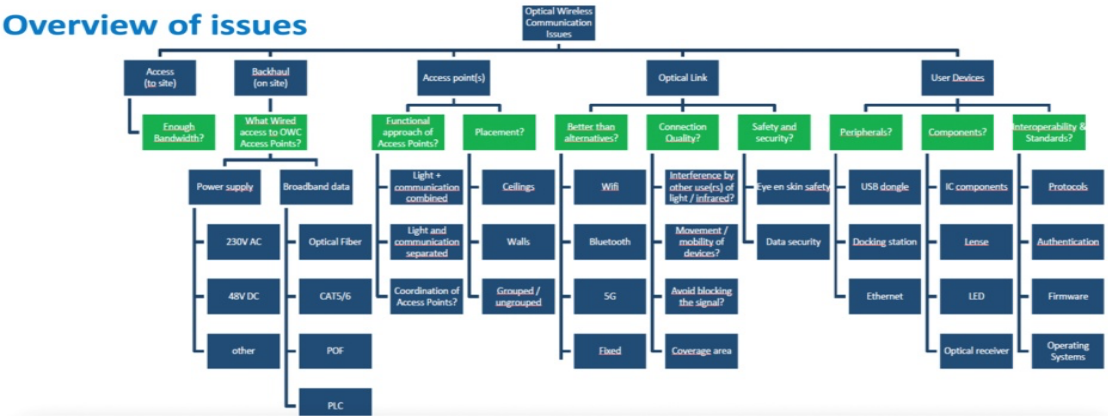


Fig. 4: Issues.

4. Approach to solve the Dilemma's of WOC

4.2 Requirements from the Customer/User side in addition to the issues stated above

VITAL: *Quality (**Reliability** of Internet connection) over **Price.*** Modern existential FEAR: low battery power, low wireless coverage.

- Robust. Especially for SME's connectivity internal as well as external is vital. They fear to lose connection. Extremely high availability (long MTBF, short MTTR, redundancy, spotting and removing SPOFs)
- Low Cost for installation and maintenance. High Quality of Help Desks???
- Do It Yourself possibility (DIY packages)
- Low Radiation (optic beam is also electro magnetic) ; no electro-smog. Regulators have declared IR and visible light links as "UnLicenced". No interference, No crosstalk.
- Low energy use, materials can be recycled. ----> Solar powered?
- Can grow into densely packed infra and scale up in performance. Estimates are a doubling in indoor capacity (exponential growth) every 16 months.
- Low and fixed latency
- 1 – 10 Gb/s symmetric connection PER DEVICE , with bursty, self similar (fractal sizes) IP datatraffic. *)
- Reduced complexity, user friendly, SAFE and confidential vs. Surveillance.
- Maintenance and measuring equipment. Addressing tools. Authentication with EduRoam/Publicroam -like tools.

4.2.1 Analysis of the Growing Bandwidth Demand *)

Intermezzo. Where does the ever-growing SPEED requirement per device and therefore the growing demand of capacity of connections come from? *"The BUS Metaphor"*

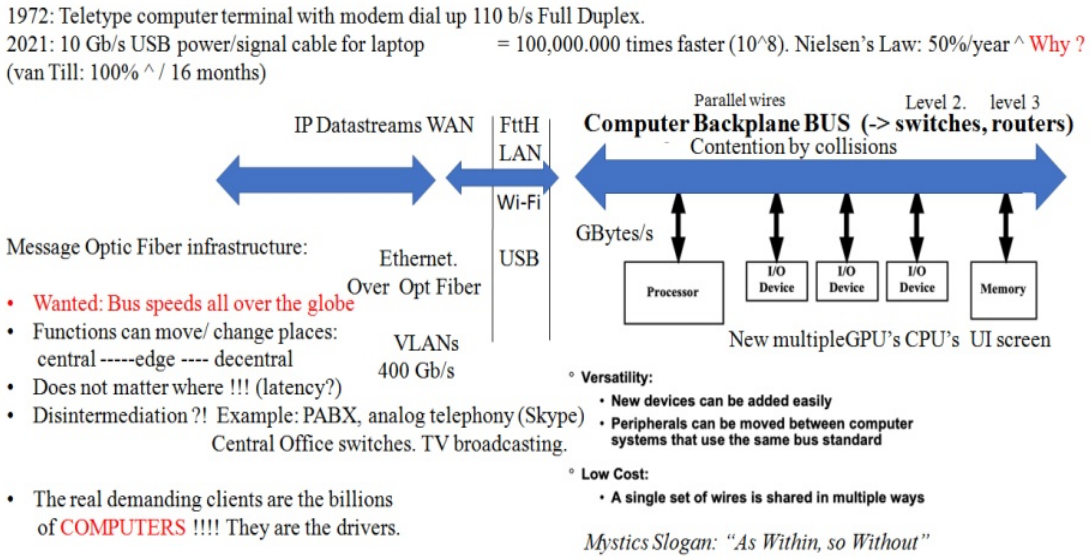


Fig. 5: The BUS Metaphor. *Ethernet, USB and Wi-Fi* now handle the contention of the bursty dataflows. Congestion and blocking however starts above 60% of load.

4.3. Earlier Proposed Solutions: Li-Fi vertical and Li-Fi with beamstearing

A. Internet from Lightsources (LEDs) = Li-Fi. Signify, part of former Philips Licht Divisie, is developing this. Source: [5]. Vertical.

B. Li-Fi with beamstearing from a high corner of a room, developed from similar technique in 5G. Prof. Dominic O'Brian, Oxford

Both A and B are data transmission links, not yet switched networks. And they have not yet reached economies of scale to take off.

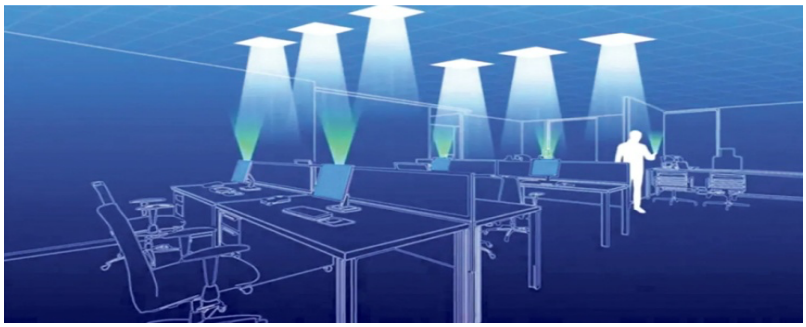


Fig. 6: Proposed solutions: Li-Fi vertical, see drawing and Li-Fi with beamstearing

5. The Proposed "Ti-Fi Network Architecture" in this paper

In order to design an architecture which employs Wireless Optical Communication parts from LiFi, which can solve the stated problems of WiFi and 5G indoors; and which can scale up to reach huge numbers of users, we recommend to do the following moves:

(1) **Extend** the requirements & issues & demands (see 4.1) with the priorities of the customer/ user side (see 4.2).

(2) But to seriously decrease the complexity of the design, **limit** the scope and environment of the solution :

I ** *Environment*: Homes (including Home offices), Offices, boardrooms, multistory apartment buildings, farmhouse & barns, classrooms, libraries, laboratories, lecture halls, railway stations, airport lounges, student dorms, and similar.

II ** *Personal Mobile "Devices"* = laptop computer, smartphone, tablet computer.

Please notice that I and II are not describing a market niche, but constitute the mainstream of present mobile device use: many hundreds of millions of people use them.

III ** *Type of use*: People on the move with their "device"; mobile but only NOMADIC = stationary for several minutes–to hours and then traveling without online connection. So **not** while driving, on bicycle, walking, in museum, in disco's, parks, beaches, on boats. That is where wifi and 4G/5G are sufficient. Please notice that Nomadic use (being stationary at work/studying) in several places during the day, is 80 % of all mobile device use!

Please notice that these choices are in no way specific to race, shoe size or gender; but are valid all over the world.

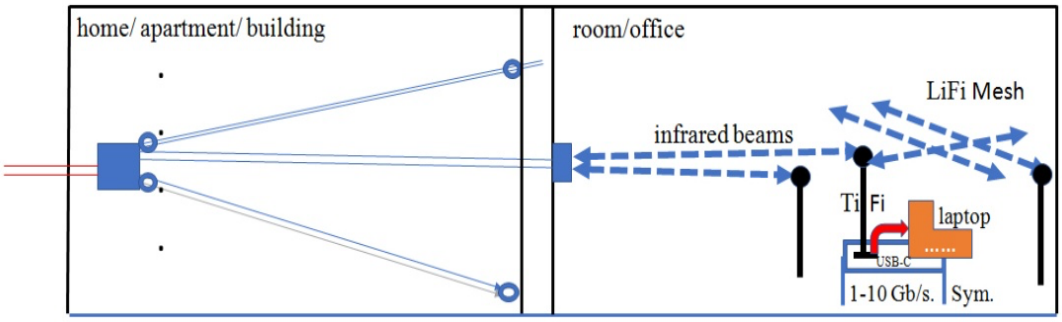


Fig. 7: Structure of the indoors Ti-Fi Architecture.

Components from left to right:

- External (FttH/FttB) interface to connect to multiGigabit capable services, enabled by XGS-PON technology, WAN on fiber optic cables [9]. Compliant with ITU-T G.9807.1 specs.
- Router/"modem", switching ethernet IP protocol streams.
- Plastic Optic Fiber **(POF)** dual cables that can be pushed through existing electric wire 'yellow tubes' in homes and offices **).
- 230V Wall contact connected to Ti-Fi room distribution point. Above head **horizontal** InfraRed Mesh with LED's and detectors.
- Ti-Fi (dongle) each with 6 bi-directional Li-Fi sender and receivers, for establishment of selfhealing MESH of InfraRed lightpaths.
- USB-C power & signal cable between Ti-Fi and tabletop nomadic device (laptop/smartphone/tablet).

Fig. 8: Ti-Fi prototype 1.

Fig. 9: Ti-Fi prototype 2. Li-Fi senders & receivers in the top of the rod. For undisturbed work and study at 1 -10 Gb/s (symmetric) speeds.

5.1 Rationale for choices of architecture components

- Plastic Optic Fiber cables (POF) **) Turns out to be easily self installed and robust, see [5]. Brings the Gigabit streams by optics **through the walls** between rooms. No interference, no decrease in signal strenght. I recommended these POF cables since July 2018, see: https://theconnectivist.wordpress.com/2018/07/12/improved-in-house-wi-fi-by-using-plastic-optic-fibre-pof/. The specs of POF say up to 40 Gb/s, which have to be verified/ certified cables for the in-house in-building distances.

- In-room/office lightpath mesh is recommended since the number of seats in such a room is limited and fixed. So implementing and maintaining light links with some store and forward operation, under control of Apps in the devices should not be too complicated. Wireless Mesh networks are available for Wi-Fi improvements from for instance KPN and VodaphoneZiggo in NL. Open source Mesh protocols between wireless devices for Bluetooth/ WiFi are available too, from for instance Briar [10], co-funded by the NLNet Foundation. The optic path meshes are **contained within rooms** since the IR light can not penetrate walls. Protocol for the Apps can be relatively simple 3 step : exploration in 6 directions, selection, establishing bi-dir. link and updating map of Mesh. Mesh availability must be developed to be selfhealing, robust and available.

- Visiblelight and Infrared (IR) communication has been formally declared as unlicenced parts of the E.M. spectrum, since that part of spectrum is huge and not scarce. In this architecture we choose to use IR lightpaths horizontal above heads of seated users; and of low intensity beams for the relatively short distances in rooms/offices

- Ti-Fi network access: password and device authentication (distributed) with EduRoam and/or GovRoam/ PubliRoam.

6. Future Research Directions

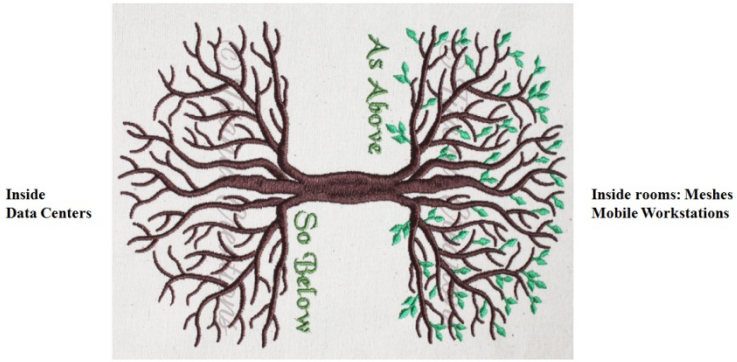
- Elimination of SPOFs. Parallel optical paths. Optic Router(s).

- In-room Mesh Prototype, Fieldtests & Trials in Dormitories. Experiments by SURFnet.

- Establishment of a “Ti-Fi Hobby Club”, supporting prototype building and installations. Similar to HCC-NL.
- Hollow Fiber? Instead of plastic? Hollow POF?
- Infrared levels and health hazards (eyes).
- Establishment of {Ti-Fi architecture, protocols & interfaces} compliancy office, with certification.
- Process of improvements, signified by versions, authorized by the compliance office.
- Development of Ti-Fi digital infrastructure towards HoloChain distributed applications.
- Can connect and have synergy with the EU GAIA-X transnational Cloud services project.
- Platform for high speed and constant latency gaming.

7. Proposed Actions

- Pilot projects.
- I hope this architecture and these actions can help to start up a process of improvements in the public digital infrastructure, including in the indoors ones, so it gives people more Freedom to Create Value together (V ~ N !).



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