TNO innovation for life

IMPROVING GLOBAL TERRESTRIAL TELECOM NETWORKS - TECHNOLOGY FOR A 10 GBPS FSO LINK OVER 2.5 KM DISTANCE

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CONTENT

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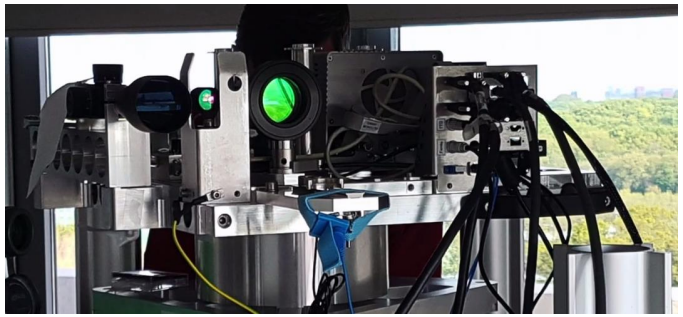
MOTIVATION

- *Motivation: Connect everyone, everywhere with a need for greater data rates and coverage.*
  - Increasing data-driven mobile traffic with higher demand for e.g. 5G applications.
  - Substantial cost reduction of bandwidth in satellite telecom industry.



Optical communication: near future[8]

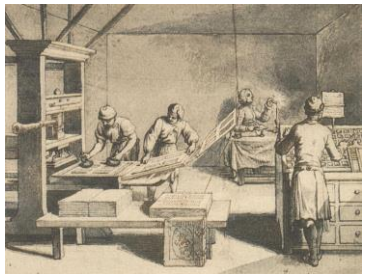
- *Aim: Build knowledge for next gen free-space optical terminals to enable 5G networks with higher bandwidth and robust connectivity.*
  - Expand 5G network to areas difficult to reach via optical fiber.
  - Compete with radio frequency links that are limited in bandwidth, government regulated and experience interference.

Origin of speech:
~150.000 – 350.000 years ago[1]

Cave paintings:
~40.000 years ago[2]

Written symbols: 6000 - 7000 years ago[3]

Invention of paper:
~2000 years ago[4]



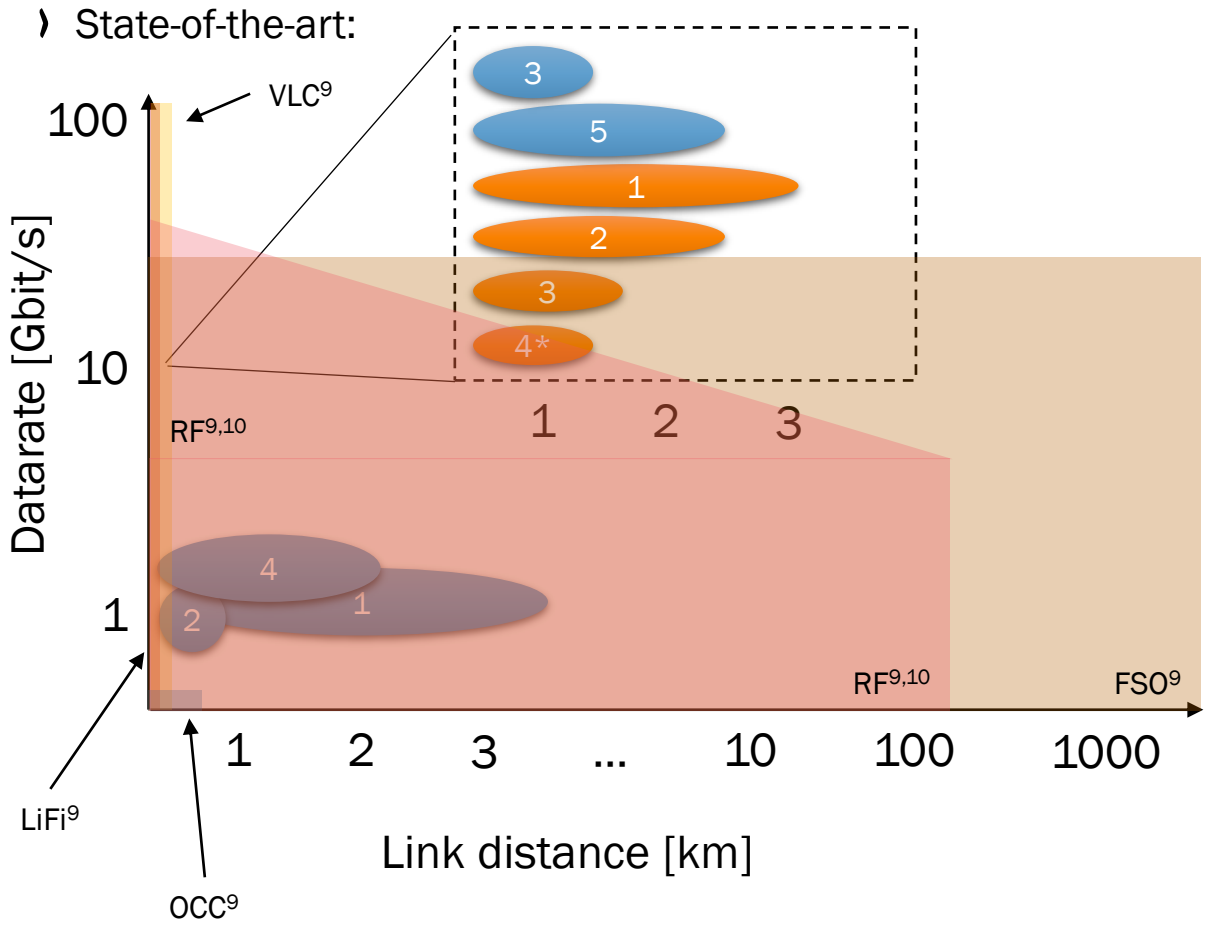
Invention of print press:
~1000 years ago[5]

Electrical telegraphy:
~200 years ago[6]

Radio communication:
~100 years ago[7]

FOCUS

- State-of-the-art:



FSO systems
1 LightPointe – FlightStrata G (1.25 Gbit/s)
~~2 Polewall – Streethopper (1 Gbit/s)~~ (seazed to exist)
3 Artolink – ARTOLINK (10 Gbit/s) (no clear info)
4 CableFree – Gigabit (1.5 Gbit/s)
5 Aircision – BLACKBIRD (10 Gbit/s)
6 Google – Project TAARA (ambition: 20 Gbit/s, 20 km)
7 Bridgecom – (proof of concept 100 Gbit/s in lab)
8 Transcelestial – (1-10 Gbit/s, unknown distance)

RF systems
1 BRIDGEWAVE FL4G-10000 - BridgeWave (9.7 Gbit/s)
2 iPASOLINK EX Advanced – NEC (10 Gbit/s)
3 EtherHaul 8010 – Siklu (10 Gbit/s)
4 WTM 4800 – Aviat (10 Gbit/s) *unknown distance

LiFi: Light Fidelity
- Spectrum: IR/VL/UV
- Datarate & distance: 100 Gbit/s, 10 m

VLC: Visible Light Communication
- Spectrum: VL
- Datarate & distance: 100 Gbit/s, 20 m

OCC: Optical Camera Communication
- Spectrum: VL
- Datarate & distance: 54 Mbit/s, 200 m

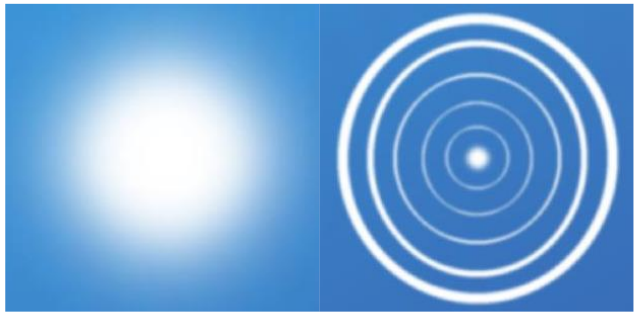
FSO: Free Space Optical
- Spectrum: IR/VL/UV
- Datarate & distance: 40 Gbit/s, >1000 km

RF: Radio Frequency
- Spectrum: Radio
- Datarate & distance: 6 Gbit/s, >100 km, up to tens of Gbps for 5G backhaul links

MAIN RESEARCH INVESTIGATIONS
WHY A FIELD TEST IS NEEDED

- Feasibility of a 10 Gbit/s link over 2.5 km distance with a Gaussian (left) and a structured beam (right).
- Comparison between Gaussian (left) and structured (right) beams in adverse weather conditions.

- No published work on validated modelling or simulation of structured beams through atmosphere. Gaussian beam is validated for G2S but not for G2G applications.



Courtesy of Aircision

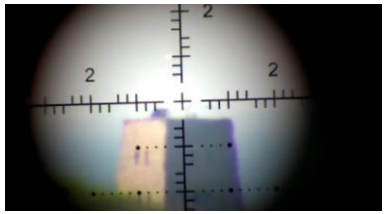
MAIN RESEARCH INVESTIGATIONS
PURPOSE OF THE FIELD TEST

Build knowledge for next gen FSO terminals to enable 5G networks with higher bandwidth and robust connectivity.

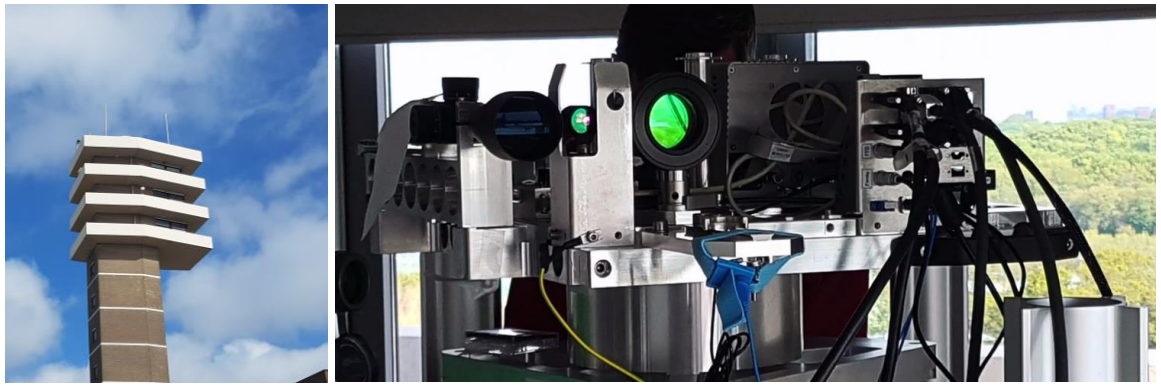
Main requirements:

1. High-throughput: 10 Gbit/s. Rationale: throughput for high-end COTS FSO systems.
2. Quasi-error free: post-Forward Error Correction (FEC) Bit Error Rate (BER) of 10^{-6} (default post-FEC value) for breadboard but 10^{-12} for long-term system.
3. High availability: ≥97%. Rationale: availability for high-end COTS FSO systems.
4. Latency of < 10 ms for 5G and <~1 ms for long term system goal. → show by design

Transmit (Tx) laser breadboard at location meteotower (Scheveningen)



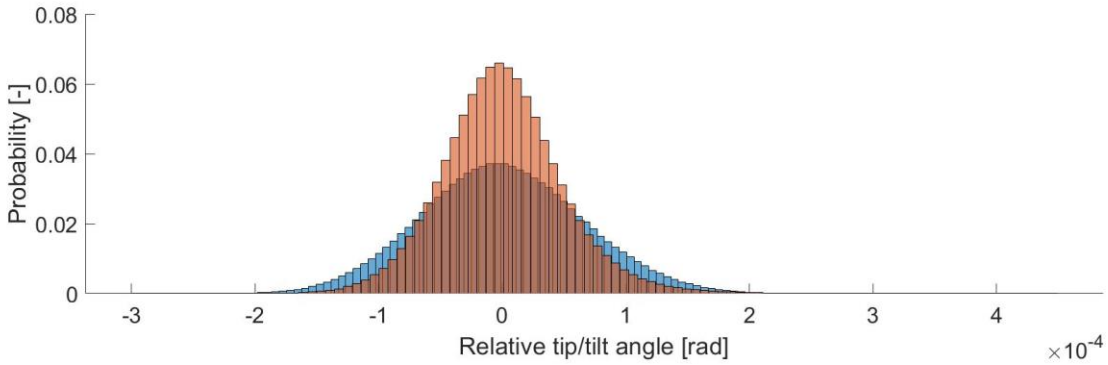
2.5 km



Receive (Rx) laser bread board at location TNO measurement tower (The Hague)

MAIN RESEARCH INVESTIGATIONS
ASSUMPTIONS AND UNCERTAINTIES

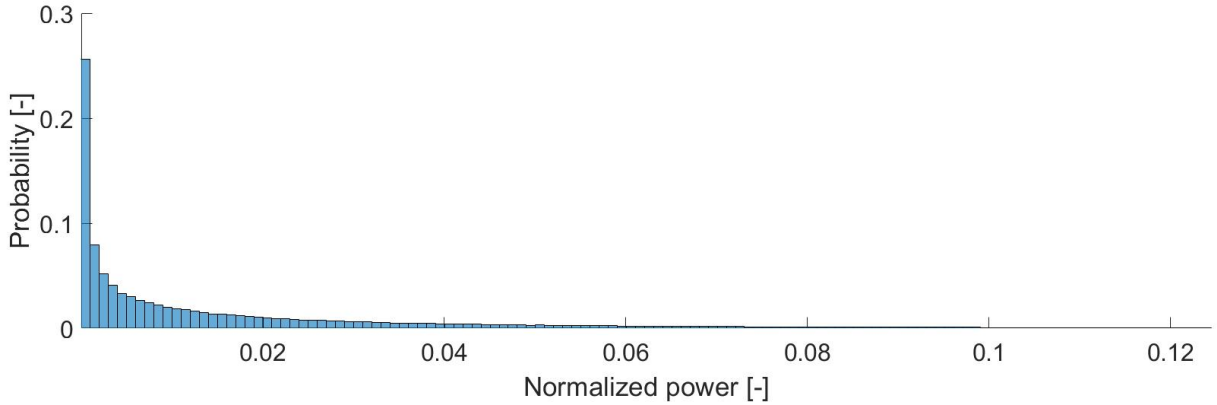
- Achieving alignment main uncertainty: Magnitude and jitter of atmospheric beam wander.
  - Coarse alignment uncertainty : Maintaining optical alignment after transport, hoisting and assembly in-field.
  - Fine alignment uncertainty : Mechanical and thermal drift.
  - Closed-loop tracking uncertainty : Pointing error reduction due to mechanical vibrations and atmospheric beam wander.
- Dynamic attenuation range of the atmosphere (scintillation measured with BLS900 scintillometer).
  - Range could fluctuate from below data detector sensitivity threshold to above damage threshold under strong turbulence.
- Outage and Bit Error Rate on the data detector.
  - Combination of scintillation and atmospheric beam wander yields rapid, 3-4 orders magnitude changes in received power.

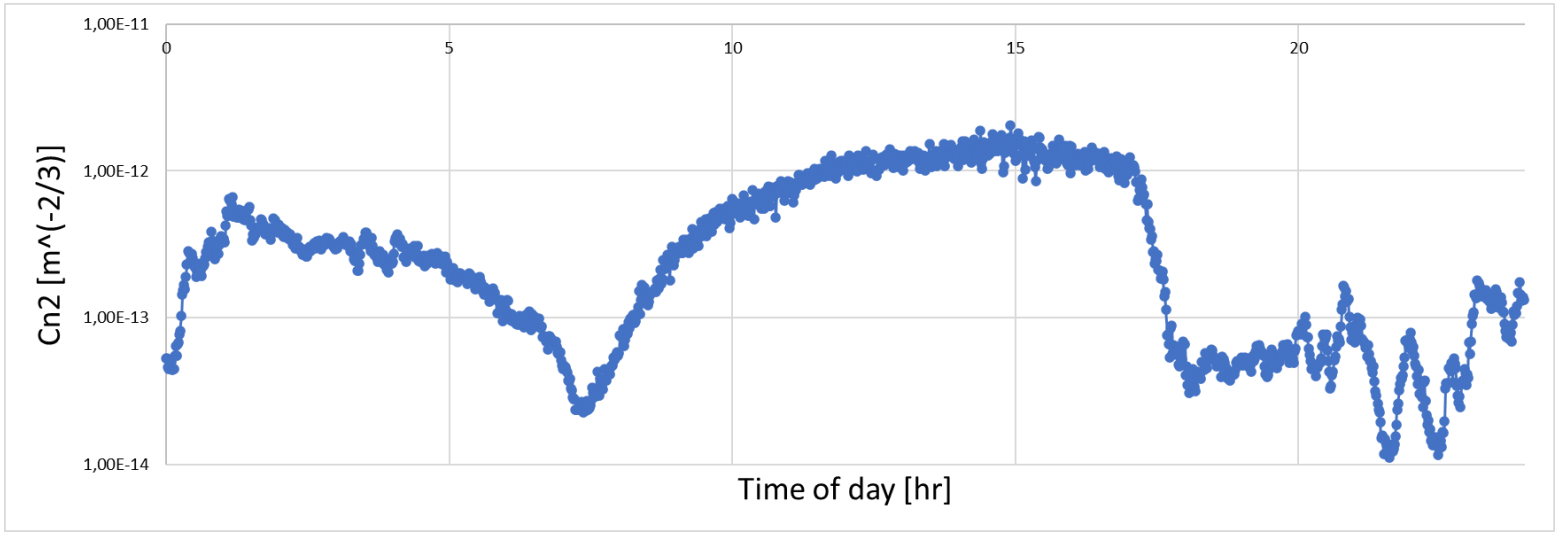


MAIN RESULTS AND CONCLUSIONS

RESULTS

- Main test data logged:
  - Received power distributions at 5 kHz sampling rate.
  - BER values derived from 10 ms data gathering ‘snapshots’.
  - Scintillation values (C_n^2) over the link distance.
  - Meteo data (e.g. wind speed, temperature, humidity, air pressure)





MAIN RESULTS AND CONCLUSIONS

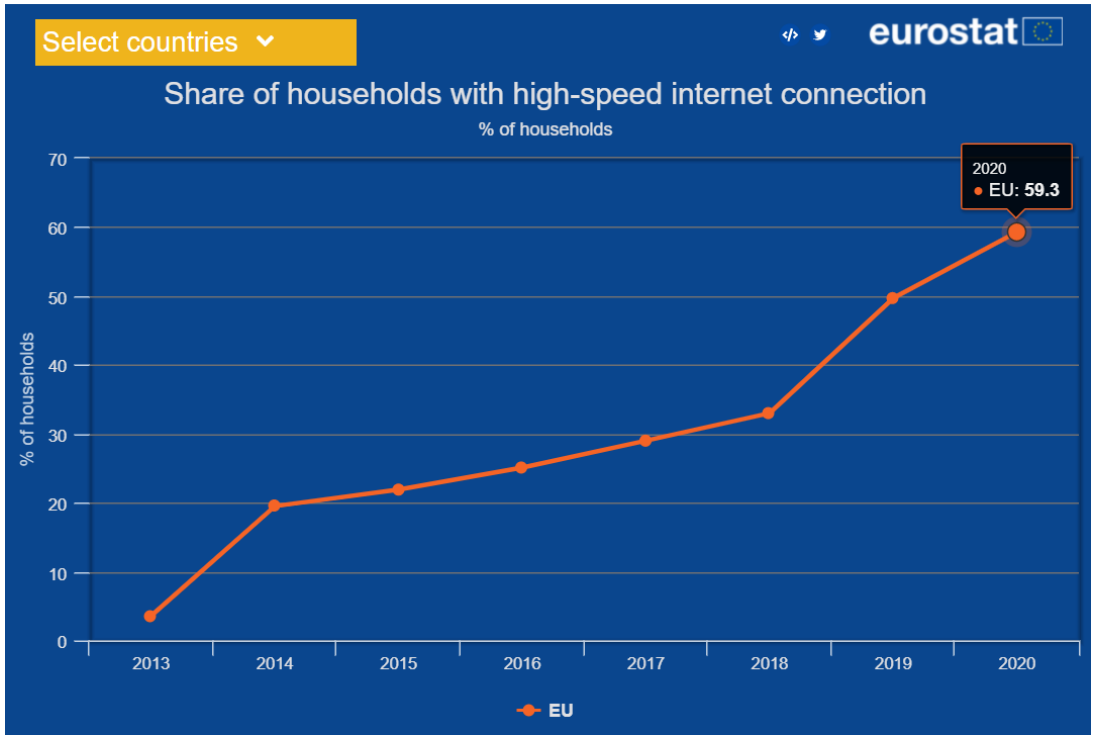
- Feasibility of a 10 Gbps and ≤ 10^{-6} BER link at 2.5 km during various weather conditions and times of day is proven in the field for both Gaussian beam and structured beam.

- System efficacy could be greatly improved with relative minor difficulty in system design.
  - Dedicated optical equipment
  - More accurate alignment
  - Greater optical power
  - Gain optimisation

- Based on the first field test neither Gaussian beam nor structured beam proved significant improvement over the other.
  - Optical system losses are comparable
  - Main difference is divergences between the (center) lobe.

POSSIBLE IMPACT

- Feasible development of ground-to-ground FSO systems capable of high (≥ 10 Gbit/s) at large (≥ 2.5 km) distances.
- One step closer to achieving Sustainable Development Goal 9 from the European Commission (see figure).
  - "…SDG 9 also seeks to increase access to financial services for small-scale enterprises and to bridge the digital divide by increasing access to information and communication technologies…."[11].



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7. Electrical engineer/inventor Guglielmo Marconi with the spark-gap transmitter (right) and coherer receiver (left) he used in some of his first long distance radiotelegraphy transmissions during the 1890s.
8. BackCAT field test setup for a 10 Gbit/s link over 2.5 km distance.
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