Free Space Optical Communications to *Connect the Unconnected* Globally in Remote Places: Technology Issues Relevant to Implementing Systems

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Abstract In this research work, I discussed the potential of free space optical communication (FSOC)/optical wireless communication [1–4] as the most viable technology solution for providing connectivity to almost half of the world population living in rural areas without any Internet access. This population is obviously missing out on the life-changing benefits of connectivity from financial services to health and education, job creation and civic/social engagement, just to name a few. Some of the reasons behind this "digital divide" include (according to World Economic Forum's Internet for All report) • infrastructure (a good, fast connection is not available, no regular electricity to many people), • affordability (a large percentage of population living below the poverty line), • education, skills and cultural issues as barriers and local adoption and use (80% of online content is only available in ten languages).

Keywords FSOC · Wi-Fi hotspots · OWC · AO · SWD-WDM

1 Introduction

How to bridge The Digital divide?

I will focus on the potential technology based on optical wireless communication (OWC) to provide global Internet connectivity including remote places *anytime anywhere*. Connectivity can mean and fall in any of the categories like not connected (without any Internet connectivity), under connected (limited/intermittent connectivity), connected (access the Internet with medium download/upload speed) and state-of-the-art connectivity (very good and uninterrupted connectivity). The concept technology discussed in this paper also addresses how to provide basic connectivity to the unconnected population.

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Some Background and Recent Statistics

Demand for High-Speed Communication and Tremendous Growth of Data traffic.

- Over 80% of the world will be connected to the Internet by 2020 via mobile phones, smart devices, social web, gaming and video-centric applications.
- There will be 5.3 billion total Internet users (66% of global population) by 2023.
- Globally, there will be nearly **628 million** public **Wi-Fi hotspots**
- **Mobile** plus everyday application services (talking, **Facebook, YouTube, Video entertainment, video gaming,** etc.) need high-speed Internet: Global Internet users will continuously increase and most will be mobile.
- Future data speed of 10 gigabit speeds in the coming years.
- Billions of people in developing world are still without Internet access, new UN report finds.

1.1 Digital Divide

Global connectivity with high-capacity communications can bridge the digital divide—critical to economic opportunity, job creation, education and civic engagement.

Potential Technology Solution:

Free Space Optical Communication by Developing Global Internet Connectivity.

Why optical wireless communications (OWC)?

- RF: 300 kHz–300 GHz
- Optical: 300 THz (1 THz = 10^{12} Hz)
- Aperture size (antenna size/telescope size) and range.

Huge Modulation Bandwidth.
RF and microwaves: bandwidth up to 20% of the carrier frequency.
Optical ~1% of carrier frequency (~10^{16} Hz), allowable bandwidth 100 THz (~10^5 times that of a typical RF carrier).
Shorter wavelength of optical beam helps to stay more focused.
"Global Internet Connectivity" or "Connecting the Unconnected".

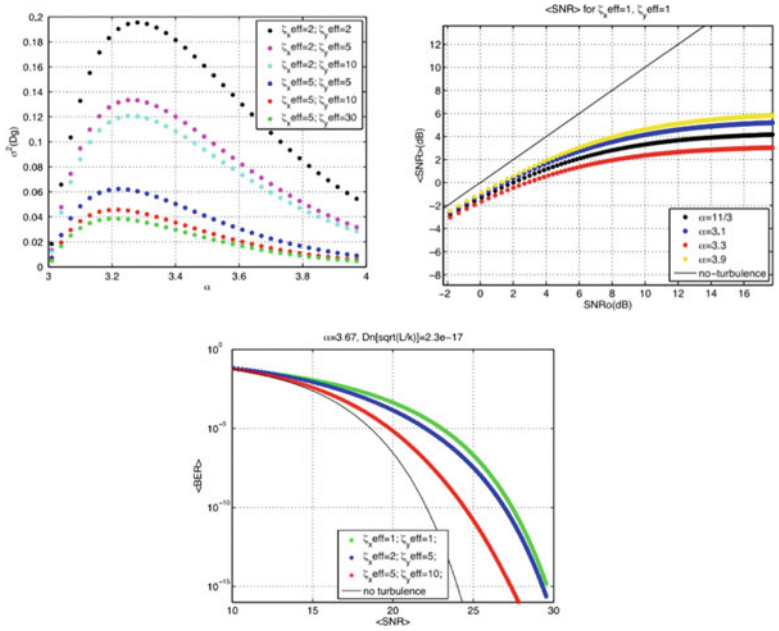
Potential Solution:

- Need to bring reliable and affordable Internet to those without it
- Requires rural backhaul connectivity (FSO links, HAP, Satellite, Underwater): High-speed backhaul in rural areas
- All optical-based free space optics (FSO) technology for creating a three-dimensional global communication grid: A powerful tool to address connectivity bottlenecks and can allow worldwide access to the Internet independent of terrestrial limitations (wireless links through air and satellite communications providing access to fixed and mobile services)

- Can handle indoor, outdoor, terrestrial, space and underwater links
- Visible Light Communication (VLC) can provide state-of-the-art practical solutions by creating Li-Fi for both fixed and mobile platforms toward all optical networks for Internet connectivity.

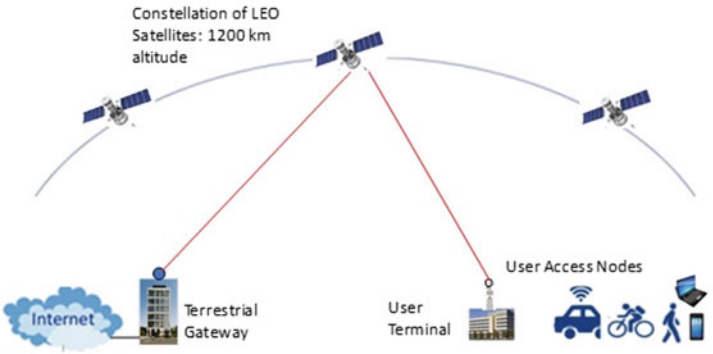
Critical issues to implement FSOC/OWC technology to accomplish global connectivity.

- Atmospheric optical propagation effects due to anisotropic turbulence (non-Kolmogorov models) (asymmetric slant paths / uplink and downlink) between fixed or moving platforms for full-duplex communication data transfer direct effects on FSO link performance (scintillation index, probability of fade, SNR and BER) for OWC systems beam spread and wander, and influence of wind speed through anisotropic non-Kolmogorov turbulence: significant effects on OWC performance
- When a constellation of satellites or a number of balloons are used to establish remote connectivity, optical propagation path/communication links characteristics change: need to use seamless switching methods to handover in the presence of slightly different propagation paths (for hybrid satellite/terrestrial networks): angular diversity and temporal variations
- Establish efficient and reliable optical networks for terrestrial, air, space and underwater terminals.

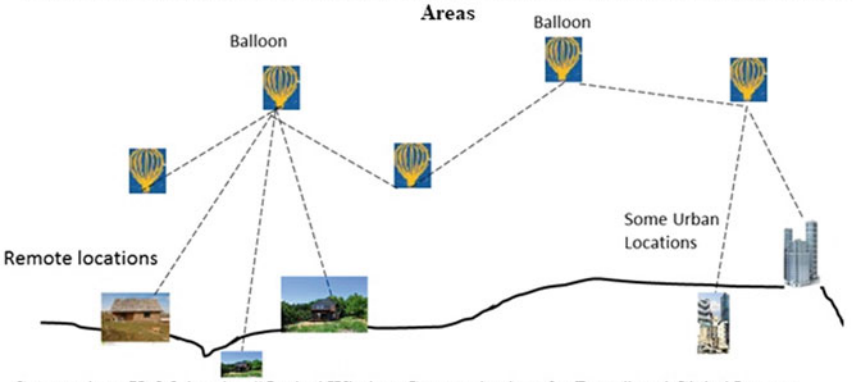


Reference: Italo Toselli and Olga Korotkova, "General scale-dependent anisotropic turbulence and its impact on free space optical communication system performance," JOSA A, Vol 32, No. 6/June 2015

Global communication networks with a constellation of satellites



A schematic of a basic concept similar to Project Loon to build ring of connectivity in Remote Areas



Source: Arun K. Majumdar, "Optical Wireless Communications for Broadband Global Internet Connectivity: Fundamental and Potential Applications," Elsevier, Amsterdam, Netherlands 2019

1.2 Some Final Comments

For very rural and remote areas to establish connectivity, important concerns will be

Very low cost: Smart phones should be available and extremely affordable
Reliability: Engineers and technicians are not available to fix the problems

Some specific potential technology solutions:

Optical satellite and (a constellation of optical satellites) providing Internet together with free space optical communications are wireless telecommunications networks to beam data over Earth's surface at nearly the speed of light, and to provide cheap, fast Internet to remote areas, airplanes, ships and cars.

The solution to the problem of our world of increasingly digitally interconnected is light. Visible light communication (VLC) technology has tremendous indoor and outdoor applications for secure network access (Li-Fi) and extensively adopting in

retail, hospitals, residential, commercial, smart cities, aviation and many more even in remote areas. VLC LED-based channels promise to deliver high-speed data in many environments with high SNR and minimum infrastructure expenses.

- Adaptive optics (AO) can offer potential solutions.
- Some recent research and development areas which will help in achieving connecting to remote areas include:
  Photonics switching hardware for fast optical networks, for example high-capacity SDM-WDM optical networks, low-latency Li-Fi mobile networks, vehicular optical camera communication (OCC) and mobile backhaul, integrated photonic switch (with the lowest signal loss in high-speed data transmission) development toward the goal of "fully optical" high-capacity switching
  Broadband over power lines and VLC using street lights
- Nanofabrication technology will hopefully be a key enabler to such integration, reducing cost and power consumption, size and weight. Adaptive optics (AO) can offer potential solutions for optical satellites or balloons solutions for accomplishing high data rate in various turbulence propagation paths.

One special example just appropriate for the current COVID-19 situation.

Assuming the all optical wireless communication connectivity is established, this special example describes a proposed architecture of establishing communication link for delivering medical consultation services in remote and isolated locations in both developed and developing countries. The technique is based on multi-hop relay-based free space optical communication link for delivering medical services in remote areas [5].

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