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In this issue

Free Space Optics in Next Generation Wireless Networks

Background

Free Space Optics (FSO) offers an attractive alternative technology to optical fiber and radio frequency (RF) communication. It obviates the need for trenching, laying fiber optic cables, securing rights of way and meeting environmental regulations. RF communications, in the licensed band, can provide higher capacity but spectrum licenses are expensive while in the unlicensed band it is limited in bandwidth. FSO links can augment RF communication links with very high (>1 Gb/s) bandwidth. It can also be used to set up communication networks by themselves.

Free Space Optics is a line of sight (LOS) technology, which utilizes beams of light to provide point to point wireless connections. The light source is usually laser as this type of light is the most suitable to provide high speed long distance connections. Low speed (typically below 10 Mbps) and short range systems however may use high power LEDs. In some cases of indoor communication FSO may also use non line of sight (NLOS) technology which utilizes an undirected source illuminating the coverage space. The high reflectivity of normal building surfaces scatters the light to produce an optical 'ether'. A receiver within the coverage space can detect this radiation, which is modulated in order to provide data transmission.

Free space optical communication typically operating in unlicensed Tera-Hertz spectrum bands (wavelength 800–1700 nm), provides several magnitudes of improvement in signal bandwidth over even the highest band signals operating in the RF environment. FSO systems offers extreme security for data connections due to narrow transmission beam which cannot be detected with spectrum analyzers or RF meters. FSO laser transmissions are optical and travel along a line of sight path that cannot be intercepted easily. It requires a matching FSO transceiver carefully aligned to complete the transmission path. Other usually cited advantages of FSO systems also include ease of installation, flexibility, interference resistant, lower costs and protocol independence. The performance of FSO systems is not affected by electromagnetic noises and is not subject to interference with traditional wireless devices such as microwave or radio systems. FSO systems have outstanding low cost per bit ratio and being protocol independent it can support multiple platform and interfaces.

On the flip side, FSO performance is highly dependent on weather conditions (rain, snow, fog, dust particles etc). Moreover FSO communication is also susceptible to atmospheric turbulence. The major effects related to atmospheric turbulence include beam broadening, beam wander, intensity fluctuation (or scintillation) and angle-of-arrival fluctuations. These phenomena cause the received signal to fluctuate in location, intensity and phase, degrading the channel and resulting in poor transmission quality and outages. Further LOS is required for optimum performance. Trees, building sway, etc. can make LOS difficult to maintain. The eye safety and laser power are important factors limiting the link distances.

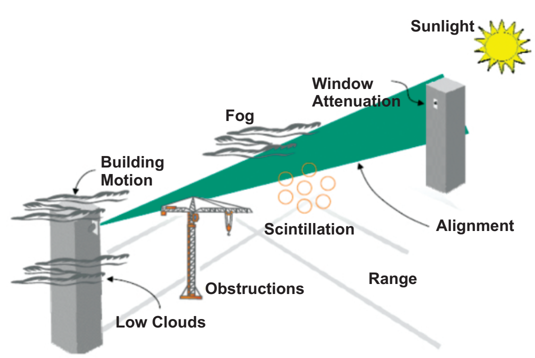

Figure 1 FSO Challenges

Applications of FSO

Free-Space Optics has several applications in Telecom Networks where an optical gap exists between the network core and the edge. FSO delivers cost-effective optical connectivity and faster returns on investment (ROI) for enterprises and service providers. The number of FSO uses in Telecom Networks and beyond continues to grow as high-bandwidth demands and the need for economically viable optical solutions outpace the deployment of fiber-optic cable. FSO has moved from niche to mainstream and some of its applications in the telecom networks include the following:

- Carrier connectivity through FSO : Carriers can deploy FSO links to close SDH rings and provide physically diverse protection. This enables the carrier to offer higher level service agreement and generate new revenue streams.

- Telecom network extensions : FSO can be deployed to extend an existing metro ring or to connect new networks. These links generally do not reach the ultimate end user, but are more an application for the core of the network.

- Enterprise : The flexibility of FSO allows it to be deployed in many enterprise applications such as LAN to LAN connectivity, storage area networks and intra-campus connections.

- Redundancy : Optical wireless products may also be deployed as a redundant link to back up fiber. Generally for business applications, service providers connect two fibers to secure a reliable service plus backup in the event of outage. Instead of deploying two fiber links, operators could opt to deploy an FSO-based optical wireless system as the redundant link.

- DWDM Services : FSO products can be used to provide optical connectivity in multiple applications, including DWDM services.

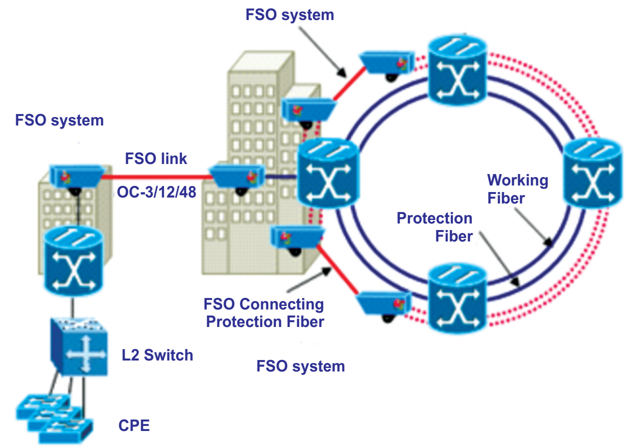

Figure 2 Network extension and fibre complement through FSO

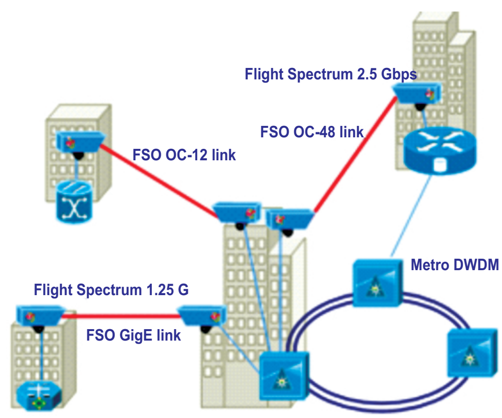

Figure 3 DWDM Services through FSO

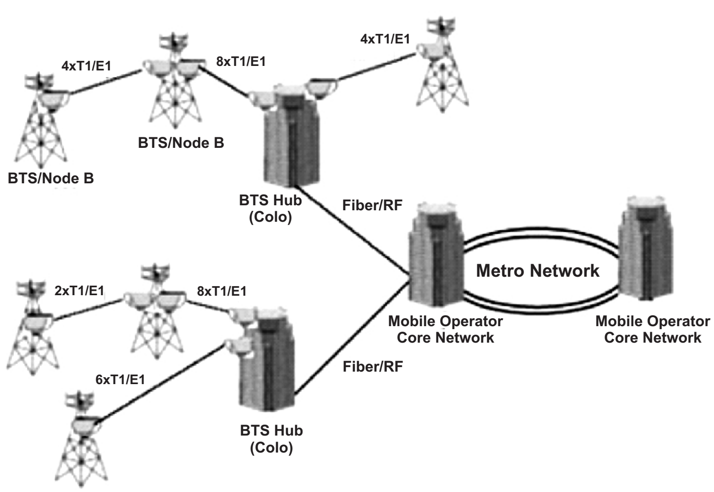

Figure 4 Backhaul connection through FSO

- Last-mile connectivity : These are the links that reach the end user. Optical Wireless can be deployed in point-to-point, point-to-multipoint, ring or mesh connections. FSO has substantial cost advantage over fibre as requires no digging, has lower installation cost and the equipment is comparatively cheaper.

- Backhaul : FSO can be used for backhaul such as local multipoint distribution service (LMDS) or cellular backhaul as well as gigabit Ethernet "off-net" to transport network backhaul.

- Mobile wireless : FSO-based products can be used for mobile wireless backhaul for today's network and next-generation architectures, including applications for base transceiver station (BTS) backhaul, temporary service and WLAN "hot spot" connectivity.

Types of FSO Systems

Conventional FSO Systems

These operate at 800 nm wavelength band and need to use Optical to Electrical and Electrical to Optical conversion before emitting/coupling optical signals from or into an optical fiber. They have been used for signal transmission, however due to power and bandwidth limitation of optical devices in this wavelength band, it is impossible to operate above 2.5 Gbps. In addition, since it involves optical and electrical conversions for connecting with fibre, signal wavelength, modulation and demodulation, and signal formats are fixed for every transmission.

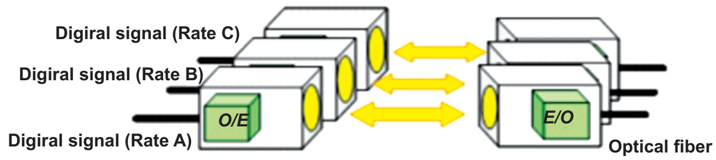

Figure 5 Conventional FSO System

Next generation FSO systems

They use light wave at 1550 nm wavelength. Unlike conventional FSO system, in the next generation FSO system the need for converting the signal from electrical to optical and vice versa before transmitting or receiving through free space is eliminated. Here signal is emitted directly to free space from fibre termination point and at the receiving end focused directly into the fibre core. Loss of the optical signal power caused by space transmission can be compensated by using a fiber amplifier using the same wavelength band of 1550 nm as an optical fiber network. Furthermore, this system is protocol transparent, the need for reconfiguration of the transmitting antenna is eliminated even when the nature of the transmitted signal changes due to varying bit-rate, signal format or wavelength channel. Since fiber and free-space optical transmission links carry the same optical signal, the scheme can utilize mature technologies and optical components developed for high bit-rate fiber transmission. For example, high-speed data transmission is enabled using 10 Gbps optical sources and receivers or even dense wavelength division multiplexing (DWDM) technology. Moreover, because it is protocol and data rate transparent the system can be used to simultaneously transmit not only a digital signal but direct RF signal transmission for example WiFi (IEEE 802.11), WiMAX (IEEE 802.16), cellular based 3G signals etc. However due to atmospheric turbulence which makes the received signal fluctuate randomly, the system needs specially designed terminals and tracking scheme. FSO links often need to custom Pointing, Acquisition, and Tracking (PAT) subsystems. PAT in FSO communications is much more challenging than in other RF systems in which the transmit and receive antennas may only be required to generally point at one another for communication to occur. Based on a next generation FSO systems, an advanced Radio on FSO (RoFSO) system have also been developed which is capable of transferring multiple wireless signals using WDM FSO channel.

NGSON

There have been several efforts to provide service aware technologies in the networks, such as the service-oriented architecture and service delivery platform. These technologies were integrated with service overlay network (SON) infrastructure to support control and delivery of services over multiple network domains. However, SON has limitations in handling the increasing needs of a ubiquitous and dynamic environment of users and services. To provide better quality of experience to users in this ubiquitous and dynamic environment, next-generation SON (NGSON) was introduced to support context-aware, dynamically adaptive, and self-organizing capabilities in SON.

NGSON provides a service overlay network over IP-based infrastructure for service control and delivery. NGSON is envisioned to include advanced service and transport level routing and forwarding schemes that are independent of the underlying networks such as IP multimedia services (IMS), next-generation networks (NGNs), peer-to-peer (P2P) overlay or the web to transmit NGSON signaling messages and/or media among its users and services. NGSON enables network operators, service/content providers, and end users to provide and consume composite services by the deployment of context-aware, dynamically adaptive, and self-organizing networking capabilities. The important capabilities of NGSON are service composition, service discovery and negotiation, service routing, context information management, content delivery, and service policy decision to enforce service and transport quality of service (QoS) to underlying networks.

Source : IEEE 2012

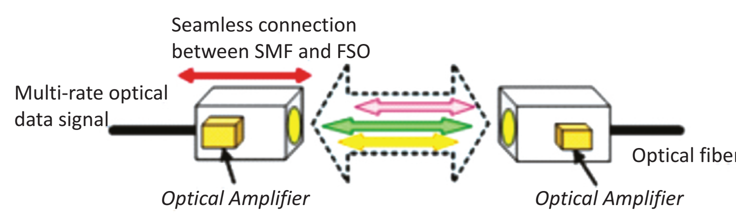

Figure 6 Next Generation FSO system

Radio-on-FSO (RoFSO) system

It is a combination of the next generation FSO system and Radio over Fiber (RoF) technology. RoFSO technology is independent of the difference in the underlying physical layers for radio system or fiber system, but realizing fusion at the service level. The RoFSO technology is available to realize a universal platform for transmitting various wireless services in a ubiquitous network environment.

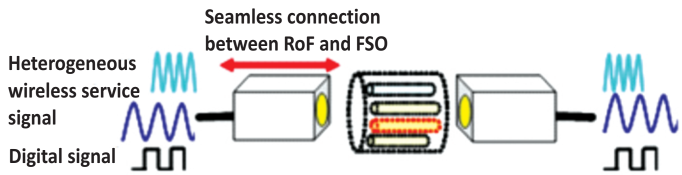

Figure 7 RoFSO system

Main advantage of RoFSO systems is that they can be used to quickly and effectively provide heterogeneous wireless services.

Hybrid RF-FSO systems

Optical wireless communication has become a feasible option to short-haul fiber link for distances of 4 Km or less and an alternative technology to last mile access. However the atmospheric attenuation of optical signals and volatility of weather conditions limits the distance and affects link availability. The link availability requirement for enterprise systems is generally greater than 99% and for carrier class it is considered to be 99.999%. To obtain such link availability a hybrid FSO/RF link can be used where RF link serves as a low-bandwidth backup to the primary optical link and can provide a carrier grade wireless system capable of ranges greater than 1 Km in all weather conditions. Carrier–class availability can be achieved for much longer link distances if the free space optics link is combined with a radio frequency backup. Hybrid FSO/RF links overcome the range restrictions forced by the requirement to achieve link reliability in adverse weather conditions .

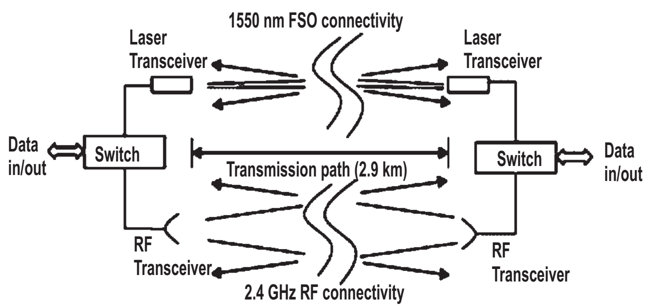

Figure 8 Hybrid RF-FSO link

Mobile FSO system

Since nearly all commercial FSO systems are mounted on fixed positions such as buildings, Mobile FSO provide mobility with high precision at considerable speeds. It employs spherical antennas covered with tightly packed LED transmitter and receiver modules, in order to maintain connectivity even when antennas are in relative motion. Spatial reuse is achieved by tessellating multiple optical transmitters and photodectors on the surface of a sphere. The tessellation not only improves the range characteristics because every direction now has an inexpensive light source (e.g. LED), but also enables multi-channel simultaneous communication through each transceiver. Another significant advantage of high resolution tessellation on spherical surfaces is that it allows electronic tracking of the light beam coming from a mobile peer, enhancing the ability to maintain Line-of-Sight (LOS) condition, without the use of mechanical tracking.

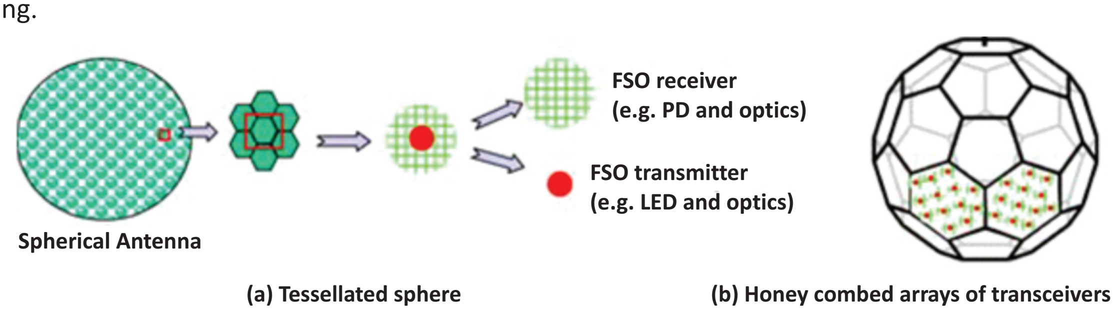

Figure 9 3-D spherical FSO systems tessellated with optical transceivers

Next generation (4G) wireless networks

Next generation wireless networks provide high bandwidth, support a huge number of protocols, interfaces and services encircling all previous and new technologies. It is estimated that the number of base stations required to cover a given area in 4G systems will be four times more than that for 3G systems in the same area. Other characteristics of next generation wireless networks include high capacity and low cost per bit, higher backhaul traffic, high mobility and seamless integration.

FSO in next generation wireless networks

Though RF channels are being extensively used within the Radio Access Network and the Core Networks however, other methods may be necessary in order to provide the faster data rates required by many new and emerging applications. Lately there has been renewed interest in FSO as they are becoming low cost, simple, easy to install, have suitable interfaces for connecting to fibre and are offering increasingly higher data rates. FSO with its inherent advantages of high data rate, protocol independence, security, free license operations and fast deployment makes it a suitable contender for use in next generation wireless networks. The rise in transmission speeds in next generation cellular networks will cause an increase in the received signal level, which in turn, will result in a decrease in cell radius thereby resulting in increase in the number of base stations leading to micro and pico cells. This may lead to increased dependence on FSO communications.

The present hierarchical tree/ring based access network topology appropriate for low bandwidth services is inflexible and cost ineffective in next generation wireless system with exceedingly uneven traffic characteristics and dynamic requirements. Mesh based network topologies consisting of short multi-hop links using FSO between network elements is well suited due to the path diversity opportunity. Moreover FSO links are easier to put into operation and scale in mesh topology than their RF counterparts because of near infinite frequency reuse. Despite of typically low FSO link availability (for instance due to adverse weather), the mesh topology allows the overall network reliability to maintain carrier grade statistics.

VAMOS

Voice services over Adaptive Multi-user channels on one slot, or VAMOS, a initiative of 3GPP, is the next step in the evolution of GSM voice services. VAMOS doubles transceiver peak capacity and optimizes spectrum utilization, while reducing radio base station power consumption. A new downlink modulation and power control feature, together with advanced radio base station receiver algorithms, ensures VAMOS is fully backwards compatible with both network and mobile equipment. VAMOS introduces the Adaptive QPSK (AQPSK) modulation scheme. An AQPSK modulator can be easily implemented in the vast majority of GSM RBSs. In the downlink the AQPSK modulation is transparent to legacy mobiles, while new VAMOS-capable mobiles will use the new modulation to their advantage. VAMOS Subchannel Power Control feature ensure that VAMOS is fully backwards compatible with legacy mobiles. Backwards compatibility toward network equipment is achieved through a simple software upgrade. VAMOS doubles uplink speech capacity by allowing a pair of VAMOS-allocated mobiles to share the same carrier frequency, time slot and TDMA frame number. The modulation technique used in uplink is GMSK. VAMOS uplink air interface, as seen from each individual mobile, is fully backwards compatible with the traditional GSM air interface. The modulation, time and frequency structure are all preserved, meaning any GSM mobile is capable of VAMOS in the uplink.

Source : Ericsson

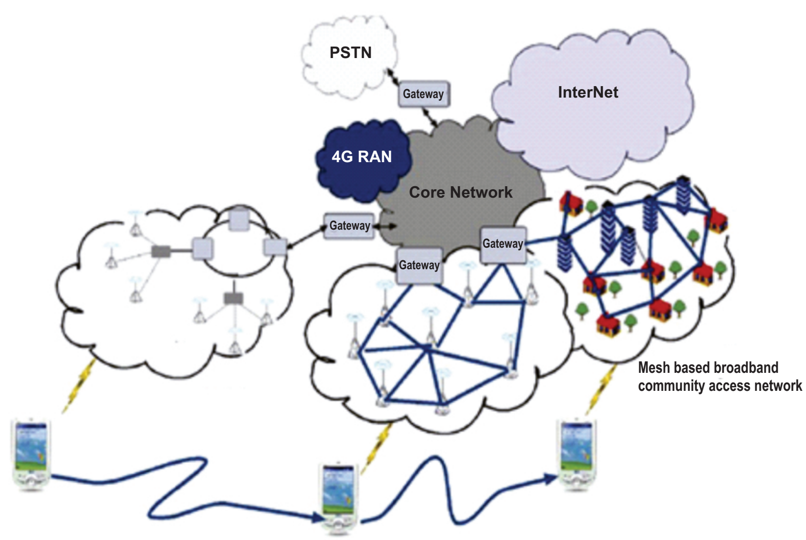

Figure 10 Mesh based topology

The “last mile” connectivity from the fiber backbone to pico base station/micro base station may not always be feasible through optical fiber, as it is mostly costly and time-consuming. FSO communication systems provide an attractive solution to the “last mile” problem, especially in densely populated urban areas where, FSO systems could be well suited to connect pico-base stations to the network.

For short range communication in next generation wireless networks, various indoor optical wireless configuration are present and these are diffuse system, Wide LOS system, Narrow LOS system with tracking, Narrow LOS using multiple beams and Quasi diffuse system.

In a diffuse system an undirected source illuminates the coverage space, to a great extent as it would be illuminated with artificial lighting. As mentioned earlier, the high reflectivity of normal building surfaces scatters the light to produce an optical 'ether'. A receiver within the coverage space can detect this radiation, which is modulated in order to provide data transmission. Diffuse systems are robust to blocking and do not require that transmitter and receiver are aligned, as numerous paths exist from transmitter to receiver. Wide LOS system employs ceiling mounted transmitters that illuminates the coverage area, but diminish reflections from walls, ensuring that a strong LOS path exists. The wide beam ensures coverage. As the beams are narrowed path loss diminishes and the allowed bit rate amplifies, although at the cost of coverage. Narrow beam systems therefore either require tracking to allow user mobility or some type of cellular architecture to allow multiple narrow beams to be used. Quasi diffuse systems minimize the number of multipath by limiting the surface reflections, but allow robust coverage by directing radiation to a number of surfaces so that a suitable receiver may select a path from one surface only. However, in indoor diffuse and quasi-diffuse systems the Inter-Symbol Interference (ISI) impairment and high path loss, results in relatively low bit rates.

As next generation wireless networks would be heterogeneous, therefore these optical wireless configurations can be easily integrated with them. For the case of high data rate connectivity, direct LOS link is necessary but diffused or quasi links can be used at lower data rates. At low bit rates (~10Mb/s) diffuse OW can offer simple and low cost effective wireless connectivity. This might find application in cost sensitive environments, such as the home, or in RF sensitive areas, such as hospitals.

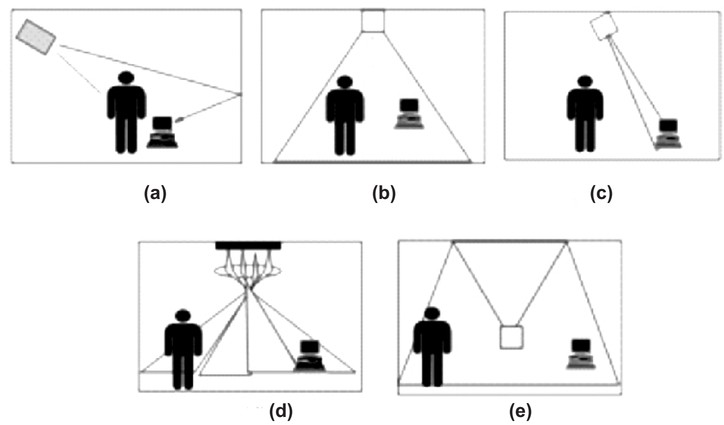

Figure 11 (a) Diffuse system. (b) Wide LOS system (c) Narrow LOS system with tracking (d) Narrow LOS system using multiple beams (e)Quasi diffuse system

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