Free space optical communications (FSOC) using unmanned aerial vehicles (UAV) for border monitoring

MD ANOWAR HOSSAIN[*], SAJJAD UR REHMAN
College of Engineering, Department of Electrical Engineering, King Saud University, Riyadh, Saudi Arabia

With the deployment of third generation (3G) communication systems, the search for next generation communication systems, commonly referred to as fourth generation (4G) systems, has begun and its goal is to provide ubiquitous connectivity and seamlessly integrated operations among different scenarios ranging from short-range, high-mobility cellular systems, to long-range, high data-rate directional systems. Free Space Optical Communication (FSOC) systems have emerged as a viable technology in the next generation indoor and outdoor broadband revolution. This paper is concerned with the study of Free Space Optical Communications (FSOC) technology and its application in flying vehicles like UAVs for border monitoring.

1. Introduction

Free-Space Optical Communication (FSOC) is a technology similar to fiber optic cable infrastructure except that no cable is involved. The light pulses are transmitted through the atmosphere in a small conical shaped beam by the means of low powered LASER or LED [1]. Free-Space Optic installations require line-of-sight (LOS) availability between the LASER/receiver units which are called link heads. Speeds range from single 10Mbps to 2.5Gbps on currently available products [2]. 40Gbps has been successfully tested in laboratories; speeds could potentially be able to reach into the Terabit range. The frequencies used by the LASERs are between 750 and 1550 GHz and do not require special licensing like other wireless devices. Fiber optic is expensive to install and the monthly recurring fees can also be very high. FSOC can be used to augment or replace fiber based Metropolitan Area Network (MAN) solutions and an important component in a corporation's disaster recovery plan. The links can normally be installed within forty eight hours or less.

2. Working principle of FSOC system

In a basic point-to-point transmissionsystem, an FSOC transceiver (link head) is placed on either side of the transmission path. The main requirement for operating an FSOC system is unobstructed line-of-sight (LOS) between the two networking locations; a simple schematic of a FSOCsystem is shown in Fig. 1.

The optical part of the transmitter involves a light source and a telescope assembly. The telescope can be designed by using either lenses or a parabolic mirror. The telescope narrows the beam and projects it toward the receiver. The transmitted light is picked up at the receiver side by using a lens or a mirror. Subsequently, the received

light is focused on a photo-detector. FSOC system can operate in full duplex operation. This means that information can be received and transmitted in parallel and at the same time.
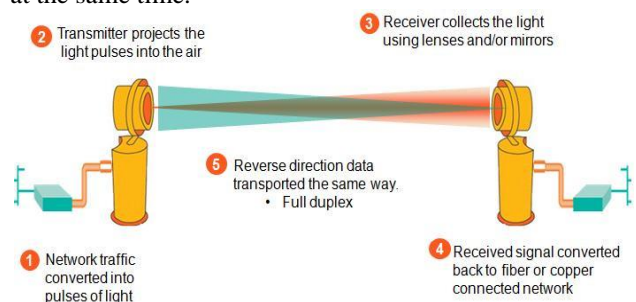

Fig. 1.Working Principle of FSOC System.

3. The Need for FSOC

To install a high speed optical network between two nodes requires trenching which in turn requires permits and rights of way from the respective authorities. This requires a lot of time and money. While using FSOC there is no need of digging, no fees to be paid to maintain the link and also no need of permits from authorities. It can be implemented in WDM-like (Wavelength Division Multiplexing) technologies [3].

While fiber-optic cable and FSOC technology share many of the same attributes, they face different challenges due to the way they transmit information. Optical wireless networks based on FSOC technology must be designed to combat changes in the atmosphere, which can affect FSOC system performance capacity. And because FSOC is a line-of-sight technology, the interconnecting points must be free from physical obstruction and able to "see" each other.

4. FSOC for Military Networks

With the deployment of ubiquitous wireless commercial communications resulting regulatory pressure, the spectrum available for military use is decreasing. Limited RF spectrum is struggling to provide the needed capacity for various military applications. Military applications need communication system with higher capacity because they need to exchange huge amount of voice, video and data.

5. FSOC among Flying UAVs

Reliability of FSOC system depends on local weather conditions. Link performance is affected by atmospheric turbulence, fog, smoke, rain, dust, smoke etc. But weather affects the link performance up to an altitude of 11 km. Vehicles flying at higher altitude (greater than 11 km) are not affected by weather parameters. Therefore, only turbulences form the major challenge.

Another important challenge is to maintain LOS due to change in relative speeds between flying UAVs. FSOC transceiver must be simultaneously pointed to each other to maintain LOS confinement for the communication to take place. The solution to mitigate this problem is backing-up the FSOC link with an RF link known as Optical/RF Hybrid or FSOC/RF Hybrid [4]. The RF module mounted along with FSOC transceiver can provide control signaling for PAT (Pointing, Acquisition and Tracking) and serves as a back-up communication link when optical channel fades [5].

The remaining part of the discussion includes the application of FSOC between flying vehicles like UAVs for border monitoring.

6. Unmanned Aerial Vehicles (UAVs)

Unmanned Aerial Vehicles (UAVs) are airplanes that fly without a pilot aboard. UAVs can be directed by an external controller or be pre-programmed.At least two of the components would be present in every system: the air vehicle and the Ground Control Station (GCS). The GCS sends commands to the air vehicle and receives data on the operation of the vehicle. It also can receive data from any sensors on board.

7. Swarm formation

The concept of operations for a micro-UAV system is adopted from nature from the appearance of flocking birds, movement of a school of fish, and swarming bees among others.

At higher altitude, the UAVs need to fly in swarm formation to cover larger geographical area and to exchange flight and mission information to each other. All UAVs in a swarm communicates with the mother ship and mother ship communicates with the ground station.
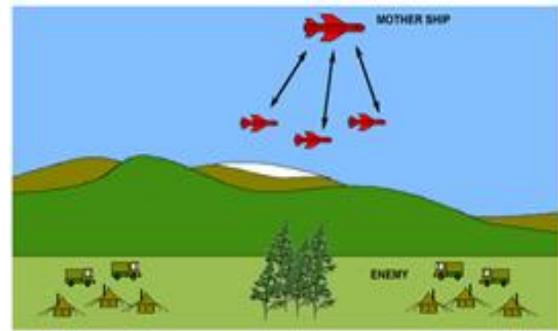

Fig. 2. Swarm Formation [6].

8. Networking Architecture of UAV Swarm

For the application of FSOC scenarios in relation to reliability and availability, different kind of networks have to be consideredsuch as ring architecture, star architecture and mesh architecture [6]. For high reliability (more secured against network failure), the optimum network architecture is a meshed network, because it combines the advantages of a star and ring architecture. However, an increase of the complexity of the optical network architecture also means a dramatically increase in the technical realization of the routing scheme.

9. FSOC for Border Monitoring Using UAV

UAVs are suitable for border monitoring because of their ability of covering large areas of remote territory. A small UAV would be less noticeable than a manned aircraft, so there would be more chance of surprising border violators. UAVs equipped with imaging sensors would follow the line of the border. Imagery would be linked either to a joint monitoring center or simultaneously to border security centers. The important issues of border monitoring using UAV are outlined in Table 1 given below.

Table 1. Border Monitoring Issues.

Concept	UAVs will monitor both sides of an international boundary for security and economic purposes.
Operational Plan	UAVs will fly along the border at random times. Known crossing-point will have near-constant serveillance.
Observables	Vehicles trying to cross border,small groups of people trying to cross border, military buildups in border region.
Sensors	EO camera, IR camera
Strengths	Large lengths of border can be covered by a few units. Individuals can be detected and identified.There is no risk to crews (unmanned).
Weakness	The entire border cannot be observed simultaneously.Weather may limit operations.

10. Case Study: Kingdom of Saudi Arabia

Border monitoring scenario in the perspective of KSA is outlined by using the map of the kingdom. For simplicity, only mother ships are shown and considered in Fig. 3.
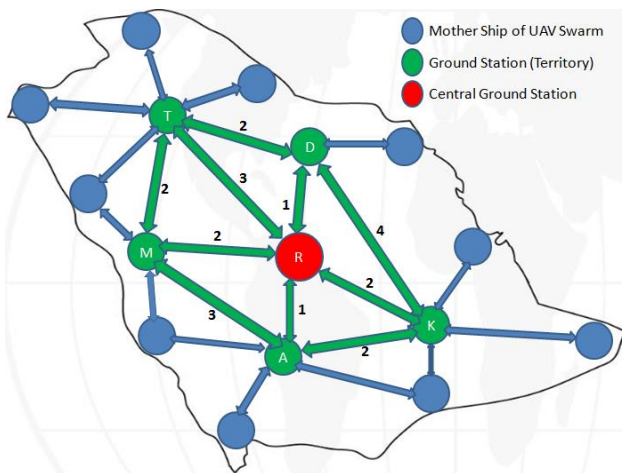

Fig. 3.Border Monitoring Scenario for KSA.

The total land boundary of KSA is 4431 km [10]. In figure, the alphabetic letters are denoted as *T-Tabuk*, *M-Madina*, *A-Abha*, *D-Dammam*, *K-Rab-Al-Khali* (desert) and *R-Riyadh* (Central Ground Station). Maximum distance between mother-ship and ground station is considered as 50 km while altitude is 18 km. The distance between two UAVs is considered as 8 Km.

According to the following data, a partially connected mesh network is developed. The topology in which some of the nodes of the network are connected to more than one other node in the network with a point-to-point link, makes it possible to take advantage of some of the redundancy that is provided by a physical fully connected mesh topology without the expense and complexity required for a connection between every node in the network. In most practical networks based upon the physical partially connected mesh topology, all of the data that is transmitted between nodes in the network takes the shortest pathbetween nodes, except in the case of a failure or break in one of the links, in which case the data takes an alternative path to the destination. This requires some type of logical 'routing' algorithm to determine the correct path to use at any particular time.

Table 2. Minimum Distance between Central Ground Station (CGS) and Ground Station (territory).

Step	N'	D(A)P(A)	D(D)P(D)	D(K)P(K)	D(M)P(M)	D(T)P(T)
0	R	1, R	1,R	2,R	2,R	3,R
1	RA	-	1,R	2,R	2,R	3,R
2	RAD	-	-	2,R	2,R	3,R
3	RADK	-	-	-	2,R	3,R
4	RADKM	-	-	-	-	-

The distance between Central Ground Station (CGS) and other terrestrial Ground Station (GS) are calculated using Link State Algorithm [7] shown in Table 2. The reason behind choosing this algorithm is that it has characteristics of fastest speed of convergence.

The border monitoring scenario discussed above is based on the following assumptions: UAV swarm moves within a pre-defined area of the border at random times and periodically update the information with the nearest ground station. All UAVs within a swarm communicates with the mother ship; mother ship communicates with its nearest terrestrial Ground Station (GS) using FSOC; all terrestrial Ground Station (GS) and Central Ground Station (CGS) communicates with each other using fiber or copper wired network. Central Ground Station (CGS) is located at the capital of the kingdom. CGS can periodically update the information with ministry of defense for the central decision.

11. Conclusion

Optical communications can provide a mechanism for increased capacity which can be delivered to the battlefield. FSOC is experimentally tested and proven way of providing high data rate communication links. The effectiveness of free space optical links between UAV swarms requires detailed scientific and theoretical studies for the technology to evolve for real world demonstration and experimentation. The importance of developing high rate links between these vehicles would keep increasing and thus developments of FSOC for such scenarios pose an interesting challenge to both the academic researchers and the technologists. FSOC is just starting to be applied to solve the Internet "last-mile" interconnectivityproblem it is a strong candidate forthe next-generation military networks.

Acknowledgement

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[*]Corresponding author: ahossain@KSU.EDU.SA