Optimized Swarm Architectures in Airborne Internet

Pardeep Kaur, Preeti and Amit Gupta

Abstract There is a tremendous growth in telecommunication networks due to the emergence of various communication techniques. Optical communications have been the major contributors to it. Free space optical communication (FSO) is a technique based on transmission of data by propagating the light in free space. This is an effective technique to transmit the data at high bit rate over short distance with the added advantage of easy and fast installation and high security. Hybrid RF/FSO technique improve the overall reliability of the system. In this paper, aerial application of the RF/FSO system, i.e., airborne Internet which includes the use of optical links in the network of unmanned aerial vehicles (UAVs) is given. Different formations of UAV swarms, few methods to combat the problems faced by unmanned aerial vehicles (UAVs) and high altitude platform (HAPs) for research work have been discussed. A model is also proposed to improve the reliability of the swarm network.

Keywords FSO · Hybrid FSO/RF · Unmanned aerial vehicles (UAVs) · High altitude platforms (HAPs) · Airborne Internet

1 Introduction

Since the evolution of mankind has been taken place, communication has become an important way to send and exchange views throughout the world as one of the principal interest of human beings. The information is sent via an electromagnetic carrier wave whose frequency can vary from MHz to THz in a communication system. As we are beginning towards a new era, various dramatic changes in communication have been coming across. For example, businesses today rely on high-speed networks to do their daily affairs [1, 2]. Large MNCs which were once

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using 155 Mbps are now using 1 Gbps connections. Thus, demand for bandwidth has been increased and at the same time the usage of those technologies which could be cost effective are to be promoted.

Free Space Optics is a new technique which is similar to optical fiber infrastructure but no cable is involved [3]. It requires line of sight connectivity between receiver and transmitter with a capability of sending up to 125 Gbps of data, voice, video communication simultaneously through air and even enable WDM like technologies to operate through free space. It has distinct advantages like no license requirement, easily upgradable, immune to RF interference, requires no safety upgrades, can be deployed everywhere, economical [4, 5]. Although FSO is gaining wide market acceptance as a functional wireless, high bandwidth access tool with license free access but still suffers from serious drawbacks. To combat that another thing becoming popular is hybrid FSO [6, 7]. It is the use of FSO with Radio Frequency (RF) link as backup. For link distances greater than approximately 140 m FSO/RF links could be used which would also solve the problem of line of sight (LOS), i.e., when there is no LOS access RF link can be used [8]. So, efficiency of the network connection would be improved but the only weather that could affect transmission of hybrid FSO/RF is heavy rain and dense fog [9, 10]. These systems fit precisely in emergency situation, for instance, earthquakes, tsunamis. In FSO/RF link system, the data rates for FSO and RF are 1.25 Gbps and 100 Mbps, respectively, with an average overall data rate of 183 Mbps [11]. Such a system would help to combat all the challenges posed to RF approach. The best utilization of this communication is between airborne and ground-based network nodes.

2 Airborne Internet

Airborne Internet means to provide high-speed wireless Internet connection by placing aircraft in fixed patters over hundreds of cities. As shown in Fig. 1, aircrafts are carrying data which they can project directly to the end user, to the other aircraft

Fig. 1 Airborne Internet

or within the plane itself for the passengers. To implement these networks, first option is using: HALO: in which lightweight planes will circle overhead and provide high-speed Internet to consumers. These HALO networks can cover the area up to 120 km in diameter but still this has to receive the approval from the aviation administration. Each city in the halo network will be allotted three piloted planes and will fly for 8 hr before next plane takes off. Second venture is to provide solar-powered, UAV that would work in similar manner to HALO. NASA is carrying out research to have solar powered lightweight planes that could fly over a city for six months at a stretch without landing and covering area up to 40 km [12].

3 FSO in Airborne Networks

Prof Nawaz has proposed the airborne Internet access through the sub marine optic cables. Internet access for passengers traveling in aircrafts is thought to be one of the unresolved major challenges for ubiquitous Internet provision [13]. Vast oceanic remote regions along the busy air routes of the world require low-cost, reliable, and high-speed Internet for the aircraft [14]. Satellite links can provide Internet coverage in such remote areas; however, their services are still costly with low bandwidth and longer delays. Fortunately, the submarine optical cables deployed across the oceans pass along the same busy air routes. These cables can be utilized as high-speed Internet backbone for wireless Internet access to the aircraft. Vehicles flying at some height from the ground can use FSO as a means of communication among themselves or to the base station at the ground. In Fig. 2, an aircraft as network hub is communicating with the ground-based halo gateway and to the end user directly, if we do not want to dig the infrastructure or need of quick network installation is there. The best utilization of aerial application o is in the 'Disaster recovery' [15, 16].

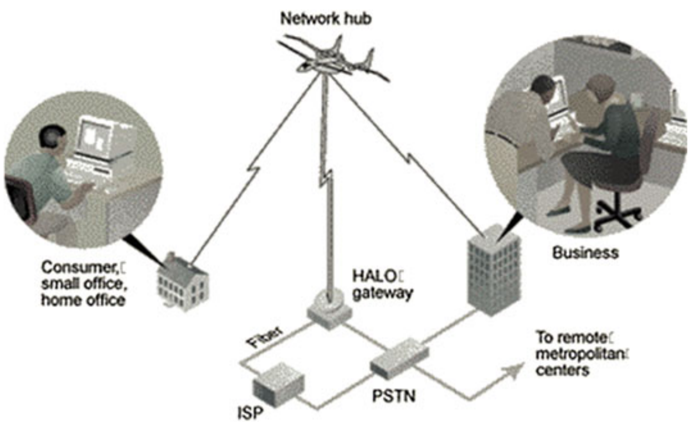

Fig. 2 Various nodes of airborne Internet

In case of a disaster, infrastructure completely collapses and air is the only means of communication with rest of the world. RF alone cannot provide the required bandwidth that is needed to transmit the live images of the disaster recovery area. So, hybrid FSO or ROFSO can be best solution for them. Hence, aerial vehicles with optimal placement of FSO transceivers form the best combination to accomplish quicker network recovery. Military uses FSO between airborne vehicles to observe hostile environments. Defense Advanced Research Projects Agency (DARPA) of U.S. has recently demonstrated aerial connection range up to 200 km and air to ground slant connection range up to 130 km exhibiting data rates from 3 to 9 Gbps on a hybrid FSO/RF link [15].

4 Unmanned Aerial Vehicles

In airborne Internet, UAV flying in swarm formations are predominantly used in civil and military applications like observing the battle field, monitoring traffic, protecting important buildings and many more. In order to have better end-to-end communication with good coordination and navigation, the number of UAVs are used which in turn also increases the range of distance by employing various topologies. UAVs have multiple wireless sensors which collect the data from ground and share it with the other UAVs in the swarm. As each UAV is equipped with numerous sensors, large data transfer takes place within the swarm, which is best suited through FSO links. Security of confidential information like battlefield arrangement and map information has led to the extensive use of these UAVs in military applications. But the greatest challenges faced by these airborne vehicles using FSO are the loss of sight due to the relative motion between them and atmospheric turbulences. So, we need to have a backup of RF transceivers in each vehicle to maintain communication even in foggy and hazy conditions and also in case of lost line of sight between them.

5 Ground–Aircraft Link

The communication for aerial vehicles start from ground station and then the information reaches UAVs or HAPs whichever are equipped. The rays have to travel different layers of atmosphere so various weather phenomenons are there which obstruct the path of optical waves namely fog, rain, snow. For optimal placement the number of trans-receivers to be used could be decided precisely so that both in good and worst weather conditions they could give better performance. The use of visibility codes have been proposed for switching to particular trans-receiver. The lifetime of hybrid FSO/RF is two times that of single RF link.

6 Inter-Airborne Communication

Inter-airborne communication means that two airplanes are communicating with each other instead of first communicating with centralized hub/station as shown in Fig. 3. We can efficiently use the FSO between the two nodes, i.e., earth station and central hub in the air in which one is stationary and utilize the best bandwidth out of these.

But between two moving airplanes, this will be tedious task so for that sub part we can use RF signals or smart tracking algorithms need to be devised, so as to capture the relative motion of two aircrafts w.r.t each other. Idea is not to replace the RF with the FSO but to create a combined smart architecture of two, so as to get the best utilization out of the two technologies.

7 Intra-Airborne Communication

In addition to this intra-airborne network is also gaining importance, i.e., in-flight communication network to provide Wi-Fi access in airplanes for videos, songs. For high data rate, control of surface illumination and FOV of receiver improves bandwidth, as proposed in, to at least 100 MHz [17]. To distinguish users in the same cell, Walsh–Hadamard codes could be used for 'movies on demand' [15]. A new method of using optical codes in FSO and indoor Visible Light Communication (VLC) is used parallel which gives better performance in terms of BER and SNR.

8 Proposed UAV Architecture

Low altitude UAV swarm can exchange the information of the battlefield with the high altitude mother ship through optical links. This swarm formation can be used in traffic regulation, tracking individual vehicles and other applications to increase

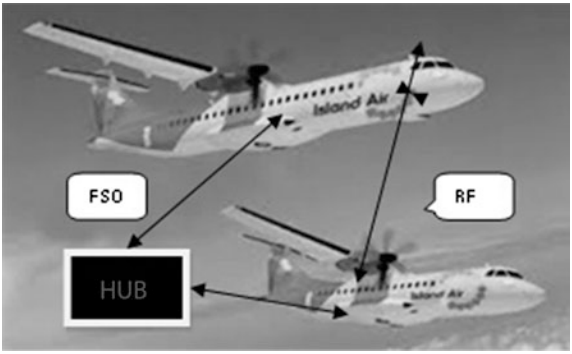

Fig. 3 Inter-airborne communication

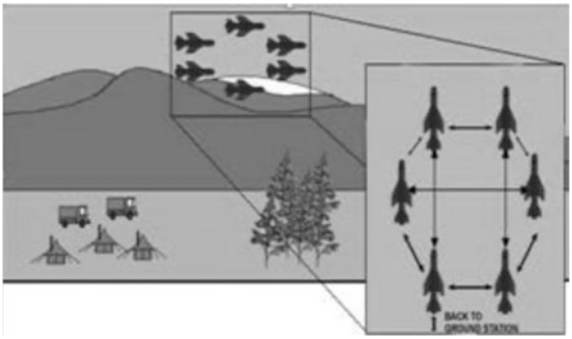

Fig. 4 Partial mesh topology

the reliability and achievability of links. The efficiency of the swarm network varies with the formations in which they are connected. These formations are called topologies or UAV architectures. A partial mesh topology is proposed as shown in Fig. 4. Here, UAVs have lesser links as compared to the full mesh topology thus reducing the network complexity and implementation cost.

This architecture combines the advantages of ring, star and mesh topology at an expectable cost and tolerable network congestion. It can be transformed into a more sophisticated network by using routing algorithms which switch the network back to shorter links of ring topology in case longer mesh links are unavailable due to obscure atmospheric conditions. Radio over Free Space optics (ROFSO), the latest development in the free space optics, in which we first modulate the data using RF modulation schemes like CDMA and then covert it to the FSO format, so as to further combine the advantages of RF and optical can also be investigated for the inter-UAV links. The connection between the HAP and the ground station using FSO/RF/ROFSO is proposed. The proposed airborne network is shown in Fig. 5. If the weather conditions are favorable then FSO and ROFSO can be used and it will automatically shift to RF alone in case the turbulence is there. By this the link availability as well as the bandwidth it supports increased many fold. For Ground station to aircraft communication, different error correcting codes can be used

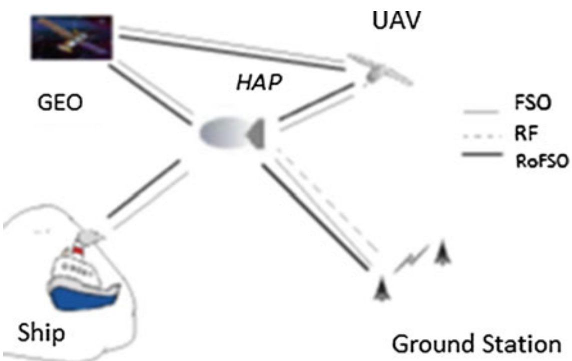

Fig. 5 Proposed airborne network

which could decrease BER and scintillation effects. RF link along with FSO link would give better performance in rain and increase the range where there would be no line of sight and using ROFSO gives good results than FSO on clear weather. For inter-airborne different wavelengths and hybrid codes can be used.

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