Multipurpose IP-Based Space Air-Ground Information Network

Abid Murtaza, Liu Jianwei
Department of electronic and Information Engineering, Beihang University, Beijing, 100191, China
Abid_murtaza47@hotmail.com

Abstract. Integration of space resources (e.g., satellites) in different orbits with the terrestrial/ground network (e.g., internet) is the new evolving era of information technology. This kind of information network can expand the ground services such as internet to the whole world with the help of satellites' broader coverage. On the other hand, it can also provide real-time access to the satellite’s useful data (e.g. images of earth), for nearly everyone on the globe. For these reasons, there has been enormous amount of research on this topic, and different network architectures are proposed for the integration of space and ground networks for different applications. However, most of them are either general abstract architecture or for the single dedicated application. Also for such a network, it is desirable that it should be based on the TCP/IP (Transmission control protocol/internet protocol) stack for interoperability with terrestrial networks. However, the biggest challenge for this is the dynamic network topologies due to orbital dynamics of space nodes. In this paper, we have addressed both of these issues by proposing a Space-Air-Ground Information Network (SAGIN) Architecture, which can provide almost all of the services of space and ground networks for all the users around the world according to varying needs of users. Our proposed SAGIN architecture is IP-based to provide interoperability and compatibility with the already deployed ground network. We have also addressed the challenge of dynamic nature of the network topology by designing a simple mechanism which automatically maintains a relatively static IPs of nodes in space (satellites), despite their rapid physical movement in orbits. This SAGIN architecture could be among optimized candidate architecture for future to have for many countries (either individually or by the cooperation of different regional countries). Because, it can provide all the services to nearly everyone in the world, in contrast to traditional individual satellites providing limited services to a limited number of users.

1. Introduction

Over the technology history, Space technologies (e.g., Satellite) and Terrestrial technologies (e.g., internet) have evolved almost independent with each other. Most of the satellites are launched in three well-known orbits; Geostationary Earth Orbit (GEO), Medium Earth orbit (MEO) and Low Earth Orbit (LEO). A vast majority of satellites are totally independent, i.e. not connected with any other satellite in the same orbit or any other orbit, while remaining few are either connected with other satellites in constellation (i.e. satellites within the same layer e.g. LEO or MEO) or connected with satellites in any other orbit [1]. On the one hand, it is established that by connecting satellites in different orbits, the coverage, access, and availability of space resources for users on the ground can be increased significantly [2]. Additionally LASER ISL (inter-satellite link) can provide high bandwidth, robust security, anti-EMI, small antenna size and low power consumption for highly
efficient transmission, exchange and access flexibility for multi-service capacity with multiple granularities [3]. Meanwhile, the demand for integrating terrestrial network with space resources has also been increasing over the years for two reasons. First to spread the benefits of terrestrial/ground networks such as internet, to the all the world using global coverage of satellite, which cannot be possible using terrestrial network [4]. Secondly, to provide access to the satellites' data (e.g., images of the earth) to a user through the ground or terrestrial networks such as the internet [5].

For these reason we have seen an enormous amount of research on the same topic of integrating or networking of different space and ground technologies with several different names such as: Space Information Network (SIN), space-based information network (SBIN), Spatial Information Network, Integrated Satellite-Terrestrial network, space–ground heterogeneous network, Interplanetary Internet, Ground Space Merged Architecture etc. More importantly, most of these network architectures are proposed while keeping a particular application in focus, e.g. internet/broadband or mobile satellite communication. Some Authors discussed about different aspects of such integration networks by focusing a more general or abstract architecture containing all possible nodes or sub-networks. Therefore, we have seen a large variety of algorithms, techniques, and protocols for network control, data routing, data transmission, security and other features for different applications of SIN [2][6]. In general, such a heterogeneous network is divided into different sub networks for ease of control and management [7]. We will provide an overview of some of these architectures in the next section.

In this paper, we have proposed a Space-Air-Ground Information Network (SAGIN) architecture that can provide almost all services for different users on the ground according to their varying needs instead of any single application. For an integrated space-ground network, it is desirable that it should be based on the IP (internet protocol), for interoperability with terrestrial networks, as well as to take advantage of synergies with all research and products developed for TCP/IP [8], [9]. However, to achieve this, among the primary challenges, one is the dynamic nature of the network topology. Ground networks usually have relatively static network topologies where the positions of and distances between nodes are relatively fixed. On the other hand nodes (satellites) continuously lose and recover line of sight due to orbital dynamics, and the path lengths between nodes also vary quickly [10]. In this paper we have proposed an IP-based SAGIN, which provide as easy interoperability with the ground network (e.g., internet), devices and protocols, etc. as desired. We have addressed the challenge of dynamic routing by designing a simple network scheme such that all the nodes in space can dynamically update their IPs which will make the nodes virtually static, similar to that on the ground. Our proposed architecture, therefore, can provide a similar to ground availability and access to network nodes in space for users.

This network can provide almost all the civilian, commercial and military services for different users using the same single network. This proposed SAGIN could be among ideal future space architecture for many countries (either individually or in cooperation with many regional countries) which currently having few, dozens or hundreds of independent satellites in space because this can provide remarkable technological and economic benefits for all those countries.

The remainder of this article is arranged as follows; Section 2 provides a quick & brief overview of related work. In Section 3 and 4 we have proposed the architecture of SAGIN and discussed its topologies. In section 5 we have described SAGIN IP scheme. Section 6 describes the dynamic IP updating mechanism. Section 7 provides an overview of services and different applications of SAGIN. Section 8 concludes the paper.

2. Related Work

As mentioned in the introduction, many research for SIN is focused while keeping any particular application in focus. For example, Feihang Dong et al. proposed a novel HAP/satellite architecture to provide emergency communication in emergency scenarios [11]. Similarly, authors in [12] discussed different aspects such as architecture, routing, modelling, and scheduling of complex space information networks from the perspectives of cooperative earth observation application. Mobile satellite communication system is also an example of this application based integration network [13].
There are two approaches towards SIN, first is to divide the whole network into sub networks according to the link characteristics and sub network function and then focus on integration, interfacing and cooperation aspects for these sub-networks. For example, NASA designed the evolvable space communication architecture model to support the Earth sensor web (SW), collaborative observation formation missions, and detailed investigation of planets, moons, and small bodies in the solar system [14]. In NASA’s space-based network architecture, network elements are divided into sub-networks.

The concept of The system of systems (SOS) was introduced into space-based networks by authors in [15] to analyze independent complex small systems/ networks and enabled them to be developed, integrated, interoperable, and optimal. Based on the SOS structure, availability and capacity of the space-based network can also be analyzed. Lei He et al. proposed a new architecture of the SDN/IP hybrid space information network, where we can use the traditional IP-based system in the ground internet and use centralized SDN in the satellite network.

The alternate approach is to examine the system as a whole single unified network such that nodes either in the ground part or space may be indistinguishable from the user's perspective. This leads the effort towards IP utilization in space part of SIN because it is already widely deployed on earth [9] [5], [16].

A new software-defined architecture for next-generation satellite networks, called Soft-Space, is presented by authors in [17], where they exploited the concepts of network function virtualization, network virtualization, and software-defined radio to facilitate the incorporation of new applications, services, and satellite communication technologies. S. Wang et al. proposed LEO-user-oriented space network architecture, where LEOs are users to the backbone, instead of parts of the backbone. The new architecture simplifies the structure of the backbone network and improves the flexibility and extendibility of it [18]. The Survey of four leading space communication architectures namely OMNI (by NASA), CCSDS, Hi-DSN, and Space VPN, performed by [19], showed that the OMNI architecture provides a sustainable architecture serving future near space exploration demands.

3. SAGIN ARCHITECTURE

Our proposed SAGIN can be divided into three groups of nodes, i.e., space nodes, air nodes and ground nodes as shown in fig. 1. Space nodes include satellites in GEO, MEO, LEO and HAP (High Altitude platform). Air nodes include airplanes, helicopter, UAVs, etc. Ground nodes include internet gateways, fixed or mobile users, terrestrial networks base stations, etc.

![Figure 1. Three Groups of Nodes in SAGIN.](image-url)
In this paper, we will not focus on ground and air node part of SAGIN for three primary reasons. The first is that many users and nodes on the ground are already connected through the internet which is by now widely deployed. Secondly, our network is IP based so there should not be any compatibility & connectivity issues of space, and air part with ground nodes of SAGIN such as internet gateways. Finally, because of being in the same network the data transmission in SAGIN will be seamless, once a data is entered in the SAGIN with IPs of source and destination, it will flow seamless irrespective of the physical location of the node (either in space air or ground).

Nodes in the air such as Airplanes, Drones, etc. can easily join the SAGIN to connect with the ground nodes because of being a part of the unified IP Network. All that these nodes need to do is to be configured with IPs & able to connect to SAGIN. Similarly, the user on the ground can access to air nodes through SAGIN. We will discuss more about this in section 7.

For designing Space part of our SAGIN architecture, we have considered advantages and disadvantages of different orbits to assign best possible services to satellites in these platforms. This means timing-critical services such as, voice and internet services are assigned to lower platform, i.e., HAP and LEO satellites, while applications which can tolerate little delays such as TV broadcasting and Earth observation are assigned to MEO and GEO satellites.

We have also assumed that next-generation satellites will be capable of serving multiple or at-least dual purposes simultaneously rather than traditional single dedicated purpose. We have already seen some practical demonstration of such multifunctional satellites such as, COMS (communication, ocean, and meteorological satellite), EGNOS (The European Geostationary Navigation Overlay Service), text messages services by Chinese navigation satellites Beidou, S&R payload on Galileo and ADSB receivers on Iridium Next for air traffic monitoring, etc.

The space part of SAGIN is composed of Satellites in four different layers as shown in fig 2;

![Figure 2. Space Components of SAGIN.](image)

*Dual purpose GEO Satellite*

In our proposed SAGIN GEO Satellite can provide two primary services; first is broadcasting, as they are typically famous for, and second is network management. In our proposed SAGIN, there may be 6 GEO satellites (3 for TV broadcasting and 3 for real-time relaying of earth observation data to ground). While among 6 GEO satellites, 3 will be responsible for network management while other will be backup for network management.

*Dual purpose MEO Satellites*

MEO Satellite in our proposed SIN can serve two purposes; first is the navigation service which is the traditional service of MEO satellites, and the second is Earth observation which typically provided by LEO Satellites. However, as we know that now thanks to technology we have already seen GEO Earth observation satellite, so having same or more advanced cameras on MEO satellite will enable us to observe earth in future even comparable to that of traditional LEO resolution.
Dual purpose LEO Satellite

LEO satellite in our proposed SAGIN can serve two services, first is internet “inward” services, and second is Aviation control, text messages, and military communications. The internet service model that we are proposing is slightly different from traditional space-based internet concept, and we will explain that in section 7. However, for now, inward internet data means uni-directional data transfer from internet server towards user.

Dual purpose High Attitude Platform

High altitude platforms are emerging platform which are supposed to be aerostatic platforms or balloons at much lower altitudes than traditional LEO satellites, i.e., from 17-30 km usually. HAP can provide several unique advantages such as larger coverage area than terrestrial towers, compatibility with conventional base station technology and terminal equipment, requires no launch vehicles for deployment like satellites, compare to LEO much shorter signal path and delay. Upgrading, repair, maintenance, and re-deployment are possible, unlike satellites. Low power consumption and low cost are also advantages of HAP.

In our SAGIN, HAP will provide two services first is bidirectional voice communication (e.g. phone calls), second is outward internet service. Means users request to a specific destination server will reach through HAP and similar to LEO of our SAGIN, this is also unidirectional service. HAP may not be fit on the definition of the satellite; however, for ease, we will use term satellite for them throughout in this paper.

4. SAGIN TOPOLOGIES

There are three kinds of data flow through space part in our SAGIN.

- Mission Control Data
- Network Configuration Data
- User Application Data

Mission control data is the telemetry and telecommand data for satellite operators to check satellite's health and for controlling the satellite to keep them in their allowed orbital window or other onboard management on satellite. For mission controlling, the MCC (mission Control center) can access any satellite directly (during its visibility) or indirectly through GEO Satellite anytime.

Network configuration data in our SAGIN is the data that flows within space nodes without the involvement of user and satellite operators to ensure correct network configuration. For the network configuration, we have proposed the tree like topology as shown in figure 3, where data only flow between two immediate layers and no data flow within any layer and we will discuss this in detail in the next two sections.

Figure 3. Tree like Topology of SAGIN
User Application data is the data that flows within the networks from terminal nodes (e.g., satellites or server on the ground) to the user and in reverse. For user application data, the topology will vary according to the application. For example for the application of real-time earth observation, images captured by satellites in MEO will be transmitted to GEO satellite that will broadcast them to the ground. So cross-layer topology is required where no data will be shared from one MEO to other MEO. Similarly, for the air traffic monitoring service, the navigation data needs to flow from one MEO to other MEO until it finds the destination nodes (desired Airplane). So for this application, data flow within the MEO layer is desired while no cross data is required. So we can say that for application data flow, the topology in MEO will be hybrid (cross-layer and within a layer). So, all MEO satellites will be connected with its every neighbouring MEO satellite as well as with GEO Satellite above though optical or RF ISL.

Similarly, for internet application and voice communication, there is no cross-layer data flow required in LEO and HAP. So, every LEO satellites will be connected with neighbouring LEO satellites. Similarly every HAP will be connected with neighbouring HAPs. We will discuss more about this in section 7.

5. IP ADDRESSING FOR SAGIN
The ground part of SAGIN is already configured with IPs. For the space part, our proposed network is self-configuring, where nodes will dynamically update their IP address. Therefore, the operator does not need to configure network configuration manually. For the explanation of our IP scheme, we are using IPv4 (internet protocol version 4) addressing. IPv4 addresses are represented in dot-decimal notation, consisting of four decimal numbers or octet (e.g., 192.168.1.5) each. Similarly, nodes (satellites) in our scheme will have IPs as shown below.

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www.xxx.yyy.zzz
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But, here we are using it with a different interpretation, which is that each octet in our IP scheme is the representation of a node in a particular layer. Which means the first octet “www” (highlighted by green) represents GEO, “XXX” (highlighted with yellow) represents MEO and similarly “YYY” and “ZZZ” represents LEO and HAP respectively. This means by using this IP scheme we can address up to 255 GEO satellites, 255 MEO Satellites, 255 LEO satellites, and 255 HAPs. However if the number of satellites in any layer (e.g., LEO & HAP) is more than 255, IPV6 simply can be used which uses 128 bits for the address.

**GEO IPs**
As GEO satellite is static for ground, so in our SAGIN, GEO satellites will have static IPs, i.e., IPs of GEO nodes will remain the same. GEO satellites will have following IPs. Assigned IPs (as shown below) are for explanation purpose, and in practice, there may be different IPs.

- Geo1-IP=1.0.0.0
- Geo2-IP=2.0.0.0
- Geo3-IP=3.0.0.0 and so on

**MEO IPs**
In our SAGIN, MEO Satellites will have following IPs

- MEO 1-IP= 1.1.0.0
- MEO 2-IP= 1.2.0.0
- MEO 3-IP= 1.3.0.0

As mentioned earlier, the highlighted green part of the IPs here is not fixed, instead it represents that MEO satellite is currently under GEO 1 satellite coverage. Similarly the MEO satellites under coverage of GEO3 will have IP as: MEO 9 - IP= 3.9.0.0

**LEO IPs**
The LEO satellites will have following IPs

- LEO 1 -IP = 1.2.1.0
- LEO 2 -IP = 1.2.2.0
- LEO 45-IP = 1.3.45.0 and so on
The highlighted green octet of above IPs represents that LEO satellite is under GEO 1 coverage. Highlighted yellow part represents that LEO 1 is under coverage of MEO 2 or MEO 3 (LEO 45). So, for example, a LEO satellite (e.g., LEO 50) which is currently under coverage of GEO3 and MEO 8, will have IP 3.8.50.0

**HAP IPs**

The IPs of HAP will be as follows

- HAP1 –IP = 1.1.1.1
- HAP2 –IP = 1.1.1.2
- HAP4 –IP = 1.1.1.4 and So on.

Similar to MEO and LEO, the highlighted green, yellow and pink part of the HAP IP represents the GEO satellite, MEO satellite, and LEO satellites respectively.

One typical scenario will be that at any particular moment one LEO satellite comes under coverage of 2 or more MEO satellites. Similarly, one HAP will come in most cases under coverage of two or more LEO satellites (as shown in fig 1). We will address this common scenario in the next section where we will explain how nodes (satellite) will dynamically update their IPs.

6. DYNAMIC UPDATING OF IP

In this section, we will describe how the IPs of nodes in space will be dynamically updating as they continue moving in the orbit.

**MEO Satellites IP Updating**

A MEO satellite, on its orbital path will continuously send a beacon message consisting of 56 bits (7 octets) towards the GEO satellite above it, and every GEO satellite will reply to these beacon with its own identity (i.e., 1,2,3 …etc) as shown below

- Beacon message from MEO towards GEO = 0.0.0.0.0.0.0
- Reply of Beacon from GEO 1 =1.1.1.1.1.1.1
- Reply of Beacon from GEO 2 =2.2.2.2.2.2.2
- Reply of Beacon from GEO 3 =3.3.3.3.3.3.3

From this reply, MEO satellite can know about identity (IP) of GEO satellite above it. Moving on its path, when MEO satellite will enter the coverage of GEO-2, leaving the GEO 1’s coverage, then reply message (i.e., 2.2.2.2.2.2.2) will tell MEO that it is now under the coverage of GEO 2. So, it will automatically change the GEO part of its IP from 1.1.0.0 to 2.1.0.0. Similar will be the case for every MEO satellite. By this method, all the MEO Satellites will dynamically update their IPs according to its current position.

The MEO part of MEO satellite IP (e.g., Highlighted yellow in 2.1.0.0) is also not static; MEO satellite will update this part of its IP based on its current coverage area on earth. Authors in [20] proposed a scheme to exploit geographical location information to make the mobility management independent from handovers. We also used the same concept, which means the whole earth can be divided into X equal parts from EO (earth observation) point of view. Where X is equal to the number of MEO satellite and each part on the ground will be assigned a number from 1 to X. During its orbital path when a MEO satellite will start covering the X part of ground, the MEO satellite will update its MEO part of IP according to that coverage area number as shown in fig. 4.
Figure 4. Updating MEO part of IP

MEO can know about its current earth coverage by two ways, either by the real-time acknowledgment from the ground (Lat & Long of ground inside user message) or mathematically as orbital paths can generally be predicted and estimated accurately in usual practice.

**LEO Satellite dynamic IPs updating**

Similar to MEO, the LEO satellite will also update their IPs dynamically as follows. LEO satellite will continually send Beacon message to MEO satellites above it as follows.

Beacon message from LEO towards MEO = 0.0.0.0.0.0.0

Every MEO will reply to this beacon with its IP as follows:

Reply of Beacon from MEO 1 = 1.20.1.20.1.20.2
Reply of Beacon from MEO 2 = 1.19.1.19.1.19.4

From the reply of MEO 1, LEO can easily deduce that it is under coverage of GEO 1 and MEO 20. Similarly, from the reply of MEO 2, LEO can know it is also under coverage of GEO 1 & MEO 19 satellites. The 7th octet in beacon message (highlighted gray) is to tell the traffic load on that particular MEO satellite. The load on the MEO satellite can be divided into, e.g., Four main categories (1=Low, 2=moderate, 3 is heavy, and 4 is full load). So in response to beacon message, if LEO satellite gets a reply from more than 1 MEO satellites, it can easily decide which MEO satellite it should use for its IP selection, i.e., with lower seventh octet number. This will also do a job of load management to a certain level, similar to DNS (Domain Name Service) on the internet.

Similar to MEO satellite case, the LEO part of LEO satellite IP will be updated based on its current area of coverage. Means earth can be divided into Y parts from LEO coverage viewpoint, and Y is the total number of LEO satellites which requires covering the whole world. Based on the orbital calculations or acknowledgment from ground, LEO can update its LEO part of IP (e.g., 1.4.21.0) accordingly.

**HAP dynamic IPs updating**

Similar to MEO and LEO, HAP will also update GEO, MEO and LEO part of HAP IP dynamically by sending beacon messages towards LEO satellites above it and according to the reply of LEO, HAP will update its GEO, MEO and LEO part of IP accordingly as shown below.

Beacon message from HAP to LEO = 0.0.0.0.0.0.0

Reply of Beacon from LEO 1 = 2.20.5.2.20.5.1
Reply of Beacon from LEO 2 = 2.19.6.2.19.6.3

From the reply of LEO 1, HAP can deduce that it is under coverage of GEO 2, MEO 20, and LEO 5. Similarly reply from LEO 2 tells HAP that it is currently under coverage of GEO 2, MEO 19 and
LEO 6. So HAP can update GEO, MEO and LEO part of its IP by considering value in the seventh octet (traffic load).

The HAPS are assumed to be stationary to the ground similar to GEO but with significantly lower coverage area than GEO. Therefore HAP part of HAP IP will be fixed for every HAP.

7. SERVICES

It is important to recall that we are assuming two kinds of users in the world. First are those who already have access to the internet and want to utilize the services of space nodes such as real-time earth images, navigation, TV broadcasting, etc. This kind of user can access all the services of space part of SAGIN through their ISP (internet service providers) who will receive IP data from the satellite using satellite terminal equipment. While others are those users who have no access to the internet, these users can use satellite terminal equipment such as (antenna, modem router, etc.) to access complete SAGIN (space, air and ground part). Our proposed SAGIN architecture can provide many services to the user; some are shown in table 1.

| Service Name                  | Layers          | Possible User                |
|-------------------------------|-----------------|------------------------------|
| Internet                      | LEO & HAP       | Everyone                     |
| Real-time earth Observation   | MEO & GEO       | RS, Aviation, Military       |
| Air traffic Monitoring & Control | MEO, GEO & LEO | Airlines/ Airports          |
| TV Broadcasting               | GEO             | Everyone                     |
| Voice and Text                | HAP             | Everyone                     |
| Navigation                    | MEO             | Everyone                     |
| Military communication        | LEO             | Military                     |

It is important to mention that services in table 1 could be provided if nodes in space can provide services as we proposed in section 3. However, our SAGIN architecture is designed such that it will not have any impact on the network if satellite provides services other than what we proposed. For example, we proposed EO services to be provided through MEO satellite; however, if EO services are provided through LEO satellite, then it will not make any difference in network and service architecture. Only EO users are required to be provided with LEO IPs instead of MEO IPs for EO. Similarly, we have divided internet services into two separate layers (LEO and HAP). However, if in practice, only LEO Satellites are used to provide complete internet services, it will not have any effect on network configuration. Similar is the case for services of any other satellite in SAGIN.

In this section, we will provide a brief overview of some of the services provided by SAGIN.

Internet

Considering long propagation delays of Geo and MEOs, two kinds of latency-optimized platforms proposed to extend broadband connectivity globally; first is to use HAP for this [21], [22] and second is to use LEOs. Both of these platforms can provide access to the internet for the user in two ways. First is that satellite or HAP platform acts as an access network where they only connect the user to gateways and the user request goes through typical ground internet network until reached destination server. Similarly, the response comes back to the gateway and then through satellite or HAP to the user as shown in fig. 5 (a) [23]. The other way is that space platforms (LEO or HAP) act as a core network as shown in fig. 5 (b). Our proposed SAGIN can be used as an access network, but it is designed and optimized as the core network.
In our SAGIN we used LEO satellite as routers, and the user can get the desired data from destination server directly through LEO satellite constellation (logically router network). However, unlike traditional ground routers LEO will only provide inward service. Means data to the user will be delivered from the server using LEO satellites. On the other hand, the data request from the user will reach to servers through HAPs (logical router network), which also provides uni-directional services like LEO but only outward data flow (from user to the server).

Many routing schemes and algorithms are proposed for data flow from source satellite to destination satellite such as [24][25][26][27]. Authors in [12] also discussed various inter satellite routing strategies and protocols. Any of the proposed routing or any further optimized routing scheme can be used in SAGIN according to requirements of the application.

Through this approach, the overall internet load can be divided into two parts (inward and outward data). At least the outward data load can be removed from LEO by this approach. Additionally, HAPs are placed at altitude very lower than LEOs, so it will reduce at least one-way time delay and hence can improve overall latency than traditional space internet. A further study to compare the performance metrics such as speed and latency of traditional space internet and our proposed internet is essential for better evaluation.

One more important aspect is that we already have projects in line from Space-x, one web, etc. to provide internet access for everyone across the globe through satellite [28]. So, in that case when everyone on the earth will get access to the internet the load on the core ground networks of the internet will be exceptionally increased which could seriously degrade the performance of internet if not completely halts. Damage of optical fiber in some occasional cases also results in disconnection of some regions with others. So considering these aspects, it is a good idea to put all new internet users’ load on nodes in space rather than putting already congested ground internet core network.

**Voice and Text Communication**

Voice communication service through HAP will be similar to that with the terrestrial network. We can imagine that the cellular network communication tower is not on the ground; instead, it will be on HAP. This can provide two fundamental advantages, first is in case of disasters such as an earthquake, flood, Tsunami, and cyclone, etc. on the ground, communication will not be interrupted, and that will help in the rescue operation. Secondly, voice communication will be expanded to nearly all over the world including areas where the terrestrial network is absent such as Sea, Mountain, air, undeveloped areas, etc. Also similar to ground cell network concept for HAP will allow frequency reuse in cells that will help in coping with frequency resources limitation.
Although many internet application can provide voice and text communication, however, these put the load on internet infrastructure (routers and internet links). Using HAP, we can reduce the internet load by separating voice and small text messaging exchange from the main internet load (e.g., web browsing). Also a vast majority of voice and text communication occurs between local users, for that local communication, sending data to such applications server too far (engaging hundreds of routers and links) may be unnecessary, using HAP for voice over IP (VOIP), can provide an efficient alternative to those local communications while it can also support long distance communication. HAPs can also provide unobstructed and better angle of signals than terrestrial networks.

Real-time earth observation

Relaying LEO satellite data through GEO to ground is not a new concept. NASA’s TDRS and EUs data relay system are more than two decades old concept [29]. However real-time transmission or broadcasting of earth observation data directly to the users is a new concept, which means seeing the earth from the eyes of satellite right now. In addition to traditional users of remote sensing/earth observation data (for example weather forecasting, agriculture, disaster monitoring, water resource, etc.), this kind of immediate access to earth observation data can open doors of new applications and users. Such as security surveillance, air traffic monitoring, ground traffic monitoring, etc.

In Our SAGIN, each earth observation MEO Satellite will transmit its captured data in IP packets to GEO EO relay satellite. GEO EO Relay Satellite will multiplex these IP packets to form an IP stream, and after encryption, it can broadcast this stream towards the ground. Authorized users on the ground with internet connectivity can access this stream through ISP, while user having no internet connection can receive that data directly from the satellite using terminal hardware.

The next generation IP based satellite communication can transfer images from satellite faster than traditional satellite communication. Saratoga [30] which is a UDP/IP protocol with reliable delivery, can be a suitable candidate protocol for data transfer from MEO to GEO and then from GEO to ground in this case. While to ensure security features, we can use the protocol of [31] for authentication, key exchange, and confidentiality in this real-time earth observation context.

Air traffic monitoring and control

Airlines and aviation authorities can receive the real-time earth observation images data as mentioned above to track the airplanes. Besides, airplanes can continuously send a beacon message to MEO satellite above it to tell MEO that airplane is in its coverage. MEO based on these beacon messages can maintain a list of airplanes under its current coverage. Aviation authorities can then send navigation data request to airplanes which in return can provide their latest navigation position with the help of onboard navigation receivers.

For Aviation control, and military control we have proposed to use LEO satellites because voice communication through MEO will have longer delays than LEO.

TV broadcasting

Similar to real-time earth observation, TV channels can be streamed up independently or through multiplexed service as DTH, and the GEO TV relay satellites will relay them back in the form of IP stream, which could be access through ISP or satellite terminal equipment.

8. CONCLUSION & FUTURE WORK

In this paper, we have proposed a Space air-ground network architecture that could provide access to all the services of satellites to internet users and internet access together with satellite service to users currently not connected with internet. We have proposed our IP-based scheme that will allow interoperability with ground network and internet protocols. We have proposed a mechanism through which each node in space can update its IP virtually static for the ground despite high physical mobility in space. This kind of scheme provides advantages in data routing in space and access to nodes for the user. We finally briefly discussed potential applications such as the internet, real-time earth observation, etc. In our future work, we will focus on applications and their protocols with in-depth details and compatibility and suitability analysis for those protocols in IP based SAGIN architecture environment context.
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