In-flight Connectivity Analysis Using Ka & Ku-band HTS with Hybrid Compatibility Solution

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In this paper, we propose a connectivity analysis solution to integrate satellite-based ground gateways with terrestrial networks capable of transmitting Terabit/s of data throughput to fast moving narrow body and wide body planes. Taking into consideration the need for higher bandwidth and lower latency communication, we propose a gateway connection for backhauling traffic through terrestrial base stations. These satellite gateway feeder links will significantly improve overall throughput by utilizing feeder links in parallel with minimal ground network topology alternations. The proposed solution will provide real-time services to LEO, MEO & GEO satellites in connection with In-Flight Connectivity (IFC). This will include all types of managed broadband services on the plane, on-board monitoring, tracking and control services available in a fiber-like connection.

Introduction

In the last decade, the aviation industry demanded satellite operators to provide worldwide connectivity to provide consistent performance. The inflight connectivity ecosystem consists of three major components: the satellite technology, the hardware onboard of the aircraft and the service and support on the ground. High throughput satellite communications can provide seamless global coverage to support any mission. Today Ku-band (12-18 GHz) is dominantly deployed while Ka-band (26-40 GHz) satellites are expected to be vastly deployed as well. L-band (1-2 GHz) satellites are also in use, though they deliver considerably lower levels of bandwidth. One of the challenges for these satellite networks is the adaptability and adjustment to the technological achievements in the LEO, MEO, GEO constellation.

Numerous analysis have been proposed for overall architecture design of aeronautical networks and satellite systems separately [1][2]. In this study, we will be delivering a hybrid architecture design for satellite system which incorporates high throughput links between satellite gateways and feeder links of microwave backhauls.

The satellite antenna usually requires one beam handoff which should take about 1-2 minutes. Using a very high throughput geostationary satellite link with user links in Ku-band or Ka-band can allow higher data throughput and provide fiber like user experience to the aircraft [3]. Every inflight connectivity approach has practical limitations based on the route being served, aircraft type and technology used for that mission. Ka and Ku-bands deliver peak data rates of up to 50 Mbps through steerable spot beams , answering demands when and where it's required [4].

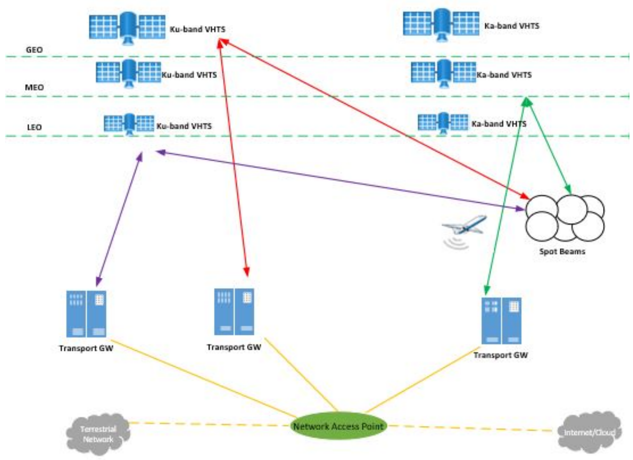

Figure 1: VHTS System Mobility Overview with Different Constellation

The operating satellite will provide broadband in-flight connectivity over north America using Q-band (33-50 GHz) and V-band (40 to 75 GHz). Using these V & Q band feeder links makes it challenging to meet availability goals at the gateway. The attenuation at 50 GHz is 1.8 dB, compared to 0.23 dB at 30 GHz. One solution is to place gateway links in low rain regions. It may seem that the higher antenna gain can be used to reduce antenna size at these higher frequencies, despite higher gain required to overcome the atmospheric loss.

The issue with user link side in Very High Throughput Satellite (VHTS) is the frequency re-use through the spot beams and on the gateway end is the optical feeder links which will be addressed by using transport gateway (TGW) located in each regional locations such as AOR, POR, etc. As seen in Figure 1, a hybrid constellation of VHTS system with different links can be considered where it is connected through terrestrial network via the Network Access Point (NAP). Implementing this approach will result in smoother transition between each constellation during the flight duration; the main three usage scenarios are addressed in the following:

1. Ka/Ku dual band antenna can deliver seamless speeds up to 400 Mbps to each aircraft while above 10,000 feet subject to link availability.

2. improved uploads, consisting of very high throughput for upholding massive data traffic growth such as Skype, FaceTime, Live Streaming, etc.

3. It is compatible with any conventional wide beam transponder in addition to spot beam technology.

System Overview

The proposed topology should support extremely high data rates for advanced connectivity and tracking. GEO, LEO and MEO constellation satellites can easily deliver on this promise were they provide UHD content broadcasting with High Efficiency Video Coding (HEVC) standards which offers improved compression rates. Lately, businesses are investing heavily in MEO and LEO networks and supporting very latency sensitive applications such as gaming or voice over IP [5]. These constellation can support backhaul networks to comply with the below 1ms latency requirements and deliver seamless throughput. These solution can support ARINC 791 standard which any modem with solid state hybrid technology can work on (Figure 2).

The end to end link is designed to have noise plus interference contributors on the user side of the link. Uplink power control is used at each gateway to reduce interference from an unfaded gateway uplink into a separate and faded gateway uplink, with very little impact to the clear skyend to end carrier to noise ratio. The proposed solution also can provide backhaul connection to several satellite-based ground networks.

Using a hybrid constellation with transport gateways can accelerate switch times between

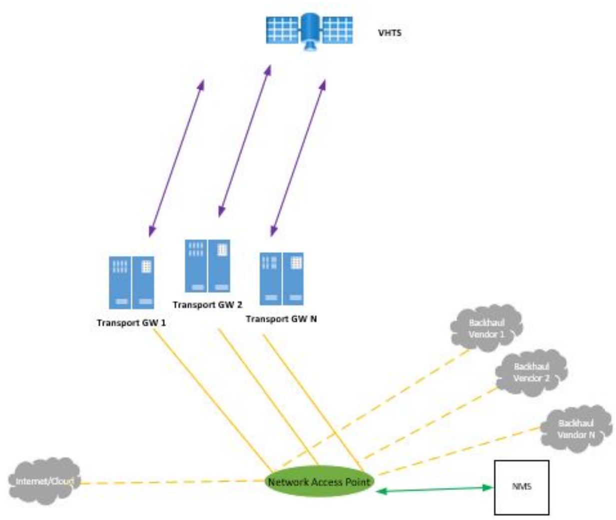

Figure 2: Mobility Ground System with multiple backhauls connected to NAP

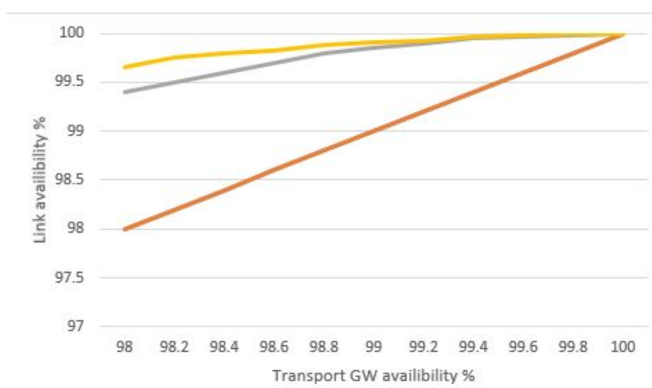

Figure 3: Transport gateway availability % vs link availability %

spot beams [6]. In addition, the delay can be mitigated at the user gateway by using a 5G relay node which is equipped with Global Navigation Satellite System that provides autonomous geo-spatial location position throughout the globe which would facilitate airlines for tracking purposes (Figure 3).

Network Architecture

The network architecture is illustrated in figures 4 & 5 with major network components and the intercommunications amongst them. The radio frequency terminals are at each geographical locations to provide diversity on the ground infrastructure. Each gateway consists of multiple elements including switches and routes which inter connect to the backhaul infrastructure. There are outroute and inroute modulators and demodulators in the gateway to handle RF signal conversion from Ka/Ku band to based-band.

The backhaul is connected to one or multiple data centers; quantity is dependent on the computation level complexity. Each data center includes two main structure. First the Transport component which operates as a bandwidth manager and second the networking layer which includes all the IP Gateways. In this design overview we have a network IPGW as well as and anero IPGW, which through switching are connected to public/private network of choice[7].

The gateways are implemented using high-density architecture to minimize floor space noise level and reduce overall power consumption. Each mentioned gateway provides full automatic redundancy for all traffic-carrying components and is designed for remote light out operations. The gateway receives user traffic destined for terminals from these data centers via the terrestrial backhaul network and sends the traffic via the satellite links to the user terminals [8].

In the return direction, the gateway receives traffic from user terminals and sends it to the data centers through the backhaul network. Another feature in addition to the traffic interfaces, is that the gateway also interfaces with the element manager for alarm handling and with the central Network Management System for configuration management and statistics gathering.

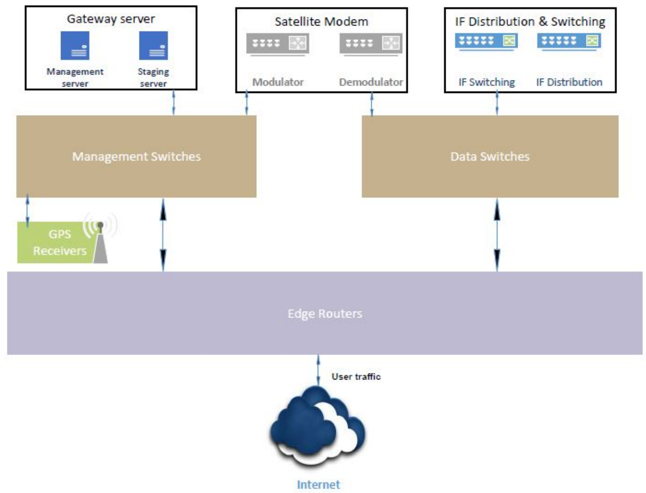

Figure 4: Platform Gateway Architecture

Gateway Platform

All the VHTS inter-connected data center platforms are implemented using a high density architecture to reduce floor space and power consumption and usees high performance multicore servers. These data center provides fully automatic redundancy for all traffic carrying components and is designed for remote light out operation. The data center receives user traffic destined for terminals from the Internet via a terrestrial link and sends thee traffic to a gateway. In the return direction, the data center receives traffic from gateways and sends it back via a terrestrial link to the Internet[8].

The characteristic of the traffic for this research can be obtained via operational scenarios in simulations. Usually the burst uplink user access requests traffic needs less bandwidth where the more lengthy and steady user traffic downlink requires a lot more bandwidth. The satellites transponder is a set of communication transceivers. The signalling channels are best served using regenerative configuration of the satellite transponder operation. This operates as a switching center and the incoming radio frequency waves can be demodulated into bit streams. In theory, the data traffic such as broadcast traffic is better served by the conventional bent-pipe operation.

Network Management System

The advanced Network Management System (NMS) provides element management for platform components and orchestration for software defined network and visualized components. In addition, it implements an application for integration with an external Operation Support System (OSS). The application provides a comprehensive set of service management functionalities towards the provisioning of network level service parameters, service plans, terminals end users, and real-time terminal status and diagnostics. The Dynamic Carrier Reconfiguration feature allows dynamic forward and return frequency plan reconfiguration along with the change of carrier sizes[9]. The interfaces with the platform and communicates plan updates in real time. The platform propagates the new carrier plan to the respective gateway's control for implementation. This dynamic carrier sizing feature also provides support for N diversity. The interface is implemented as part of the overall NMS platfrom.

The user terminals communicate with existing remote and the associated gateway through the satellite for any service to gain access to Internet and other networks. A scenario is an Internet access request from a user in a remote location. The baseband level will determine which Internet gateway handles the requests. The network management service will oversee the overall operation from a networking and transport level.

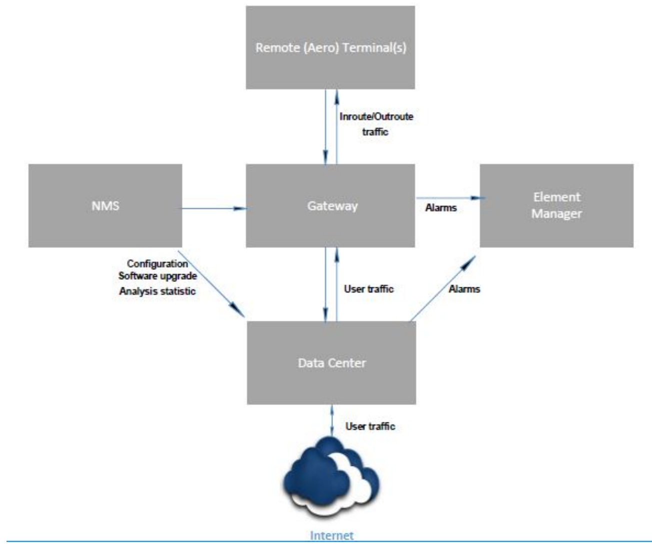

Figure 5: Network Management System

Conclusion

The ground segment of the proposed system uses frequency and polarization reuse over the spot beams for user terminals and the same among larger regional spot beams for the defined gateways. This study shows high throughput with efficient spectrum usage improvement using higher baseband modulation using Forward Error Control (FEC) and Adaptive Coding and modulation (ACM).

Three major use cases for integrating VHTS satellite constellations to providing In-flight connectivity has been summarized. We have studied a transport gateway architecture for back-hauling connection of a satellite link through a terrestrial network, based on the most up to dated 3GPP specifications. In addition, we have studied the significance of this approach in GEO, MEO & LEO satellite air interface.

Conflict of Interest

The authors of this paper have no conflict of interest relevant to this article.

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