In-Flight User Terminals Based On Active Array Antenna For LEO Scenario Including Soft Handover

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Abstract. In-Flight Connectivity services through satellite systems are expected to grow exponentially throughout the 2020 decade. The deployment of new geostationary orbit satellites with superior bandwidth and, particularly, the coming of mega-constellations in low and medium earth orbits (LEO/MEO) with high throughput and low latency, which is ideal for real time services, will result in higher demand and lower running costs. However, there is a significant issue to consider in this type of scenario, the high density of satellites available and their movement introduce not only a continuous tracking in the user terminal but also a mandatory handover when the communication needs to be transferred from one satellite to the next one. Nowadays, user terminals based on reflectors and flat panels with electro-mechanical steering lose the communication during the handover because break-before-make procedure is applied. Beam re-pointing and signal re-connection take a certain time, consequently, the quality of service (QoS) is degraded. Alternatively, two-reflector/flat panel terminals can mitigate this effect and provide make-before-break functionality for seamless handovers in RX, while in TX it can be omitted. However, this solution is not convenient for in-flight terminals which are expected to be compact and low profile to reduce the impact on fuel consumption. In this paper, to approach LEO/MEO scenarios with frequent handovers and high quality of service, the active phased array antennas are addressed to offer better performance than the reflectors. The advantages are listed as follows: much faster beam re-pointing; more compact size and lower profile; reconfigurability of the aperture; and, multiple beam capable for seamless handovers. These characteristics are desired by satellite operators, service providers and airlines, who can get ancillary revenues by offering In-Flight connectivity and entertainment to passengers as well as supporting flight operations and airlines/aircrafts services and maintenance.

1. Introduction

In-Flight Connectivity (IFC) services have combined air to ground (A2G) and satellite communications (SATCOM) to expand the passenger experience and to provide more detailed flight operations and airline/aircraft services. As result, the concept "Connected Airline" was created [1], which involved aircraft manufactures, airlines, service providers and hardware/equipment manufacturers in a new paradigm to offer next features:

- In-Flight services. Broadband connectivity and entertainment for passengers, which are used to provide superior experience and additional revenues to airlines.
- Flight operation. To support cabin crew by means a complex, technical and very automated datalink with operation information, among others, live navigation charts, weather patterns, take-off performance numbers, and weight and balance closeouts.

- Maintenance. Historically, maintenance personnel were on the ground and not connected to airline data networks. In-Flight connectivity offers a powerful channel to access to real-time information related to the aircraft.
- Aircraft Systems. The automation and connectivity around aircraft systems provide high potential, since machine-to-machine (M2M) operations and Internet-of-Things (IoT) will be part of connected aircraft.

A typical implementation of In-Flight Connectivity based on satellite communication link is depicted in the Figure 1. It is composed by the outdoor equipment (SATCOM antenna) and indoor equipment (antenna controller, power supply and IP network addressing multiple devices for passengers and cabin crew).

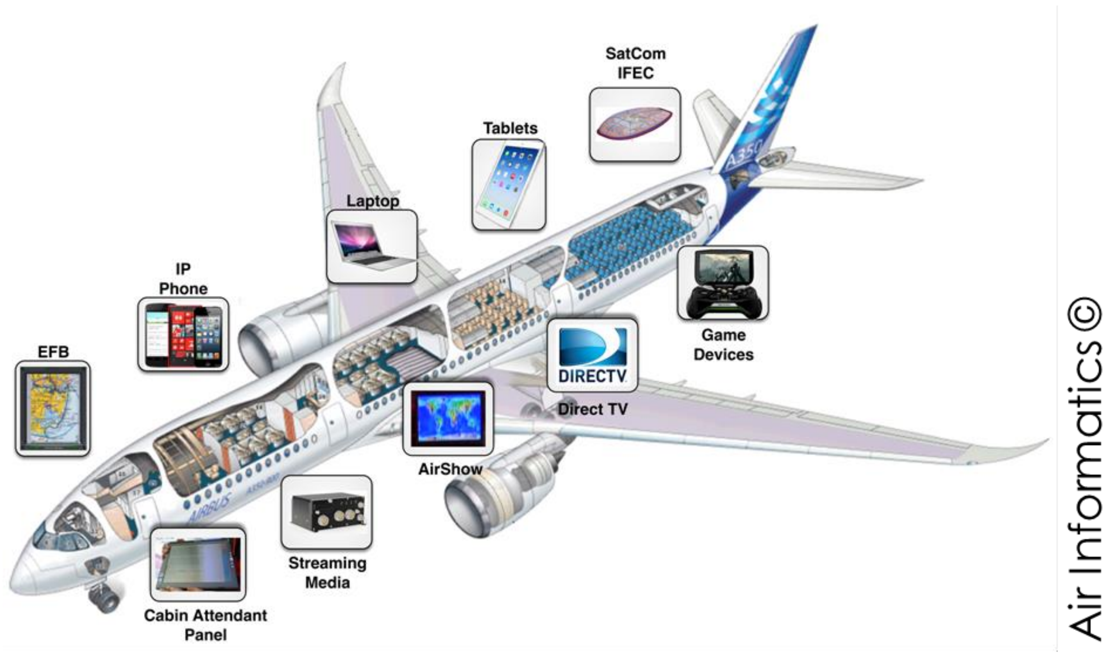


Figure 1. A typical implementation of In-Flight Connectivity System.

In the present decade, the global market for IFC is expected to grow exponentially (see Figure 2), despite COVID-19 pandemic and the imposed limitation in mobility. A higher demand of connectivity and more competitors with the satellite capacity are reducing the operating costs of the service and increasing the revenues. Several advisors in the sector have announced an updated prediction for the 2020 decade with an impressive expansion [2][3].

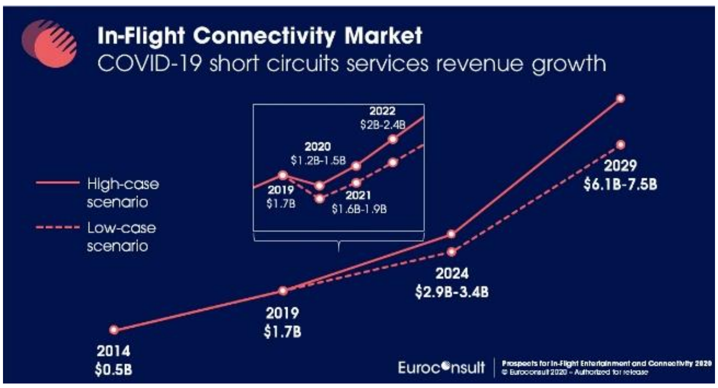


Figure 2. IFC market prediction in 2020 decade, EuroConsult®.

To support this new capacity, satellite operators are deploying new high throughput satellites in geostationary orbits (GEO) and mega-constellations in low and medium non-geostationary orbits (LEO and MEO). Both systems are described in next chapters.

1.1. SATCOM systems based on GEO satellites

Satellite communications via GEO satellites are consolidated solutions that dominate today's In-Flight Connectivity. This system is characterised by a wide coverage, typically focused on the continental areas, and medium capacity. The running costs are in fact the real limitation of this business case due to the limited bandwidth available in the GEO market. There are other drawbacks that affect to the quality of service, among others, the maintenance of the SATCOM equipment, the latency of the signal and the permitted transmission power in the uplink. On one hand, the typical implementations of the SATCOM terminals are based on electro-mechanical solutions, whose maintenance, especially the motorized parts, becomes a significant cost of the service. Second, imposed by the nature of the geostationary scenario, the latency of the signal in up- and down-links cannot be mitigated, consequently, the service is not convenient for real time applications. On the other hand, regulatory organisms limit transmission power in the geostationary orbits to prevent interference in adjacent satellites. This is particularly relevant when the antennas are operating in high scan angles and high skew angles, resulting lower permitted equivalent isotropically radiated power (EIRP) spectral density, this is, lower link capacity.

Recently, the GEO scenario is being changed significantly with the new High Throughput Satellites (HTS) in geostationary orbits. These satellites are creating a group of small spot-beams as footprint, that allow a cellular-like approach increasing the bandwidth available since can be reused in some of the spots (see Figure 3). This system allows to drop the cost per bit but introduce some challenges for the ground/air stations, especially for those on the move. While the station is moving from a spot to the next one, a change in frequency and/or change in polarization is likely to be needed. This means a handover needs to be done, even if the same satellite and station are the ones in the link. Therefore, a handover procedure becomes a new feature to be considered in the system requirements.

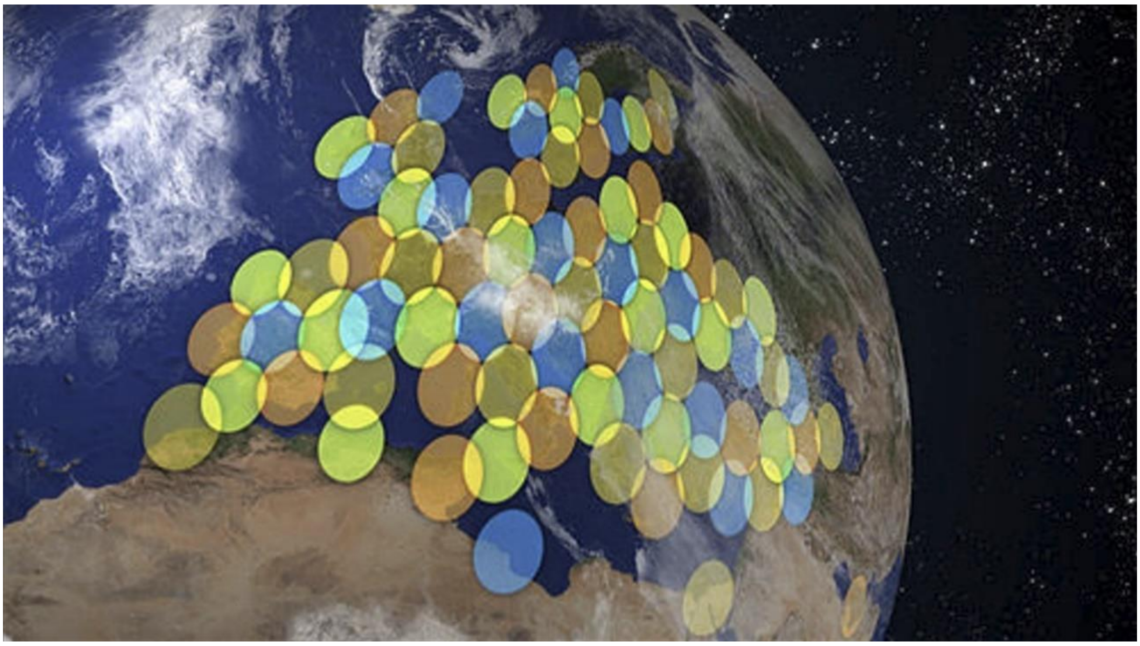


Figure 3. Example of HTS coverage with spot-beams implementation.

1.2. SATCOM systems based on LEO/MEO satellites

The coming of mega-constellations in low and medium earth orbits will result higher bandwidth, higher demand and lower running costs. There are inherent advantages in this scenario. In example, satellites in lower altitude provides lower latency in comparison to GEO that is ideal for real time applications. Also, the fact that a large number of satellites with narrow coverage are used creates spot-like footprint with a high level of frequency and polarization reuse, increasing therefore the amount of available capacity for users. Next figures show a MEO scenario, consisting on five orbital planes with thirty-six satellites.

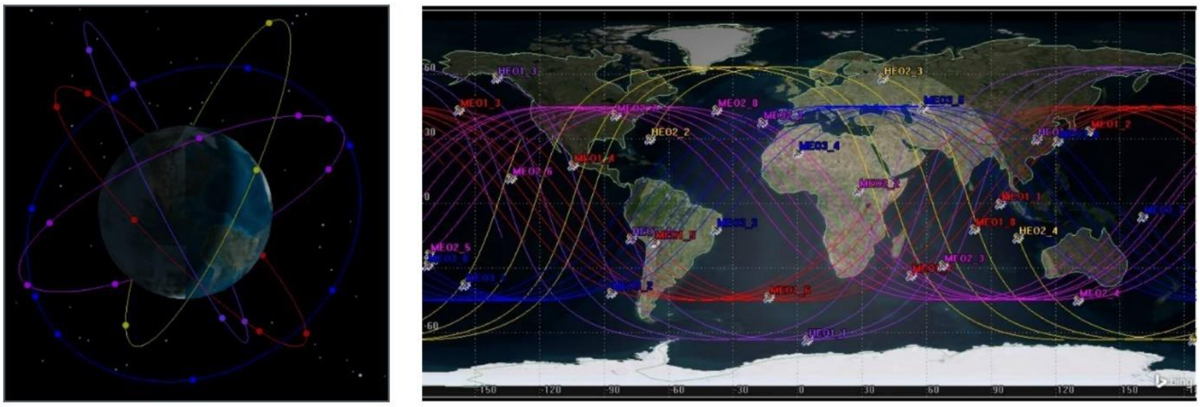


Figure 4. Example of MEO constellation.

Other constellations based on polar planes and low earth orbit require a very large number of satellites, which means, at the same time, a very large number of spots on ground. Although a user station is able to steer multiple satellites in its field of view (green circle in Figure 5a), each satellite creates narrower coverage by overlapping several spots (blue highly asymmetric ellipses in Figure 5b). Between neighbor satellites (either the same or the adjacent orbital plane), the coverage is also overlapped to guarantee the service (in Figure 5b: blue and green areas, or, blue and yellow areas).

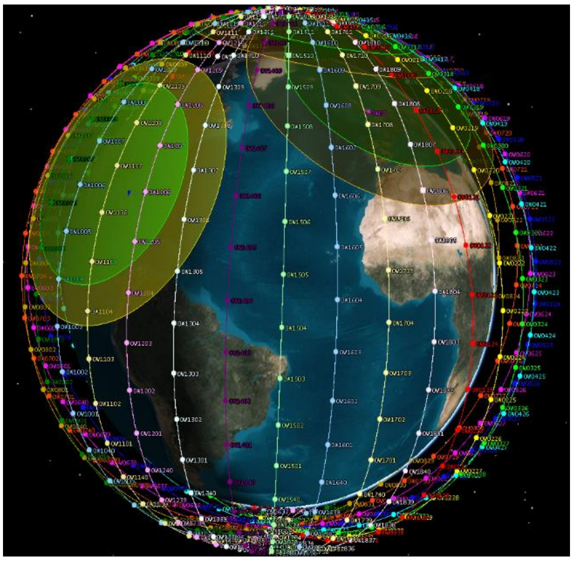


Figure 5a. Example of LEO constellation.

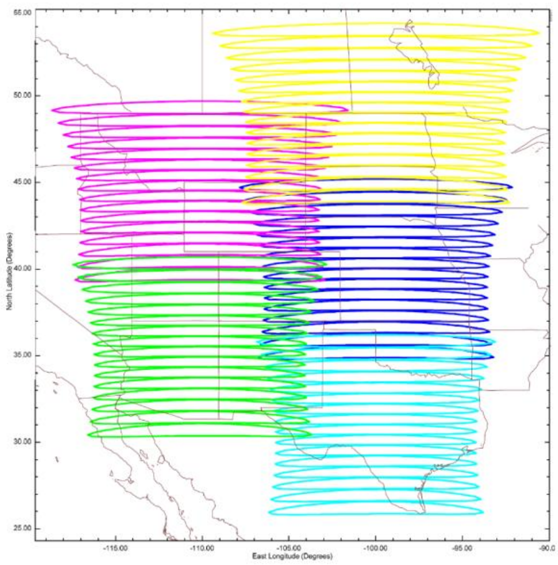


Figure 5b. Example of LEO coverage.

The higher density of the constellation, the higher number of handovers needed. In fixed stations a lower angular scanning range is needed be track the satellites. In contrast, in mobile platforms the scanning range must be increased to compensate the attitude of the vehicle.

1.3 Handover Procedure in SATCOM Scenarios

User terminals in relative motion to satellites must continuously track the satellite as a function of satellite and user terminal positions and dynamics. In the new scenarios, either GEO scenarios with spot-beams or LEO/MEO mega-constellations, the presence of handovers implies a new feature that has to be implemented. The user terminal not only tracks the satellite but also has to manage the signal to transfer the communication from one satellite to the next one with the minimum loss of connectivity.

Nowadays, user terminals based on reflectors and flat panels with electro-mechanical steering suffer cuts in the communication during the handover because break-before-make procedure is applied. Beam re-pointing and signal re-connection take a certain time, consequently, the quality of service (QoS) is degraded. Alternatively, two-reflector/flat panel terminals (see Figure 6) can mitigate this effect and provide make-before-break functionality for seamless handovers in RX, while in TX it can be omitted.

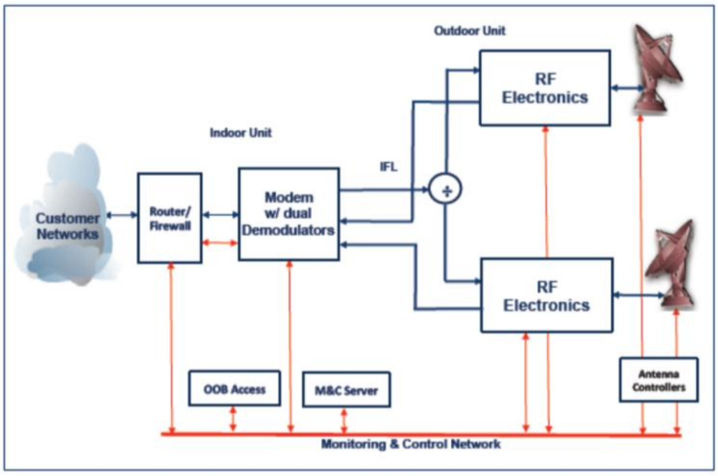


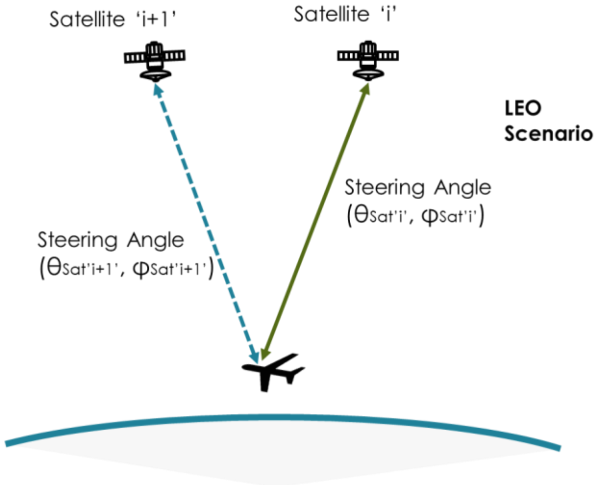
Figure 6. Two antennas architecture for seamless handover.

In this architecture, two parallel reception chains are implemented: two antennas and two demodulators embedded in the modem. This allows the tracking of two satellites during handover procedure and to avoid a modem de-synchronization. However, this solution is not convenient for in-flight terminals which are expected to be compact and low profile to reduce in impact on fuel consumption.

2. Active Antenna Arrays for LEO/MEO Scenarios

To approach LEO/MEO scenarios with frequent handovers and high quality of service, the active antenna arrays are considered to offer better performance than the reflectors. The main advantages are listed as follows: much faster beam re-pointing; more compact size and lower profile; reconfigurability of the aperture; and, multiple beam capable for seamless handovers. These characteristics are desired by satellite operators, service providers and airlines, who can get ancillary revenues by offering In-Flight connectivity and entertainment to passengers as well as supporting flight operations and airlines/aircrafts services and maintenance.

Although in a certain scenario the amount and the repetition of handovers depend on the constellation and user terminal characteristics, the handover procedure for transferring the communication from one satellite to the next is common to all the situations. First, one satellite is actively tracked and reception is locked; second the handover procedure is carried out while the user terminal might receive from two satellites; finally, a new satellite is tracked and new reception is locked. This procedure is repeated according to orbits and user terminal motion, as depicted in the next figures:



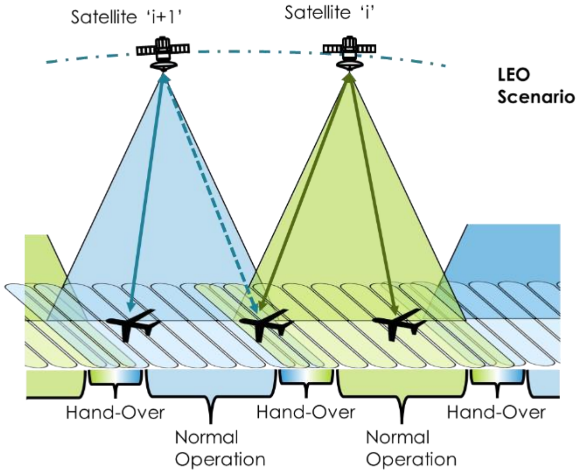
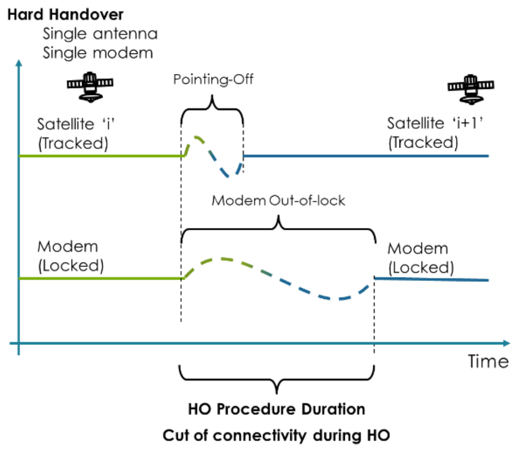


Figure 7a. At certain moment, an In-Flight terminal is covered by two satellites in LEO scenario.

Figure 7b. Operating timeline for In-Flight terminals in LEO scenarios.

Hard handover represents the break-before-make procedure, where antenna is steered to the new incoming satellite when the previous satellite gets out of the field of view. This type of solution takes a certain time to re-point the antenna and to re-connect again, this is, to lock the modem to the new satellite link. Figure 8 depicts the timeline during hard handover procedure. The lack of throughput, generally few seconds to two minutes maximum, depends on the antenna technology being typically worse for the reflector-based and flat panel antennas than the active phased array ones. This cut is a main issue in LEO scenarios, since they are specially interesting for applications demanding a high QoS with a low latency.



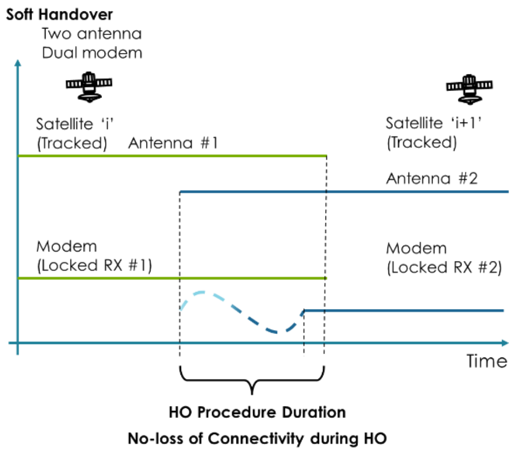


Figure 8. Hard Handover timeline.

Figure 9. Soft Handover timeline.

To cover this limitation a group of solutions based on active antenna arrays (lower profile and more compact size than reflectors) are considered to implement the soft handover. The soft handover features make-before-break procedure based on two antennas and a modem that integrates two receivers. During the handover, one antenna is tracking the actual satellite, while the other antenna is in the waiting position for the incoming satellite. In this condition, the connectivity is not interrupted, this is, the two receptions can be working at the same time. In contrast, the transmission is switched at the right moment to maintain the return link. Figure 9 depicts the timeline during soft handover procedure.

As result of Project LESAF activities [4], several techniques are studied for active phased array antennas. In order to implement the soft handover in this kind of antennas, it is proposed to create a dynamically configurable RX aperture in such a way that the full aperture can normally track a satellite and when the handover process needs to be implemented, instead of re-pointing the whole antenna only a portion is pointed to the new incoming satellite. Obviously, the reception figure of merit (G/T) of the two resultant apertures will be reduced compared to the full aperture working together. In other words, the reception operates as three different TIER terminals: full-size (most the time, highest performance) and large/small portions (short periods during handovers process, high/medium performance).

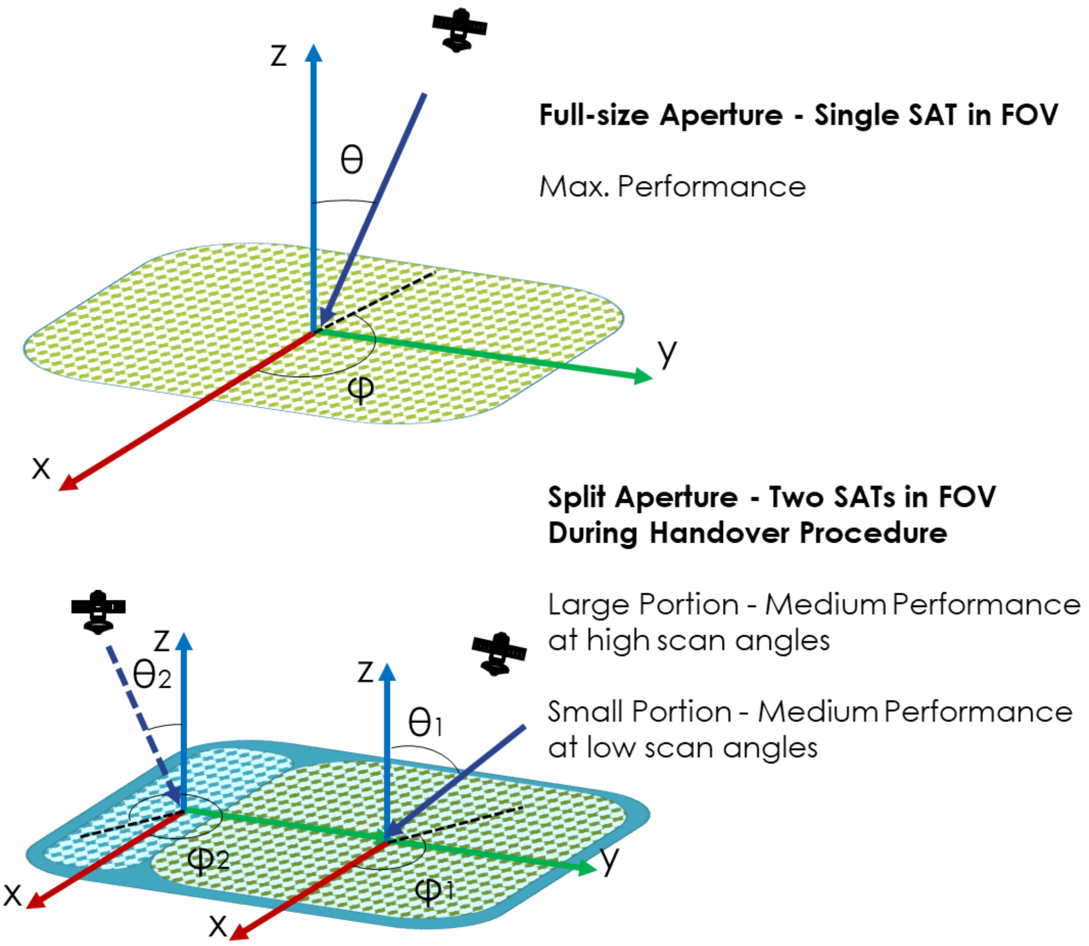


Figure 10. Aperture reconfiguration: Normal operation versus Handover procedure.

The configurability of the RX aperture will allow to select if one beam needs a higher G/T than the other during the handover process and based on the different scan angles created. It is important to remark that in a LEO scenario the G/T needed is a function of the elevation angle and, additionally, the scan losses are a function of the scan angle. Therefore, the usage of the antenna can be optimized by means an algorithm matched to the scenario, among other, to the satellite constellation, motion indicators and quality of service. It is expected a slight degradation in BER during handover periods, but it can be managed. The main goal, to avoid an unlock in the modem during the handover, is achieved with this technique.

3. Conclusions

The present paper introduces a technique to create two simultaneous beams, that can be working in the same or different frequency and polarization, with the aim of improving significantly the handover procedure. It is particularly applicable to In-Flight user terminals based on active array antennas for LEO scenarios, where the handover procedure is quite often due to the high density of satellites and represents a degradation for services demanding a high QoS.

The most suitable approach for keeping a good throughput with no lack of communication during re-pointing to the incoming satellite and new lock of the modem after that re-pointing is by generating two beams simultaneously. Instead of creating these two beams based on two independent antennas, which would imply the manufacturing and assembling of two complete apertures that are only used at the same time during a short fraction of time, this paper proposes a technique where the same aperture can be working as two independent apertures during that handover process and as a single aperture during most of the time, providing the highest performance possible during all the time of the communication.
The flexibility in the reconfiguration of the aperture is providing an extra feature that is used to match the scenario during the handover, maximizing performance for the two independent beams created, since different pointing angles will demand different performance of the aperture.

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Disclaimer
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