



# **IRIS Space Router Key Capabilities and Benefits**

## **White Paper**



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## Executive Summary

Customers and their end users expect future satellite networks to provide seamless connectivity and inter-operability to their evolving ground networks for next-generation applications and services. Increasingly, business applications rely on multiple service components for information assurance and communications requirements, requiring better management of end-to-end service quality across multiple networks. With Internet Protocol (IP) connectivity, multi-media based communication is becoming the norm, while personal mobility and cross-functional collaboration are driving a need for more network services. Therefore service providers seek continuous evolution of their service and network capabilities independent of access technology and geographic footprint.

To satellite service providers, the space segment is a major asset and the adoption of new technology in the space segment must be timely to meet new requirements and create new opportunities. Satellite service provider investment must be provided considerable protection and returns. Studies show that requirements and opportunities exist for the future service provider space segment to support the hosting of multiple types of payloads to address different types of customers and services. These payloads require flexibility of use and easy management of resources. Innovative use of the space segment is a major consideration for service providers and service users. It is here that the adoption of terrestrial networking capabilities has the potential to extend the Internet's innovative platform into space. To achieve this innovation, the space segment must integrate with the ground segment to become part of a converged IP network. Cisco examines the benefits of including networking capabilities within communications satellites, essentially making them nodes on the network and extending a rich set of Internet services into space.

The key considerations are the need for, and benefits of, an on-board router, which can transform the role of the satellite from its traditional bent-pipe signal relay function into an active node in the future network. The term "Space Router" refers to the integrated on-board capabilities to support signal regeneration, networking Layer 2/3, higher layer traffic processing, and advanced IP services. These capabilities allow the satellite to become a fully-processed payload and an active part of the end-to-end communication network.

The first Internet Routing In Space (IRIS) Space Router was developed as a technology demonstrator, implemented as a hosted payload on Intelsat IS-14, and employs Cisco's Internet Operating System (IOS) technology for the on-board networking and routing. The service benefits of using Cisco's 18000 Series Space Router developed as part of the IRIS initiative are numerous:

- New and enhanced service opportunities (e.g., Hub-less Very Small Aperture Transmission (VSAT) services, resilient telephony, legacy interconnect through cross-banded links, efficient delivery of converged services, enhanced mobility and multicasting)

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- Improved traffic performance resulting from the reduced latency (any link can be single-hop) and dynamic routing, along with improved Quality of Service (QoS)
  - Improved service admission control (reduced service establishment time, dynamic resource management)
  - Improved utilization (spectral efficiency and higher link margins to improve link performance and throughput)
  - Improved connectivity (single-hop/dynamic links for mesh, cross-beam, cross-band connectivity)
  - Improved operational performance (potential enhancements to the Service Fulfilment and Assurance process, improved network resiliency, improvement in the Size, Weight, and Power (SWaP) for the satellite ground terminal).

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## 1. IP Satellite Background

ASTRIUM Services (ASV) and Cisco Systems Inc. (Cisco) are studying the benefits of using space-based routing to deliver both military and commercial services, under a Technology Partnership Agreement (TPA). The Space Router in this context is the IRIS Space Router, implemented on Intelsat's IS-14 satellite, which uses the Cisco IOS technology for on-board networking and routing.

An important objective under the TPA was a demonstration of IRIS capabilities through a set of real-time, over-the-air voice, data, and video services to the U.K. Ministry of Defence (MoD) and NATO. This was successfully completed during the last week of October 2010 and serves to test and validate the likely benefits of a Space Router.

The IRIS architecture and a summary of testable benefits of the IRIS Space Router capabilities show that the satellite meets and exceeds baseline capabilities. The underlying on-board signal regeneration and on-board route processing provide better bandwidth usage. IRIS demonstrates some of the key capabilities and benefits of a Space Router for customer applications.

The capabilities listed were witnessed at the demonstrations and are from the analysis of information presented. It is not based on engineering tests or field validation against any pre-defined measurement criteria.

### 1.1 Regenerative Satellite Networks

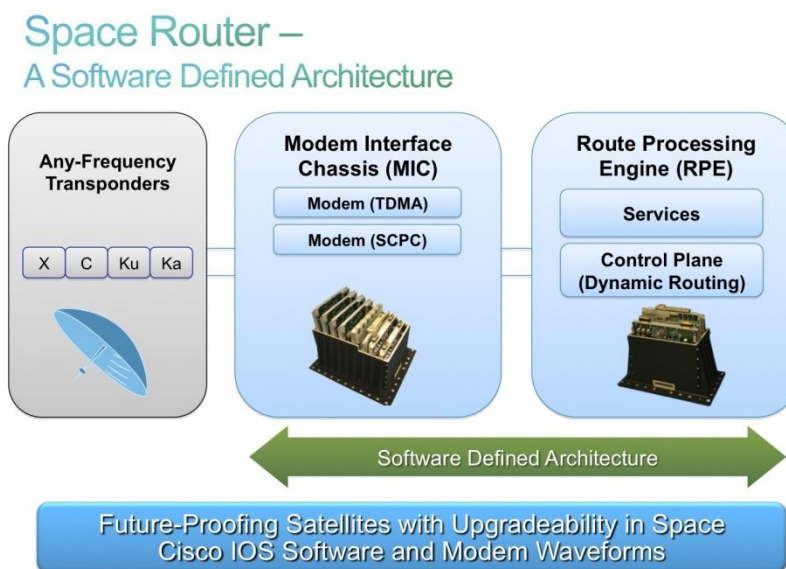
In the current transparent satellite network, the payload is traditionally seen as a bent-pipe that translates the received uplink carrier signals to another set of downlink carrier regardless of signal format. By enhancing the signal with limited on-board processing, the bent-pipe can be employed as a partially processed payload in order to perform transponder-level switching. This may also include demodulation and re-modulation of the signal using various schemes in order to manage the differences in the channel conditions between uplink and downlink.

Compared to the current network; in an IP-based regenerative satellite network, the payload is fully processed and performs the recovery of the traffic data from the uplink signal through demodulation and decoding. Then the data is subsequently processed at baseband level before regenerating the signals through coding and modulation for the appropriate downlink.

## 1.2 IRIS Space Router

Cisco teamed with Intelsat General Corporation and a group of industry partners to deliver an IRIS proof of concept on the Intelsat IS-14 satellite<sup>1</sup> for the United States Department of Defense (DOD). As quoted by Intelsat, “IRIS Hosted Payload program was aimed at the Joint Capability Technology Demonstration (JCTD) for examining the potential utility of augmenting joint, interagency, intergovernmental, and multi-national information transport with space-based IP routing and processing.”

The IRIS Space Router is a fully processed payload (**Figure 1**). The IRIS Space Router payload consists of two core on-board subsystems, namely the Modem Interface Chassis (MIC) containing Software-Defined Radios (SDRs) that perform modem functions, and the Route Processing Engine (RPE) that performs the IP layer packet processing.



**Figure 1. IRIS Payload Architecture**

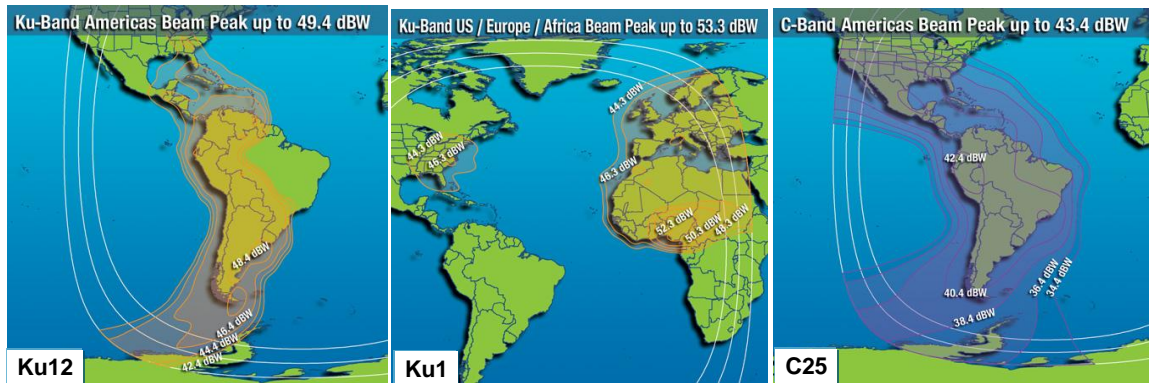
The MIC provides at present a set of two waveforms: Time Division Multiple Access (TDMA) (based on Viasat Linkway) and Single Carrier Per Channel (SCPC). With the SDR-based implementation, multiple and different waveforms can be supported in the future.

The MIC interfaces with the RPE, which is based on a general purpose high-performance processor, running Cisco’s IOS software. The upgrade to the SDR-based waveforms and the embedded IOS image of the RPE can be performed from the ground, which means the on-board capability can be maintained at par with the corresponding advances in the ground network components.

<sup>1</sup> IRIS as a hosted payload, refer to <http://www.cisco.com/go/iris>

To date, several software upgrades have been successfully performed from the ground on the Space Router on IS-14.

The IS-14 spacecraft architecture provides for flexible IP packet routing across the coverage areas (cross-beam) and the different frequency bands (cross-band), limited only by the number of pre-defined transponders that are connected to the Space Router. The Space Router on IS-14 supports three transponders (two in Ku-band and one in C-band), with the coverage areas as shown in (Figure 2). Also see [www.intelsat.com/network/satellite](http://www.intelsat.com/network/satellite) for further details.



**Figure 2. Band Coverage Area as of April 2009**

## 2. Tested Benefits

The Space Router offers the combined benefits of regenerative payload and on-board route processing capabilities.

With the current transparent payloads, the on-board frequency-switching capability in translating the uplink carriers into downlink carriers in different beams provides only a carrier-level granularity.

Compared to this, in regenerative payloads, the on-board processing allows frame/packet-level granularity. This offers the capability for:

- Separating the uplink and downlink
- Applying different input/output formats
- Applying different data rates
- Aggregating or deaggregating multiple low-speed carrier inputs.

The regenerative capability when augmented with on-board route processing capability, offers packet/service level granularity for managing the traffic flow. This capability can be effectively used to improve network utilization, end-to-end service performance, and operational efficiency.

### 2.1 Traffic Performance

From the service user's perspective, end-to-end traffic performance is based on how well the service is managed at the edge of the network (e.g., service admission control, security, and QoS policy enforcement) and across the network (e.g., adherence to service level specification for routing and QoS). The delay, latency, packet loss, and Bit Error Rate (BER) are some of the key variables that impact the end-to-end traffic performance.

The key benefits of the Space Router for the end-to-end traffic performance are highlighted in the following sections.

#### 2.1.1 Latency Reduction

The inherent latency of Geostationary (GEO) satellites is generally budgeted into the end-to-end service performance of satellites. Typically, there is about 320ms of round-trip propagation delay (270ms + an assumed processing delay of about 50ms) for each GEO satellite hop.

In a transparent system when there is no direct mesh connectivity, a minimum of two hops are required for communications between two remote satellite ground terminals. Also note that two or more satellite hops are required for the control plane exchanges (e.g., in the case of dynamic capacity allocation, to request and receive capacity assignments), depending upon the location of the ground-based dynamic resource manager.

Therefore, satellite hop reduction improves both end-to-end communications for user traffic and control plane exchanges for resource allocation and service admission control.

With the use of the Space Router:

- **Single hop latency** can be assumed for all links since connectivity among remote satellite ground terminals within the satellite footprint can be set-up using direct mesh
- **Use of on-board bandwidth-on-demand** means that control plane exchanges for resource allocation and service admission control will benefit from reduced latency.

### 2.1.2 Service Admission Control

Service admission control refers to the networking Layer 2/3 or higher layer traffic processing for managing service admission based on criteria such as subscriber profile and service level specification. From the traffic performance perspective, it is necessary to implement service admission control, especially for real-time and conversational class of services. In the case of VoIP for example, the call admission control is usually performed by the call control agent function at the VoIP gateway on the ground.

With the Space Router:

- **On-board service admission control** is possible either to replace, augment, or backup the associated ground-based capability. This improves both service admission latency and resiliency.
- **Varying service management capability** is possible, depending on the implementation of the Space Router. This can be leveraged to support:
  - Resilient voice fall-back service to support survivability requirements
  - Virtualized hub services to disparate ground terminals.

### 2.1.3 Clocking

Typically the bent-pipe transponder configuration uses two independent clock sources, one on the ground and one on the satellite (for frequency conversion). To achieve code/carrier coherency, it is necessary for the ground station to monitor reference signals and steer the ground-based clock accordingly.

With the Space Router:

- The regenerative payload hosts an on-board clock as the master that can steer both the satellite's clock and provide reference to the ground terminals
- The satellite can be the timing and frequency reference for both the uplink and downlink for all beams and the signals in all beams are synchronous
- On-board clocks will provide significant benefit in the processing of signalling data.

## 2.1.4 Enhanced QoS

The end-to-end QoS for traffic delivery relies upon the QoS policy, the implementation design and adherence by the delivery network. Typically, these include:

- **‘service establishment phase,’** covering service admission control (e.g., resource management), service access control (e.g., authorization), QoS mapping (e.g., specification to configuration), QoS negotiations (e.g., resource allocations)
- **‘traffic delivery phase’** which include traffic shaping, resource separation (e.g., based on classes, flows, users) and policy enforcement
- **‘reporting phase’** which include QoS measurements and performance reporting.

In a transparent payload, the end-to-end QoS is largely managed within the ground network.

With the use of the Space Router:

- **Use of packet and service level granularity** onboard means additional policy enforcement can be implemented to improve the end-to-end QoS
- **Improved QoS measurements** can be achieved. With the decoupling of uplink and downlink and the availability of QoS metrics for each link, the onboard router can report and utilize end-to-end QoS metrics in its routing decisions
- **The flexibility of the configuration** of the onboard router means the Space Router’s role in the delivery of end-to-end QoS can be tailored to the mission requirements.

## 2.1.5 Radio-Aware Routing

Unlike in the LAN environment, in a satellite radio environment, the link layer may include different types of radio connectivity with varying characteristics and data rates. For example, a satellite radio environment may include satellite ground terminals with multi-carrier links, or varying effects of radio propagation on each link. Routing efficiency can be achieved if the varying performance characteristics of the underlying radio layers are taken into consideration for the routing decisions at the network layer or above. Such radio-aware routing capabilities are implemented in ground-based networks to improve the local routing and to support the end-to-end QoS in a radio environment.

With the Space Router:

- As the RPE is software based, industry advances such as the radio-aware routing algorithms can be implemented on the operational Space Router
- With the availability of onboard radio metrics for the uplink and downlink channels, the routing and queue management decisions can be further improved. Thus the use of radio aware routing on the Space Router further enhances the end-to-end QoS.

## 2.2 Improved Utilization

A key objective for the satellite service provider is maximizing the power and bandwidth efficiency while minimizing overall BER for the satellite users. The use of the Space Router contributes to this objective.

### 2.2.1 Spectral Efficiency

The bandwidth efficiency must extend beyond the throughput measurements (e.g., bits/Hz) in terms of maximizing the use of the channel. Capabilities such as multiple access scheme, frequency reuse, and efficient modulation to support low-level adjacent channel interference, efficient coding, and power control techniques are some of the major contributors for achieving required bandwidth efficiency.

With the regenerative payload, the Space Router:

- **Improves channel efficiency** compared to bent-pipe transponders. In a transparent payload, multiple carriers may require multiple channels, and also inter-modulation measures between carriers and specific back-off power needs. Both of which impact channel efficiency. A regenerative payload does not suffer from this constraint.
- **Improves frame efficiency** as the immediacy of the onboard switching requirement between transmitting and receiving antenna is no longer required with the onboard routing. This allows for the satellite ground terminals to transmit information in a single burst per frame, thereby reducing the number of bursts per frame and thus increasing the overall frame efficiency.
- **Increases system flexibility** by using onboard capability. For example, by performing the role of hub, thereby resulting in increased capacity, reduced errors, and greater throughput. IRIS supports hub-less VSAT links.
- **Improves interconnectivity** to perform onboard aggregation or segregation of channels across the beams.
- **Improves channel** assignment compared to the bent-pipe transponders, in dynamic resource allocation. As the allocation can be done separately for uplink and downlink, better handling of slot fragmentation and channel assignment can be achieved.
- **Data rate variability** between the uplink and downlink allows carrier usage optimization. The inability to vary data rates between the uplink and downlink is one of the reasons for double-hop connectivity in a transparent payload. This impediment is removed.

### 2.2.2 Link Performance

The overall link performance is based on both uplink and downlink performance. In a transparent transponder, the uplink and downlink are coupled and therefore in order to compensate for any

noise in the uplink and the satellite power constraint on the downlink, the overall link margins are typically reduced.

With the Space Router:

- There are gains from the decoupling of uplink and downlink.
  - Gains come mainly because the uplink noise is not transported into the downlink. This advantage is considered to be useful up to the point where the uplink noise becomes negligible. However in practice, where the real channels are non-linear, and with interferences, the regenerative payload will achieve between 2 – 5dB gain even when there is high uplink Carrier-To-Noise (C/N) ratio density.
  - Improves resistance to uplink or downlink signal fading. Published research shows that improvement on the order of 8 dB is possible by regenerative payload over transparent payload in the presence of severe uplink rain fading. This is a key consideration for Ka-band services that require more stringent mitigation techniques against rain-fade.
- Advantage in the link margin can be traded off against interference in an interference limited situation, to increase the power efficiency of the system, resulting either in an increased range of the communication system during rain fade or alternatively, in bandwidth-limited systems for increased throughput.

## 2.3 Flexible Connectivity

Network flexibility requires the ability to connect different end-points, dynamically and on demand. In a ground network, such flexibility is enhanced by the use of IP at the network layer as it supports dynamic addressing, path discovery, and routing protocols etc. In a satellite environment, although such network layer capability can be utilized, flexibility is impacted by the circuit-switched nature of the underlying radio links and how these are planned, configured, and used. Typically in a transparent payload, the flexibility in the radio layer connectivity is influenced by:

- Frequency bands
- Beam coverage
- Data rate requirements
- Radio characteristics of connecting satellite ground terminals
- Onboard switching granularity, resulting in multiple-hop requirements.

### 2.3.1 Mesh Connectivity

Single-hop mesh connectivity in a transparent network is constrained by a number of factors. As the uplink and downlink are tightly coupled, there is no scope for data rate variability between the uplink and downlink, so double-hop connectivity is required to support disadvantaged

terminals. In addition, as new terminals are added to the mesh, power levels need to be rebalanced across the network. This limits flexibility and increases complexity of operations.

With the Space Router:

- **Single-hop connectivity** is possible between any two satellite ground terminals, within the same beam, across different beams, or across different bands in the case of a hybrid payload.
- **Dynamic mesh connectivity** is possible in addition to the pre-planned mesh and hub-spoke star networks. This refers to the dynamic allocation of links depending on the location of the satellite ground terminal and using the most efficient downlink channel. The Space Router enables anytime, anywhere, on-demand connectivity, which provides users the flexibility to dynamically communicate and reach back to needed resources without requiring extensive planning and collaboration to setup connections. End-user traffic is dynamically routed across the satellite network efficiently using standard routing protocols for both multicast and unicast traffic. Furthermore, the use of Radio Aware Routing (RAR) and Data Link Exchange Protocol (DLEP) ensures that users are routed over the most efficient and speedy path via Beyond Line Of Sight (BLOS) or Line of Sight (LOS) connections. This will have a significant benefit in service planning.

### 2.3.2 Cross-Beam Connectivity

Although dynamic connectivity of end systems across different coverage beams is possible in traditional bent-pipe and partially processed payloads, cross-beam planning requires careful consideration of the terminal characteristics and their link performance, primarily because of the uplink/downlink coupling and the need for double hops.

With the Space Router, as the downlink and uplink are decoupled, data rate can be varied, and link performance is improved for disadvantaged terminals and the ability to set-up single-hop mesh, cross-beam implementation will be easier and more spectrally efficient.

### 2.3.3 Cross-Band Connectivity

Typically, connectivity between end-terminals operating in different frequency bands is achieved through ground-based band conversions, thus requiring multiple satellite hops. In the case of hybrid-satellites (with multi-band communication payloads), cross-band services are implemented by cross-strapping a pre-defined number of transponders prior to the satellite launch such that the uplink and downlink can be paired in different frequency bands.

With the implementation of the Space Router:

- Cross-banded services in the hybrid payload can be dynamically routed within the identified pool of transponders of different frequency bands
- Flexibility is improved for the hybrid payload service providers and for customers
- Support is provided for service level integration of legacy VSAT networks in the mission.

### 2.3.4 Ad-Hoc Network Connectivity

Typically, an ad-hoc network refers to an aggregate of mobile terminals that can establish voice and narrow-band data communications with or without a hub providing only limited resource management capacity. The use of IP to enhance inter-operability, addressability (e.g., IP addressing), mobility (Mobile IP), etc. are already proving to be the key trend towards network layer integration of ad-hoc networks with IP networks.

From the satellite network point of view, ad-hoc networks are seen as the edge networks to support. For example, closed user group communications (such as tactical radio) or last mile extension (wireless local loop) as parts of the satellite mission are supported. Generally, the transparent satellite network is used to provide reach-back services to the tactical networks or to provide inter-connectivity among the ad-hoc networks. The inherent delay of satellite hops and the general processing overheads for inter-operability at the air-interface level were traditionally seen as the key impediments to implement reliable subscriber level communications between users of satellite network and the ad-hoc networks.

With the Space Router, improved connectivity for ad-hoc networks can be achieved. This is primarily due to the IP-based interoperability at the network layer and the use of link performance and single hop connectivity with the onboard functions.

## 2.4 IP Multicasting

The satellite service user expects IP multicasting service to offer an ability similar to that in the LAN. For example, to advertise/learn multicast availability and to selectively join/leave the multicasting group without any service level pre-provisioning requirements.

From the satellite network provider's perspective, multicasting service must make efficient use of system resources that include dynamic resource allocation and traffic routing.

In a conventional terrestrial LAN, multicast control messages, such as Internet Group Management Protocol (IGMP) Report, are heard by the other multicast receivers. However, in a satellite system, as the satellite ground terminals cannot hear each other, specific multicasting mechanisms have been developed. At the simplest level static multicasting is used, typically from the uplink gateway to one or more downlink terminal routers based on pre-defined group membership. In this case, the multicast traffic is transmitted to each terminal, utilizing one or more downlink channels, with no IGMP traffic sent over the air interface. This wastes satellite capacity if there are no active members on the downlink.

An improved approach would be to transmit multicast traffic through the satellite channel, if it has one or more active multicast group members. This requires IGMP message exchanges using the over-the-air interface, including techniques such as IGMP snooping where required. To support dynamic multicasting, any user must be allowed to be a multicast provider or subscriber, and efficient management of IGMP messages is required. Although onboard switching capabilities are essential and useful for link layer optimization, onboard network layer routing capabilities are required for higher layer efficiency. For example, for an onboard ATM switch to support dynamic multicasting and to retransmit IGMP messages, multipoint-to-multipoint virtual circuits must be established at the ground stations within each coverage spot.

For a transparent satellite network, typically the hub is considered as the virtual source of all multicast traffic within a star network. In this configuration, all external sources appear as sources at the hub and all clients first forward their packet to the hub for redistribution. In a mesh network, any satellite ground terminal can be the multicast source.

With the Space Router:

- The satellite is now part of the multicast network and multicast topology decisions. A more efficient multicast routing protocol, Protocol Independent Multicast (PIM), can now be configured in the Layer 3 routed satellite network. IGMP messages can be isolated to the LAN segment of ground terminals therefore the IGMP snooping is no longer required within the satellite network. Ground terminals that have received an IGMP message to join a multicast group from their LAN-facing network will trigger a PIM join request to be sent to the Space Router. Once the ground terminal has joined a group, subsequent IGMP join requests do not require a PIM join message to be sent to the Space Router, therefore reducing the amount of multicast control traffic on satellite RF links.
- Based on support for direct mesh connectivity and onboard replication of multicast traffic, it becomes more efficient and less RF bandwidth consuming to support multicast traffic within the satellite IP network. Efficient support means that replication of multicast traffic no longer takes place at the hub for redistribution to remote terminals which reduces required bandwidth for multicast support at the hub. This bandwidth can now be reclaimed to provide additional services to remote terminals or used as extra bandwidth capacity for hub. The hub will only receive multicast traffic on its RF link if it has receivers in a multicast group and conversely the hub will only send multicast traffic if it is the source to the Space Router for replication to remote terminals requesting the traffic.

Additionally, when the multicast traffic needs to be exchanged across multiple administrative domains (intra-domain multicasting) or if the shared tree protocols are used to support scalability, the Space Router can be the rendezvous point and thus simplify the implementation design. This is especially relevant when multicasting needs to be supported among mobile networks.

## 2.5 Mobility

The terminal mobility and the hand-off requirements are more significant for Ka-band services, which offer relatively larger bandwidths but require higher satellite Effective Isotropic Radiated Power (EIRP) to compensate for higher link fading. This in turn requires satellite antennas capable of radiating a large number of narrow band spot beams, to offer efficient service areas. Either through multiple antennas or direct radiating phased arrays, a large number of spot beams are served. So, efficient spot-beam handover is a critical factor.

Another aspect of mobility relates to the support for mobile IP environment where, for example, mobile theatre networks require transparent connectivity from different points of attachment at different times.

### 2.5.1 Terminal Mobility

Terminal mobility increases the constraints for service performance as it induces variation in path delay and Doppler effects, and so introduces the need to track the time and frequency drift. Traffic continuity to terminals moving across the spots is typically handled through link layer hand-off.

The terminal mobility also raises the management of multicast group membership. Terminals moving across different spot-beams should be able to maintain their multicast group membership. Otherwise, each hand-off will create the requirement on the terminals to exchange control plane messages for rejoining multicast groups. This is inefficient. IRIS can potentially address these constraints.

With the Space Router:

- **Performance** of the satellite is the timing and frequency reference for both the uplink and downlink for all beams, which means signals in all beams are synchronous. This is advantageous to support terminal mobility. Also in a typical satellite network, mobile terminals require double-hop connectivity. With the Space Router, this constraint is also removed.
- **Network-layer hand-off** can be done at the network layer on the satellite by dynamically maintaining the coupling between the MAC address changes and the logical IP address.
- **Multicast membership** can be managed with the network layer hand-off. Additionally, with the Space Router, the onboard networking can improve support for mobility and IP multicasting.

### 2.5.2 Mobile IP Nodes

The Space Router also contributes in the management of potential requirements for deploying mobile theatre networks, using mobile IP. Mobile IP is based on the concept of Home Agent (HA) and Foreign Agent (FA) for routing packets between the points of attachment. During the

hand-off between the HA and FA, the mobile terminal needs to register with the FA, wait for channel allocation and update location details for the HA before the service can continue. This normally results in high hand-off latency, high packet loss, inefficient routing, and potential security issues. In a satellite environment, these factors will further impact the end-to-end service delivery due to the inherent delay in the transparent payloads.

With the Space Router, mobile IP support is enhanced as the onboard router can be configured to perform the role of the HA to support mobility.

## 2.6 Operational Performance

The impact of the Space Router to the overall operational performance will depend on a number of factors, for example:

- **Concept of System** in terms of how the management system capabilities are implemented (e.g., Bandwidth on Demand, Service Planning, Network Configuration)
- **Concept of Use** of the Space Router in terms of its scope and roles (e.g., Black Core, higher-layer service management functions)
- **Concept of Operations** (CONOPS) of service user.

With the use of the Space Router:

- Potential improvements in normal workflow can be achieved. For example, once the initial deployment is established, subsequent changes to support terminal mobility and service upgrades can be efficiently handled and simplified with the Space Router since it supports onboard bandwidth on-demand, service admission control, and dynamic routing capabilities.
- Potential cost reduction due to eliminating steps in the normal workflow. For example, the decoupling of uplink and downlink does not require dispatch or truck roll to both hub and remote sites. Once a remote site is connected to IRIS, any-to-any IP connectivity is possible without changes at the hub site. This decoupling of uplink and downlink for IRIS also creates potential time-to-service savings as a single site interference survey is performed only at the remote site. In essence the network is managed per link to the satellite rather than per connection between terminals.

### 2.6.1 Improved Resiliency

The ground-based hubs are used typically as a ‘traffic hub’ for forwarding traffic between indirectly connected (multi-hop) terminals and as a ‘signalling hub’ to perform resource management and signalling services to those remote terminals. A ground-based hub can also combine the role of both traffic and signalling hub.

With the Space Router:

- A ground-based traffic hub
  - **May not be required** with the possibility to support single-hop mesh connectivity across different coverage areas.
  - **Has Improved Resiliency** as the Space Router can be configured to perform the role of the ground-based traffic hub in case of failure, dynamically reroute traffic to a backup ground-hub when the primary ground hub fails, load balance traffic across two redundant ground hubs either centrally located or geographically dispersed, as well as dynamically route around network failures for continued ground hub access.
- A ground based signalling hub
  - **Can be backed up** using the bandwidth on demand capability the Space Router. This can be implemented either as backup or in lieu of the ground-based signalling hub.

In both cases, the Space Router contributes to the improved resiliency of the hub and improved efficiency and cost saving.

## 2.6.2 Traffic Security

For government users, secure satellite communication services must support Communications Security (COMSEC), Transmission Security (TRANSEC), and Emission Security (EMSEC) requirements as part of the network capability. Although the level and complexities of the security functions and the associated cryptographic requirements will vary across different customers, the security architecture from the service providers' perspective must lend itself to support scalable and variably segregated use of network resources to simultaneously serve different customer groups.

From the satellite service provider perspective, the service delivery boundaries define the scope of the end-to-end core network and the level of security over this core network.

Generally, to provide secure communication, the end-to-end core network is configured as a Black Core Network (BCN) such that traffic passed between the end-points is securely encrypted (e.g., IPSec) and treated as "unclassified" within the BCN.

The Space Router is seen as part of the BCN, thereby treating all its traffic as unclassified.

## 2.6.3 Geo-Location Threat

In secure applications over transparent networks, techniques such as header compression, encryption, etc. are used; however, the uplink and downlink are coupled and the source of traffic is still coming from the ground segment. This association of uplink and downlink may pose some risk as looking at the downlink can derive the source of traffic. It is desirable to prevent this geo-location ability and the resulting threats.

With the Space Router, as the uplink and downlink are decoupled and the packets regenerated, the source of the downlink stream is the Space Router itself so nothing can be inferred about the source sender or their uplink. This can be seen as a level of mitigation against geo-location threats.

## 2.6.4 New Services

The ability to define and orchestrate new services based on existing service components and capabilities is a key motivation for any business. With the capabilities and benefits of the Space Router identified above, clearly services can be enhanced and new services defined and introduced. Some examples are:

- **Closed-User Group Services:** Ability to offer dynamic multicast and unicast services to support remote work-group interactions based on converged services (audio/video conference, interactive multi-media). The user groups for these services can be kept secure within their community of interest while sharing the same physical transmission media on the satellite.
- **Dial-Tone in the Sky:** Ability for the onboard Space Router to provide VoIP telephony services for remote terminal locations without having to access ground-based telephony hubs. In the event of significant disruption to terrestrial infrastructure, for example a natural disaster, telephony service can be established for emergency services personnel and other critical support staff.
- **Survivable Remote Site Telephony (SRST):** The role of onboard Space Router can be dynamically configured to perform as a SRST router. In this role, the Space Router will take the responsibility to perform voice call admission control in the case of failures for the ground-based telephony gateway failures. The feature can be used to provide redundancy and telephony service resiliency
- **Hub-Less VSAT:** Leveraging the ability to provide direct mesh connectivity and onboard bandwidth on demand capability, remote theatre deployments can be supported without a need for dedicated traffic routing hub on the ground. This will reduce the SWaP for the deployment mission, provide opportunity for virtualized mesh networks for small theatre, and support point-to-point or point-to-multipoint applications.
- **Legacy VSAT Inter-Connect Services:** Use of cross-banding capability in the case of hybrid satellite networks will offer seamless integration of the legacy VSAT networks with the mission. An application of direct-mesh and single-hop capability is to deploy hub-less VSAT services. This dramatically simplifies the ground segment. In addition, this allows technology upgrades to the ground segment to be rolled out over time as opposed to doing a forklift upgrade.

## 2.7 Ground Terminal SWaP

There are two perpetual requirements for the core satellite ground terminal equipment:

- How can the Size Weight and Power (SWaP) be reduced without compromising the intended performance requirements?
- Given the SWaP, how can the advances in system design increase the performance of existing ground equipment?

Although ground terminal SWaP is also influenced by other subsystem requirements (such as access switches, multiple modems, application servers etc.) the focus here is on the core radio transmission subsystems and the impact to the satellite ground terminal SWaP. The key requirement is the link layer performance with metrics such as the EIRP and the Gain Over Temperature (G/T).

With the Space Router:

- **EIRP** requirements are improved. Typically, for the satellite ground terminal the uplink is overdimensioned in order for the total link performance to be achieved, given the downlink is limited by the satellite power available. This is related to the ratio between uplink and downlink Error/Noise ( $E/N_0$ ) ( $\alpha$ ). This ratio is typically planned to be at 10dB for a transparent payload. However, in the case of the Space Router, this ratio becomes considerably less (about 2dB), mainly because the uplink and downlink are decoupled and the uplink error probability is considered to be negligible for the downlink performance. What this means is the required EIRP of the satellite ground terminal can be lower.
- **G/T:** Also in a regenerative payload, the satellite operates at saturation and the downlink benefits from the maximum EIRP from the satellite. This means the G/T of the earth station can be reduced, depending on the data rate and coverage requirements.
- **The Space Router also improves existing ground terminal performance:** As discussed above, the link budget gains can be used to compensate, which improves throughput and performance. The increased link budget for the terminal can also translate into reduced SWaP which means a smaller dish or smaller power amplifier can be used to achieve the same data rate as a transparent payload.

### 3. Demonstrated Capabilities

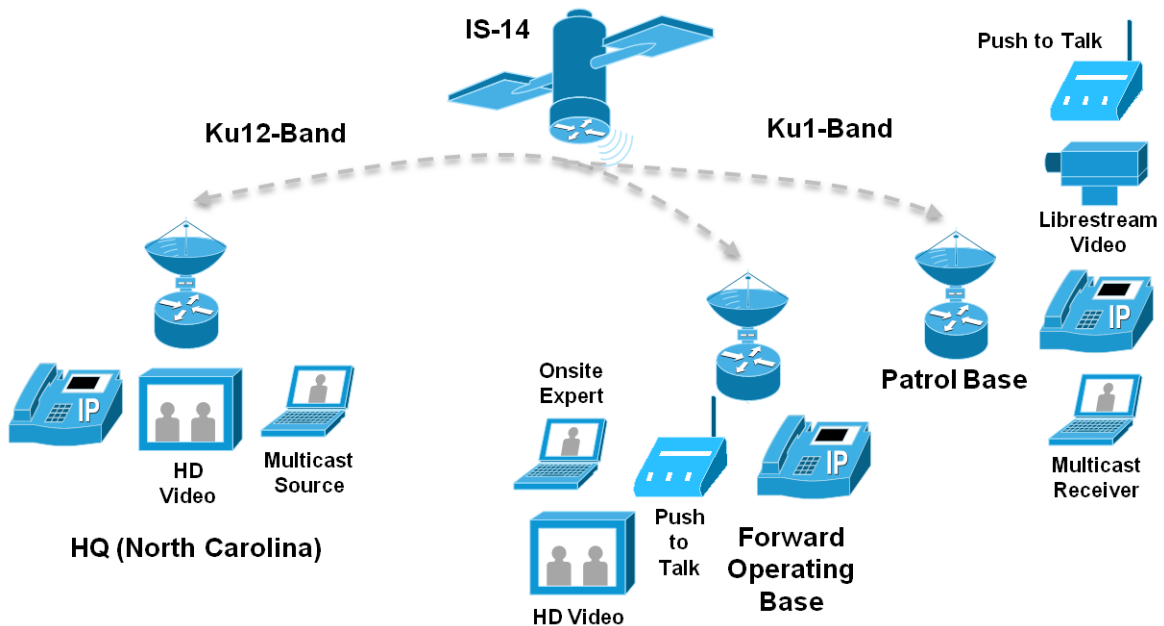
The IRIS Space Router is deployed as a technology demonstrator on the Intelsat 14 spacecraft. This section provides the summary of the IRIS demonstration performed in the U.K. during October 2010 for the U.K. MoD and NATO.

This demonstration provided overview presentations of the IRIS Space Router and hands-on demonstration of applications using the Space Router (single-hop cross-beam meshed voice services, simulated Unmanned Aerial Vehicle (UAV) feed for video, interactive multi-media, multicasting, land mobile radio over satellite).

The demonstration:

- Showed how IRIS technology can improve current operational efficiencies
- Highlighted the additional performance efficiencies through specific demonstrations using:
  - Single-hop connectivity, VoIP, Multicast, and Videoconferencing
- Offered insight into potential for increased functionality with cost benefits.

**Figure 3** shows the deployed segment of the network in a steady set. In this state, there are two remote ground terminals under the coverage beam (Ku-1), one representing Field Operations Base (FOB) and the other the Patrol Base. Also shown is the Headquarter (HQ) under a different coverage beam (Ku-12). All three ground terminals are provisioned for 512 kbps for both forward and return data rates, with the Service Level Agreement (SLA) allowing them to burst as necessary to available additional bandwidth on demand.

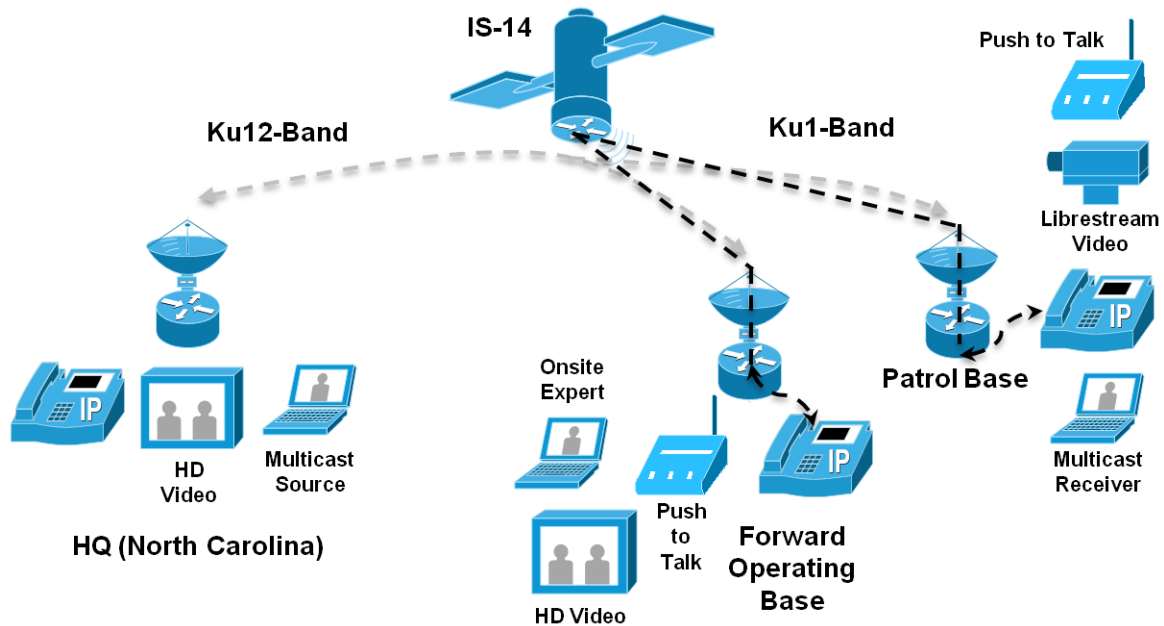


**Figure 3. Steady State Scenario**

**Figure 4** shows the scenario when dial-tone is generated from the on-board Space Router using Cisco Unified Call Manager Express (CUCME) and a VoIP call is set up between the two ground terminals under the same beam. The purpose of the demo is to highlight:

- Single-hop connectivity
- On-board service admission and call control
- Service quality in terms of efficient call set-up and voice quality.

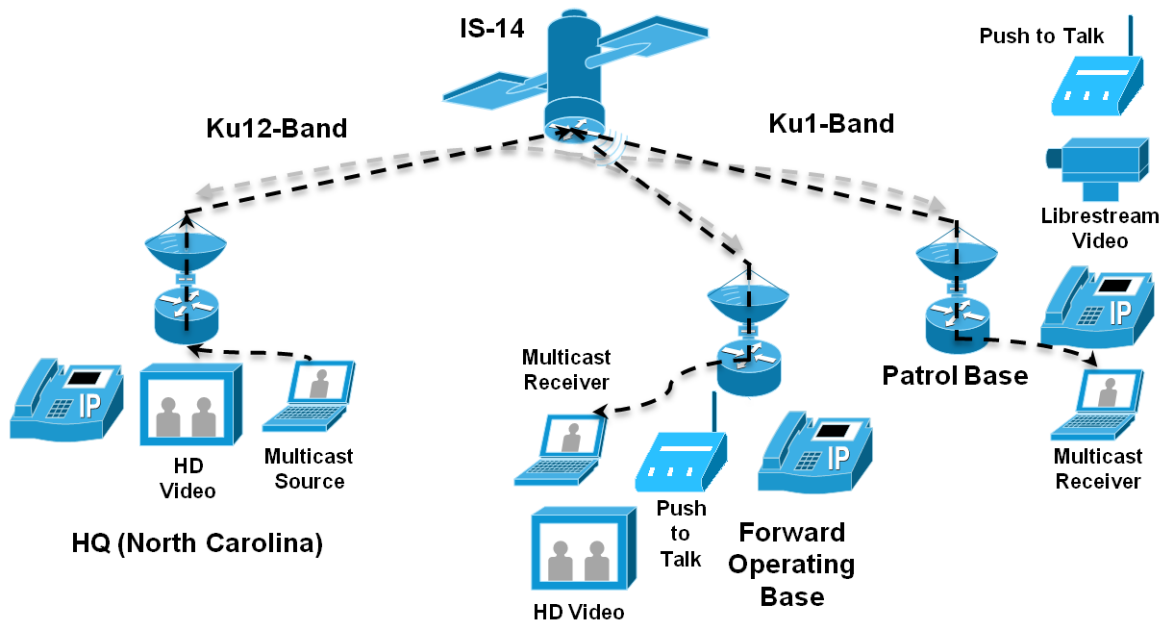
The demo also showed improved network resiliency as the VoIP service admission control was done on the onboard Space Router. This showed the flexibility for distributing service management functions to other parts of the network, and thereby increasing overall resiliency.



**Figure 4. VoIP with Dynamic Routing**

**Figure 5** shows the scenario when the gateway transmits simulated UAV data over multicast channels to the ground terminals. The purpose of the demo is to show:

- Onboard multicast performing traffic replication
- Dynamic capacity allocation
- Efficient use of single downlink per beam
- The multicast video quality.

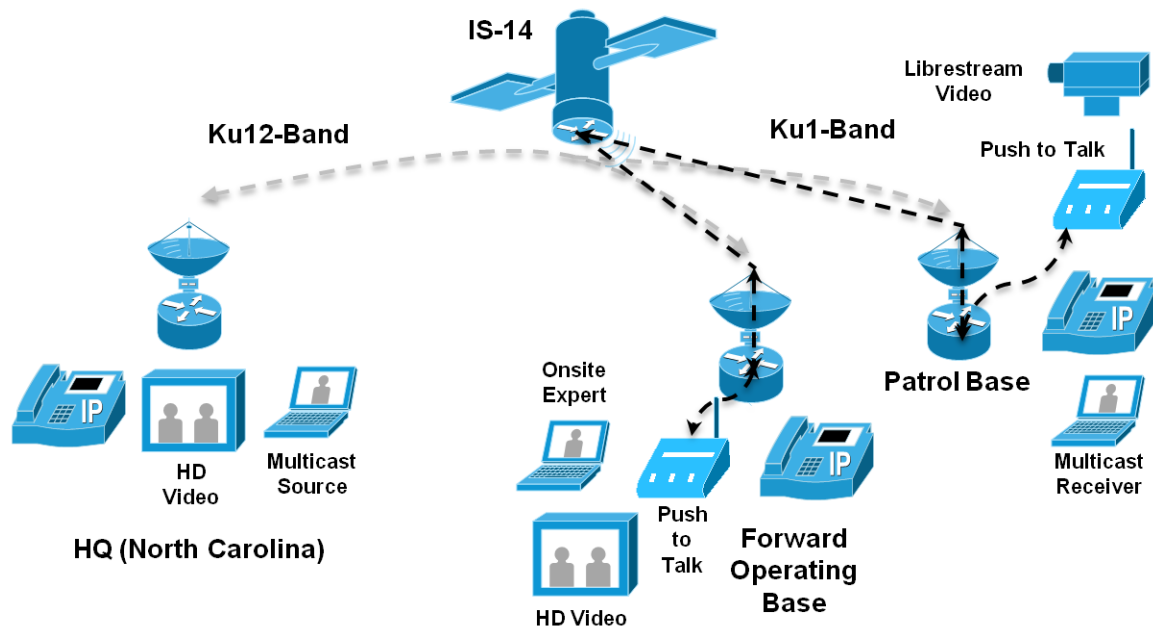


**Figure 5. UAV Feed – Multicast**

**Figure 6** shows the scenario where the FOB makes a tactical VoIP call to the Patrol Base, for example to instruct an action triggered from the UAV feed. The UAV feed is being received at the same time as a multicast feed from the HQ at both FOB and Patrol Base. The purpose of the demo is to show:

- Land Mobile Radio (LMR) over satellite
- Simultaneous services
- Dynamic capacity allocation.

Although the demo had a single LMR radio interface at the routers of FOB and Patrol Base, the potential is to use the LMR gateways to connect LOS terminals over the BLOS network.



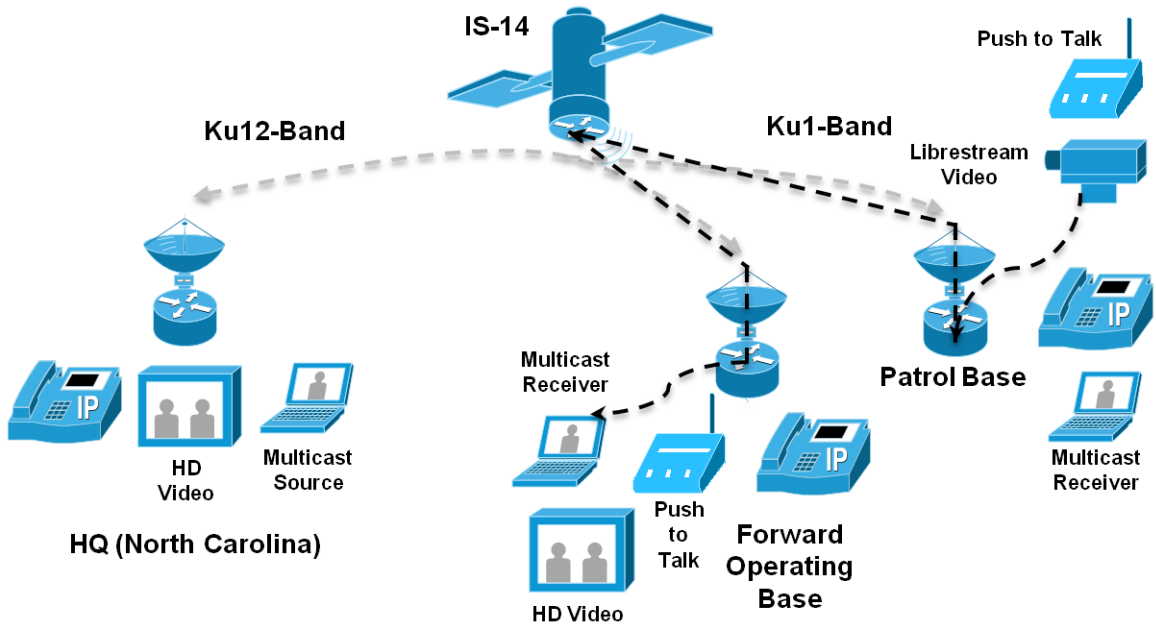
**Figure 6. LMR over Satellite (Concurrent Multicast Video)**

**Figure 7** shows video streaming from the Patrol Base to the FOB. The Patrol Base used a hand-held wireless video device, with multiplexed data stream (for example, live electronic tagging of areas of captured video). The purpose of the demo is to show

- Video and multi-media streaming from any source to any destination
- Potential application for Patrol Base to support situational awareness, both as a provider and receiver.

The demonstration included simultaneous use of all traffic streams and in summary showed:

- Single-hop voice connectivity within a coverage area and across different coverage areas
- With the CUCME on the Space Router, improved service establishment time
- Source-specific multicasting with dynamic bandwidth on demand
- Land-mobile tactical radio and data call over the satellite network
- Multi-cast and unicast video streaming
- Interactive multi-media
- TelePresence between HQ and FOB.



**Figure 7. Video Transmission**

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## 4. Conclusion

The benefits that the IRIS Space Router's capabilities can provide to satellite service providers and to service users far outweigh the risks in moving to IP-based routing in space.

From the service user's perspective, the Space Router will enhance the networking capabilities for remote users, improve the overall service operation and the traffic performance, while reducing the overall cost. Specifically, for MILCOM services that increasingly demand support for mobility, multicasting, and inter-operability among autonomous deployments, the Space Router offers improved capabilities and benefits. From the service provider's perspective, the Space Router will contribute to the overall network efficiency due to improved utilization of network resources, flexibility for supporting multiple user groups simultaneously, and enhanced service offerings.

The scope and the realization of these benefits will depend on how the Space Router is employed in future networks and also how these are mapped to the evolving CONOPS of its key customers. The benefits warrant further study on the use of Space Router in the context of the next generation of satellite and network architecture and the service delivery framework.

For more information, visit [www.cisco.com/go/iris](http://www.cisco.com/go/iris).

## Acronyms

ASV	ASTRIUM Services
ATM	Asynchronous Transfer Mode
BCN	Black Core Network
BER	Bit Error Rate
BLOS	Beyond Line of Sight
CLEO	Cisco Low Earth Orbit
COMSEC	Communications Security
CONOPS	Concept of Operations
CUCME	Cisco Unified Call Manager Express
DLEP	Data Link Exchange Protocol
DOD	Department of Defense
EIRP	Effective Isotropic Radiated Power
EMSEC	Emission Security
FA	Foreign Agent
FOB	Field Operations Base
G/T	Gain Over Temperature
HA	Home Agent
HQ	Head Quarter
IGMP	Internet Group Management Protocol
IOS	Internet Operating System
IP	Internet Protocol
IRIS	Internet Routing in Space
JCTD	Joint Capability Technology Demonstration
LAN	Local Area Network
LMR	Land Mobile Radio
LOS	Line of Sight
MAC	Maintaining the Coupling
MIC	Modem Interface Chassis
MILCOM	Military Communications
MoD	Ministry of Defence
NATO	North Atlantic Treaty Organization
PIM	Protocol Independent Multicast
QoS	Quality of Service
RAR	Radio Aware Routing
RF	Radio Frequency
RPE	Route Processing Engine
SCPC	Single Carrier per Channel
SDR	Software Defined Radios
SLA	Service Level Agreement

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SRST	Survivable Remote Site Telephony
SWaP	Size Weight and Power
TDMA	Time Division Multiple Access
TPA	Technology Partnership Agreement
TRANSEC	Transmission Security
UK	United Kingdom
UAV	Unmanned Aerial Vehicle
VoIP	Voice over Internet Protocol
VSAT	Very Small Aperture Transmission