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Delivery of Unmanned Aerial Vehicle Data

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Abstract

To support much of NASA's Upper Atmosphere Research Program science, NASA has acquired two Global Hawk Unmanned Aerial Vehicles (UAVs). Two major missions are currently planned using the Global Hawk: the Global Hawk Pacific (GloPac) and the Genesis and Rapid Intensification Processes (GRIP) missions. This paper briefly describes GloPac and GRIP, the concept of operations and the resulting requirements and communication architectures. Also discussed are requirements for future missions that may use satellite systems and networks owned and operated by third parties.

1.0 Background

To enhance upper atmospheric science being supported by NASA's Earth Science Project Office (ESPO),[1] NASA has acquired two Global Hawk Unmanned Aerial Vehicles (UAVs). The Global Hawks reside at the Dryden Research Center. The Global Hawks have a flight duration of up to 30 hr which allows them to take unique measurements in a fixed area over a full solar day. This is unlike satellite measurements which may pass a given point on Earth once per orbit or only once every few days depending on the orbit. As such, the Global Hawk measurements are complimentary to satellite data. Many of the planned missions have the Global Hawk flying beneath NASA's A-Train (Ref. 1) of sensor satellites to supplement the satellite data with upper atmospheric measurements.

2.0 Global Hawk Characteristics

The Global Hawk has a maximum endurance of 42 hr with an on-station endurance of 24 hr at 3,000 Nm form point of departure. It can loiter at 343 kn and has a maximum altitude of 65,000 ft which is above the weather and above the commercial air space.

The scientific sensors onboard the Global Hawk are controlled by a central onboard processing unit. This controller provides time correlation meta-data to the instrumentation data and stores all sensor data as files. The communication processor has an Internet Protocol stack and all communication between payload and ground is performed using standard Internet Protocols.

Communication with the experimental payload is by a Ku-Band satellite link. Initial deployment used a 2 Mbps bidirectional link. At 2 Mbps, the Ku-Band connectivity has been demonstrated to approximately 75° N latitude (approximated 3° elevation angle). Future flights are expected to use up to 8 Mbps links. The system is capable of approximately 50 Mbps but the cost to operate at such rates is prohibitive. Furthermore, there currently is not a requirement for that volume of data. Four Iridium L-Band modems have been multiplexed together to provide some low-rate (kbps) communication to the experimental payloads for simple commanding.

3.0 Missions

There are four major regions that have been identified for possible exploration. These are shown in Figure 1. Three use the NASA Dryden Research Center (DRC) as base of operations. The two major funded missions correspond to the top and bottom left, the Global Hawk Pacific (GloPac) and top-right Genesis and Rapid Intensification Processes (GRIP) missions.

3.1 GloPac

The GloPac mission has been successfully completed during March and April of 2010. The GloPac mission was conducted in support of the Aura Validation Experiment (AVE). Aura (Ref. 2) is one of the A-Train satellites supported by NASA's Earth Observation System. The first GloPac flight was performed to confirm operations and test payloads (Ref. 3). Three science flights followed (Refs. 4, 5, and 6. These flights where designed to address various science objectives:

- Validation and scientific collaboration with NASA Earth-monitoring satellite missions, principally the Aura satellite,

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[1] NASA's Earth Science Project Office customers consist of NASA's Upper Atmosphere Research Program, the Atmospheric Chemistry and Modeling Analysis Program, the Tropospheric Chemistry Program, the Radiation Sciences Program, Atmospheric Dynamics and Remote Sensing, the Suborbital Science Program

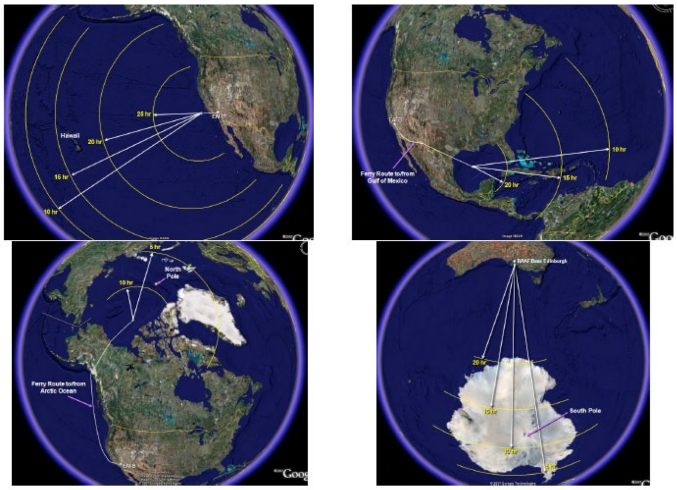

Figure 1.—Global Hawk operational capability.

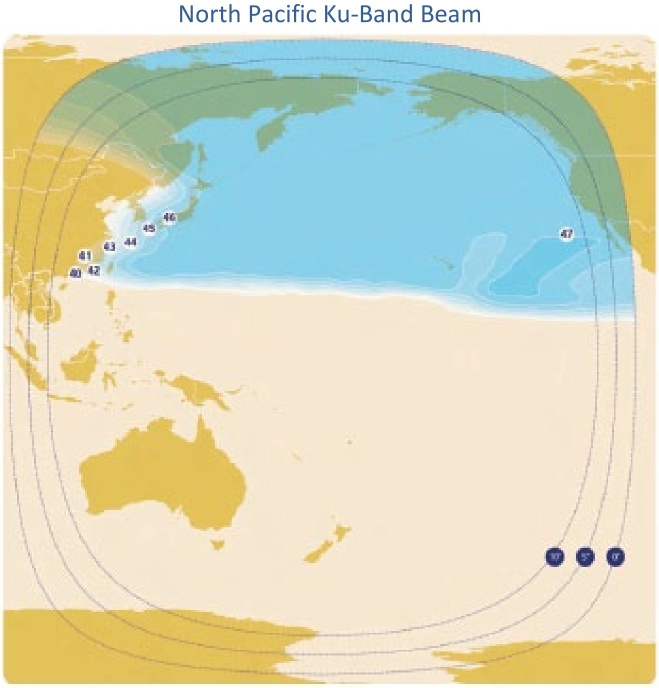

Figure 2.—GE 23 Ku-band beam coverage.

- Observations of stratospheric trace gases in the upper troposphere and lower stratosphere from the mid-latitudes into the tropics,
- Sampling of polar stratospheric air and the break-up fragments of the air that move into the mid-latitudes,
- Measurements of dust, smoke, and pollution that cross the Pacific from Asia and Siberia, and,
- Measurements of streamers of moist air from the central tropical Pacific that move onto the West Coast of the United States.

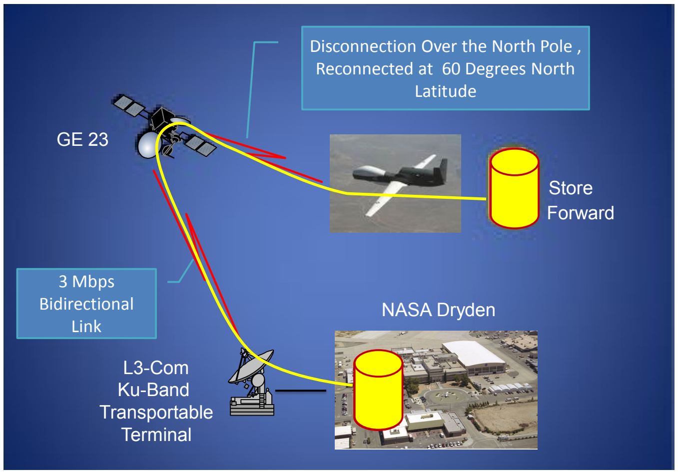

Figure 3.—GloPac communication network.

For GloPac, communication to the scientific payload was via Ku-Band using GE-23, a geostationary satellite positioned at 172.0° E longitude with a footprint can be seen by a ground station at DRC (Fig. 2). The Global Hawk was able to communicate through GE-23 until approximately 75° N latitude which equates to a 3° look angle. This was approximately 10° farther north than anticipated.

A simplified communication architecture is shown in Figure 3. For this mission, NASA does not share any of the communication links. In addition, the ground station is located at DRC, effectively adjacent to the science payload command and control center. For GloPac, the Ku-Band uplink and downlink transmission rate was 2 Mbps. The Global Hawk was in constant communication with DRC while within the Ku-Band beam. Near the North Pole, at 75° N latitude, the Global Hawk lost communication over the Ku-Band link, the link between the scientific payload and the science payload command and control center. During times of disconnection, the scientific data was stored onboard. Upon reconnection, that stored data was transmitted to the ground thereby enabling the scientific data to be processed as early as possible. In the future, this near-real-time science data could be used to modify the sensors settings and/or flight pattern during mission operations. This near-real-time information may also be used to trigger some other sensors either onboard the UAV or on other platforms (i.e., satellites or web-based sensors).

3.2 GRIP

The Genesis and Rapid Intensification Processes (GRIP) mission is scheduled to be conducted in the late summer and fall of 2010. Its goal is to obtain a better understanding of how tropical storms form and develop into major hurricanes (Ref. 7). GRIP will deploy new remote sensing instruments for wind and temperature that should lead to improved characterization of storm structure and environment. NASA plans to use the DC-8 aircraft and the Global Hawk Unmanned Airborne System (UAS) for this mission. The spaceborne, suborbital, and airborne observational capabilities of NASA put it in a unique position to assist the hurricane research community in addressing shortcomings in the current state of the science.

The communication architecture for the GRIP mission is shown in Figure 4. The communication path is effectively identical to that of GloPac with three exceptions. First, the UAV will communicate through two or more Ku-Band satellites with all satellites' beams in view of the Ku-Band ground terminal at DRC. This will result in a loss of communications with the science payload for the time it takes to re-point both the ground station and the UAV antennas. Such disconnection will be on the order of a few minutes or less. Second, the UAV's mission takes it over the Gulf of Mexico and Caribbean rather than the Pacific. The UAV should always be within some Ku-Band beam. Therefore, GRIP communication will mostly be concerned with full utilization of the available communication link in real-time rather than utilizing any store-and-forward techniques. A persistent file transfer application combined with a rate-base protocol is all that is necessary. Finally, the Global Hawk is flying at low latitudes which translate to good antenna look angles resulting in better communications links to the Ku-band satellites. Data rates of up to 8 Mbps are anticipated.

3.3 Future Missions

Figure 5 depicts architecture for future missions. In this scenario, the UAV may have multiple service provides and use multiple ground stations resulting in a multi-hopped, store-and-forward network. Here, storage has to occur between the UAV and ground stations. Once information is received at the ground station storage unit, it can be forwarded through the network to the science data archiving and distribution center. Note, there also may be large rate mismatches between various links. For example, the space link may have a downlink on the order of 100 Mbps while the shared link over the terrestrial internet may provide an effective throughput of only a few Mbps or less.

Because there are at least two separate ground stations and these ground stations may be owned and operated by different service providers the UAV will be connecting to different subnetworks as it moves between the various service provider networks. As such, this scenario will require some type of mobile networking to operate correctly. A detailed investigation of the current internet networking and addressing of the NASA Global Hawk communication currently precludes use of Internet Protocol (IP) mobility (mobile-ip). The system is currently designed to operate with a custom modem and only one ground station. Use of mobile-ip would require some redesign and is only practical if other users would require such operations.

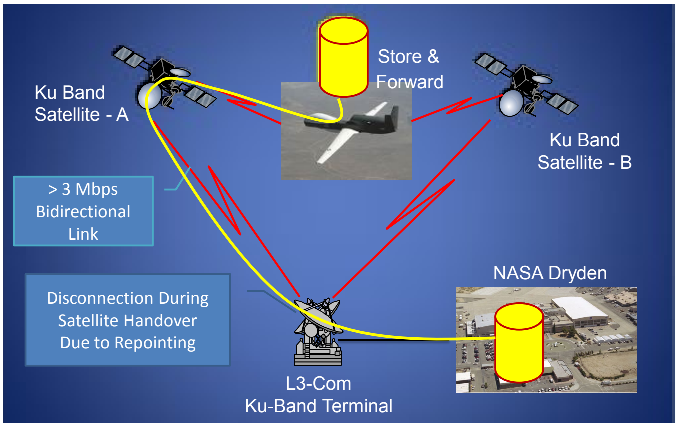

Figure 4.—Genesis and rapid intensification processes.

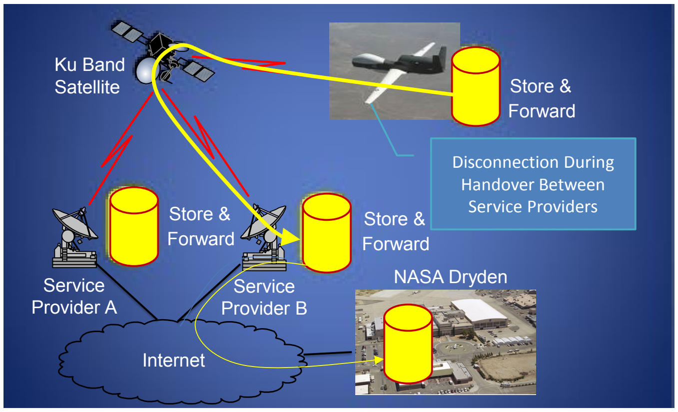

Figure 5.—Future missions.

Applying Delay Tolerant Networking (DTN) to handle store and forward and mobility is another potential solution. Such solutions require adding hardware to each service providers' ground stations.

Since the uplink and downlink modulation system is unique, any use of third party ground stations requires significant cooperation and coordination with the service providers and may not be economically viable unless done on a large scale. NASA only anticipates a few flights per year, which would not be sufficient to provide a business case for third party ground station service providers.

4.0 Requirements

4.1 General Requirements

The general requirement for the delivery of Unmanned Aerial Vehicle (UAV) data is to improve the data throughput and utilization of current UAV remote sensing by developing and deploying technologies that enable efficient use of the available radio frequency (RF) communications links. These links are not shared by other systems and therefore, congestion control and fairness are not major issues. However, if data and video are simultaneously utilizing the same RF link, some form of congestion control or auto-sensing of available bandwidth by the file transfer application is desirable.

A secondary requirement is to, if necessary, develop and deploy a mobile communication architecture based on Internet technologies.

4.2 GloPac and GRIP

The GloPac and GRIP architectures are nearly identical. One exception is that the Global Hawk is almost always in contact with the science payload command and control center during the GRIP mission. In GloPac, the Global Hawk was disconnected for long periods of time due to operation over the North Pole and an inability to see GE-23. For GRIP, disconnection will be very short—on the order of a few minutes. Regardless, all scientific data is archived onboard the Global Hawk for later retrieval in case of a failure of the Ku-Band communication system. Therefore, onboard storage capacity is the same for both missions.

It is important to note that GloPac and GRIP are direct source-to-sink architectures. Multi-hop capability is not required. Also, all Science Sensor Data is stored onboard the UAV in the form of files.

The following requirements are needed for GloPac and GRIP mission scenarios and may be useful for future missions:

(1) A method, trigger, or signal that indicates the Global Hawk is in communication with the ground network must be provided.

(2) A transport protocol must utilize the link as soon as it becomes available and also immediately fill (saturate) the satellite communication link.

(3) A file transfer application must be reliable and ensure payload integrity.

(4) The combination of the persistent file transfer application and transport protocol must be aware of when a link becomes disconnected and suspend transmission until the link is re-established.

(5) The transport protocol must not exceed a specified transmission rate, but should be able to adapt to congestion due to competing video traffic.

4.3 Future Missions

The following additional requirements are needed for future missions:

(1) The system must operate in a multi-hop environment.

(2) Payload integrity must be maintained hop-by-hop, and end-to-end if so desired.

(3) There must be an option to configure support for end-to-end integrity checking of files on a per-transfer basis.

(4) Hop-by-hop integrity checking must be performed on smaller units of data, in order to efficiently replace errored portions of a large transfer. This could be per-packet or per-bundle and could be performed at any or all for the following: the data-link, transport layer or the store-and-forward protocol. The rational is to improve efficiency and reduce processing of large data sets. For example, one can identify that “packet 6 is corrupted” rather than “somewhere in this 5 GB file, a bit is flipped”. These checks should include the relevant fields identifying the end-to-end flow (source and destination address/port/etc) regardless of the underlying protocol being used.

(5) The system must be able to reliably transfer files from the UAV to the science payload command and control center even if the UAV transitions through various networks (network mobility).

(6) The system MUST be able to transfer data end-to-end without a requirement for network time synchronization. The rational is that data may transition through numerous networks and since some of these networks may be controlled by third parties, one cannot assume that these networks are synchronized.

(7) One must be able to communicate with the payload using Internet Protocols during times when the UAV is in contact with various ground stations. This enables reuse of existing commercial protocols and equipment.

4.4 Security Requirements

The following are the security requirements for all missions:

(1) Deployment of security is optional. This implies that security and payload integrity MUST be implemented independently.

(2) Security may be deployed at multiple levels or a single level (i.e., One may wish to secure the payload, but not necessarily the network or vice versa.).

(3) There must be a capability to ensure payload confidentiality.

(4) There must be a capability to ensure confidentiality of communications between the UAV and the science payload command and control center.

5.0 Conceptual Design

5.1 GloPac and GRIP

GloPac and GRIP have an identical architecture to the Surrey Satellite Technology Limited (SSTL) Disaster Monitoring Constellation (DMC) space/ground network (Fig. 6). For the DMC architecture, the onboard controller has a direct connection to the radio and data storage and hosts the

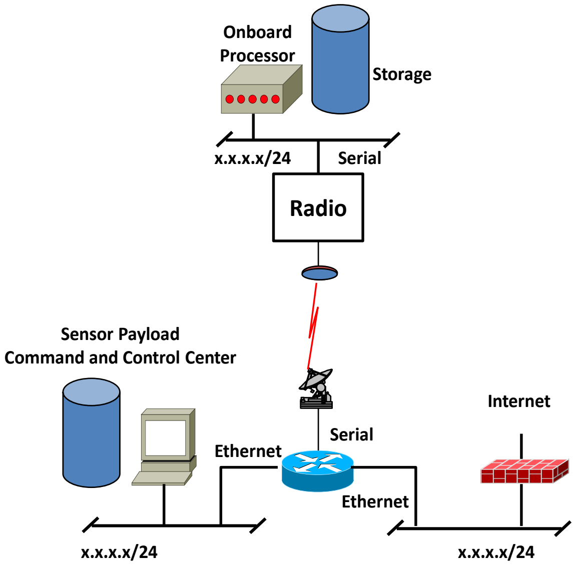

Figure 6.—SSTL DMC architecture.

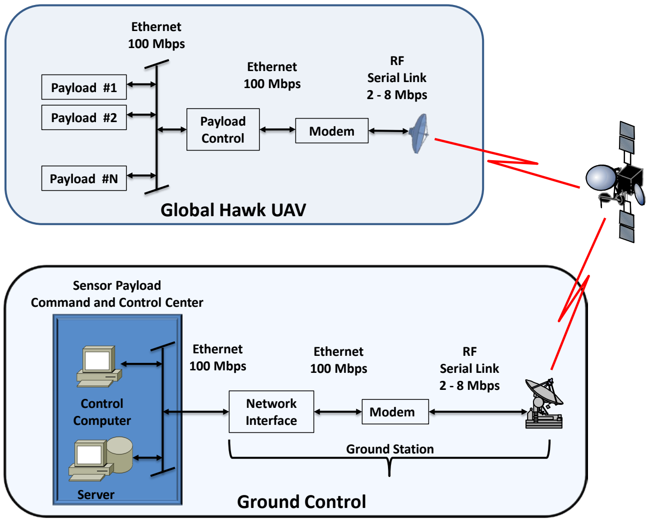

Figure 7.—NASA Global Hawk communiction system.

file transfer protocol. File transfer occurs at line rate; thus, there is no need for a sophisticated protocol between application and radio to determine link conditions such as data rate (Ref. 8).

The SSTL DMC uses the version 0 of the Saratoga file transport protocol. Saratoga version 1 has been proposed in an Internet Draft as a possible transport protocol that could eventually be standardized (Ref. 9). This protocol was originally developed for delivery of large imagery files over highly asymmetric links. The server portion of Saratoga provides a periodic beacon that can be used by the client to determine connectivity. Two additional features need to be developed to be useful for the NASA UAV remote sensing platform. One feature is a rate-setting mechanism as Saratoga currently transmits at line-rate. A second feature is a persistent file transfer where transmission suspends during periods when the line between client and server goes down.

Figure 7 depicts a generalized architecture for the NASA Global Hawk communication system. There is no network mobility. All addressing is fixed (static). There is no multi-hop networking so there is no need for a special store-and-forward protocol. The command system is manned during flights, so automation is an issue. The RF communication link is not shared. Therefore, to improve throughput efficiency from the UAV to ground, all that is required is an efficient reliable transport protocol between the UAV payload control computer and the science payload command and control center computer. However, since file transfers may occur concurrently with streaming video, it is highly desirable to have the transport protocol sense congestion and adapt accordingly.

5.2 Future Missions

A future generic mission using a generic UAV may have an architecture similar to that shown in Figure 8. Here, in order to maintain communication over greater distances, there may be two or more satellite service providers or at least two or more different ground stations that the Global Hawk will come into view of. In such a case, the system will have to handle network mobility. In addition, this becomes a multi-hop network. Intermediate store and forward will have to take place at the ground stations in order to maximize the downlink transmissions by separating communication control loops.

As in the GloPac/GRIP architecture, the onboard controller has a direct connection to the radio and data storage and will host the file transfer protocol. Therefore, there is no need for a sophisticated protocol between application and the radio to determine link conditions such as data rate.

For GloPac and GRIP, one does not require access to the open Internet to obtain connectivity with the Global Hawk. The ground station is connected to the science payload command and control center via a small private network with all addressing controlled by NASA. This may not be the case for future missions where the ground stations are only reachable via the open Internet. For this generic architecture, network mobility could be handled by deploying mobile-ip for simple payload commanding since command packets of files are small and transport reliability is required, but link efficiency is not an issue. Store and forward of large files could be handled by some other process. Currently DTN bundling is a possibility. Store-and-forward techniques might also help resolve the network mobility issues if the UAV air/ground link is inflexible to the extent that dynamic addressing is not possible. Without dynamic addressing, network mobility at the IP layer is not appropriate.

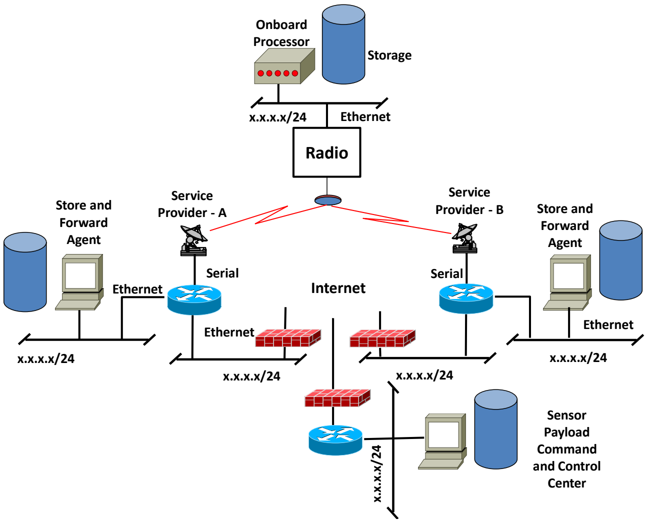

Figure 8.—Generic multi-terminal network architecture.

6.0 Conclusions

The current UAV communication system and network used to perform advanced atmospheric research closely resembles that of a remote sensing satellite. All communication is over a direct point-to-point link with no true network mobility and no real requirement for multi-hop store and forward. All that is required of this system is a reliable high-rate, bandwidth-efficient transport protocol that can be rate-limited. For missions that may have simultaneous competing downlink traffic such as streaming video and large file transfers, a transport protocol with some mechanism of self-sensing congestion control is highly desirable.

Future Global Hawk missions or future UAV sensor platforms may use third party ground stations or may not have the science payload command and control center directly connected to the ground station. Instead, communication between the science payload command and control center and the UAV would be over a multi-hop network. Such architectures will find routable store-and-forward technologies and IP-based mobile networking beneficial.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

To support much of NASA’s Upper Atmosphere Research Program science, NASA has acquired two Global Hawk Unmanned Aerial Vehicles (UAVs). Two major missions are currently planned using the Global Hawk: the Global Hawk Pacific (GloPac) and the Genesis and Rapid Intensification Processes (GRIP) missions. This paper briefly describes GloPac and GRIP, the concept of operations and the resulting requirements and communication architectures. Also discussed are requirements for future missions that may use satellite systems and networks owned and operated by third parties.

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