NORTHROP GRUMMAN
NASA
DRYDEN FLIGHT RESEARCH CENTER

An Evaluation of Protocols for UAV Science Applications

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COMMUNICATIONS ARCHITECTURES

Security

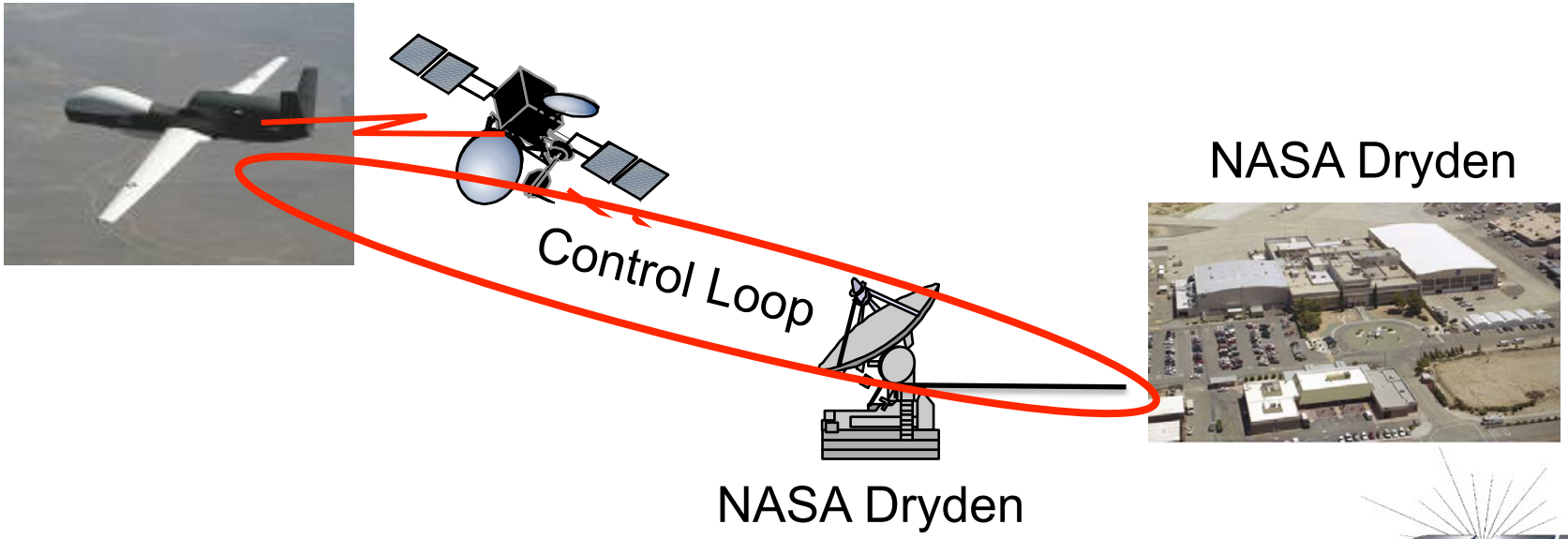
- NASA's Global Hawks command and control communications is completely separate from the experimental payloads' command and control.
  - Enables different security methodologies to be deployed for each system
  - The security required for payload operations becomes much less stringent
    - Enables greater flexibility of payload deployment
    - Enables direct real-time access to payload instrumentation by the various principle investigators.
- Payload Security
  - Currently User access accounts and Secure Shell (SSH)
  - Currently no requirement for Internet Protocol Security (IPsec) between the ground control and aircraft payload as this is a private link.

Satellite Communications Characteristics

- KU-Band satellite communications
  - 2 to 8 Mbps bidirectional links
  - Modems capable of 50 Mbps (but cost prohibitive)
  - Connectivity demonstrated to 75 degrees latititude
- Near Error Free Link
- Approximately 600 msec round trip times (RTT)
  - Includes satellite link delay, ground delay and processing.

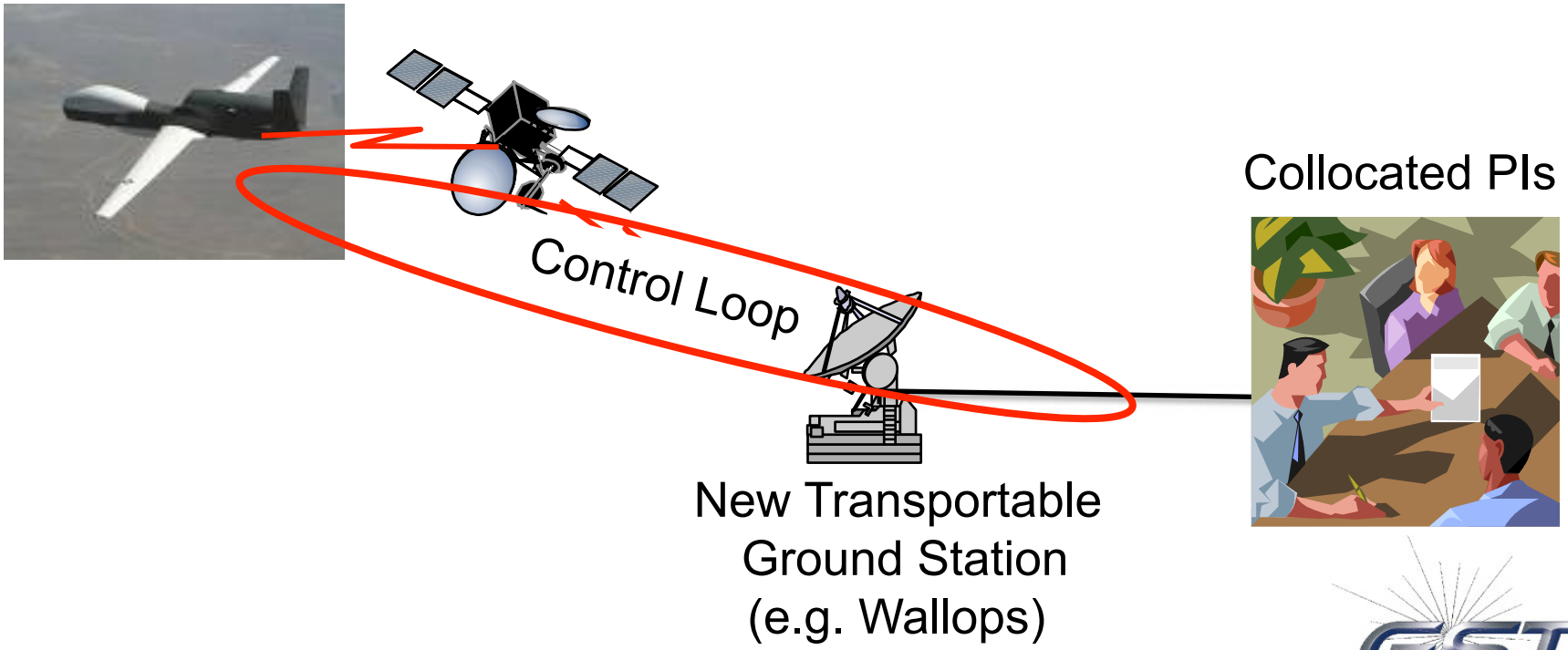
Current Communication Architecture

- Global Hawk ground station is located at Dryden as are the Principle Investigators
  - No multi-hop store and forward.
  - Single control loop
  - Delay is up to 600 msec round trip time due to Geostationary Satellite delay.



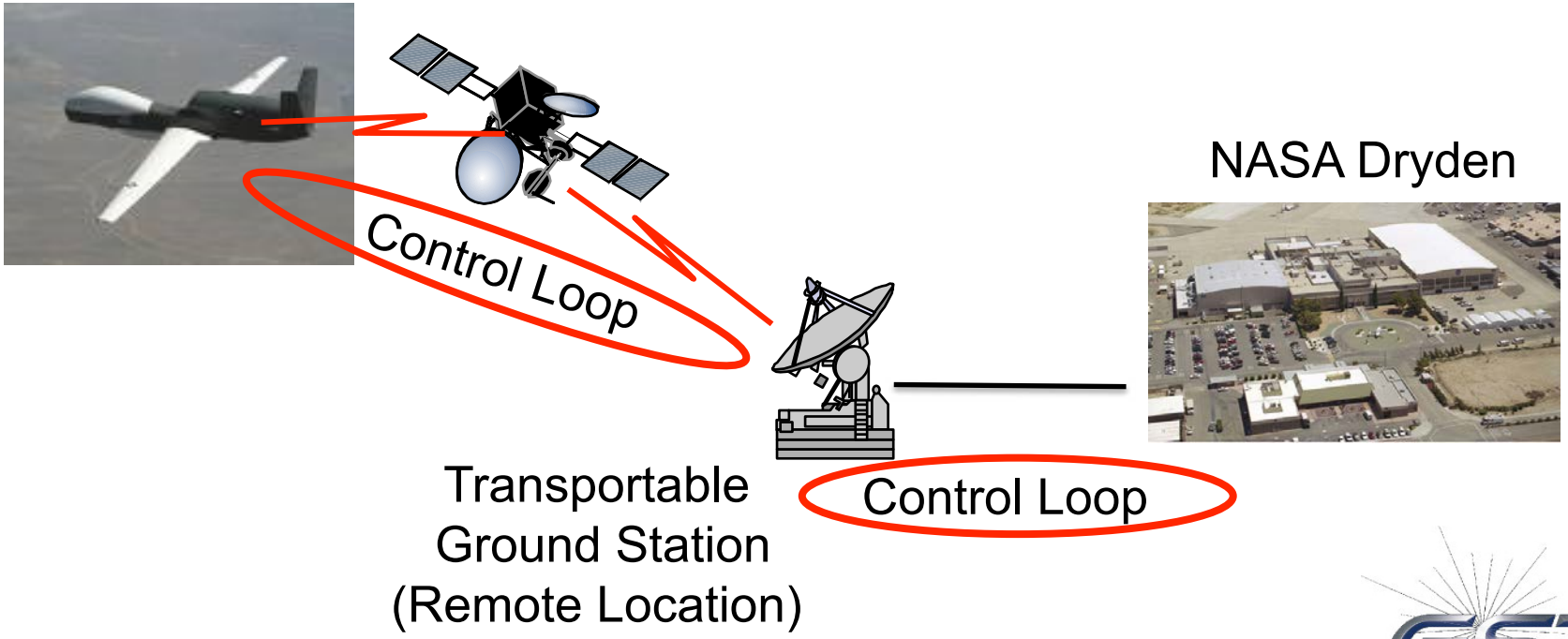
Venture Mission
(Atlantic Campaign)

- Global Hawk ground station is located at near mission and PIs are collocated near ground station.
  - No multi-hop store and forward or network mobility.
  - Delay is up to 600 msec round trip time due to Geostationary Satellite delay.
  - Single control loop



Future Deployment Possibilities

- Aircraft Operators and Principle Investigators located at Dryden or remote
  - Some PIs with payload
- Ground Station at Remote Location
  - Simple two-stage store and forward.
  - No need for special store and forward protocol



Collocated PIs

- Pros
  - Eases coordination between PIs as well as between PIs and aircraft controllers
  - Ensures commitment
  - Builds teams and teamwork
  - Cross pollination of ideas
  - Collocated with Global Hawk ground base provides access to payload for pre-flight checkout.
    - But, that probably does not have to be everybody and probably does not have to be at the ground station.
- Cons
  - Travel time
  - Travel costs
  - Away from home

The technology exists to allow Principle Investigators to operate from remote locations.

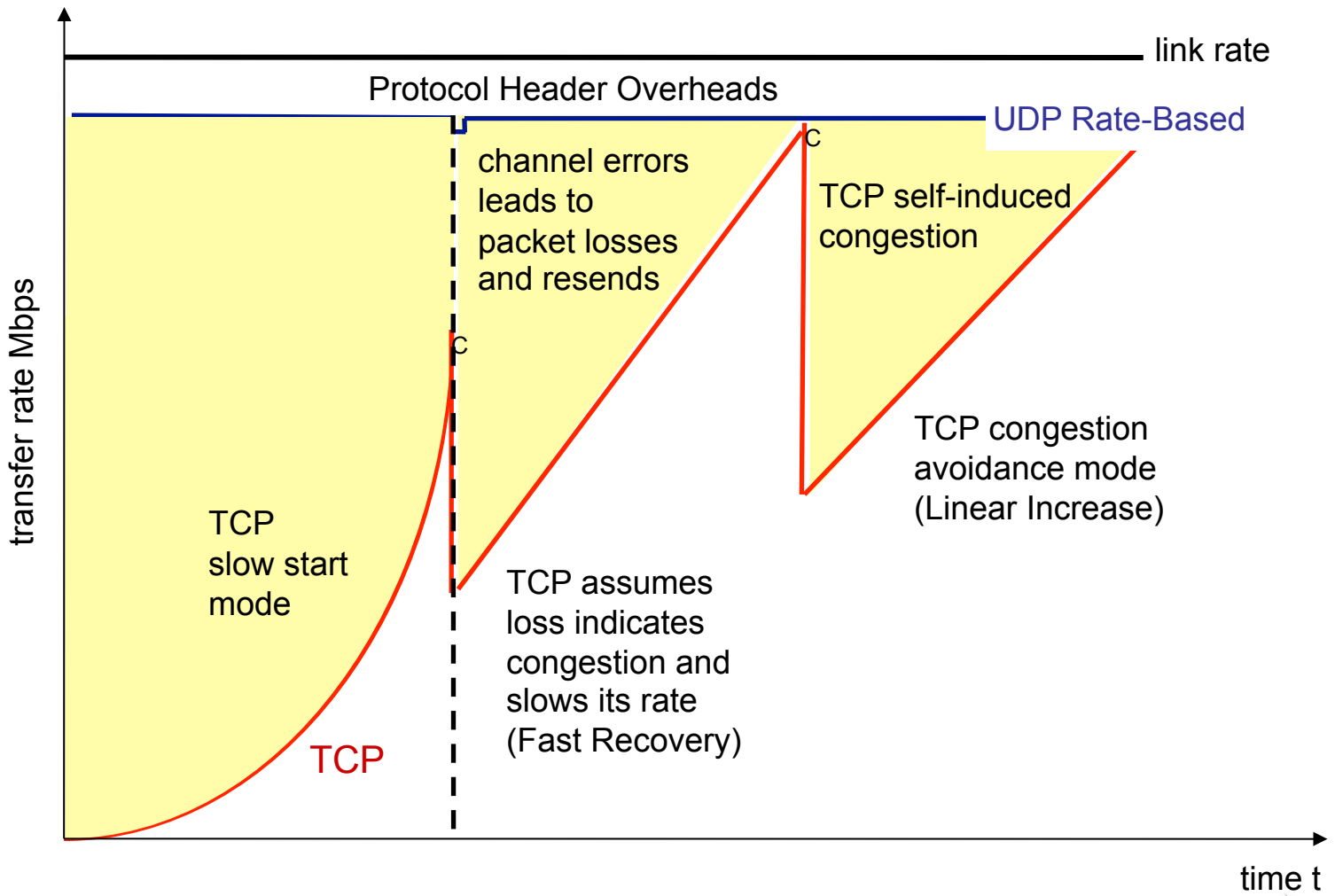
Protocol Requirements

- Provide a good user experience
  - Get the required science data down in a timely manner
  - Ease of use and maximum delivery of science data
- Remain as indistinguishable as possible from existing Internet protocols.
  - Allows the scientists to test their instruments and data collecting in the lab, on the ground, and in flight using the same protocols, commands, and scripts.
  - Currently used Protocols
    - Transmission Control Protocol (TCP) based protocols
      - Telnet, Secure Shell (SSH), and file transfer protocols (i.e. File Transfer Protocol (FTP), Secure Copy Protocol (SCP), Secure File Transfer Protocol (SFTP), Remote Synchronization (RSYNC)

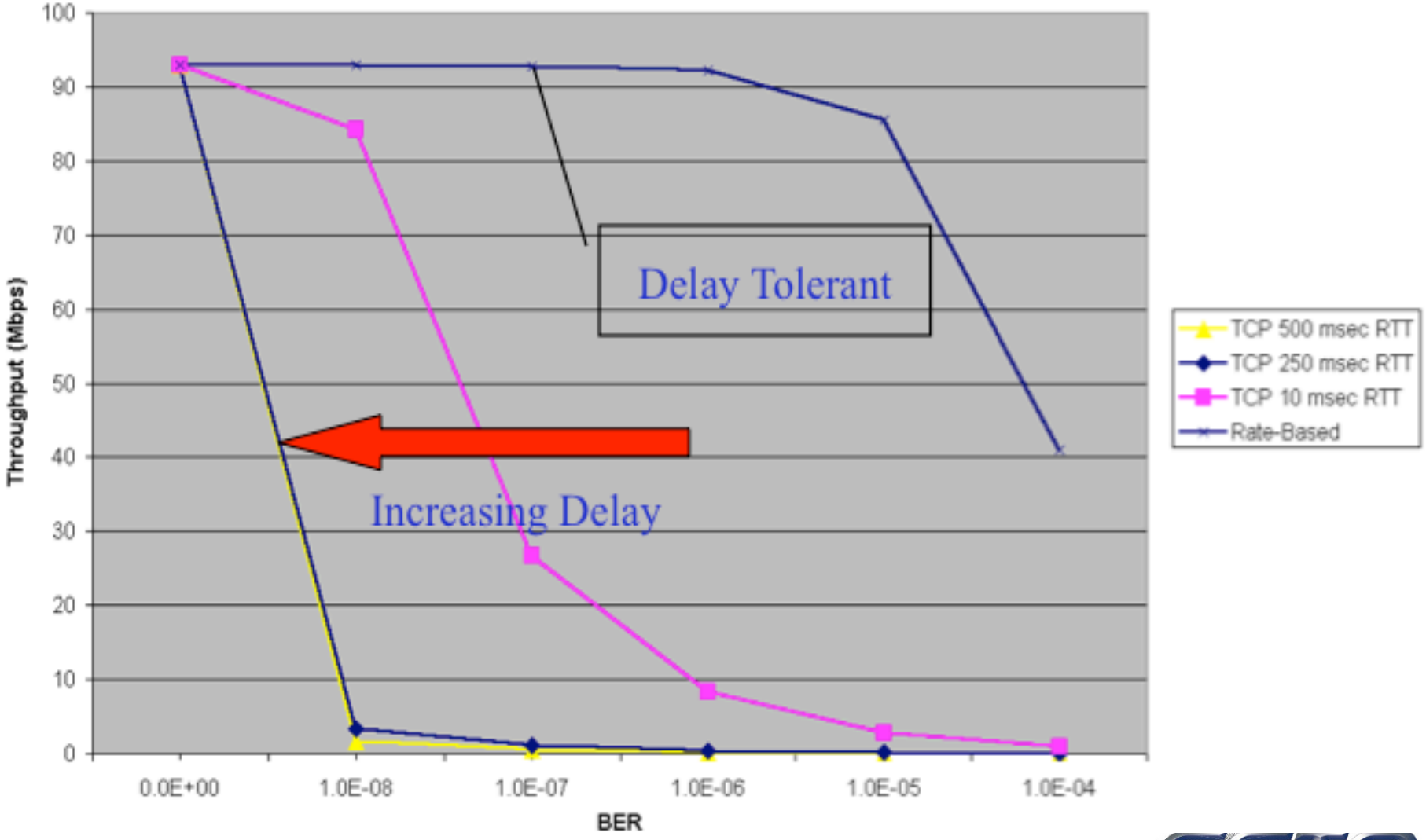
Research Requirements

- Lightning Instrumentation Package (LIP)
  - Measures lightning, electric fields, electric field changes, and air conductivity.
  - The data throughput requirement is kbps
- High Altitude MMIC Sounding Radiometer (HAMSR)
  - Provides measurements that can be used to infer the 3-D distribution of temperature, water vapor, and cloud liquid water in the atmosphere.
  - Data requirements are approximately 200 Mbytes over duration of mission (24 hours) with instantaneous throughputs of 10s to 100s of kbps.
  - Current system uses RSYNC over TCP to synchronize the ground database with payload database
- High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)
  - HIWRAP is able to image winds by measuring volume backscattering from clouds and precipitation.
  - Data requirements for GRIP was approximately 1 Gigabyte per minute (approximately 130 Mbps) which vastly exceed available link rate.
    - By deploying such onboard processing on future flights, the data-rate should be reduced by a factor of about 15, or 66 MB per minute (8.8 Mbps link requirement).
    - Using FPGA-based processing, Quicklook products such as images would be produced that would greatly reduce the data downlink requirements to well within the current bandwidth of the Ku-band communication system.
  - Operators currently use telnet or SSH to check payload status. Data is distributed once the Global Hawk returns (see Saratoga Transport Protocol)

TCP Operation vs. UDP Rate-base Operation



Theoretical Throughput of TCP vs. Rate-Based Protocols for 1024 byte packets



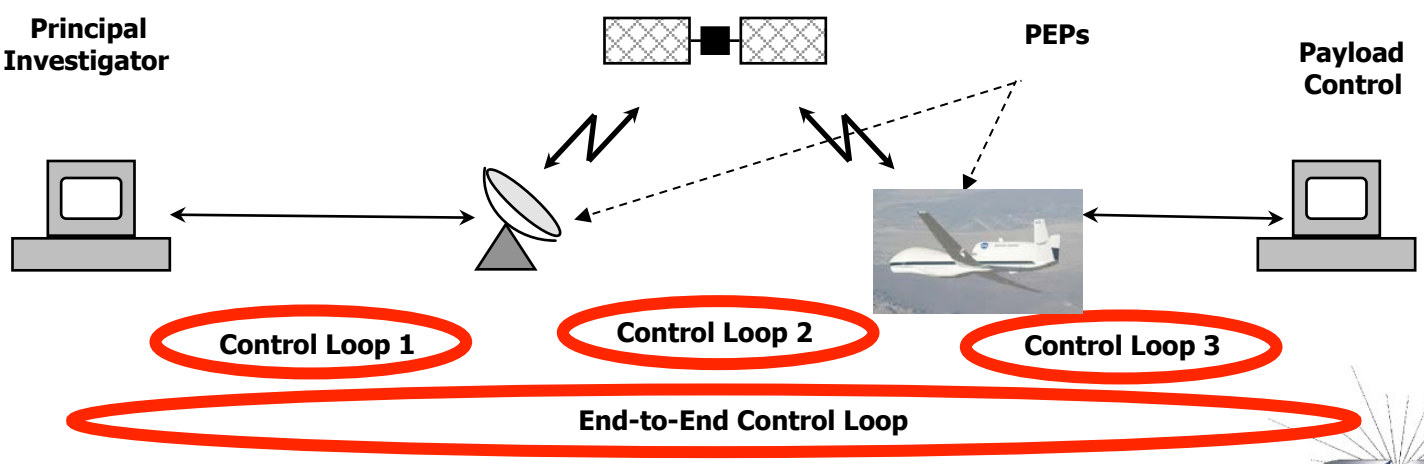
Earth Science Technology Office

UDP-base Transport Protocols

- Operate at line-rate or at some set rate-limit.
- Generally assume no congestion and thus deploy no congestion control algorithms.
  - No need to probe the system to determine available bandwidth or to reduce data-rates when losses occur as all losses are assumed to be due to errors rather than congestion.
- UDP-based transport protocols utilize a negative acknowledgement algorithm (NACK) for transport reliability
- UDP-based transport protocols
  - Saratoga
    - Initially Developed by Surrey Satellite Technology Limited for reliable, efficient image transmission from space to ground
    - Plans for use to transport massive radio astronomy data sets (Terabyte per day) generated in the Australian Square Kilometer Array Pathfinder (ASKAP)
  - Negative Acknowledgement (NACK) - Oriented Reliable Multicast (NORM)
    - Initially developed by the Naval Research Laboratory (NRL)
  - Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol (CFDP).
    - Developed for Space Communication
    - Very heavy state maintenance – necessary to suspend timers
    - A mix of application, transport protocols, and data-link
  - Licklider Transmission Protocol (LTP)
    - Origins are CFDP with the intent to implement layering (heavy state maintenance)
    - Target use is Space Communications

Protocol Enhancing Proxies (PEPs)

- Used to improve TCP performance over long delays.
- Break the end-to-end control loop into multiple control loops such that one can utilize a protocol that performs well over long-delay, error prone links without modifications to the end users system (protocols).
- PEPs have known problems.
  - Require a reasonable amount of additional processing,
  - Often require special configuration and tuning
  - Must see TCP packets so IPsec is problematic
- Note: PEPs will not help interactive communications, as PEPs cannot remove the propagation delay.



Conclusions

- GloPac and GRIP missions
  - Principle Investigators using standard Internet protocols with no PEPs deployed.
  - The user experience was positive even without PEPs.
  - Larger file transfers for GRIP and GloPac were performed in the background using RSYNC for remote synchronization. As such, any TCP inefficiencies were not apparent to the user.
- Future deployments
  - Real-time delivery of larger data will be required and efficient use of the communication links will be necessary
  - Either PEPs or an efficient, rate-based protocol such as Saratoga or both will be installed depending on the performance needs are architectural deployment.
    - PEP Performance is currently under investigation
  - Use of only a rate-based protocol is preferred over deployment of PEPs in order to keep the communication system as simple as possible.
  - Possible use of the Saratoga transport protocol to move large data sets (such as those generated by High-Altitude Imaging Wind and Rain Airborne Profiler) ground-to-ground once the Global Hawk lands.