SatNet: A Federated Tracking Network for CubeSats

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Smaller Form-Factor, Similar Challenges

- CubeSat ground segment shares similar challenges with larger missions
  - Multiple mission support
  - Requirement to reuse ground segment between missions
  - Desire to share / lease ground resources between entities
  - Automated operations
  - Status monitoring

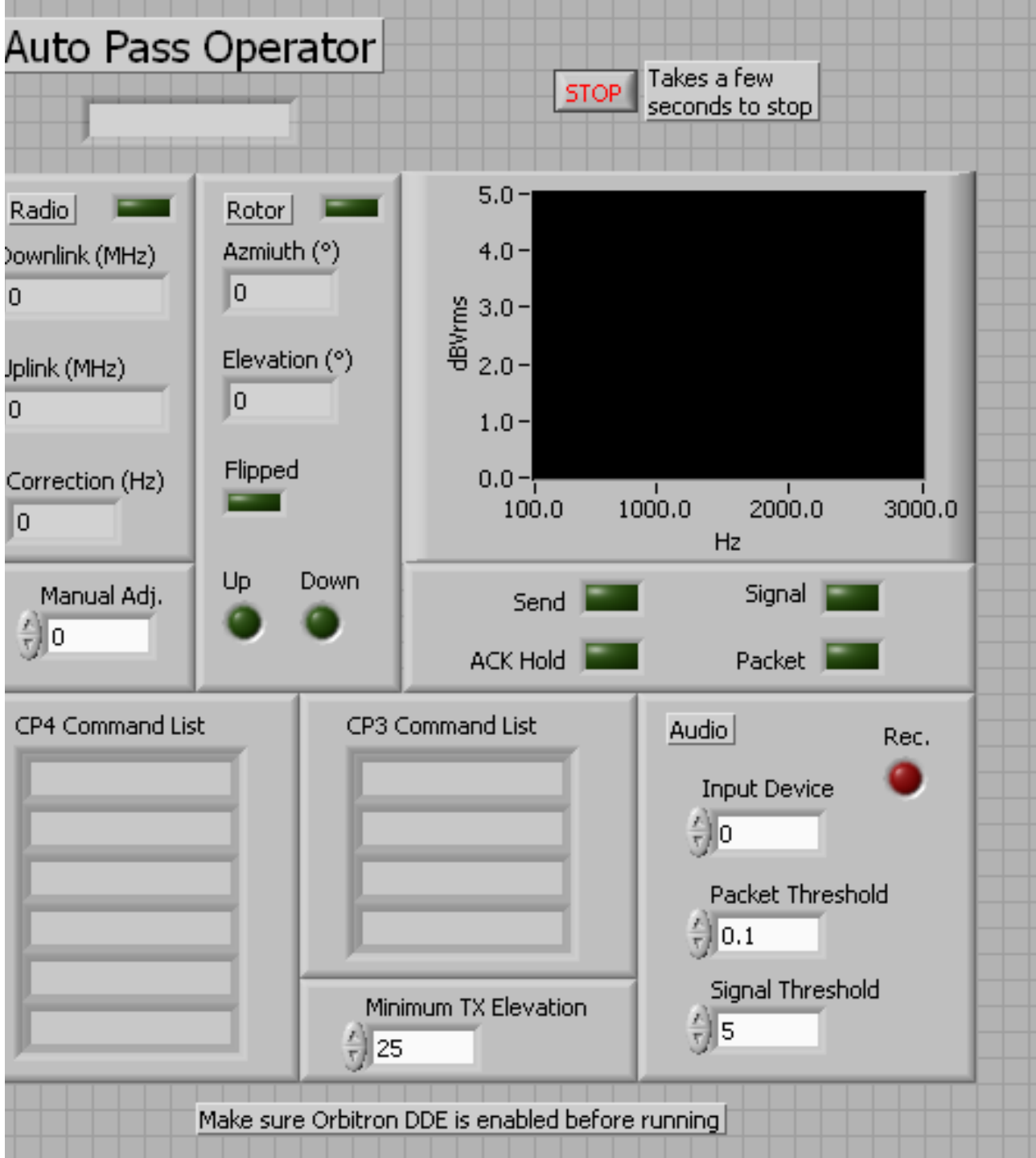
Humble Beginnings

- Low-budget tracking stations
- Repurpose amateur radio equipment not designed for the exact usage
- Manual operations
  - Pass setup
  - Commanding

2nd Generation Systems

- Combine off-the-shelf SW components
  - Automate a single tracking station
  - APO

- Typically a manual process to reconfigure for each different spacecraft
- Minimal support for a network of tracking stations
- No support for sharing tracking resources between organizations



SatNet

- Cal Poly's current tracking network solution
- Fully automated
  - Tracking
  - Resource allocation
  - Operations
- Automated operations since late 2013

SatNet

- Clean-slate design to support multiple missions and federated operations
- Satellite communication protocol agnostic

- Software solution
  - Implemented incrementally over 3 years and counting
  - Approx. 3-4 person-months

- Retained compatibility with existing COTS hardware (radios, antenna, TNCs)
- Must work across multiple missions

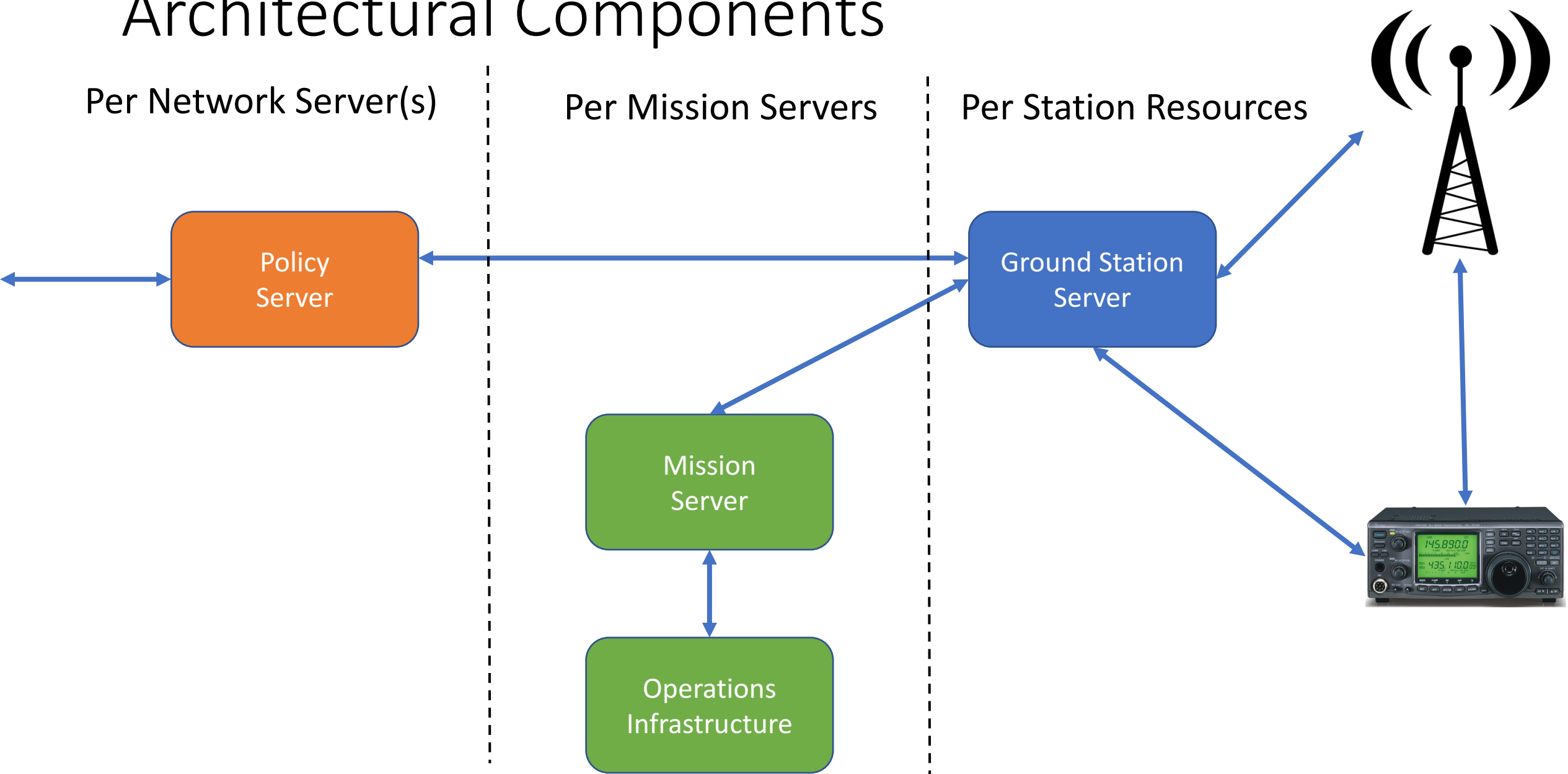
Design Principles

- Data is sent directly from ground station to mission ops
  - Avoid intentionally routing data through 3rd party data relays
- All data is encrypted using industry standard TLS
- All communication endpoints can be authenticated with digital certificates as needed

Design Principles

- Keep policy and mechanism separate
- Policy examples
  - Decide which spacecraft to track
  - Manage which other organizations are permitted to use other’s resources
- Mechanisms implement the policy
  - Protocol used to communicate between computer systems
  - Specific protocol used by spacecraft
  - Rotor control specifics

Architectural Components

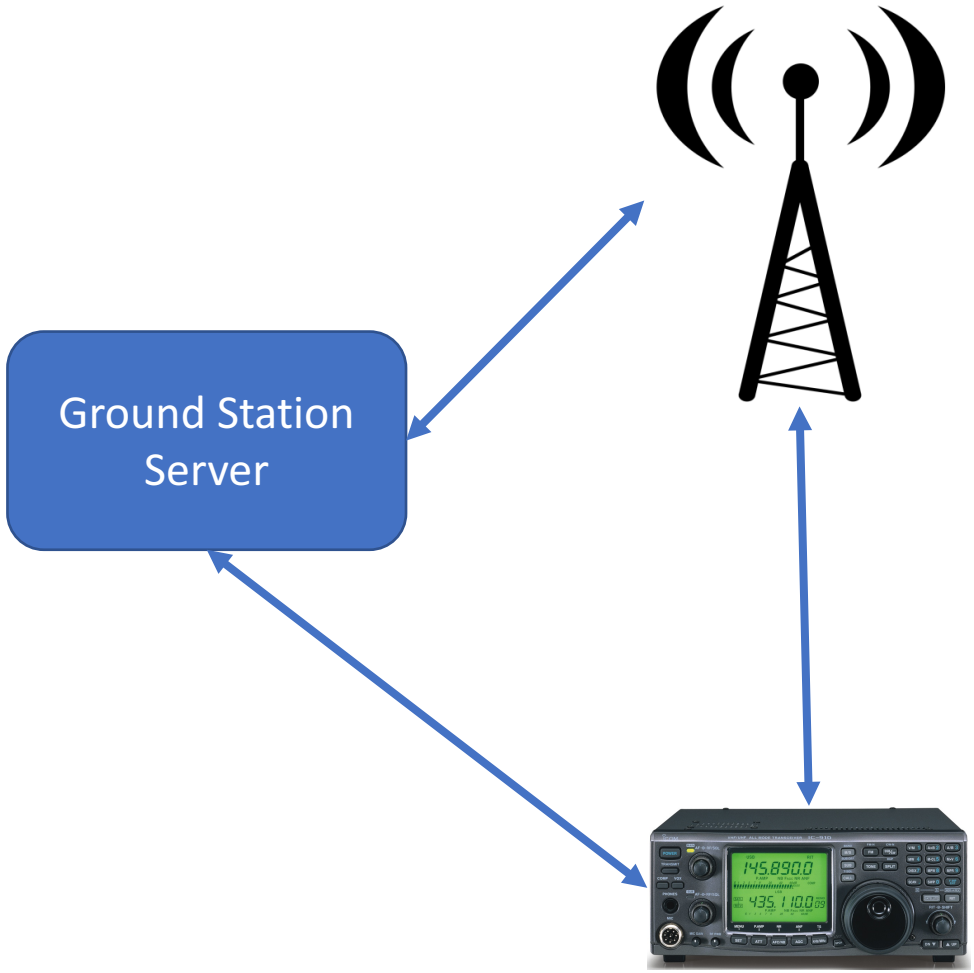


Ground Station

- Modulation and de-modulation
  - TNC or SDR
- Forwards demodulated bits to mission server

- Latency sensitive hardware control
  - Point antenna
  - Tune radio

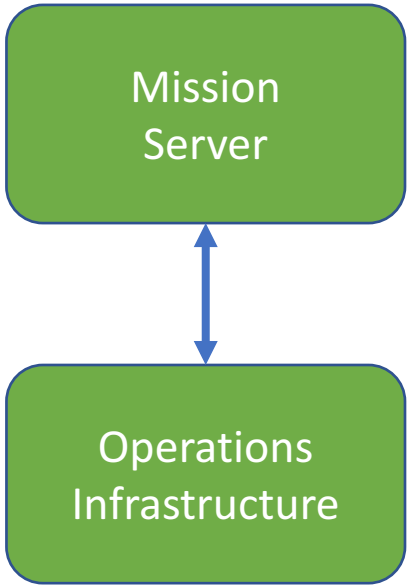
- One per ground station



Mission Server

- Tells ground stations how to track the spacecraft
  - orbital elements, fixed pointing, etc
- Coordinates multiple simultaneous tracking stations
- Interfaces with operations infrastructure
  - Encryption, telemetry storage, etc

- One per mission

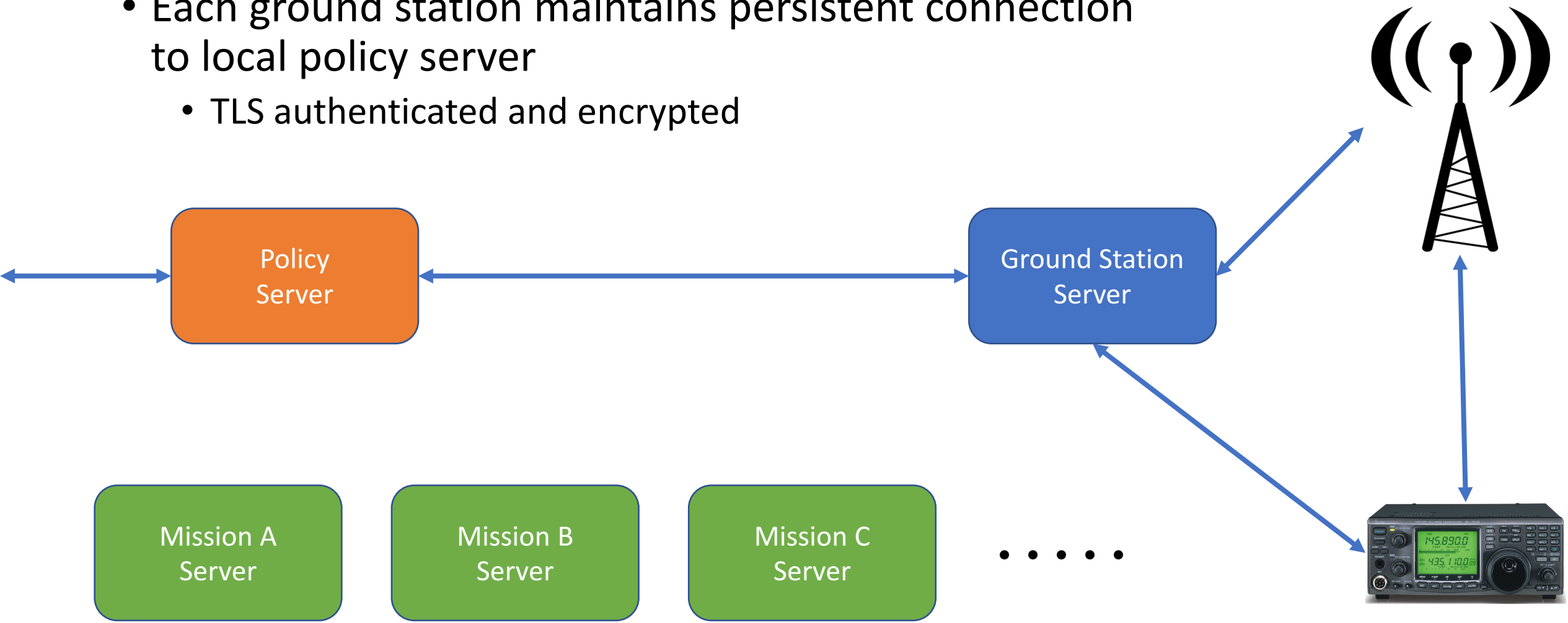


Policy Server

- Assign ground station to mission based on local policy
  - First visible satellite
  - Strict priority
  - Static allocation
- At least one per organization

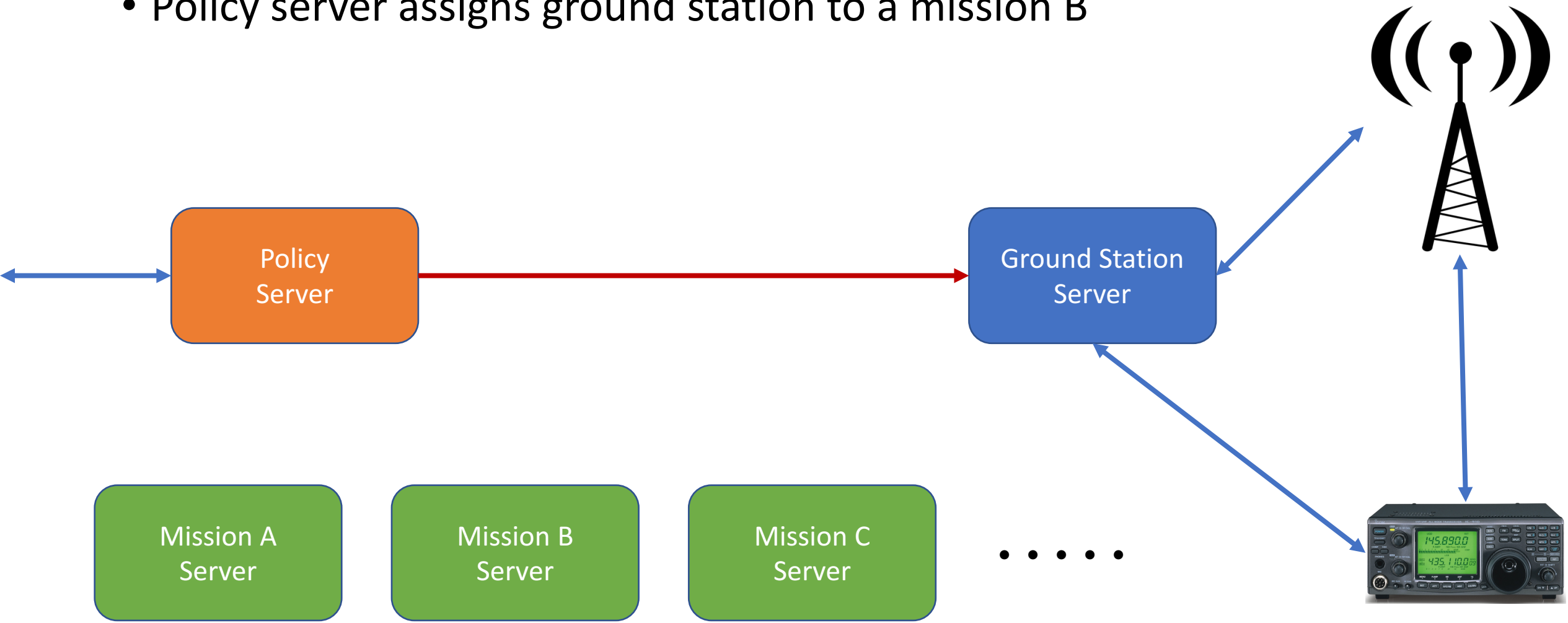
Communication Example

- Each ground station maintains persistent connection to local policy server
  - TLS authenticated and encrypted



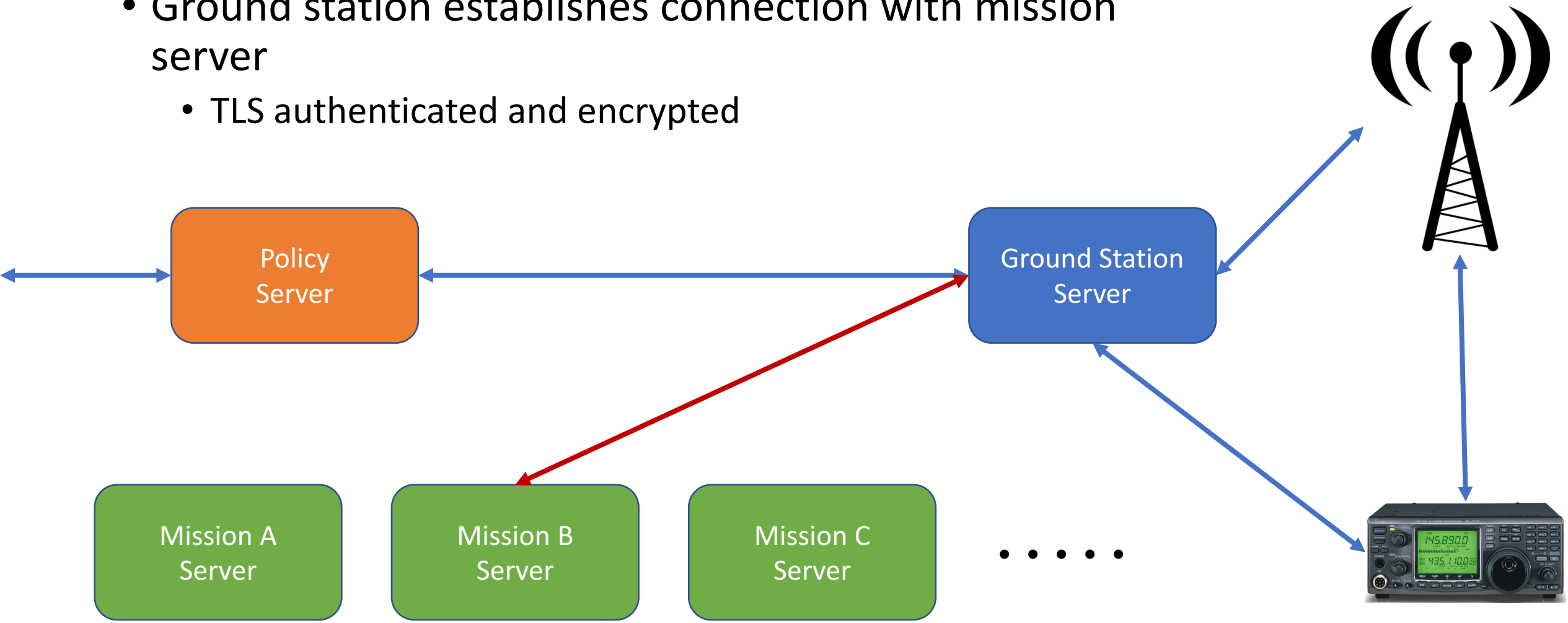
Communication Example

- Policy server assigns ground station to a mission B



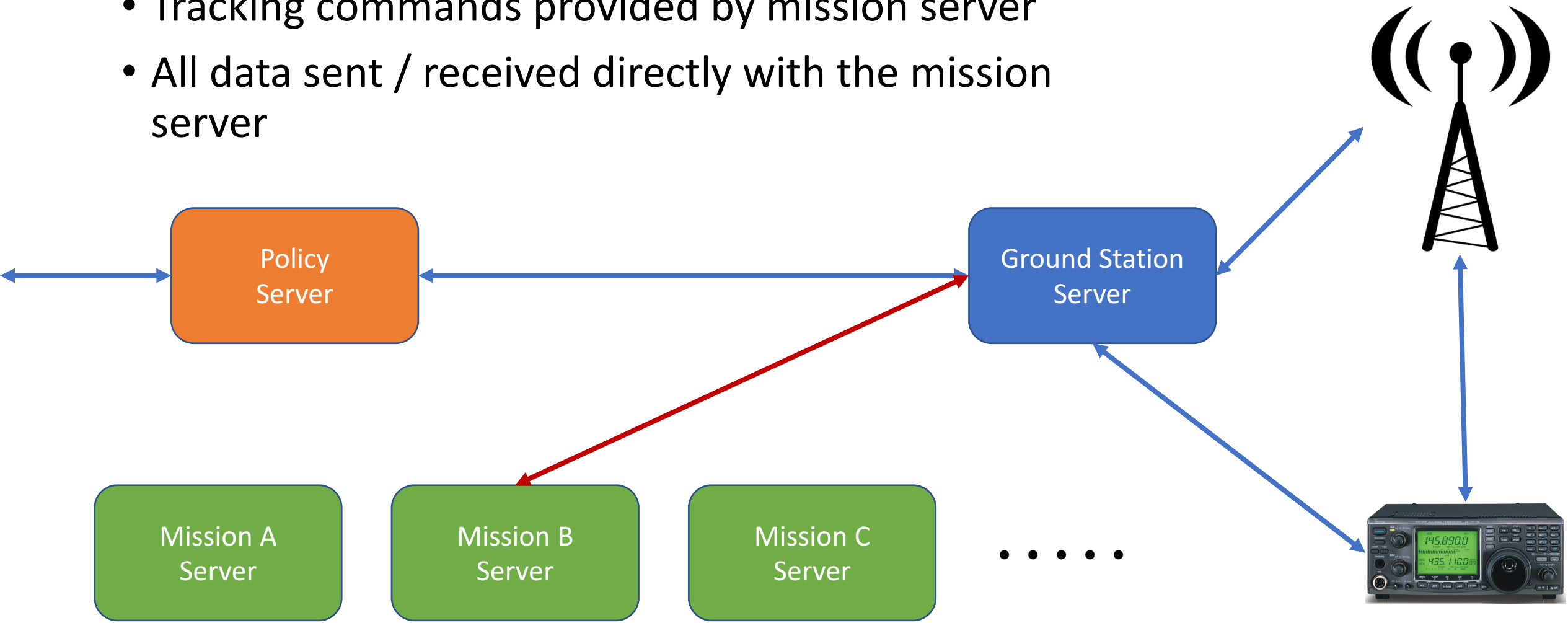
Communication Example

- Ground station establishes connection with mission server
  - TLS authenticated and encrypted



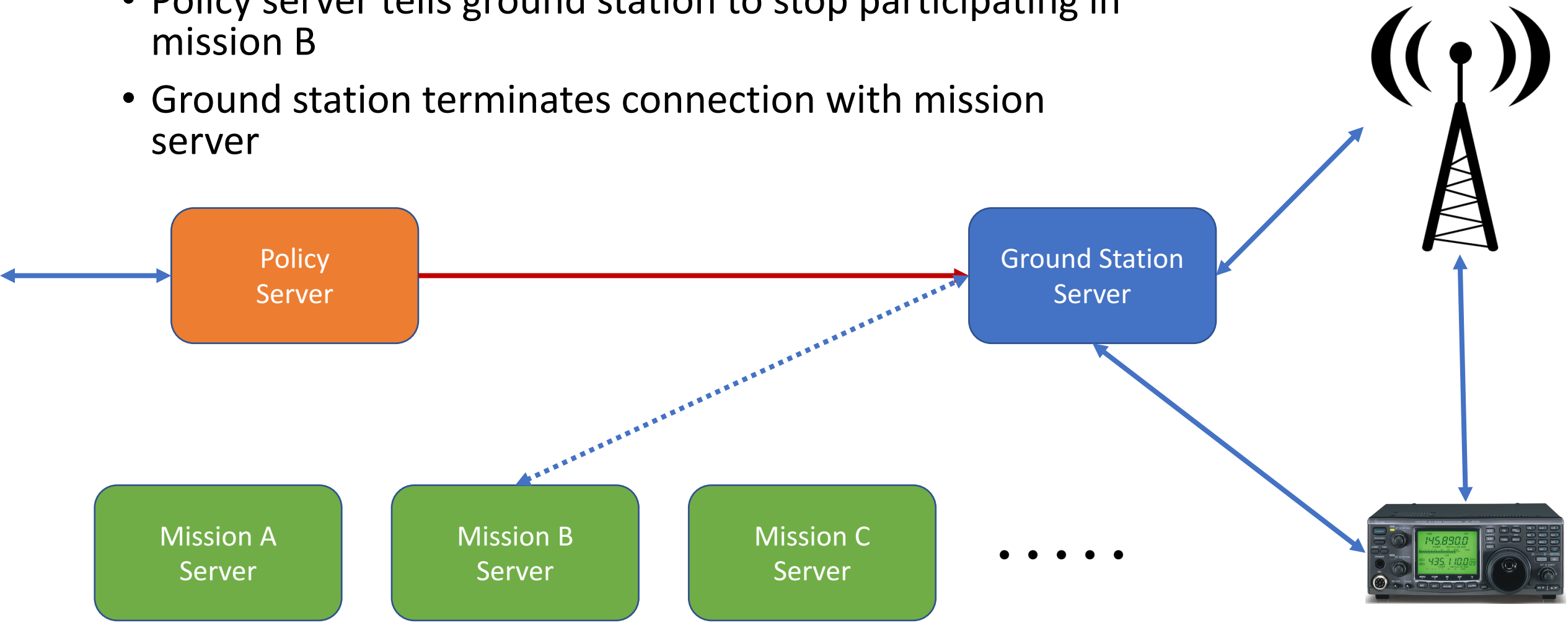
Communication Example

- Tracking commands provided by mission server
- All data sent / received directly with the mission server



Communication Example

- Policy server tells ground station to stop participating in mission B
- Ground station terminates connection with mission server



Federation

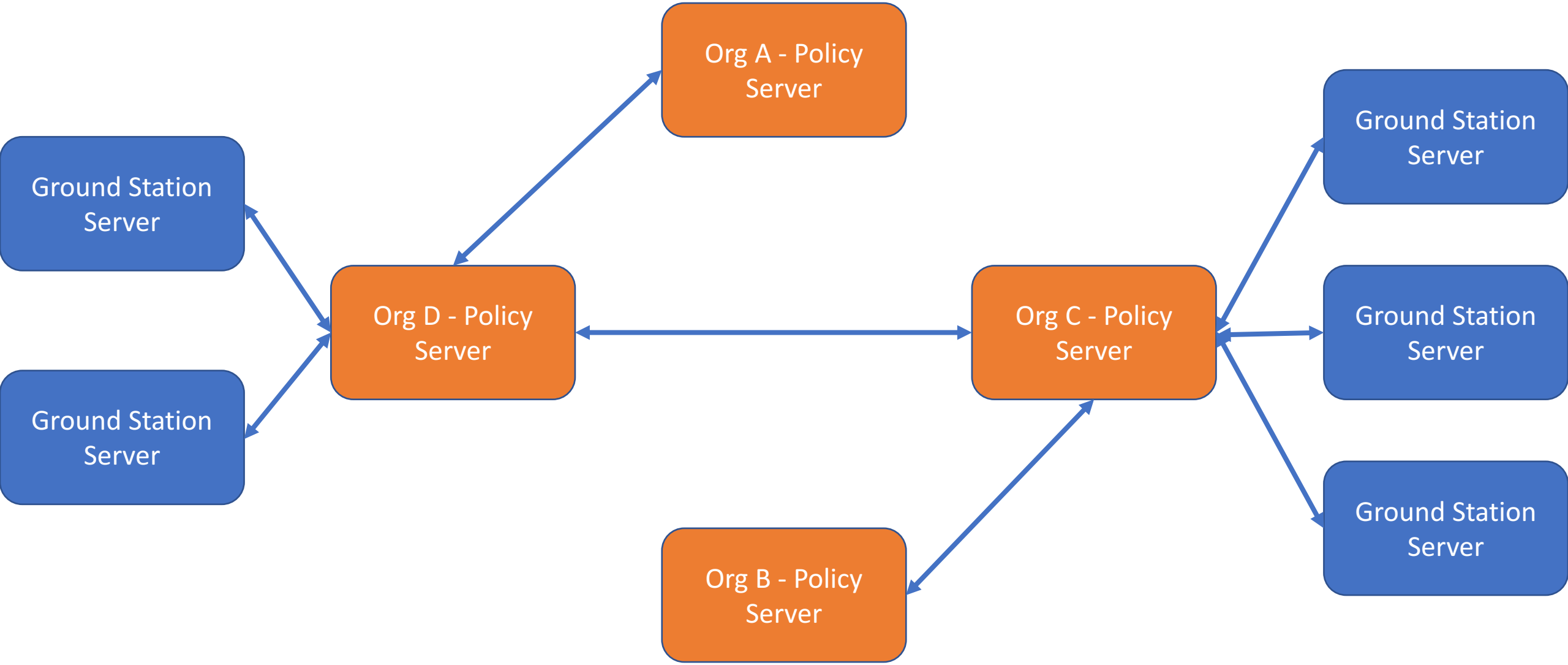
- SatNet uses a federated architecture to enable
  - Sharing tracking resources
  - Interoperability
  - Decentralized autonomous operation

- Potential use cases for federation
  - Community service
  - Fee-based
  - Mutual agreement

Federation

- Inspired by internet routing architectures between independent organizations
  - Independent organizations interconnect their policy servers
  - Policy servers exchange details on individual station availability
  - Policy servers make resource requests amongst themselves
  - Organizations maintain complete control over local policy server

Federation - Example



Operational Experience

- Architecture has proven very successful within a single organization (Cal Poly)
  - Easy to add and remove mission servers
    - Currently have approximately 15 set up
  - Easy to add and remove ground stations
    - 3 located at Cal Poly
    - Other temporary bent-pipe stations
      - Stanford dish, Wallops Island, SRI
      - Development ground stations
  - Seamless operation of multiple spacecraft simultaneously
  - Seamless handoff of single spacecraft between tracking stations

Summary

- Described motivation and design of SatNet
  - Clean separation of policy and mechanism
  - Federated architecture based loosely on internet routing architecture
- Grew organically as part of Cal Poly's CubeSat program
  - Shares some of the design goals of ground infrastructure supporting larger spacecraft
- Reviewed operational experiences

Questions?

- Thanks for your attention

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