



Great networks start with
great nodes...

*Building “Routers” for the Solar
System Internet*



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Why something new?

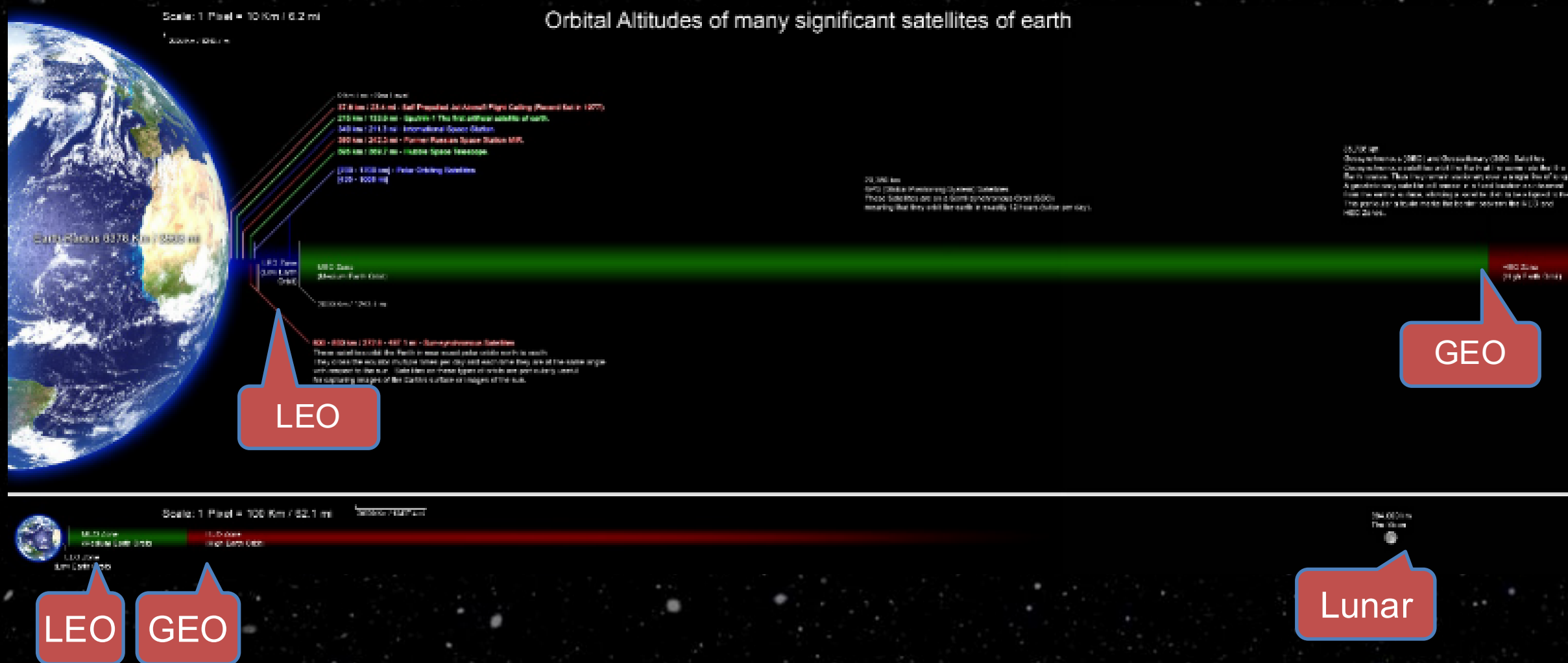
Space is hard.

Space networks have different characteristics.



Services fail as delays increase

The moon is the closest “far” thing and it requires rethinking architecture



<https://www.jhuapl.edu/Content/documents/CislunarSecurityNationalTechnicalVision.pdf>



There Are Many Open Challenges

Some are closer to being solved than others

- **Accommodate Topology Changes**
 - Nodes join/leave network over time
 - Power, pointing, congestion, opsec
 - Across network this can look chaotic
 - Network might always be partitioned
- **Survive Unfavorable Environments**
 - Congestion and Contested
- **Avoid Unsited Protocols**
 - Round-Trip Time (RTT) Issues
 - Built in assumptions
 - End-to-end measurement
 - Any link is a good link
 - Inefficient loss recovery
- **Avoid Interoperability Gaps**
 - Competing proprietary solutions not compatible
 - IPv4/IPv6 as a data structure
 - Use reserved bits or repurpose header data
- **Accelerate Standards**
 - SDOs working these problems
 - IETF, IEEE, CCSDS, ITU
 - Trickle to industry lags by years
- **Retire Network Technical Debt**
 - Devices built to specific architectures/uses
 - Cheaper if and only if you are repurposing kit
 - Space needs to be a cleaner slate
 - No SWAP to carry network technical debt

Protocols Address Some of Them

Focus mostly on data plane technologies - like DTN

- **Store and Forward Data Exchange**
 - Do not assume a path exists all at once
 - Do not assume endpoints remember things for you
 - Do not retransmit from the source
 - Store important data
 - Carry metadata
- **End-to-end Security**
 - Do not rely solely on physical layer security
 - Do secure different parts of a packet separately
 - Optimize security at rest
- **Autonomy as Network Management**
 - Do not assume an operator in the loop
 - Incorporate autonomy and automation
 - Push information proactively into the network
- **Routing**
 - Adjust to time-variant topologies

Heavy focus on data exchange. Less so on Management and control.

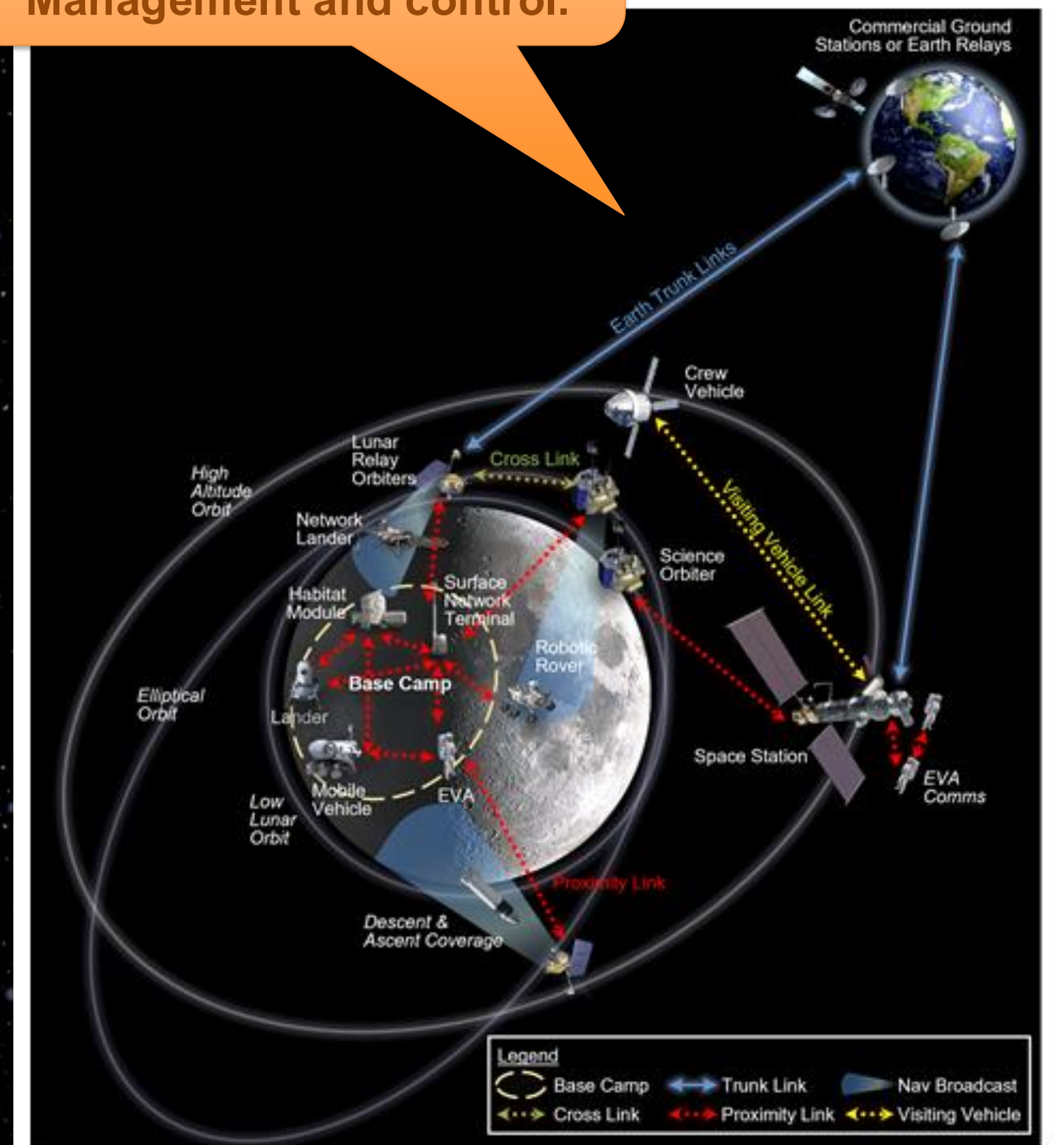
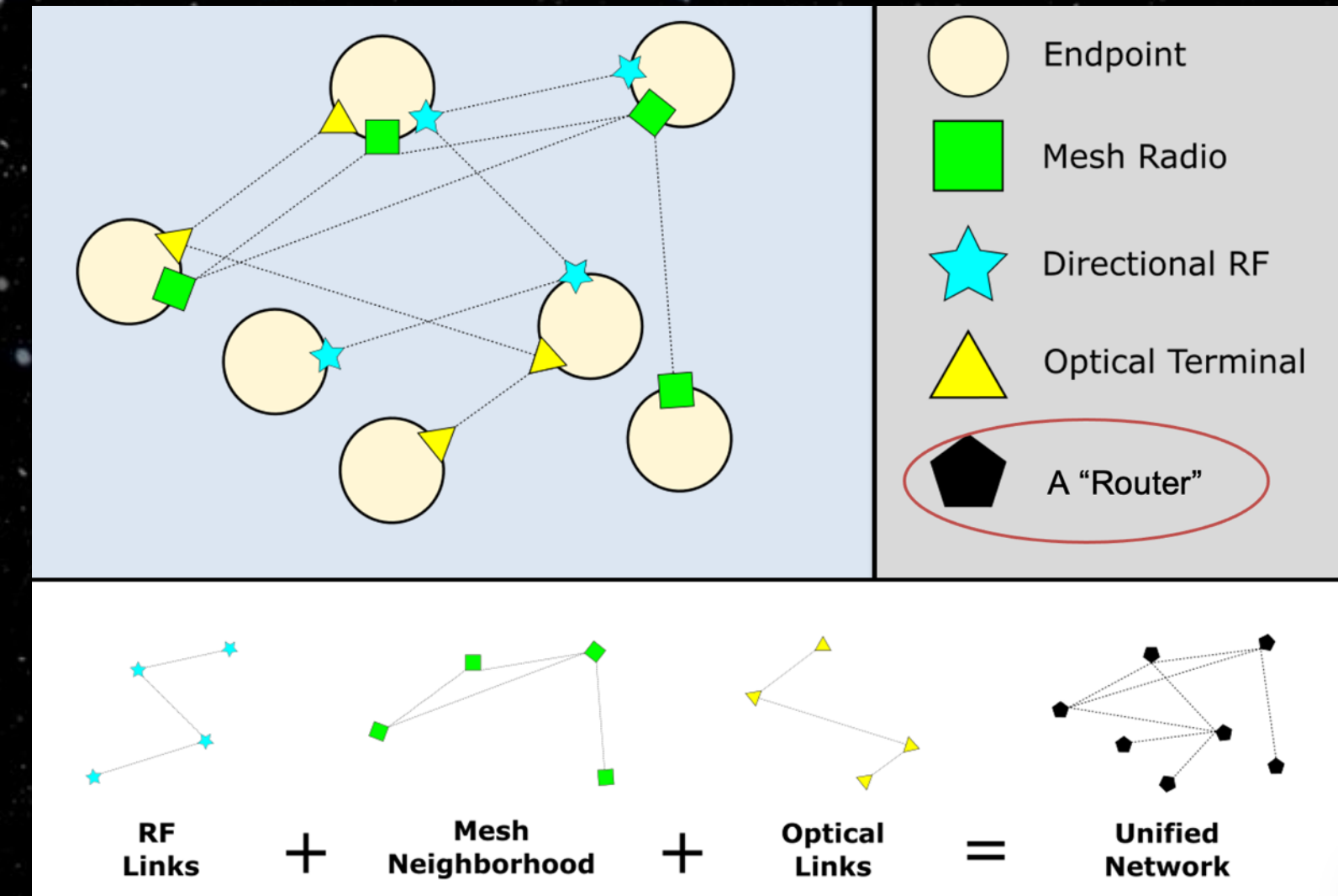


Fig. 1. LunaNet Architecture

What do we need to build networks?

Need more than a link and more than a data protocol

- Too much focus on links and protocols...
 - A “network” is not a relay or a circuit
 - An end-to-end overlay is not one data plane
 - Management and control are paramount
- Networks bridge multiple links and protocols
 - Spacecraft (and ground) have multiple terminals
 - Mesh, Directional RF, Optical
 - Different personalities. Different security/performance
 - Different protocols used in different network segments
 - Ground segments, space segments
- “Unite” assets to survive diverse/contested space
 - Make resiliency independent of terminals
 - Coordinate traffic engineering across terminals
 - Stop custom implementations of common behaviors
 - Stop making networking a “roll your own” activity

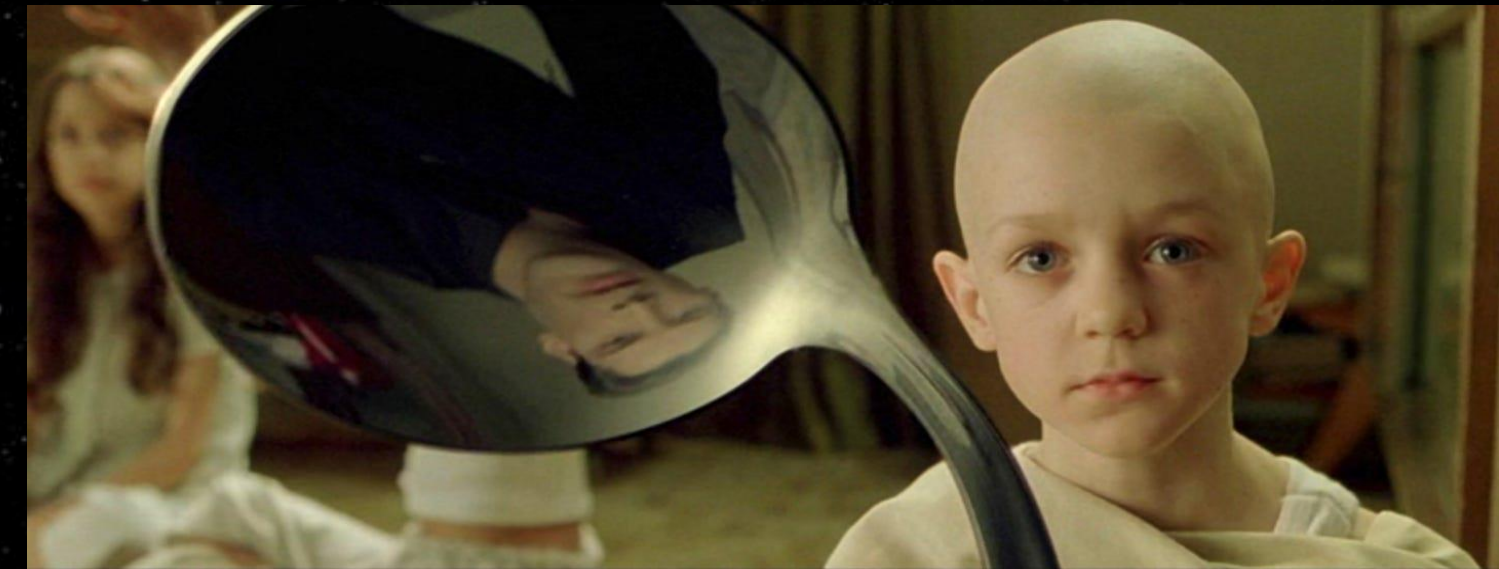


- A Unified Network is...
 - Emergent behavior of new networking devices
 - “Routers”
 - A single topology for applications
 - Traffic engineering & management services
 - Interoperable, standardized ***syntactic*** behavior
 - Consistent, configurable ***semantic*** behavior

The Role of Network Devices

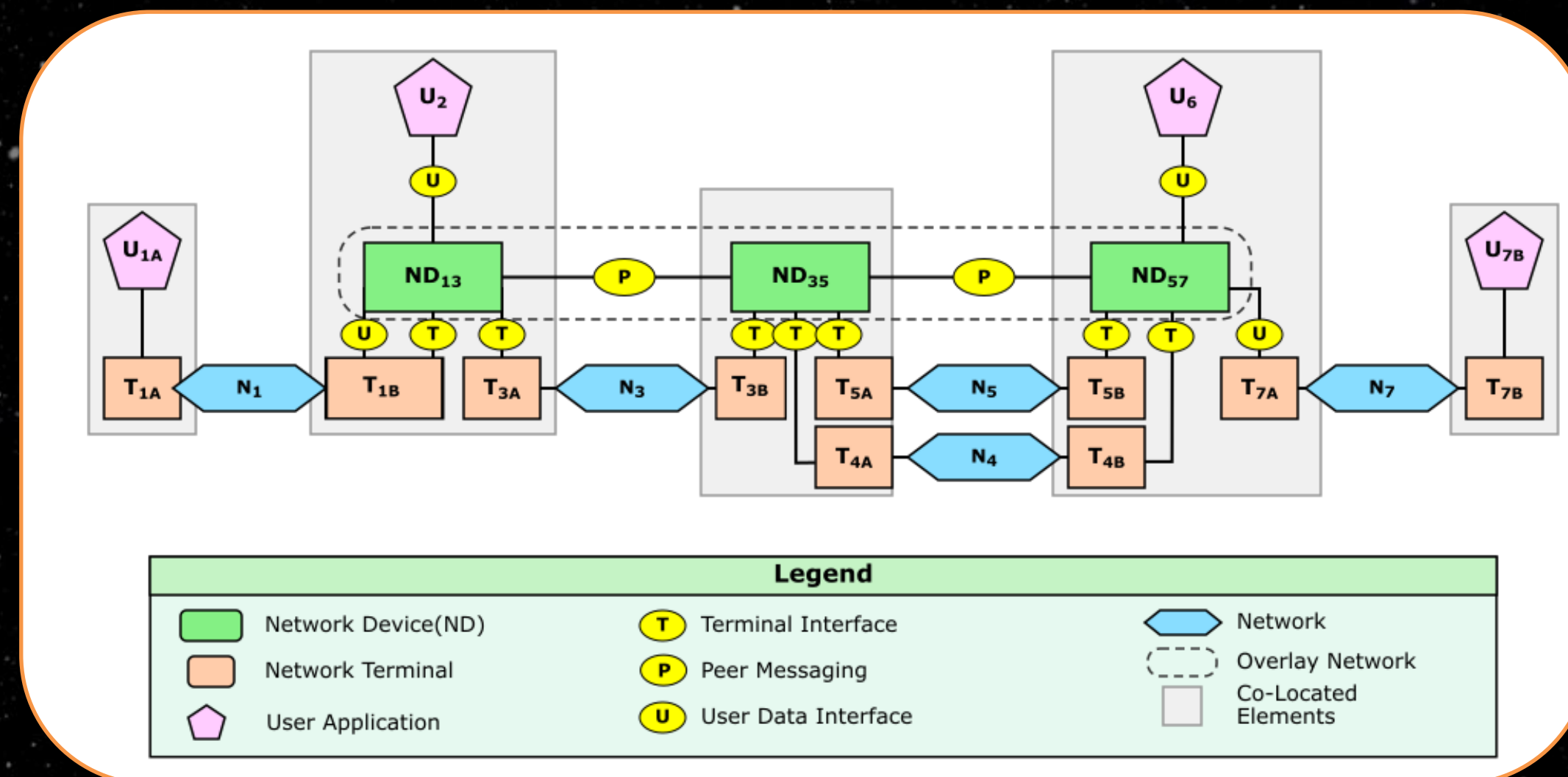
Devices Define Network Capabilities

- A network is not a physical thing
 - There is no “network store” that sells them
 - A “network” is
 - Emergent behavior of networking devices working together
 - New network behaviors come from new network devices with new features



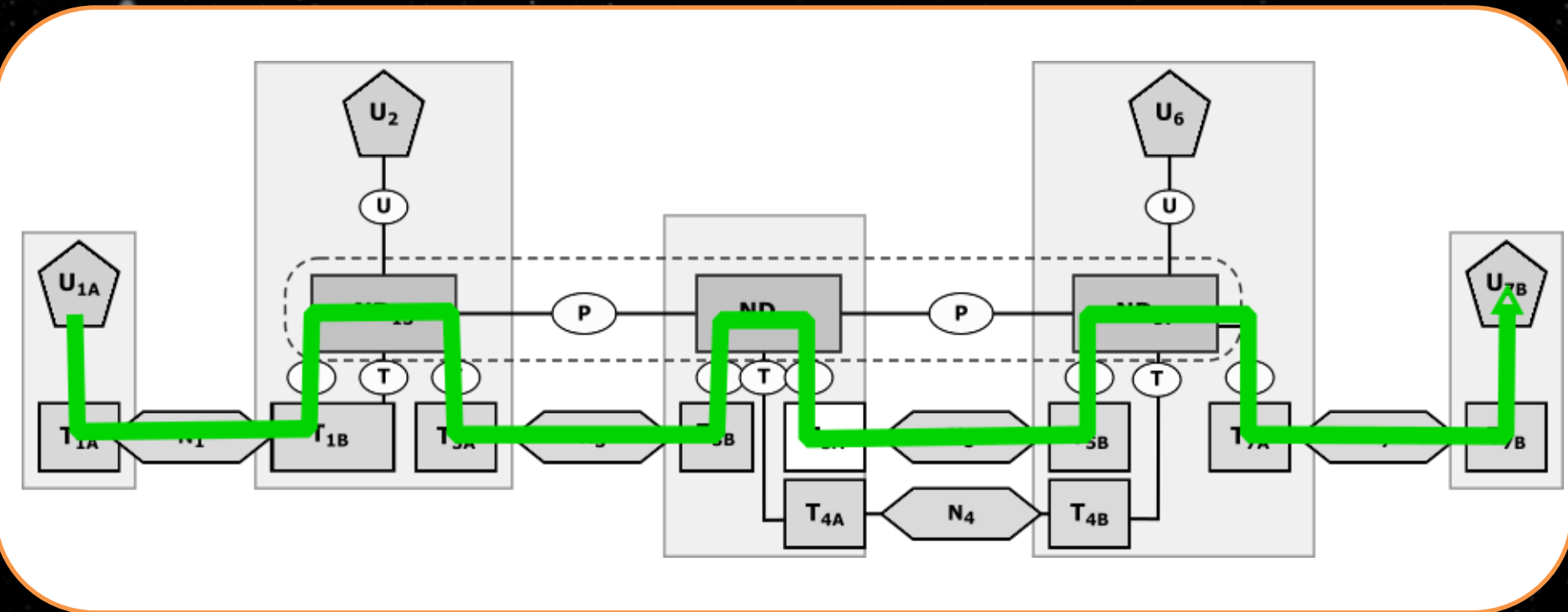
“Do not try and bend the spoon – that’s impossible. Instead, only try to realize the truth ... there is no spoon.”

The Matrix

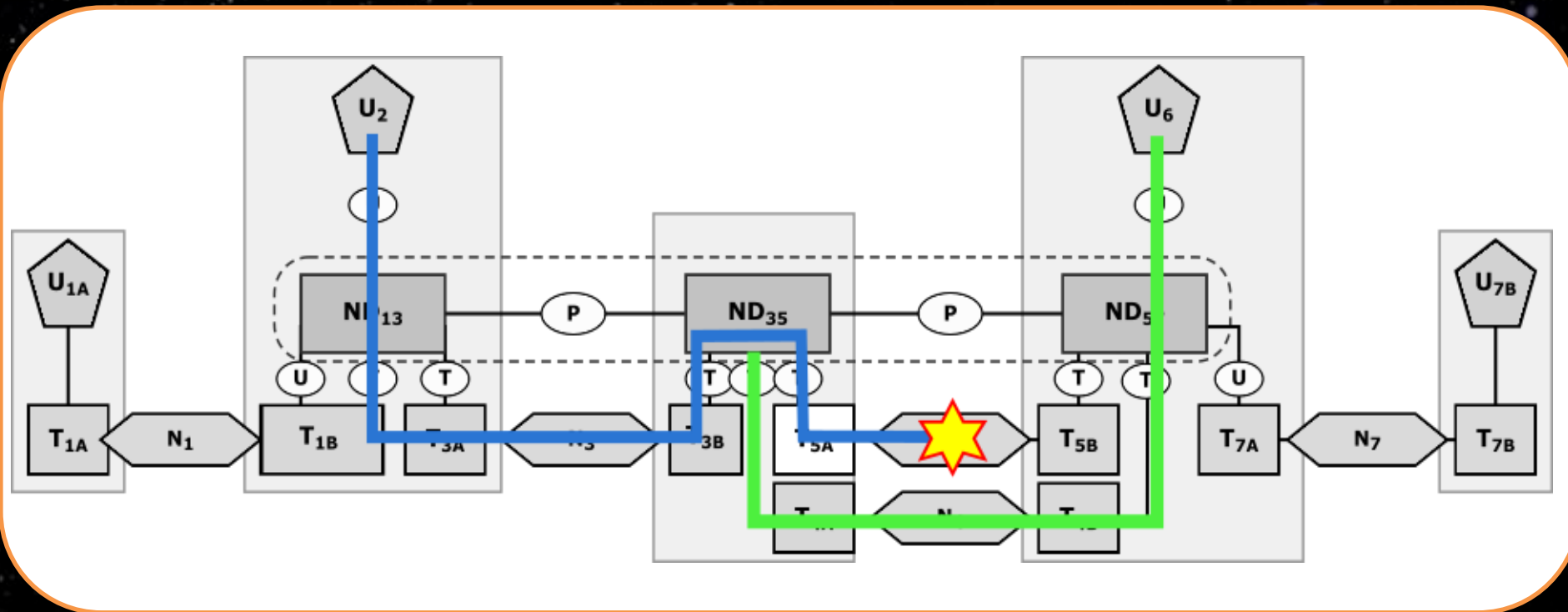


Complex Network Use Cases

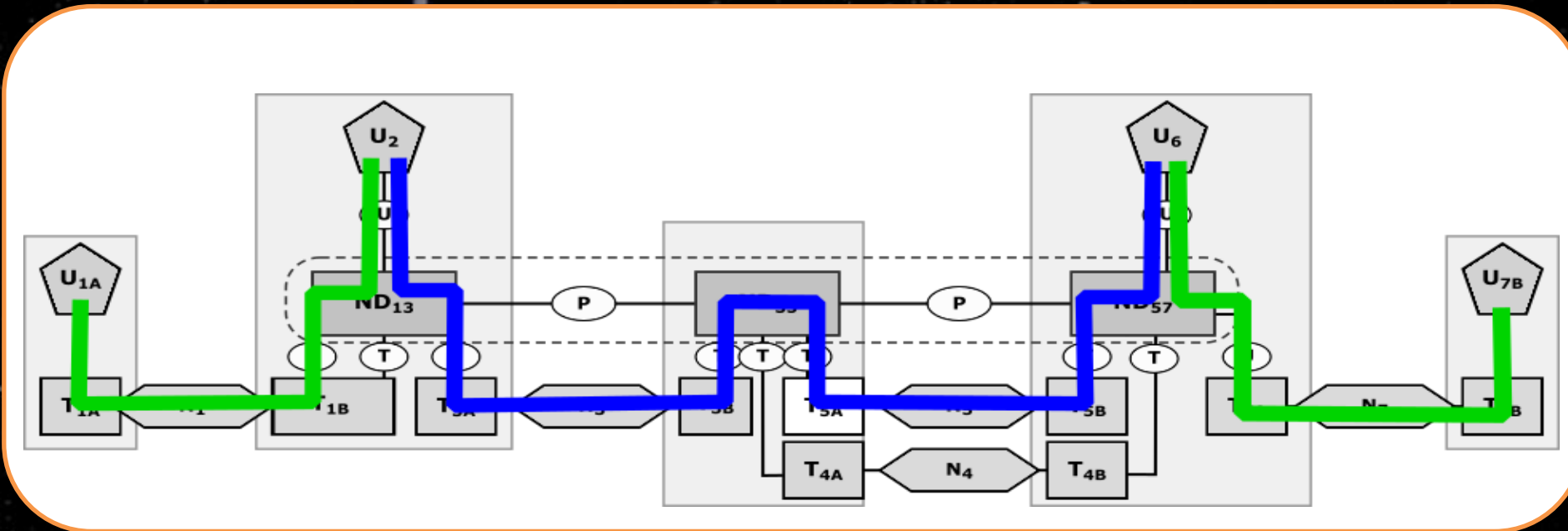
Message Tunneling



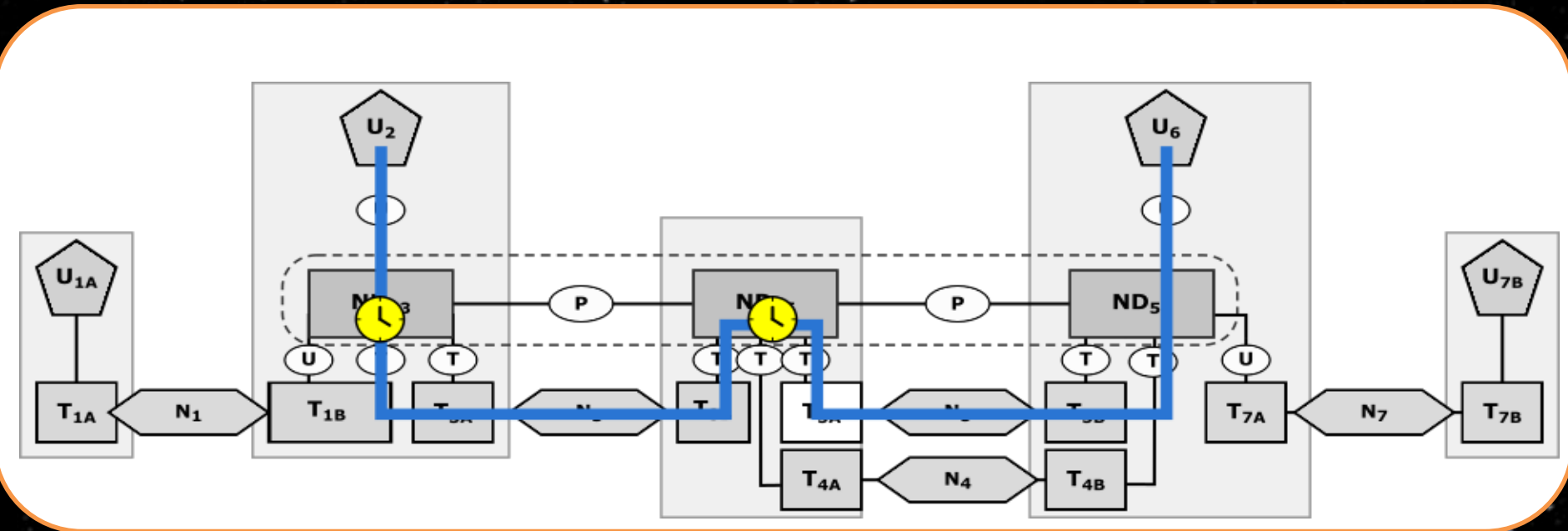
Network Failover



Data Proxy Services



Store and Forward



What Makes A Space Networking Device?

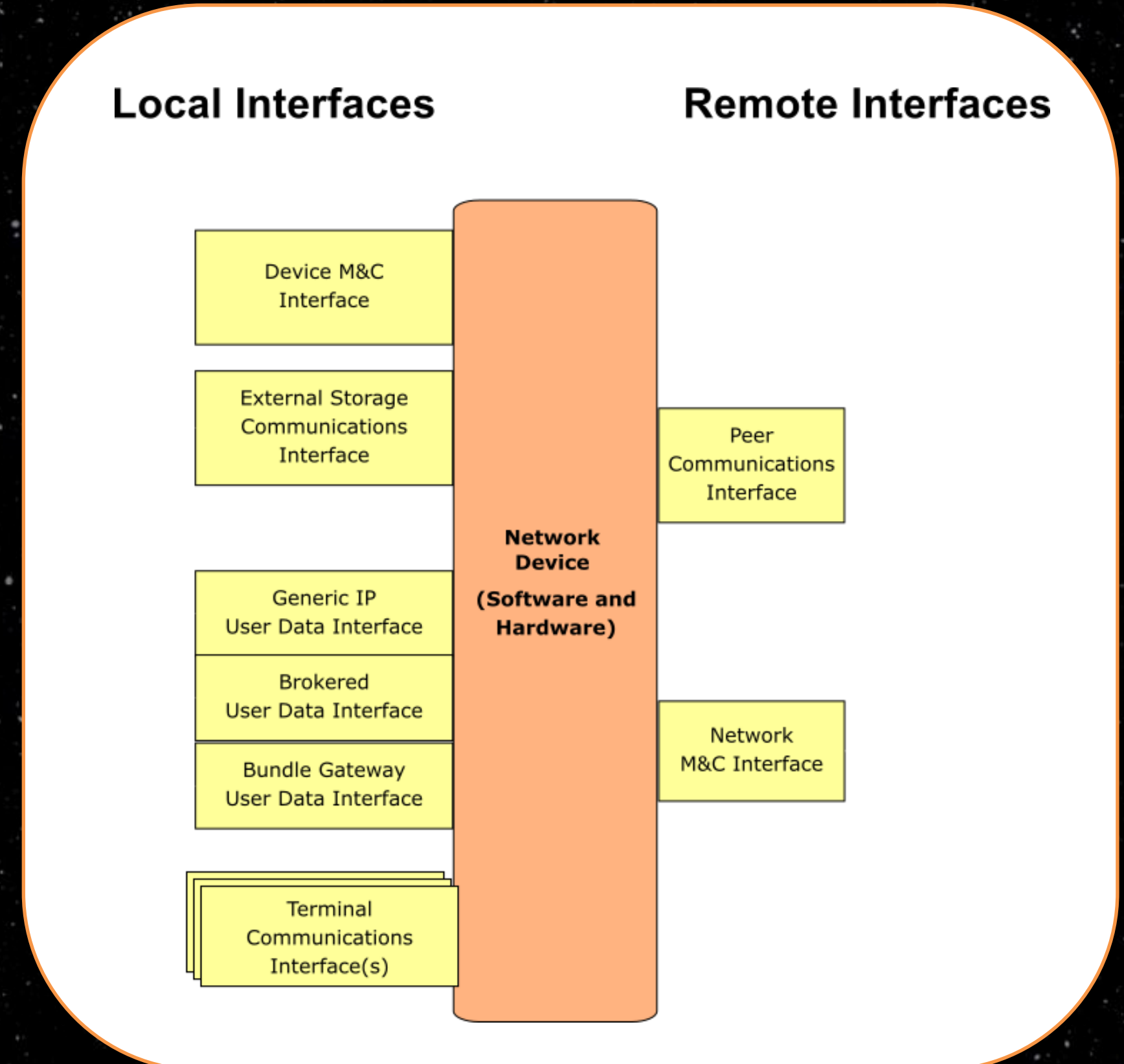
*Protocols are only a small part of this story...
An enterprise router is more than an IP stack...*



External Interfaces

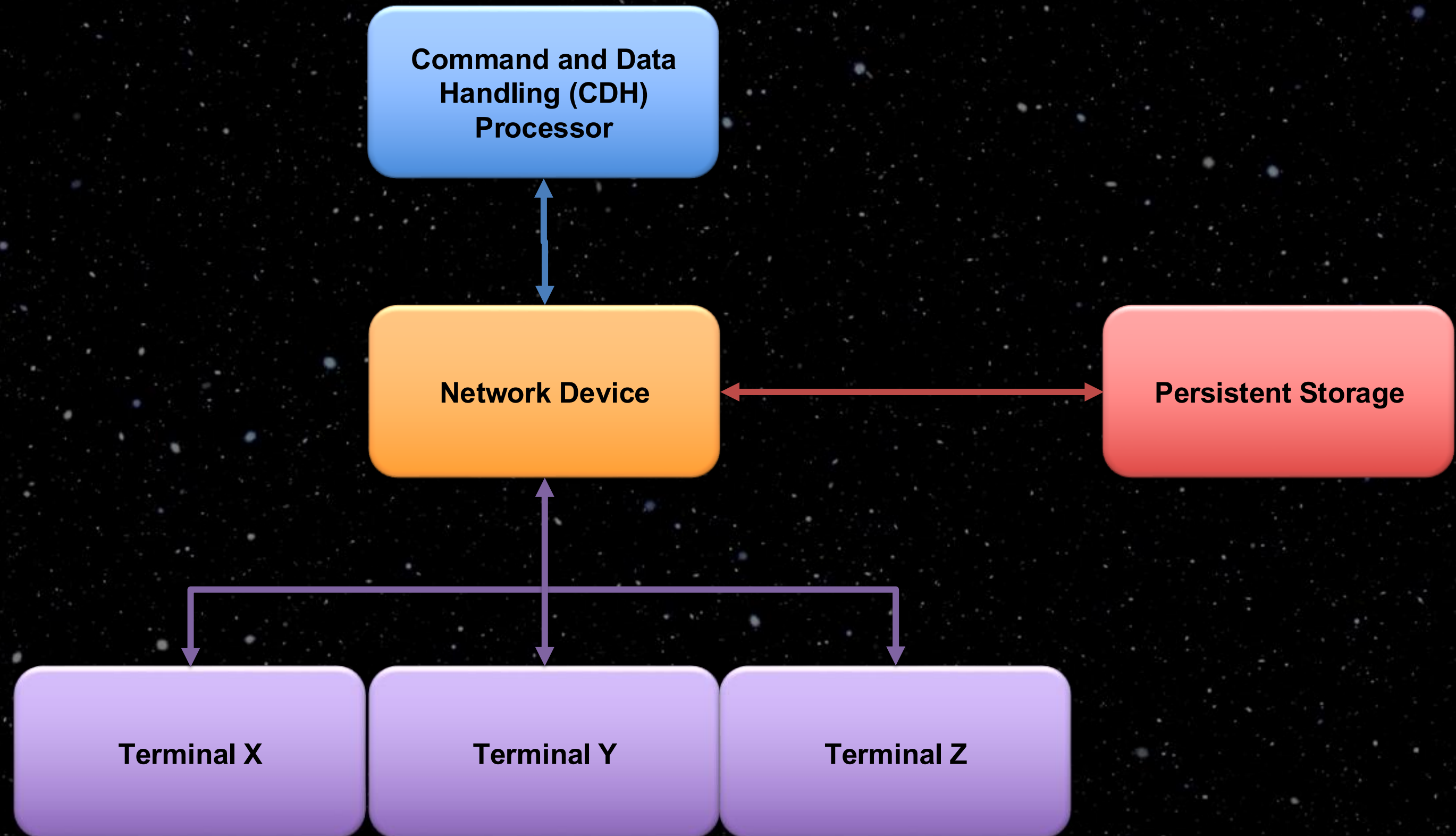
Network devices are part of an on-board ecosystem

- **Device Management**
 - Safe modes and fault autonomy
 - Software updates
- **Network Management**
 - Software-defined networking
 - Security, topology, customers
- **Multi-Protocol Inputs**
 - IP, BP, and raw data
- **Peering Interfaces**
 - Handshaking devices in the overlay
- **On-Board Integrations**
 - Interface with SSR storage
 - Manage/buffer terminals (RF/Optical)



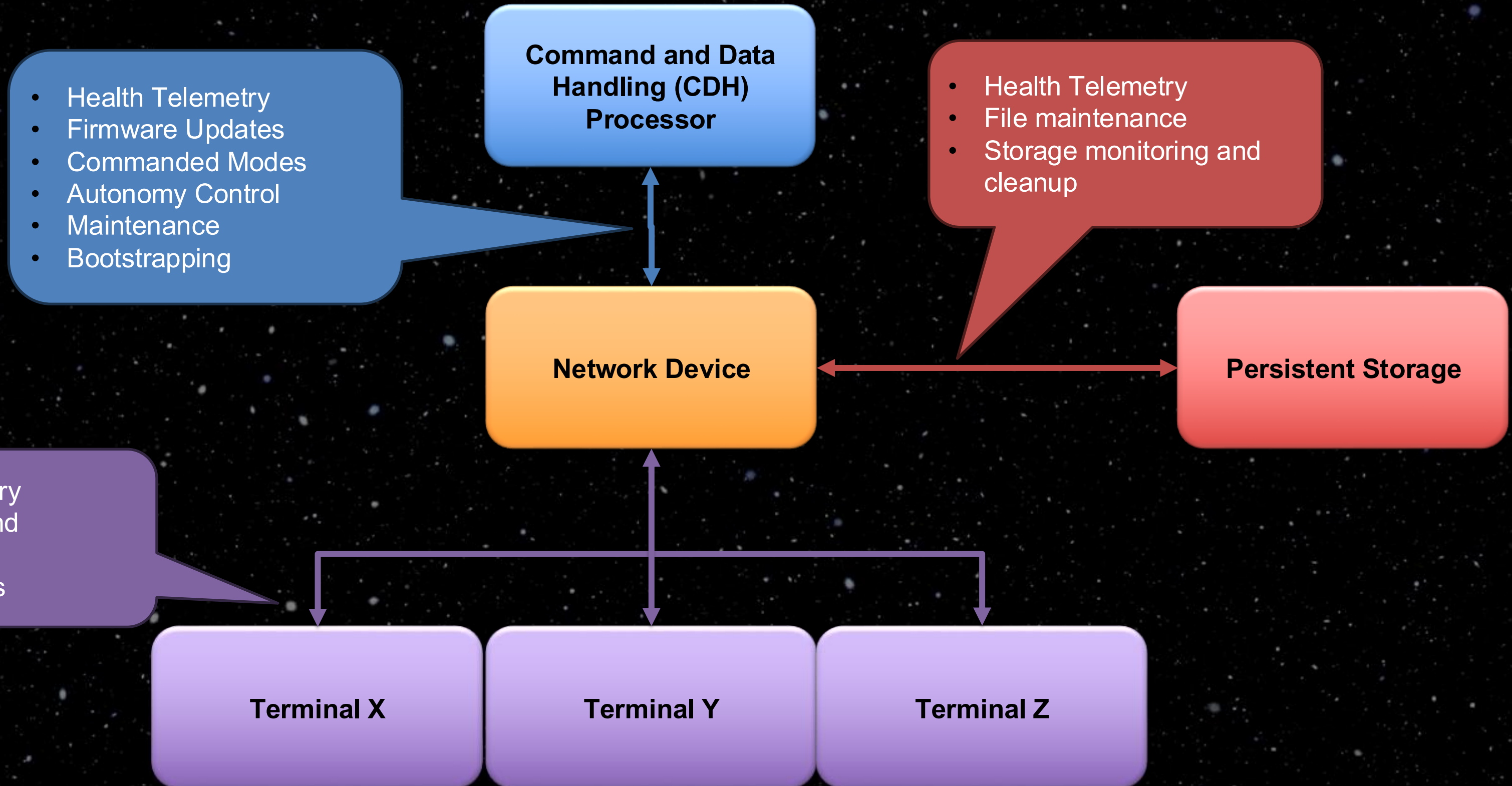
On-Board Control Integration

Devices must integrate – not replace – in-situ control



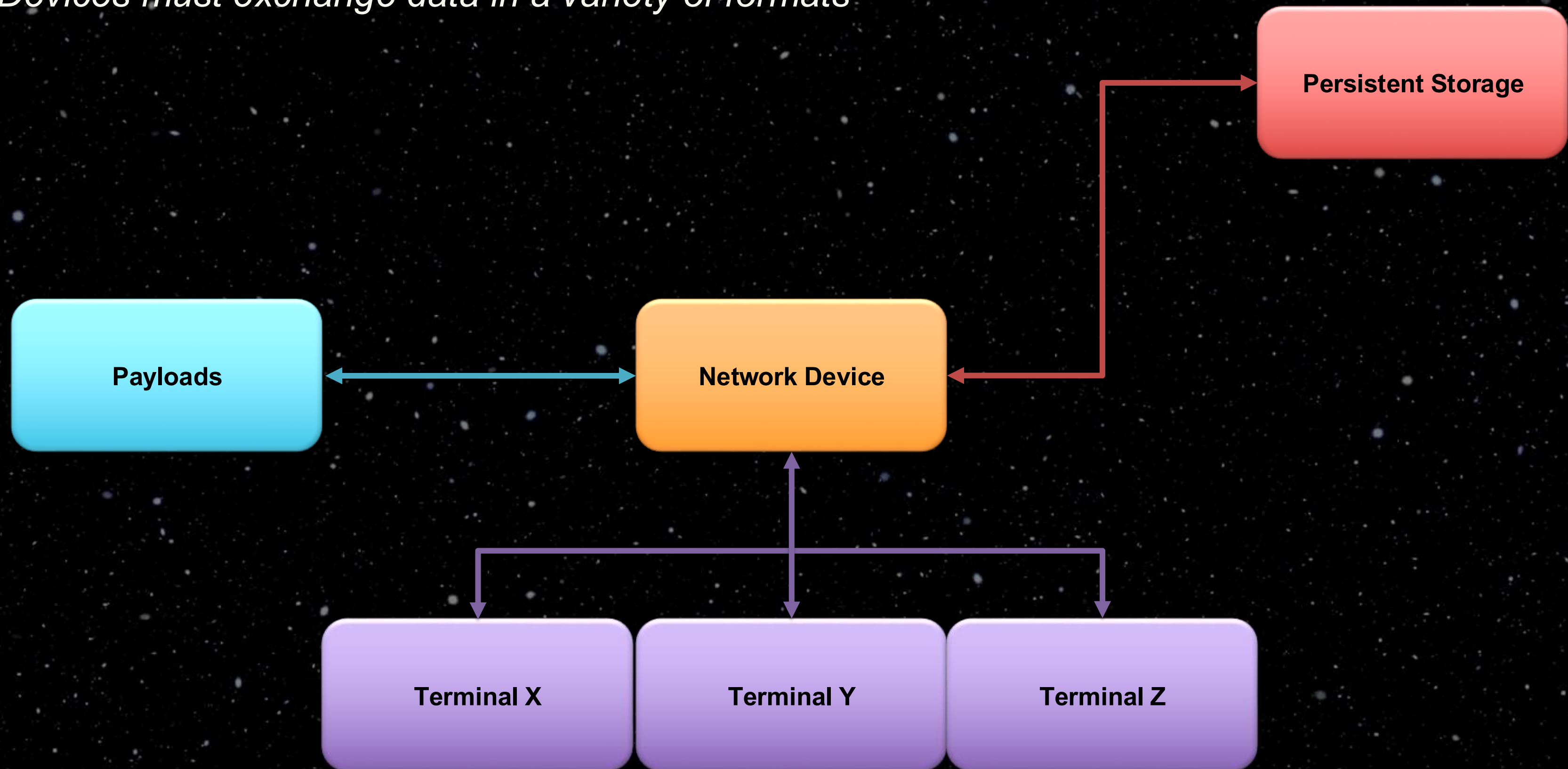
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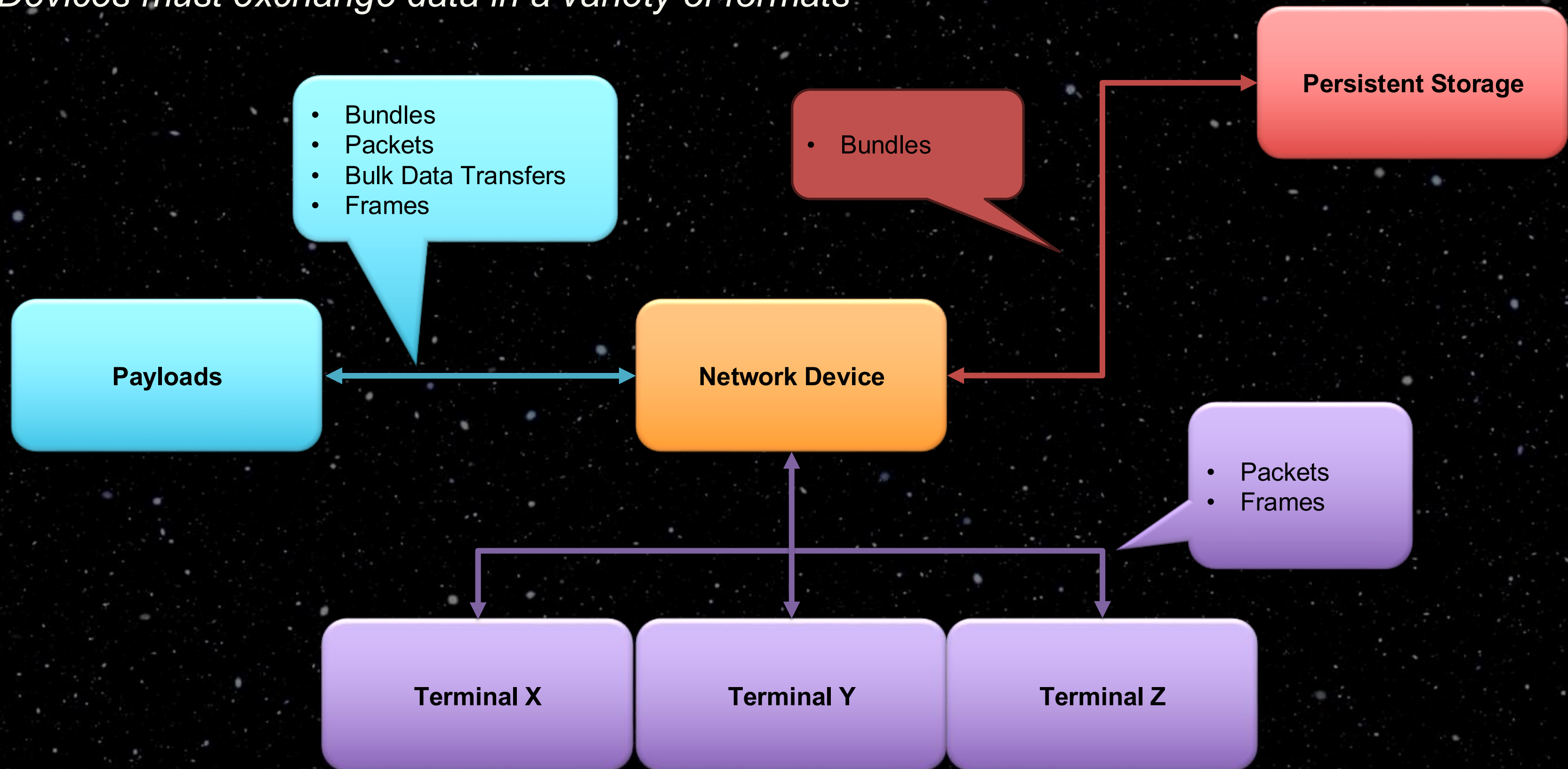
On-Board Data Integration

Devices must exchange data in a variety of formats



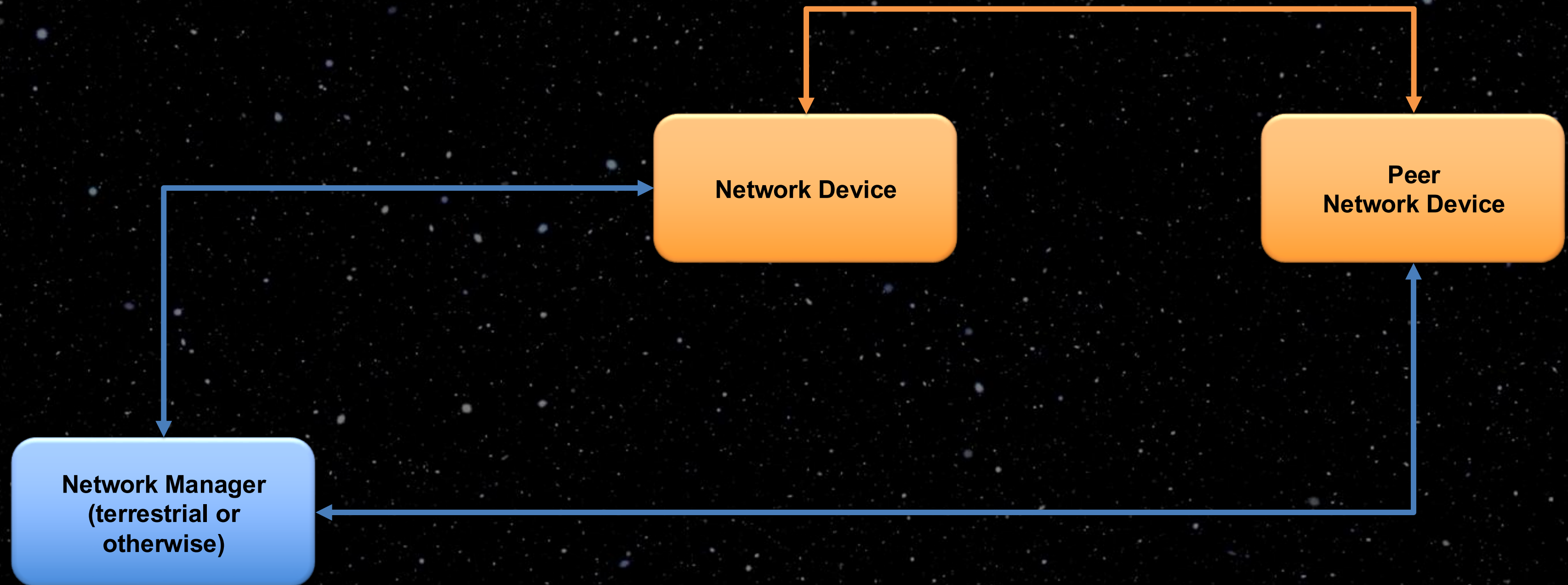
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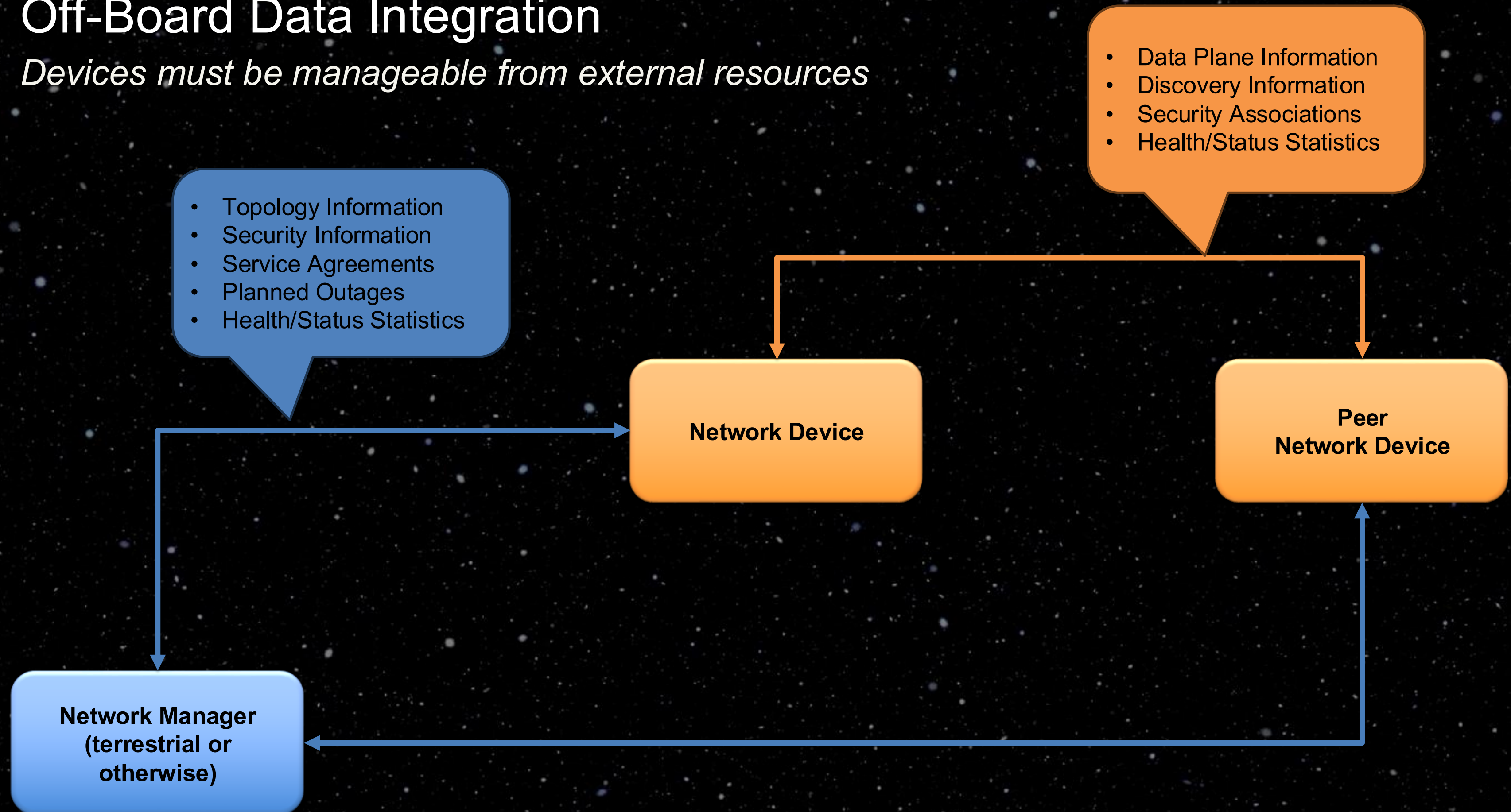
Off-Board Data Integration

Devices must be manageable from external resources



Off-Board Data Integration

Devices must be manageable from external resources



Summary

We are at the beginning of serious space-based network deployments

- **Deep space networks are being built!**
 - Networks at the Moon
 - Networks at Mars
- **Technical challenges remain**
 - We need operational systems
 - Operational data drives evolution
- **Protocols and data planes are not enough**
 - Networks integrate multiple elements
 - Maturity means not "rolling your own" network from scratch each time
- **Network devices are what we need**
 - Common solution to common problems
 - Built to integrate with spacecraft and other embedded systems
 - Including, but much more than, a data plane and associated protocols
 - Keeps multiple networks interoperable even when managed by different entities

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Syntactic and semantic interoperability.

Questions?

