A Real-Time Publish-Subscribe Control Plane for a COTM Node

HPEC

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Outline

- Introduction
  - Assumptions
  - Requests
- Problem Statement
  - Project Vision and System Context
  - System Architecture
  - Software Architecture Problem
- Software Architecture
  - Quality Attributes and Architectural Styles
  - Architectural Reasoning
  - Quality Attribute Tradeoffs
  - Runtime View
- Design and Implementation
  - Designing Topics
  - Topic Mapping
  - Handling Exceptions
- Conclusion
  - Lessons Learned
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Assumptions and Requests

- **Assumptions:**
  - You know what MIT Lincoln Laboratory does
  - You recognize the value of buying vs. building software
  - You know that there's no such thing as a "silver bullet"
  - You are familiar with the concepts of call-return middleware
  - Many of you are familiar with real-time publish-subscribe
- **Requests**
  - If you'd like to discuss any of these assumptions, please talk with me offline
  - Please hold your questions until the end of the talk

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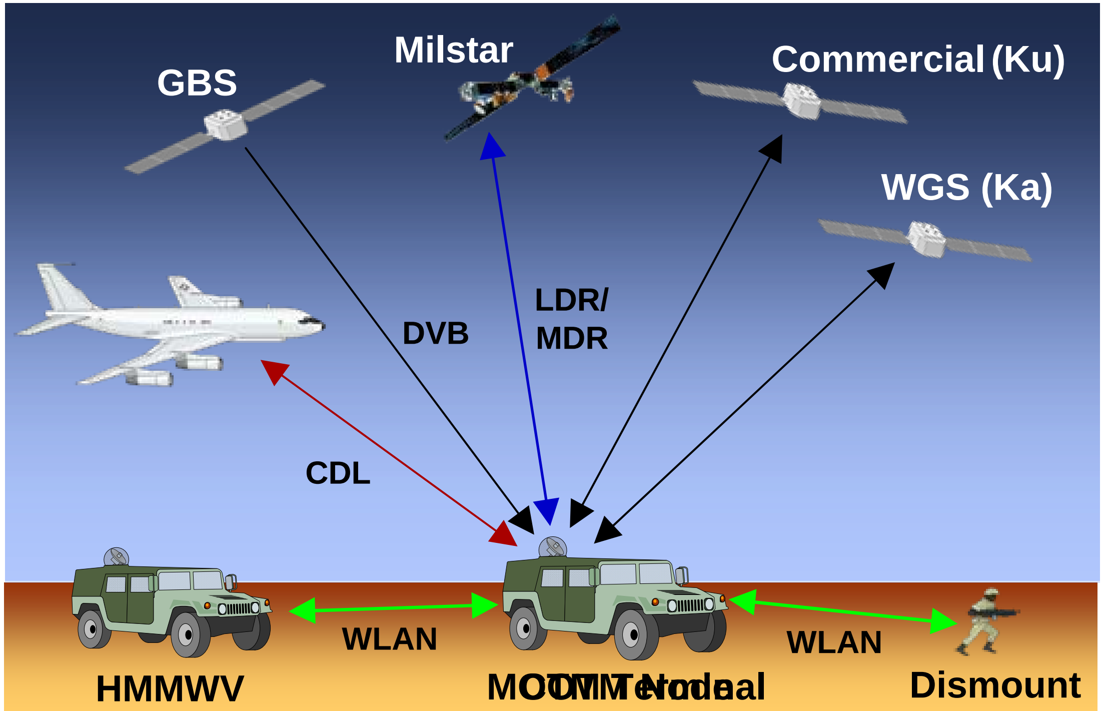
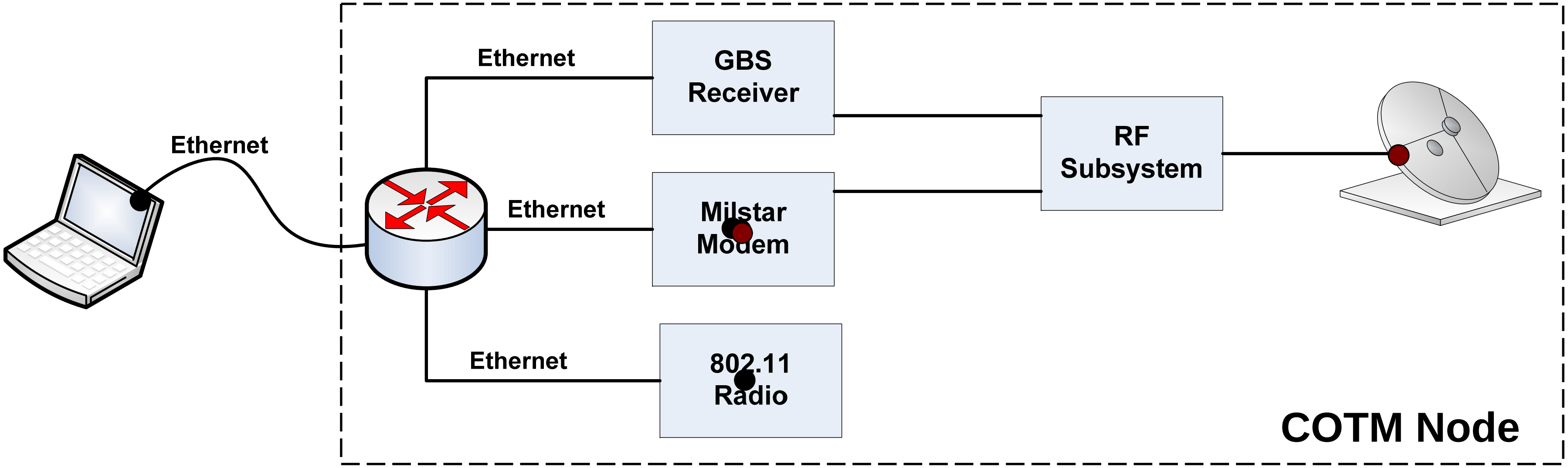
Vision: Evolution of Terminal to Node

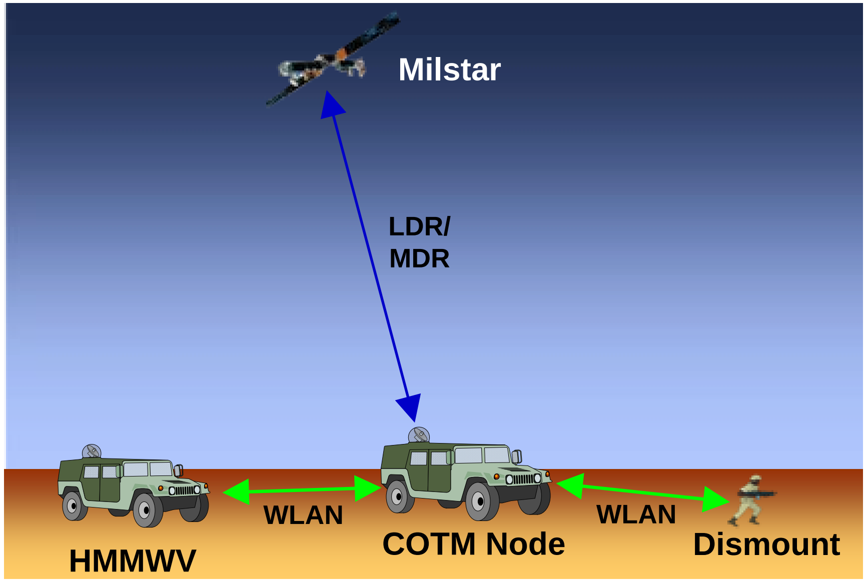
- Milstar On-The-Move (MOTM) Terminal
  - 3-axis positioner (MITLL)
  - Multi-band antenna and feed (44/30/20 GHz)
  - Blockage mitigation technology for COTM
  - IP over Milstar capability
  - Single link capability

- COTM Node
  - Manage multiple links
  - Compose links from modular HW/SW components
  - Facilitate integration of “stovepipe” COTS radios
  - Dynamic routing for cooperative networking
  - Support for insertion of additional radios



COTM Node: Phase 0 Data Plane

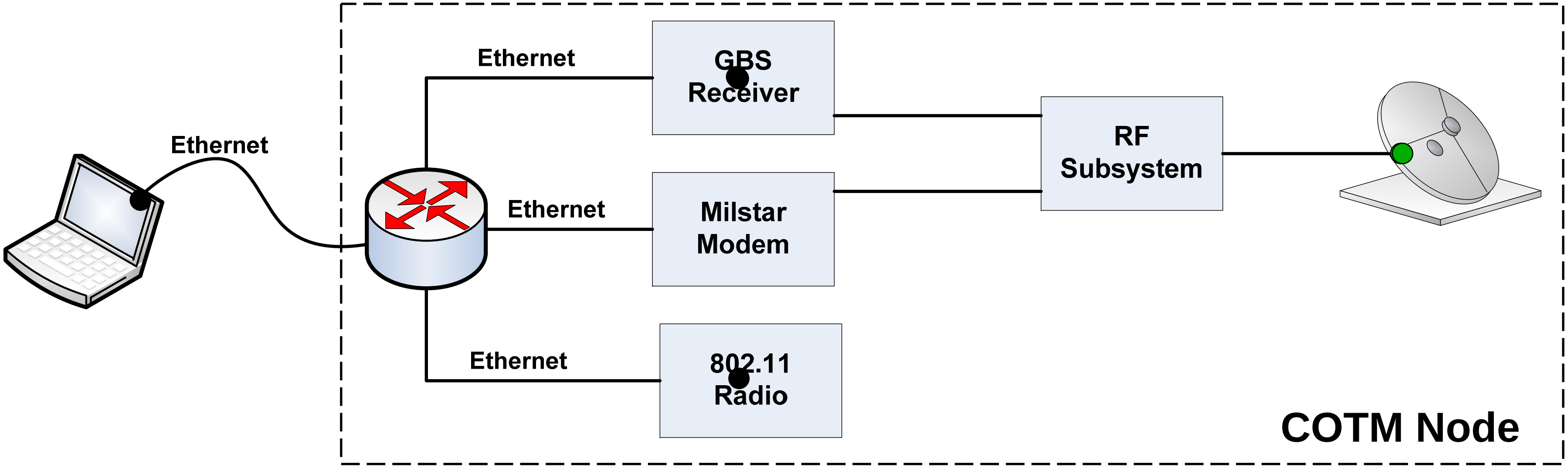


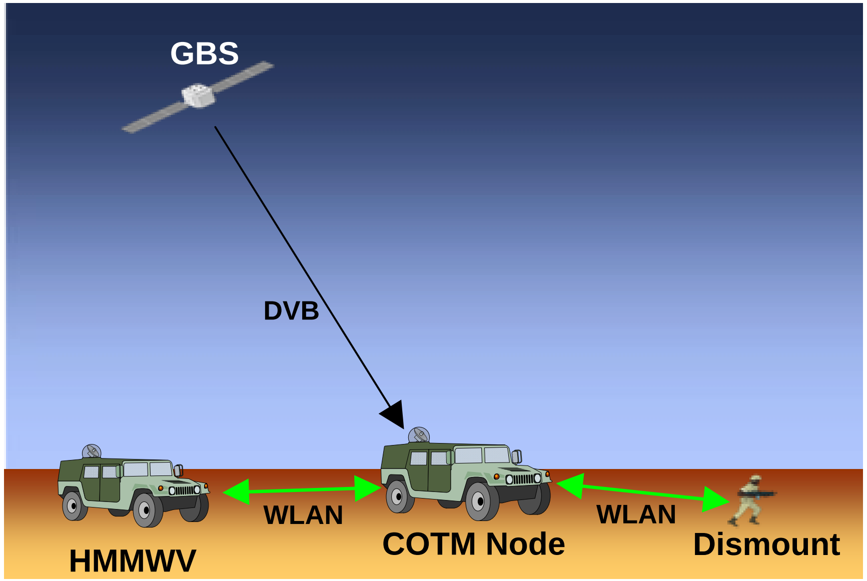


KEY

🔴 Milstar
🟢 DVB
⚫ IP

COTM Node: Phase 0 Data Plane





KEY

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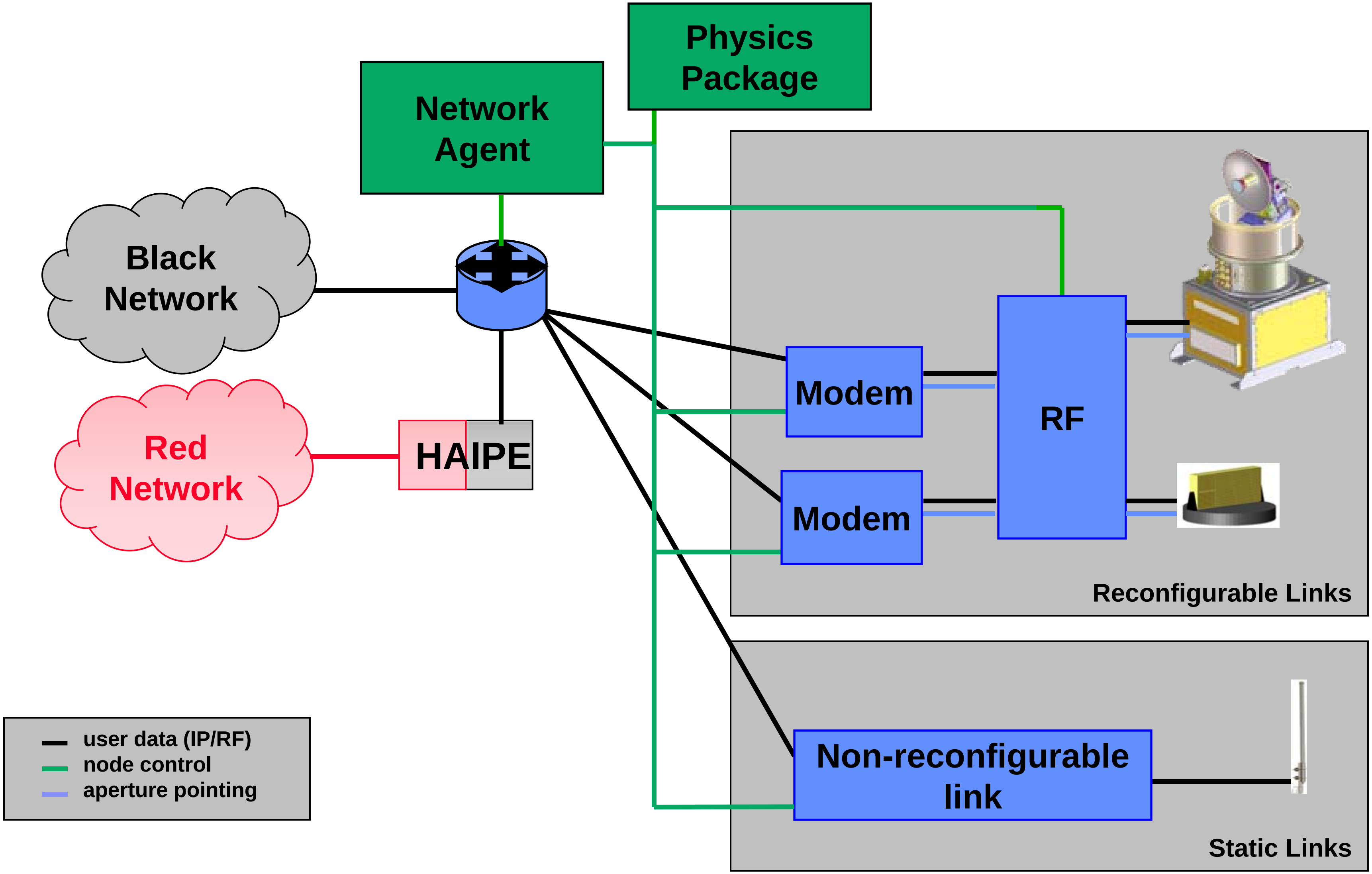
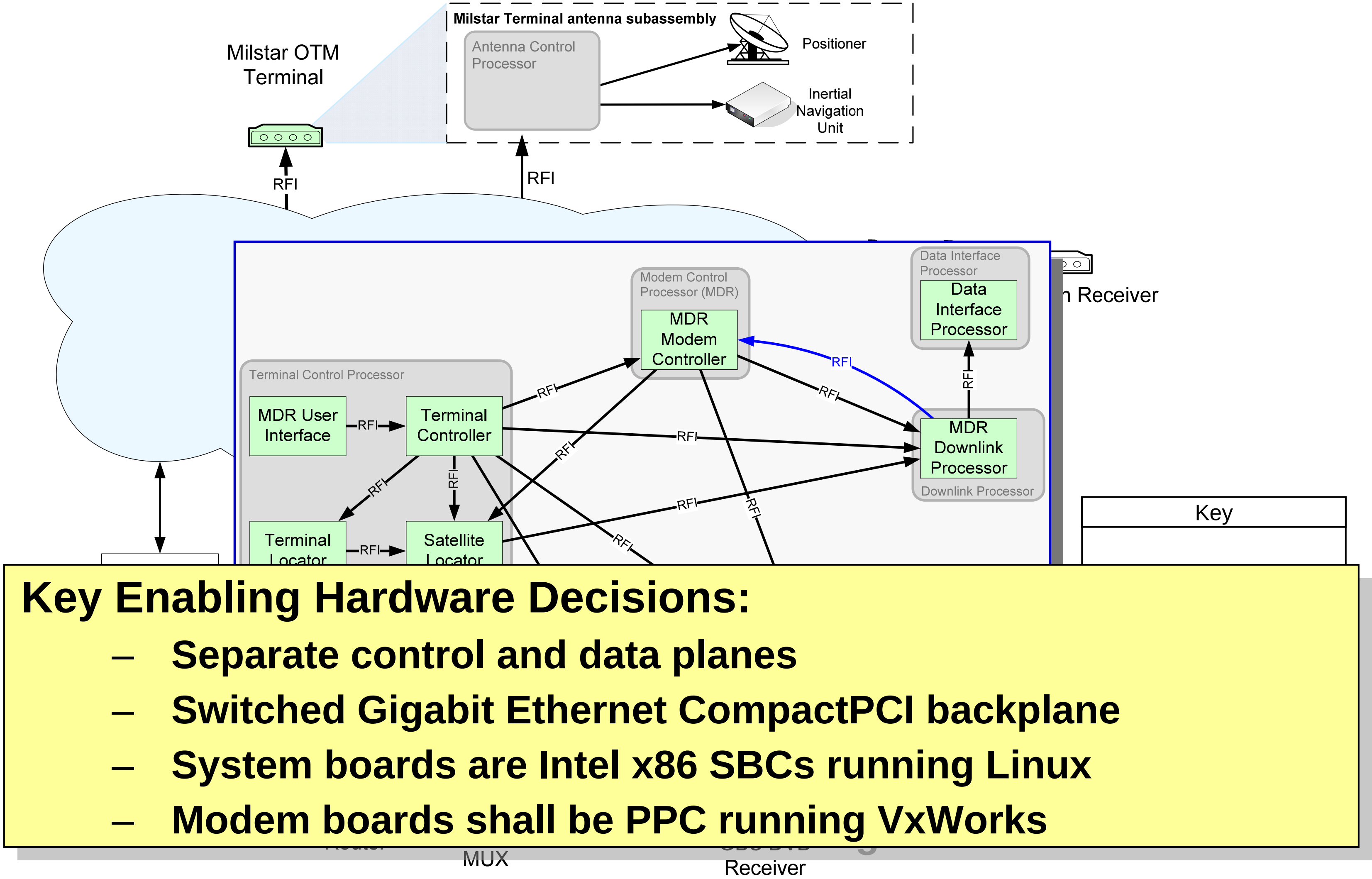
System Architecture Concept



Software Architecture Problem



Key Enabling Hardware Decisions:

- Separate control and data planes
- Switched Gigabit Ethernet CompactPCI backplane
- System boards are Intel x86 SBCs running Linux
- Modem boards shall be PPC running VxWorks

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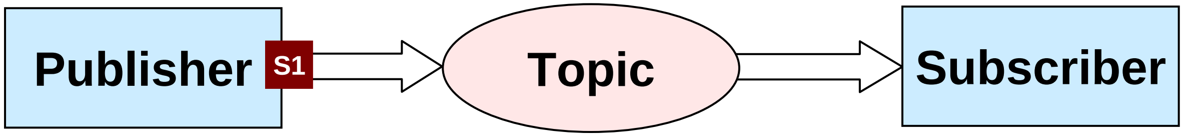
Quality Attributes and Architectural Styles

- **Essential Qualities**
  - **Predictability: Ability to anticipate task scheduling requirements**
  - **Timeliness: Ability to meet real-time constraints**
  - **Reliability: Ensures delivery of critical control data**
- **Desirable Qualities**
  - **Modularity: Facilitates decomposition and encapsulation**
  - **Extensibility: Facilitates addition of components (i.e. functionality)**
  - **Simplicity: Component development should be straightforward**
- **Architectural Styles**

Style	**Example Design Patterns**
Call-return	Client-server, forwarder-receiver
Implicit Invocation	GoF Observer, Publish-subscribe

Publish-Subscribe

- Subscribers register to collect *issues* to a particular Topic
- Publishers register to distribute *issues* to a particular Topic
- A Topic acts as a GoF Mediator to decouple Publishers and Subscribers



“VehiclePosition”

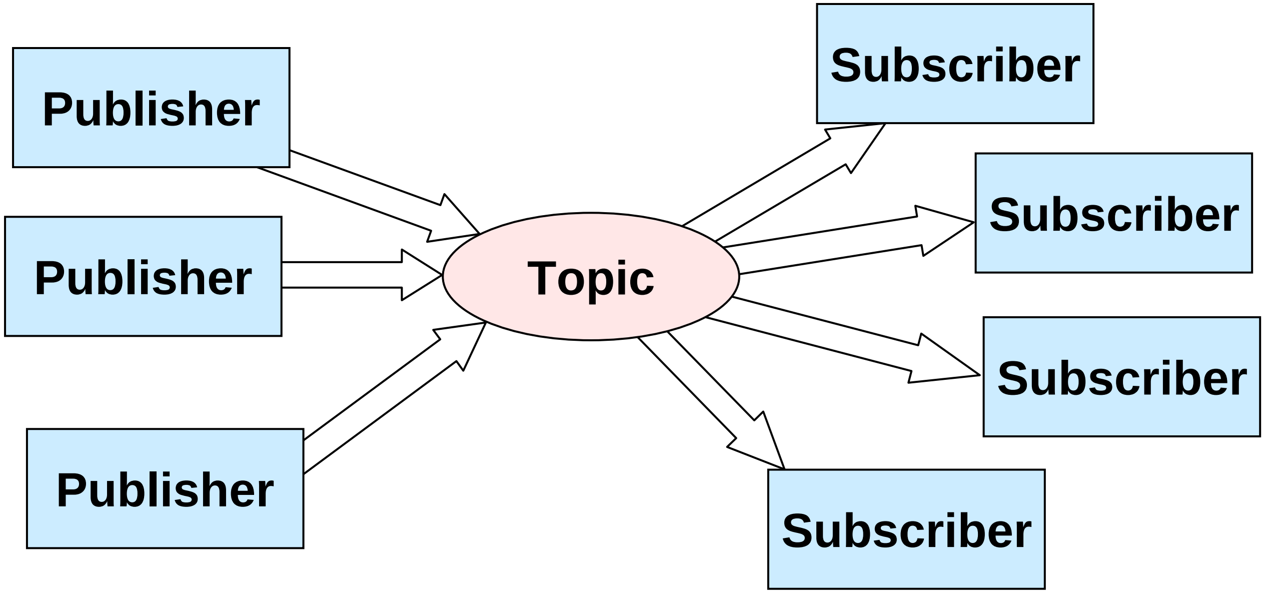
```
struct Position {
   double latitude;
   double longitude;
   double altitude;
}
```

Issue 1

```
longitude = -71.225
latitude = 42.447
altitude = 44.8
```

Publish-Subscribe

- May be zero or more publishers per topic
- May be zero or more subscribers per topic

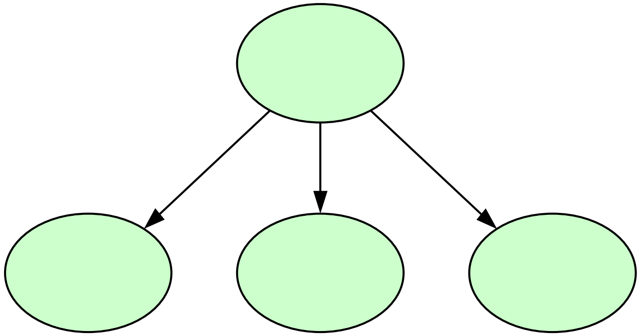


Architectural Reasoning

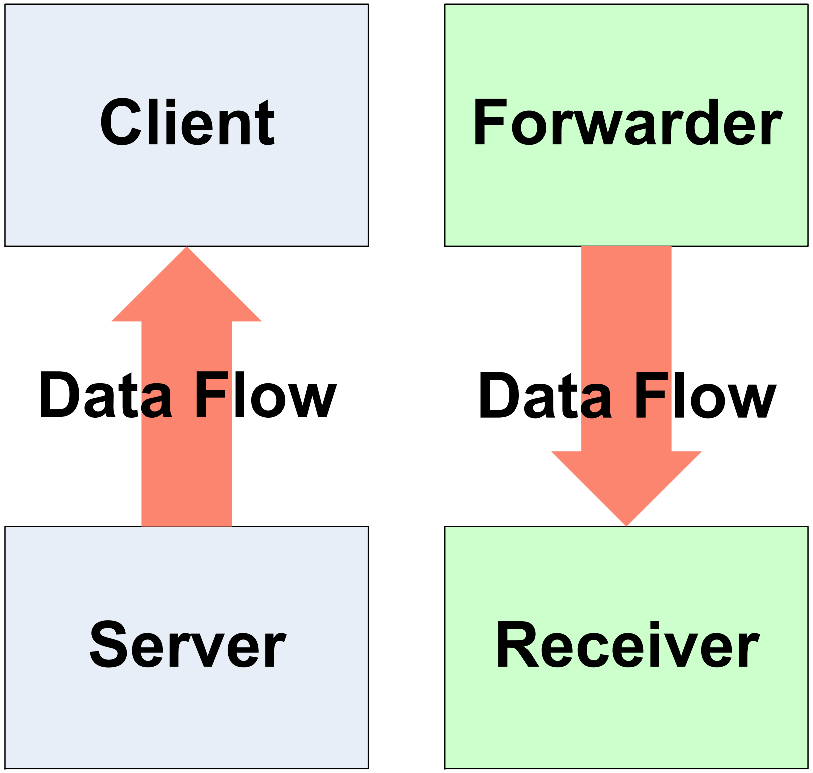
Publish-Subscribe

- Ideal for one-to-many or many-to-many relationships
- Promotes predictability
- Data-centric (data identifier)
- No assumption of existence
- Data source always initiates communication

Result: decoupled interaction



Call-return



Client

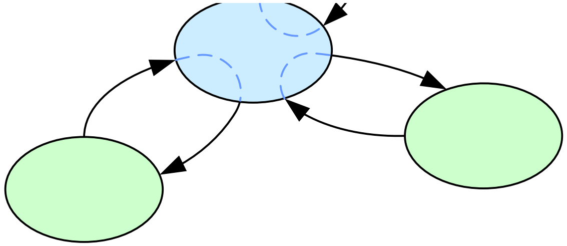
Forwarder

Data Flow

Data Flow

Server

Receiver



Quality Attribute Tradeoffs

Publish-Subscribe

- Timeliness
- Predictability
- Modularity
- Extensibility

Call-return

- Reliability
- Simplicity

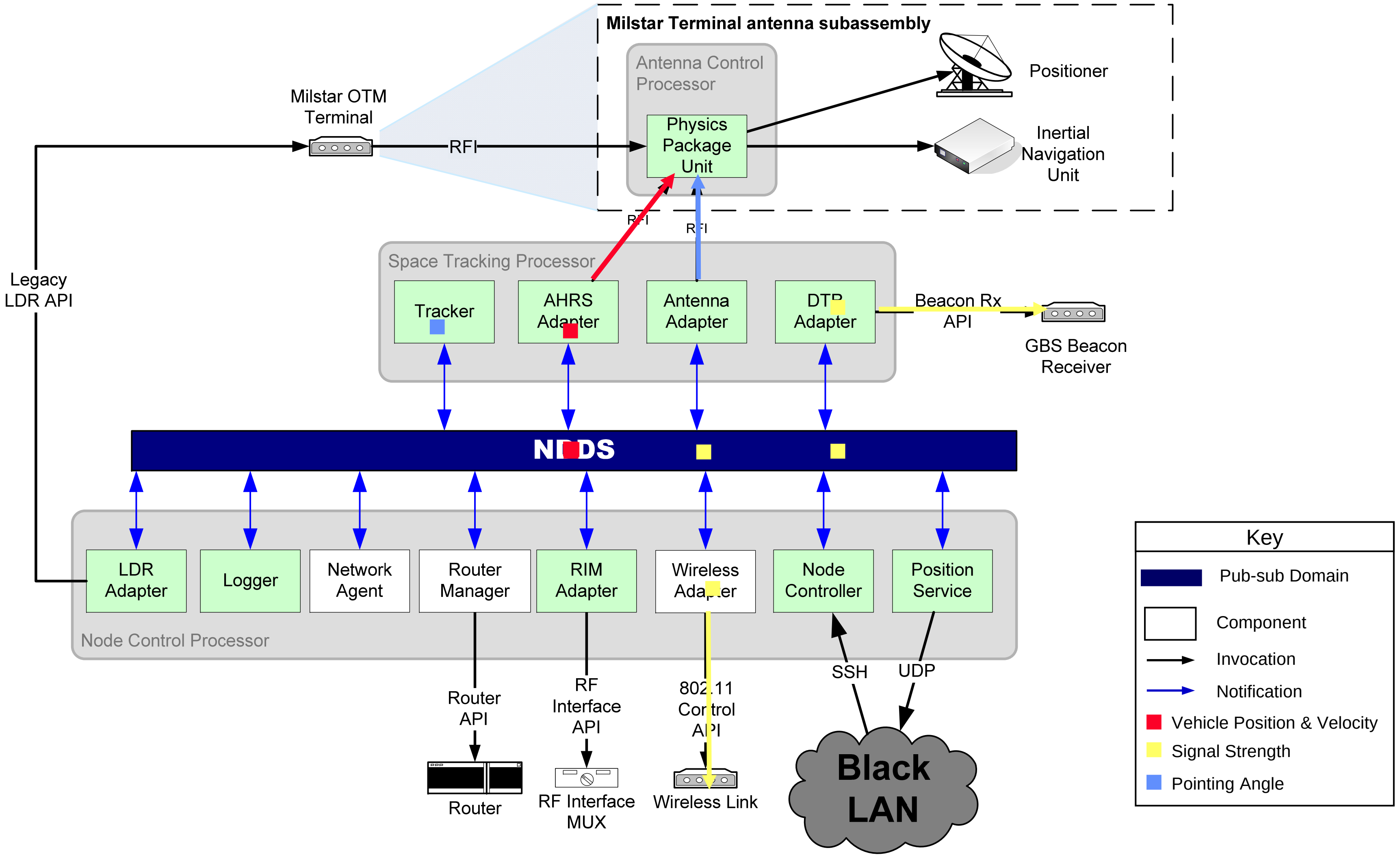
Real-time Publish-Subscribe with NDDS

- The Netw publish-
  subscrib vations, Inc.
- NDDS w ns
- Provides collection
  and dist
- At the ti pecification
  was still
- RTI was pecification
  effort
- RTI had DS spec
- RTI had

Quality of Service Parameters

Deadline	Presentation
Destination Order	Reliability
Durability	Resource Limits
Entity Factory	Time-Based Filter
History	Transport Priority
Latency Budget	Group Data
Lifespan	Topic Data
Liveliness	User Data
Ownership	Reader Data Lifecycle
Ownership Strength	Writer Data Lifecycle
Partition	

Software Architecture: Runtime View



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Designing Topics

- **Samples – periodic, independent measurements of the environment**

  Examples:
  - **Vehicle position and velocity**
  - **Link state**
  - **Modem signal strength**
  - **Satellite location and velocity**
  - **UTC Time**

RELIABILITY: BEST EFFORT

HISTORY: KEEP LAST

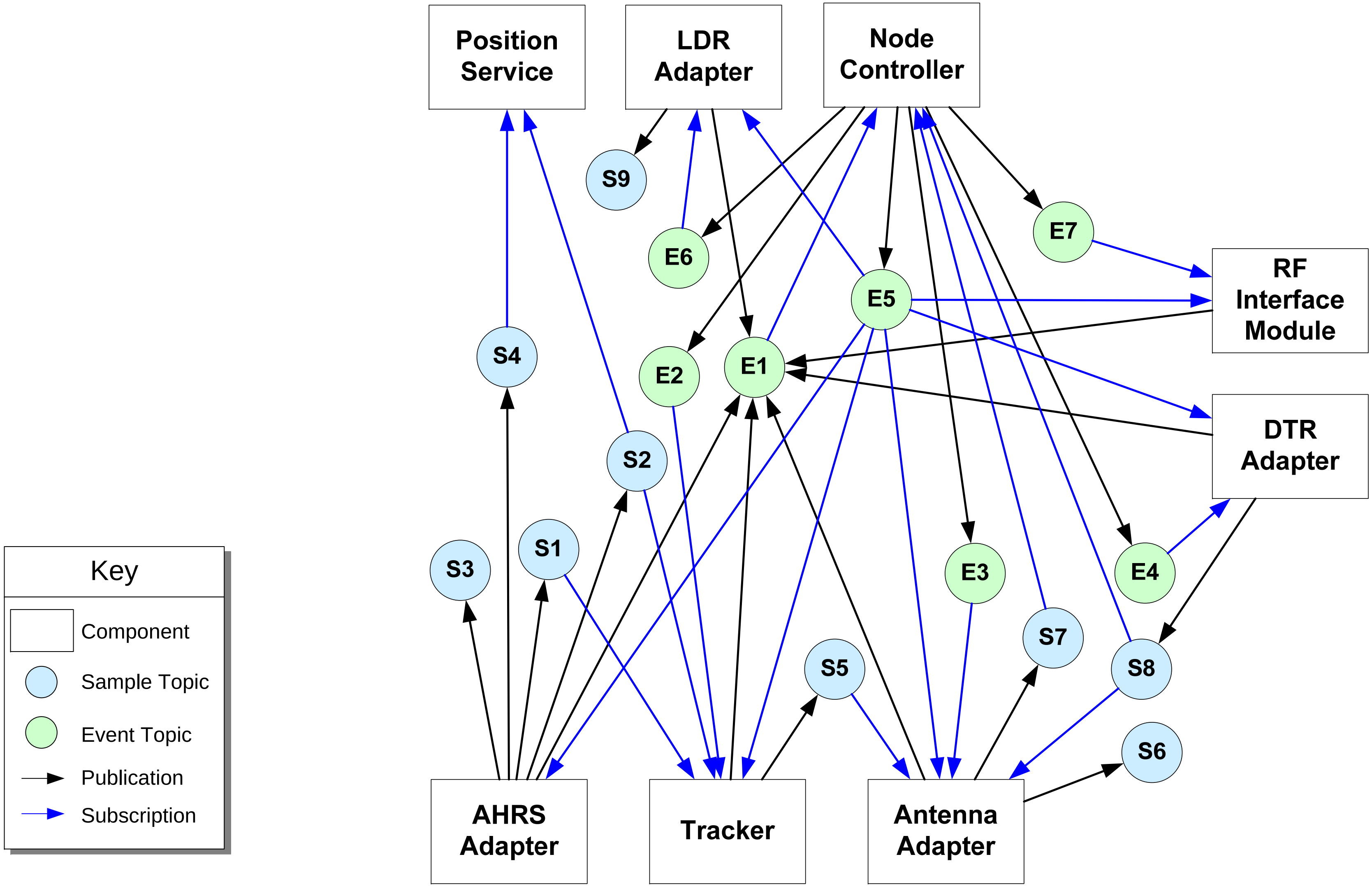
- **Events – sporadic, relative changes in system state**

  Examples:
  - **Link formation and teardown**
  - **Status messages**
  - **Error messages**
  - **Parameter changes**
  - **Routing changes**

RELIABILITY: RELIABLE

HISTORY: KEEP ALL

Topic Mapping



Topic Mapping: Samples

Samples

S1 – UTCTime

S2 – AHRSLocation

S3 – AHRSDisplacement

S4 – AHRSVelocity

S5 – AntennaReferenceAngle

S6 – AcquisitionMetric

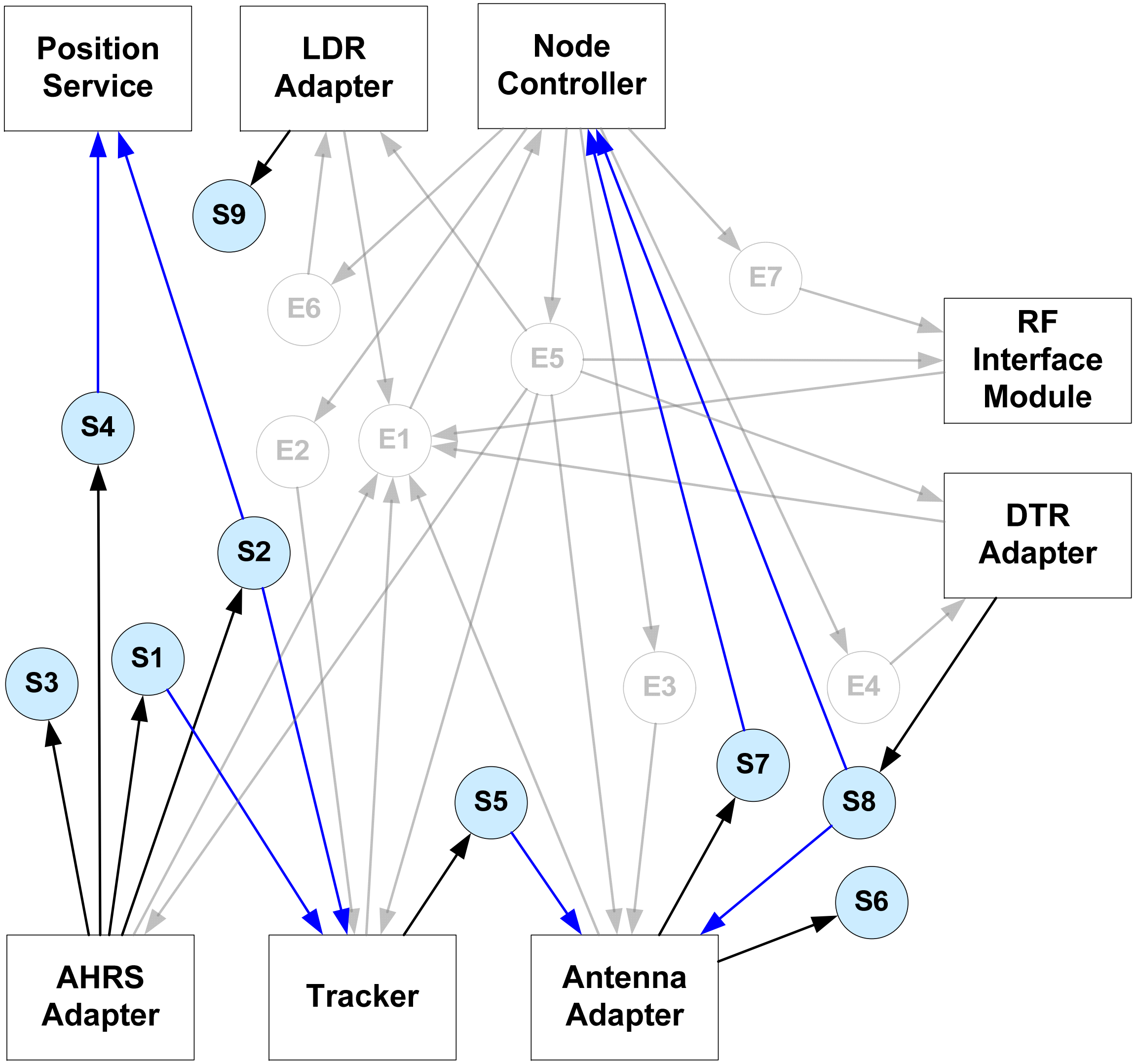
S7 – AntennaAngles

S8 – DTRSamples

S9 – LDREnergyMetric

Key

□	Component
○	Sample Topic
○	Event Topic
→	Publication
→	Subscription



Topic Mapping: Events

Events

E1 – DeviceStatus

E2 – TrackCommand

E3 – AntennaCommand

E4 – DTRParams

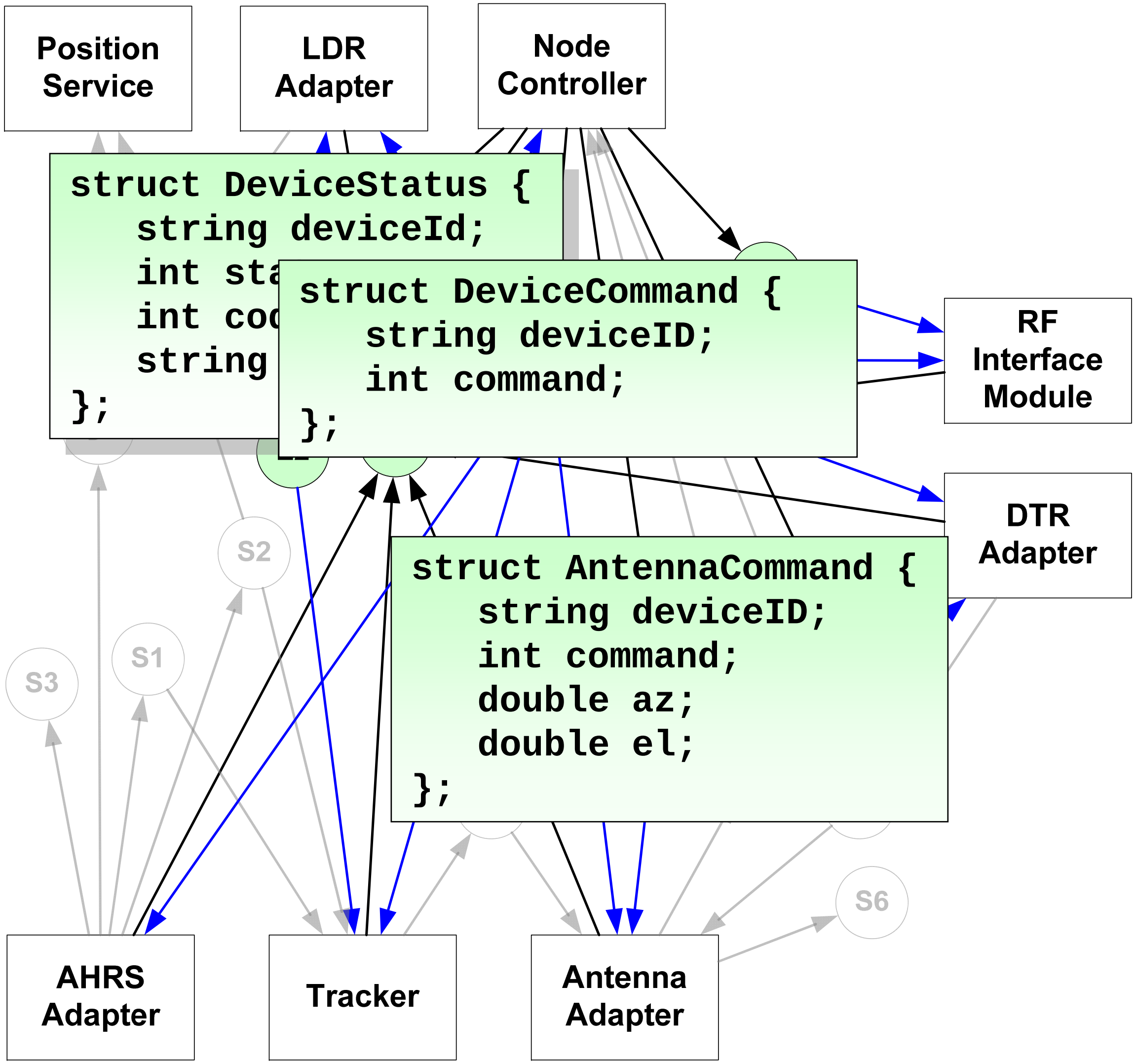
E5 – DeviceCommand

E6 – LDRCommand

E7 – RIMCommand

Key

- ▭ Component
- ● Sample Topic
- ● Event Topic
- → Publication
- → Subscription



```
struct DeviceStatus {
    string deviceId;
    int sta
    int coo
    string
};
```

```
struct DeviceCommand {
    string deviceID;
    int command;
};
```

```
struct AntennaCommand {
    string deviceID;
    int command;
    double az;
    double el;
};
```

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Lessons Learned

- Using publish-subscribe:
  - Made component development slightly more complicated
  - Greatly facilitated software integration
  - Enabled us to successfully defer some components, while still making progress on the project
  - Is not as straightforward when you are marshalling parameters with commands
- Respect the invariants of the architectural style:
  - NodeController could be killed and later restarted with no detrimental impact to system in steady state
  - Debug topics could be published for later use with negligible impact on system performance
- Actively managing consistency of QoS settings was essential
- Having a commercial vendor to delegate middleware support concerns to was very helpful

Acknowledgements

- Sponsor: PM WIN-T, Ft. Monmouth
- Group Leaders: Dr. Marc Zissman and Scott Sharp
- Systems Engineer: Dr. Andrew Worthen
- RF team: Dr. Jim Vian, John Murphy, Ted O’Connell
- Hardware team: Steve Pisuk, John Delisle, Jason Hillger
- Software team: Darby Mitchell, Curran (Nachbar) Schiefelbein, Marc Siegel, Marie Heath
- Testing team: Dr. Mark Smith, Ted O’Connell

Current Work

- TSAT Reference Terminal (TRT)
  - A joint project with Group 64 based on TRUST-T
  - A COTM Node that is based on the Software Communications Architecture (SCA) for software defined radios.
  - The SCA mandates the use of CORBA middleware, so DDS will not be used.
- Network and Link Emulation Testbed (NLET)
  - A distributed network emulation testbed
  - Uses DDS for a distributed real-time context simulation and real-time dynamic control of link emulation.

References

- Mitchell et. al. "Applying Publish-Subscribe to COTM Node Control", *MIT Lincoln Laboratory Journal*, Volume 16, No. 2, December 2006.

  http://www.ll.mit.edu/news/journal/journal.html

- L. Bass, P. Clements and R. Kazman, *Software Architecture in Practice*, Addison Wesley, 1998.
- Garlan, D. and M. Shaw, *Software Architecture: Perspectives on an Emerging Discipline*, Prentice Hall, 1996.

Questions?

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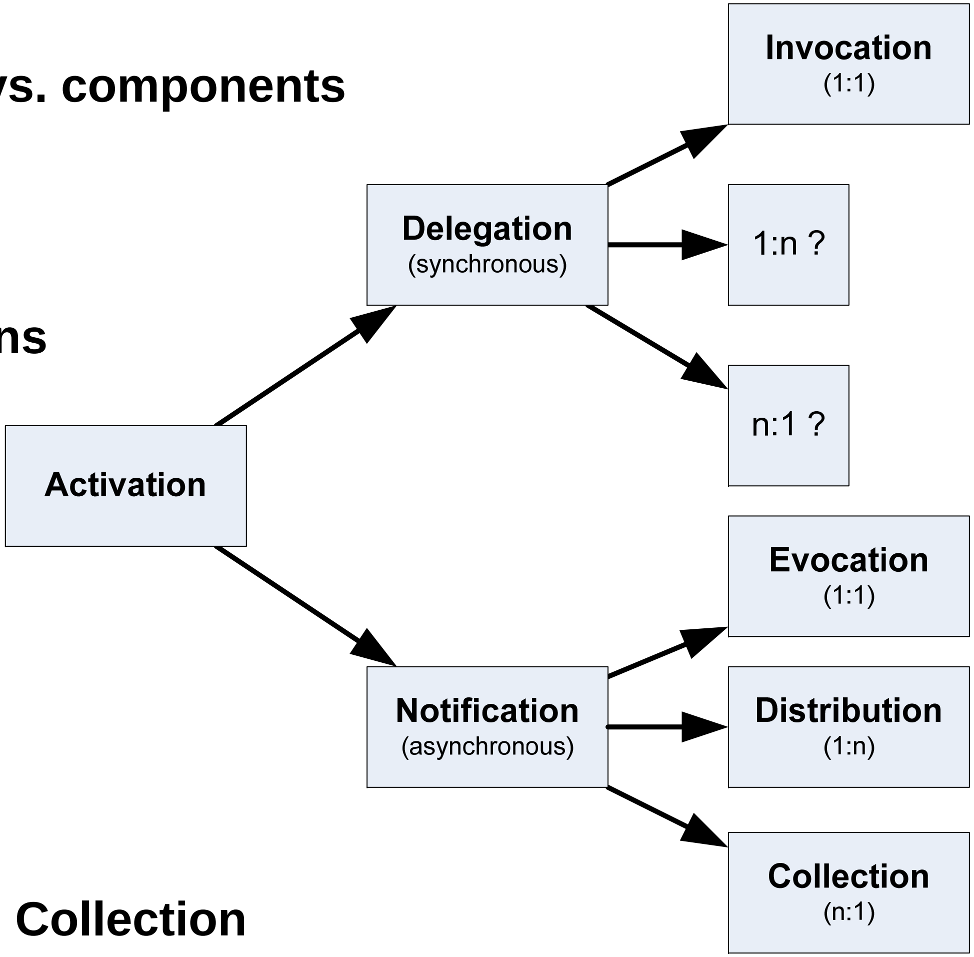
Backup Slides

Reasoning About Connectors

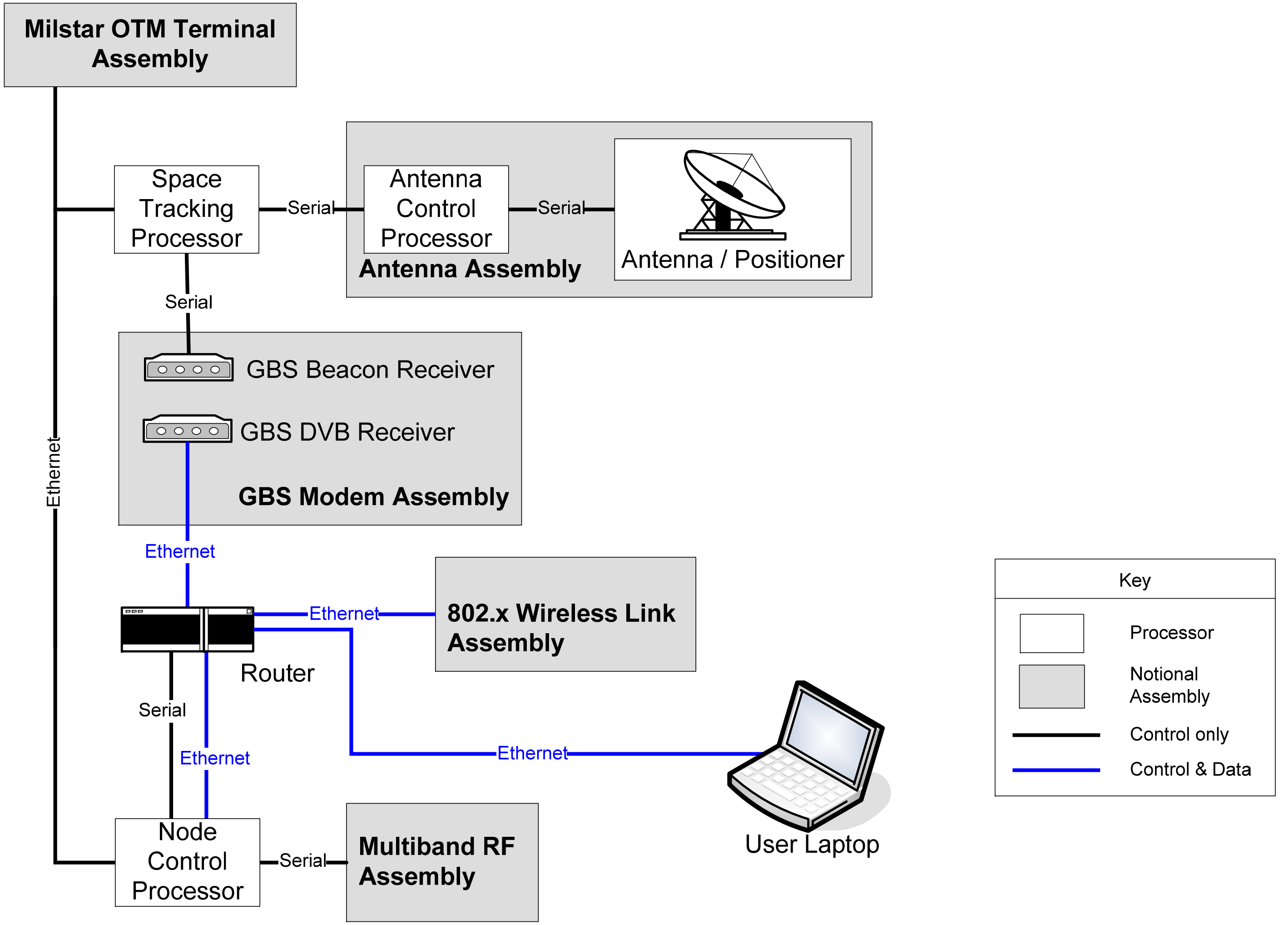
- Reasoning about connectors vs. components
- Consider several dimensions:
  - synchronous vs. asynch
  - cardinality (1 : 1 vs. 1 : n)
- Ignore implementation concerns



Publish-subscribe =

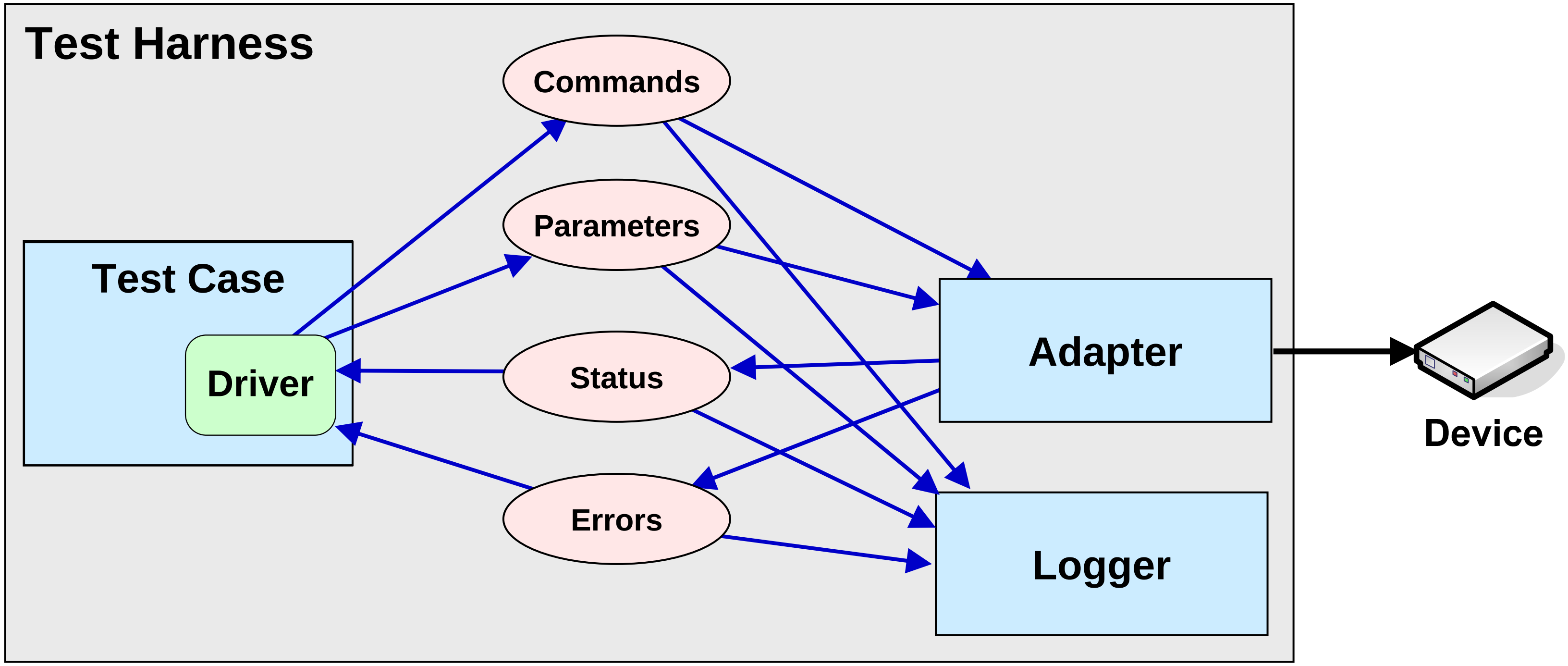
Distribution + Implicit Invocation + Collection

System Architecture: Connection View



Driver and Adapters

- There is a one to one relationship between Drivers and Adapters
- Node Controller only interacts with an Adapter through its Driver
- A Driver caches Status and Error updates from its Adapter
- Adapters may interact with other Adapters



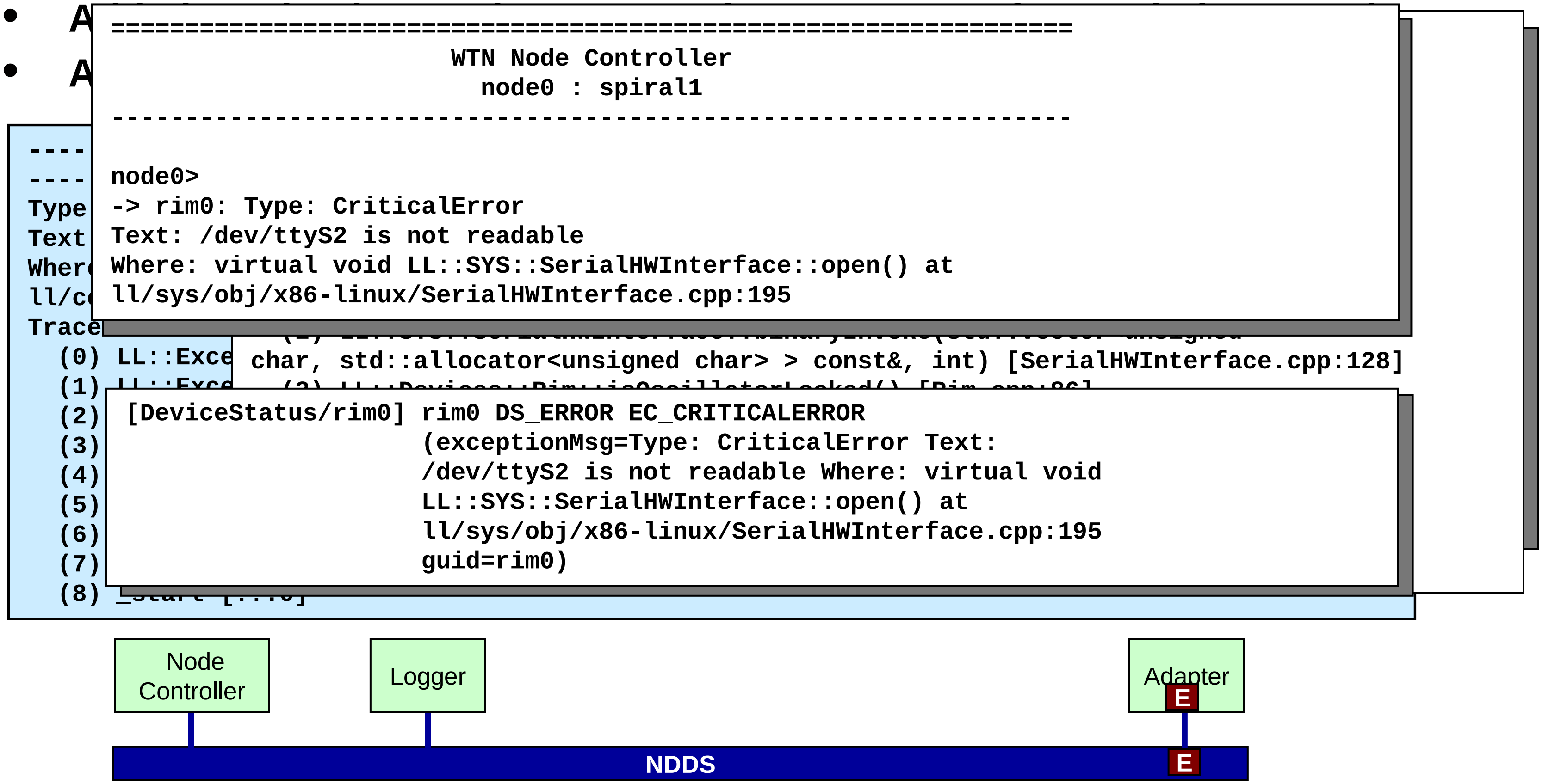
Exception Handling

- **Based on concepts from online article:**

  Agarwal, Sachin, “C++ Exception-Handling Tricks for Linux”, IBM Software Labs, Feb 2005.

  http://www-128.ibm.com/developerworks/linux/library/l-cppexcep.html?ca=dgr-lnxw1fExceptionTricks

- **A**
- **A**



```
================================================================
                      WTN Node Controller
                        node0 : spiral1
----------------------------------------------------------------

node0>
-> rim0: Type: CriticalError
Text: /dev/ttyS2 is not readable
Where: virtual void LL::SYS::SerialHWInterface::open() at
ll/sys/obj/x86-linux/SerialHWInterface.cpp:195
```

```
----
----
Type
Text
Where
ll/c
Trace
  (0) LL::Exce
  (1) LL::Exce
  (2)
  (3)
  (4)
  (5)
  (6)
  (7)
  (8) _start [...0]
```

```
  (1) LL::SYS::SerialHWInterface::binaryInvoke(std::vector<unsigned
char, std::allocator<unsigned char> > const&, int) [SerialHWInterface.cpp:128]
  (2) LL::Devices::Rim::isOscillatorLocked() [Rim.cpp:86]
```

```
[DeviceStatus/rim0] rim0 DS_ERROR EC_CRITICALERROR
                    (exceptionMsg=Type: CriticalError Text:
                    /dev/ttyS2 is not readable Where: virtual void
                    LL::SYS::SerialHWInterface::open() at
                    ll/sys/obj/x86-linux/SerialHWInterface.cpp:195
                    guid=rim0)
```