Your systems.
Working as one.

Connecting Autonomous Systems in the IIoT

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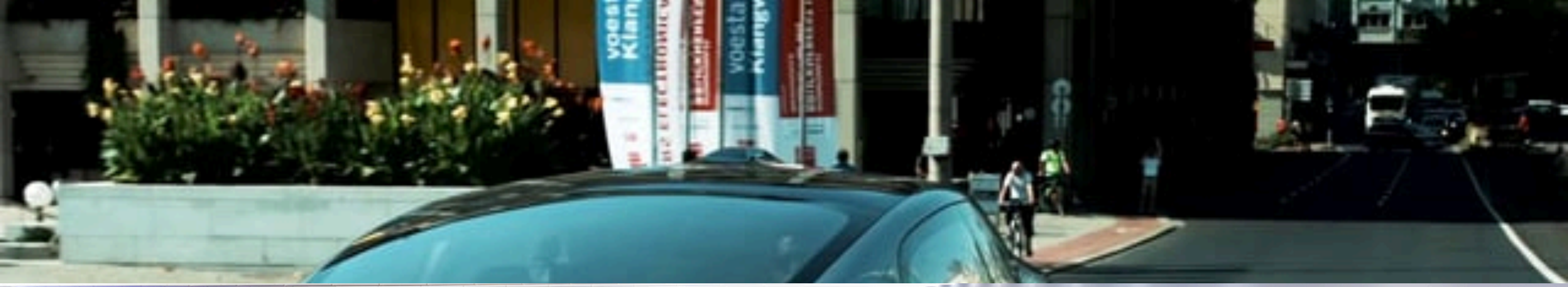
Chief Technology Officer, RTI

Singapore ConnextCon, October 2019

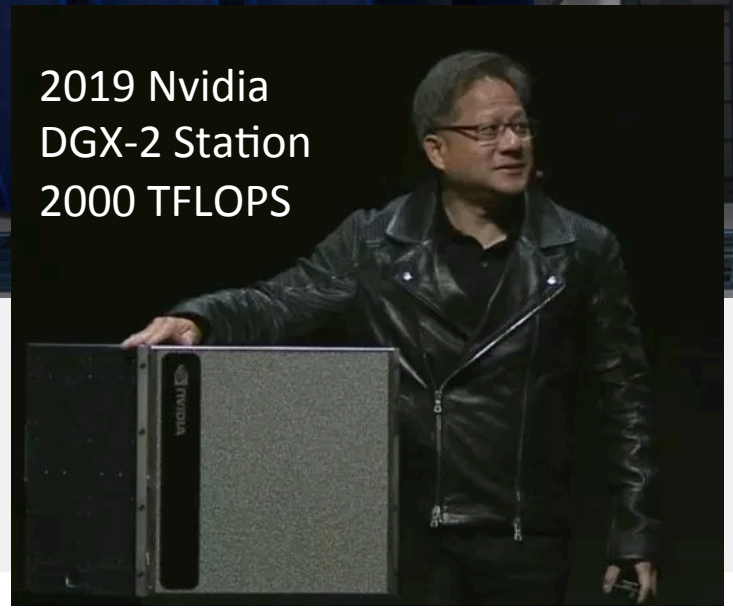
Edge Intelligence/Autonomy Future



Autonomous car is a “datacenter” on wheels

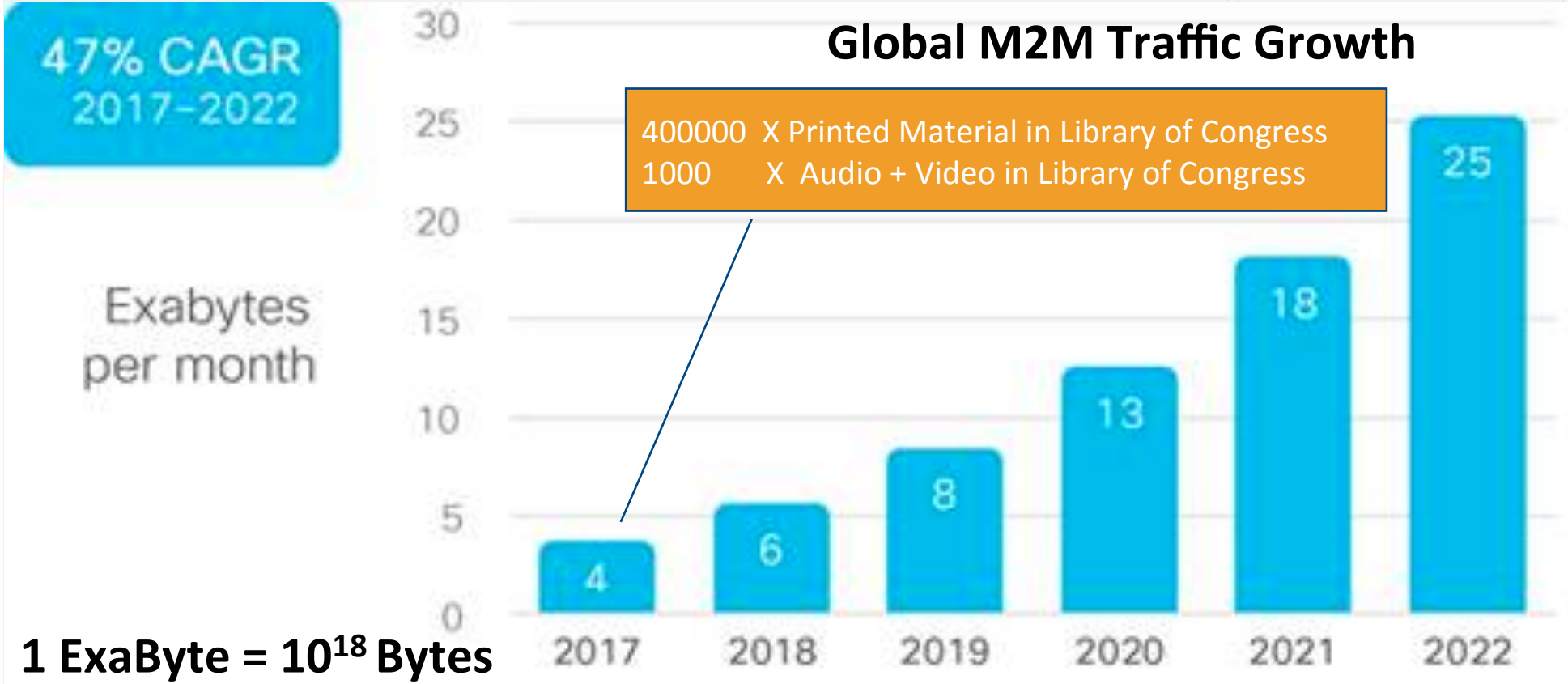
Increase in computational power

40 TFLOPS Data Center circa 2002 (NEC Earth Simulation Computer)



2007 IBM Blue Gene/L, 400 TFOPS

Increase in Machine to Machine traffic



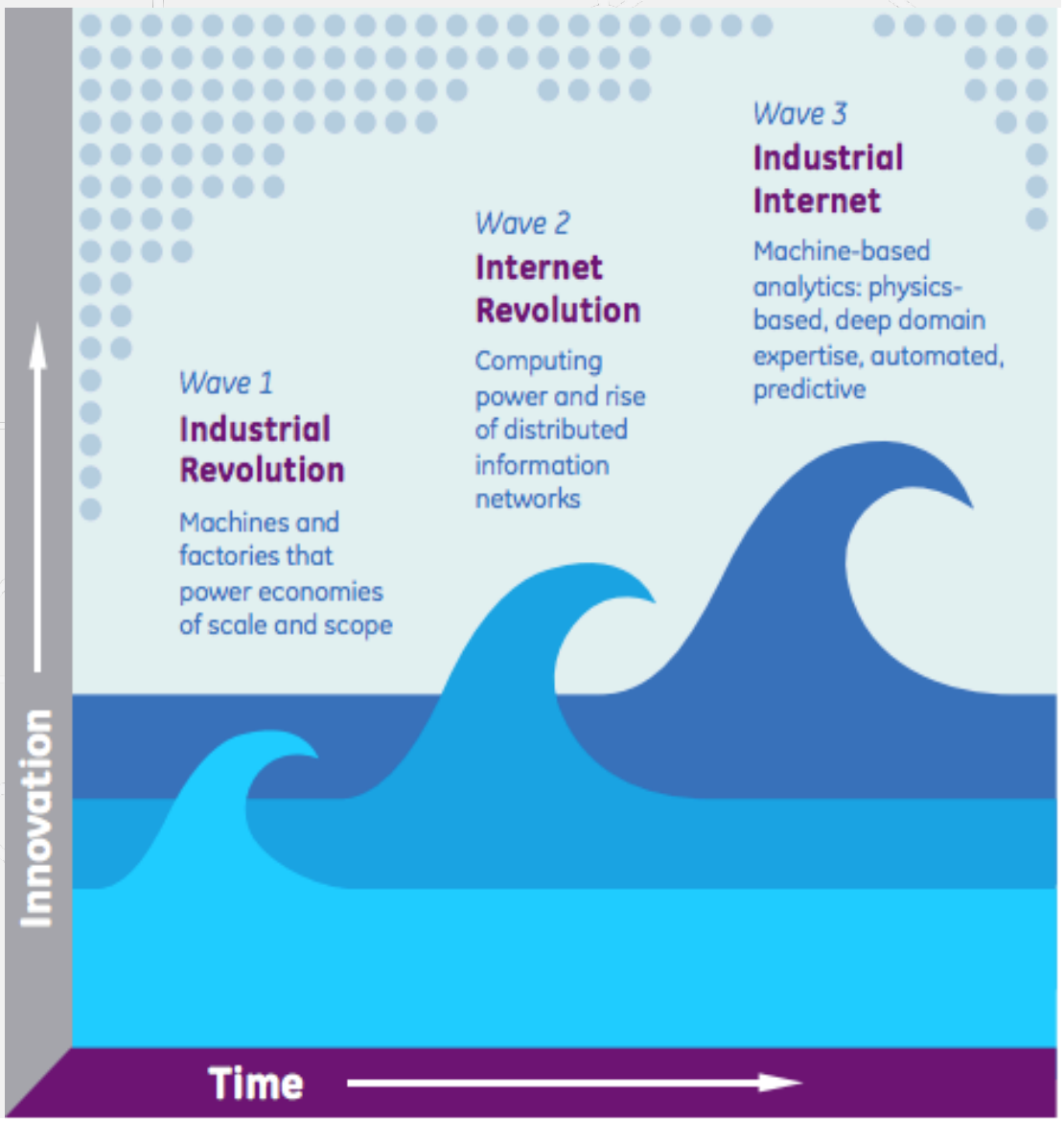
1 ExaByte = 10^{18} Bytes

1 TeraByte = 10^{12} Bytes

Source: Cisco VNI Global IP Traffic Forecast, 2017-2022

From computing to networking and autonomy

- Computing / Moore's Law:
  - The number of transistors doubles every 18 months
- Internet / Metcalf Law:
  - The value of a network grows as the SQUARE of (connected) nodes
  - #Nodes doubles every 2 years
- IIoT / Edge Autonomy Law?
  - Value of Connected Platform = **NodeComplexity * ConectedNodes^2**



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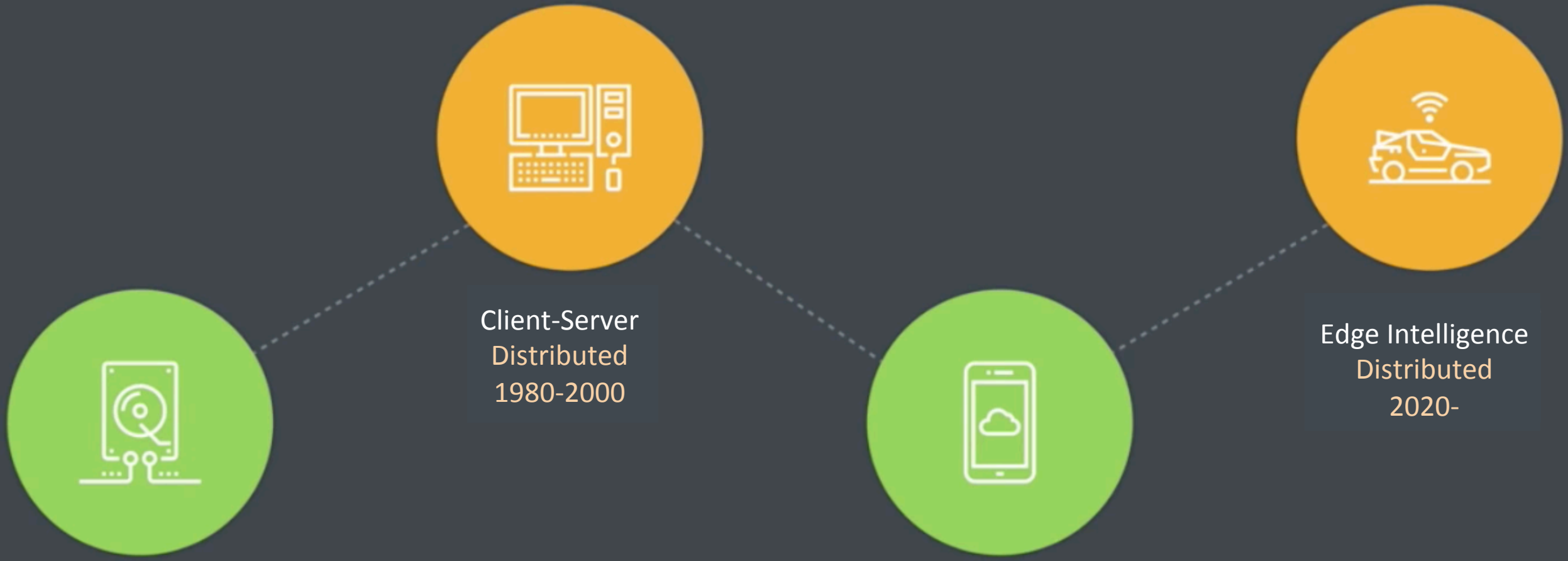
Edge Autonomy Trend



Credit: Peter Levine, Andreessen Horowitz

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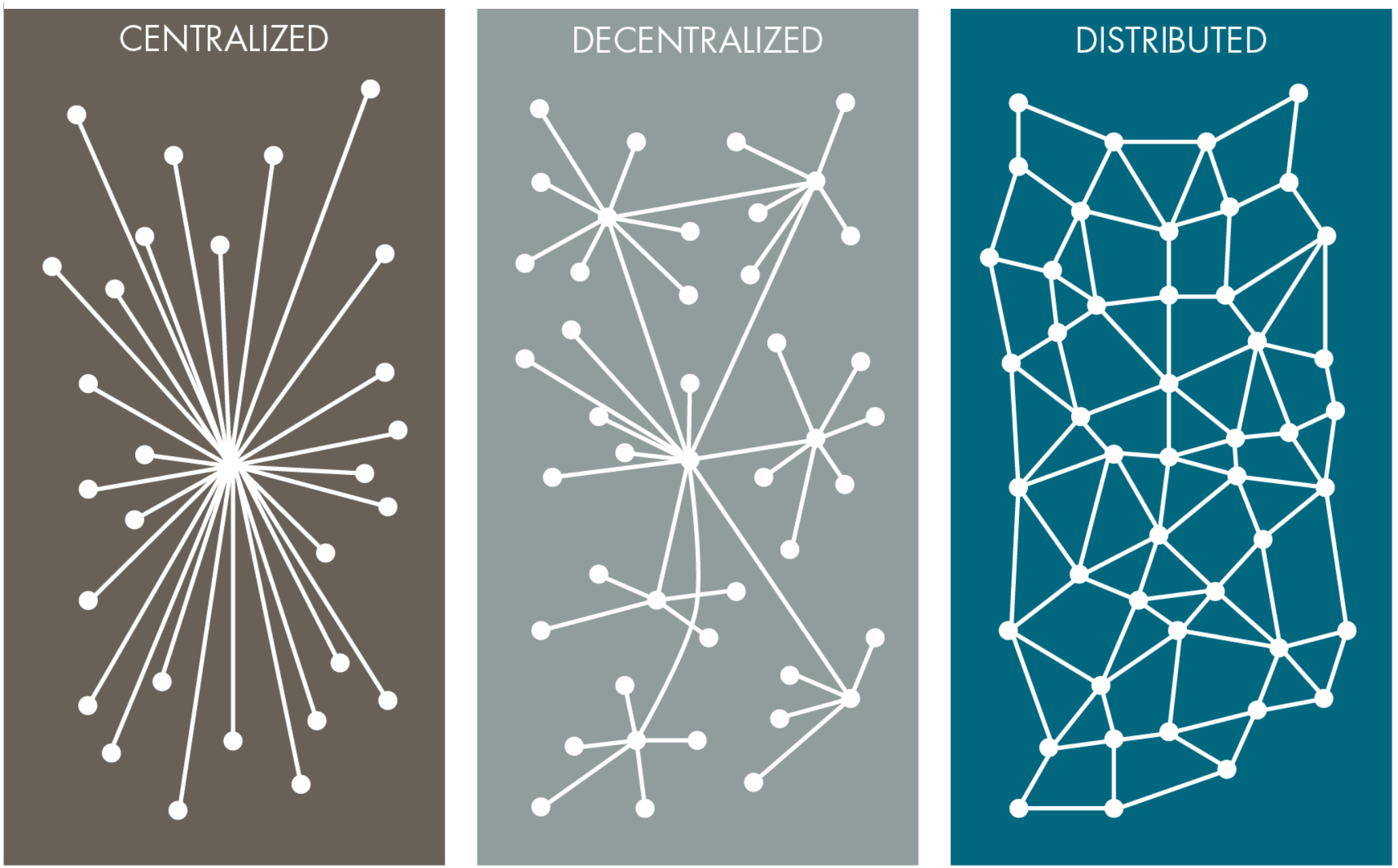
DECENTRALIZED PEER TO PEER SYSTEMS



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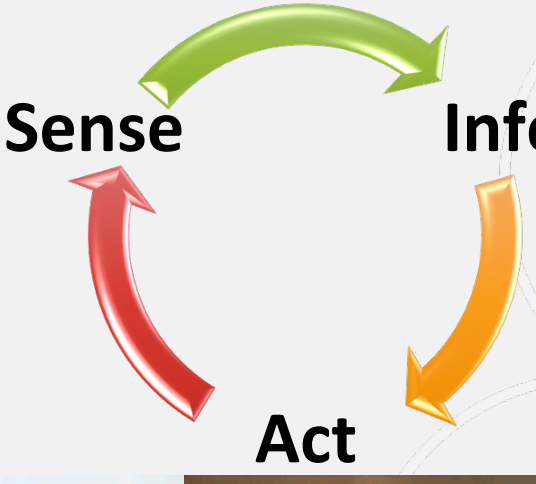
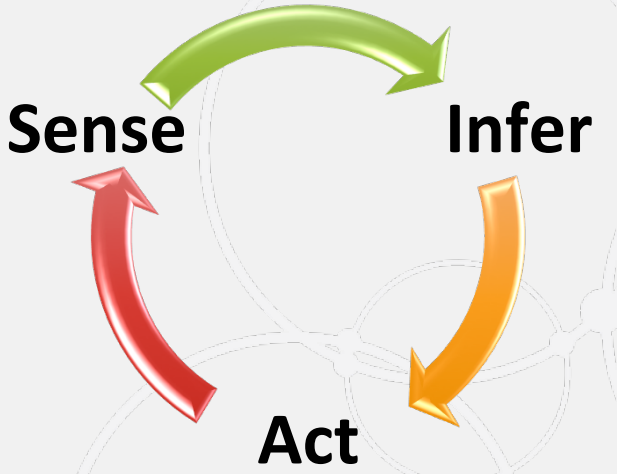
Agility versus Power



Agility over Power

- Sense:
  - Massive Amounts od Data
    - Self-Driving Car 10GB data/mile)
    - Too much for the Cloud
- Infer / Understand:
  - Processing & Machine learning
  - Derive task-specific information
- Action / React:
  - Low-latency. Real-time
  - Reliability, Availability



Why Edge Autonomy?

- Scalability
- Real-Time / Real-World Performance
- Safety, Robustness & Availability
- Security/Privacy
- Also Entirely new applications

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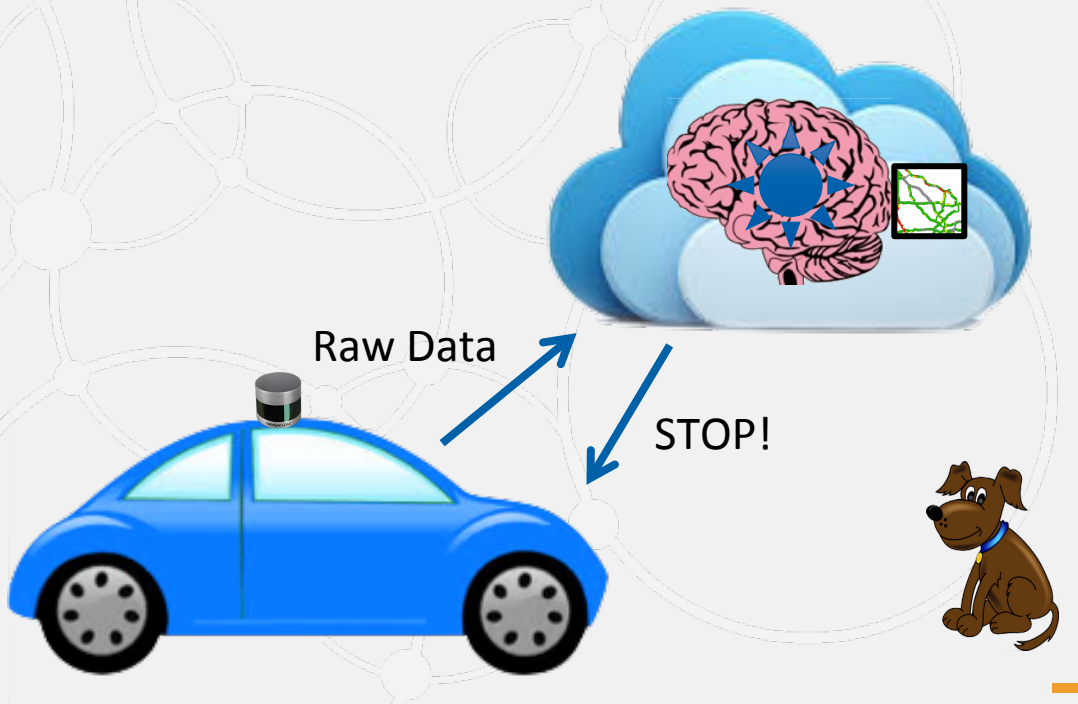
An example

- **Centralized**:
  - Cameras send raw video and lidar to cloud
  - Cloud processes, sends command to steer and break to car



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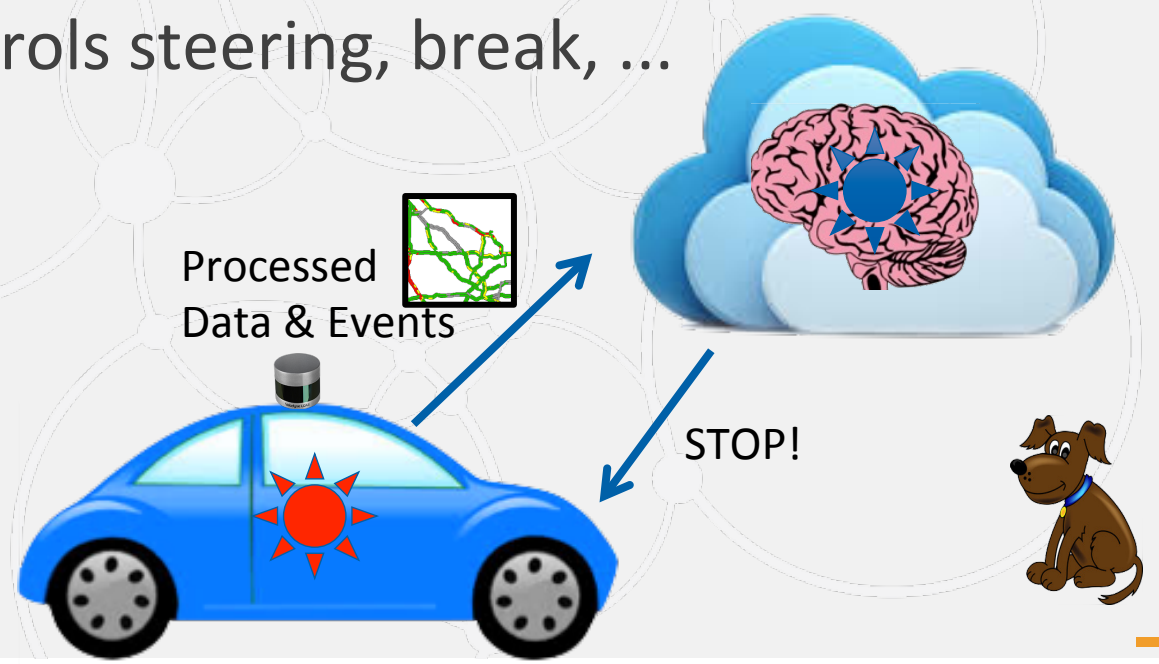
An example

- Centralized:
- **Edge Processing:**
  - Local sensor processing. Detect obstacles, road, …
  - Car sends environment model events to cloud
  - Cloud makes decisions, controls steering, break, …



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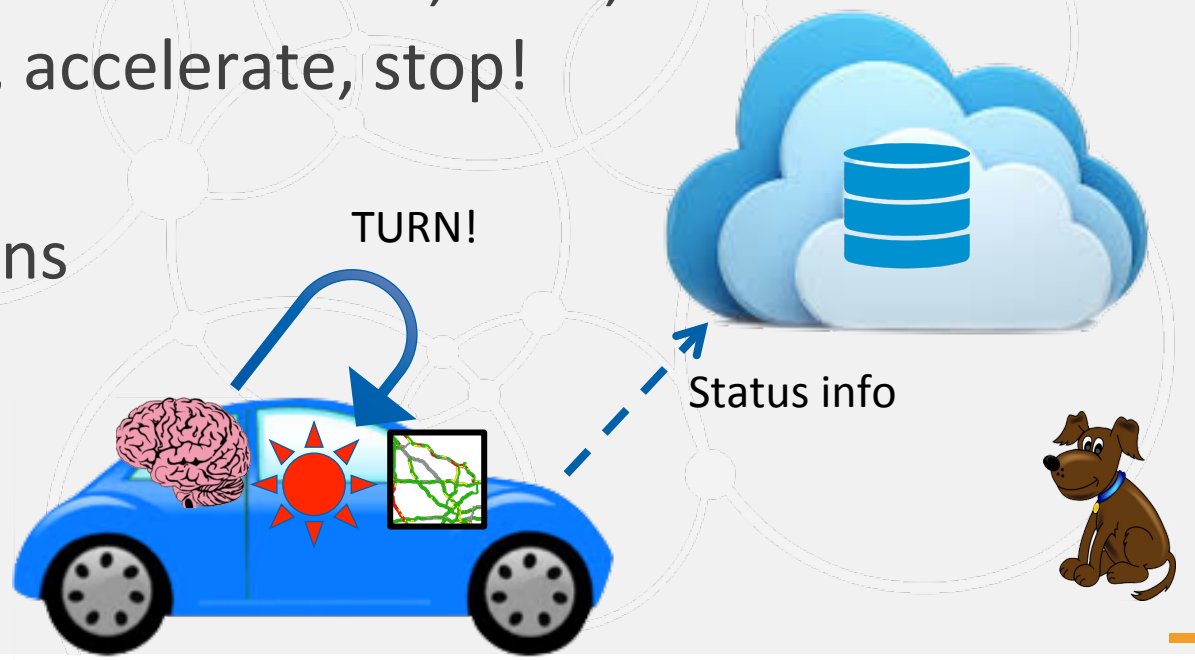
An example

- Centralized:
- Edge Processing:
- **Edge Autonomy**
  - Local sensor processing. Detect obstacles, road, ...
  - Car makes decisions! Turn, accelerate, stop!
  - Car to Car communication
  - Cloud stores, analyzes, learns



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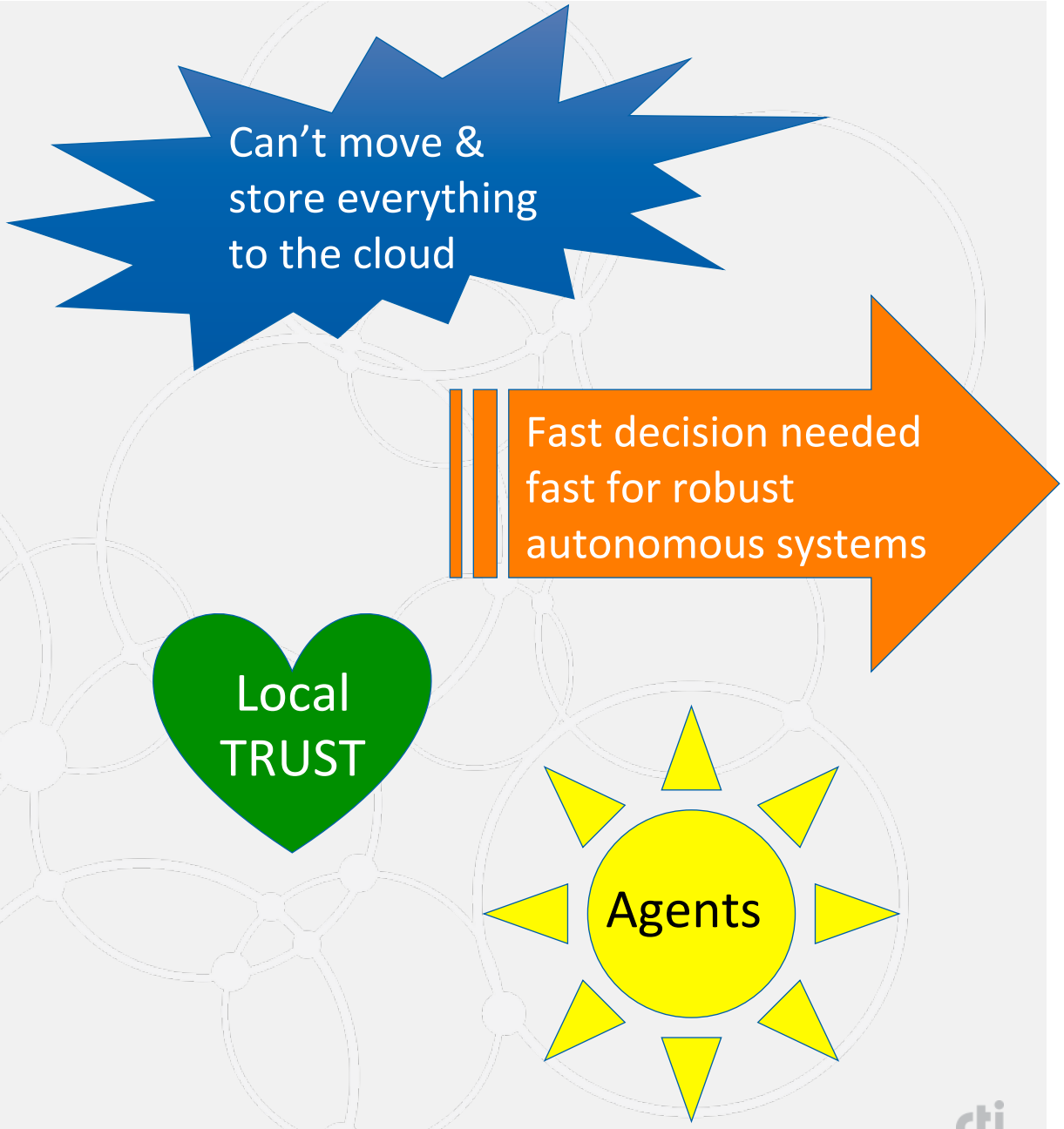
Why Edge Autonomy?

- Scalability
- Real-Time / Real-World Performance
- Safety, Robustness & Availability
- Security/Privacy
- Entirely new applications based on AUTONOMY



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IIOT Connectivity Frameworks

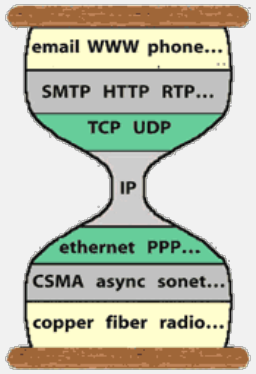
Evolution of the IIoT Connectivity Stack

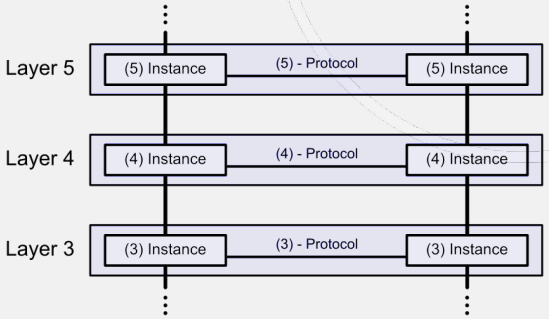
4-Layer Internet Stack Model (1989)

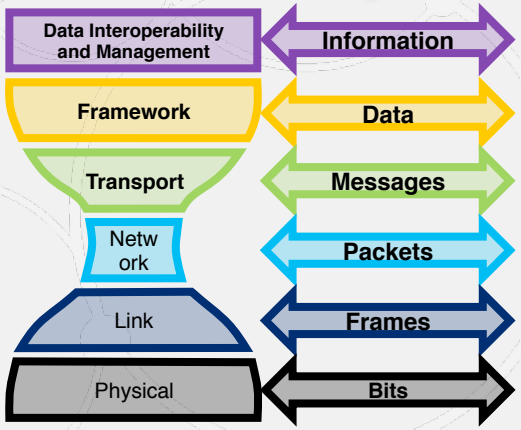
7-Layer OSI Stack Model (1994)

Industrial IoT (2014)

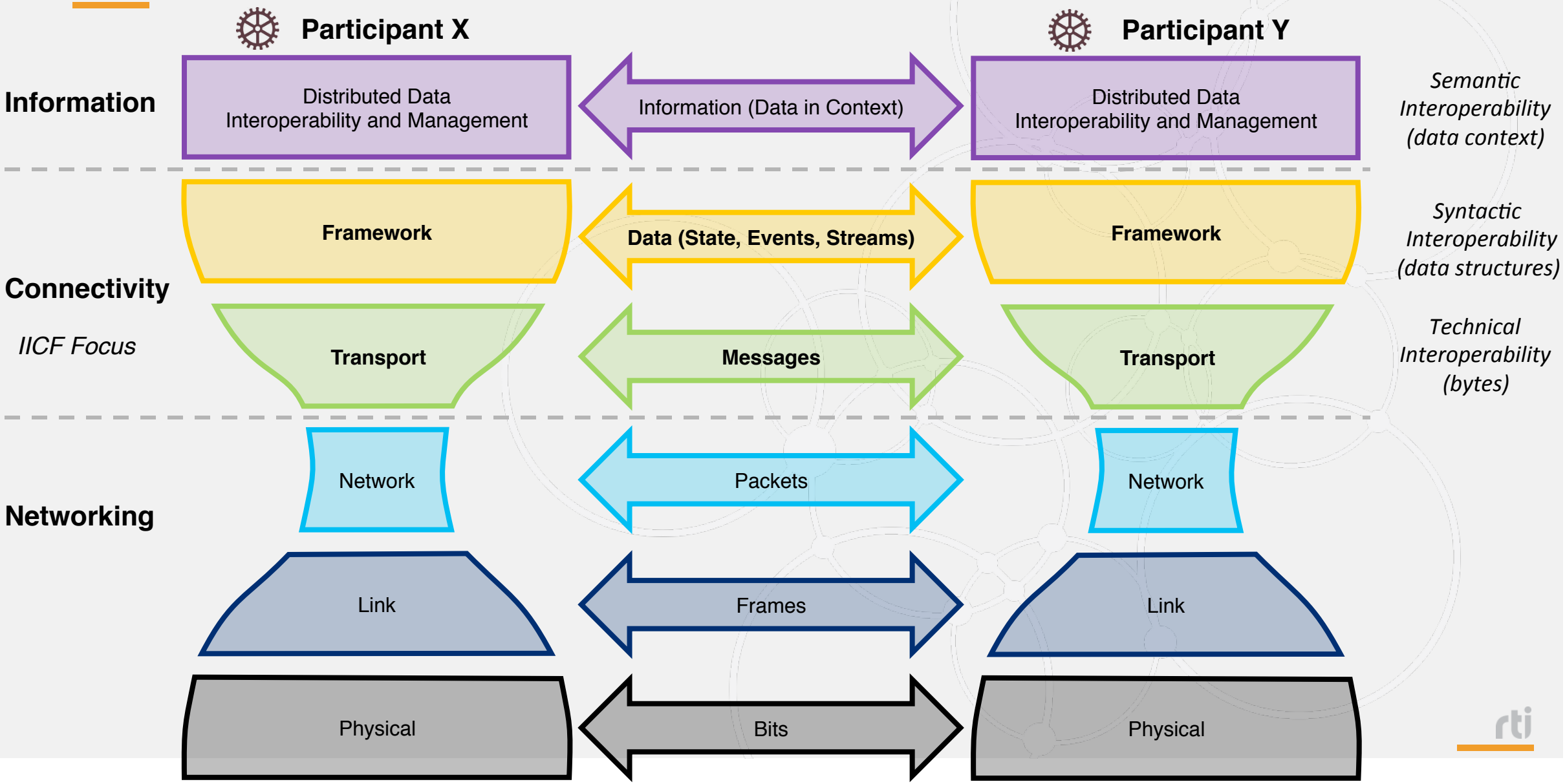
IIoT Connectivity Stack Model (2017)



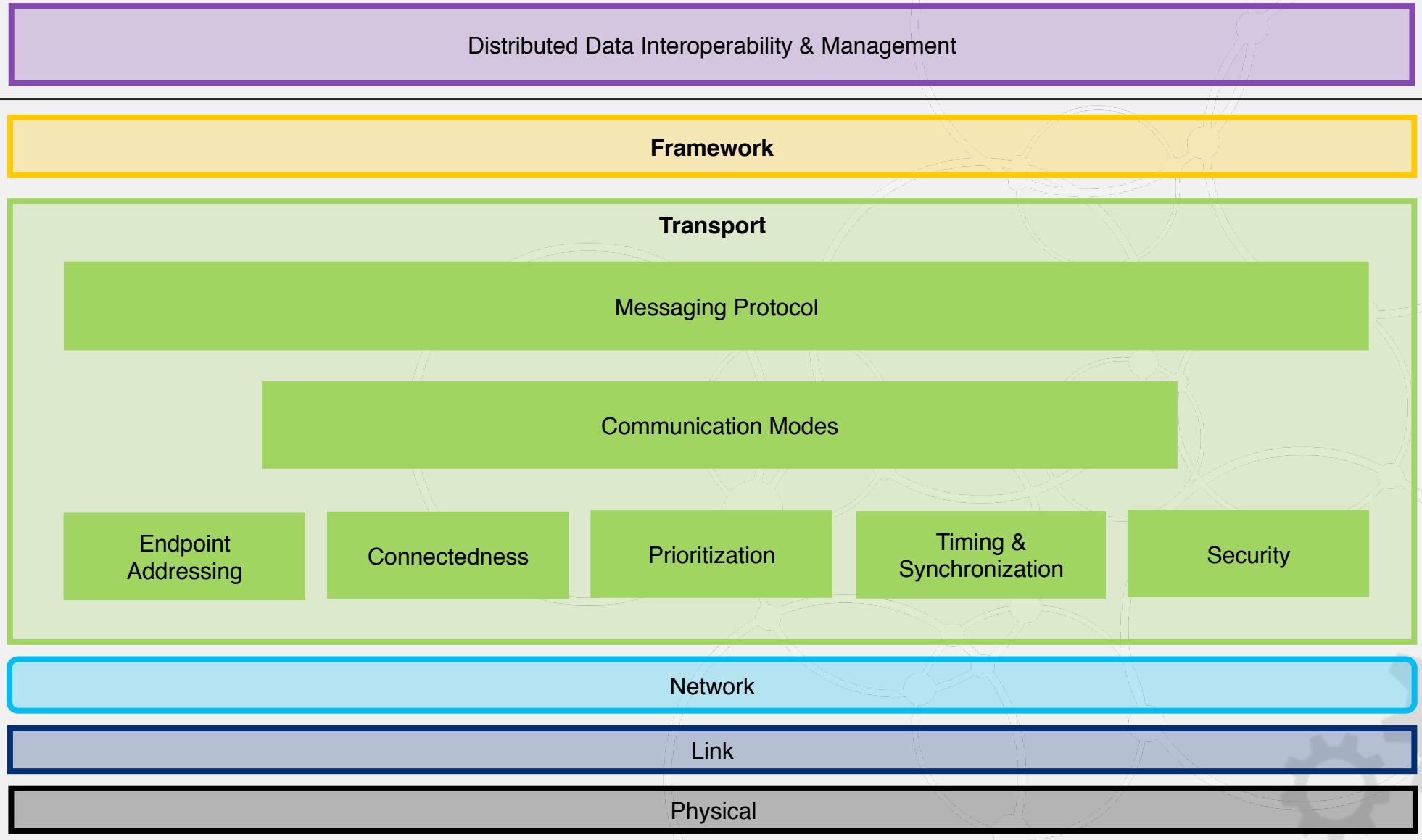




IIoT Connectivity Stack Model



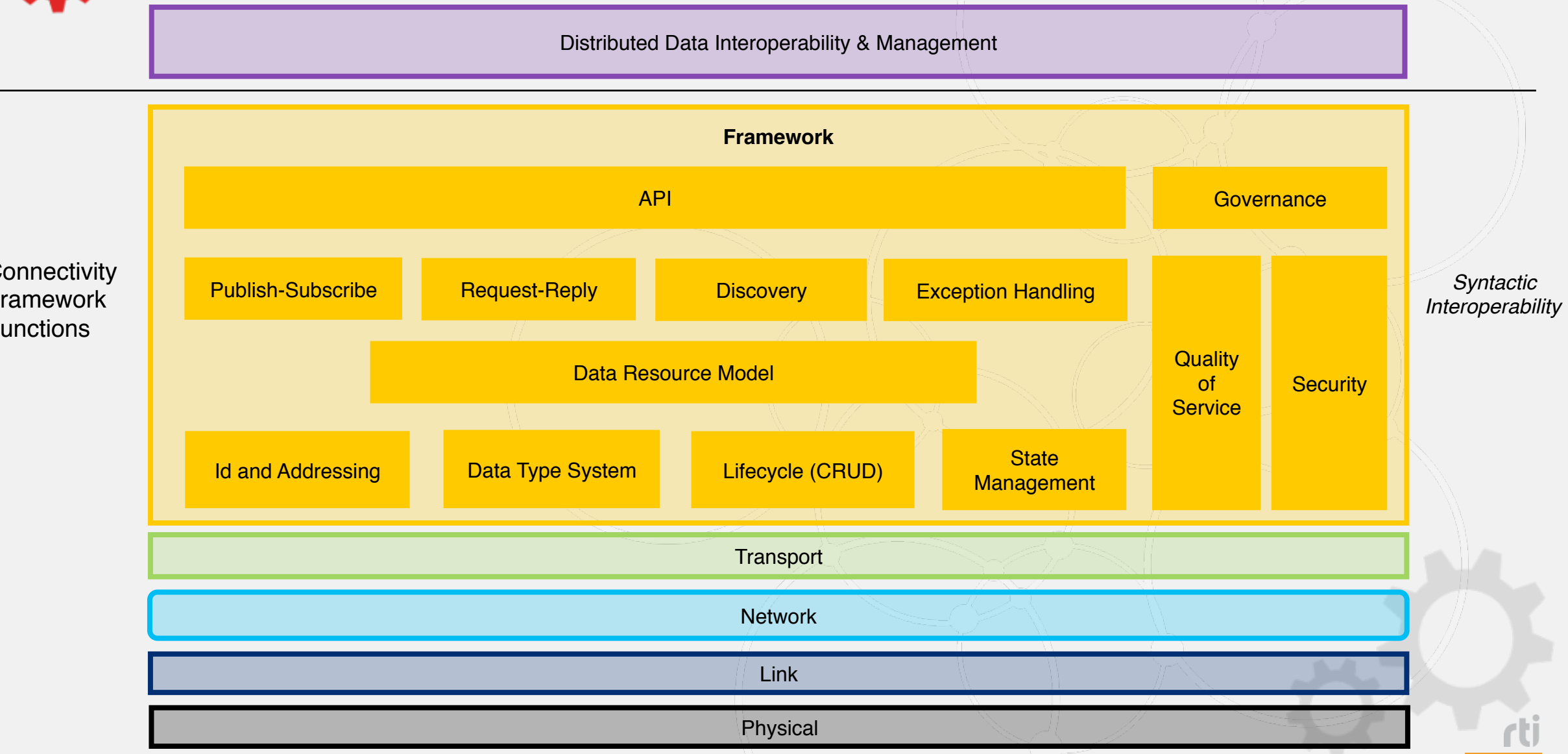
Connectivity Transport Layer



Connectivity Transport Functions

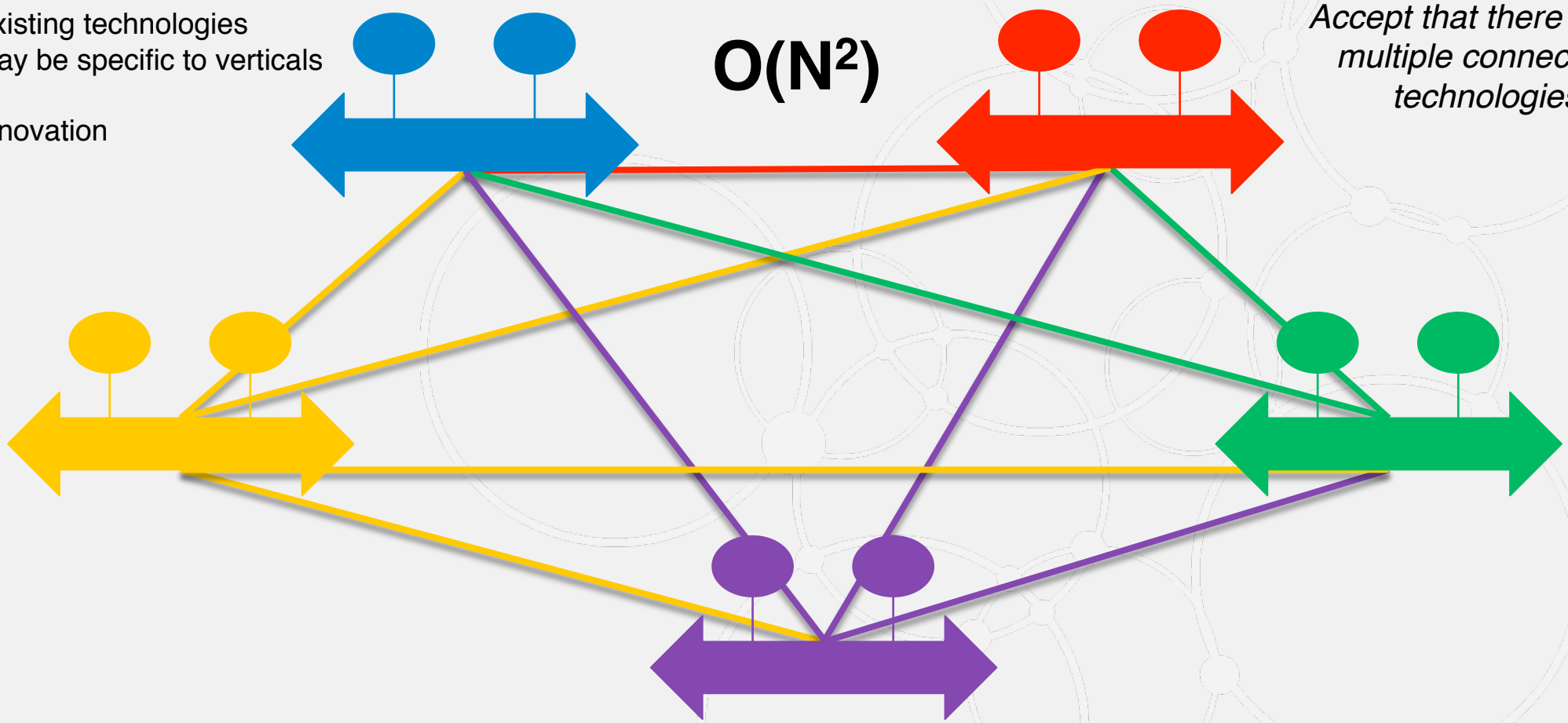
Technical Interoperability

Connectivity Framework Layer



Fundamental N^2 Connectivity Challenge

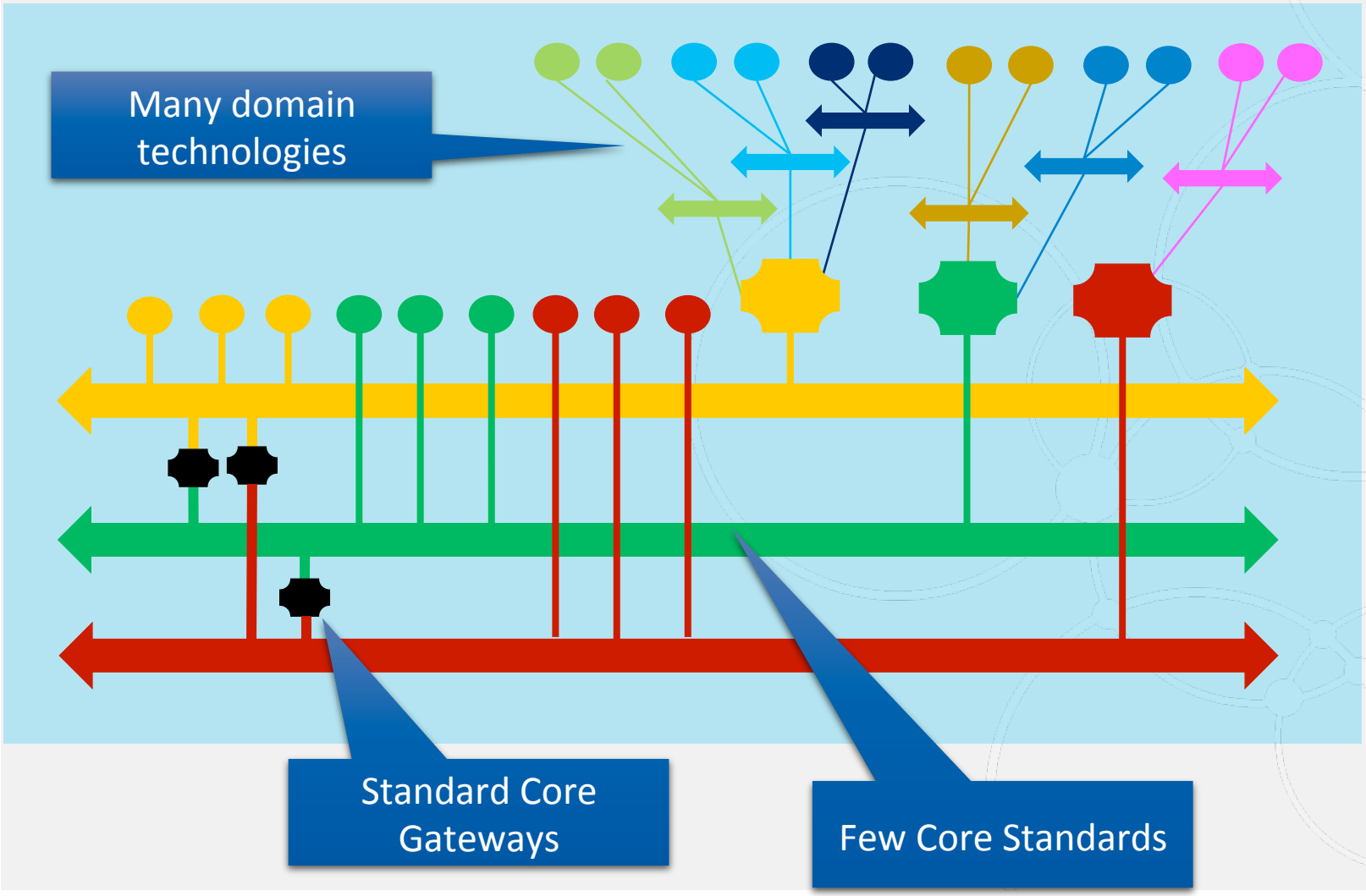
- Brownfield
  - Existing technologies
  - May be specific to verticals
- Greenfield
  - Innovation



Reality Check

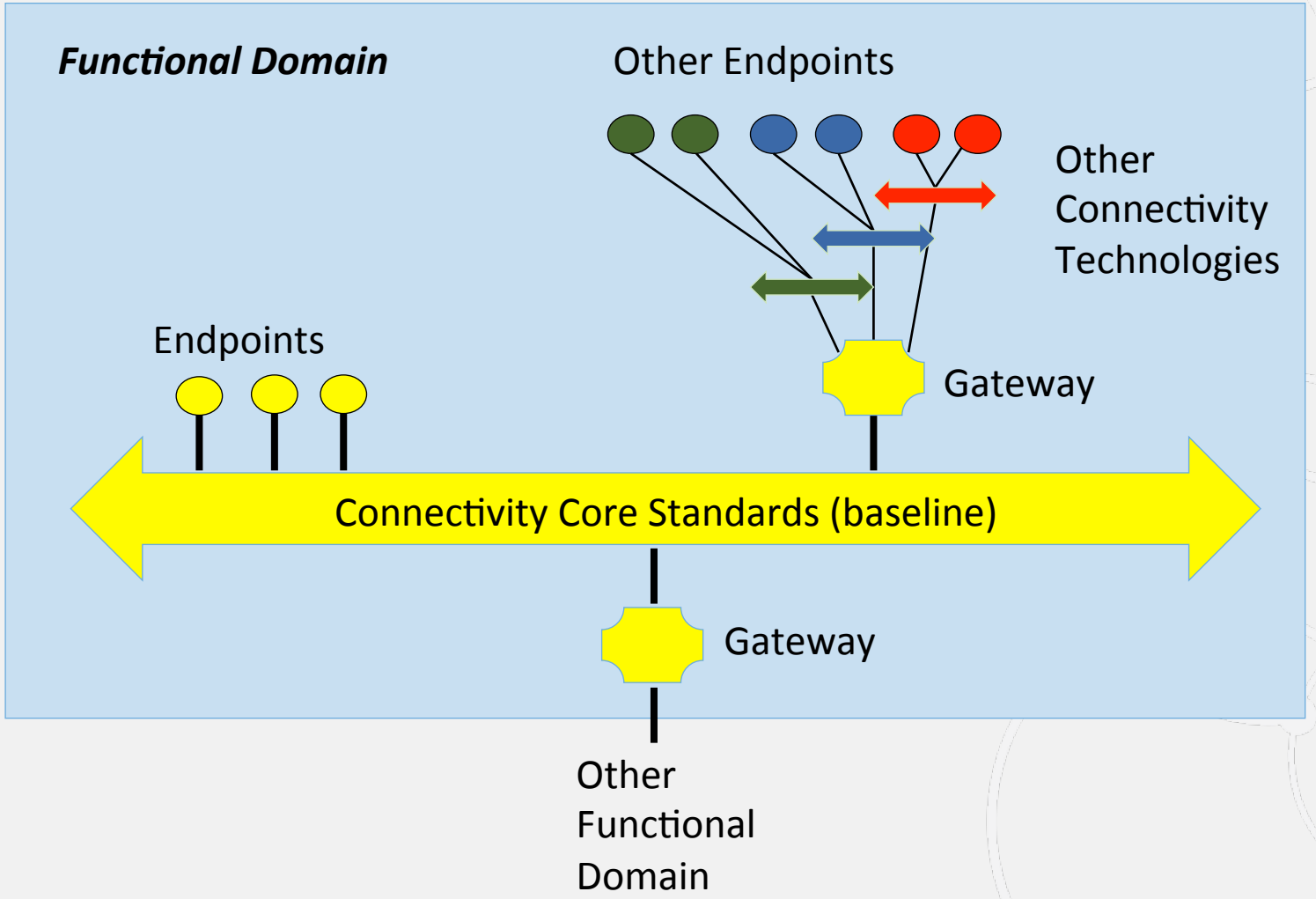
Accept that there will be multiple connectivity technologies

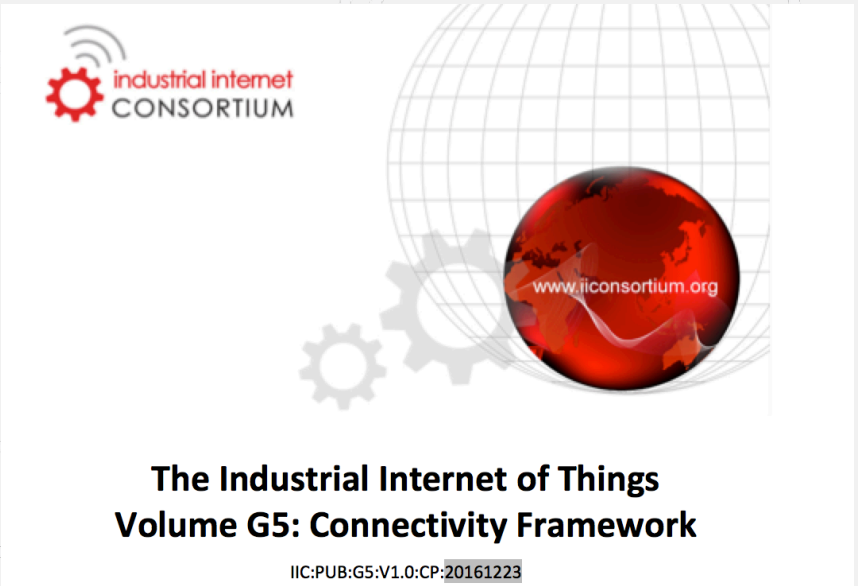
Connectivity Core Standards Architecture



- Connectivity Core Standards
  - Provide syntactic interoperability
  - Stable, deployed, open standard
  - Standard *Core Gateways* to all other CCS
- Domain-Specific Connectivity Technologies
  - Connect via non-standard gateway to any connectivity core standard

IIC Layered Databus architecture





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What is a good language for normalizing?

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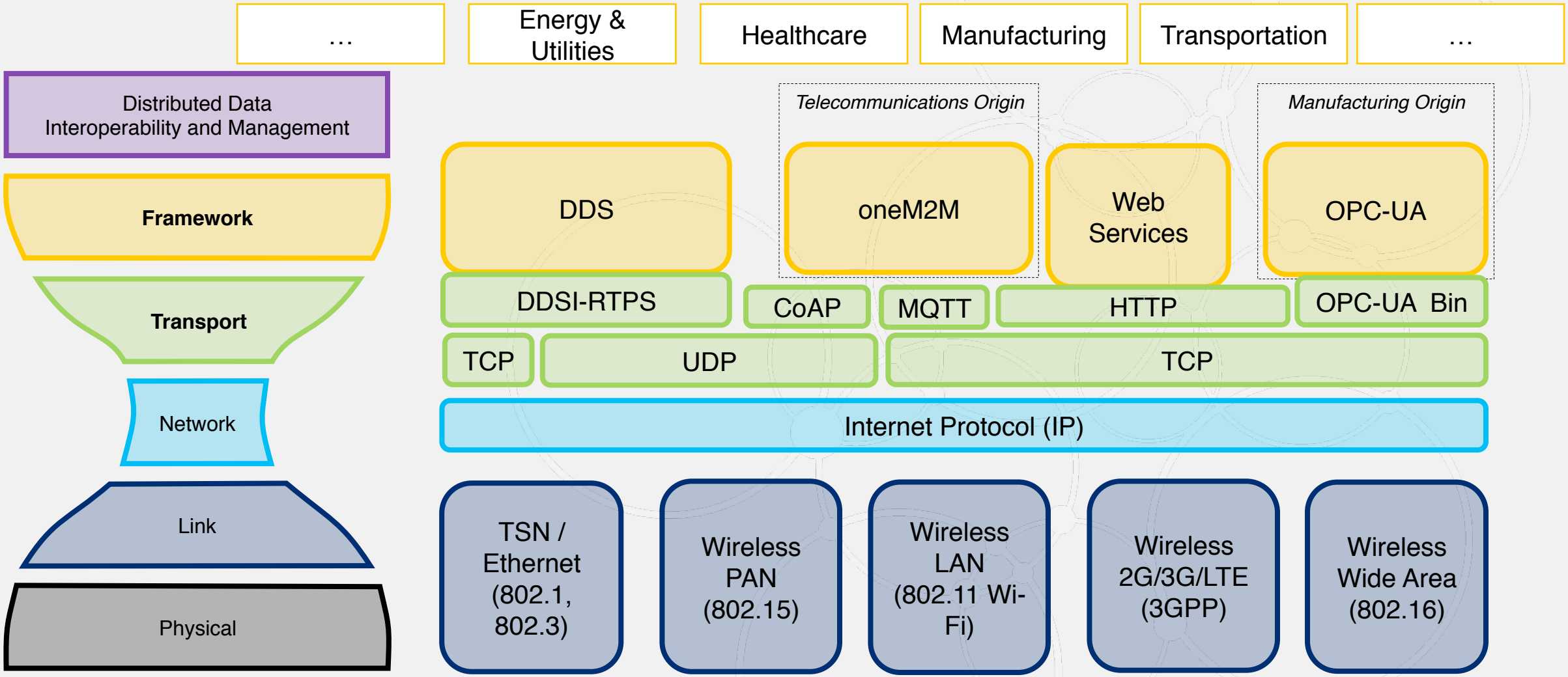
IIOT Connectivity Standards



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Selection Criteria

	Core Standard Criterion	DDS	Web Services	OPC-UA	oneM2M
1	Provide **syntactic interoperability**	✔	Need XML or JSON	✔	✔
2	Open standard with strong **independent, international** governance	✔	✔	✔	✔
3	**Horizontal** and neutral in its applicability across industries	✔	✔	✔	✔
4	**Stable** and **proven** across multiple vertical industries	Software Integration & Autonomy	✔	Manufacturing	Smart City Pilots*
5	Have **standards-defined *Core Gateways*** to *all* other core connectivity standards	Web Services, OPC-UA, oneM2M*	DDS, OPC-UA, oneM2M	Web Services, DDS, oneM2M*	Web Services, DDS*
6	Meet the connectivity framework **functional** requirements	✔	✗	Pub-Sub in development	
7	Meet **non-functional** requirements of performance, scalability, reliability, resilience	✔	✗	Real-time in development	Reports not yet documented or public
8	Meet **security** and safety requirements	✔	✔	✔	✔
9	Not require any single component from any single vendor	✔	✔	✔	✔
10	Have readily-available SDKs both **commercial** and **open source**	✔	✔	✔	✔

* = work in progress , ✔ = supported, ✗ = **not** supported

GREEN = Gating Criteria

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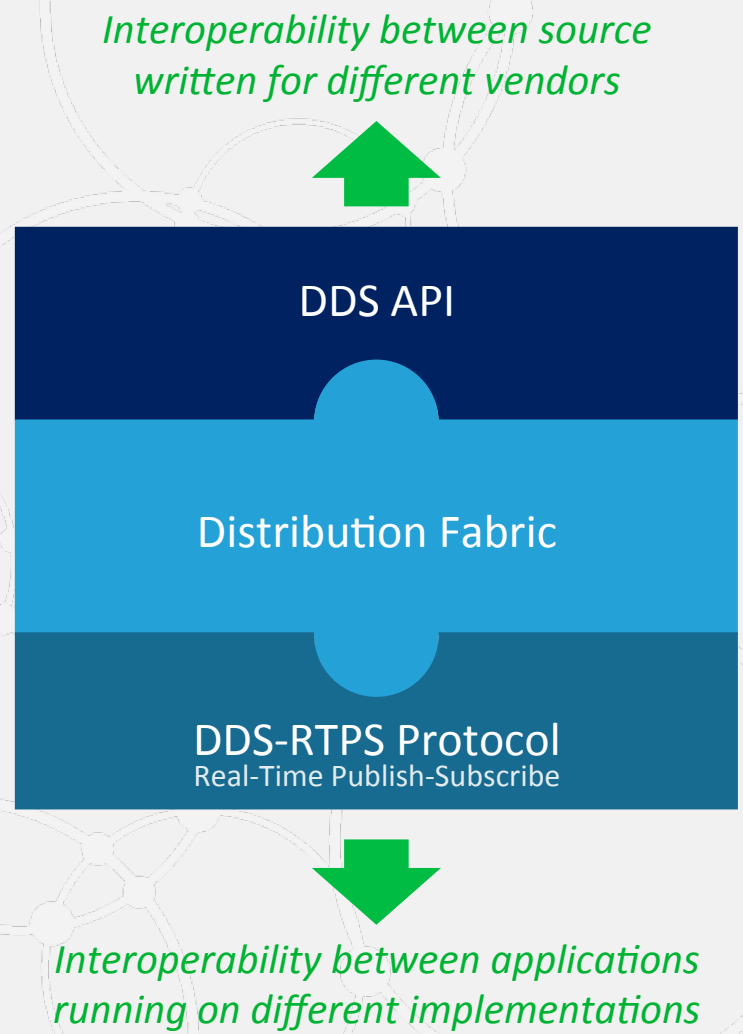
Connext DDS Databus

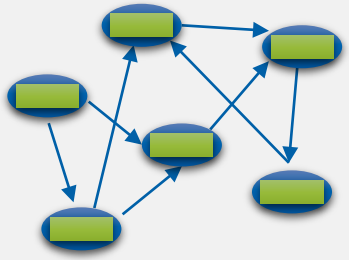
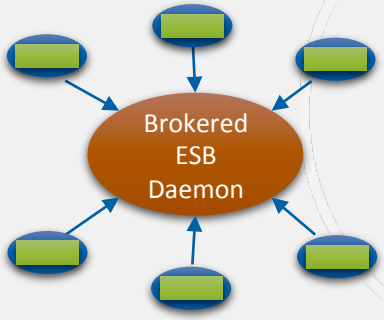
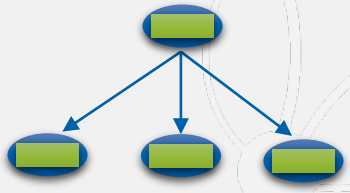
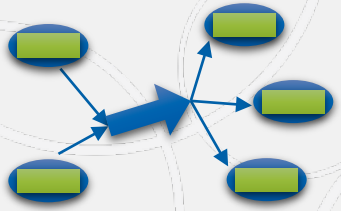
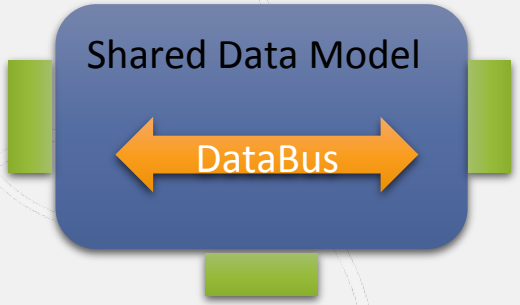
The foundation for Edge Autonomy

The DDS Standard

- DDS is the Proven Data Connectivity Standard for the IoT
- OMG: world's largest systems software standards org
  - UML, DDS, Industrial Internet Consortium
- DDS: open and cross-vendor
  - Open Standard and Open Source
  - 12+ implementations



DDS is Different!

Point-to-Point	Client/Server	Publish/Subscribe	Queuing	Data-Centric
				
				
TCP Sockets	MQTT XMPP OPC CORBA	Fieldbus CANbus ZeroMQ JMS	AMQP Active MQ	DDS

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DDS "virtual" Data-Centric Global Data Space

Programming Model

Shared Global Dataspace (Domain)

DDS

Source (Key)	Speed	Power	Position
CAR1	37.4	122.0	(37.41, -122.01)
CAR2	10.7	74.0	(36.95, -122.05)
CAR3	50.2	150.07	(37.42, -122.17)

QoS

Topic D

DATABUS

QoS

Topic D

Persistence Service

Recording Service

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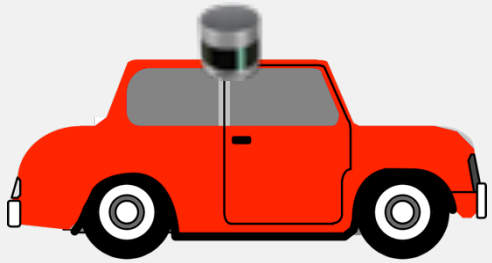
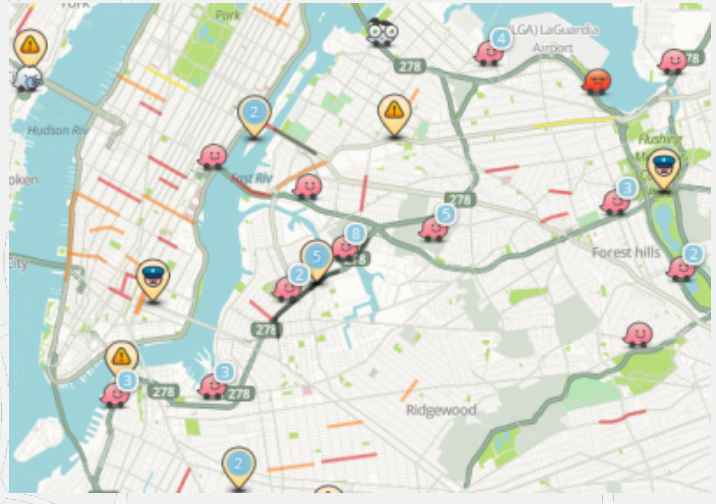
Typical Multi-Key Scenario

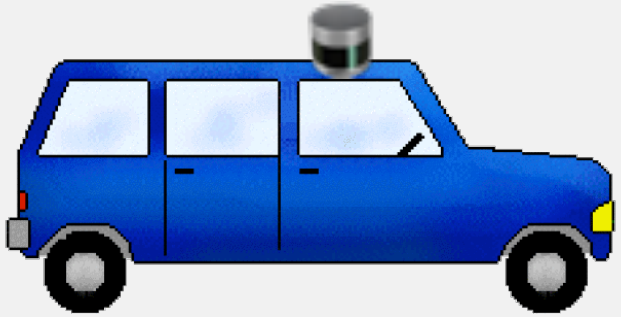
Key=VIN1



Key=VIN2

VehicleState





Key=VIN3

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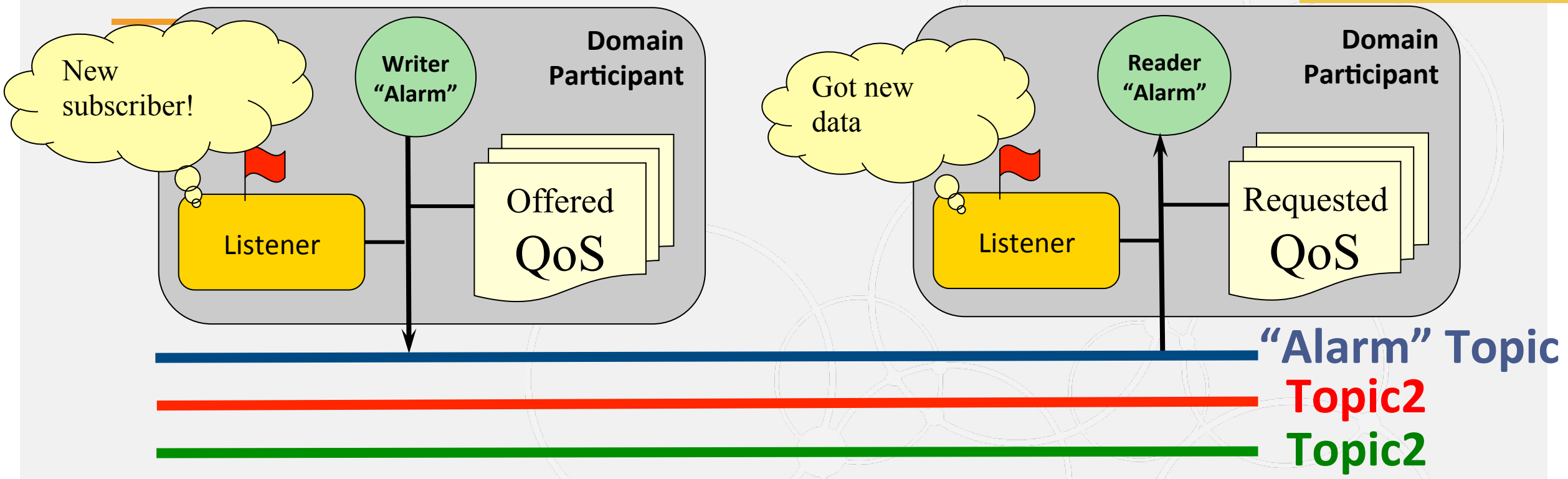
Data-Centric Communications Model



- **DomainParticipant** connects to the global data space (domain)
- **Topics** define the data-objects (collections of subjects)
- **DataWriters** publish data on Topics. **Publishers** are used to group DataWriters.
- **DataReaders** subscribe to data on Topics. **Subscribers** are used to group DataReaders
- **QoS Policies** are used configure the system
- **Listeners** are used to notify the application of events

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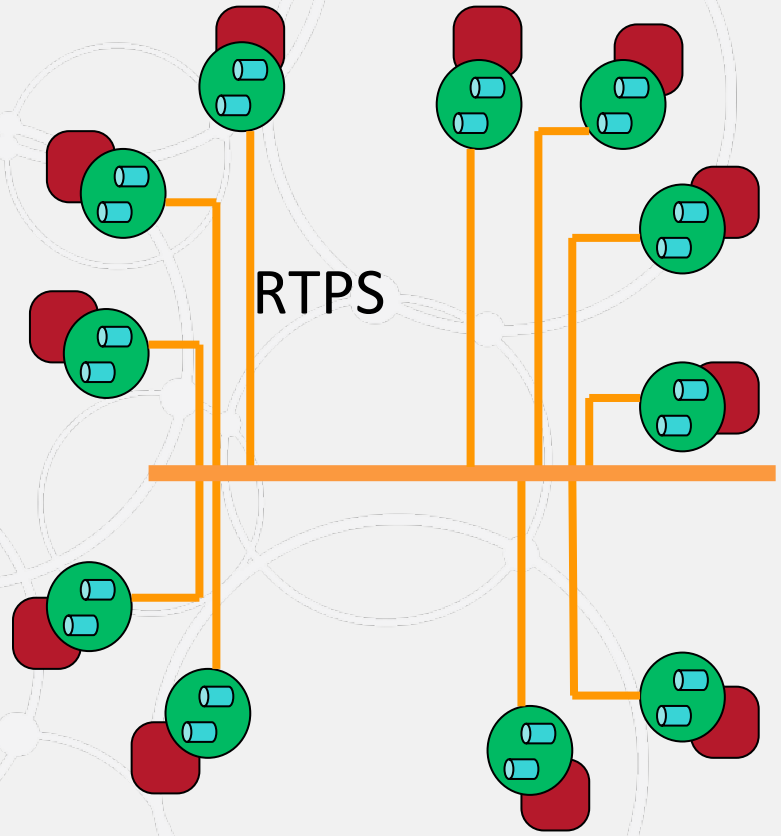
Quality of Service (QoS) Policies

	QoS Policy
Cache	**DURABILITY**
	HISTORY
	LIFESPAN
Resources	WRITER DATA LIFECYCLE
	READER DATA LIFECYCLE
	ENTITY FACTORY
	RESOURCE LIMITS
Delivery	**RELIABILITY**
	TIME BASED FILTER
	DEADLINE
	CONTENT FILTERS

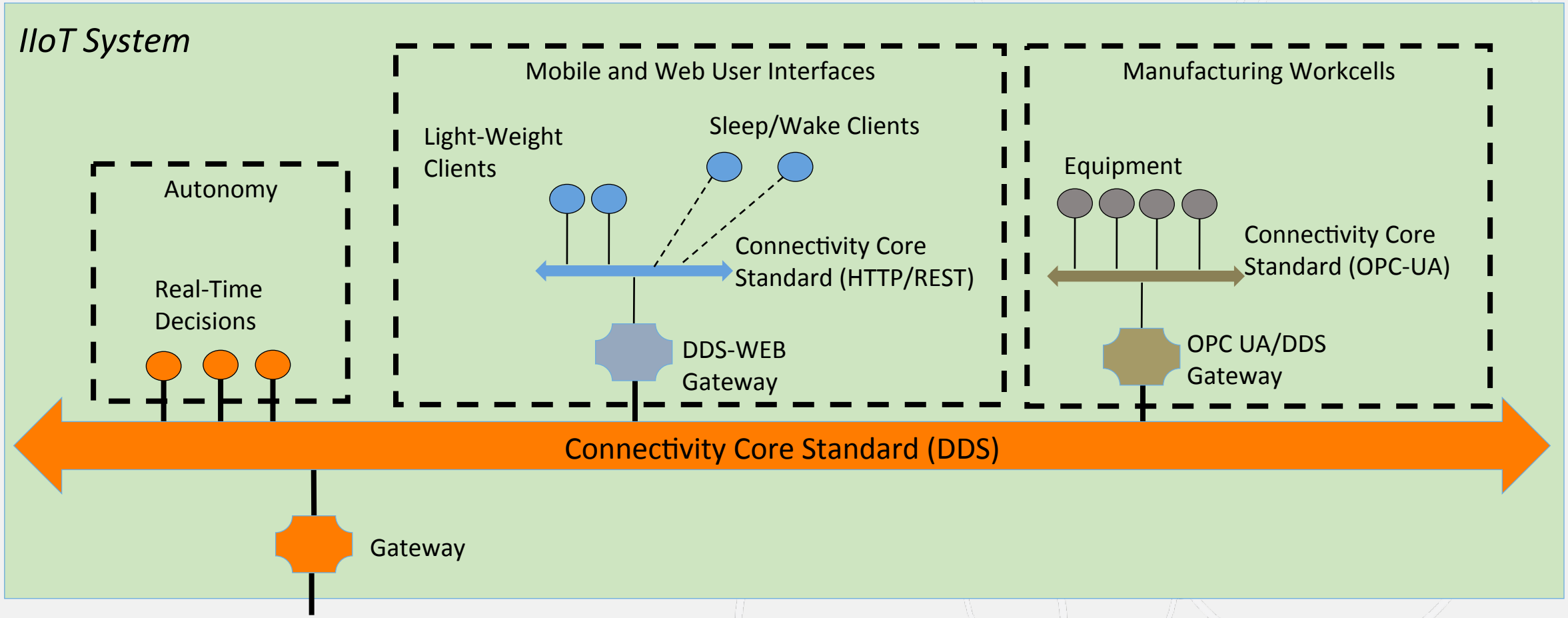
	QoS Policy
User QoS	USER DATA
	TOPIC DATA
	GROUP DATA
Presentation	**PARTITION**
	PRESENTATION
	DESTINATION ORDER
Availability	**OWNERSHIP**
	OWNERSHIP STRENGTH
	LIVELINESS
Transport	**LATENCY BUDGET**
	TRANSPORT PRIORITY

RTPS Protocol optimized for real-time

- Full peer-to-peer protocol
  - No required brokers or servers
- Adaptable via QoS
  - Reliability, timeouts, message priority
- Native reliable multicast support
  - Uses transport multicast, if available, else unicast UDP
- Robust to disconnects
  - Maintains session above (UDP) transport
- Efficient data serialization
  - Binary XCDR
- Built-in availability and durability
  - Durable & Persistent data, Historical cache, Failover support



DDS–Based Integration



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DDS Databus - Unified Data Edge to Cloud

- End-User Applications
- Connect with RESTful/Web Sockets

Public Internet

- Teleoperation
- Traffic Management
  - Traffic Light Control
  - Congestion Management
- Road Management
  - Environmental & Road Conditions

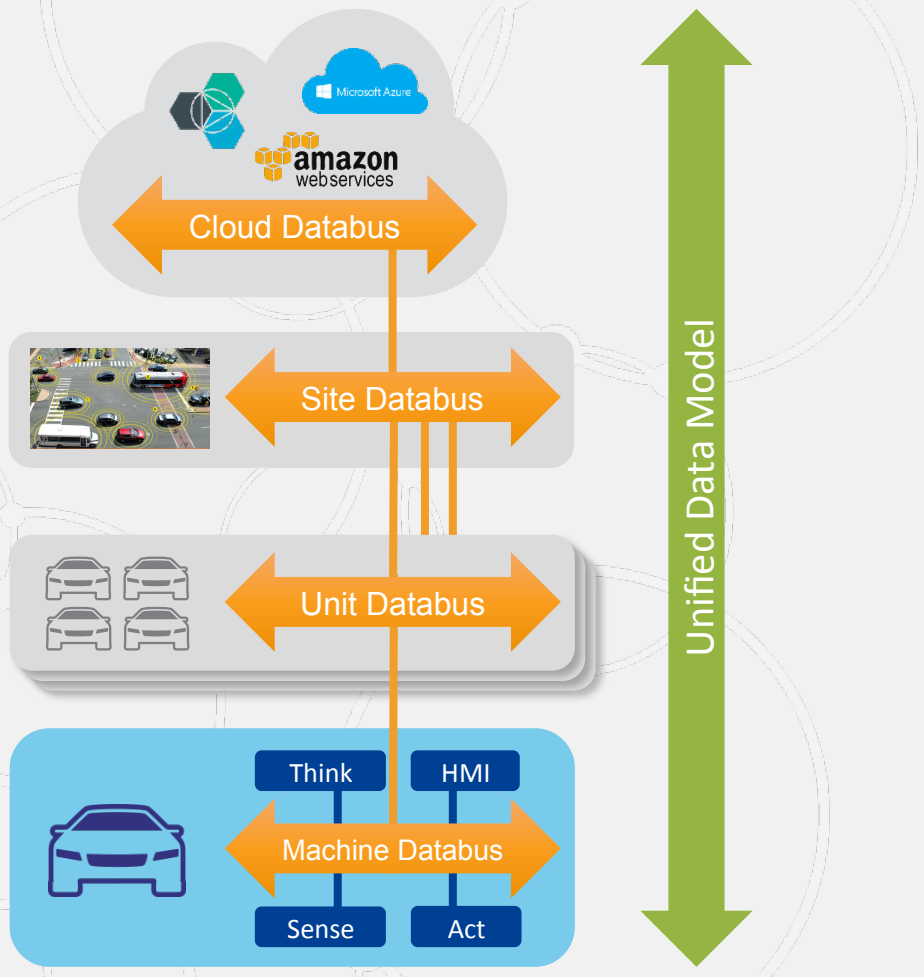
Fleet Management

- Probe Data Collection (Sensors)
- Environmental Weather
- Dynamic Vehicle Location

V2V & V2X

- Collision Avoidance
- Navigation
- Safety Certified

In-Car Platform



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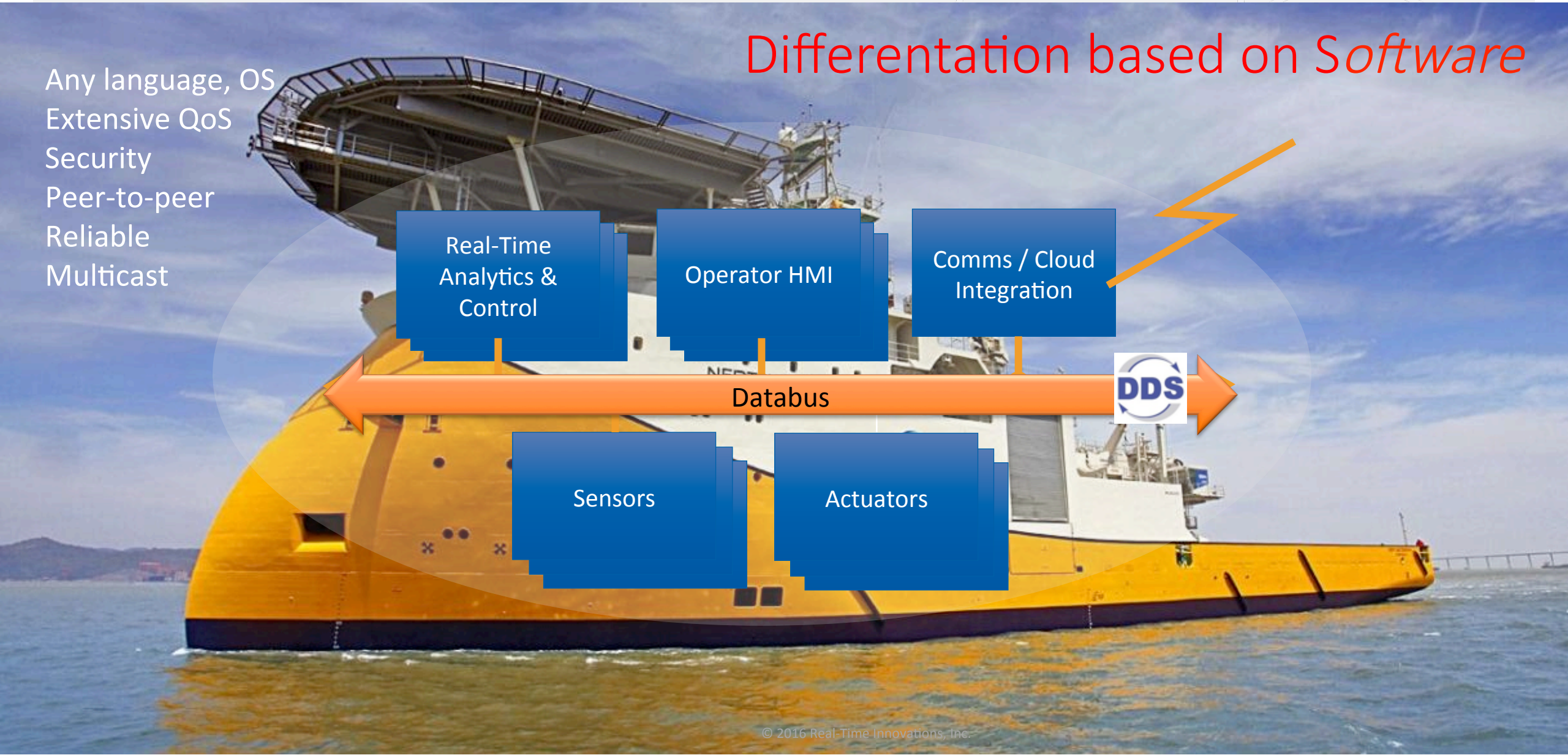
Integrated Ship Control Architecture



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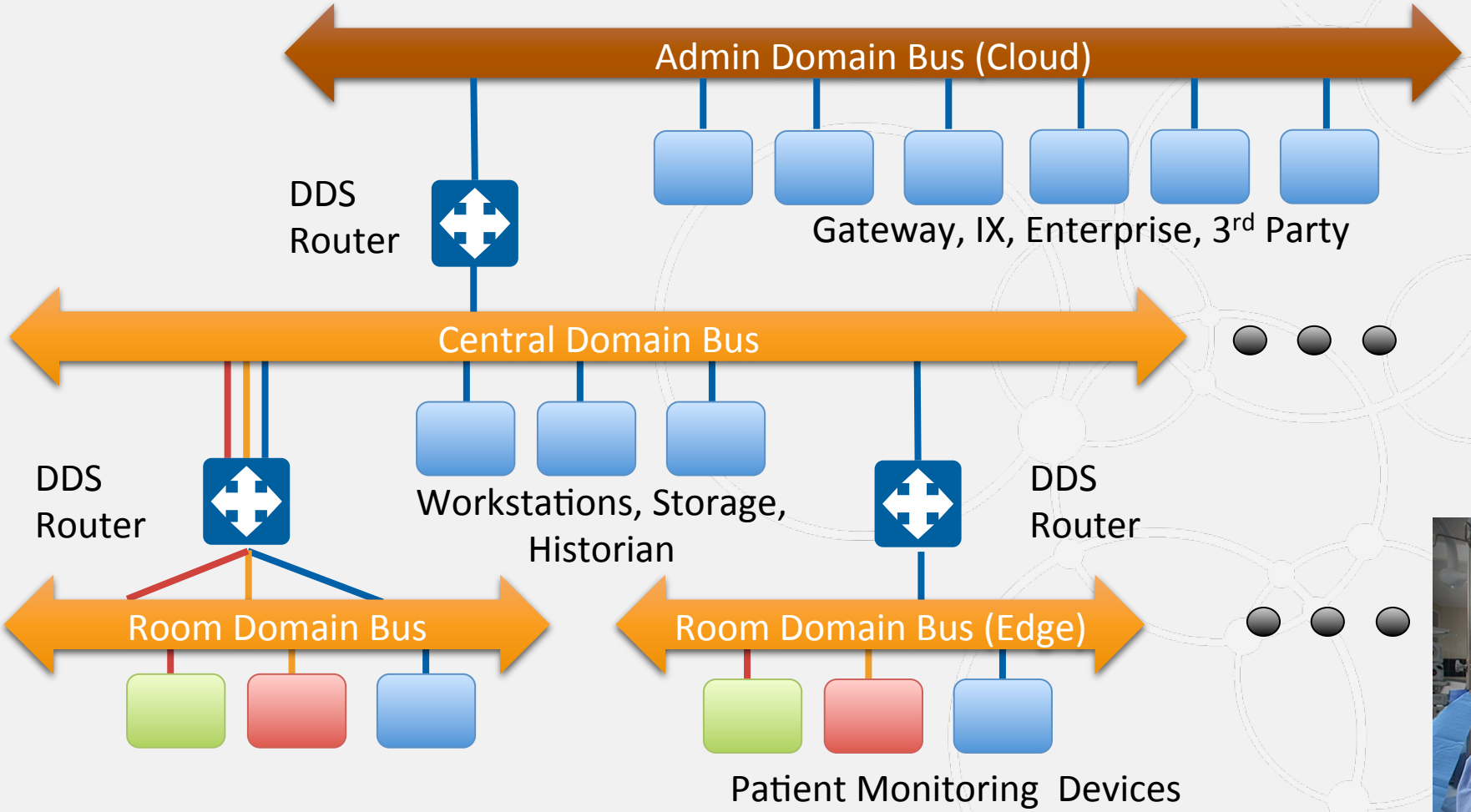
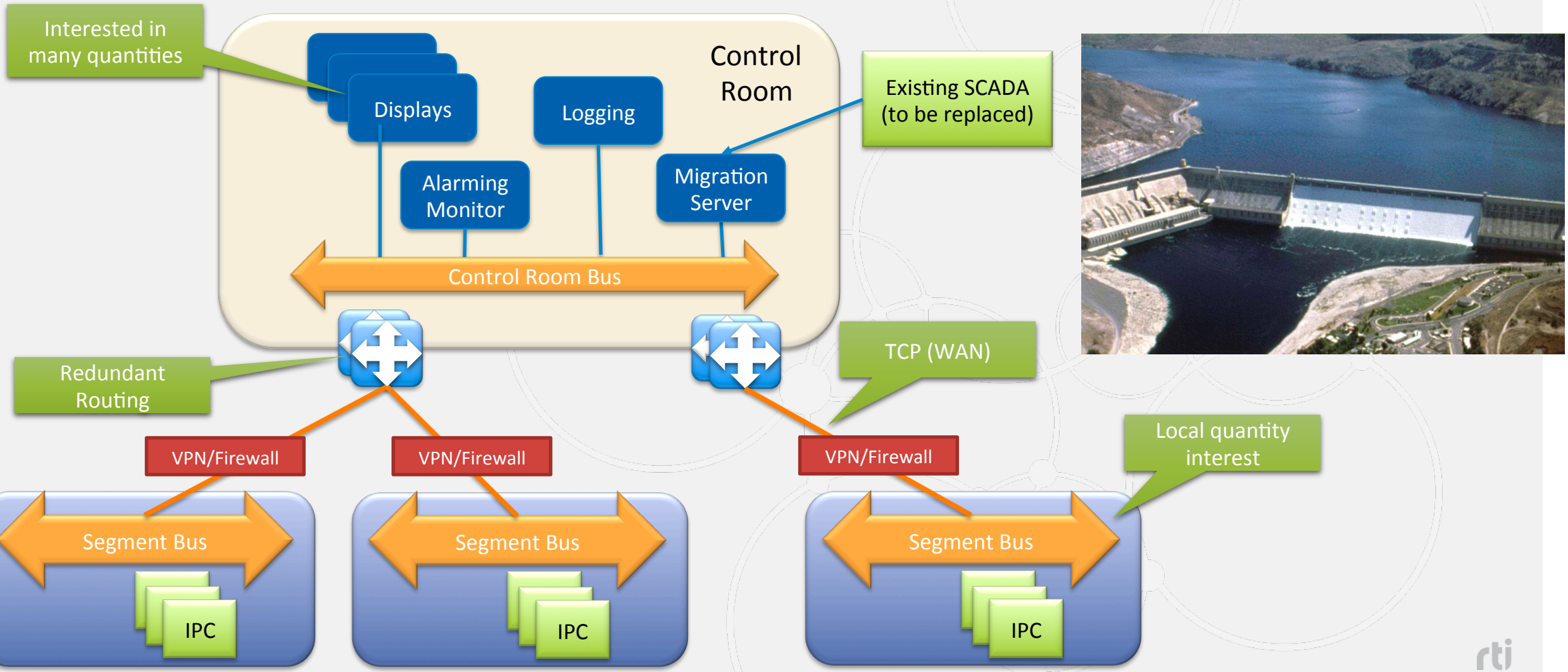
Example: Clinical Decision System Architecture



Example: Grand Coulee Dam



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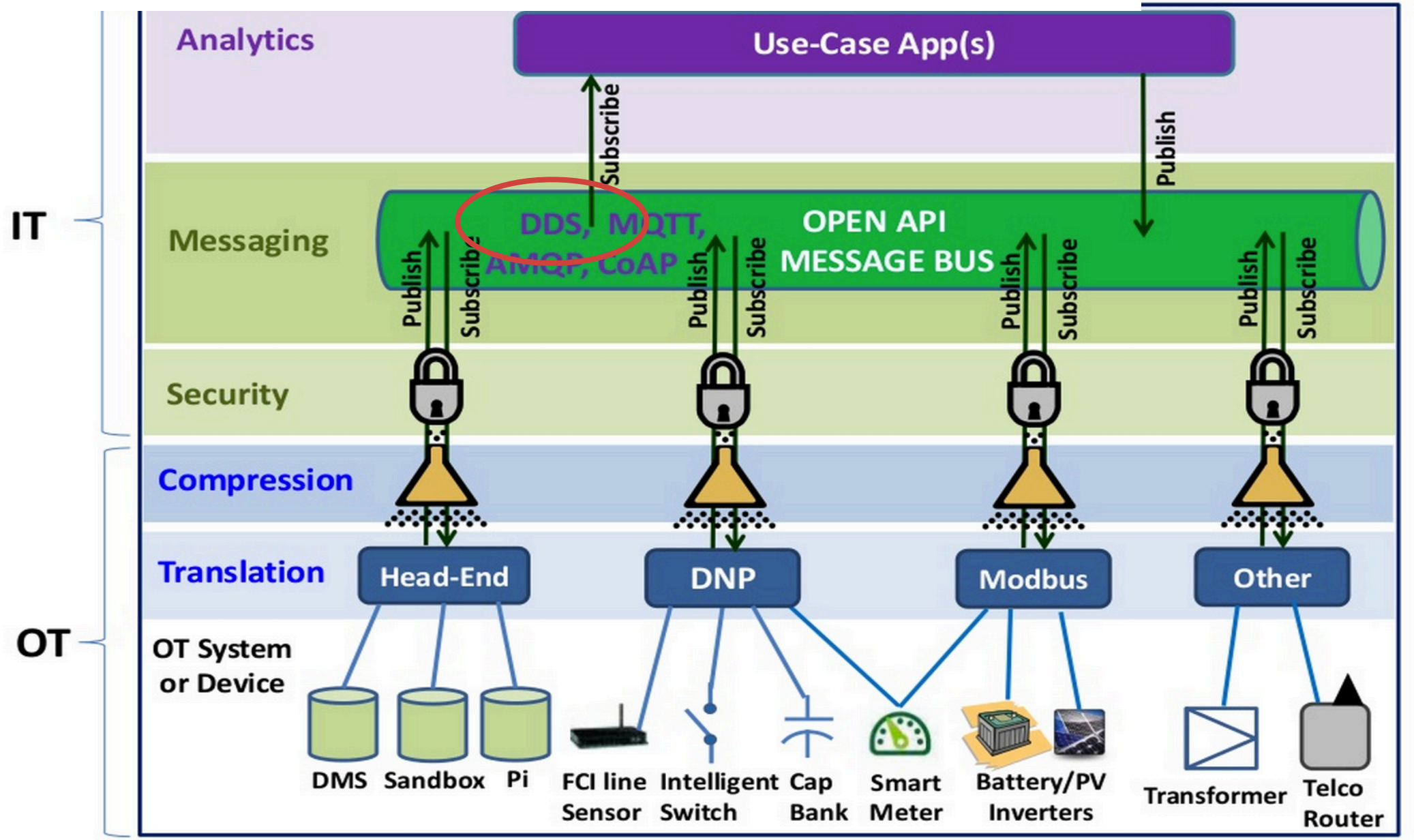
Example: Duke Energy



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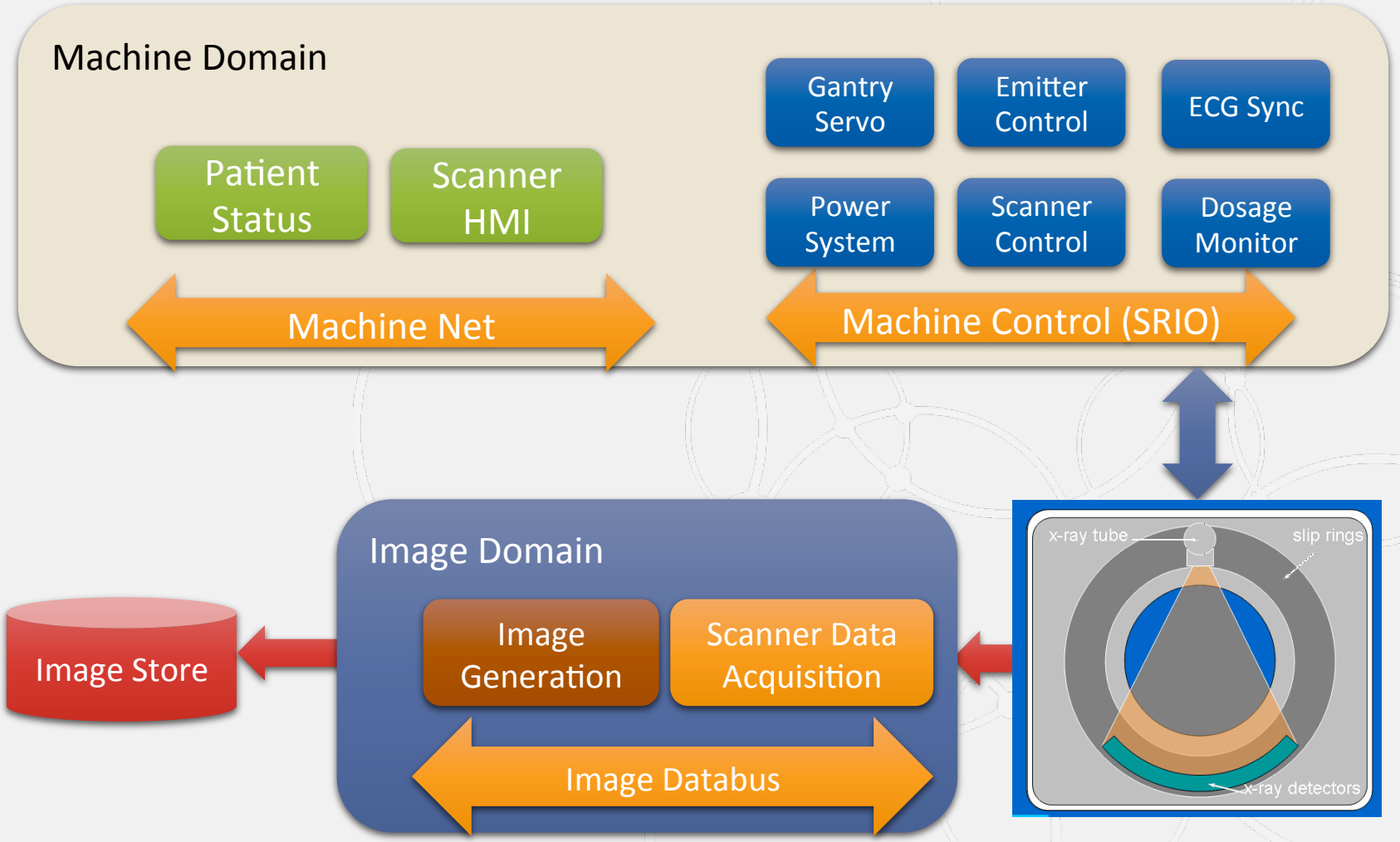
Example: CT Scanners



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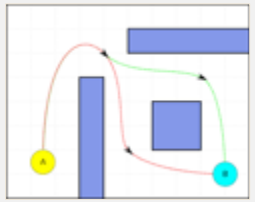
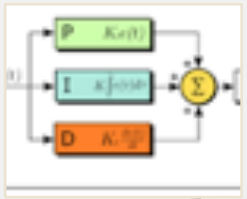
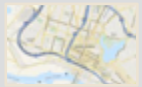
Example: Autonomous Vehicles







Traffic

Maps

CONNEXT DDS DATABUS

Situation Awareness

Planning

Vehicle Control

Logging

Error Management

CONNEXT DDS DATABUS

Sensing

Cameras, LIDAR, Radar…

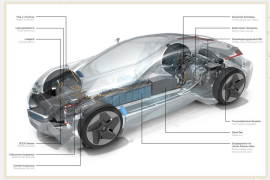
Data Fusion

Localization

Vehicle Platform

Visualization

Navigation



Key Technical Details

Security

Flexible Type System

Scalability

Ecosystem

Performance

Tools

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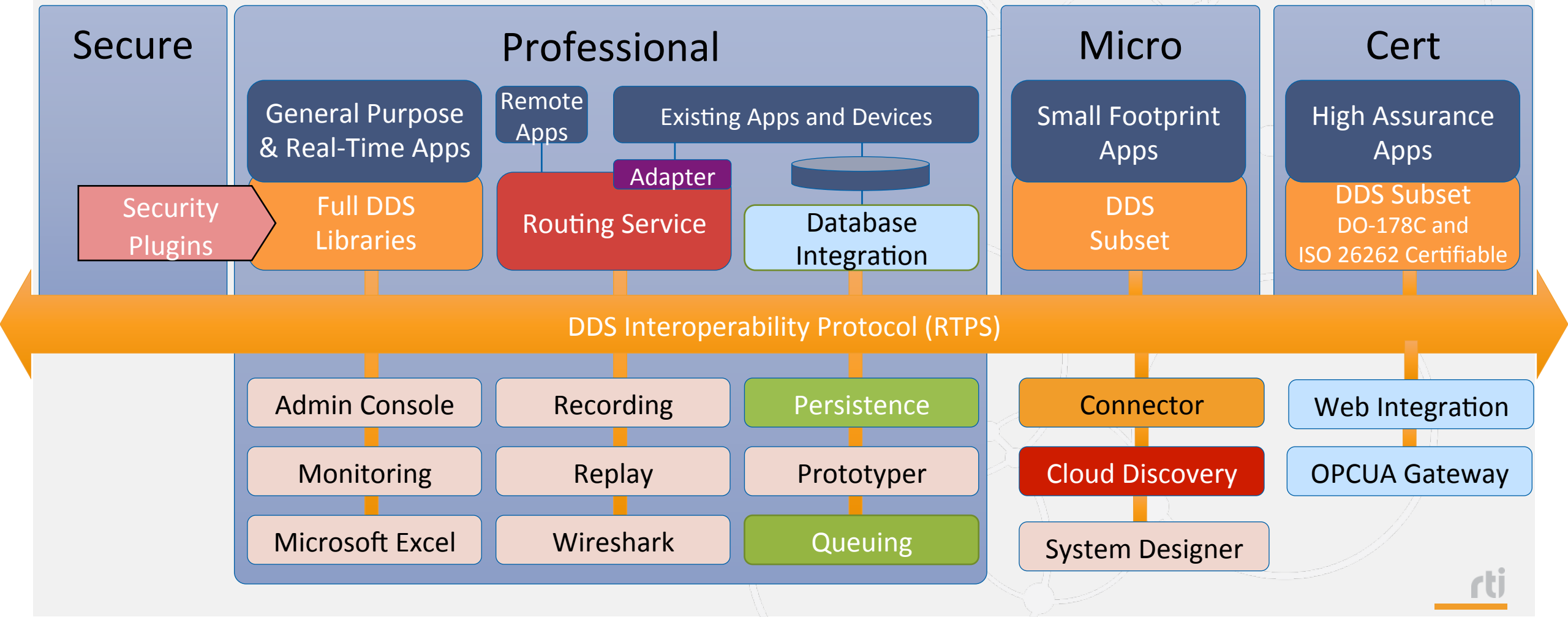
RTI Connext DDS Product Family

Security | Scalability | Tools | Ecosystem

Language APIs | Communication Patterns



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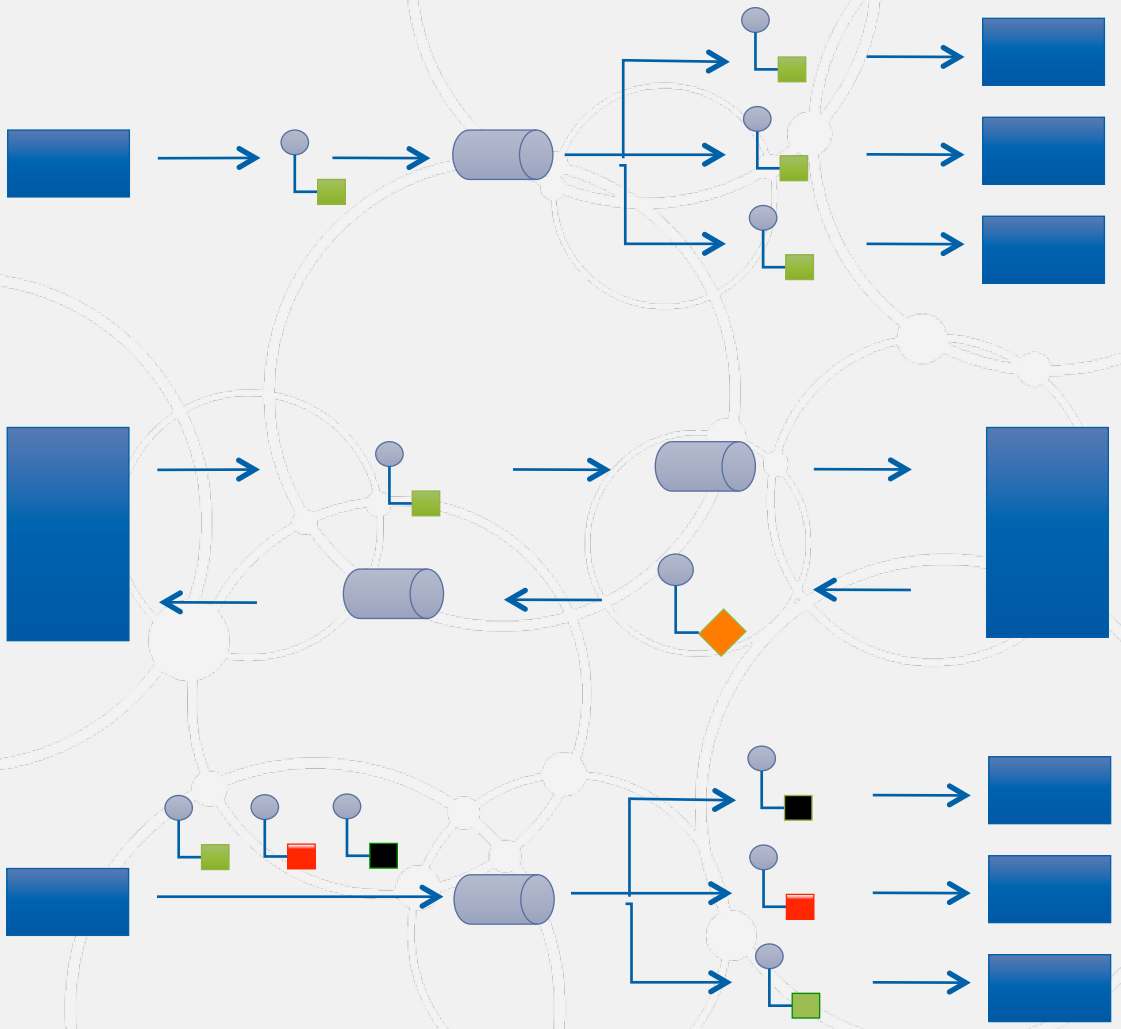
Supports All Critical Patterns

Communication Patterns

- Publish-Subscribe (2004)
- Request / Reply (2013)
- Queuing (2015)



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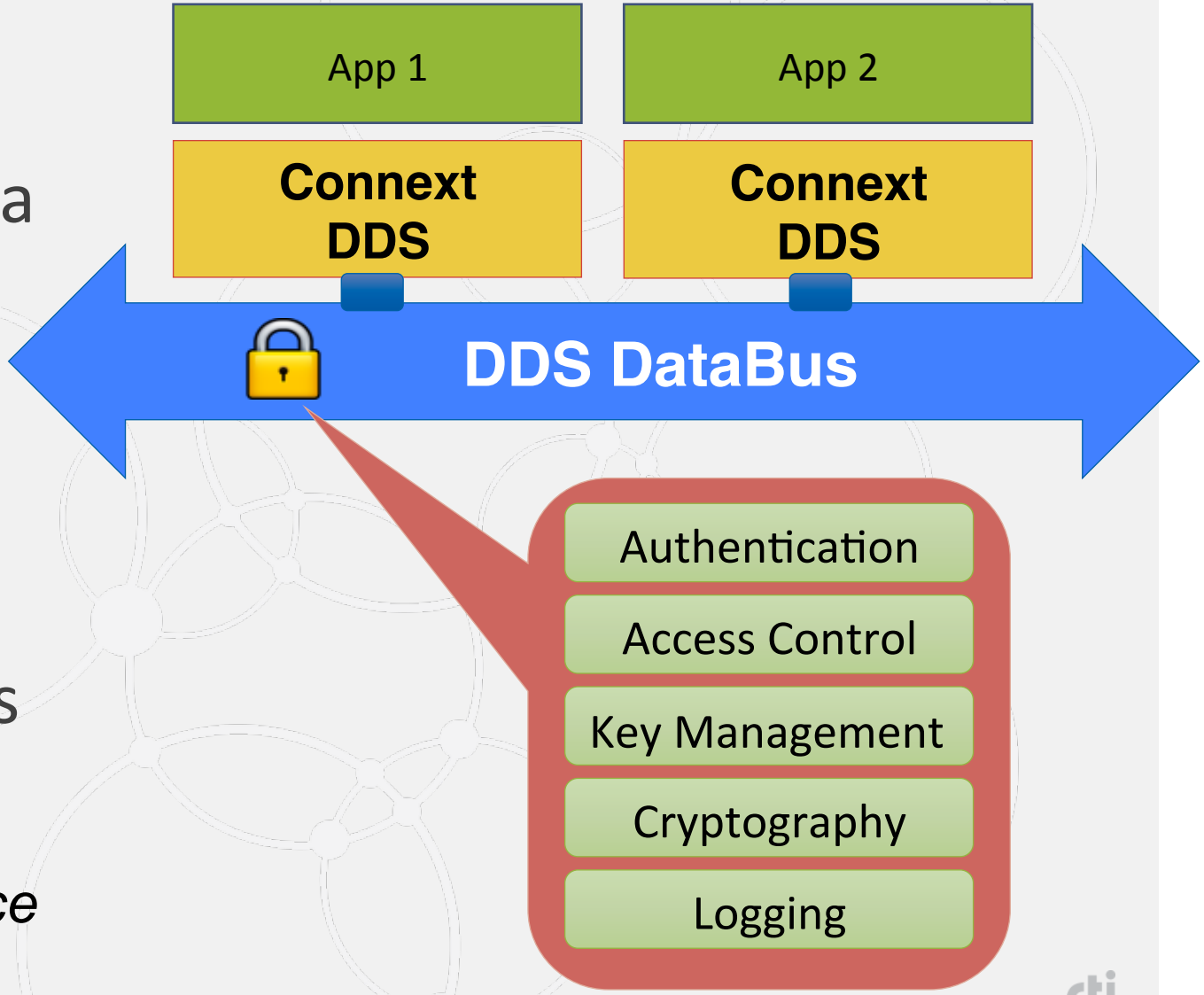
DDS Security (an OMG Standard)

- Authenticate subjects
- Enforce access control to data objects
- Ensure data integrity
- Ensure data confidentiality
- Enforce non-repudiation
- Provide availability of data
- Create auditable security logs

….while maintaining high performance



What is Security? (the old Bank analogy)

- Authentication:
  - The bank knows who you are; you must show ID.
- Access Control:
  - The bank only lets those on an access list into your box.
- Confidentiality:
  - You are alone in the room Nobody can see the contents of the box.
- Integrity:
  - The box is sealed. If anybody touches it you will know.
- Non repudiation:
  - You sign when you come in and out so you can't claim that you weren't there.
- Availability:
  - The bank is always open.

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Secure the Data, Not the Connection

DDS Domain

Topic

Line	Flight	Dest	Arv
UA	5		7:32
AA	4		9:15
AA		LAX	9:15
AA		LAX	9:15

Squawk	Line	Flight
1234	A	567
7654	A	432
765		432

Squawk	Long	Lat	Alt
1234		2.0	500.0
7654		.0	250.0
7654		74.0	250.0
7654		-74.0	250.0

Fine-Grained, DDS Security at the Topic Level

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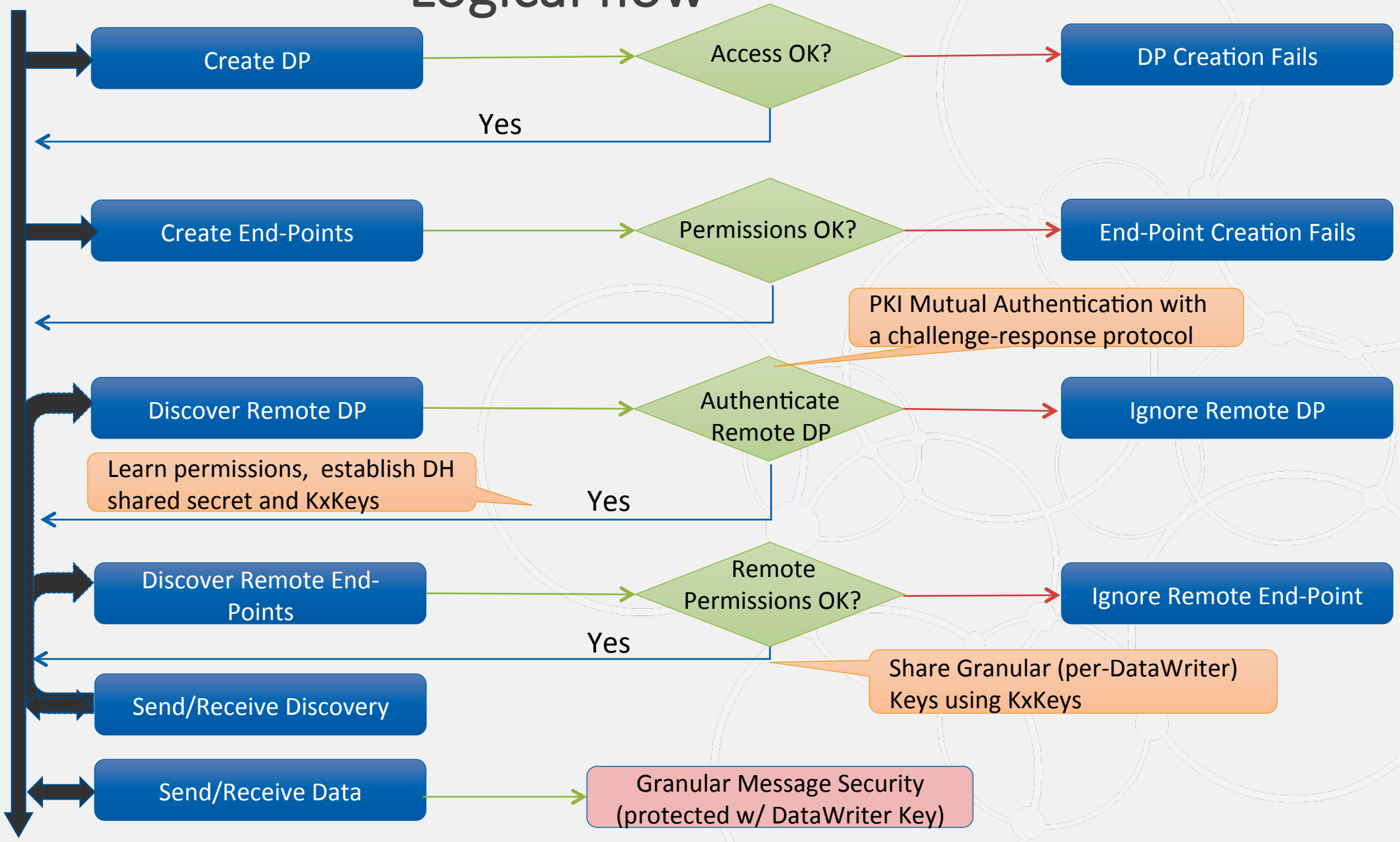
DP = Domain Participant
Endpoint = Reader / Writer

Logical flow



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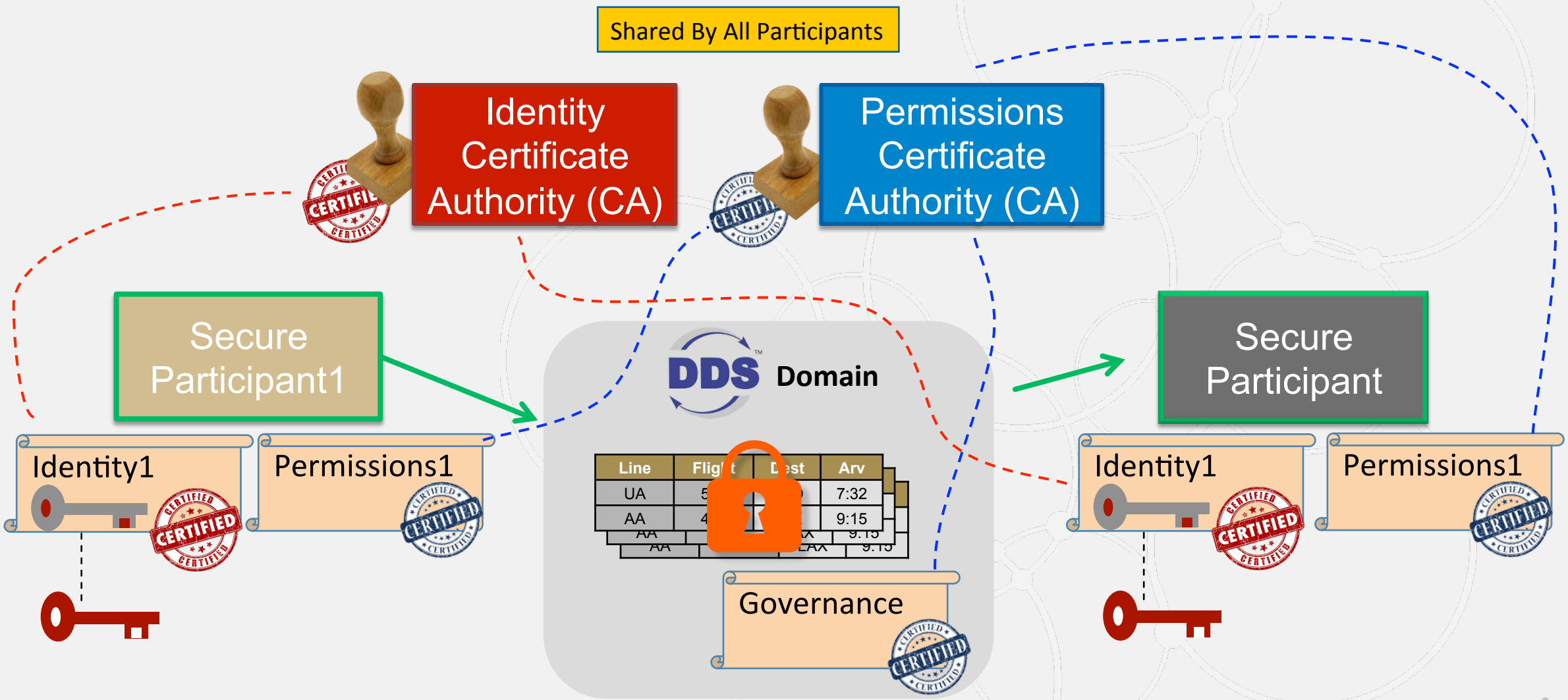
DDS Security Configuration



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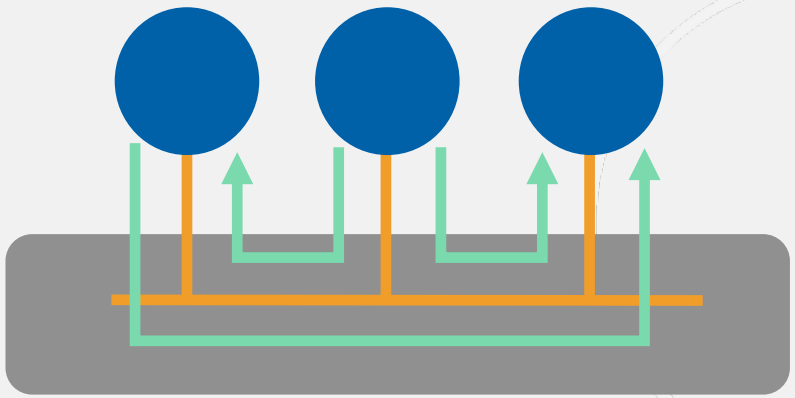
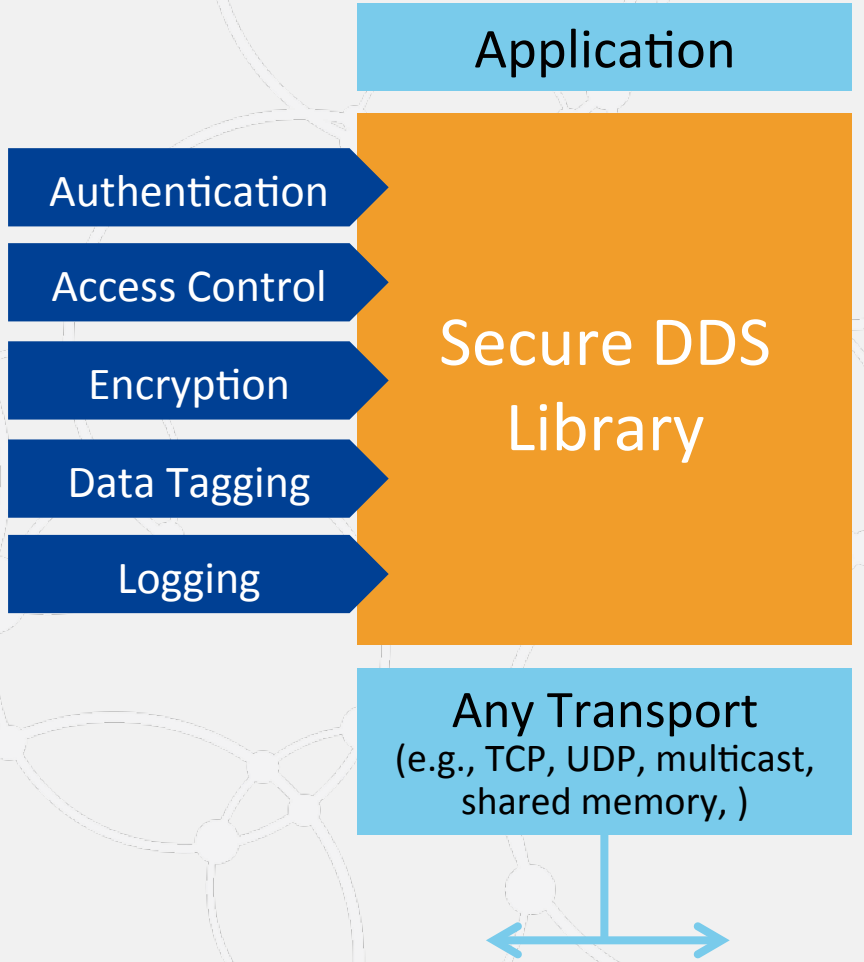
Security Plugin architecture

Data Flow Security, by Topic





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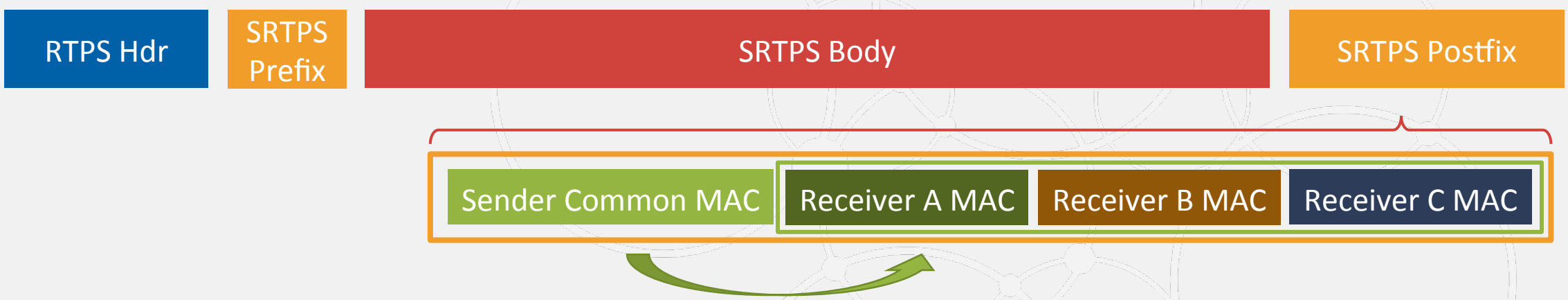
Origin Authentication Protection Kind

- Enforce Permission to Read vs Write
- Prevent Insider Attacks



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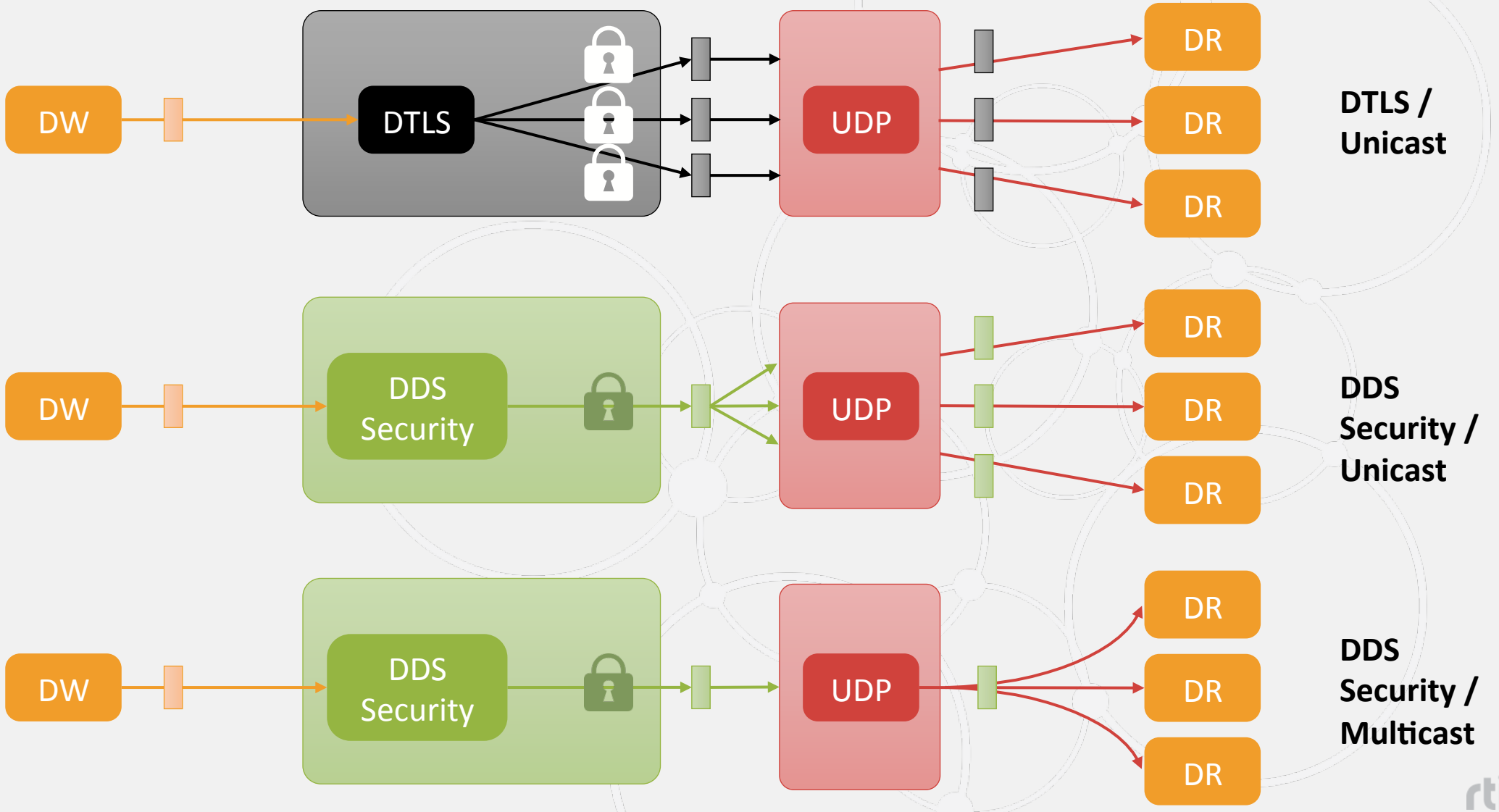
Transport Security vs DDS Security



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Performance Impact of enabling Security in DDS

Using rtiperftest: https://github.com/rticommunity/rtiperftest

Testing platform:

- CPU: Intel i7 6-core CPU 3.33GHz, 12 GB RAM
- NIC: Intel I350, 1 Gb/s
- CentOS Linux 7.1
- C++ API

1 to 1 throughput (Mbps)

Data Size	No Security	Sign Message	Sign Message + Encrypt Data	Sign Message + Encrypt Data + Origin Auth
32 B	22	18	16	15.5
256 B	177	132	122	120
2 KB	939	895	803	779
16 KB	988	984	981	980
128 KB	991	990	953	957
1 MB	980	985	887	888
Overhead		**0% - 25%**	**1% - 31%**	**1% - 32 %**

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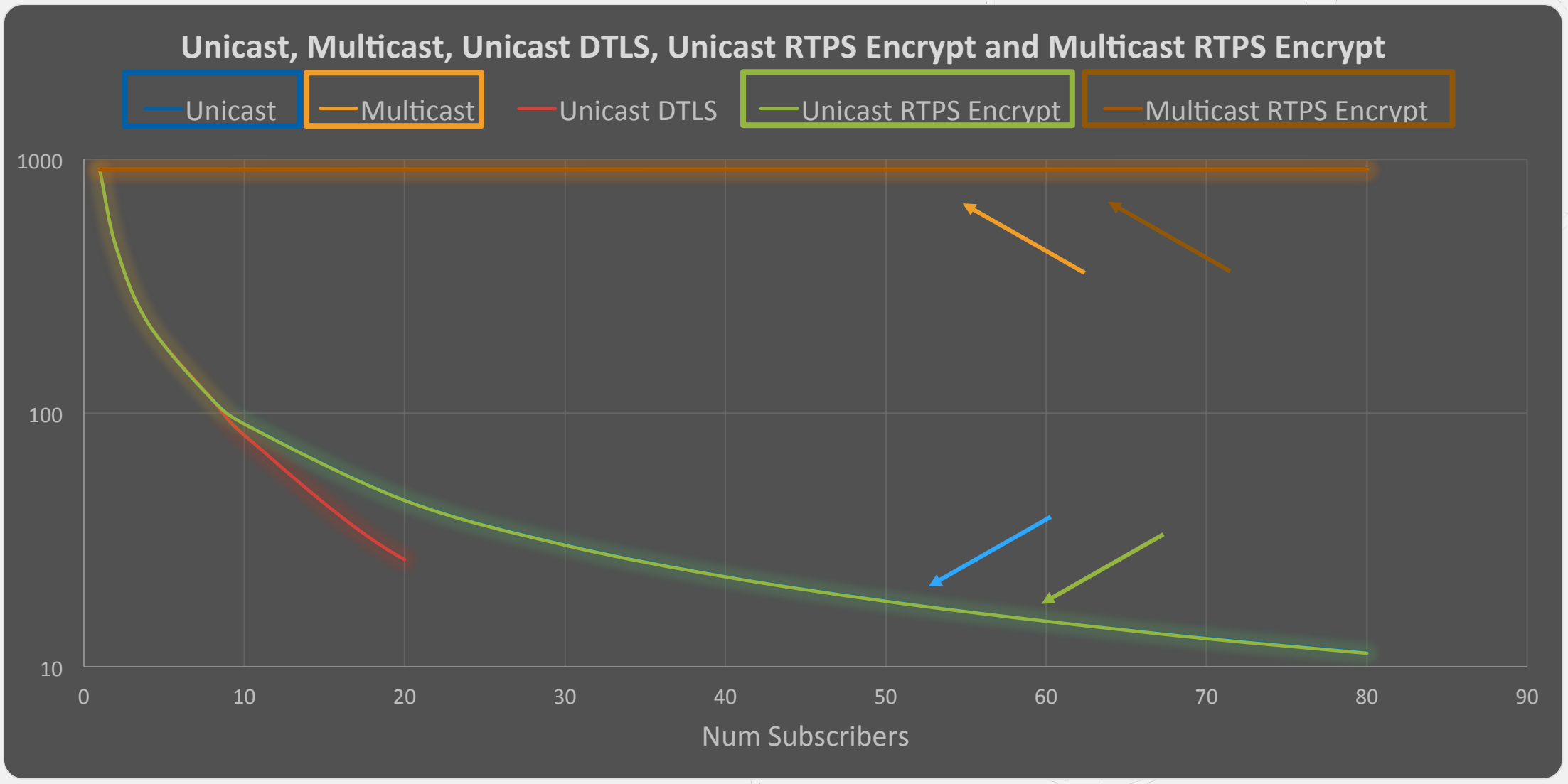
Transport Security vs DDS Security



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DDS Security is the only solution that meets the requirements of Edge Autonomy

- DDS is Standard, Interoperable and Widely deployed in IIoT
- Performant and Scalable
  - Best-of-class cryptography (Elliptic Curve, Diffie Hellman, AES)
  - Single payload encryption multiple destinations, **multicast support**
- Fine-grained:
  - Access Control at the Node/Topic/Service level
- Flexible:
  - Choice of Encryption vs Authentication vs Origin Authentication
  - Build your own plugins
- Infrastructure-independent:
  - Works over any Transport with any Qos
  - Does not depend on IPSEC, Trusted Routers, Pre-Shared Keys,…
- **Transparent: No changes to Application Code!**
- **Tools being developed to facilitate config and deployment**

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Key Technical Details

- Security
- Flexible Type System
- Scalability
- Ecosystem
- Performance
- Tools

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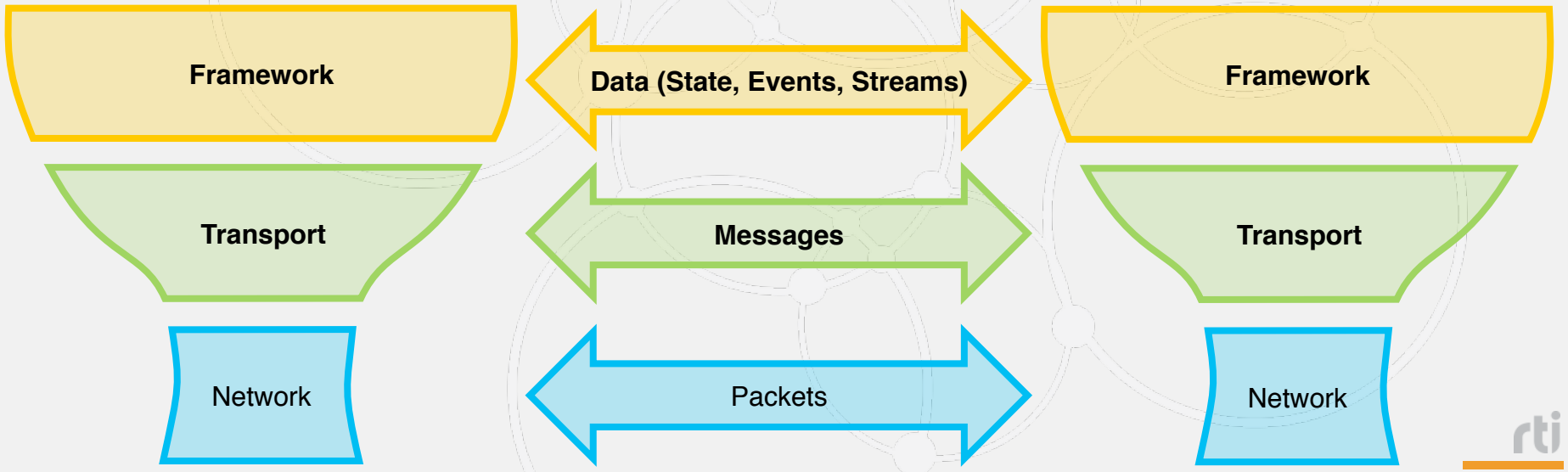
Type System, Type Compatibility & Evolution

- What are the valid data types?
- How are they expressed independent of programming-languages?
- Can types evolve and remain compatible?
- How are types represented on the network?

Syntactic Interoperability (data structures)



Flexible Types (IDL 4.2 + XTYPES 1.3)

```
@appendable
struct ShapeType {
    @key string color;
    @range(0, 200)  int32 x;
    @range(0, 250) int32 y;
    @optional @min(5) uint32 size;
};
struct ShapeTypeExt : ShapeType
{
    @optional @unit("radian")
    @default(0)   float angle;
};
```

- Basis for defining Datamodels
- Becoming ISO standard
- Better performance
- Better extensibility

- Normalization format for IIOT data models:
  - XSD, JSON, ROS-IDL, Ad-hoc …
  - 3rd party tooling support - UML, Matlab, LabView,

Connext6 supports:
@default @min @max
@range @unit

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Type System, Type Compatibility Evolution

Two types may differ from one another in the additional, removal, and/or transposition of members

```
struct TrackData_v1 {
    @key long id;
    long x;
    long y;
};
```


```
struct TrackData_v2 {
    long x;
    @key long id;
    long y;
    long z;
};
```

Three extensibility kinds:

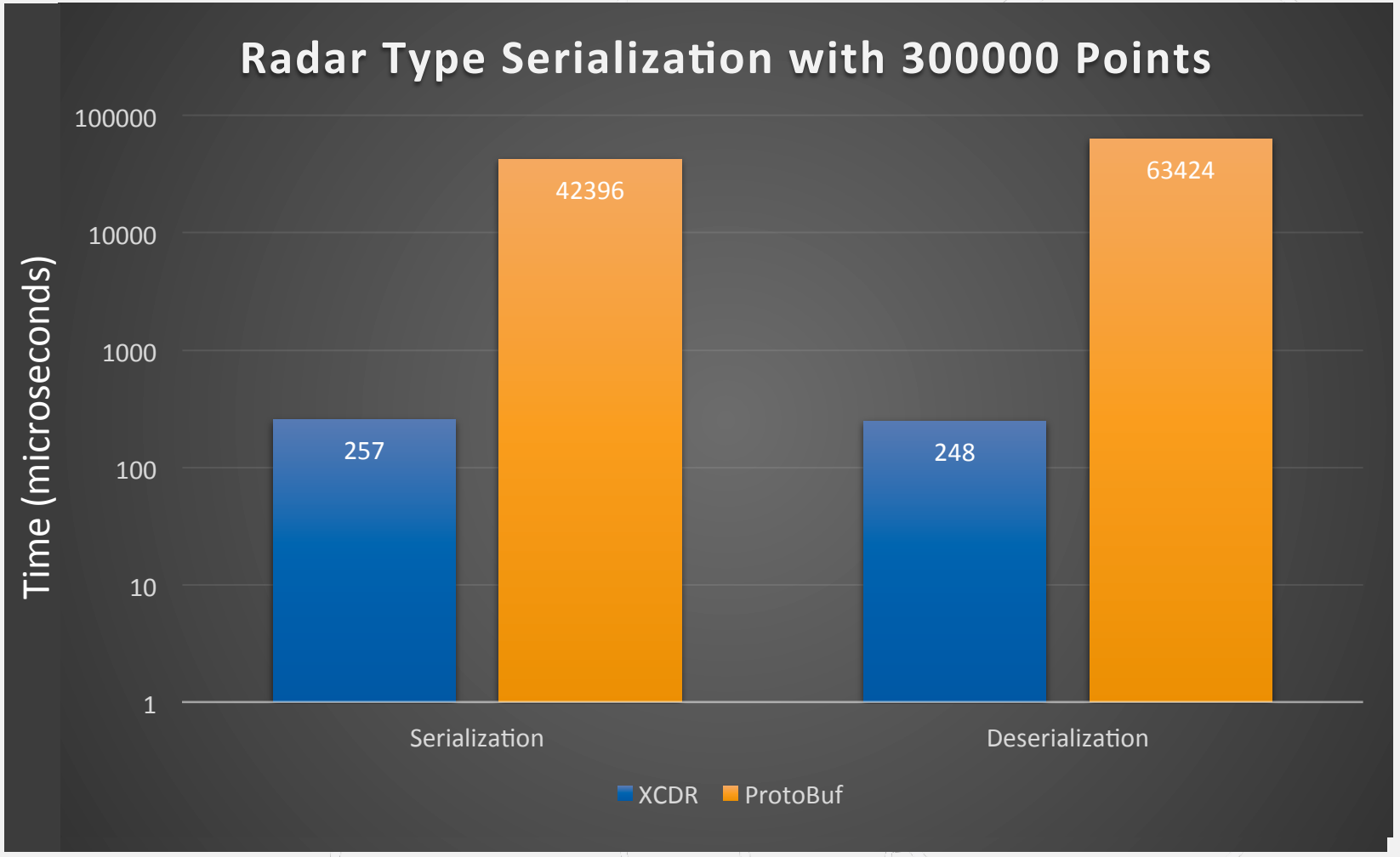
- **Final:** Types must be the same
- **Appendable:** Types may add fields at the end
- **Mutable:** Types may have fields reordered, added, or removed anywhere

XCDR versus ProtoBuf

```
@final
struct Point
{
  float A;
  float B;
};

typedef sequence< Point,
maxSize> SequenceOfPoints;

@final
struct RadarSweep
{
   …
   SequenceOfPoints samples;
};
```



New high-performance Interpreter-based serialization

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Key Technical Details

Security

Flexible Type System

Scalability

Ecosystem

Performance

Tools

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Large Data scenarios

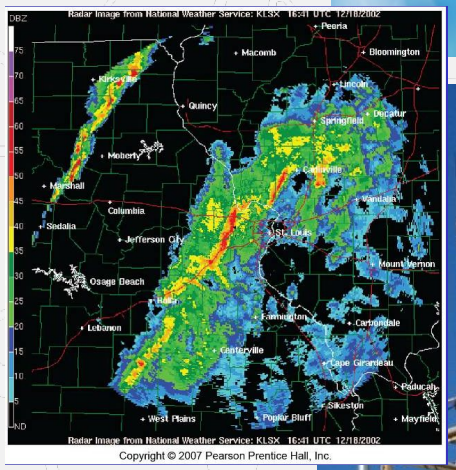
Lidar:

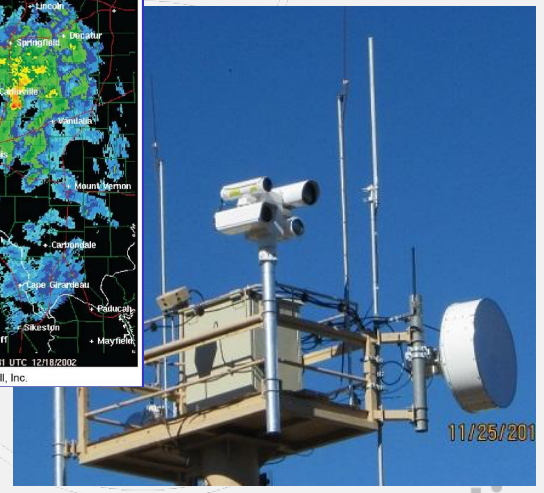
Radar:

REDUCE COPIES

Images: Video, Radar, …

Medical Scanners (CT, PET)





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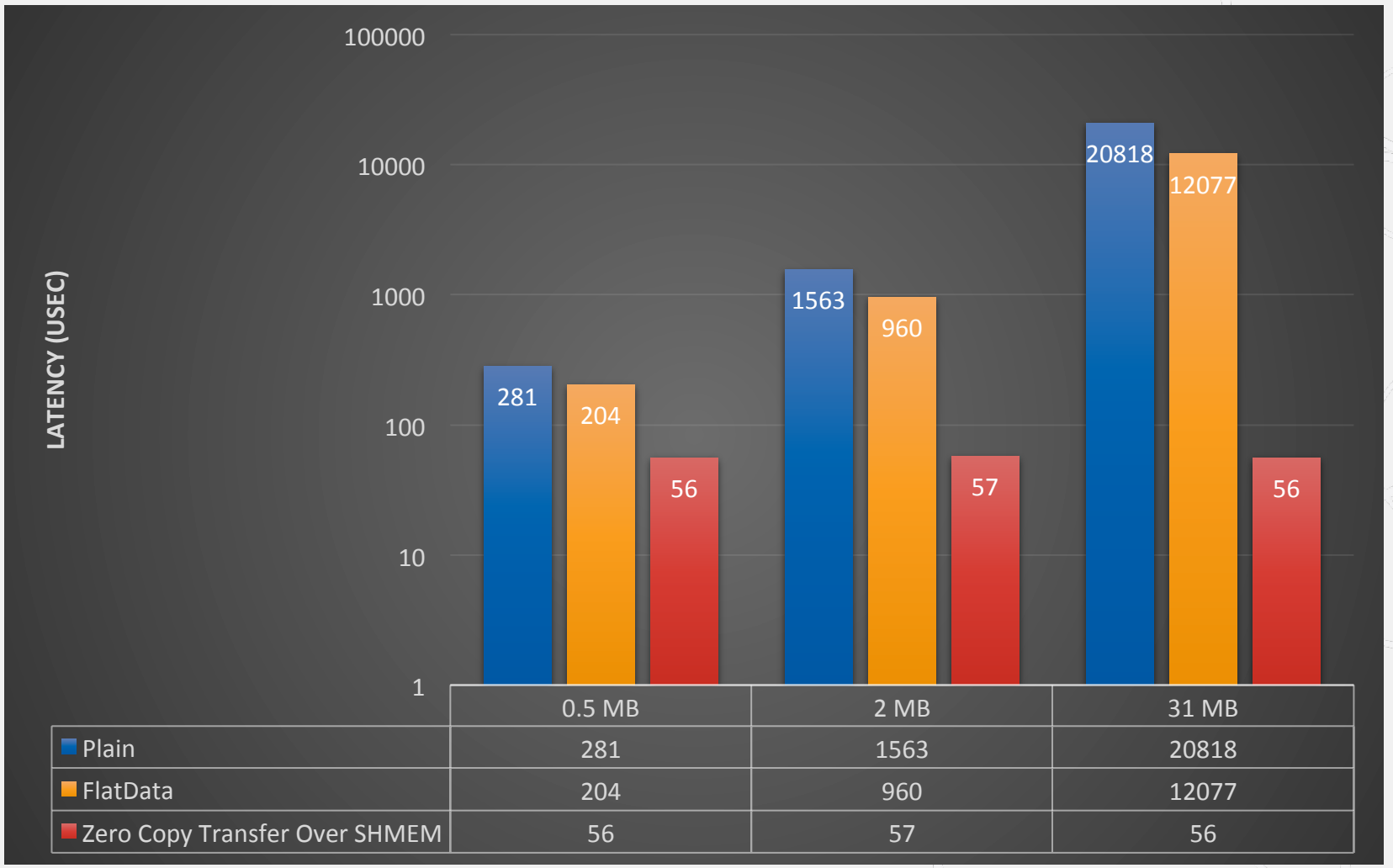
Large Data Performance Single Node



	0.5 MB	2 MB	31 MB
Plain	281	1563	20818
FlatData	204	960	12077
Zero Copy Transfer Over SHMEM	56	57	56

Platform

Intel i7 6-core CPU
3.33GHz
12 GB RAM
CentOS Linux

Optimized shared memory latency **constant** independently of the message size

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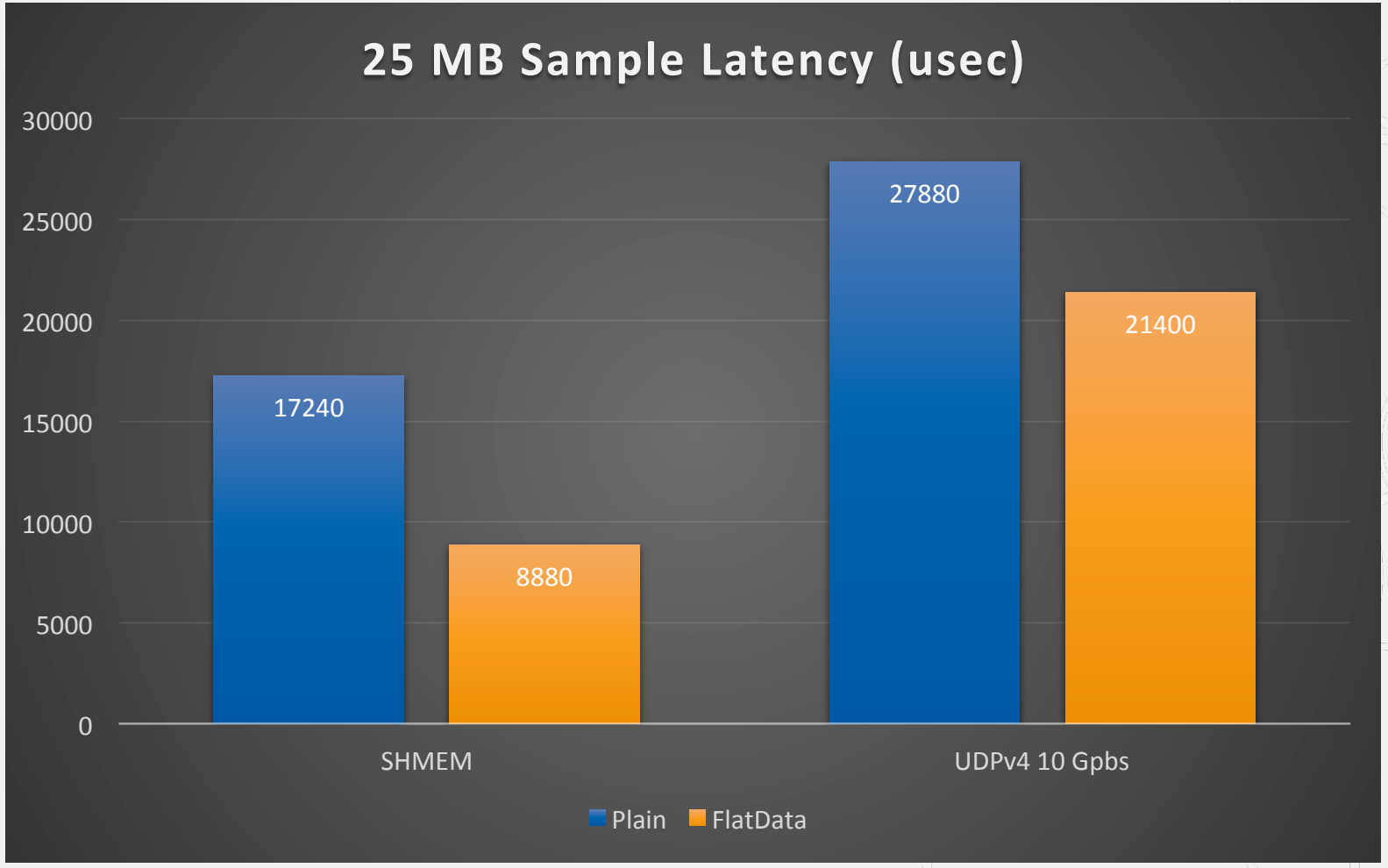
FlatData Performance Across Nodes



Platform

Intel i7 6-core CPU
3.33GHz
12 GB RAM
CentOS Linux
10 Gb network

25 MB sample copy time = 3370 usec

25 MB over 10Gb/s time = 2000 usec

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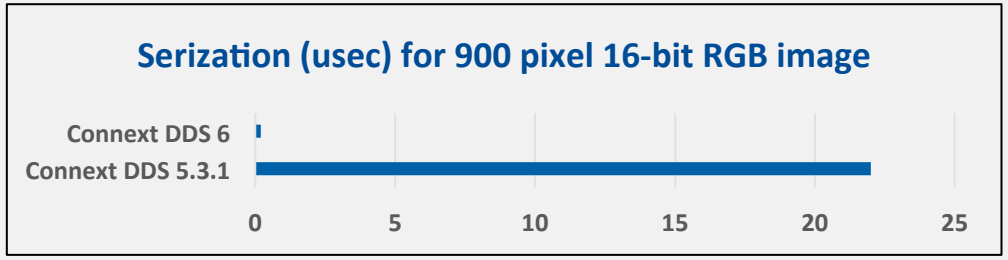
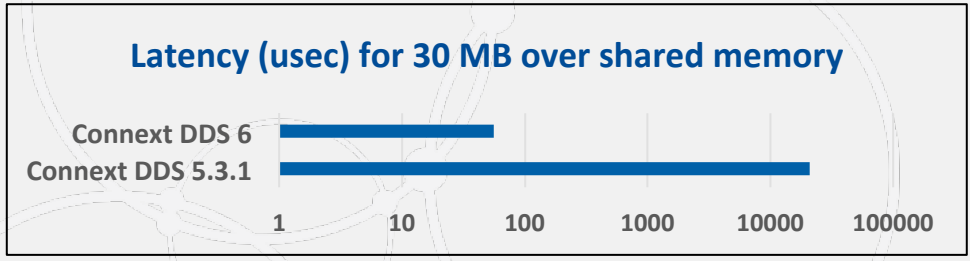
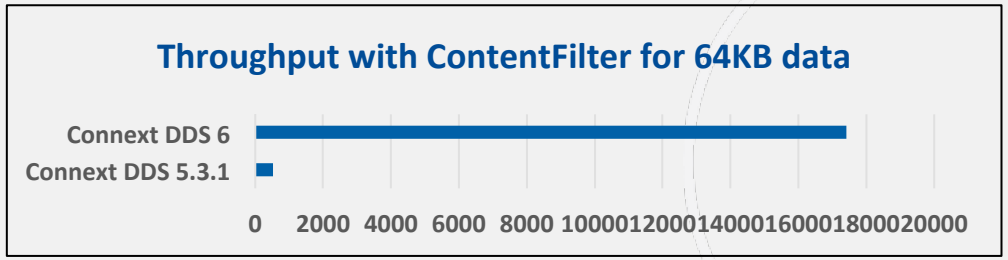
Performance & Scalability Improvements: 10% to 100x or more



Serialization/Deser. : 2x to 100x or more

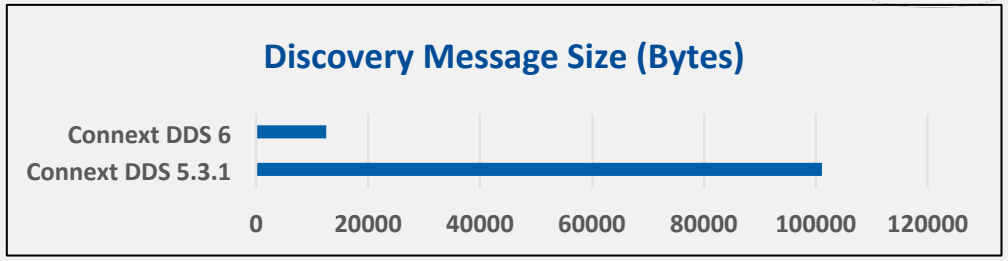


Large Data: 2x to 300x or more

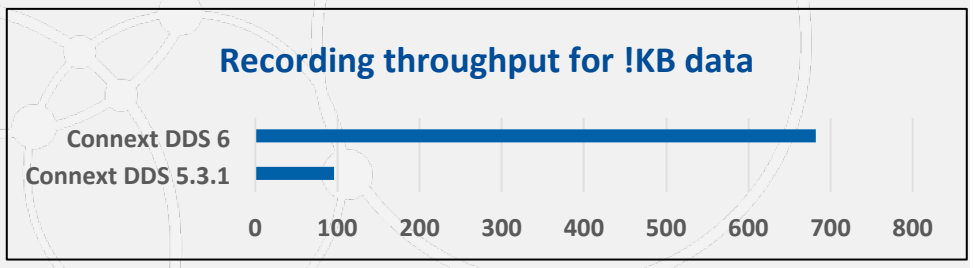


Content Filters: 20% to 30x or more

Dynamic Data: 2x to 100x or more



Discovery bandwidth: 2x to 10x or more



Recording Service: 10% to 7x

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Key Technical Details

- Security
- Flexible Type System
- Scalability
- Ecosystem
- Performance
- Tools

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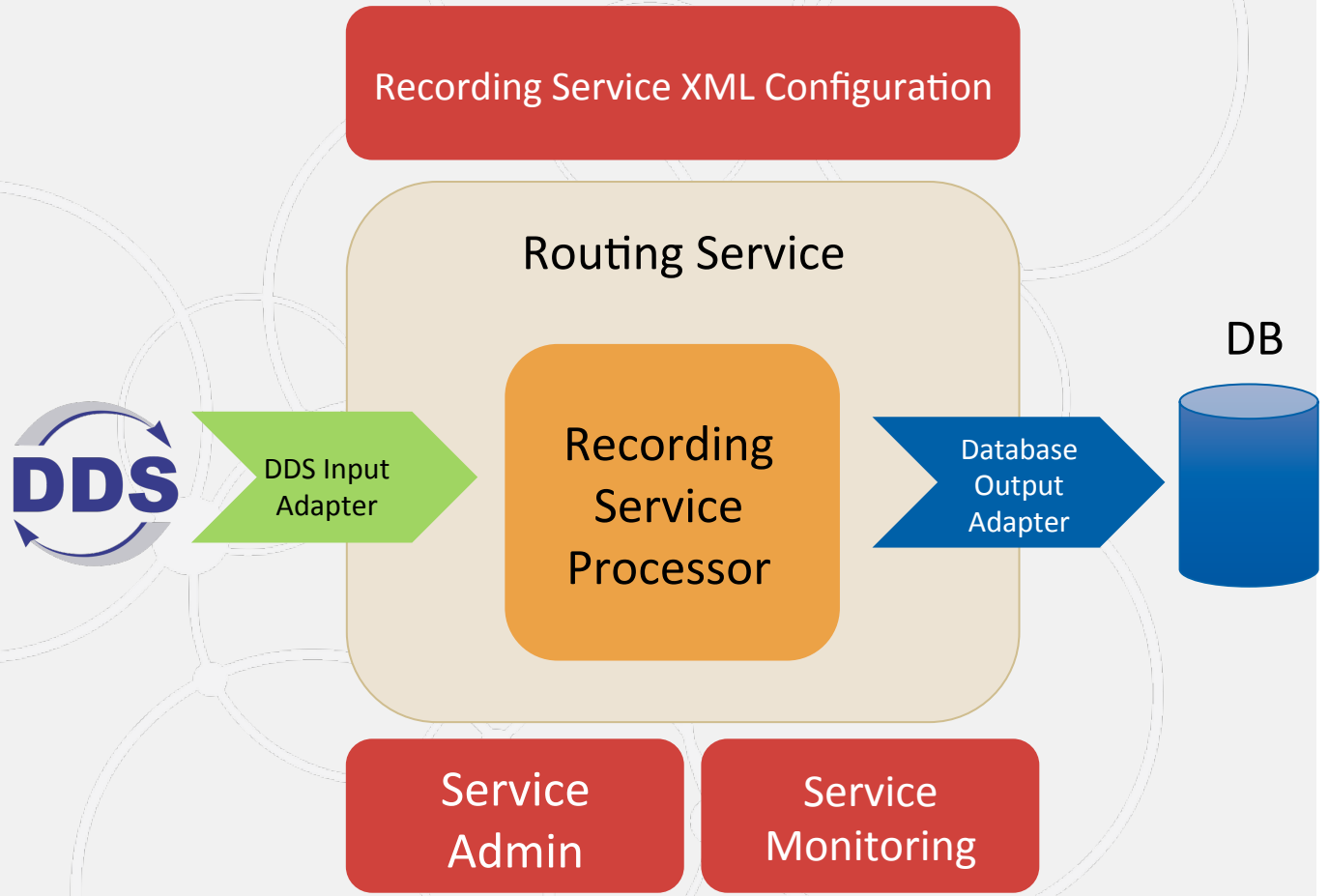
Connext 6 Recording Service

Tools | Ecosystem | Performance

- Built on Routing Service
- **Higher performance** (~ 20%-7X)
- Pluggable Storage
- Support for Transformations
- Content filtered Topics
- Overcome column limitations
  - Use JSON to store de-serialized
- Better Debuggability & Monitoring
- Simpler configuration



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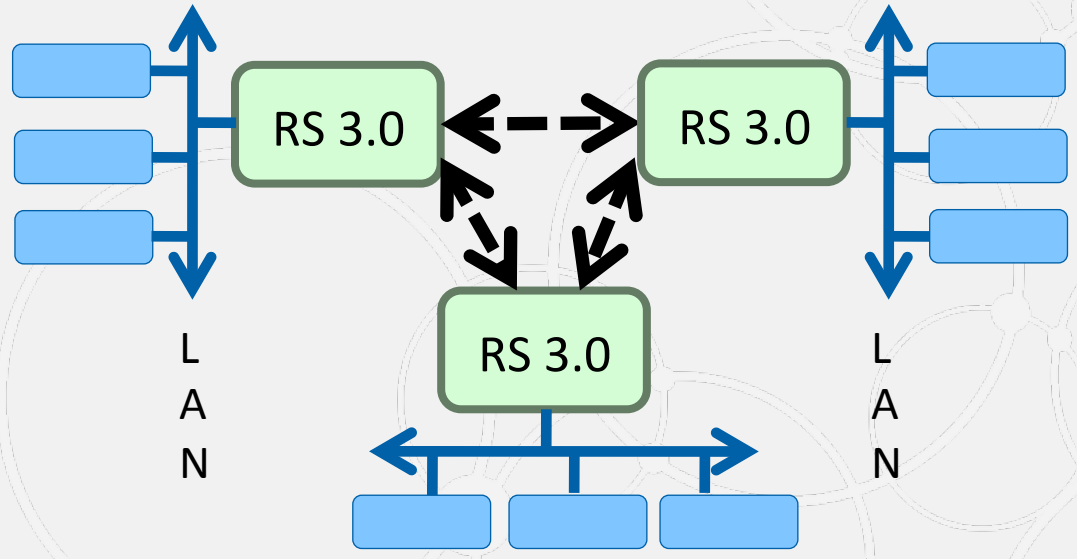
Connext 6 Routing Service

Ecosystem

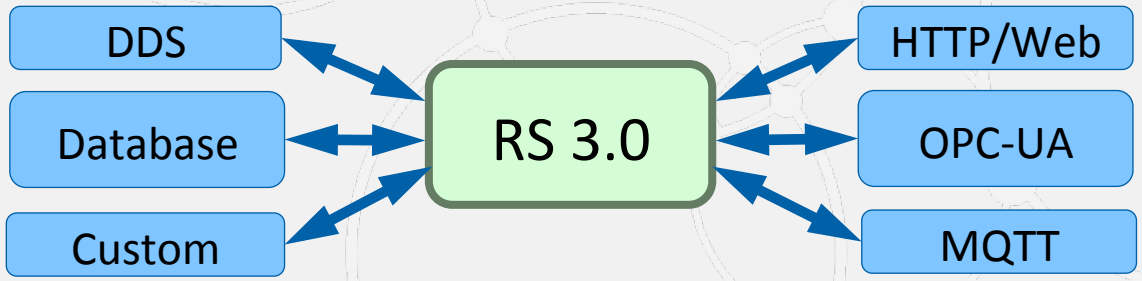
Scalability

Address two complementary use-cases:

1. Federation



2. Mediation



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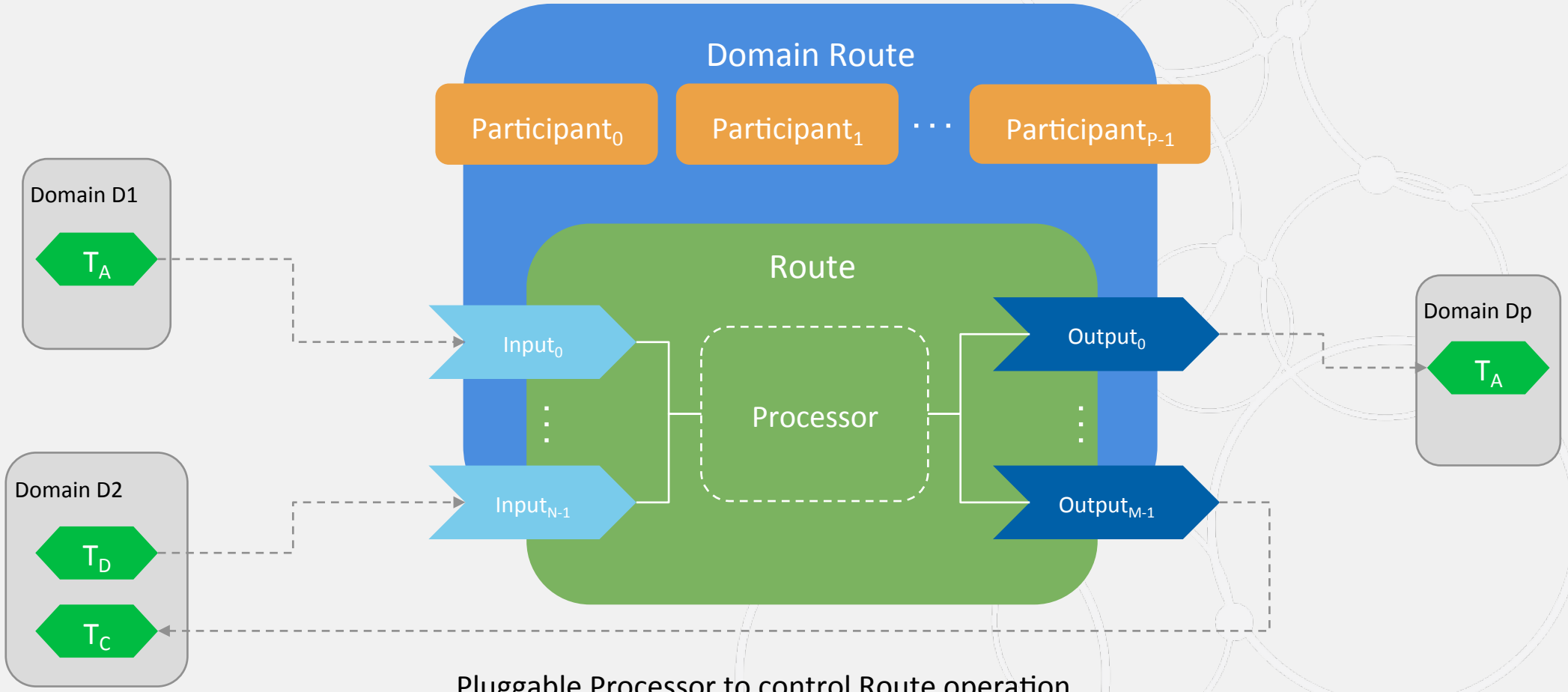
Connext 6 Routing Service Architecture

Multiple participants in a DomainRoute

Multiple inputs and outputs in a Route



Pluggable Processor to control Route operation

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Integration: MQTT Gateway

MQTT Enabled Service

Built on Routing Service

Application
MQTT Client

Application
MQTT Client

MQTT Broker

MQTT.ORG

Gateway
MQTT Client
DDS

DDS Databus

DDS

Application
DDS

Application
DDS

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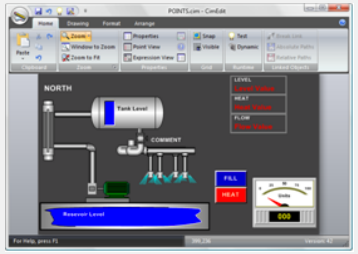
Integration: DDS-OPCUA Gateway



OPCUA Enabled App.

Built on Routing Service

Application

OPC UA Client

Application

OPC UA Server

Gateway

OPC UA Server

OPC UA Client

DDS

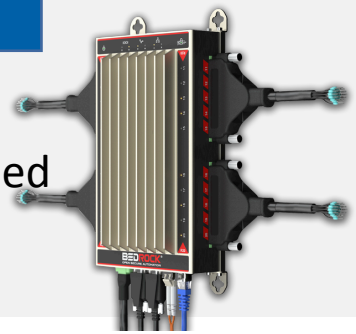
DDS Databus

Application

DDS

Application

DDS



OPCUA Enabled Device

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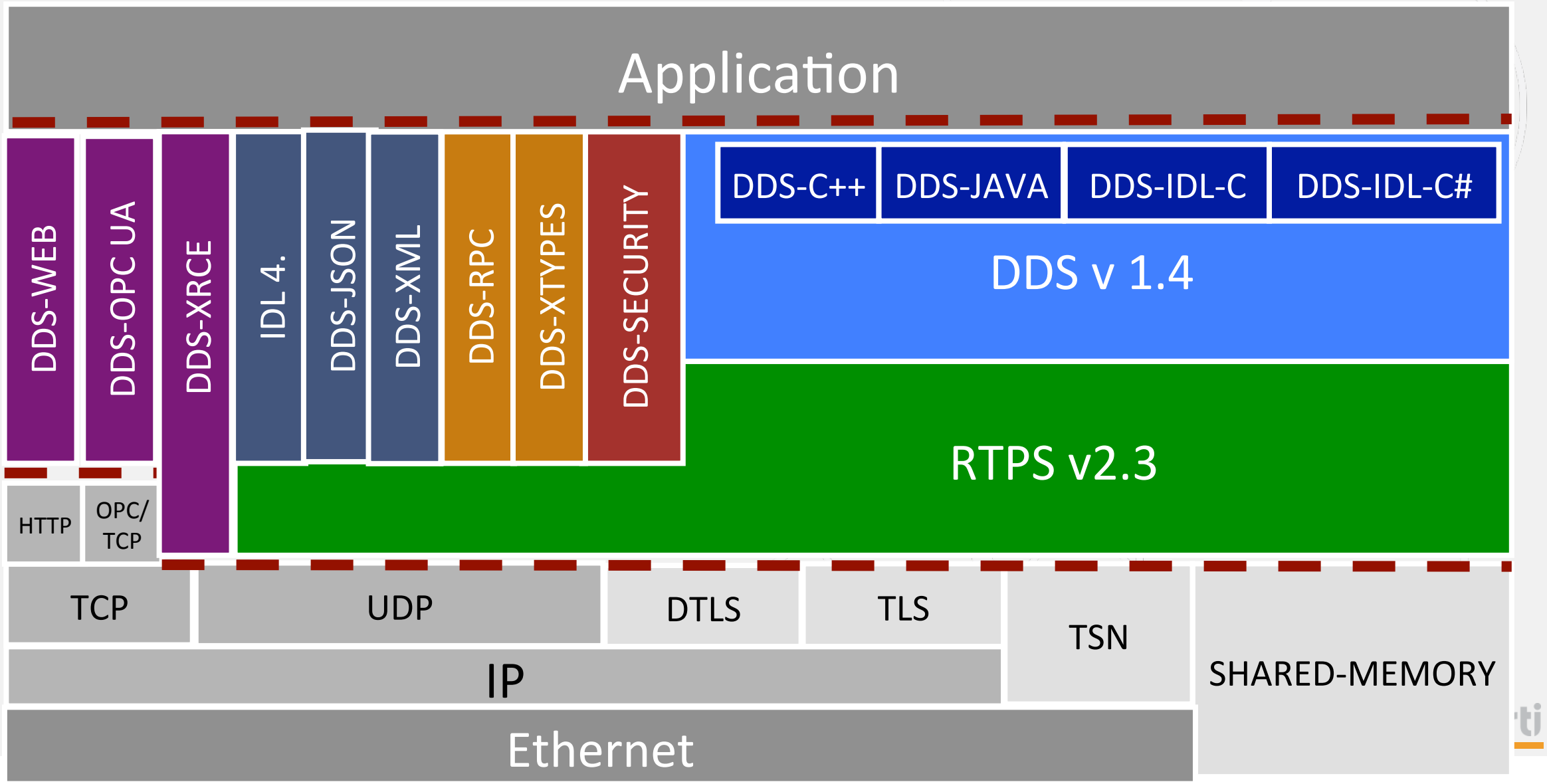
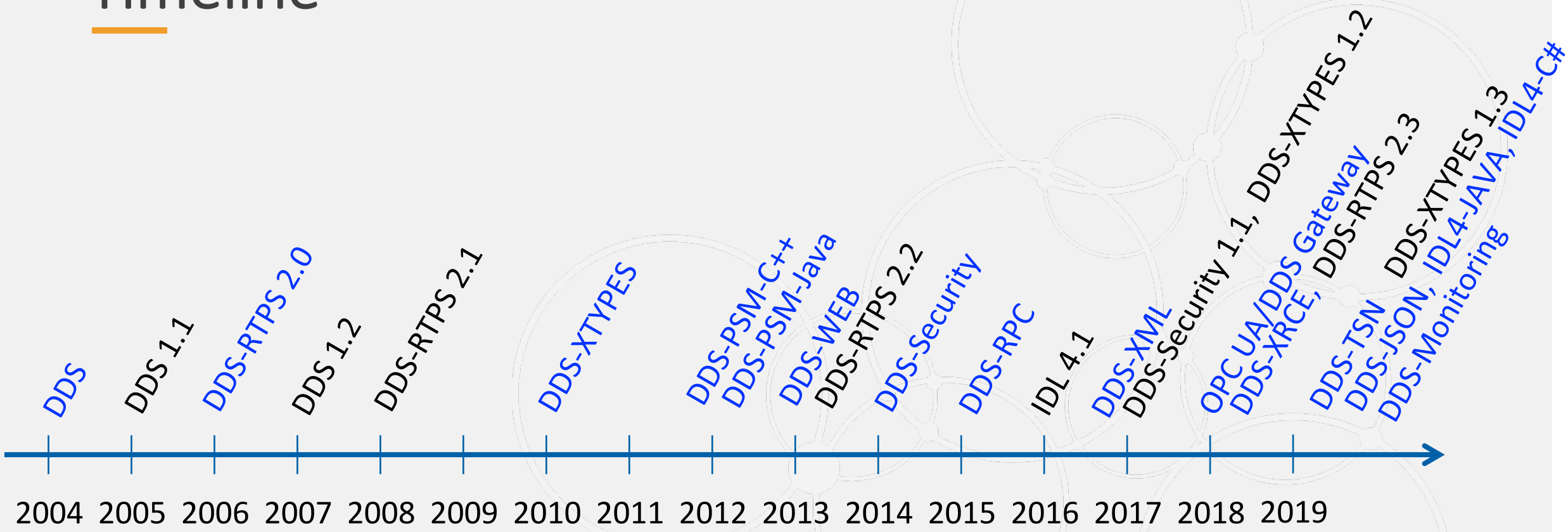
Standards & Communities

DDS Specification family



Timeline



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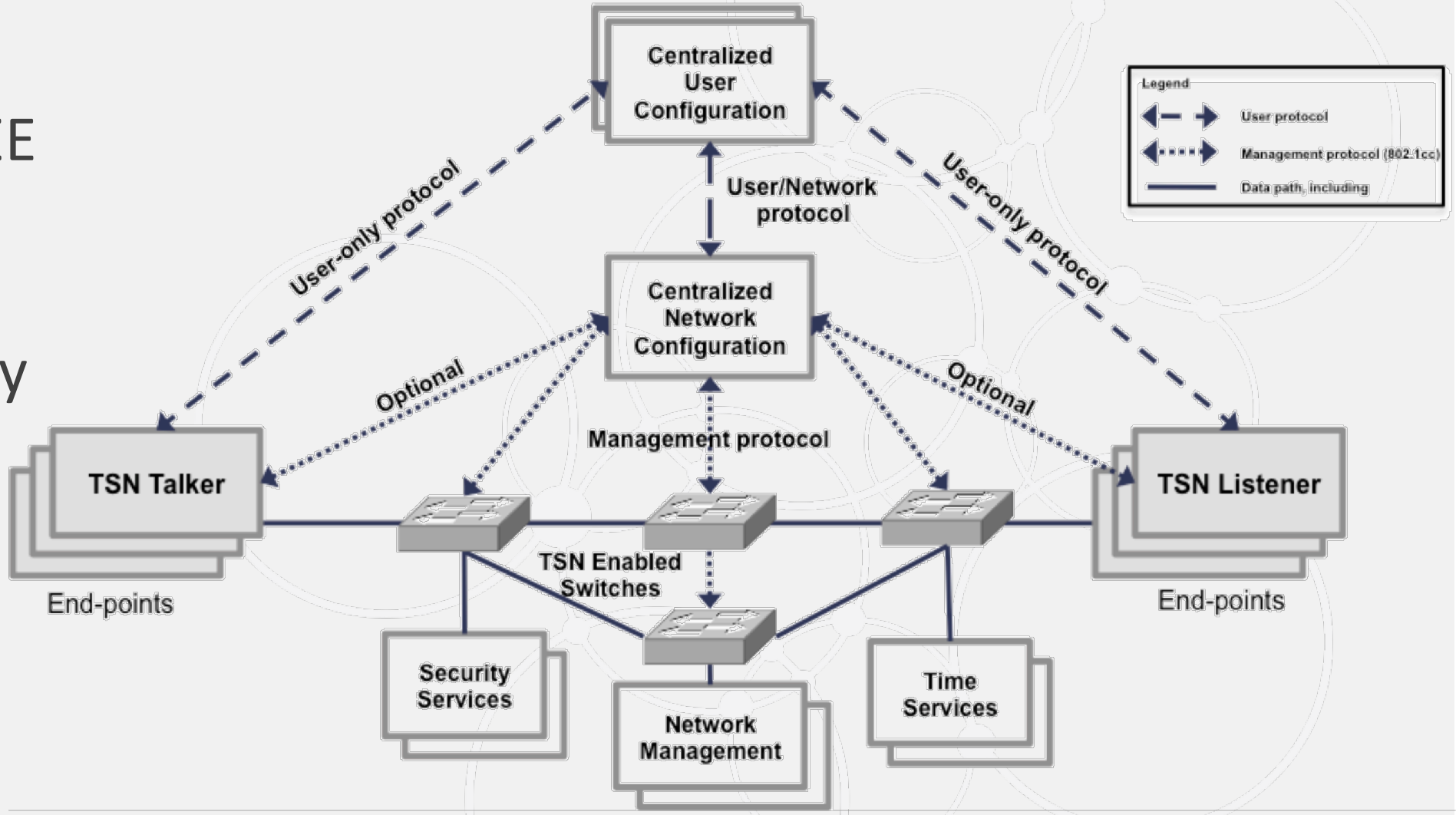
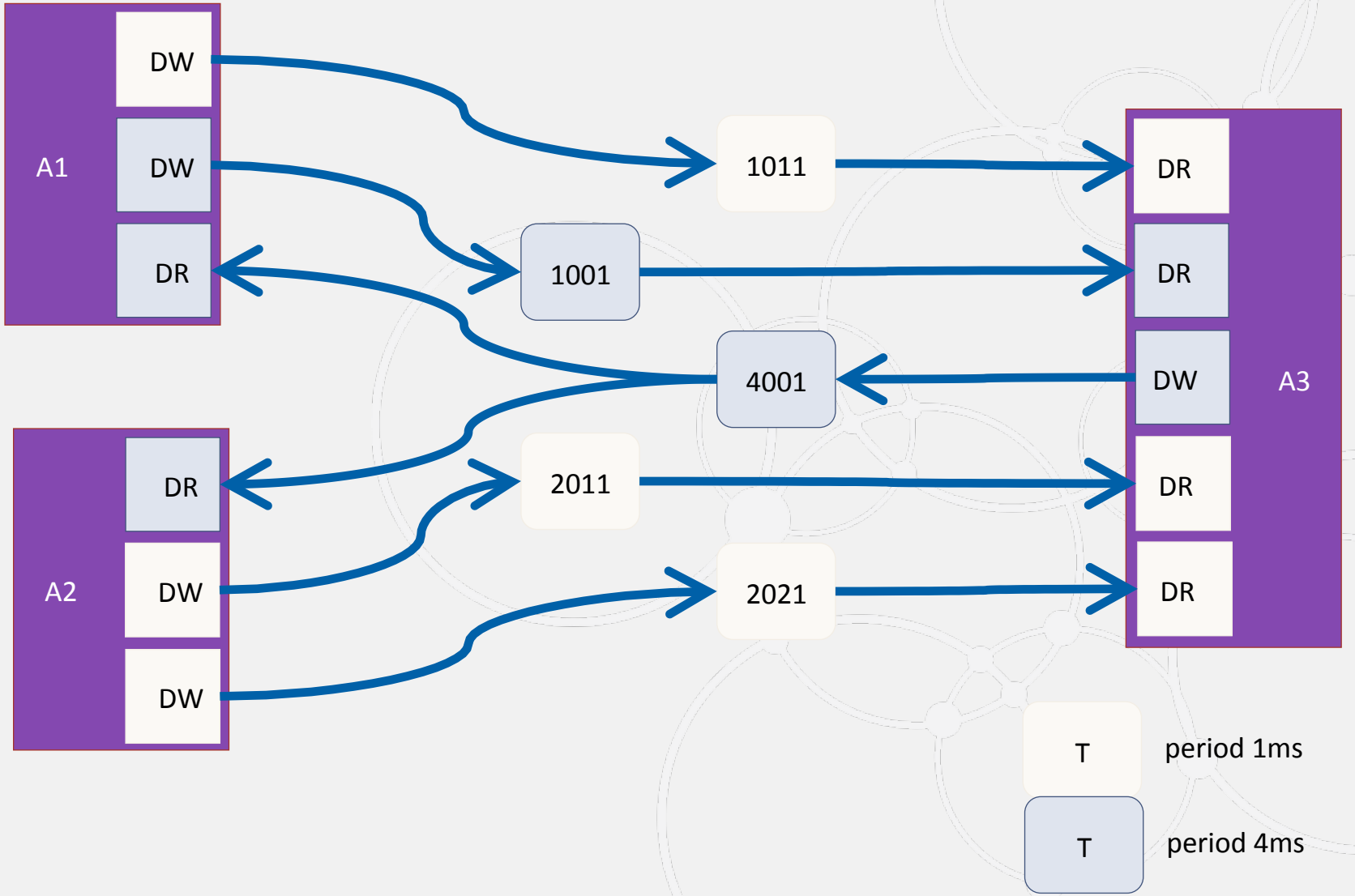
Time Sensitive Networks

- New set of IEEE standards
- Deterministic packet delivery on standard Ethernet



DDS + TSN (Time Sensitive Networking)



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DDS-TSN

- DDS and TSN are a good fit:
  - Low Latency, Predictability, and Qos
  - TSN data flows naturally match DDS data flows
- DDS can leverage TSN to implement and guarantee Qos:
  - Use TSN clock for time-stamping and global data ordering
  - Automatically define TSN flows per DDS Topic
  - Identify critical flows based on Qos (e.g. latency budget, deadline)
  - Ensure Qos can be met (deadline, liveliness)
  - Derive TSN schedule from DDS configuration & deployment

Use TSN as a deterministic transport for DDS over Ethernet

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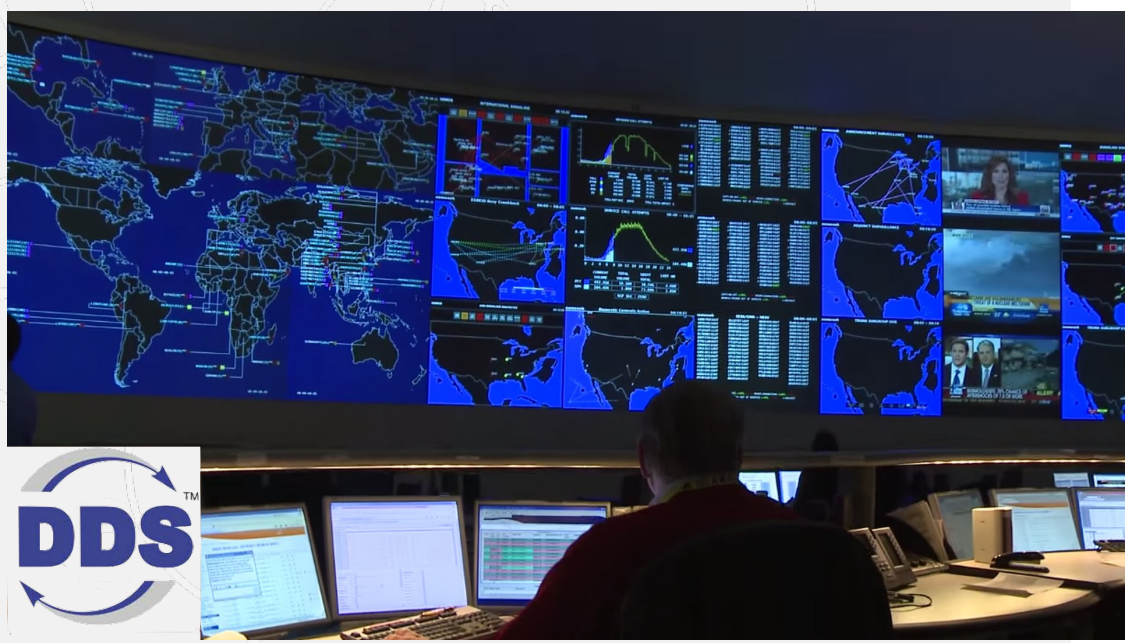
DDS-Monitoring

- Standardized way to monitor the health status of the DDS databus during live operation
  - Information Model for Monitoring Metrics
  - DDS API's to locally access status information
  - Mechanism to remotely configure and monitor
- Non-functional:
  - Built-in, always-available
  - Light-weight
    - No additional discovery
    - Minimal impact on running system



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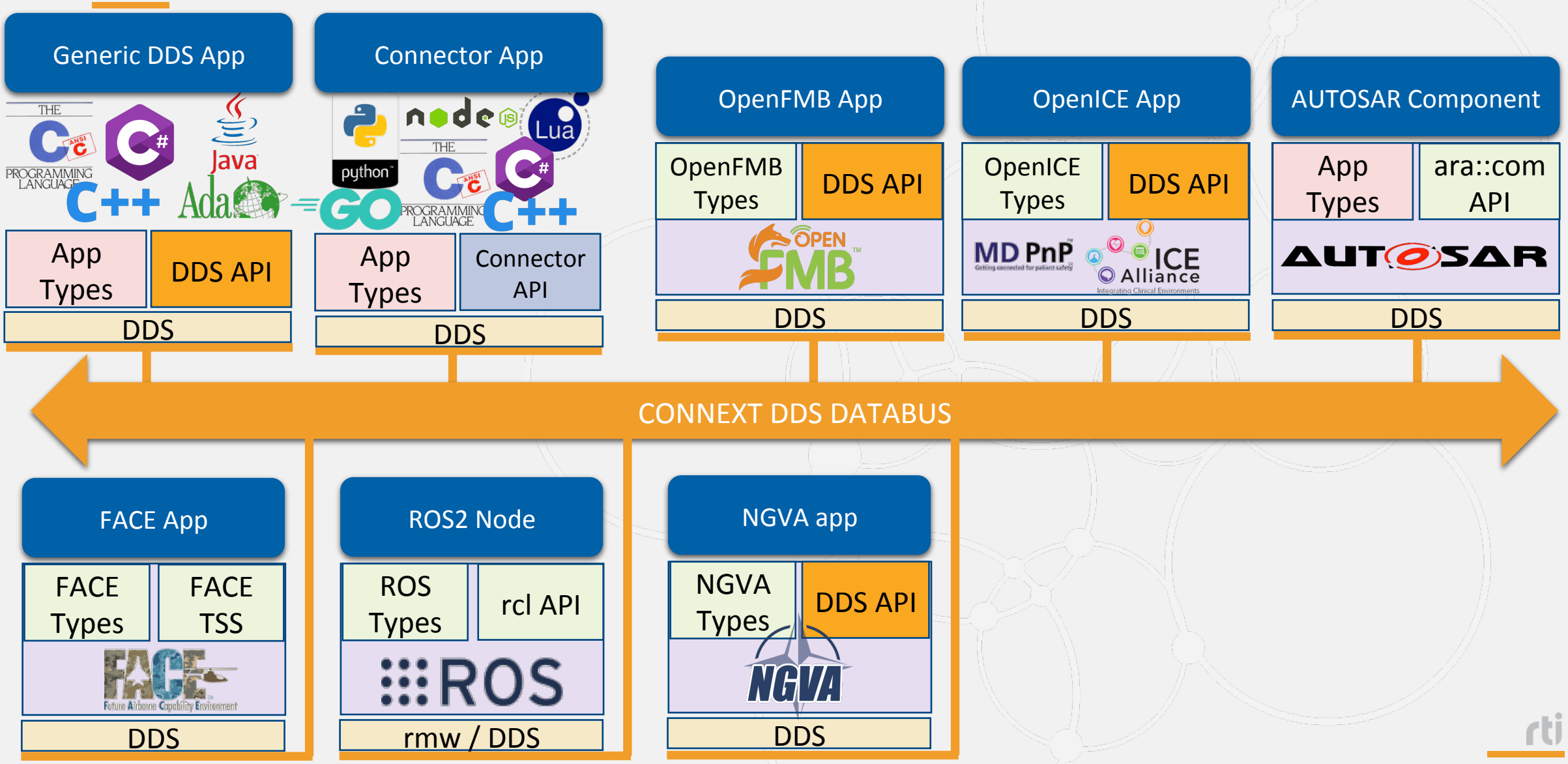
Connext DDS as Core Connectivity Framework



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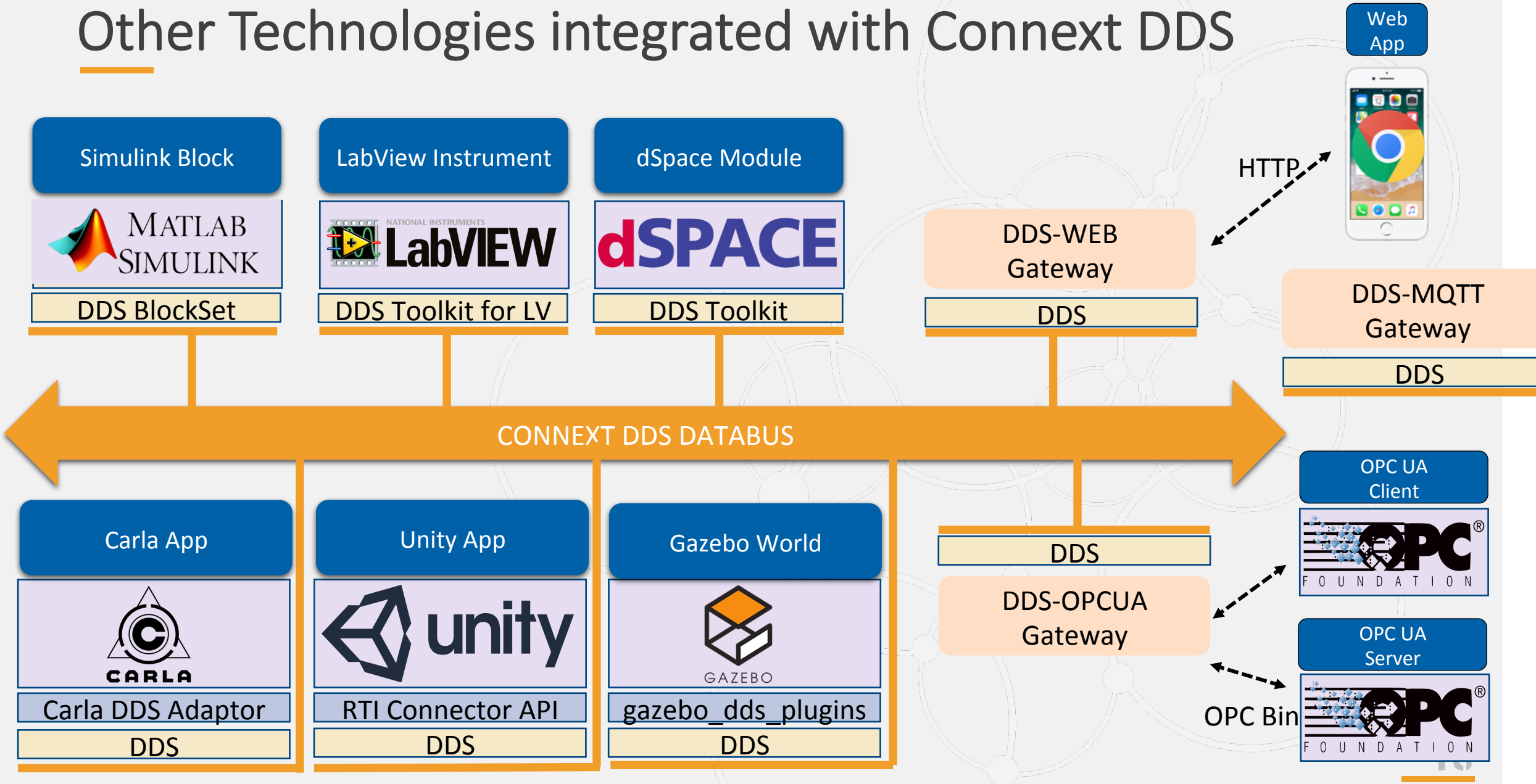
Other Technologies integrated with Connext DDS



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Tools

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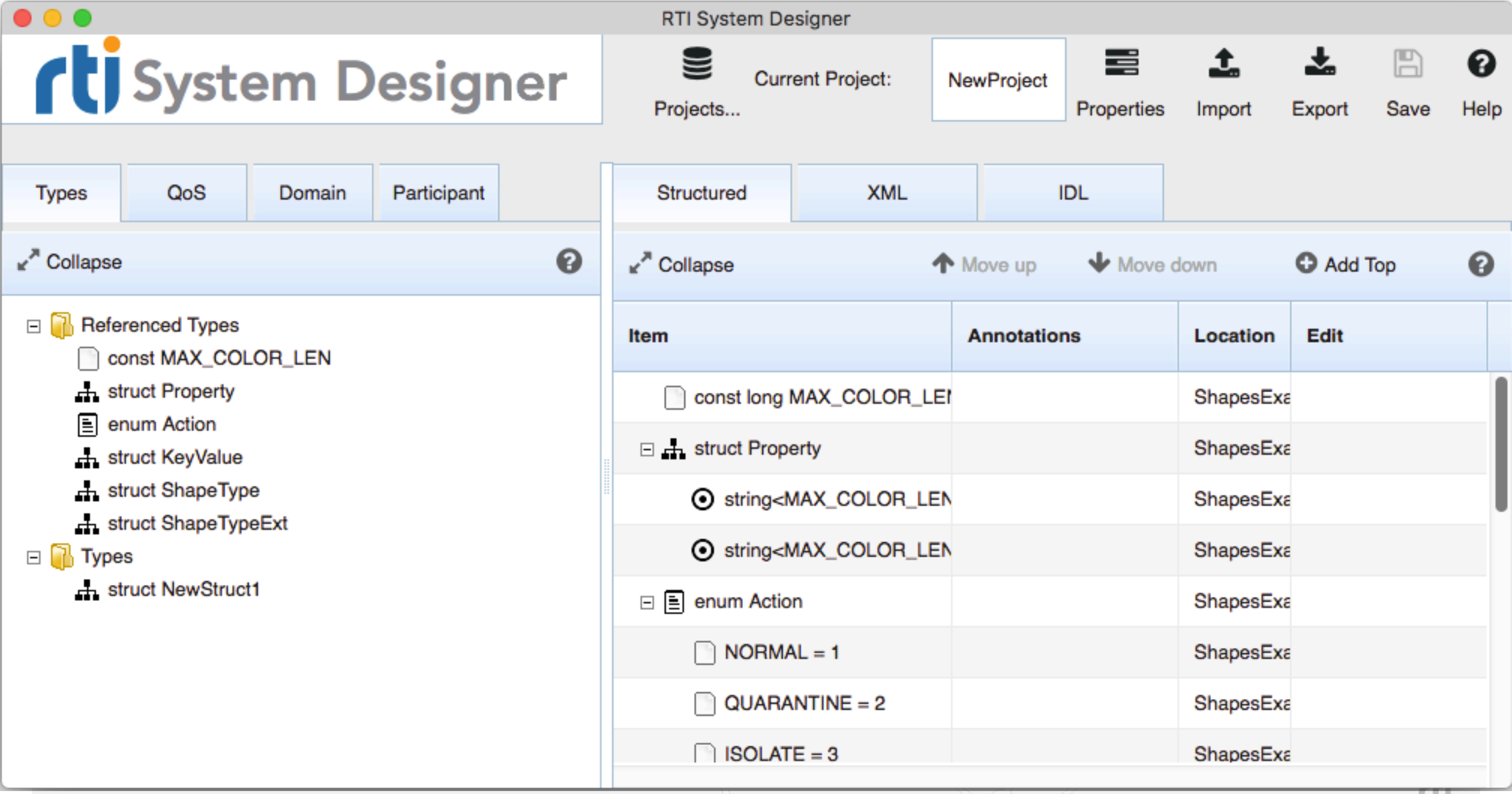

http://demo.rti.com/system-designer

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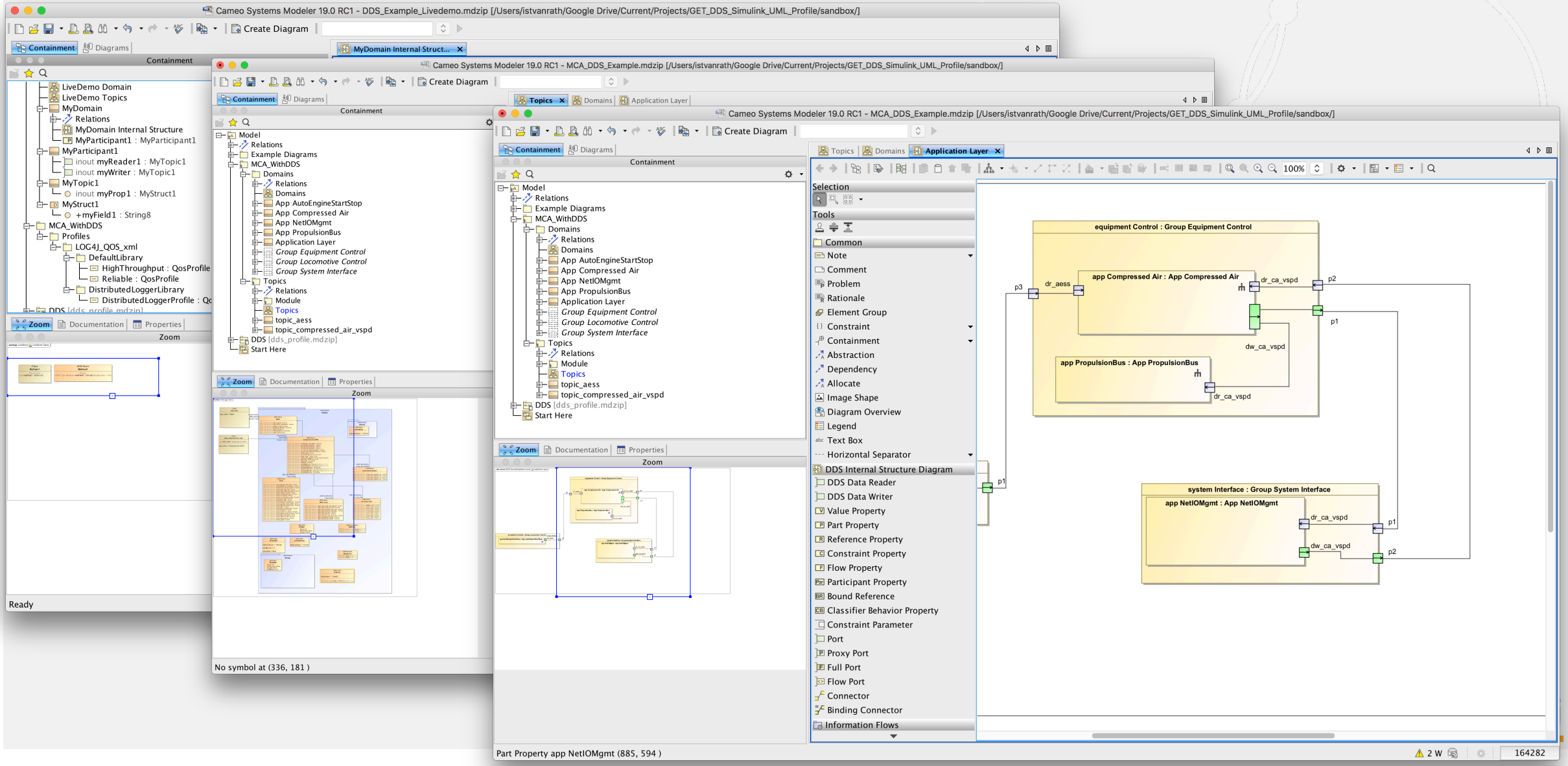
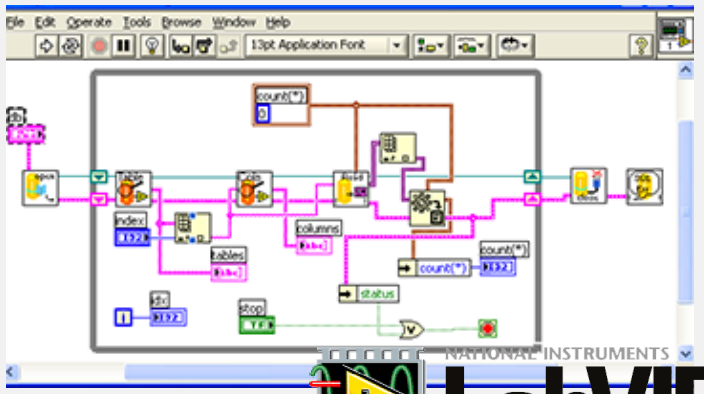
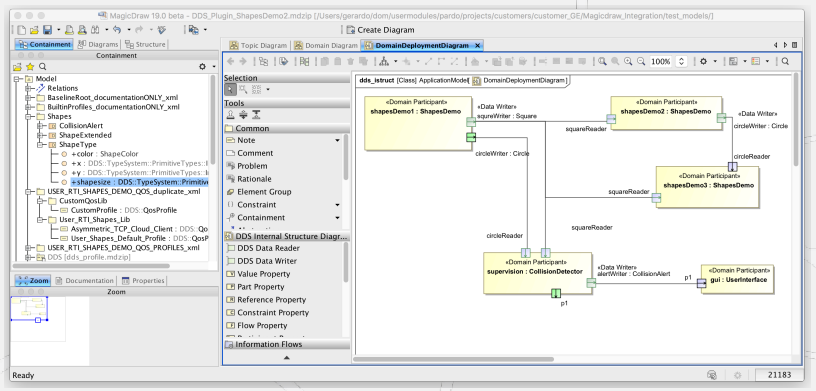
UML/SysML Integration (with Nomagic/MagicDraw)



Integrating 3rd party tooling

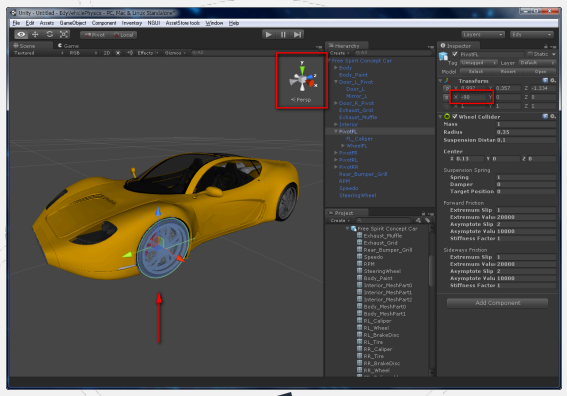


NATIONAL INSTRUMENTS LabVIEW

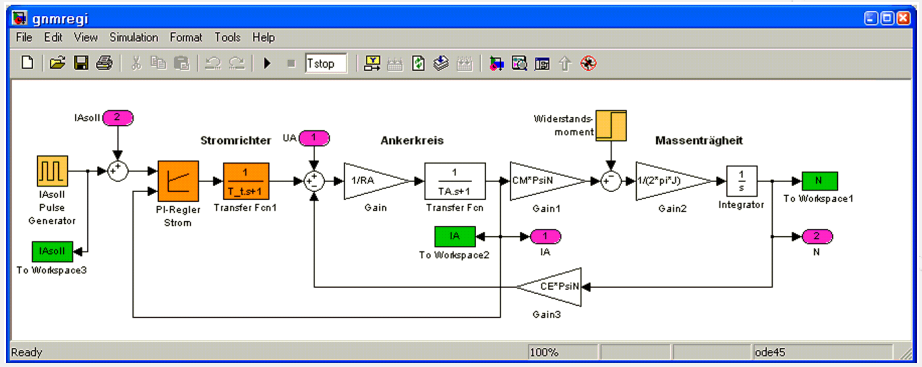


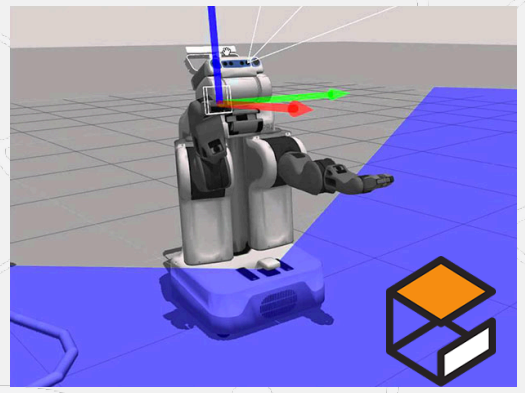
magicdraw

SysML



unity



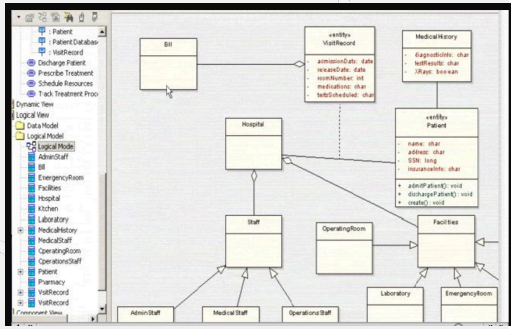


GAZEBO

CARLA

ENTERPRISE ARCHITECT

MATLAB SIMULINK



Future Directions

Scaling and Securing IIoT Systems

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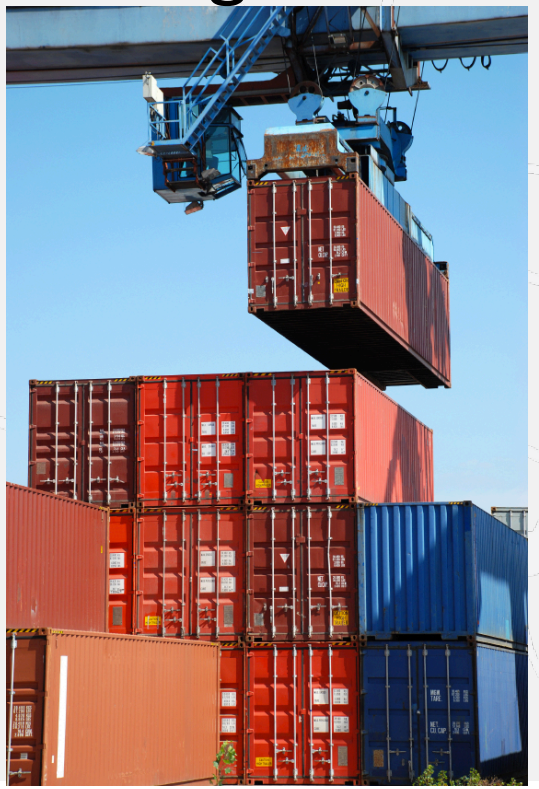
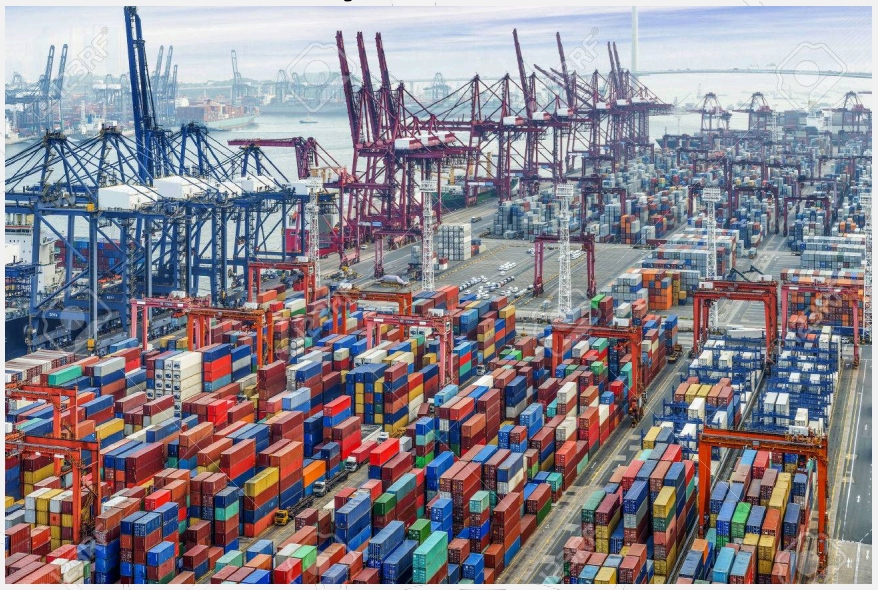
Key Challenges

Debuggability

Instance Management



Scalability



Instance and RPC security

Integration

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Debuggability

Dec 27 email from XYZ (RTI customer):

*… practically they are in **production like situation** – having a deadline to the most important activity that **will very much define their existence**…*

*… the kind of situation of a customer wrongly using the product … a very complex situation … our **ability to find the problems**…*

Dec 1 email from XYZ (RTI customer):

*This morning (Saturday 9am) I reached out to AAA about a problem we were having in our ZZZ development. We are driving to an intermediate **goal that is very important to our business** and we hit a snag. We **had a team of about 20 people working through the weekend to meet the goal and an unexpected volume of errors** started to occur in our logs…*

Essential to succeed in deployment

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Instance Management & Scalability

- Instances are a big value added by using DDS
  - Saves huge amounts of application code
  - Makes application flexible and scalable
  - Increases decoupling robustness and availability

- But instance management is complex
  - Hard to observe & debug
  - Complex resource management
  - Feature interactions (e.g. Content Filtering with Dispose)

Addressing this is a top priority

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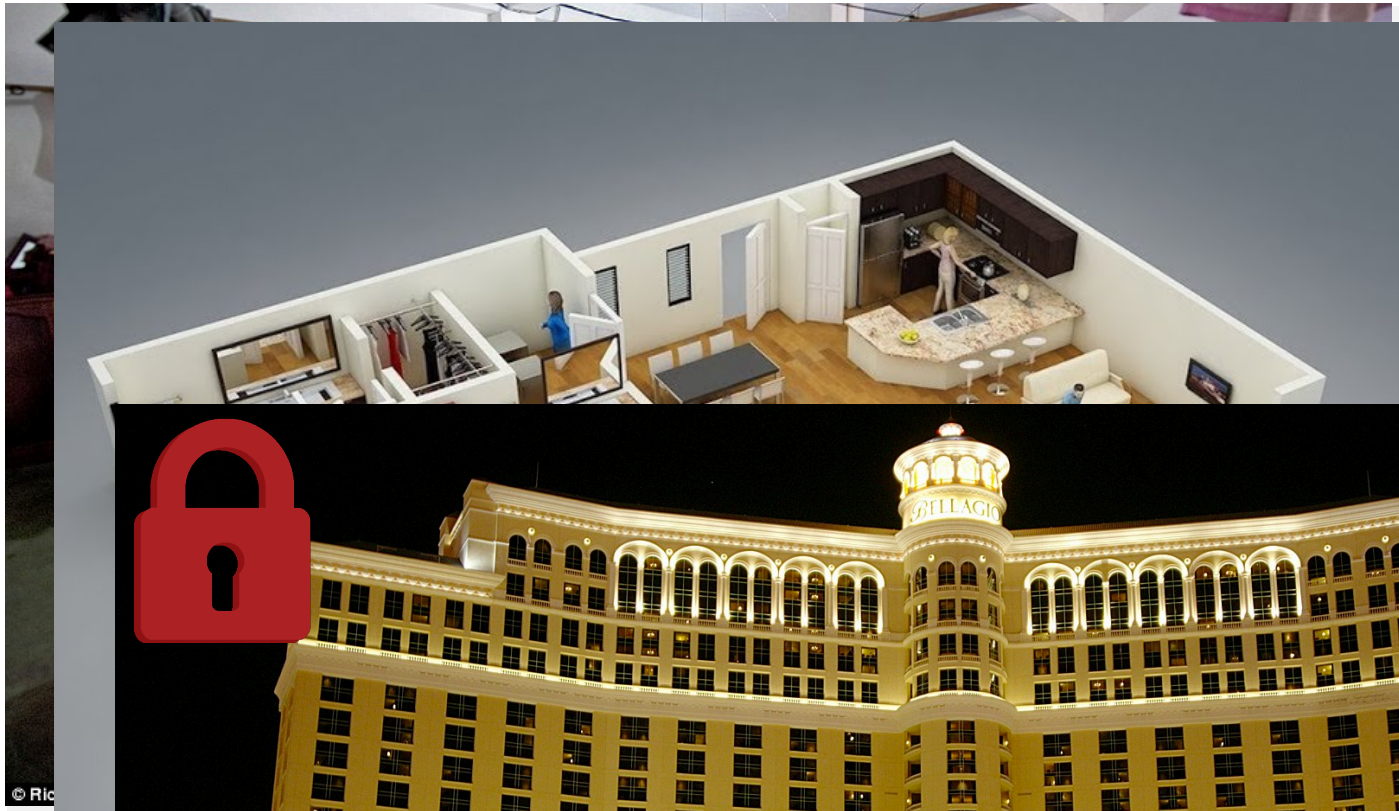

n DDS Solution
parse Security)

DDS Solution
evel Security)

Future DDS Solution
(Instance-level Security
+ CERT revocation)

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Integration: Support for Ultra-Small Devices

Built on Routing Service

Application

XRCE Client

Application

XRCE Client

XRCE Agent

XRCE Agent

DDS

DDS Databus

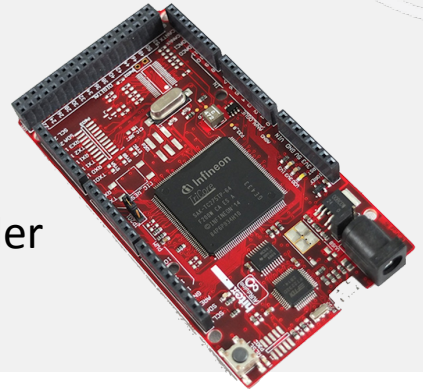
Application

DDS

Application

DDS

DDS



Microcontroller

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Edge Autonomy presents a huge opportunity

Thank You!

Stay Connected

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Free trial of Connext DDS

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Speed of Autonomy Change

How does RTI help?

Easter Parades in New York City

Year 1900: One Motor Vehicle

Year 1913: One Horse & Carriage

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The Industry is facing disruption

If you don't like change, you're going to like irrelevance even less."

- General Eric Shinseki

© 2014 R

NATO Generic Vehicle Architecture (DDS at the core)

- Began as UK GVA
- Evolved into NATO STANAG 4754
- Adopts DDS API, Wire Protocol (RTPS) and the Land Data Model

More details

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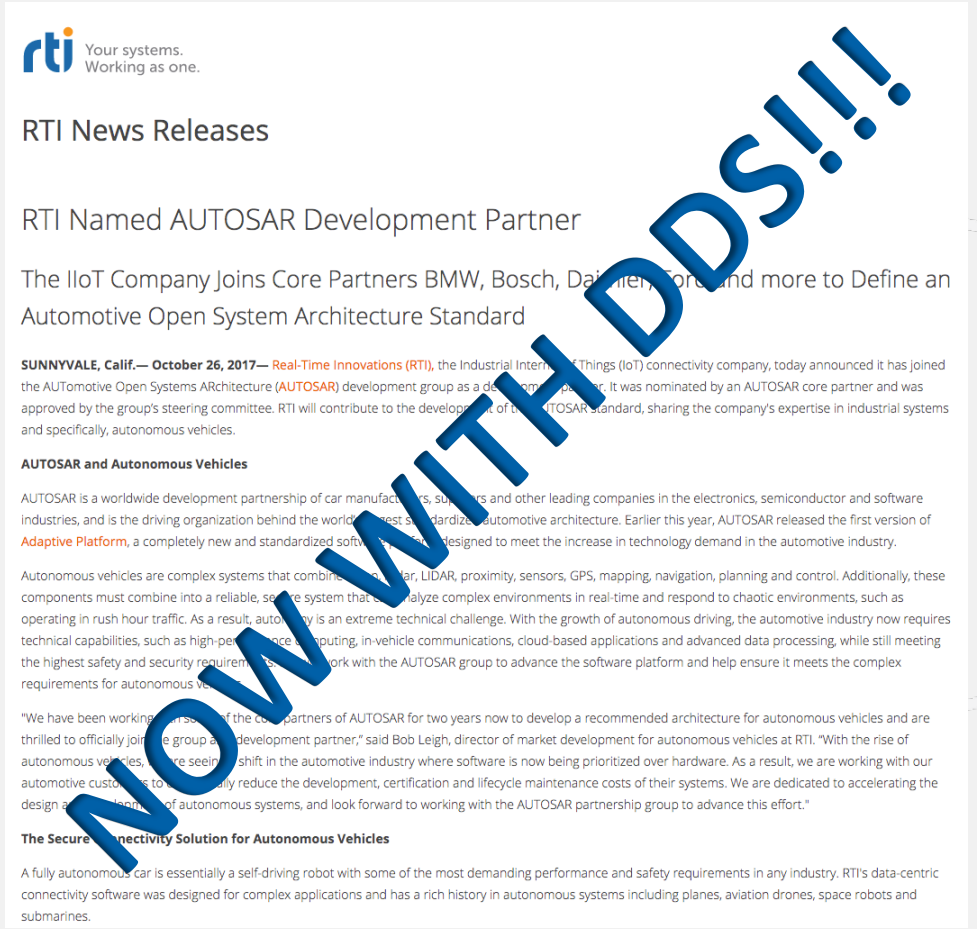
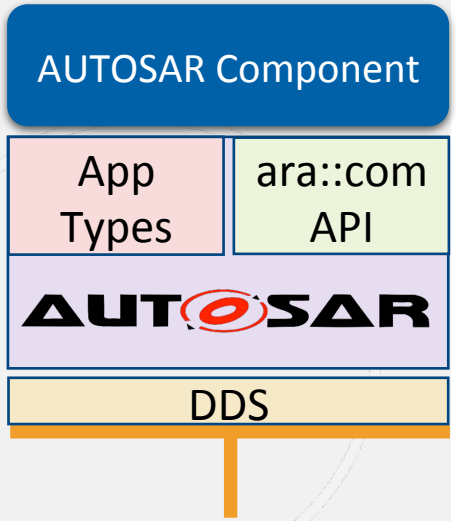
AUTOSAR



NOW WITH DDS!!!



- RTI joined fall 2017
- Working in FT-CM
- Adaptive Platform Release 18.10
  - DDS added as alternative network binding under ara::com
  - SWS Communication Management
  - TPS Manifest

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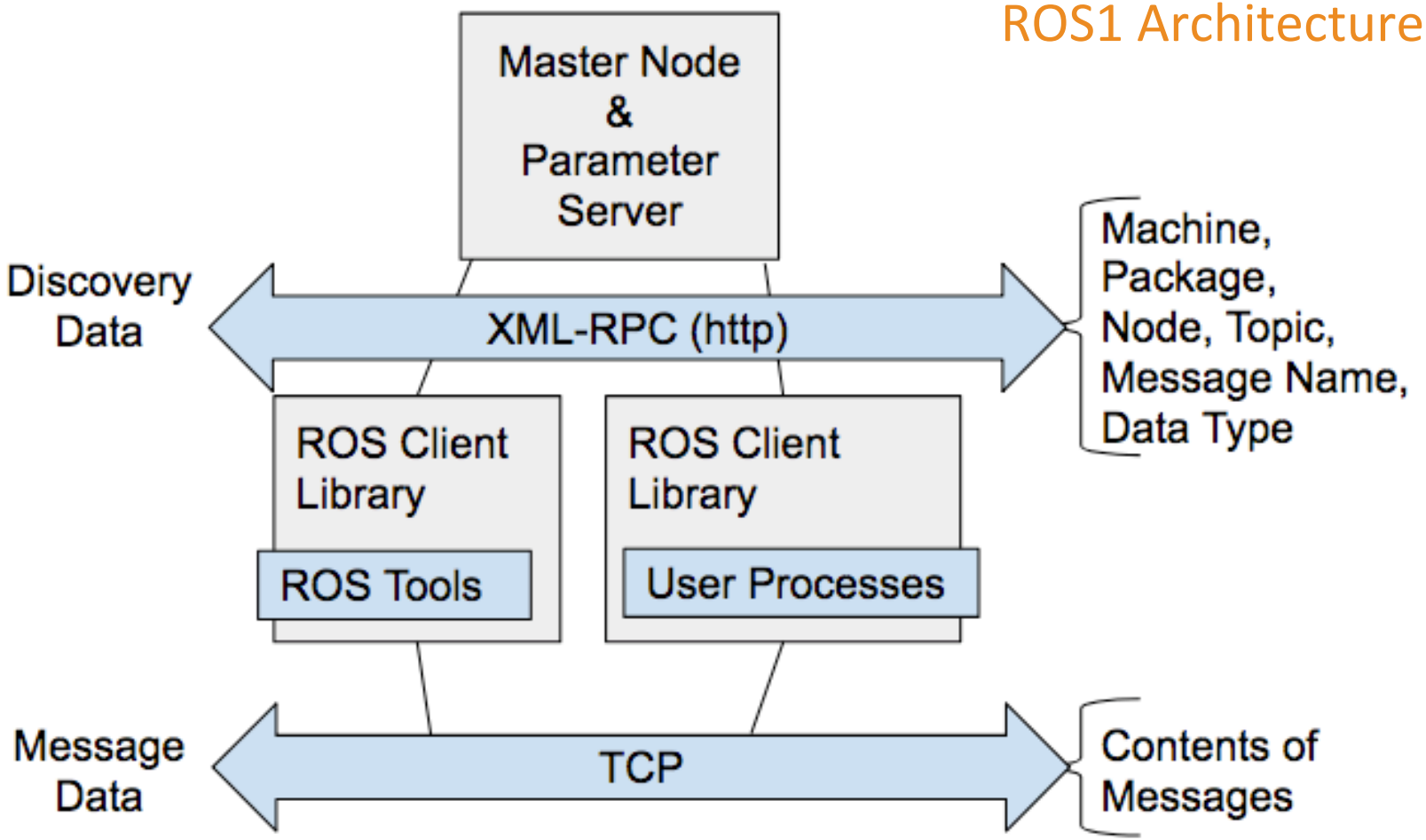
Why build ROS 2 on DDS?

Open Source Ro

ROS1 Architecture



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