Product Advancements for Scaling and Securing IIoT Systems

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Outline

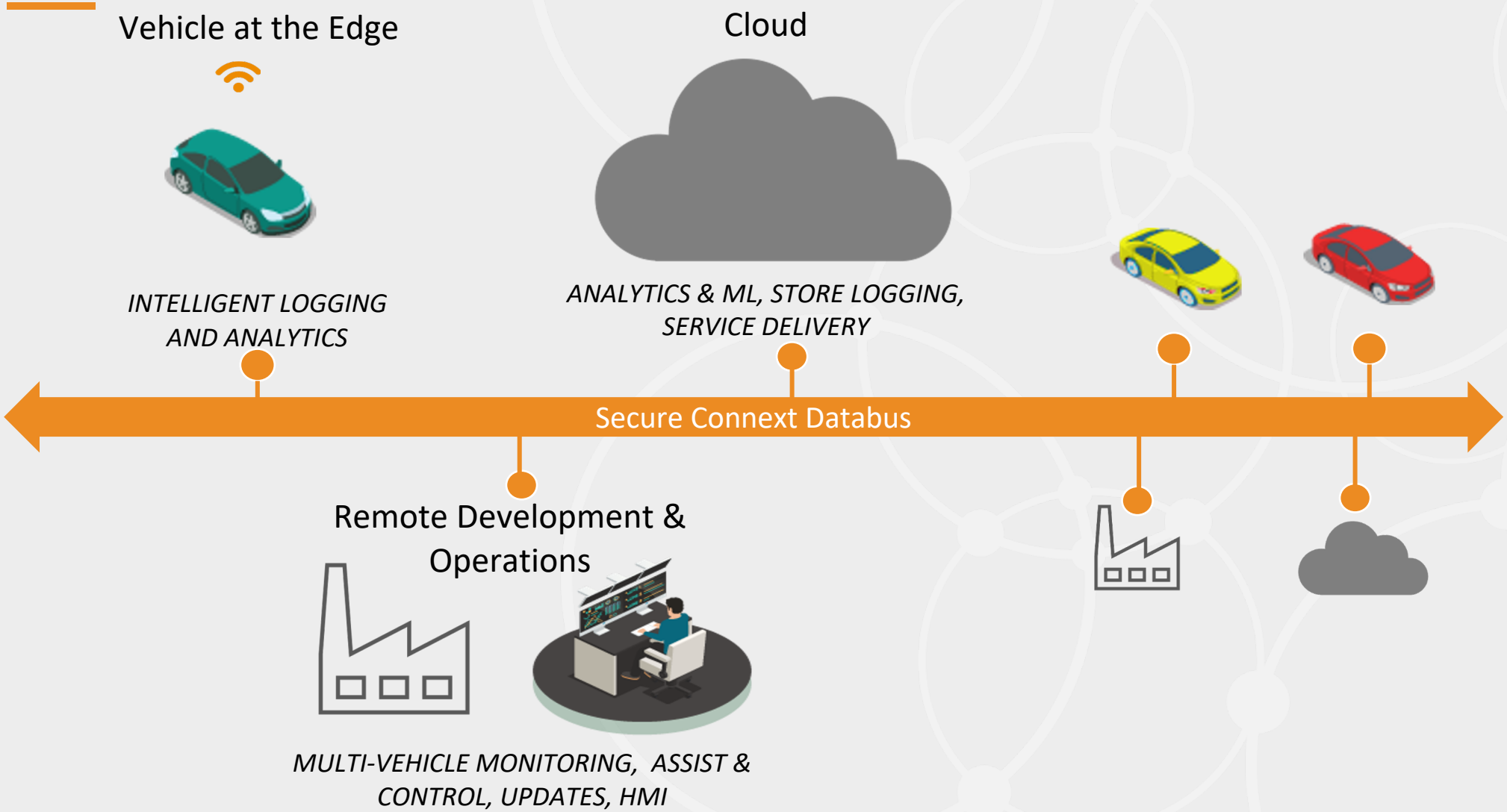
Wide Area Network Connectivity	Health Management	Scalability	Accessibility
New scalable and secure solution for Wide Area Network connectivity including 5G and other cellular networks	Advancements to bring better observability into Connext distributed systems	New features and improvements to scale to thousands of endpoints	Language bindings and API advancements

COMING SOON IN 2021

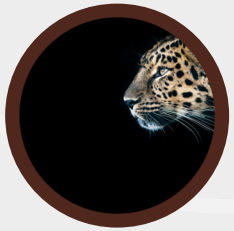
Wide Area Network Connectivity

Connect from anywhere

Use Cases: Remote Device Management, Monitoring, Analytics and Assistance



WAN Environments Present Unique Challenges



PERFORMANCE

Large variations in latency and bandwidth availability make communication unreliable for performance-sensitive applications

SECURITY

WAN environments are susceptible to more cyber-attacks as data traverse public networks and infrastructure

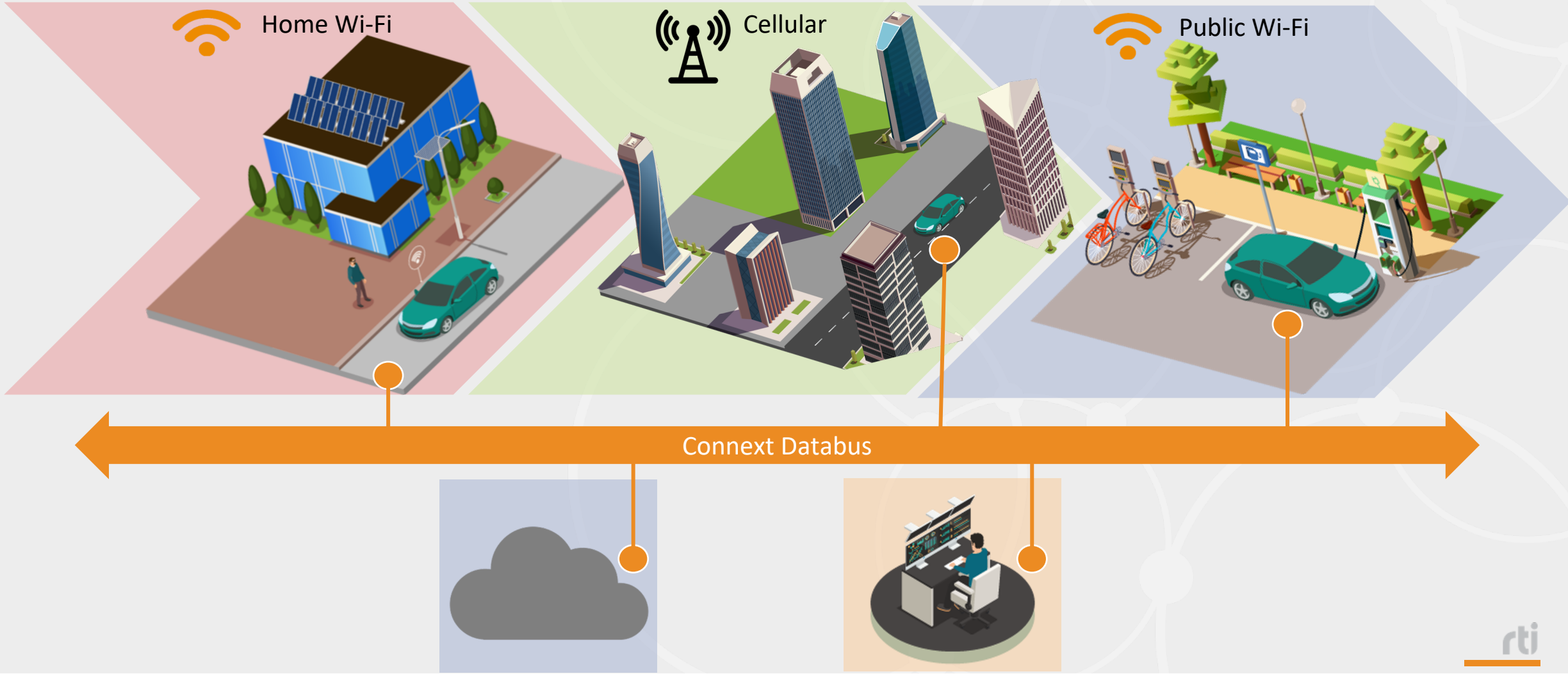
ROAMING AND CONNECTIVITY ACROSS DIVERSE NETWORKS

Devices can roam between different networks, including cellular networks, changing addresses and connectivity conditions

SCALABILITY

The number of endpoints running in a WAN environment can be orders of magnitude bigger than the endpoints running in a closed LAN-based system.

Challenge: Maintain Bidirectional Connectivity While Moving Across Network Boundaries



Connext DDS WAN Connectivity Solution

Core

FEATURE	DESCRIPTION
Underlying IP Transports	UDP (Connext also works with TCP)
NAT Traversal	Facilitates peer-to-peer connections, including external-internal and internal-internal asymmetric
Network Transitions	Handles changes of IP addresses while roaming
Delivery Controls	Many options to control communication reliability and speed (Reliable, Partially Reliable, Best Effort)

Endpoint Discovery

FEATURE	DESCRIPTION
Peer Discovery	Ability to discover endpoints
Signaling and Negotiation	Exchange of capabilities and candidate addresses
Interoperable with RTI Discovery Service (CDS)	Discovery at large scale, where both endpoints are behind Cone NATs; Simplified directory service that facilitates endpoint discovery

Connext DDS WAN Connectivity Solution

Performance and Scalability

FEATURE	DESCRIPTION
Stream Multiplex	Handles multiple streams within a connection to avoid head-of-line (HOL) blocking problems that limit performance
Flow Control	Manages the rate of transmission based on endpoint and network conditions to minimize data losses
Built-in Data Compression	Compresses user data to save bandwidth
Bonding (Post 6.1.0)	Combining two or more network connections to send data in an intelligent way that allows the end user to utilize the combined bandwidth in the most efficient way.

Security and Privacy

FEATURE	DESCRIPTION
Authentication	Verify the identity of the endpoints exchanging data
Access control	Per Connection, and fine-grained per Data Stream
Cryptography	Encryption and decryption, hashing, digital signatures, etc.

Connext 6.1.0 WAN Connectivity Solution

Real-time WAN Transport

UDP-based transport supporting NAT traversal & network roaming

+

(Cloud) Discovery Service

Facilitates endpoint discovery and NAT traversal process

→

WAN Connectivity Solution

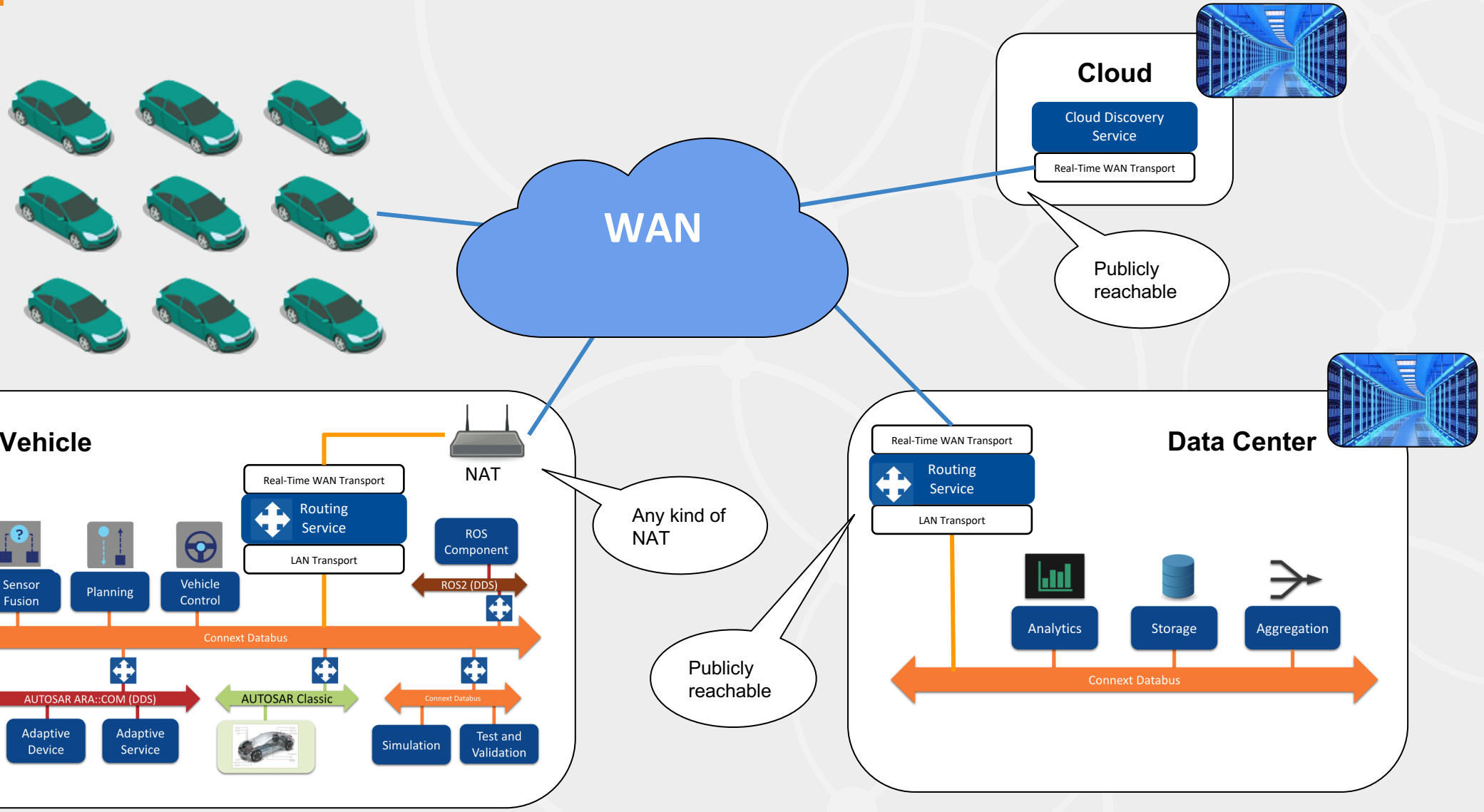
Seamlessly and reliably share data across WANs, including cellular networks, without compromising security

No need to integrate other technologies or security technologies

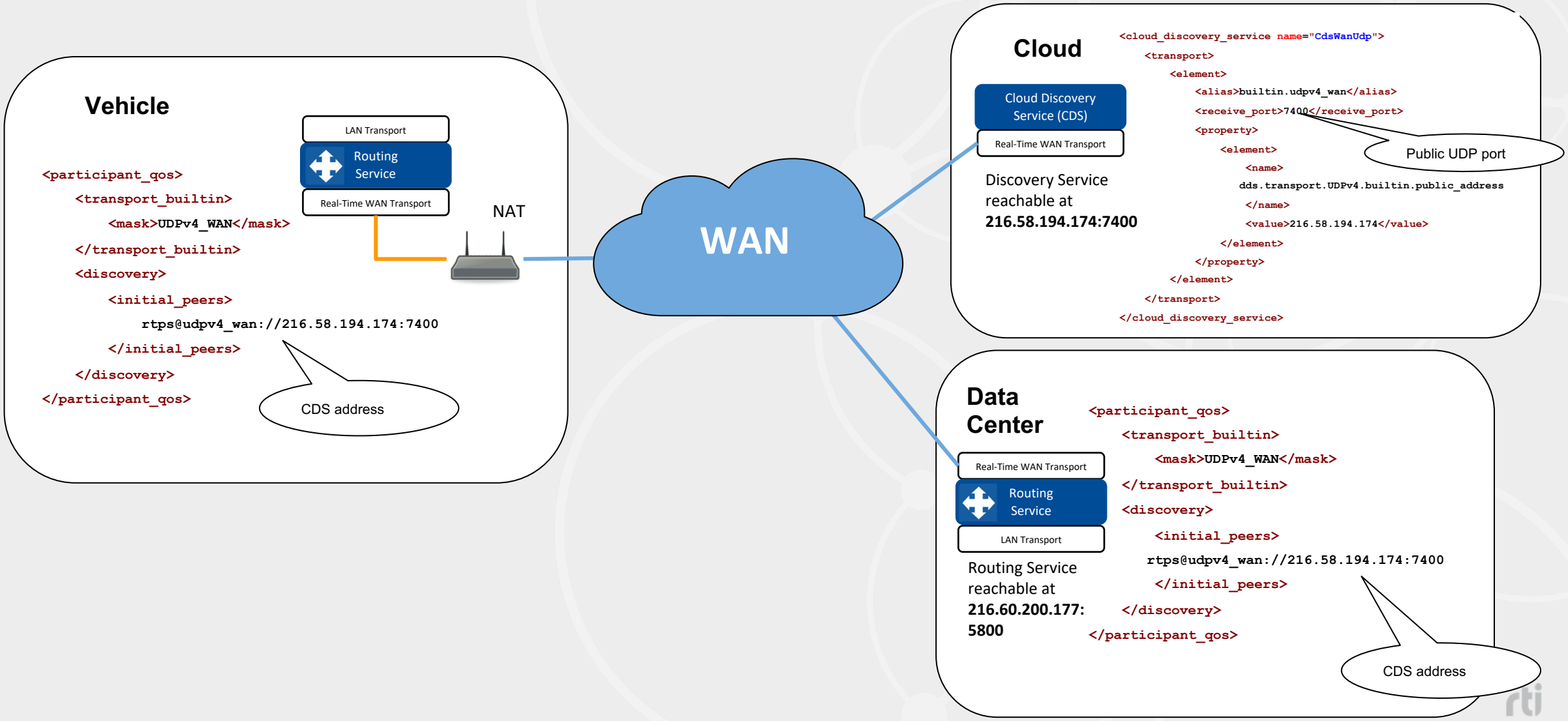
Single Programming Model

No API Changes

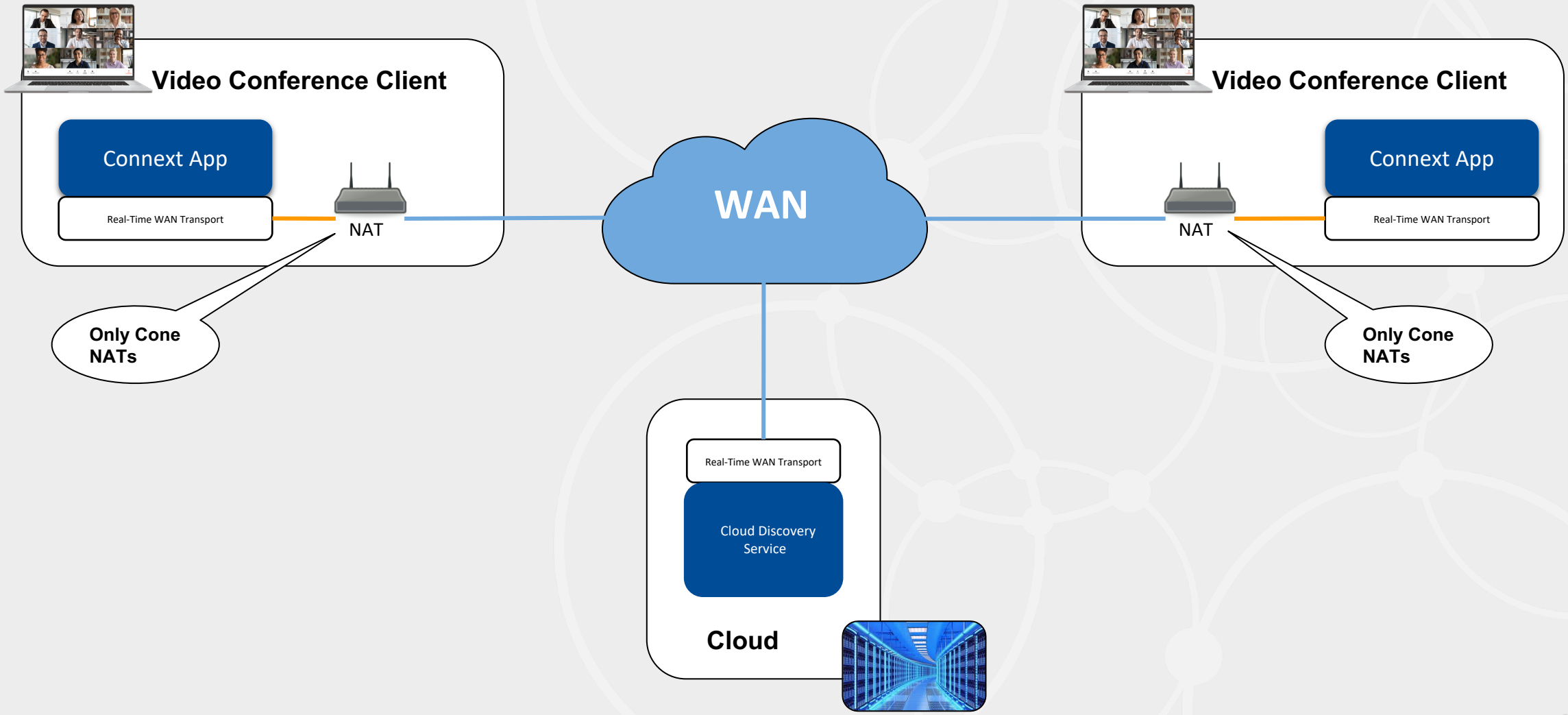
WAN Deployment Scenario: Edge to Cloud



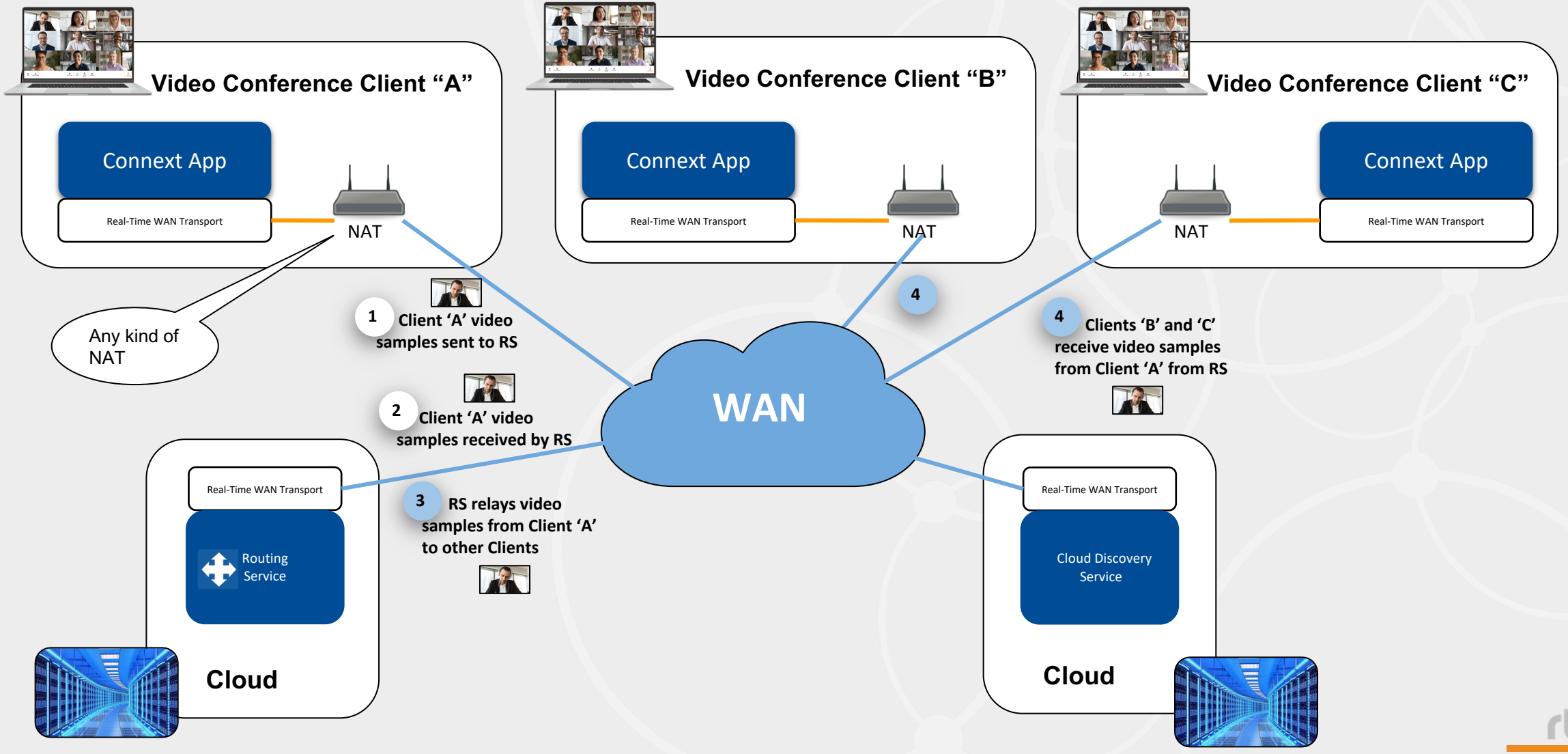
WAN Deployment Scenario: Edge to Cloud



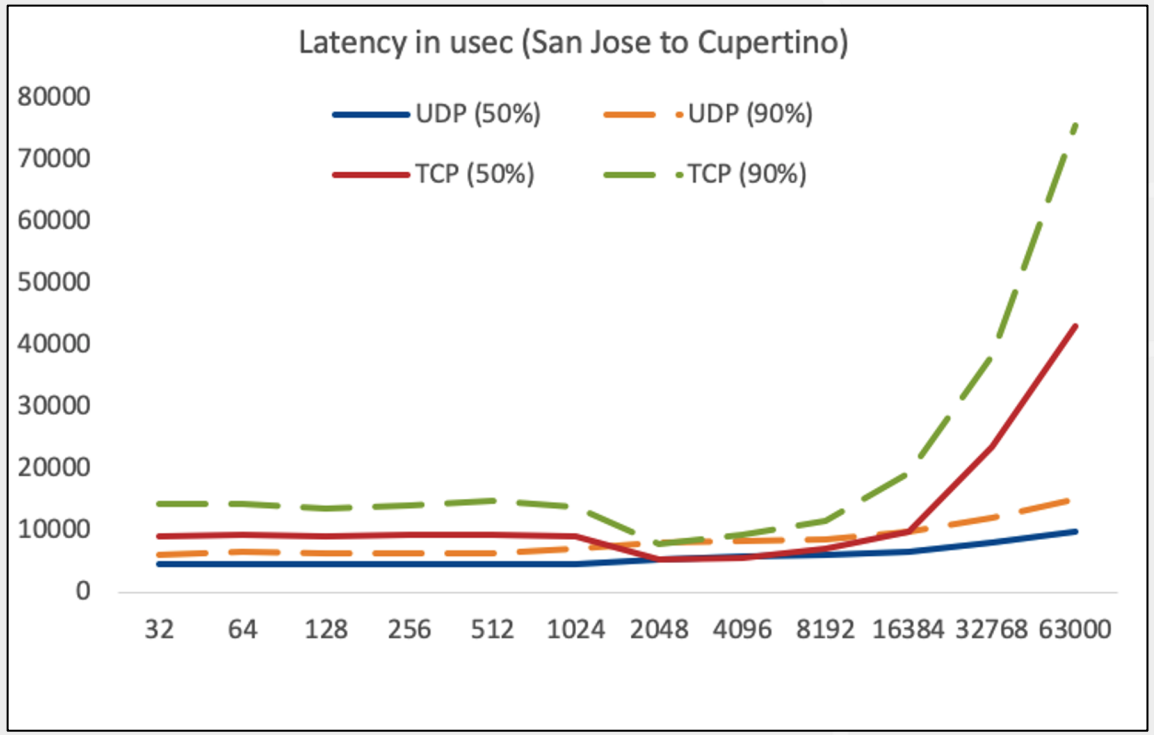
WAN Deployment Scenario: Peer-to-Peer Edge to Edge

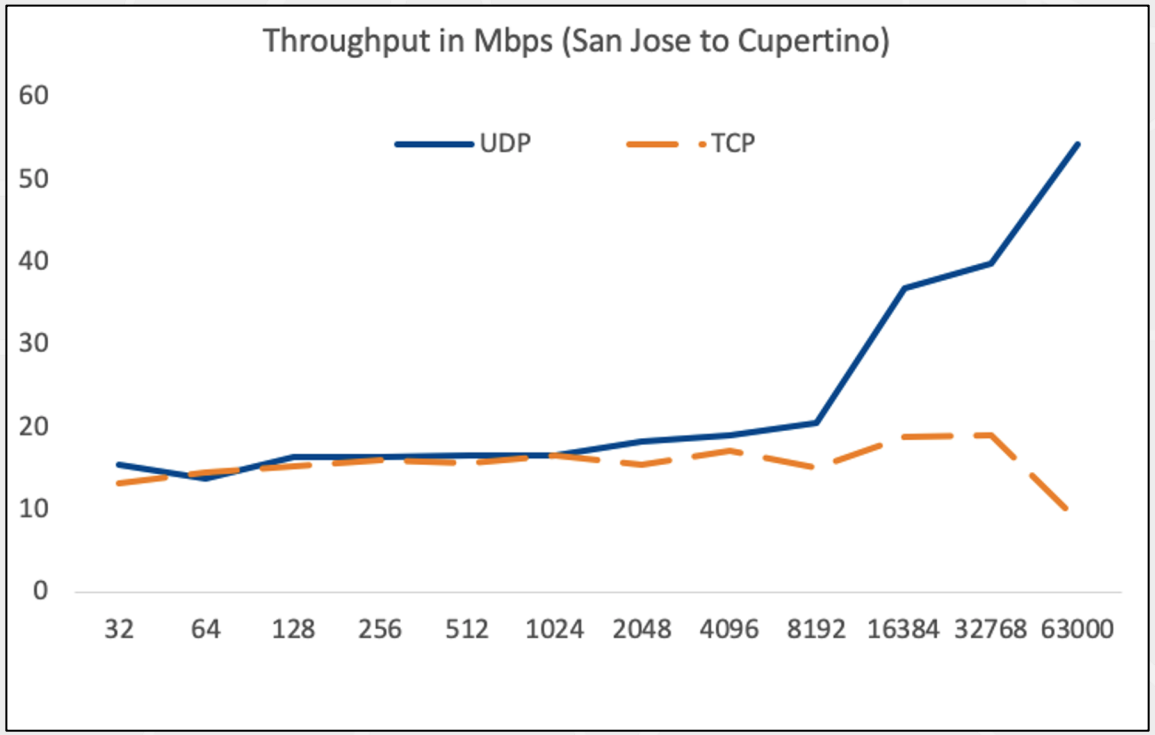


WAN Deployment Scenario: Relayed Edge to Edge



Performance: TCP WAN vs UDP WAN over Wi-Fi

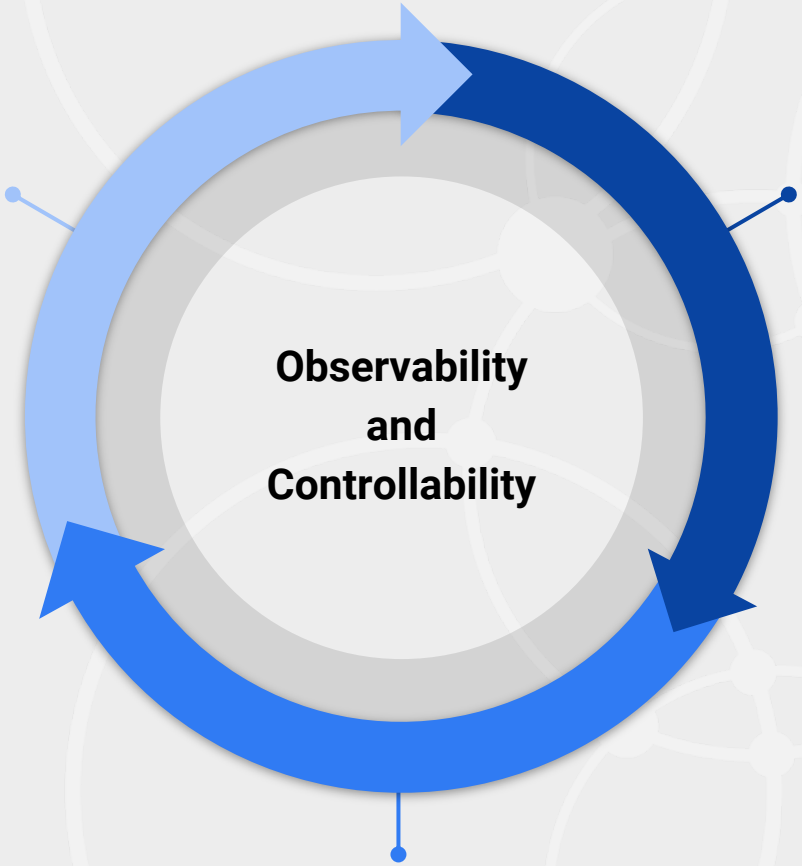




Continuous Health Management

Bringing Better **Observability** and Faster Problem **Resolution** into Connext DDS

Health Management Activities



Resolution

Solve issues and restoring the system into service with minimal impact on service availability.

Non Intrusive Health Monitoring and Alerting

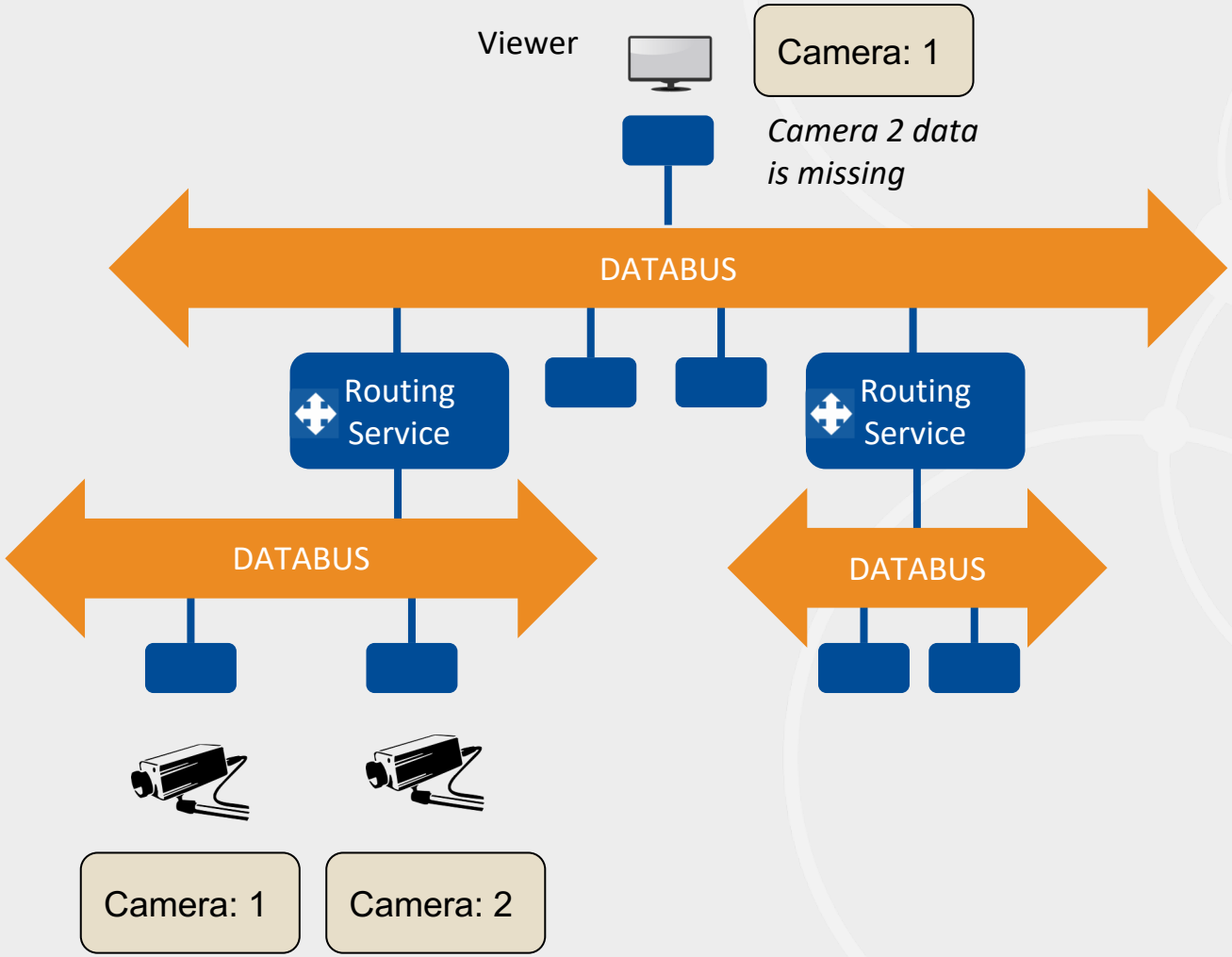
Provide real-time visibility into the system behavior to assess functionality and alert about potential issues

Non intrusive

Diagnosis

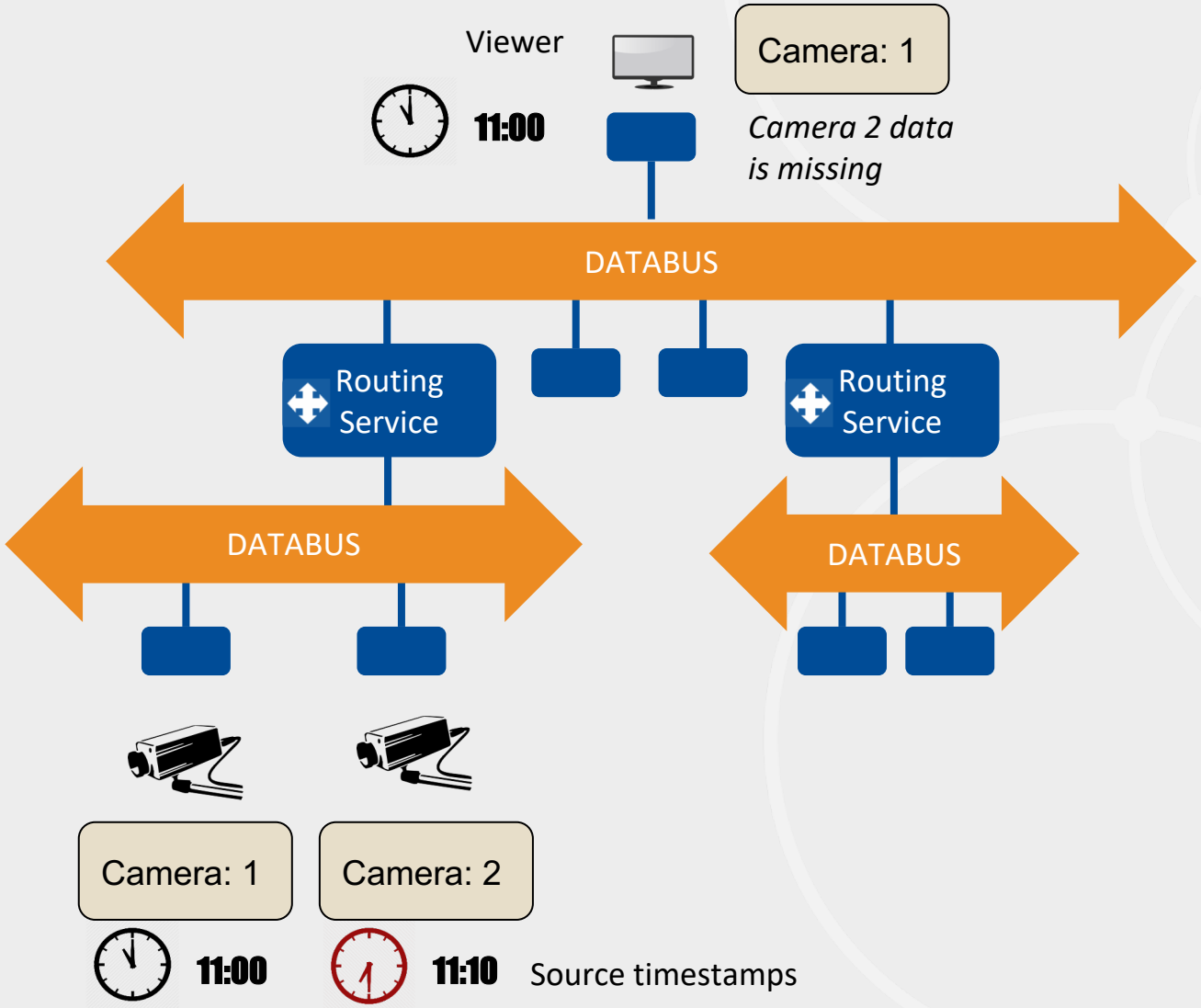
Debug or isolate issues to root cause analysis

Observability Challenge 1: Problem



- **Health Issue:** Viewer does not receive information from Camera
- **Known Information:**
  - **Platform**. Camera platform for camera 1 and 2 is the same (hardware and software)
  - **Online**. Camera 2 system can be pinged so it is online
  - **Logs**. Logs don't indicate any failure
  - **Inconsistent behavior.** Viewer received information in the past from both cameras

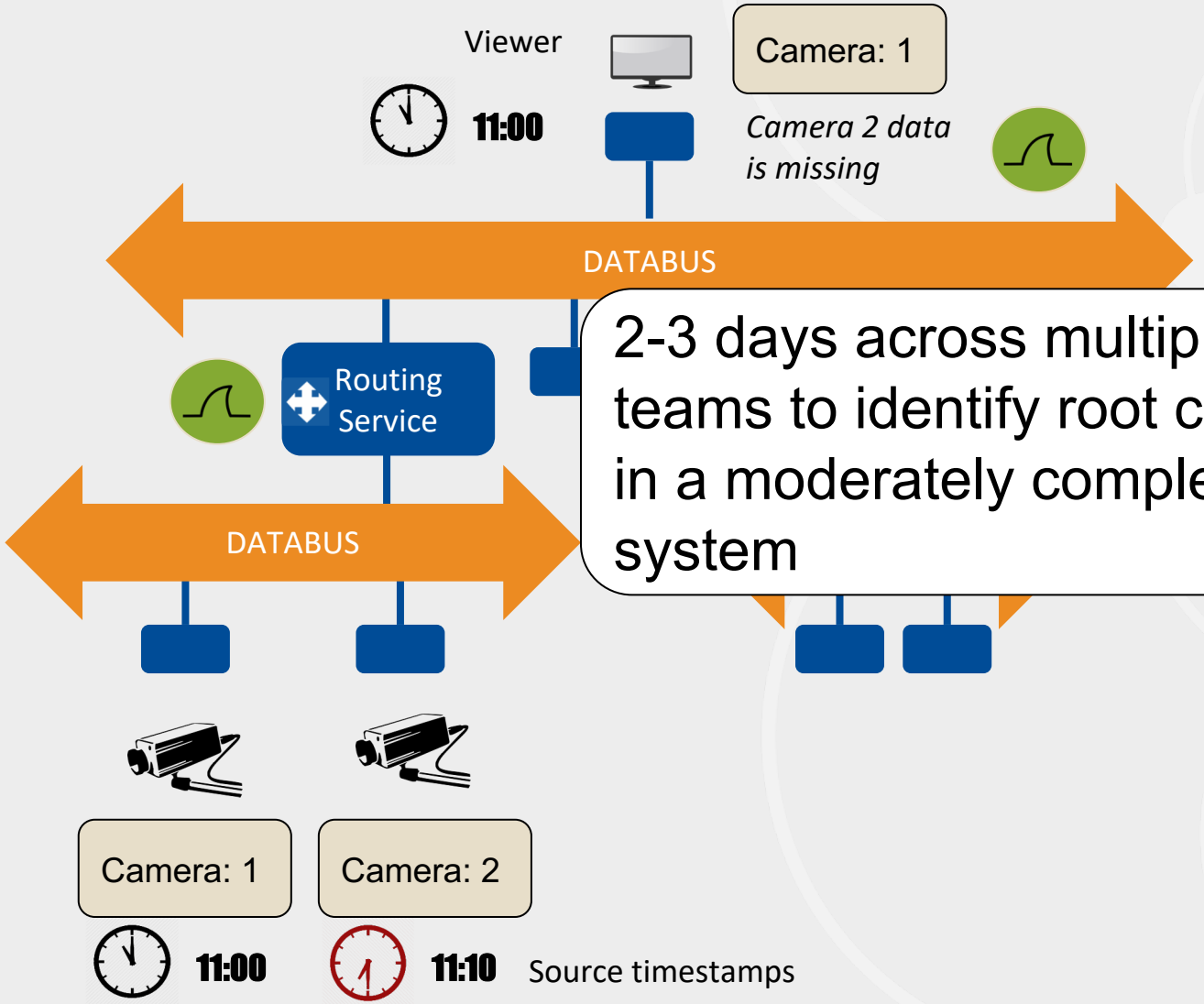
Observability Challenge 1: Root Cause



Clock Synchronization Issue:

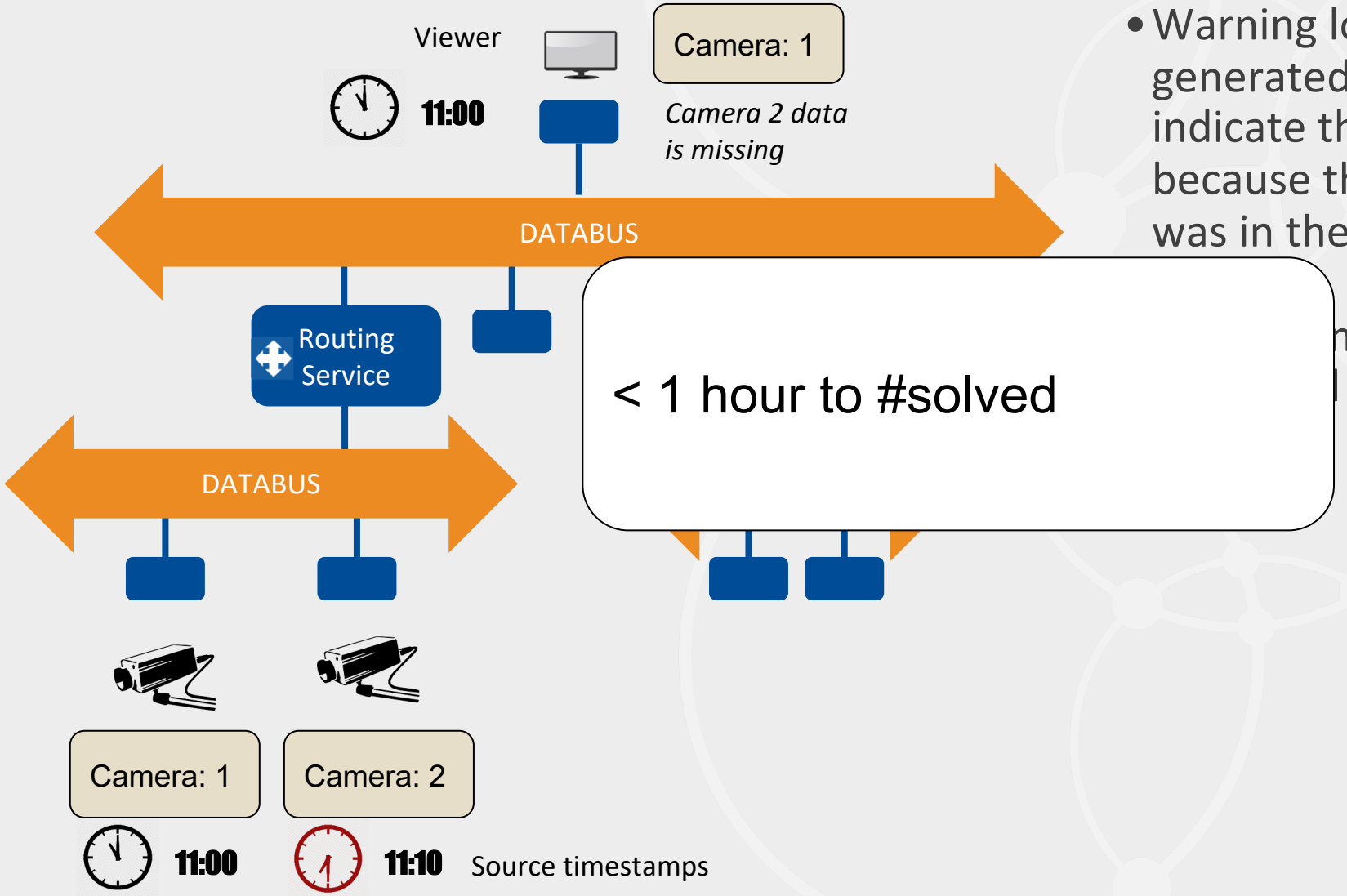
System is configured to use destination order by **SOURCE** timestamp and Connext DDS has a protection mechanism in which the data published by an application is ignored if published into the future.

Observability Challenge 1: 5.3.1 Diagnosis



- To determine where the data was lost we ran Wireshark in Viewer first, and then in Routing Service
- The Data was received by Routing …e but somehow was not …gated to the viewer
- … Not obvious. Is it lost on …iddleware stack? on the socket buffers?
- Finally we realized the source timestamp of the incoming packets was **10 minutes ahead of expected**

Observability Challenge 1: 6.1.0 Diagnosis



- Warning log message and metrics generated by Routing Service indicate that it dropped samples because their source timestamp was in the future

message received and
by Admin Console

< 1 hour to #solved

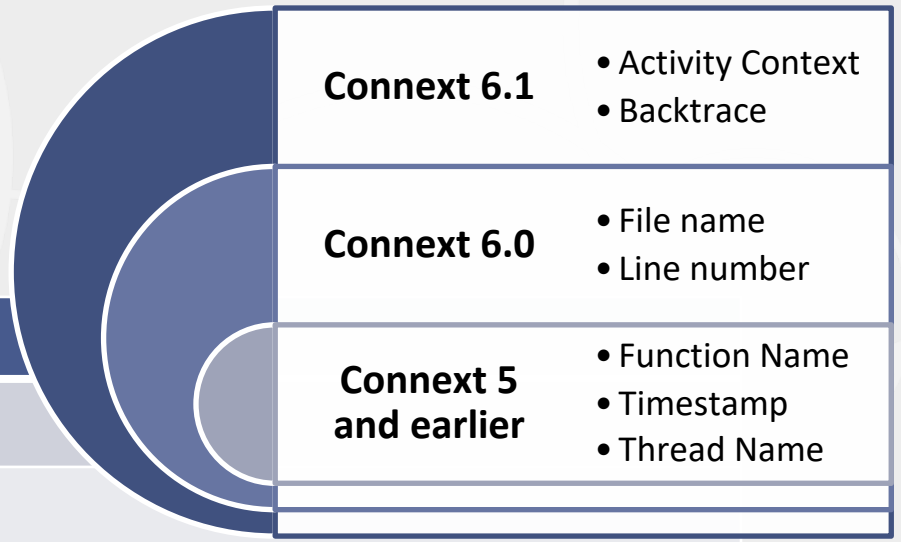
New Observability Capabilities

Available in upcoming 6.1.0 release

Logging Improvements

Rich and configurable logging format

	Print Format	Example
Timestamp	BIT_TIMESTAMP	[2020-10-15 00:38:55.168092]
Thread Name	BIT_THREAD_ID	U000000010e0ad5c0_
Activity Context	BIT_ACTIVITY_CONTEXT	[0x01018087,0xDC43F9E2,0xF22EE887:0x80000003{E=DW,T=HelloWorld,C=HelloWorld,D=0}|WRITE]
File and Line	BIT_LOCATION_FILELINE	Writer History Driver.c:731
Function Name	BIT_LOCATION_METHOD	PRESWriterHistoryDriver_addWrite
Backtrace	BIT_BACKTRACE	Backtrace: #4 MyType_publisher 0x00000001058538e8 WriterHistoryMemoryPlugin_addSample + 2104 #5 MyType_publisher 0x000000010566ff78 PRESWriterHistoryDriver_addWrite + 3576 #6 MyType_publisher 0x00000001056c048c PRESPsWriter_writeInternal + 9820



Logging Improvements

New **activity context** associated with log messages including information to identify the **source** of the message: Topic, Type, GUID, etc.

5.3.1 (Before)

```
WriterHistoryMemoryPlugin_addSample:out of order
PRESWriterHistoryDriver_addWrite:!timestamp order
PRESPsWriter_writeInternal:!timestamp order
```

6.1.0 **Activity context identifies the source (Topic, Type, GUID, etc)**

```
[0x0101D82C,0x034CEB6D,0xC6A44AA8:0x80000003{E=DW,T=HelloWorld,C=HelloWorld,D=0}|WRITE]
WriterHistoryMemoryPlugin_addSample:out of order
[0x0101D82C,0x034CEB6D,0xC6A44AA8:0x80000003{E=DW,T=HelloWorld,C=HelloWorld,D=0}|WRITE]
PRESWriterHistoryDriver_addWrite:!timestamp order in topic 'HelloWorld'
[0x0101D82C,0x034CEB6D,0xC6A44AA8:0x80000003{E=DW,T=HelloWorld,C=HelloWorld,D=0}|WRITE]
PRESPsWriter_writeInternal:!timestamp order
```

Logging Improvements

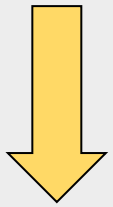
- Built-in **backtraces** help diagnose problems
- Automatically enabled for precondition or fatal errors

```
            Backtrace:
            #4   MyType_publisher              0x00000001058538e8 WriterHistoryMemoryPlugin_addSample + 2104
            #5   MyType_publisher              0x000000010566ff78 PRESWriterHistoryDriver_addWrite + 3576
            #6   MyType_publisher              0x00000001056c048c PRESPsWriter_writeInternal + 9820
            #7   MyType_publisher              0x00000001051f5d80 DDS_DataWriter_write_w_timestamp_untyped_generall + 2384
            #8   MyType_publisher              0x0000000104f99bcb HelloWorldDataWriter_write_w_timestamp + 75
            #9   MyType_publisher              0x0000000104f93713 publisher_main + 915
            #10  MyType_publisher               0x0000000104f93903 main + 99
            #11  libdyld.dylib                0x00007fff64ea83d5 start + 1
            #12  ???                         0x0000000000000001 0x0 + 1
[2020-10-15 00:38:55.165457] U000000010e0ad5c0_
[0x01018087,0xDC43F9E2,0xF22EE887:0x80000003{K=DW,T=HelloWorld,Y=HelloWorld,D=0}|WRITE]
  Mx16:Memory.c:7433:WriterHistoryMemoryPlugin_addSample:RTI0x2161002:out of order
```

Monitoring Improvements: Instance Metrics

- Customer question without a clear answer in a running system:

"How many patients are admitted, how many are discharged, is the system working as designed?



DDS Translation

"How many instances are registered, how many are disposed, is the system working as designed?

Monitoring Improvements: Instance Metrics

- In 6.1.0, the user will be able to answer this question by inspecting instance metrics.
- Also, available in **Monitor UI**.

```
struct DDS_DataReaderCacheStatus {
    ...
    DDS_LongLong alive_instance_count;
    DDS_LongLong alive_instance_count_peak;
    DDS_LongLong no_writers_instance_count;
    DDS_LongLong no_writers_instance_count_peak;
    DDS_LongLong disposed_instance_count;
    DDS_LongLong disposed_instance_count_peak;
    DDS_LongLong detached_instance_count;
    DDS_LongLong detached_instance_count_peak;
};
```

```
struct DDS_DataWriterCacheStatus {
    ...
    DDS_LongLong sample_count_peak;
    DDS_LongLong sample_count;
    DDS_LongLong alive_instance_count;
    DDS_LongLong alive_instance_count_peak;
    DDS_LongLong disposed_instance_count;
    DDS_LongLong disposed_instance_count_peak;
    DDS_LongLong unregistered_instance_count;
    DDS_LongLong unregistered_instance_count_peak;
};
```

Monitoring Improvements: Other Metrics

"Why am I not receiving data?

- **DataWriterProtocolStatus** and **DataReaderProtocolStatus** extended to include metrics related to fragmented data.

- **DataReaderCacheStatus** and **DataWriterCacheStatus** extended to provide information about all samples (relevant and not relevant) dropped by Connext DDS.

Built-in Enhanced Network Capture

Wireshark is widely used at development time to **capture** and **analyze** RTPS packet traces

Limitations capturing traffic with Wireshark

- Capturing is usually restricted to users with root privileges
- Wireshark and tcpdump are often not available in production or deployed embedded targets
- Wireshark cannot capture traffic over shared memory
- Not very useful when encryption is enabled

Built-in Enhanced Network Capture

Connext 6.1.0 release resolves capturing limitations to help with the debugging process

Capture inbound and/or outbound network traffic from multiple Domain Participants

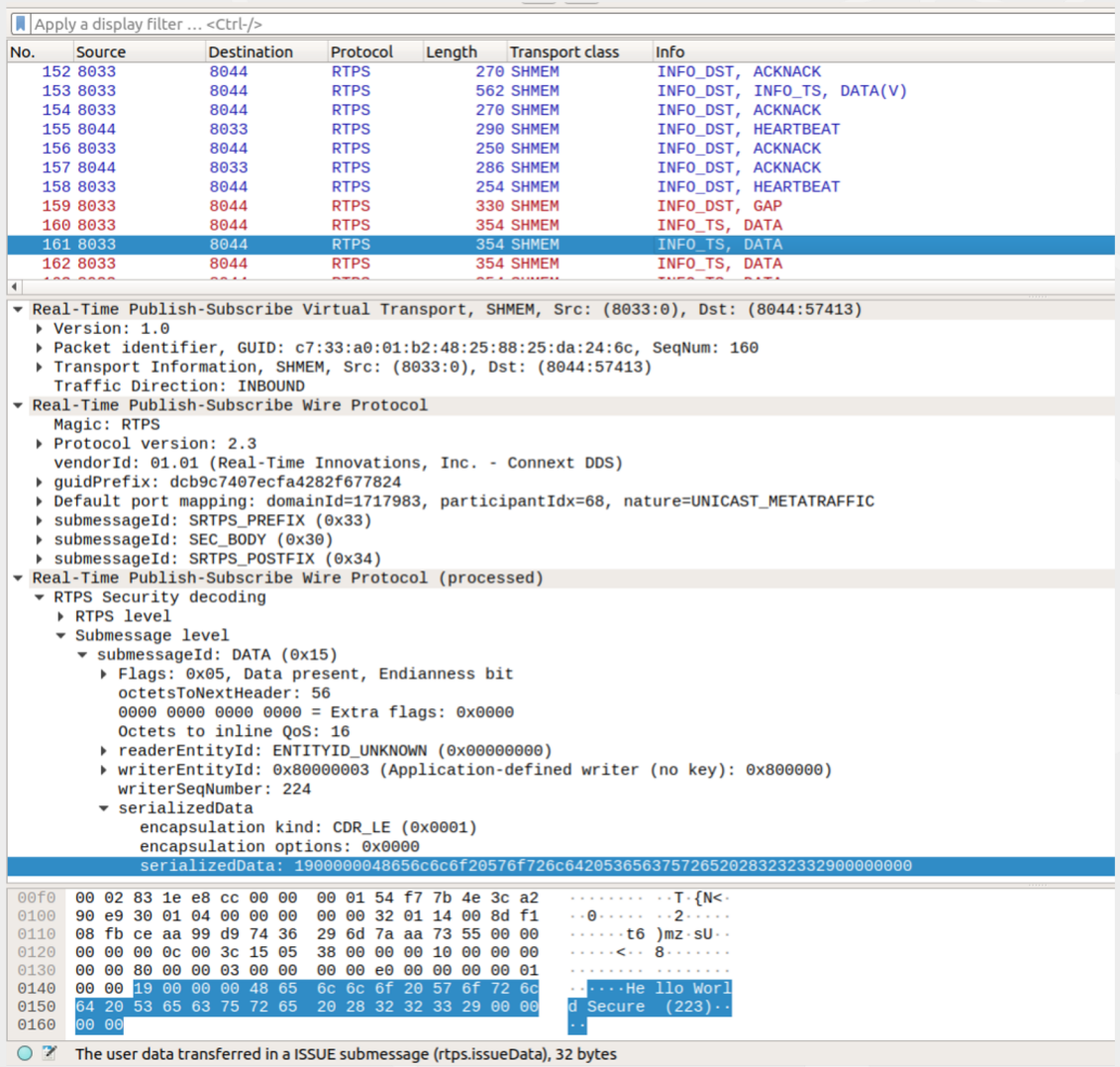
- No need to have root access
- Available for all platforms
- Available for all transports including shared memory, TCP, UDP, etc
- Generates PCAP files that can be analyzed with Wireshark
- Security friendly: RTPS packets decryption

Built-in Enhanced Network Capture

- Programmatic API

```
rti::util::network_capture::enable();
rti::util::network_capture::start(participant, "MyCapture.pcap");
rti::util::network_capture::stop(participant);
rti::util::network_capture::disable();
```

Built-in Enhanced Network Capture



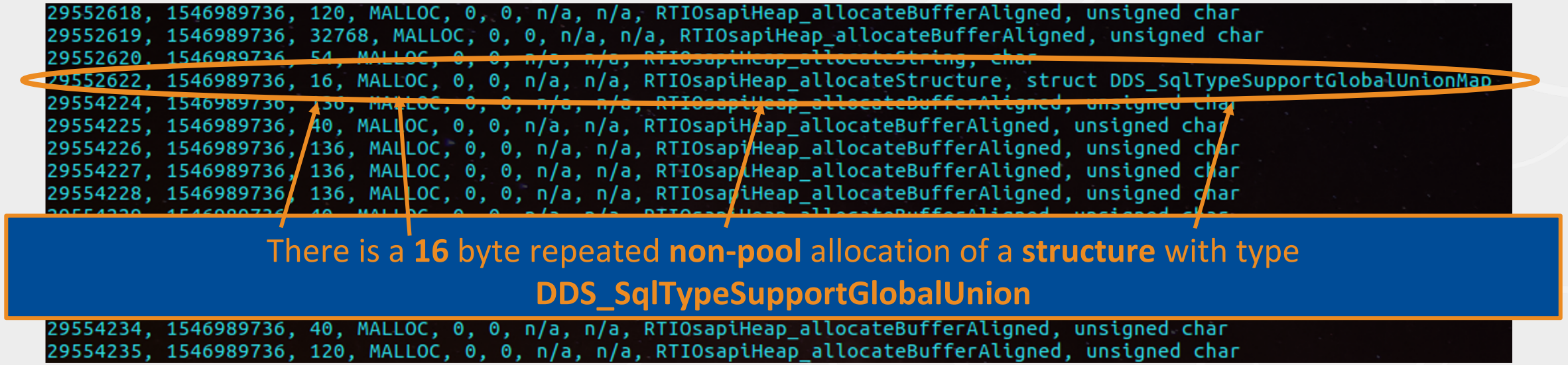
Heap Monitoring

- Heap monitoring was introduced in Connext 6 to monitor memory allocations and debug unexpected memory growth

- Typical problem that can be debugged with heap monitoring:

  "Creating (and destroying) DataReaders is causing memory growth in our application. … The growth seems to be in native space, as java heap remains consistent."

Heap Analysis



There is a **16** byte repeated **non-pool** allocation of a **structure** with type **DDS_SqlTypeSupportGlobalUnion**

"Creating (and destroying) DataReaders is causing memory growth in our application. … The growth seems to be in native space, as java heap remains consistent."

"Customer was creating both, DataReaders and ContentFilteredTopics, but only deleting the DataReaders

Heap Analysis

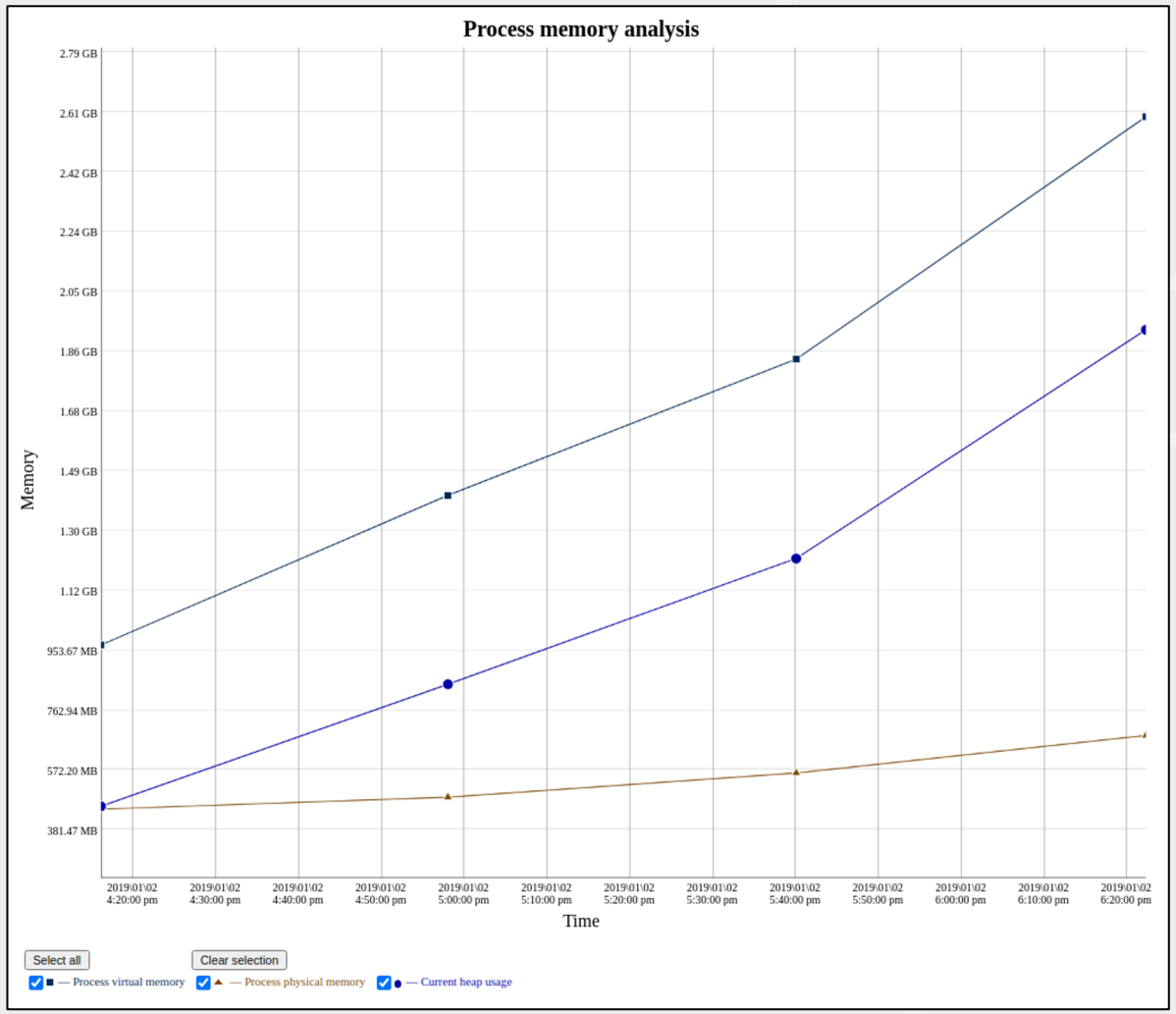
Snapshot analysis is complicated. It usually requires sending snapshots to RTI

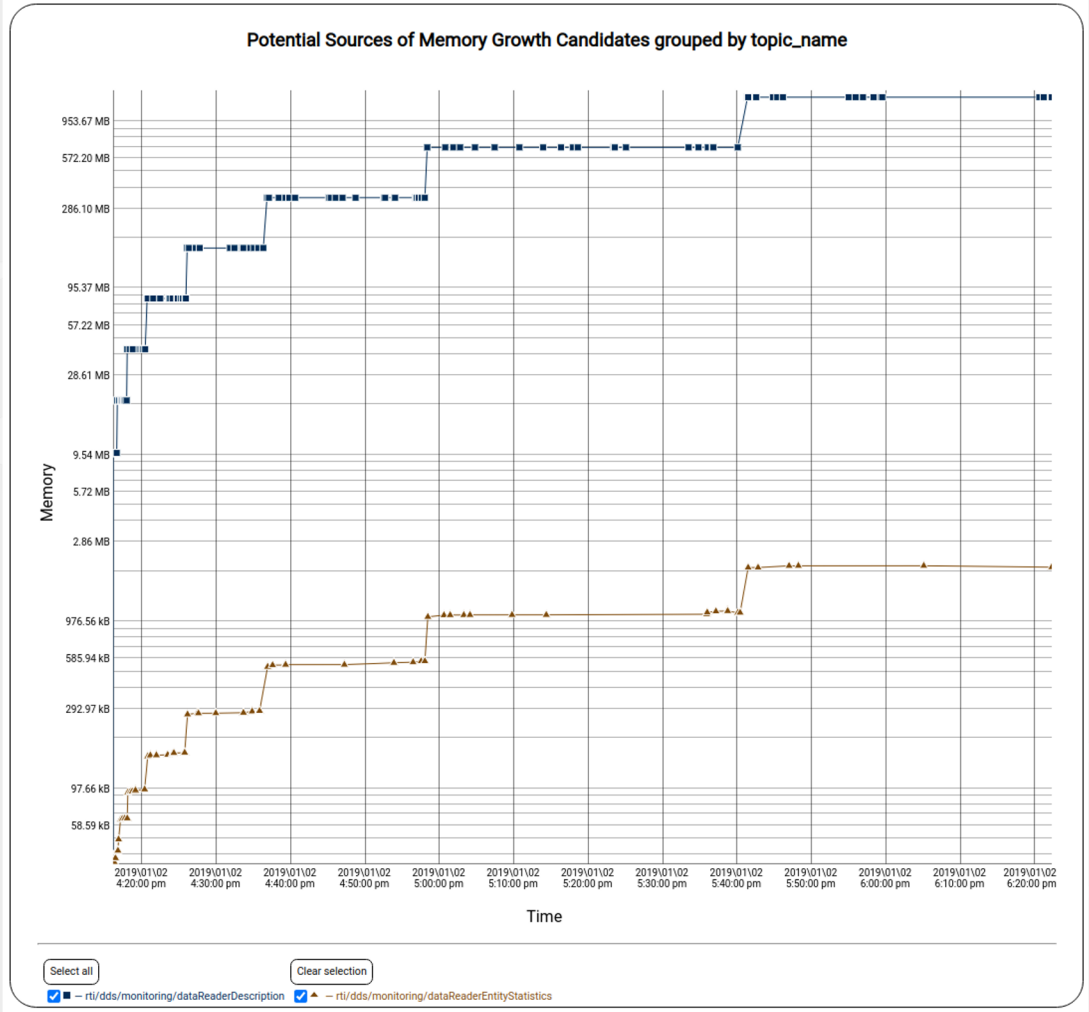
New **Heap Analyzer**

A cmd line tool for heap snapshot analysis

- Facilitates memory growth analysis
- Enables user debugging

Heap Analyzer



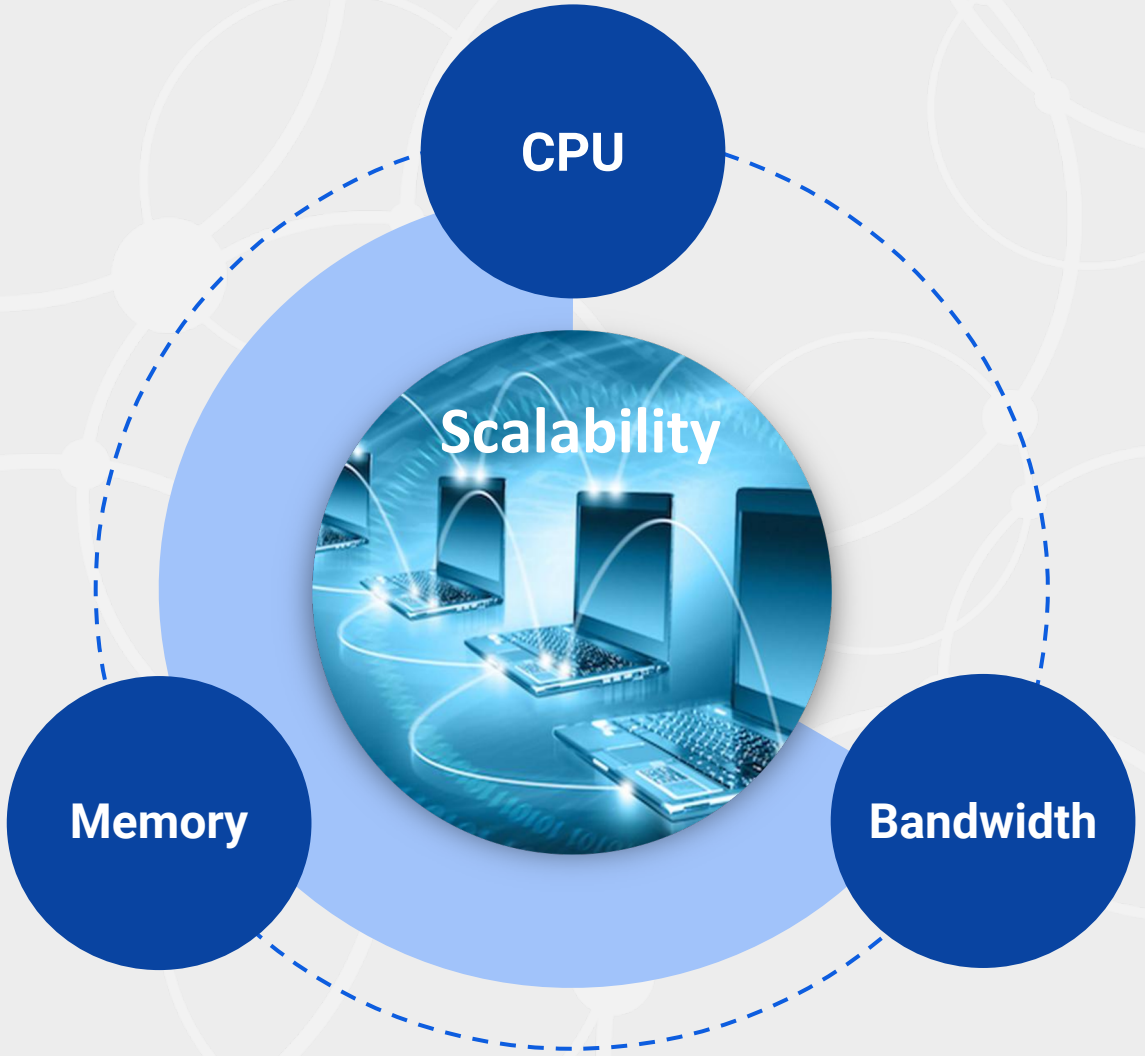


Scalability

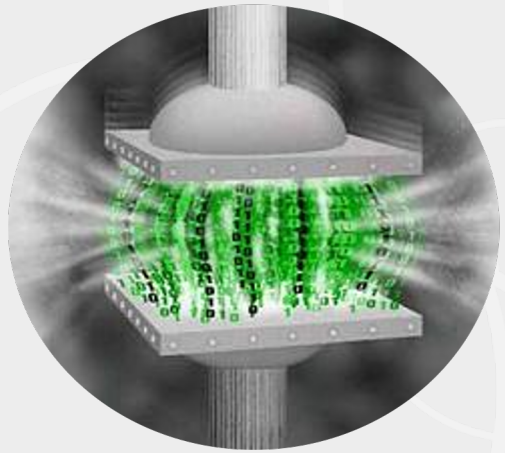
Meet the changing needs of IIoT systems in the future

The What and Why of Scalability

Allowing *You* to build systems that continue to perform as your resource needs evolve and grow



Bandwidth: User Data Compression



Pre-6.1.0:

- Limited Bandwidth Transport Plugin Add-on
- Compress with each send

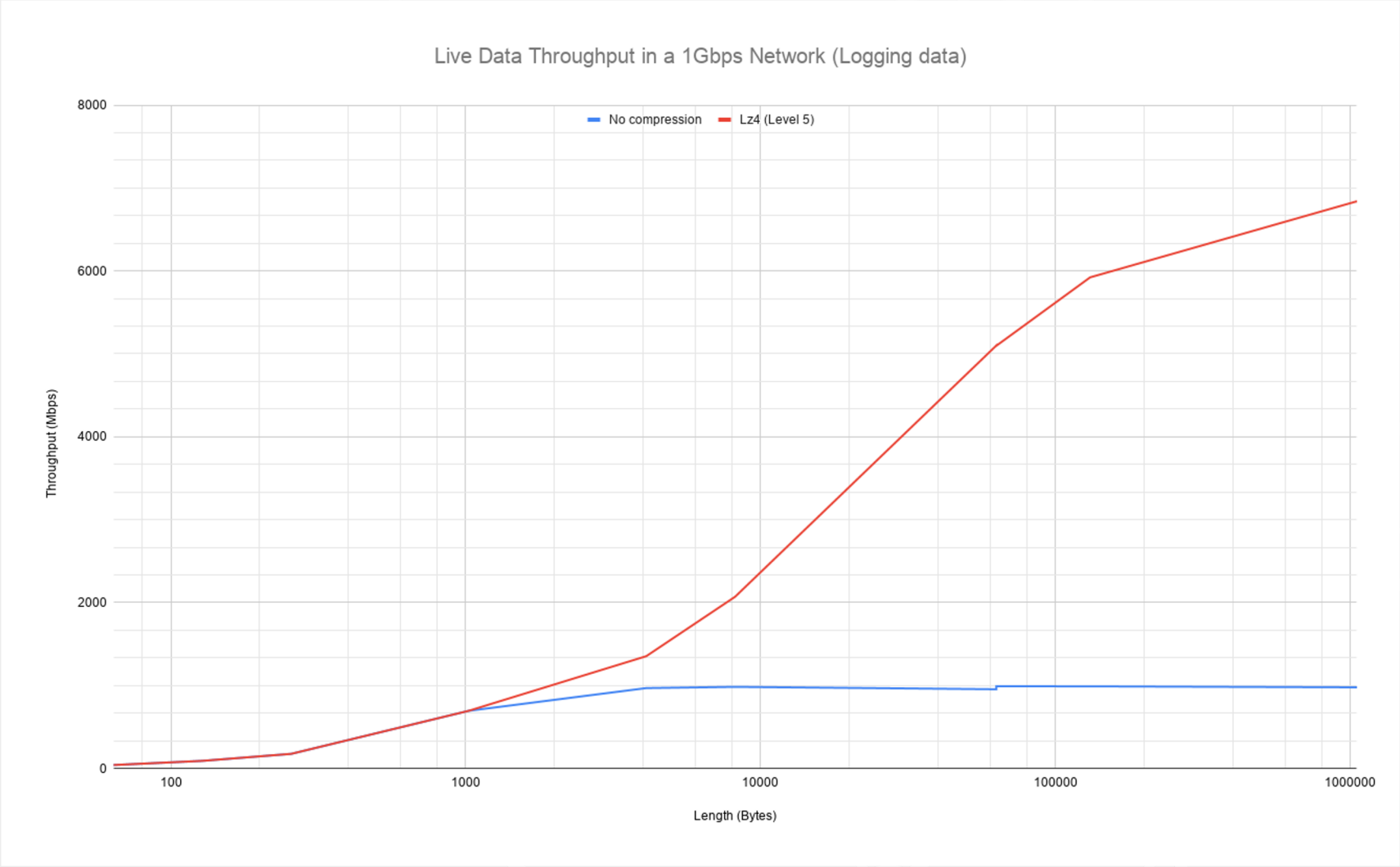
6.1.0:

- No Additional Libraries needed
- 3 Built-in Compression Algorithms: ZLib, BZip2, LZ4
- Compress once, send n times

```
struct DDS_CompressionSettings_t {
    DDS_CompressionIdMask compression_ids;
    DDS_UnsignedLong writer_compression_level;
    DDS_Long writer_compression_threshold;
};

struct DDS_DataRepresentationQosPolicy {
    ...
    struct DDS_CompressionSettings_t compression_settings;
};
```

Bandwidth: Compression Performance



Bandwidth: Decoupling Reliability and Durability

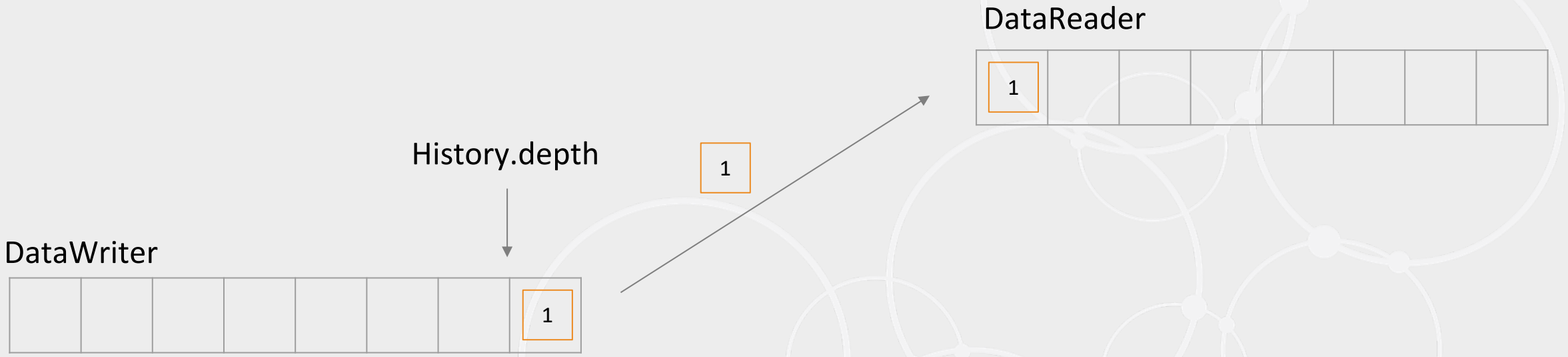
Problems:

- There was previously no way to have strict-reliability for live data and a limited sample history for late-joiners
- Even if you do not require strict-reliability, there was no way to separate the reliability window from the late-joiner windows

Pre-6.1.0:

- Both configured with a single depth parameter in HistoryQosPolicy

Problem: Replacing Unacknowledged Samples



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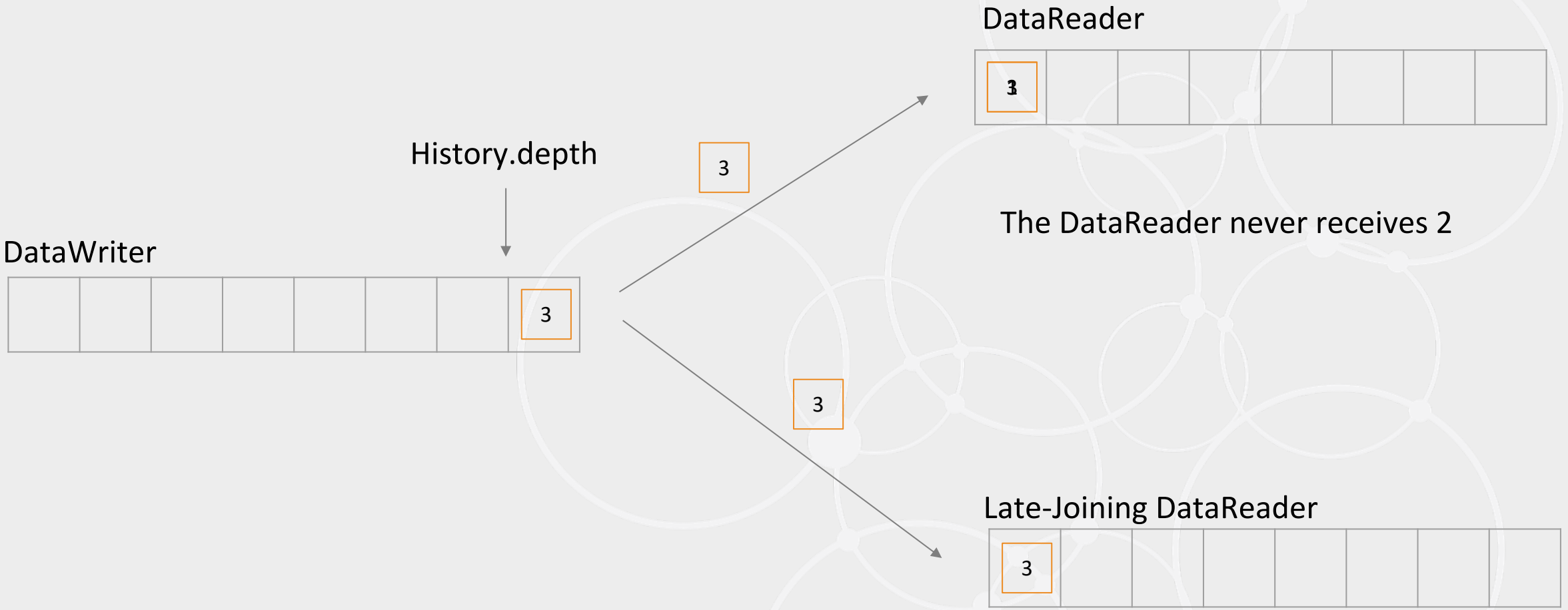

Problem: Too many durable samples

History.kind = KEEP_ALL

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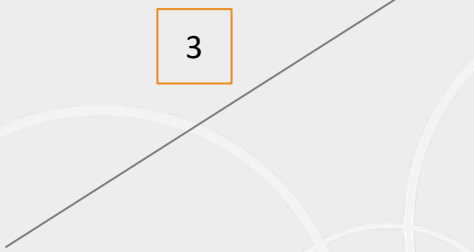


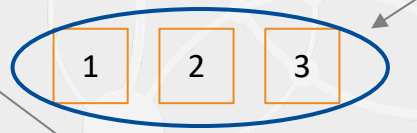
Problem: Too many durable samples

History.kind = KEEP_ALL

DataWriter

DataReader

Wasted Bandwidth



Late-Joining DataReader

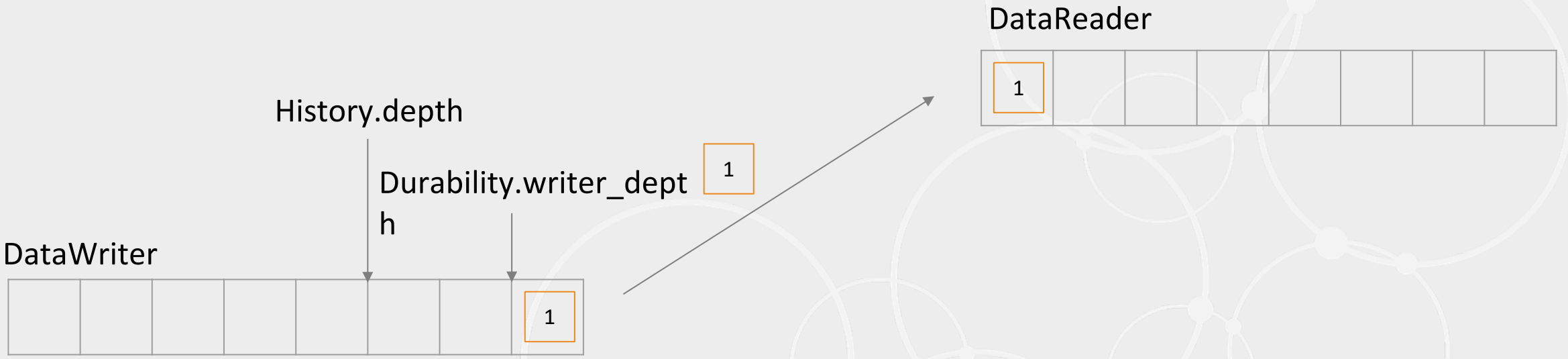
History.depth

Bandwidth: Decoupling Reliability and Durability

6.1.0: New DurabilityQosPolicy.writer_depth QoS

- Reliability window (KEEP_LAST) ⇒ HistoryQos.depth
- Durability window ⇒ DurabilityQos.writer_depth

Solution: Decouple Reliability and Durability Depths



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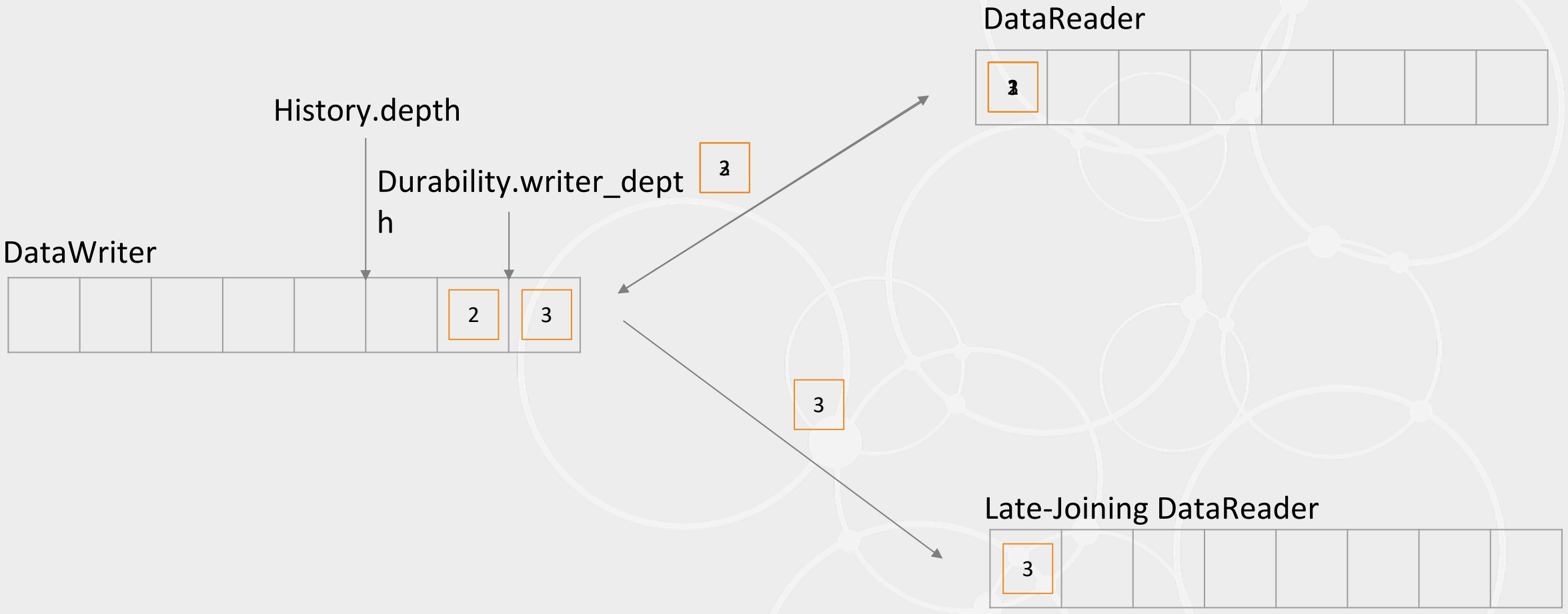


Memory: DataReader Instance Replacement Policy

Bound the resources consumed by your applications while supporting dynamic and unbounded sets of data

```
enum DataReaderInstanceRemovalKind {
    NO_INSTANCE_REMOVAL,
    EMPTY_INSTANCE_REMOVAL,
    FULLY_PROCESSED_INSTANCE_REMOVAL,
    ANY_INSTANCE_REMOVAL
};

struct DataReaderResourceLimitsInstanceReplacementSettings {
    DataReaderInstanceRemovalKind alive_instance_replacement;
    DataReaderInstanceRemovalKind no_writers_instance_replacement;
    DataReaderInstanceRemovalKind disposed_instance_replacement;
};
```

Accessibility

Access Connext from a variety of development environments and languages

New and Improved Language Bindings

Fully redesign, modern, multi-platform .NET API

New RPC for IDL interfaces.
C++11 improvements

New experimental Python API

New .NET API

.NET

New fully redesigned, OMG-standard, .NET 5 compatible C# API

Compatibility

- Built for **.NET Standard 2.0** & compatible with **.NET 5**, .NET Core, Unity, .NET Framework
- Runs on **Linux**, **macOS**, **Windows…**
- Deployed with **Nuget**
- OMG-standard IDL mapping

API

- **Fully redesigned** with .NET best-practices, naming conventions, & idioms.
- Generics
- Entities are **IDisposable**
- Standard collection interfaces
- Status updates and Conditions use **events**
- Immutable types
- OMG standardization in progress

```
using DomainParticipant participant =
    DomainParticipantFactory.Instance.CreateParticipant(domainId);

var provider = new QosProvider("hello_world.xml");
Topic<DynamicData> topic = participant.CreateTopic(
    "Example HelloWorld",
    provider.GetType("HelloWorld"));

Subscriber subscriber = participant.CreateSubscriber();
DataReader<DynamicData> reader = subscriber.CreateDataReader(topic);

StatusCondition statusCondition = reader.StatusCondition;
statusCondition.EnabledStatuses = StatusMask.DataAvailable;
statusCondition.Triggered += condition =>
{
    using var samples = reader.Take();
    foreach (var sample in samples)
    {
        Console.WriteLine($"Received: {sample}");
    }
};

var waitset = new WaitSet();
waitset.AttachCondition(statusCondition);
waitset.Dispatch(Duration.FromSeconds(4));
```

Preview available @ https://www.nuget.org/packages/Rti.ConnextDds/

New Python API (experimental)

PYTHON

Full access to Connext DDS from Python
Python-friendly design built on the Modern C++ API

Full access to Connext DDS features:

- Dynamic Data
- Built-in types
- DDS Entities in code and XML
- DDS QoS in code and XML
- Content Filters
- Built-in discovery Topics
- Status updates
- Listeners
- Wait Sets
- Conditions

```
with dds.DomainParticipant(domain_id) as participant:
    provider = dds.QosProvider(FILE)
    topic = dds.DynamicData.Topic(
        participant, "Example HelloWorld", provider.type("HelloWorld"))

    subscriber = dds.Subscriber(participant)
    reader = dds.DynamicData.DataReader(subscriber, topic)

    status_condition = dds.StatusCondition(reader)
    status_condition.enabled_statuses = dds.StatusMask.data_available()

    samples_read = 0
    def hander(_):
        nonlocal samples_read
        nonlocal reader
        samples_read += process_data(reader)
    status_condition.handler(hander)

    waitset = dds.WaitSet()
    waitset += status_condition
    while samples_read < sample_count:
        print("Hello World subscriber sleeping for 4 seconds...")
        waitset.dispatch(dds.Duration(4))
```

Available now @ https://github.com/rticommunity/connextdds-py
Read about it @ https://www.rti.com/blog/introducing-the-rti-python-api

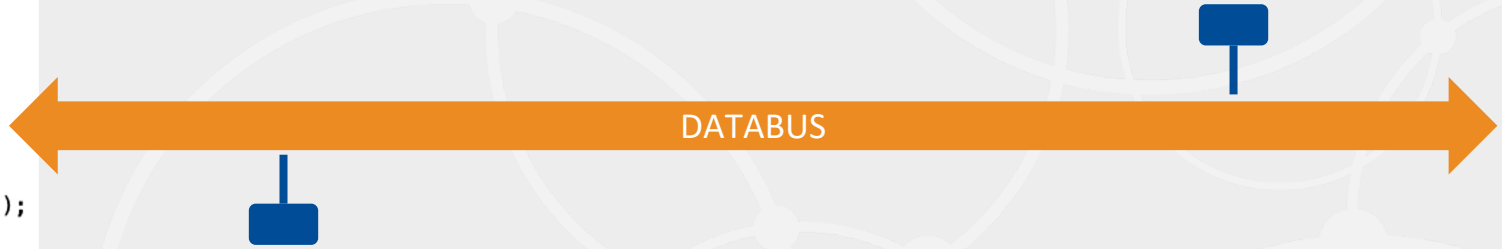
New RPC for IDL interfaces (experimental)

CarControl_service.cxx
(generated by rtiddsgen)

```
class MyCarControl : public CarControl {
public:
    void set_speed(int32_t speed) override { speed_ = speed; }
    int32_t get_speed() override { return speed_; }

    bool run_diagnostics(const DiagnosticOptions &options) override
    {
        return check_car_status(options);
    }

  private:
    int32_t speed_;
};
```

CarControl.idl

```
struct DiagnosticOptions {
    // ...
};

@service
interface CarControl {
    attribute int32 speed;
    boolean run_diagnostics(in DiagnosticOptions options);
};
```




```
CarControlClient client;
client.wait_for_service();

client.set_speed(client.get_speed() * 2);
if (!client.run_diagnostics(options)) {
    cout << "Attention! Car diagnostics failed!\n";
}
```

CarControl_client.cxx
(generated by rtiddsgen)

Coming soon for C++11

Connector improvements (py, js)

- Instance management
  - Instances can now be disposed and unregistered
  - Subscriptions can look up disposed keys
- Dynamic Library Support for pluggable RTI components
  - Monitoring
  - Security
- JavaScript: Node 12 support
  - Support for Node 14 coming later

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