Practical Aspects of Using RTI Connext DDS in UGV

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Together ahead. RUAG

Short History of UGV at RUAG
Gecko, 2008 to 2011

- Vehicle Gecko, sequential hybrid with four hub motors
- Teleoperate/Control thru VHF radio
- Autonomy with preplanned/teach-in & follower
- Vehicle and Control Station in C++

RTI DDS in Control Station but not in vehicle yet!

Short History of UGV at RUAG
Eagle IV with VERO, 2012 to 2015

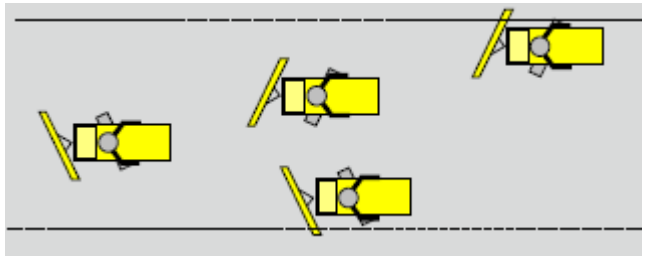
- Vehicle Robotics Kit VERO
- Autonomy: As Gecko with added collision avoidance using Radar

- Vehicle in C++ with DDS, control station rewrite in C#
- Concept for multiple control stations and multiple vehicles

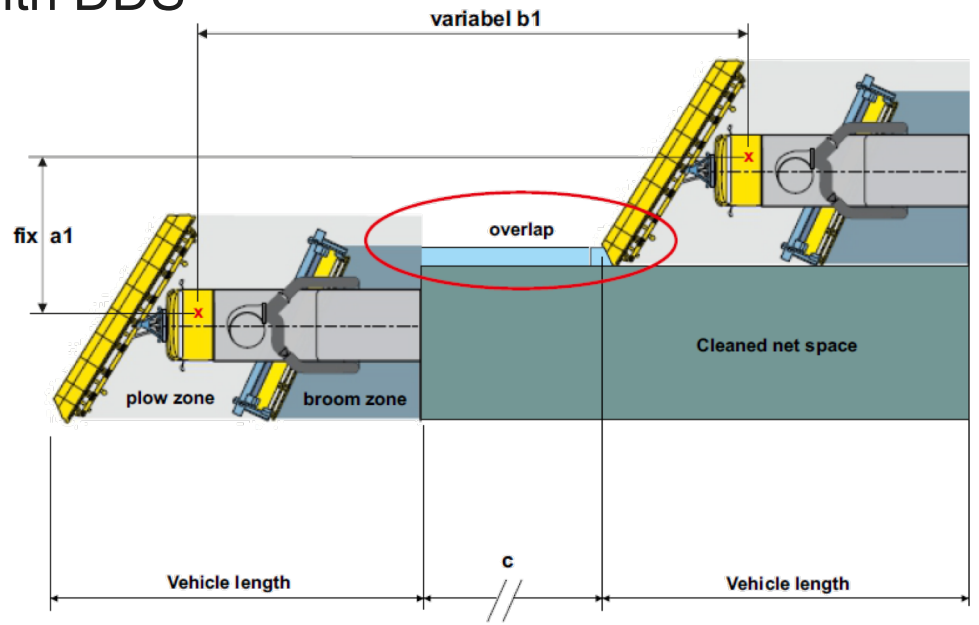
RTI DDS in Control Station and Vehicle!
Custom DDS-Router for multiple control stations & vehicles

Short History of UGV at RUAG
BASR, 2016 to 2018

- Boschung Automated Snow Removal
- Snow clearance on airports
- Vehicles in formation only



- Modular Architecture Lite/Full in C++ with DDS
- Vehicle to Vehicle Communication
- DDS-Routing thru 4G planned
- Trials in fall 2018 were promising

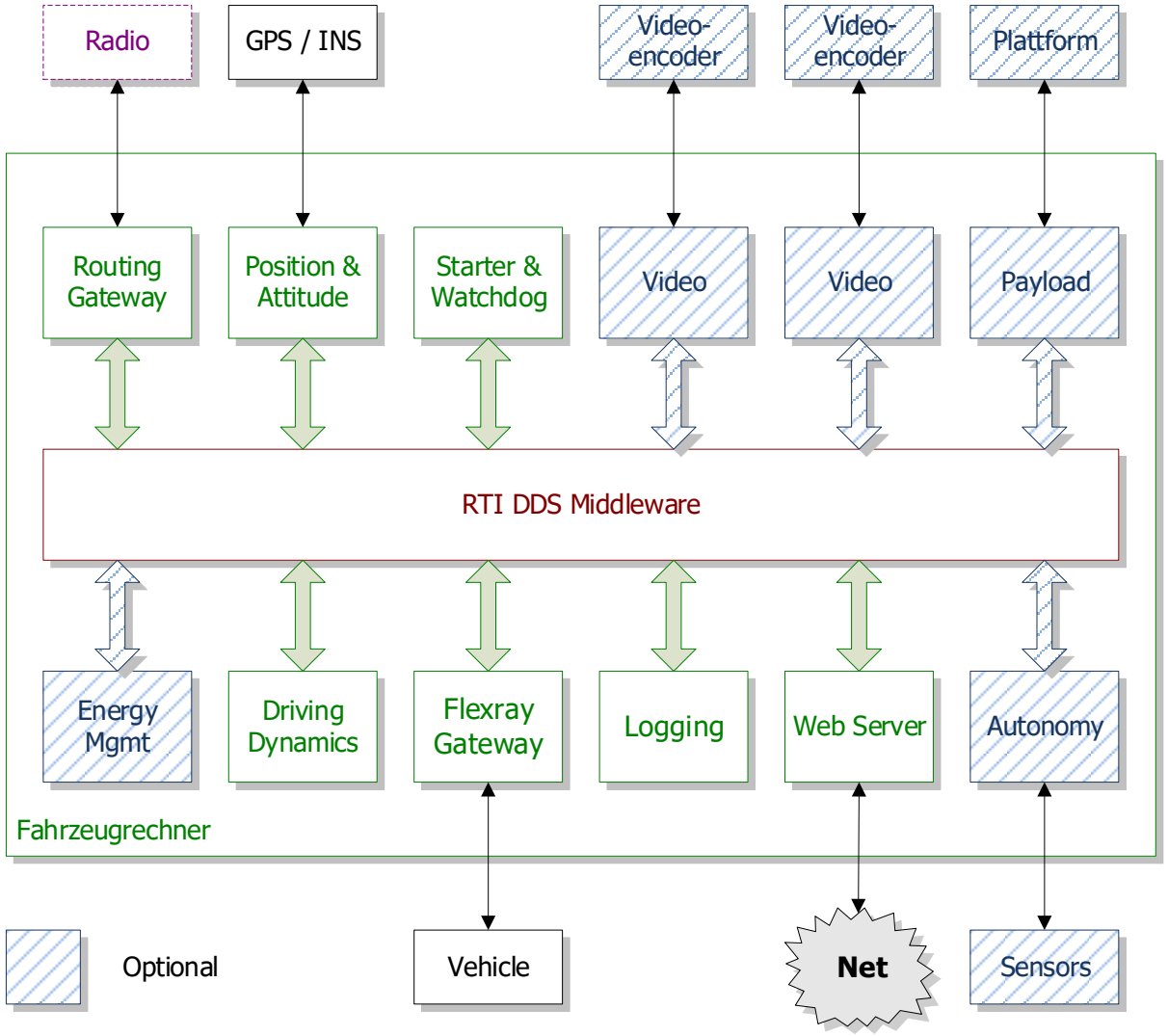


- End of robotics at RUAG due to company restructuring in 2019/20

Modular Architecture

- Almost everybody today talks about ‘system of systems’ or IoT
- This will be more and more important but is (in my opinion) mostly a communication and synchronization challenge
- Of course DDS will help you there
- But the ‘old’ software challenges still exist:
  - Modular Architecture
  - Maintainability
  - Testability
  - Scalability
- And DDS can help you there also
- We used DDS mainly to create a modular architecture for our control stations and vehicles

Modular Architecture in Vehicle



Modular Architecture in Vehicle and C2

- Implementation in the vehicle:
  - Every module is own Linux executable with DDS-Interface
  - Starter starts modules and monitors them (thru DDS lifeliness)

- Implementation in the control station is similar:
  - Every module is own Windows executable with DDS-Interface
  - Basic idea: Every window is an own executable
    e.g. dashboard, video in multiple instances, map

Modular Architecture in Vehicle and C2

- Advantages:
  - Modules can be optional and running in multiple instances (e.g. autonomy and video systems)
  - Implementation of modules either in central computer or separate hardware, changeable later without affecting other modules
  - The DDS middleware provides a fully documented layer of abstraction
  - Every module is independently testable on the DDS interface
  - Modules can be implemented in different programming languages
  - Many combinations possible for integration and testing e.g. Vehicle with Positioning, Logging and Web-Server
  - For testing the Routing Gateways can be eliminated and the DDS domains directly connected

- Challenges:
  - Process-Priorities must be configured correctly

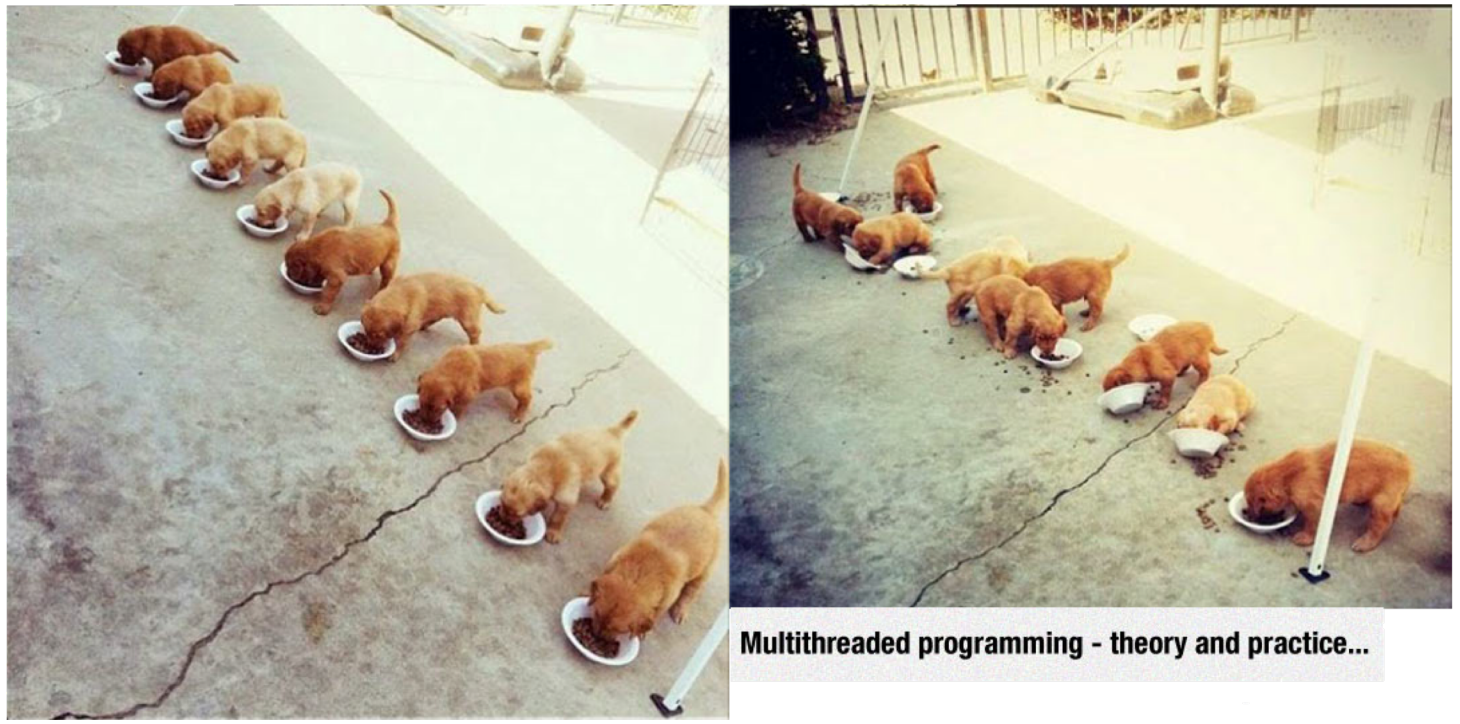
Adressing of Modules / Systems

- For modular systems all modules must conform at least to the following requirements:
  - Every module is addressable with an unique address
  - The source address is a ‘key’ in every topic
  - Every module implements a common interface with topics
    - Alive and status
    - Logistics data (e.g. software-version)
    - Error reporting & recovery
    - Logging

- Module addressing has evolved over time:
  - Gecko had only keys ‘AppID’ and ‘CEP’ (command&control only)
  - Eagle has ‘groupId’, ‘systemId’, ‘subsystemId’ and ‘’moduleId’
  - BASR has ‘vehicleId’, ‘typeId’ and ‘instanceId’ (inspired by GVA)

Now to practical aspects and examples

- Required knowledge for following samples:
  - C/C++
  - IDL files
  - RTI DDS QoS and profiles



Addressing of Modules / Systems
Source Address

- We defined a base structure for all topics and used inheritance to include it in all topic types
- The name was ‘BaseAV’ for ‘Actual Value’

```
// Basic Indentifier types
typedef unsigned long  VehicleId;
typedef unsigned short TypeId;
typedef unsigned short InstanceId;

// Address of an object
struct ObjectId
{
    VehicleId  vehicleId;
    TypeId     typeId;
    InstanceId instanceId;

}; //@top-level false
```

```
// Timestamp
struct Timestamp
{
    long long     seconds;
    unsigned long nanoseconds;

}; //@top-level false

// Base struct for all actual values
struct BaseAV
{
    ObjectId  sourceID; //@key
    Timestamp timeOfGeneration;

}; //@top-level false
```

Addressing of Modules / Systems
Source Address

- And it was used like this, e.g. in the logging topic

```
// System wide logging
struct LoggingAV : BaseAV
{
    Severity    severity;
    ShortString info;
    LongString  data;
    ErrorCode   errorCode;

}; //@Extensibility FINAL_EXTENSIBILITY
```

Addressing of Modules / Systems
Recipient Address = Directed Send

- Sometimes you need to send data specifically to a module
- This is contrary to the Pub / Sub idiom where the publisher should not know about the subscribers!

```
// Base struct for all nominal values
struct BaseNV
{
    ObjectId  sourceID; //@key
    ObjectId  recipientID; //@key
    Timestamp timeOfGeneration;

}; //@top-level false
```

```
// System wide error masking
struct ErrorMaskNV : BaseNV
{
    ErrorCode errorCode; //@key

}; //@Extensibility FINAL_EXTENSIBILITY
```

QoS Profiles

- Define QoS Profiles in XML and load the XML explicit during startup
- It is easily ‘adjustable’ during integration & debugging
- Define topic QoS only in profiles and create a ‘minimum’ working set
- Use inheritance to structure the profiles

```
<!-- Commands, keep the last value -->
<qos_profile name="BASR.Command" base_name="BASR.Base.KeepLastReliable"/>

<!-- Pulsed command, it disappears after the lifespan -->
<qos_profile name="BASR.Pulse" base_name="BASR.Base.StrictReliable.Volatile">
  <datawriter_qos>
    <lifespan>
      <duration>
        <sec>2</sec>
        <nanosec>DURATION_ZERO_NSEC</nanosec>
      </duration>
    </lifespan>
  </datawriter_qos>
</qos_profile>
```

Structure Topic Names

- Caution: All topic names are in a global namespace per domain (like global variables in a whole system)
- Make sure the names don‘t collide, like ‚Status‘ or ‚Mode‘
- Modules (namespace in IDL) don’t help here
- We used a structure in topic names, chars like ‘.’ or ‘/’ are possible

```
"BASR.Common.LoggingAV"
"BASR.Common.ErrorAV"
"BASR.Position.GlobalPositionAV"
"BASR.Navigation.SolutionAV"
"BASR.Navigation.AutonomousModeAV"
"BASR.MissionData.MissionNV"
"BASR.Gui.StatusAV"
"BASR.Safety.StatusAV"
```

Readable IDL Files

- It really helps to define topic type, name and QoS profile together
- The QoS profile is of the writer, the reader can differ (but mostly is same)

```
// System wide logging
struct LoggingAV : BaseAV
{
    Severity    severity;
    ShortString info;
    LongString  data;
    ErrorCode   errorCode;

}; //@Extensibility FINAL_EXTENSIBILITY

// Topic name and QoS profile
const string TOPIC_LOGGING_AV   = "BASR.Common.LoggingAV";
const string PROFILE_LOGGING_AV = "BASR.Logging";
```

Be Aware of Traffic
QoS Minimum Separation

- Sometimes a publisher has data with a high frequency
  e.g. INU attitude data with 50 Hz or more
- And has multiple subscribers like Navigation and GUI
- If the GUI now just subscribes it will ‘wake up’ way to often
  (a typical GUI update rate is 10 Hz for a ‘smooth’ display)

- The solution is QoS 'Minimum Separation’
  – to reduce CPU load and to avoid 'sample lost'
  – to reduce traffic

- The INU writer publishes with Best-Effort profile `"BASR.PeriodicData"`
- The Navigation reader uses the same profile to get max. speed
- The GUI reader uses the profile `"BASR.PeriodicData.10Hz"`
  which has a minimum separation of 100ms (= 10 Hz)

Be Aware of Traffic
Content Filter

- Often applications need topic data from a specific source only
- E.g. our vehicles listen only to their ‘assigned’ control station
- But all control stations publish on the same topic (keyed with sourceID)
- ‘Normally’ applications wake up on data, see if it is for them and throw the sample away if it is not for them (in reader callback code)

- But the discarded sample has already generated traffic and CPU load!

- The solution is to set a ‘Content Filter’ on the sourceID in the reader
- The filtering will then be done in the writer separately for every reader!

- Note: Set the content filter before creation of the reader
  (otherwise the 'historical' samples won't be filtered)

Writer and Reader Lifecycle

- Create all writer & readers at application startup
  - do not create writers 'on demand’
  - do not destroy writers
  - You can create readers ‘on demand’ but try to avoid it
- Create writers before readers
  - most likely writer topics will be updated on response to reader data
  - You cannot (and should not) create writers in reader listeners
- When specifying a listener in create_datareader() be prepared to handle data of the reader when the reader is created
  (reader listeners can be called before create_datareader() returns!)

- We used a two-stage approach (init/run) where all writers & readers were created in ‘init’ and all listeners / waitsets started in ‘run’
- Generally prefer Waitsets over Listeners!

Application Error Reporting
Motivation

- For a real-world system you need to have a ‘standardized’ way to report errors and react to them
- In our system the ‘error topic’ has evolved over time:
  - Gecko: Topic with 64-bit bitfield in an ‘unsigned long long’
  - VERO: Topic with sequence<unsigned short>

- Problem of this approach: Setting / Clearing an error is a Read-Modify-Write operation on the writer side and therefore needs a global variable and locking!

- Solution:
  - BASR: Keyed topic with error number as key
  - Use ‘Write’ to set an error, ‘Dispose’ to clear an error
  - No locking required

Application Error Reporting
Example

```
module basr
{
    module common
    {
        // Suggested action to fix an error. Will be sent with the error.
        enum FixErrorMethod
        {
            FIX_GOOD = 0,           // No error, nothing to do
            FIX_RESET_MODULE,       // Reset module thru Reset() function
            FIX_RESTART_MODULE,     // Restart module thru unload/load
            FIX_RESTART_SYSTEM,     // Restart whole system ('warm start')
            FIX_POWER_CYCLE,        // Cold start system
            FIX_MAINTENANCE         // Call maintenance
        };

        // Basic Error Code
        typedef unsigned long ErrorCode;

        // Common severity using QtMsgType
        typedef unsigned long Severity;
```

Application Error Reporting
Example, cont.

```
        // System wide error reporting
        struct ErrorAV : BaseAV
        {
            ErrorCode       code; //@key
            FixErrorMethod fixMethod;
            Severity        severity;

            // There is intentionally no string here!
            // The GUI needs to have error messages in all supported languages
            // Detailed error infos should be saved in the log

        }; //@Extensibility FINAL_EXTENSIBILITY

        // Topic name and QoS
        const string TOPIC_ERROR_AV   = "BASR.Common.ErrorAV";
        const string PROFILE_ERROR_AV = "BASR.Data";

    }; // end of namespace 'common‘

}; // end of namespace 'basr'
```

Summary, Lessions Learned
'Best Practices' or 'Do's'

- Use QoS profiles and a minimum ‘understandable’ set of them
- Structure Topic Names
- Create ‘readable’ IDL files containing type, name and writer QoS profile
- Use modules (namespaces) in IDL files to structure types
- Use content filter and minimum separation to reduce traffic
- Create writers before readers and never destroy them
- Define an error reporting scheme based on keys

Challenges
when using DDS in Real-World-Applications

- Time Sync of all nodes is required
  - The good news are that encryption is then also possible
  - Typical symptom: Data flows only in one direction
  - We used a local NTP server, GPS time or both
  - Challenge: If the time is really ‚off‘, e.g. 1.1.1970, then a ‚jump‘ is needed and we need to wait for time-sync before starting DDS apps

- Discovery
  - Discovery is not 'realtime'
  - Default Discovery uses Multicast
    - You do not want multicast via radio links
    - WLAN falls back to lowest available speed on multicast frames
    - Switches turn to hubs when IGMP is not enabled
  - Static Discovery increases application startup time

Challenges
when using DDS in Real-World-Applications, cont

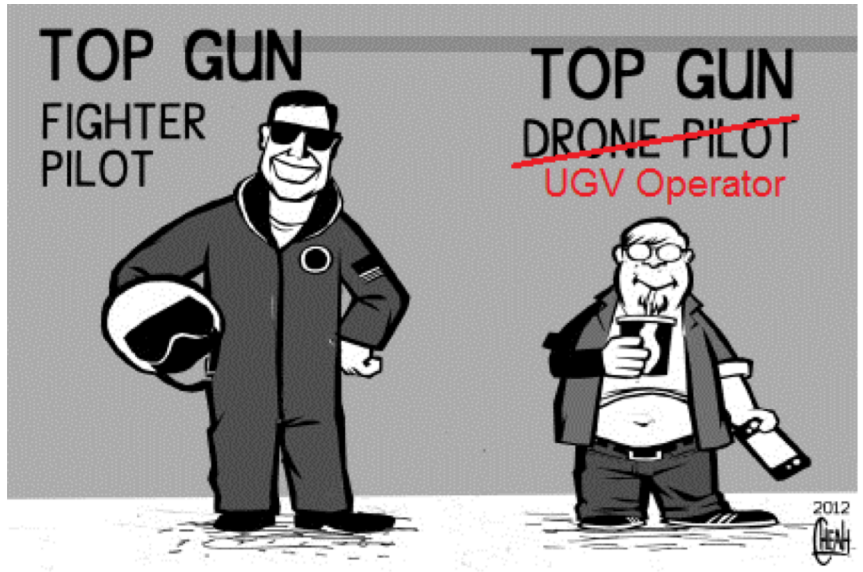
- MaxMTU
  - Yocto Linux typically has MaxMTU < 1500 and no fragments
  - Discovery typecode size exceeds MaxMTU in real-world scenarios
  - Topic data size can exceed MaxMTU

- RTPS2 over narrow radio links
  - Verbose, minimum header size > 200 bytes
  - Compression negligible
  - In our routing gateway the sender strips the RTPS2 header and the receiver attaches it again (but this has some drawbacks and is a lot more complicated than it sounds)

- Be aware that ‚normal‘ writers send UDP packets to all discovered readers separately
  - This scales quickly, e.g. 10 writers to 10 readers = 100 UDP packets
  - A multicast writer would reduce this to 10 packets

Thank you for your attention!

I’m looking forward to answer your questions



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