D7.11
Exploitation Plan - Year 2

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Abstract	SWOT and business analysis for right positioning of micro-ROS. Individual exploitation plans.

Changes compared with the last annual report

Change	Section	Short description
ALR 1	3.3 Strategic Approach to Materialize the Vision	ALR sections have been revisited and updated accordingly with ALR not participating in the project anymore
Mico XRCE-DDS	3.3.1 DDS-XRCE & Micro XRCE-DDS	Updated DDS-XRCE & Micro XRCE-DDS information
Client library	3.3.2 ROS 2 Embedded Client Library and Building Blocks	Update client library components
Brand	3.3.4 micro-ROS brand	Update brand status
Competition and SWOT	3.4 Competition and SWOT analysis	Update competition and SWOT
Dissemination and communication	3.6 Revision of Actions and Priorities regarding Communication and dissemination Activities	Updated dissemination and communication actions
Individual exploitation plans	4 Individual Exploitation Plans	Added a revised version of individual exploitation plans

Abbreviations

Term	Definition
DDS	Data Distribution Service
DDS XRCE	DDS for extremely resource-constrained environments
IMU	inertial measurement unit
MCU	microcontroller
SOSS	System Of Systems Synthesizer
rcl	ROS 2 client support library
rmw	ROS 2 middleware interface
ROS	Robot Operating System
RTOS	real-time operating system

1 Introduction

1.1 Executive summary

The exploitation of the outcomes from OFERA project has been updated and completed from the original version presented in D7.10 Exploitation Plan - Initial.

The general exploitation plan has not suffered major changes or deviations, keeping the same vision of enabling European companies to rapidly deliver robotics products integrating highly resource-constrained devices (microcontrollers).

No new stakeholders or customers have been identified or removed from the original analysis.

During this year the strategic approach has been faced more directly as chosen architecture and design decision has been taken in alignment with it. Thus keeping ROS 2 architecture and packages on those places where this is possible. And only adding new packages for pieces lacking in ROS 2 or that has been proven invalid for the project purpose. This Strategic approach has already received the first round of community feedback in the different events and forums where ROS 2 is the chosen technology, seeing an increased interest in this OFERA approach.

Regarding key results small modifications have been made, the more remarkable ones are:

1. Acutronic Robotics left the project thus Key results associated with them have been updated accordingly.
2. Client library: Has been suffering some technical decisions that do not affect its functionality rather its deployment method. We have decided to approach it in a modular way where there is not a monolithic unique library and the users can choose which part they need based on their requirements.
3. TF library has been dropped from the micro-ROS building blocks and others have been added such as a build system and traceability tools.

Regarding competition and SWOT analysis, new players have emerged with the first releases of Micro XRCE-DDS. These new players are not seen as direct competition as their approach is using the same middleware and architectural approach only differing in their interfaces. Current conversations are being taken with them so we can merge all the approaches under the same micro-ROS denomination.

Our target communities have been updated with these changes:

- ISO 299: It is not appealing to the project. See *D7.8_Annual_Report_on_Standardization_Y2* .
- OPC Foundation: There are no further plans or actions to be taken in this community from the Acutronic side.
- HROS: This users community has not been materialized as the partner which leads this technology has been terminated, Acutronic Link Robotics AG.

Dissemination activities are kept untouched apart from removing those in Acutronic dissemination plan.

1.2 Purpose of Document

In this new version of the exploitation plan, we revisited the initial exploitation plan updating the main targets with the latest project and Consortium changes. This document's starting point is the previous document: D7.10 Exploitation Plan – Initial.

In this document, we will revisit the initial OFERA exploitation plan detailing the changes from that foundation document and completing it with new content.

At the end of the document, we will introduce to new sections that were postponed for a future step in the project in the last deliverable:

- Following the updates and modifications, we will introduce each partner's individual exploitation plan where each one of the partners will list their potential exploitation points and associated plans.
- Following individual plans, we will introduce the long term maintenance plan followed by the first view on a possible evolution plan.

The document concludes with an updated version of dissemination plans.

1.3 Partners Involved

Short Name	Full Name	Contribution
Bosch	Robert Bosch GmbH	Co-writing
eProsima	Proyectos y Sistemas de Mantenimiento S.L.	Leading author
Łukasiewicz-PIAP	Łukasiewicz Research Network - Industrial Institute for Automation and Measurements	Support
FIWARE	FIWARE Foundation	Support

2 General Exploitation Plan

2.1 Project's Mission and Vision

Robots today are networks of mixed devices which include general-purpose microprocessors and microcontrollers. Often, these networks are summarized as the interconnection of all networks into a (robot) global one, the robot network. Most often, microcontrollers within the robot network are used within sensors or actuators, coupled with additional electronics to interface appropriately.

micro-ROS vision is to enable European companies to rapidly deliver robotic products integrating highly resource-constrained devices (microcontrollers). micro -ROS aims to bridge the technological gap between the established robotic software platform for high-performance computational devices and the low-level libraries for microcontrollers. To do so, the project's mission is to bring microcontrollers as first-class participants of the Robot Operating System (ROS) 2 robot ecosystem, the de facto standard for robot application development.

2.2 Target Customers and Stakeholders

Target customers include:

- robot hardware/component vendors
- robot OEMs
- general hardware vendors
- microcontroller OEMs
- embedded engineers
- researchers

Although we do not foresee other stakeholders at the time of writing, we acknowledge the strong interest that the project has received from the community and expect further additions to this section in future exploitation reports.

Also, see the dissemination report for stakeholder-targeted dissemination activities.

2.3 Strategic Approach to Materialize the Vision

To materialize a reality where microprocessors and microcontrollers could be mixed together seamlessly in any robotic system, the project aims to expand the ROS 2 robot ecosystem to such devices, preferably through modifying ROS 2, where possible, but also through supplying complementary pieces where the

current ROS 2 approach is unsuitable or non-existent. This strategy reduces the sustainability burden and eases adoption.

In addition, the growth of the resulting, larger ecosystem is supported through standardization and community building efforts. Through these efforts, in particular, the project also achieves enhanced visibility and influence of European actors in the world-wide ROS 2 community.

Specifically, the project's key results, as currently known (i.e. existing or planned), contribute to this as follows:

Key result	Type	Contribution
DDS-XRCE	OMG Standard	Ensures vendor-independent interoperability for deeply embedded devices.
Micro XRCE-DDS	Open Source	The reference implementation for DDS-XRCE, available for use and enhancement by the community. Also already provides message-level compatibility with ROS 2.
ROS 2 Embedded Client Library	Open Source	Optimal performance for embedded devices in the ROS 2 eco-system through a small runtime, and specialized scheduling support.
ROS 2 Embedded Building Blocks	Open Source	Useful building blocks for embedded applications, e.g., build-system, traceability.
micro-ROS	Brand	A unifying brand name for ROS 2 efforts targeted at deeply embedded devices

All of the corresponding activities are based upon the following core principles:

- Commercial exploitation - with a particular focus on Europe
- Alignment with ongoing initiatives
- International community acceptance

In the following, we will discuss each one of the key results.

2.3.1 DDS-XRCE & Micro XRCE-DDS

This result of the project has been upgraded multiple times with new releases during the project and has meanwhile been adopted by several organizations, such as Robotis, Auterion, Renesas, and others, based on a clear unique selling point: Easy integration with the existing ROS 2 ecosystem through the agent.

This is an example of a mutually beneficial cycle: The project drives awareness of the DDS-XRCE standard, and the Micro XRCE-DDS implementation drives demand for, and adoption of additional layers of the stack. In this sense, Micro XRCE-DDS has benefic from feedback from micro-ROS users and DDS-XRCE has incorporated to the standard new mechanisms required in micro-ROS.

To further increase ease-of-use, integration with the standard ROS 2 middleware interface, rmw, has also been provided. This rmw implementation is an undergoing project being aligned with the latest ROS 2 versions, both on the Agent side and in the API level.

2.3.1.1 DDS-XRCE Barriers and Risks

Beyond the current ad hoc benchmarks, more usage data will be collected in the benchmarking activity and used to further improve the current implementation.

Apart from that, real-world experience with the performance of the DDS-XRCE protocol is currently limited.

Initial indications are promising but challenging use cases will need more evidence. Again, this is being collected as part of the project already.

rmw implementation limitations are being identified and have suffered some difficulties keeping up to date to the latest ROS 2 releases.

2.3.1.2 Input from users

The project already includes users (Bosch, Łukasiewicz-PIAP), and a number of external users are providing feedback directly to partner eProsima.

2.3.1.3 Roles of the partners

Partner eProsima is leading standardization, development and productization, partners Bosch is exploring use cases in their products, and partner Łukasiewicz-PIAP is exploring a research use case as well as performing benchmarking.

2.3.2 ROS 2 Embedded Client Library and Building Blocks

The client library represents the main entry-point for developers using ROS 2.

Modifying the existing client libraries, particularly for reduced resource usage, will greatly improve performance and enhance the user experience of newcomers to embedded devices.

Supplying embedded-specific building blocks, such as specialized executors with domain-specific scheduling APIs, improved system composition concepts and an embedded TF are all crucial to realize the potential of micro-controllers. Therefore, both uses within their own products, as well as the development of supporting products are natural exploitation pathways.

To control this development, the consortium has initiated a ROS 2 Embedded Special Interest Group, which has been nominated an official working group by the ROS 2 Technical Steering Committee (TSC) in early 2019. Furthermore, four members of the consortium are participating actively in the new Real-Time Working Group established in April 2019.

2.3.2.1 Barriers and Risks

With regard to the client libraries itself, the most important barrier is cultural: rcl, rmw and rclcp are not written in the way of most embedded libraries. On the other hand, newcomers to embedded devices expect something Linux-like. Striking a balance between these two worlds could be characterized as the basic problem of the overall project, and a great deal of analysis and planning has been carried out in the first year to understand the situation fully.

The project has now committed to modifying the existing client libraries, rather than coding it from scratch. While this carries the risks of not being able to address the smallest use cases, it greatly increases the chances of keeping, and growing, the existing community and thus prevent the risk of a fork.

A second barrier is the use of the C++ standard library in the primary client library, rclcpp. The C++ standard library is not available on all platforms and only limited testing on its resource use could be carried out, yet, so there is also the risk of increased resource use. This will be addressed using more benchmarking and the exploration of greater modularization, to selectively use only what's necessary.

Last, but not least, there is also the risk of organizations "just" integrating Micro XRCE-DDS in their existing client code, and foregoing the full ROS2 implementation. We consider this risk minor – firstly, it would still represent a use of a key project result, and secondly, over time, we expect that as people come to realize that many of the features they require are already provided by ROS 2, they would migrate.

2.3.2.2 Input from users

As the consortium includes several users already, concrete feedback is always present.

Moreover, the project consortium has engaged the community in the ROS 2 Embedded Interest Group, where it will carry out regular interactions, as outlined in the dissemination and collaboration reports.

2.3.2.3 Roles of the partners

Partner eProsima has performed the porting of the basic client libraries, partner Bosch is assisting with the basic libraries and working on the embedded building blocks. Partner Łukasiewicz-PIAP provides benchmarking, crucial both for improvement and for promotion. Partners eProsima, Bosch currently organize the ROS 2 Embedded interactions. All partners contribute to the SIG's design papers.

2.3.4 micro-ROS brand

In its first year, the project has already established the name "micro-ROS" to stand for a deeply embedded version of ROS. While other activities exist, most notably Robotis' XEL network, these are far more limited in scope and tied to single companies. In contrast, "micro-ROS" has already become known as the community effort, due to the consortium's dissemination activities, the formation of a ROS Embedded WG, and our push for a joint effort that is in keeping with the spirit – and the code – of the ROS community.

This situation represents an opportunity to establish this name as a conduit for the interests embedded community as a whole, thus increasing Europe's influence on the overall ROS 2 eco-system.

To pursue this, the consortium will strive to further establish the "micro-ROS" name as something akin to a brand name, increasing its prominence and focus. The first step in this direction has been to distinguish "micro-ROS" from the name of the European project, to clearly mark it as something which is supposed to live on after the project. Such a vision of future sustainability is important to increase trust.

It is also already clear that to pursue this strategy, the wider community needs to be involved. The ROS community has already been engaged through the ROS 2 Embedded WG, but the wider embedded community is an important stakeholder as well.

2.3.4.1 Barriers and Risks

A barrier to pursue this strategy is that to target the embedded community more broadly, i.e. beyond the parts already present within the ROS community, would require additional resources. Moreover, in its current stage, the project results represent a different cultural approach than that typically followed by the embedded community. Therefore, there is a risk that addressing the community right now could have adverse effects that are difficult to counter afterwards. Arguably, this has already happened to some extent with ROS in general.

To address this, hard data, such as benchmarks, could be leveraged. Also, current pain points in the embedded community that micro-ROS could address would be important to find out. There is already some corresponding knowledge within the consortium, but it would need to be distilled further.

A further risk is that the overall ROS community will not accept the consortium's leadership in this regard. So far, this does not appear to be the case, but new players can always emerge. Moreover, due to the activity being funded as a fixed-term project, questions of sustainability have already arisen.

Therefore, it appears prudent to involve an organization which is perceived as having a long-term mandate and which is at the same neutral so as not to invite the competition. It should ideally be one in which the consortium has a strong representation.

2.3.4.2 Inputs from users

Input from parts of the target audience has already been sought and is continued to be sought within the ROS 2 Embedded WG. Bosch is also pursuing this internally, to gather inputs from its core embedded development business units. Similar input can likely be provided by all partners.

2.3.4.3 Roles of the partners

Each of the partners is using the "micro-ROS" name in its dissemination activities related to the project, and all of them have taken steps to publicize its activities, as outlined in the dissemination report. On behalf of the whole consortium, eProsima, Bosch and ALR are currently organizing the meetings of the ROS 2 Embedded WG. All partners have contributed to the WG first pull request, and continue to contribute to further documents. ALR has registered a trademark "micro-ROS" and all partners are currently engaged in discussing how to further handle the brand name.

2.4 Competition and SWOT analysis

Generally, we see three major embedded device classes, with characteristics as described in the following table. Naturally, some devices are in-between these, but they are much more rare.

	SBC	**Regular MCU**		**Tiny MCU**
Example	Raspberry Pi	STM32F4		Arduino
Hardware	X86, ARM Cortex-A	>= ARM Cortex-M4		<= ARM Cortex-M0
Resources	>256MB RAM, >1G Storage	>100kB RAM, >1MB Storage		~16 kB RAM, ~256K Storage
Communications	Ethernet, 802.11 WiFi	Serial, WPAN, Ethernet		Serial, WPAN
Operating System	Linux, QNX, etc.	RTOS (e.g., NuttX, FreeRTOS)		-
Middleware	DDS variant	XRCE-DDS		Custom
Framework	ROS 2	**Micro-ROS**	**Custom**	Custom
MW Abstraction	RMW	RMW	-	-
Client Library	RCLCPP	RCL	-	-
Execution Layer	RCLCPP/RCLPY/...	RCL + RCLCPP	-	-
Executors	Standard	Static, LET	-	-

Micro-ROS is intended for the “Regular MCU” case, whereas the classic “rosserial” approach from ROS 1 is intended primarily for the “Tiny MCU” case.

Regarding Micro-ROS, we are currently seeing two cases of adoption: In the first approach, the full Micro-ROS stack is adopted. In the second approach, only the XRCE-DDS middleware is adopted. This enables ROS 2 interoperability on the message exchange level, but lacks any further features, such as parameters, the lifecycle, services, etc.

It must be acknowledged that as of right now, the 2nd approach (XRCE-DDS only) is more common and has been used by (at least) Robotis, Auterion, and Renesas. The major reason for this is most likely that Micro-XRCE-DDS already enables partial ROS 2 interoperability and has been available for much longer (since early 2017) than then entire Micro-ROS stack.

Renesas is collaborating (as part of the Embedded Working Group) to upgrade to full Micro-ROS. For the two others, no such plans are currently known, though we are staying in contact.

At the previous deliverable time, the SWOT analysis was updated as follows:

- **Strengths:**
  - Cooperation with industry and SMEs
  - Experienced partners
  - ROS 2 compatibility (through a bridged device)
  - Big community
  - Based on standards (particularly including DDS-XRCE)
  - Good channels for dissemination and exploitation
  - Open source license
  - Captivating new concept/product
  - ROS 2 Concepts and API
- **Weaknesses:**
  - Lack of adoption and use of DDS in the deeply embedded world
  - The mixture of patterns: pub/sub and client/server
- **Opportunities:**
  - Emerging market
  - No big competitors
  - Digitising European Industry as flagship initiative of EU Digital Single Market Strategy
  - FIWARE involvement
  - Good platform for researchers
  - Novel development environment for deeply embedded devices based on containers
  - OEM players adopting micro-ROS
  - A strong positive response from selected ROS community members
- **Threats:**
  - Reduced number of developers
  - Slow adoption
  - Overall implementation is too heavy for certain microcontrollers (alternatives have been considered)
  - The tradeoff between capabilities/performance
  - Final performance unsatisfactory over wireless or serial mediums
  - Appropriate governance is critical for the sustainability of the project

The partners can already appreciate some changes. In contrast with the previously described competing initiatives, currently and according to the partners and the insight and reactions received from the community, the SWOT analysis looks as follows (text in **bold** indicates additions while ~~crossed-over~~ text, removal):

- **Strengths:**
  - Cooperation with industry and SMEs
  - Experienced partners
  - ROS 2 compatibility (through a bridged device)
  - Big community
  - Based on standards (particularly including DDS-XRCE)
  - Good channels for dissemination and exploitation

    - Open source license
    - Captivating new concept/product
    - ROS 2 Concepts and API
- **Weaknesses:**
    - Lack of adoption and use of DDS in the deeply embedded world
    - The mixture of patterns: pub/sub and client/server
    - **Scattered market regarding hardware (boards) and RTOs (FreeRTOS, Thephyr..)**
- **Opportunities:**
    - Emerging market
    - No big competitors
    - Digitising European Industry as flagship initiative of EU Digital Single Market Strategy
    - FIWARE involvement
    - Good platform for researchers
    - Novel development environment for deeply embedded devices based on containers
    - OEM players adopting micro-ROS
    - A strong positive response from selected ROS community members
- **Threats:**
    - Reduced number of developers
    - **Don't keep aligned with ROS 2 releases. "Fast" paced release schedule.**
    - **DDS taking over ROS 2 API.**
    - Slow adoption
    - Overall implementation is too heavy for certain microcontrollers (alternatives have been considered)
    - The tradeoff between capabilities/performance
    - Final performance unsatisfactory over wireless or serial mediums
    - Appropriate governance is critical for the sustainability of the project

2.5 Unique Selling Propositions (USPs)

micro-ROS offer a unique proposition in the areas of embedding ROS 2 on resource-constrained devices and get tiny computation devices as first-class participants of the ROS ecosystem. The project, pushed by experienced partners in the area of robotics, include all the necessary competences to release a worldwide technical trend. The partners are committed to driving results towards the interest of commercial entities and most, will themselves launch products based on micro-ROS. Moreover, the consortium members have relevant experience in Open Source and are committed to satisfying community needs for further growth of the project.

Thanks to the European leadership and strong presence in the area of microcontrollers, micro-ROS aims to become the de facto framework for deep embedded (microcontroller-based) robot application development.

2.6 Revision of Actions and Priorities regarding Communication and Dissemination Activities

In addition to the above-listed collaboration and standardization activities, the exploitation strategies also materialize in communication and dissemination activities.

Target communities and working groups. The following table provides a revised list of the communities identified as targets for raising awareness of the project results. For each of them, partners already involved in the community which will be responsible for raising such awareness are listed.

Target community	Partner(s) responsible for raising awareness
ROS, ROS 2 Embedded WG, ROS 2 TSC and Open Robotics Foundation	BOSCH, EPROS, Łukasiewicz-PIAP
OPC Foundation	BOSCH
FIWARE	FF, EPROS
Internet Industrial Consortium	FF
International Data Spaces Association	FF
OMG	EPROS
DroneCode.org	EPROS

The previous table was updated removing 1) HROS, 2) Advanced Robotics for Manufacturing Institute (ARM) and 3) ISO 299 as they are communities in which Acutronic was the unique Consortium representative involved.

Project-wide activities. The following table provides a revised list of communication and dissemination activities defined for the whole project consortium along with the current year achievements. In **bold** are marked new additions.

Communication and dissemination activity - Target Goal	Defined Actions	Target KPIs	Achieved KPIs
micro-ROS Website - Provide general information	Frequent updates of the micro-ROS website and Search Engine	micro-ROS website within the 5 first SERPs (Search Engine Results	micro-ROS website is the first page in SERPS.

	Optimization (SEO)	Pages)	Even the first 6 entries are micro-ROS related. (Google)
Publication of project results in relevant target community websites and forums - Gain visibility within target communities	Publication on ROS Community Forum	>5 posts/year	20 posts mentioning micro-ROS directly (rosdiscourse search "micro-ROS" hits)
Participation in technical conferences and workshops - Raise awareness on technical and scientific community, particularly the ROS community	Presence at ROSCon Presence at FIWARE Summit Presence at relevant ROS-Industrial conferences and workshops	>5/15/20 (year 1/year 2/year 3) technical presentations by end of first/second/third year of the project >125/375/500 attendees in total by the end of first/second/third year of the project >12/37/50 downloads from Slideshare by end of first/second/third year of the project	7/14 (cf. Appendix)
On-site demonstrations and presentations - Attract customers and raise awareness	Presentations and or demonstrations to target customers/users	50 proposed 35 responded 35 performed	3 public presentations
Scientific publications - Scientific dissemination	Publication to journals and magazines	> 10 publications	2 (cf. Appendix)
Presence at major trade fairs - Market awareness, Go-To market	Presence with dedicated space within FIWARE's or some partner's booth	>=2 large trade fairs (Hannover-Messe Industry Fair, some other)	1 - IoTSWC
Active presence on social networks - Raise awareness on Social Media	Regular posts through FIWARE channels	>3 posts/month (Twitter, LinkedIn, Facebook) 1 video/year on YouTube >10 average likes /share per post	The report on this KPI is available in D7.2

Featured blog posts - Social awareness	Blog posts or articles within the **micro-ROS website,** FIWARE website or other websites	> 10 posts/year > 1000 visits/year	10 posts with 225 visits (micro-ROS.github .io blog seccition & google analytics)
Production of marketing material - Promotion	Flyers, brochures, promotional material	1 flyer 1 brochure 1 poster 1 infographic	1 Brochure, 1 video produced, >1000 stickers
Press releases - Awareness of decision and policymakers	Official communications	>=2 / year	The report on this KPI is available in D7.2
One-to-one communication - Awareness of target audiences	Newsletters Mailings	Featured article every two FIWARE monthly newsletters >1 featured mailings/year	The report on this KPI is available in D7.2

There has been updates regarding H-ROS website not being a communication or dissemination channel anymore.

Partners dissemination plans. In the following revised lists of the individual communication and dissemination activities of each partner are provided. (text in **bold** indicates additions while ~~crossed-over~~ text, removal) .

EPROS:

Planned activities	**Implementation**
Presentation of the project on the Project and EPROS website, Press Release	● Hosted and maintained www.ofera.eu ● Added micro-ROS and Micro XRCE-DDS related news and releases into EPROS website: https://eprosima.com/index.php/company-all/news
Concept Demos to eProsima Customers	● Presented micro-ROS to spanish customers ● Presented micro-ROS to international partners: SONY, Auterion.

Promotion within ROS as ROS contributor and as ROS TSC member • micro-ROS Website inside ROS.org, as a module of ROS. • Presentations at the next ROS Conferences 2017-2020 [ROSCON] • Articles, Blog posts.	• Along with the rest of the partners, promote and maintain micro-ROS websites. www.micro-ROS.github.io • Post in rosdiscourse announcements regarding micro-ROS. • Presented micro-ROS together with BOSCH at ROSCon2019. • Booth in ROSCon2019 with a dedicated space to micro-ROS materials and community demos. • Participate in discussions on the ROS community regarding embedded WG and in real-time WG. • Update ROS 2 TSC with micro-ROS and embedded WG news. • Active presence in rosdiscourse and in micro-ROS slack. • ROS Developers Podcast participation.
Promotion within FIWARE as FIWARE Foundation Chapter leader for Robotics and Middleware (Presentations, Articles, Examples, Web content, etc) • Presentations and workshops at FIWARE summits. • micro-ROS demos using FIWARE stands in important fairs (IoT Congress, Hannover Messe, etc) • Web content for a new FIWARE website area devoted to robotics.	• micro-ROS status updates presented to FIWARE TSC. • Presented micro-ROS in FIWARE summit in Porto (May 2018) and Genoa (May 2019) • Prepared Crazyflie community demo and show-case it along with FIWARE and BOSCH in IoT Solutions World Congress. • Micro XRCE-DDS manual presence in FIWARE website.
Promotion within Dronecode.org (Presentations, Articles, Examples, Web content, etc)	• Made presentation to Auterion • Support Micro XRCE-DDS implementation used to bridge to ROS 2.
Presentations as a success case at OMG meetings.	• Proposed changes based on micro-ROS use cases.

Łukasiewicz-PIAP:

Planned activities	**Implementation**

Promotion within several robotic conferences and forums, including showcasing of demonstration platform.	• Presentation of demo box on RobMoSys - OFERA - ROSIN workshop in Luxembourg • ROS2 Embedded WG benchmarking tools presentation
Presentation of the micro-ROS benchmarking results at the ROS Conference (ROSCon), joint with EPROS.	Video of benchmarking result show-cased in EPROS booth. https://youtu.be/Ydc2RdT9w1k

BOSCH:

Planned activities	**Implementation**
Promotion at ROS-Industrial meetings/ conferences (Bosch is a full member of ROS-I EU)	• Presented micro-ROS at ROS-Industrial Conference 2018 • Presented micro-ROS at ROS-I Spring Workshop • Presented selected works from OFERA at ROS Meet-ups in Stuttgart, organized by ROS-I EU coordinator Fraunhofer IPA • Presented runtime tracing tools developed in OFERA at ROS-Industrial Conference 2019
Promotion within the ROS 2 community, in ROS 2 Technical Steering Committee (TSC) and at ROSCon	• Presented works from OFERA at ROSCon 2018 • Presented micro-ROS together with eProsima at ROSCon 2019 • Participating actively in discussions on ROS for embedded systems, real-time execution management, runtime configuration and other relevant topics from OFERA in respective working groups, in ROS 2 TSC, in ROS Discourse, and in ROS Answers forum.
Presentation at relevant non-robotic conferences from the Cyber-Physical-Systems and Real-Time Community (e.g., CPS-Week and DATE)	• Presented overview to micro-ROS and OFERA during full-day ROS Tutorial at CPS-Week 2018 in Porto • Provided invited talk on micro-ROS at ASD Workshop at DATE conference 2019 in Florence • Provided talk and presented a poster on execution management for ROS at ECRTS 2019 in Stuttgart
Presentation within Bosch in annual reports and on the Wiki of the internal	• Presenting works from micro-ROS and status of OFERA project three times per year in Bosch-internal research project on systems and software

project that will back the micro-ROS activities of Bosch	engineering for robotics lead by Ralph Lange ● Presented micro-ROS and OFERA project in various talks at Bosch Corporate Research and selected business units ● Maintaining internal Wiki on systems and software engineering for robotics with various pages works from micro-ROS

FF:

Planned activities	**Implementation**
FIWARE Summits, Sessions, workshops, hackathons, etc.	● The FIWARE summit now accounts for a dedicated session on robotics. ● micro-ROS was present in the robotics track within the FIWARE Summit in May (Genoa) ● micro-ROS was present in the robotics track within the FIWARE SUmmit in October (Berlin) ● A dedicated FIWARE's Working Group focused on robotics has started this year. The status of micro-ROS is reported in the meetings of this WG
Web content: Press Releases, Blog posts, new Robotic area, etc.	● New Robotics area within the FIWARE Catalogue [link] ● The Micro XRCE-DDS component has been added to this FIWARE Catalogue as an incubated enabler ● micro-ROS was presented as part of the FIWARE technology in the robotics webinar [link] ● micro-ROS and IoTSWC entries in the FIWARE's blog ● IoTSWC booth and micro-ROS promotional videos are available in the FIWARE's Youtube Channel
Global Fairs (Hannover Messe, IoT Congress, Mobile World Congress, etc)	● micro-ROS and OFERA project had a dedicated space at the FIWARE's booth in the IoT Solutions World Congress 2019 (Barcelona, Spain) ● Check the booth at the IoTSWC video [link] ● The micro-ROS promotional video was presented at the booth [link]

From the previous revision, all the promotion activities from ALR has been removed.

3 Individual Exploitation Plans

The individual exploitation plans of each partner of the OFERA project are presented in the following sections.

3.1 EPROS

eProsima will exploit the project innovations in several ways:

The platform will be used to increase eProsima presence in the Robotics market as a key ROS contributor, easing the ROS adoption, and new features will be added to eProsima main middleware products and released as OSS. eProsima will transfer the result of the projects to its current and future customer base with special emphasis in **the IoT** and the UAV areas, driving the adoption of micro-ROS in drones, continuing the ongoing work within Dronecode organization. As an OMG member, eProsima will bring the results of the project to this standardization bodies incorporating the lessons learned to ongoing standards such as XRCE-DDS, and proposing new specifications.

Measures/KPIs:

- 3+ Press Releases.
- **3 Improved Products (OSS): eProsima Micro XRCE-DDS (Additional features), SOSS Core and SOSS-FIWARE system handlers (FIWARE Orion Context broker Interoperability with micro-ROS).**
- Improved FIWARE GEs (OSS): Micro XRCE-DDS will be incorporated as an Incubated GE, SOSS will be promoted.
- XRCE-DDS OMG Standard contributions.

In bold it is marked the main change regarding the original strategy. This change is derived from a technology change which ends up with the creation of SOSS. SOSS is the replacement for FIROS2 and Routing Services for RTPS. In this new product, the functionalities from FIROS2 and Routing services for RTPS are incorporated in SOSS, with SOSS Core allowing the creation of new connection plugins such as SOSS-FIWARE. eProsima will benefit from the Improvement off SOSS Core and SOSS plugins required for micro-ROS interoperability with other systems as for example FIWARE.

Apart from that major change, a naming update was done changing micro RTPS for Micro XRCE-DDS.

outcome 1:

Last years proposed changes and improvements to the XRCE-DDS standard have been accepted and included in the new revision. This year new changes are on the way to be proposed and included in the standard. Also this has increased the quality of EPROS' XRCE-DDS open-source implementation Micro XRCE-DDS.

outcome 2:

Micro XRCE-DDS technology, has been contributed to FIWARE as Incubated FIWARE GE to the collection of enablers focused on interfacing with IoT devices, robotics and 3rd party systems. See D7.5_Annual_report_on_collaboration_Y2 for more details.

outcome 3:

SOSS - FIWARE system handler. SOSS is a framework to communicate multiple systems using a common standard representation. One of these systems is the new FIWARE System Handler which allows a FIWARE context broker to communicate with any other system. Appealing to micro-ROS, are the connections to ROS 2 and with micro-ROS, allowing to communicate micro-ROS with FIWARE Context broker.

3.2 BOSCH

Bosch has a long history with ROS. As one of the eleven recipients of a PR2 robot in the PR2 Beta Program by Willow Garage,[1] researchers at the Bosch Research and Technology Center in California worked with ROS and contributed to ROS from the early beginnings.

Today, ROS is used in a number of research and advance development projects at Bosch, from component development to robotics and autonomous driving. The first internal product based on ROS has been the Autobod,[2] an autonomous transport platform for the shop floor, presented to the public in 2016. Recently, the first external product based on ROS has been launched: A Development Starter Kit for Automation (DESKA) by the Bosch Engineering GmbH[3].

General exploitation goals regarding ROS

This open-source activity is exploited to promote Bosch as a modern company active in robotics, acquire talented personnel, and, crucially, by providing building blocks for the community, we increase the quality of freely available components for future product development.

Previous examples of such contributions include

- the zero-copy middleware Iceoryx with corresponding ROS 2 middleware adapter (https://projects.eclipse.org/proposals/eclipse-iceoryx, https://github.com/ros2/rmw_iceoryx),
- hooks in the ROS core layers for tracing with the Linux Trace Toolkit NG (https://github.com/boschresearch/ros1_tracetools),
- Gazebo plugins and tools for simulating unmanned underwater vehicles (https://github.com/uuvsimulator),
- a scripting library for procedural scene generation for Gazebo (https://github.com/boschresearch/pcg_gazebo_pkgs/), and
- an adapter for integrating Functional Mock-up Units according to the FMI Standard with ROS (https://github.com/boschresearch/fmi_adapter, -_ros2).

[1] https://spectrum.ieee.org/automaton/robotics/robotics-software/the-origin-story-of-ros-the-linux-of-robotics
[2] https://www.produktion.de/trends-innovationen/bosch-entwickelt-autobod-fuer-die-intralogistik-212.html (in German)

[3] https://developer.bosch.com/web/deska/

All of these have been taken up by the community with great interest and lead to greatly increased prominence of Bosch in the robotics domain.

Exploitation goals regarding micro-ROS
The primary goal for micro-ROS has been to reduce the barrier in transfer of software and data between advance development/research and series development. Naturally, the specifics of this depend on the concrete product and business unit. *To date, the most relevant and concrete exploitation activity has already been described in the Use-Case Deliverable D6.5.*

Beyond this, we have more far-reaching exploitation activities ongoing. These will be detailed with respect to the concrete exploitable outcomes.

Outcome 1: The RTOS-based micro-ROS stack. Within Bosch Corporate Research, several other studies have already used Micro-ROS for integrating microcontroller-based prototypes within the ROS ecosystem, particularly for exploration of new sensors, remote control of small robots, data acquisition and similar applications. We are also contributing micro-ROS to a Bosch-wide microcontroller development kit.

Outcome 2: Micro-ROS client library technologies. The modular client library of micro-ROS comes with several technologies that can be exploited independently of the underlying middleware and operating system. On the part of Bosch Corporate Research, we aim at bringing these technologies into relevant business unit projects as reusable software assets and tools:

1. *System Modes:* This is a very generic concept and deemed to be relevant for most robotics systems. The present implementation is even largely independent of ROS but assumes some basic runtime component lifecycle only, which can be found in many component frameworks. The system modes concept reduces the complexity in robotics deliberation significantly and allows the developer of the deliberation layer of a robotic system to focus on the overall platform instead of the many individual software components. On the part of Bosch Corporate Research, the exploitation of this technology is fostered by internal trainings and consulting. In 2019, a first transfer to a business unit project has been prepared. A second will follow in 2020. In addition, this technology is exploited in the Integrated Technical Project (ITP) Metacontrol for ROS 2 (MROS) in the second open call of the EU project RobMoSys, cf. Deliverable D7.5.

2. *Real-Time Execution Management:* The execution management concept developed for ROS 2 largely differs from the concept in ROS 1. On the one hand, it comes with much more flexibility and particularly allows implementing own Executors. On the other hand, the default Executor does not provide any deterministic processing guarantees – not even the known FIFO processing known from ROS 1. We consider this as a hurdle in the adoption of ROS 2. By the works on predictable scheduling and execution in Task 4.2, this issue is resolved in close collaboration with the ROS community – in particular in the new Real-Time Working Group (cf. Deliverable D7.5). By bringing the necessary changes and extensions into the ROS 2 mainline repositories, they are also transferred to all Bosch-internal projects that use ROS 2 or micro-ROS.

3. *Tracing:* In a new task (as decided in the project review on 10 September 2019 in Luxembourg), mechanisms in the ROS 2 core layers for runtime performance tracing have been developed and contributed the ROS 2 mainline repositories (integrated since the November 2019 “Eloquent” release). These mechanisms enable detailed runtime analysis of ROS 2 and micro-ROS-based

systems and the identification of performance, synchronization, and scheduling issues at very little development efforts. In the past, developers typically implemented own specific solutions for each algorithm or software asset to analyze. On the part of Corporate Research, the use of this technology in relevant applications and systems projects will be fostered by internal trainings, consulting and collaboration with the ROS 2 Tool Working Group.

3.3 Łukasiewicz-PIAP

Łukasiewicz-PIAP has a lot in common with ROS and ROS2, mainly due to its practical use. Łukasiewicz-PIAP uses it in many research projects. In addition, we have ROS2 benchmarking experience related to participation in the R5COP project.

Micro-ROS will be used in subsequent projects or modifications to existing ones - generally wherever microcontrollers can be used. One of the products we intend to use micro-ROS results is our own line of mobile robot accessories. We aim to improve power consumption and faster development cycle of new products in that line.

In Łukasiewicz-PIAP we intend to use experience gained and software developed in micro-ROS to help support both our internal product development and external industrial customers.

Specific areas will include:

- increase development speed and end quality of low power energy modules based
- ease transfer of research results to production, thanks to better easier transfer of components developed in ROS environment
- improve quality of communication systems in low power environment,
- provide customers with quantitative benchmarks of solutions developed thanks to benchmarking solutions.

Specifically we want to continue to develop micro-ROS benchmarking solutions. It is offered as open source and we intend to support it as part of our offering for industry partners. This will be provided in form of source code containing instrumentation for conducting benchmarks on open source license as well as papers presenting the results. Additionally, benchmarking tools will be developed and supported in cooperation with the ROS community.

Measures/KPIs:

- Papers in peer reviewed journals: 2+
- Extension of open source project https://github.com/piappl/ros2_benchmarking
- An open source package of benchmarking tools for microROS developers and users

3.4 FIWARE

FIWARE aims at building an open sustainable ecosystem around public, royalty-free and implementation-driven software platform standards that will ease the development of new Smart Applications in multiple sectors. The FIWARE Foundation (FF) serves this purpose and it is evident that robotics will play a key role in smart applications of the future. Thus, in general terms, the main reason why FIWARE is participating in this project is to encourage focused activities and improve its positioning within this sector.

From this perspective, the FF understands that the micro-ROS project will be instrumental in helping that the FIWARE and ROS communities meet each other. The uses cases developed under the micro-ROS project will showcase how micro-ROS based robots can interact with context information to implement a smart behaviour, demonstrating the complementarities between ROS/micro-ROS and FIWARE de-facto standards. The ultimate goal is to convince developers that FIWARE is their open source platform of choice when incorporating management and processing of context information (coming from IoT sensor networks or a diverse number of sources) in robotics solutions.

In this line, the project begins to have results and the next year is very promising from the FIWARE perspective. For instance, micro-ROS activities are increasing the FIWARE's presence at relevant robotics events with meaningful activities and use cases (e.g., micro-ROS paves the way to the adoption of FIWARE in industrial settings). The synergy and interoperability between FIWARE, ROS and micro-ROS technology is attracting the interest of ROS developers and this is leading to the generation of meaningful content regarding robotics, which stimulates the growth of the FIWARE ecosystem, the adoption of FIWARE technologies and the number of potential members that have an interest in becoming part of the FIWARE community.

Last but not least, the first contribution of micro-ROS results to the FIWARE Catalogue has been materialized this year, Micro XRCE-DDS has been contributed to the FIWARE Catalogue, it is a FIWARE incubated enabler, its status is reported at the level of the FIWARE's Technical Steering Committee and is one of the key technologies present in the FIWARE's technical roadmap (FIWARE Robotics WG). Moreover, this increased activity in the field of robotics is also reflected in the presence of the specific robotics session that has been established at the FIWARE Global Summit events. In the coming year, the development of the FIWARE joint use case (T6.5) will start and will be key to strengthen and grow all these synergies between FIWARE and robotic applications by the hand of micro-ROS.

Appendix 1: Scientific Publications

List of all scientific publications (in reverse chronological order) related to micro-ROS as input for the corresponding achieved KPI in Section 3.6

1. Daniel Casini, Tobias Blass, Ingo Lütkebohle, and Björn B. Brandenburg: "Response-Time Analysis of ROS 2 Processing Chains under Reservation-Based Scheduling." *Proceedings of 31st Euromicro Conference on Real-Time Systems (ECRTS 2019), Stuttgart, Germany, July 2019.*

2. Irati Zamalloa, Iñigo Muguruza, Alejandro Hernández, Risto Kojcev, Víctor Mayoral: "An information model for modular robots: the Hardware Robot Information Model (HRIM)." *CoRR arXiv:1802.01459, Feb 2018.*

Appendix 2: Technical Presentations

List of all technical presentations (in reverse chronological order) related to micro-ROS as input for the corresponding achieved KPI in Section 3.6

#	Date	Title	Location	Presenter(s)
2019				
1	December, 24th	ROS in micro controllers using u-ROS	ROS Developers Podcast	Borja Outerelo Gamarra
2	November 11th	ROS 2 Tracing: Performance Analysis and Execution Monitoring	ROS-Industrial Europe Conference, Stuttgart, Germany	Ingo Lütkebohle
3	November 2nd	micro-ROS: ROS 2 on microcontrollers	ROSCon 2019, Macau, China	Ingo Lütkebohle Borja Outerelo Gamarra
4	October 31st	Execution in ROS 2 - Determinism (or lack thereof), performance, and the way forward.	Real-Time Workshop at ROSCon 2019, Macau China	Ingo Lütkebohle
5	October 24th	Applying Context Data Principles to Robots	FIWARE Summit Berlin	Francisco Melendez
6	October 24th	Building Interfaces with ROS2-based Robotics Systems	FIWARE Summit Berlin	Francisco Melendez
7	September 23th	Micro-ROS - benchmarking	ROS2 Embedded WG #5	Tomasz Kołcon
8	July 10th	Practical and Easy to Use Real-Time Execution Mechanisms for ROS	31st Euromicro Conference on Real-Time	Ralph Lange

			Systems (ECRTS), Stuttgart, Germany	
9	July 10th	Response-Time Analysis of ROS 2 Processing Chains under Reservation-Based Scheduling	ibd	Tobias Blass
10	May 22th	FIWARE Robotics: ROS2 & micro-ROS	FIWARE Summit Genoa	Jaime Martin-Losa
11	May 7th	Micro-ROS	ROS Industrial Spring Workshop, Stuttgart, Germany	Ingo Lütkebohle
12	May 7th	System Modes and Execution Management	ROS Industrial Spring Workshop, Stuttgart, Germany	Ralph Lange
13	March 29th	Bringing the Next Generation Robot Operating System on Deeply Embedded Autonomous Platforms	Workshop on Autonomous Systems Design (ASD) at the DATE conference, Florence Italy	Ralph Lange
14	March 22th	OFERA - Open Framework for Embedded Robot Applications	European Robotics Forum TG Software & System Engineering Meeting	Ingo Lütkebohle Borja Outerelo Gamarra
2018				
15	December 12	ROS on Embedded Devices - Recent Developments	ROS Industrial Europe Conference 2018, Stuttgart, Germany	Ingo Lütkebohle
16	December 12	System Integration and Modularity in Robotics using ROS	ROS Industrial Europe Conference 2018, Stuttgart, Germany	Victor Mayoral Vilches
17	November 28th	micro-ROS	FIWARE Summit Malaga	Jaime Martin-Losa
18	November 13th	micro-ROS	ROS Developers Podcast	Ralph Lange
19	September 29th	Callback-group-level Executor	ROSCon 2018, Madrid, Spain	Ralph Lange

20	May 9th	micro-ROS introduction	FIWARE Summit Porto	Jaime Martin-Losa
21	April 10th	Fundamentals of the Robot Operating System (ROS)	CPS Week, Porto Portugal	Ralph Lange