



D2.1: ECOSYSTEM DEFINITION AND REQUIREMENTS

ANNEX 5: CLUSTER 1 DEFINITION AND REQUIREMENTS

This annex covers Cluster 1 - Computing Platform Integration for Mining, exploring how COP-PILOT can address the unique safety, security, and infrastructure challenges of the mining environment. It demonstrates how industry partners can leverage alternative digital solutions to overcome scalability, interoperability, and deployment barriers within complex mining ecosystems.

D2.1: Ecosystem definition and requirements

Work package	WP Number 2
Task	Task Number T2.1, T2.2, T2.3
Due date	14/05/2026
Submission date	12/05/2026
Deliverable lead	RedZinc
Version	1.1
Authors	LULEA UNIVERSITY OF TECHNOLOGY (LTU) RISE RESEARCH INSTITUTES OF SWEDEN AB (RISE) HOSCH FÖRDERTECHNIK RECKLINGHAUSEN GmbH (HOSCH) THINGWAVE AB (TAB) PREEDGE AB (PAB) ROCKSIGMA (ROC) LTU BUSINESS AB (LTUB)
Reviewers	NETCOMPANY-INTRASOFT SA (INTRA) GIOUMPITEK MELETI SCHEDIASMOS YLOPOIISI KAI POLISI ERGON PLIROFORIKIS ETAIREIA PERIORISMENIS EFTHYNIS (UBI) NOVA TELECOMMUNICATIONS & MEDIA SINGLE MEMBER SA (NOVA) ORGANISMOS TILEPIKOINONION TIS ELLADOS OTE AE (OTE)
Abstract	<p>The COP-PILOT platform is an open collaborative system for managing services across IoT, edge and core computing environments. COP-PILOT is built to enable secure and intelligent operations that connect diverse sectors.</p> <p>This document brings together an ecosystem of technical blueprints and services models across 5 main domains to support the development of these infrastructures. With a focus on seamless cross domain integration, it lays the foundation for private edge deployments and digital ecosystems across Europe.</p> <p>This deliverable sets the direction for building a platform that drives smarter, more secure, and collaborative digital transformations across multiple industries.</p>
Keywords	IoT Interoperability. Edge Computing. 5G Connectivity, System Intelligence, Automation, Private Edge Systems, Large Scale. Mining, Ports and Logistics, Energy, Agriculture, Viticulture,

Document Revision History

Version	Date	Description of change	List of contributors(s)
V0.1a	3.7.2025	Table of Contents	Donal Morris, RedZinc
V0.1b	4.7.2025	Table of Contents PMT Review	PMT
V0.1c	10.7.2025	Table of Contents WP2 Review	WP2
V0.2	24.9.2025	Working Draft	WP2
V0.3	15.10.2025	Working Draft	WP2
V0.4	15.10.2025	Working Draft	WP2
V0.5	20.10.2025	Working Draft	WP2
V0.6	15.10.2025	Working Draft	WP2
V0.7	24.10.2025	Review Document	WP2
V0.8	25.10.2025	Quality Control Document	WP2
V0.9	25.10.2025	Quality Control Document	RedZinc Team
V1.0	31.10.2025	Final Version for Submission	RedZinc Team NetCompany
V1.0	22.1.2025	Final Version for Submission with info graphics	RedZinc Team NetCompany
V1.0	12.05.2026	Sections made into a separate annexes	RedZinc Team NetCompany

Grant Agreement No: 101189819 | **Topic:** HORIZON-CL4-2024-DATA-01-03
Call: HORIZON-CL4-2024-DATA-01 | **Type of action:** HORIZON-IA

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Co-funded by
the European Union

Project funded by



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Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
**State Secretariat for Education,
Research and Innovation SERI**

Co-funded by the European Union (COP-PILOT, 101189819). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them. This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

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Project Co-funded by the European Commission in the Horizon Europe Programme		
Nature of the deliverable:	R	
Dissemination Level		
PU	Public, fully open, e.g. web (Deliverables flagged as public will be automatically published in CORDIS project's page)	X
SEN	Sensitive, limited under the conditions of the Grant Agreement	
Classified R-UE/ EU-R	<i>EU RESTRICTED under the Commission Decision No2015/ 444</i>	
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* R: Document, report (excluding the periodic and final reports)

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

DATA: Data sets, microdata, etc.

DMP: Data management plan

ETHICS: Deliverables related to ethics issues.

SECURITY: Deliverables related to security issues

OTHER: Software, technical diagram, algorithms, models, etc.

INTRODUCTION TO CLUSTER 1

Cluster 1 will work on computing platform integration for mining operators. Modern IT systems and computing platforms can enable advanced software applications, which can improve safety, efficiency and profitability of mining operation. However, a mine is a challenging environment, where data access and security are very restricted, as even the smallest disturbance to the operation can have devastating impact on the operation, both from a safety and business point of view.

The industry partners of Cluster 1, (RockSigma, Thingwave, Predge and Hosch) all bring valuable services, but are all challenged by scalability and deployment due to the complex digital infrastructure reality in the mining environment. The Cluster aims to demonstrate alternative digital solutions to overcome today's scaling, interoperability and deployment challenges.

ANNEX 3.A: UC - 1.1 IOT MINING SEISMICS

Description

This use-case is centered around large-scale micro seismic sensing, data collection and processing for underground mining.

Underground mining operations, blasting and material extraction, cause induced seismicity. As drives are developed and as ore is being mined out, stress conditions change, inducing seismic events. While this is normal and expected, the potential for large and damaging seismic events must be carefully managed. Additionally, mines can learn a lot about the conditions of the rock mass by analysing seismicity.

The use-case is designed to achieve multi-technology and multi-vendor micro seismic sensing, in a unified processing solution and workflow to augment rock mass understanding for mines. This involves sensing, data acquisition, data transfer, processing and visualization in the context of a mine operator. Non-functional aspects of the use-case include support for flexible service deployment and data access options regarding the processing and visualization software to accommodate mine operator requirements and constraints regarding data jurisdictions and compute infrastructure.

RockSigma is currently developing its BEMIS solution for seismic processing. BEMIS will be used for use case 1.1, and extended with COP-PILOT features to improve data access for multi-vendor and multi-technology sensor networks as well as to enable edge-to-cloud service deployment and orchestration.

Short Description

This use case focuses on large-scale microseismic monitoring for underground mining to manage induced seismicity and improve rock mass understanding. It enables multi-technology, multi-vendor sensing through a unified processing and visualization workflow, with flexible deployment and data access options to meet mine operators' infrastructure and data governance needs.

Complete Description

RockSigma is currently developing its BEMIS solution for seismic processing. BEMIS implements novel algorithms for seismic data processing based on a unique data-driven and self-calibrating mine resource model, implemented in containerised microservices software. BEMIS will be used for use case 1.1, and extended with COP-PILOT features to improve data access for multi-vendor and multi-technology sensor networks as well as to enable edge-to-cloud service deployment and orchestration.

Enabling multi-technology and multi-vendor micro seismic sensing is a novel concept in micro seismic monitoring for underground mines, a market niche that is dominated by vertically integrated single-vendor solutions where data is siloed and deployment is restricted to on-prem physical or virtual servers.

This use case will showcase how multi-vendor and multi-technology solutions can create value for the mining industry and foster innovation in a solution space that has been stagnant for the past decades. This is part of the overall digitalization of mines, where demand for analysis of consolidated data from multiple heterogeneous sources is increasing.

With multi-technology support, mine operators are free to design sensing arrays using the most suitable technology for each situation and have all the collected data unified in a common processing solution and seismic catalogue. More specifically, this allows the combination of traditional sensors such as geophones with optical fibers and Distributed Acoustic Sensing (DAS).

Today, it is not uncommon for a mine to have multiple separate and completely siloed geotechnical monitoring systems and vendors (e.g., micro seismic, strain, convergence, subsidence and more). While attempts have been made, there are very few successful examples of cross-system data integration.

In addition to the functional benefit of consolidating multi-vendor sensor data, the use-case also involves concepts of edge-to-cloud service deployment and orchestration and generalized data access. The typical mine operator environment does not allow for sensor data to escape the premises, nor does it employ modern service-oriented architectures and generalized data access methods. Within this use-case, we aim to demonstrate how COP-PILOT concepts, if implemented and made available in the mine operator context, will facilitate application development and foster innovation by breaking silos and enabling flexible service deployment and orchestration across the edge-to-cloud continuum (within one corporate entity).

This is a radical improvement over current best practices which involve vendor specific integrations, transferring data manually, sometimes using physical hard drives, and very rigid software/service deployment options.

Main actors and roles

Table 5.1 UC1.1 Main Actors and Roles.

Actor name	Actor type	Actor Description and Role
Rock Mechanics / Geotechnical Engineer(s)	End-user	Responsible for monitoring and interpretation of seismicity, reacting to anomalies in near real-time (e.g., activating exclusion zones or evacuation) and providing ground support designs based on the rock mass response to mining. Uses data output and visualisation tools to gain insights.
Seismic Specialist Mine Planner	End-user	Responsible for interpreting seismic data for long-term planning purposes, providing mine design inputs based on longer term forecasts. Uses data output and visualization tools, combined with specialist tools such as numerical modelling, to gain insights and compile management reports.
Production Engineer	End-user	Responsible for daily production operations, balancing production targets with safety concerns. Correlates seismic and production data to achieve targets safely.

Seismic Technician	End-user	Responsible for day-to-day operation and maintenance of the seismic system, with uptime KPI's. Uses secondary data outputs and tools to gain insights regarding the operating state of the seismic system.
Control room operator	End-user	Monitors seismicity in a 24/7 control room setting and invokes specialists or rock mechanics engineers as needed.
Mine Manager	Management	Responsible for people, processes and production in the mine. Takes periodic seismic reports as part of the overall management review process.
IT/Cybersecurity engineer	Engineer/Operator	Oversees the deployment of application software, enforces data policies and provides (managed) hosting services.

Ambition, Motivation and Objectives

There are huge financial incentives for investing in monitoring systems to be able to detect, analyze, model, forecast and prevent seismicity. For example, the Swedish mine operator LKAB experienced a large seismic event in 2020, causing them to close an area of the mine and leave ore corresponding to three years production, worth billions of Euros in revenues. There are similar examples all around the world, ranging from relatively short disruptions of production in limited areas to several months of mine-wide production stops.

Seismic monitoring has been in place in underground mines for decades, using mainly geophone sensors to observe seismicity. As mines go deeper and experience increased rates of seismicity, the need for improved sensing technology as well as data processing solutions is growing.

Additionally, there is a growing demand for solutions that consolidate data from multiple geotechnical monitoring systems. Mines commonly have five or more separate monitoring systems in the geotechnical domain (seismicity being one). Combining data from these different monitoring systems into sophisticated analysis and decision support solutions is a large area of investment.

From an IoT and digital capabilities point of view (vs. the functional domain which is rock mass understanding) the challenges addressed are:

- Scalability and the management of large data volumes. Ability to scale the solution up/down to meet local mine requirements.
- Cost/time of processing and the need to be able to distribute jobs across a continuum from the far IoT edge to the cloud (whether that exists in on-prem resources, a private cloud or in the public cloud).

- Jurisdiction requirements, such as “our data stays here”. Flexible support for a multitude of deployment scenarios.
- Platform independence as it relates to the sophistication of the target hosting environment, which ranges from very low to high, depending on the individual mine. The availability of on-prem managed services varies from nothing to fully managed Kubernetes.
- Job design and delivery model variations. In some cases, requirements match those of HPC style workloads with high peak loads for batch projects and model training, while in others the requirements are to support continuous service workloads for “as a service” delivery.
- Multi-vendor and multi-technology solutions require open interfaces and interoperability.

UC Mapping with Project Objectives:

Obj 1.1: Enabling edge-to-cloud computing continuum within each company.

This use case demonstrates a self-adaptive edge-to-cloud continuum that supports dynamic workload orchestration, cloud bursting, and autoscaling. The goal is to ensure SLA compliance while optimising performance and cost efficiency within each participating organisation.

Obj 1.2: Enabling edge-to-cloud computing continuum between participating companies and their joint customer.

This use case focuses on Rock Sigma’s real-time seismic monitoring solution, enabling secure and efficient data exchange across company boundaries. Using ColonyOS, it integrates distributed sensing and processing pipelines across edge and cloud infrastructures to support low-latency seismic event detection and collaborative decision-making.

Obj 1.3: Validation of edge-to-cloud compute continuum at TRL6.

This use case develops an emulated mining environment to replicate operational and geological conditions for scalable testing. Resource orchestration and workload deployment are managed through an abstraction mechanism that can be integrated with, for example, the COP-PILOT architecture, to validate automation, scalability, and system reliability under near-real conditions.

UC Mapping with Project Innovations

The RockSigma use case contributes to several COP-PILOT innovation areas as follows:

IA#1 – Application-aware IoT device and data management across collaborative domains:

Use case 1.1 will focus on expanding the currently vendor specific micro seismic sensor data space present in the mining industry. It will unify data management by centralising processing of several sensor vendors in one single system

IA#2 – Secure and programmable cross-domain resource and data service exposure:

Implements controlled access to distributed compute and data services across partners through COP-PILOT’s orchestration framework and ColonyOS’s zero-trust execution model.

IA#3 – Ultra-scalable end-to-end service and infrastructure orchestration:

Uses COP-PILOT to provision and scale compute resources automatically within an emulated mining environment, validating orchestration and automation capabilities under realistic workloads.

IA#4 – Intelligent and automation tools for high-TRL vertical service onboarding and preservation:

Not applicable.

IA#5 – Promotion of innovative cross-sector vertical services through large-scale pilots:

By focusing on the mining industry, the use-case is promoting the adoption of COP-PILOT concepts in an industry that is generally far less sophisticated in terms of data sharing and application deployment, hosting and orchestration.

Rationale for the Use of the COP-PILOT Platform

The COP-PILOT platform will be used to provision and manage compute resources across distributed test environments. Its orchestration framework enables automatic allocation and scaling of resources needed for the emulated mining environment. This allows experiments to reproduce realistic workloads and network conditions without manual setup.

Challenges addressed

The following challenges are addressed in this use case:

1. Progress in the application and service implementation
2. Deployment and orchestration within the mining industry, to increase the pace of digitalization towards the need for seismic monitoring to extend in scope and scale.
3. To include multiple sensor technologies and increased density of sensors
4. Accessibility of data for consolidated and unified data analysis

Expected outcomes

This use-case contributes to the following expected outcomes.

1. Integrated edge2cloud compute continuum based on Eclipse Arrowhead and ColonyOS.
2. Demonstration of business integration across participating companies supported by edge HPC.
3. Edge2cloud continuum security.

Key pain points

Heterogeneous environments: Managing applications across cloud, and edge requires different tools, models, and operational practices.

Manual orchestration: Failures, retries, and recovery are handled manually, increasing operational risk and effort.

Fragile workflows: Complex, multi-step pipelines break easily when any component fails or changes.

Scaling complexity: Adding or reconfiguring clusters demands deep technical expertise and significant manual setup.

Operational overhead: Debugging distributed systems and ensuring resilience across diverse infrastructures remains costly and time-consuming.

Data access and security restrictions: Mine operators face strict network segmentation and access controls that limit connectivity between operational systems, edge devices, and cloud resources, complicating remote management and monitoring.

UC Diagrams

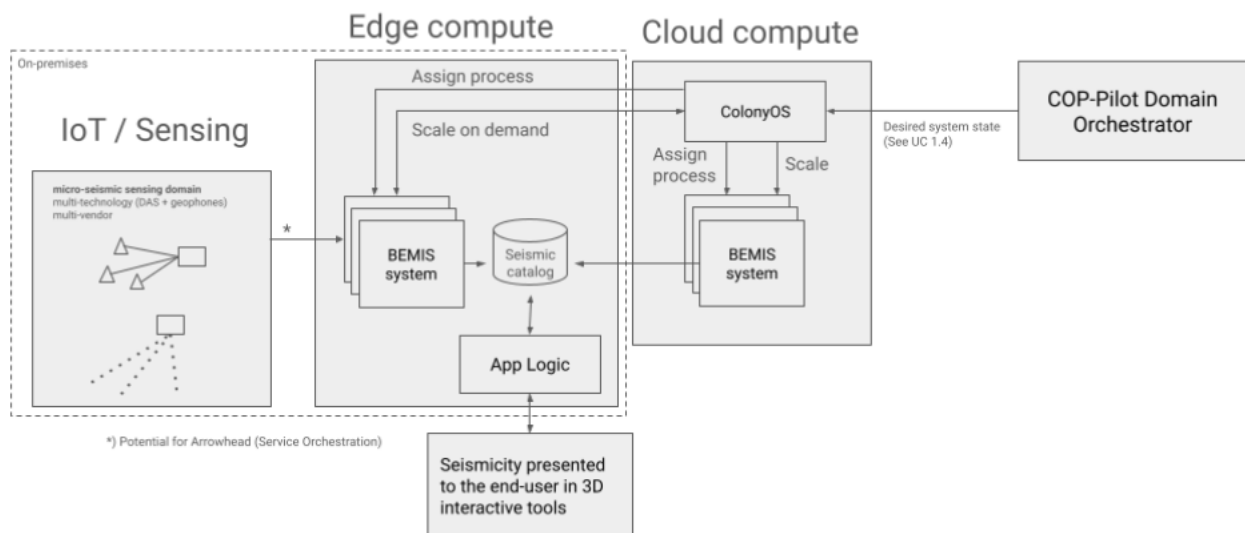


Figure 5.1: Uce case overview diagram

The figure shows a high-level functional architecture of the target solution. In the IoT/Sensing-domain (left), there are several types of sensor technologies, with different interfaces and provided by different vendors.

The computational domain (middle) consists of two deployments containing several functional blocks. Software both on-premises (edge) and on the cloud collaborate to provide a stable processing environment. The main deployment orchestrator component is ColonyOS which provides

scaling criteria based on current metrics and the desired system state, it also acts as a scheduler for the RockSigma BEMIS Compute Engine.

The seismic processing and the seismic catalogue, are implemented using the existing RockSigma BEMIS products. The App Logic component is a novel piece of software that does the coordination of micro-seismic data to provide higher level insights to mine operators.

The presentation domain (bottom) consists of a front-end application where the micro-seismic data is presented to the user.

In the sensing domain, there are multiple IoT vendors and technologies and a large number of sensors (approximately 300 geophones alone in a large mine), making it a strong candidate for service oriented IoT solutions. In some cases, especially where Distributed Acoustic Sensing (DAS) is involved, there will be very high data rates generated by the sensor networks, why far edge processing is an attractive approach. The Processing/Backend components come with very demanding requirements on scalability, availability, compute and memory and deployment flexibility. This results in cases where the hardware on the edge is not enough, which is where an Edge2Cloud solution is optimal.

Requirements

Functional requirements

Table 5.2 Use Case functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
FR1	Seismic Sensors	Must	Provide trigger-based, sliced data on micro-seismic events
FR2	Data visualization	Must	Show both historical and near-live data of induced seismic events within the mine
FR3	System	Should	Enable automated provisioning of compute resources through COP-PILOT integration APIs where technically feasible
FR4	System node(s)	Should	Strive to process and forward event data with latency close to {50ms} under nominal condition
FR5	Communication link(s)	Should	Provide reliable data transfer with uptime targeted at approximately {99.9%}, subject to environmental factors

Non-functional requirements

Table 5.3 Use Case non-functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
NFR1	IoT/Sensor Time sync	Should	Aim to achieve time sync accuracy of around {0.1ms, corresponding approximately to 5m spatial precision}
NFR2	Availability	Should	be able to handle {>99.9%} of incoming requests.
NFR3	Resilience and recovery from failure	Should	One, multiple or all system components should be able to go down without a large impact on the processing of seismic events.
NFR4	Sustained data rate	Must	The system should be able to handle sustained data rates of up to {50 seismograms per second} whilst keeping active cloud resources at a minimum.
NFR5	Peak load	Must	The system should be able to handle large bursts of {>5k triggered seismograms at once}.
NFR7	Number of sensors	Must	The system must be able to handle {>5k sensors (or channels)}
NFR8	Processing delay	Should	The system should maintain near-real-time processing. An event should be expected to be processed within {15m} of its trigger at most.

Business Requirements

1. Sustainability business requirements

Table 5.4 Use Case sustainability requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
SR1	Mine operator, extending the 'life of mine'.	Should	Improved seismic monitoring enables deeper excavations and a longer mine lifecycle, which in turn means a reduced environmental footprint per unit of output over time	Ability to mine deeper - Qualitative assessment through interviews

2. Societal business requirements

Table 5.5 Use Case societal requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
SC1	Underground workers, improved safety	Should	Improve underground worker safety by better understanding of seismic events and the rock mass response to mining	Reduced number of safety incidents caused by seismic events - Qualitative assessment through interviews
SC2	Data privacy compliance	Must	Ensure that any handled data is subject to mining companies data restriction demands	Any compliance audits passed successfully
SC3	Mine operators and nearby communities, better communication regarding seismic events and impacts	Should	With a stronger basic capability to process seismic data, mine operators can improve how they forecast and communicate regarding seismic events and how they impact nearby communities	Reduced number of incidents and/or complaints from nearby communities – Qualitative assessment through interviews

3. Market business requirements

Table 5.6 Use Case market(business) requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
BR1	Mine operator, improved productivity	Should	Improved seismic data processing leads to a better understanding of the rockmass response to mining, which enables production to be optimised through reduced incident related production disruptions.	Fewer seismic incident related production disruptions - Qualitative assessment through interviews
BR2	Application developers, need support for	Should	Adopt a framework that allows for flexibility and speed in the design of where in the compute	Distributed compute enabled (Y/N) - the value can be assessed through future interviews

	distributed compute flexibility		continuum that computational work is assigned, to meet the unique needs of each customer	
BR3	Application developers, need support for processing power scalability	Should	Adopt a microservice-based architecture that allows for upscaling to arbitrary numbers of CPU which allows for processing of larger amounts of data when needed	CPU scalability enabled (Y/N) - the value can be assessed through future interviews

ANNEX 3.B: UC - 1.2 LOGISTICS IOT

Description

Use case 1.2 in Cluster 1 is focused on developing a novel solution for high accuracy asset tracking in combination with IoT-enabled rock bolts. Assets can be human workers, vehicles or equipment. Today, a mine's staff waste considerable time just by finding different assets. This slows down production and leads to waste of time, money, and efficiency.

ThingWave is currently developing its Digitalized Ground Support (DGS) solution with sensors deployed deep underground to monitor rock mass movement. Use case 1.2 will be based on DGS, but extend it with better sensor solutions, positioning solutions and asset tracking. By combining the wireless IoT network created by rock bolt sensors with a logistics engine, the plan is to use the smart rock bolts as a network infrastructure to enable asset tracking.

The smart rock bolts deliver sensor data that can be used to assess the structural integrity of e.g. tunnels underground. If there is for example a seismic event that causes severe structural damage, the smart bolts can then detect the magnitude and location of the damage. By combining awareness of the location of human staff it is then possible to generate alarms to staff working in hazardous regions, and at the same time alert the mine's operation center that there are staff in dangerous areas.

Short Description

Use case 1.2 in Cluster 1 is focused on developing a novel solution for high accuracy asset tracking in combination with IoT-enabled rock bolts. ThingWave is currently developing its Digitalized Ground Support (DGS) solution with sensors deployed deep underground to monitor rock mass movement. Use case 1.2 will be based on DGS but extend it with positioning solutions and asset tracking. By combining the wireless IoT network created by rock bolt sensors with a logistics engine, the plan is to use the smart rock bolts as a network infrastructure to enable asset tracking. Assets can be human workers, vehicles or equipment. Today, a mine's staff waste considerable time just by finding different assets. This slows down production and leads to waste of time, money, and efficiency.

Complete Description

Use case 1.2 in Cluster 1 is focused on developing a novel solution for high accuracy asset tracking in combination with IoT-enabled rock bolts. ThingWave is currently developing its Digitalized Ground Support (DGS) solution with sensors deployed deep underground to monitor rock mass movement. UC1.2 will further contribute to R&D around ThingWave DGS, and will implement important (currently missing) features.

Use case 1.2 will thus be based on DGS but extend it with key features such as new positioning solutions, asset tracking, AI data processing, as Digital Twins. By combining the wireless IoT network created by rock bolt sensors with a logistics engine, the plan is to use the smart rock bolts as a network infrastructure to enable asset tracking. Assets can be human workers, vehicles or equipment. Today, a mine's staff waste considerable time just by finding different assets. This slows down production and leads to waste of time, money, and efficiency.

This use case addresses the monitoring challenges of critical infrastructure and logistics in mining operations. Key success factors include:

- Live asset tracking
- Accurate infrastructure data
- Decision support software

Each of these factors are described in detail below, followed by a detailed list of the activities involved in the use case.

a) Tracking assets in an underground environment can help keep personnel safe and help keep track of vital equipment. The development of an underground tracking system by combining current rock bolt sensor solutions with a positional sensor is the goal of this use case. The idea is to implement a mesh network using developed rock bolt sensors and then to use that to position assets to certain areas of a larger underground location. This tracking also requires visualization tools to be developed. This type of solution can also be developed to help indicate danger and use rock bolt sensors to indicate this while showing a way to safety.

b) Accurate infrastructure data is provided based on ThingWave's DGS solution, but the DGS will be extended with better sensor solutions. A critical part is improved scalability of the sensor solution to provide accurate data over a larger area. This improves accurate data for a mine as a whole, instead of only receiving data from a small area. To achieve sustainable scalability, there are two factors that are of utmost importance, price and installation complexity. Verification of sensor data through independent testing is also a crucial part here, as it creates trust from the market in the solution. Independent testing will also provide important feedback, so that during the COP-PILOT project, the right missing features will be implemented.

c) ThingWave's Smart rock bolt sensors for ground support can provide real-time structural data from tunnels. However, to enable smarter analysis of extracted data, the software needs to be augmented to get information about events such as blasting and earthquakes and then figure out what data from which bolts are relevant and how that affects regular mining operations. This system needs resilience towards scalability of the number of sensors, both in hardware and in software processing and data visualization. Improving the processing and visualization capabilities can be done with the help of AI. This scalability also enables live asset tracking, as live asset tracking requires a scalability of smart sensors to create helpful tracking.

Activities involved in UC#1.2:

- Develop technology to connect TW Smart tags to TW RBM-XR and RBM-VX mesh networks to enable real-time underground asset tracking.
- Develop software to help visualize assets in underground environments (a)
- Improve system scalability to build sufficiently large mesh-networks to enable asset tracking. Aim is 1000+ sensors per gateway (a)
- Develop a real-time alert system for miners using asset tracking technology (a)
- Improve software integration using ColonyOS and/or Arrowhead (a)

- Develop signal processing software to extract and visualize bolt data during seismic events (blasts/earthquakes) (b)
- Improve software regarding data extraction from large quantity of bolts at the same time (b)
- Smart processing of data extraction from a large quantity of bolts in order to enable decision support through visual tool (c)
 - Identifying and cooperating with suitable mines for field tests (a, b, c)
 - Identifying key barriers to overcome for wide market penetration (a, b, c)
 - Collection of feedback from key mine partners and other relevant actors in the mining business, and compilation of new business development strategies. (a, b, c)
 - Update ThingWave’s business development strategy to meet market expectations (a, b, c)

Main actors and roles

The table below presents the different actors and their role on the overall solution.

Table 5.7: Presentation of the different actors and their role on the overall solution.

Actor name		Actor type	Actor Description and Role
Geotechnical staff	End user		This actor is the main benefactor of the structural data from TAB’s Smart rock bolts. This type of end user makes all the decisions regarding safety for staff and production.
Mine planner	Operator		Mine planners make tactical decisions regarding blasting, and or extraction activities. They need relevant and timely information about the rock mass stability to make good decisions.
Mine staff	End user		For asset tracking, mine staff working underground is the primary actor. By being able to know the location of virtually any asset of value, a lot of time waste can be mitigated
Bolt supplier	End user		By being able to know the status of their installed bolts in real time, they can be alerted if their ground support products are reaching the capacity.
Bolting staff	Operator		Bolting is a very important task for underground mines. Rock bolts must be installed in order to keep the structural integrity of tunnels and drives intact.

Mine management	Management	The management staff are responsible for the overall management of a mine. They require high quality information about how the production is ongoing, any major problems with equipment, and status from the geotechnical staff.
Digitalization staff	End user	This category includes mine's local staff working with IT and Digitalization, and any consultants etc. supporting the digitalization activities of a mining company.

Ambition, Motivation and Objectives

Motivation

Underground mining presents unique challenges due to limited visibility, confined spaces, and hazardous working conditions. Implementing IoT-based asset tracking and ground support monitoring enhances safety, efficiency, and decision-making. Real-time tracking of equipment and personnel improves operational coordination and emergency response, while continuous monitoring of ground support structures such as rock bolts provides early warnings of instability. This proactive approach helps prevent accidents, reduces downtime, and extends the life of a mine, making ore extraction operations safer, and more productive. ThingWave has therefore been developing advanced digital solutions for both ground support monitoring and real-time asset tracking.

Ambition

At ThingWave, we are driven by a strong commitment to transform the mining industry through innovative IoT-based solutions tailored for underground environments. We recognize the critical need for enhanced safety, efficiency, and asset visibility in challenging underground working environments. Our ambition is to empower mining companies with cutting-edge technologies that enable real-time asset tracking and continuous ground support monitoring. By integrating smart sensors, wireless communication networks, and advanced data analytics (including AI), we aim to provide mining companies with timely, actionable insights that improve situational awareness and operational control. Our goal is not only to minimize risks and reduce unplanned downtime, but also to support sustainable mining practices by extending equipment lifespan and optimizing resource allocation. Through the close collaboration in the COP-PILOT project, we aim to build solutions that are robust, scalable, and tailored to the realities of the mine. We believe that by bringing intelligence underground, we can help shape a safer, more resilient, and more productive future for the mining sector. And by using Eclipse Arrowhead, we enable secure and robust data integration and systems of systems opportunities.

UC Mapping with Project Objectives

Below is a list of use case mappings to overall project objectives:

Obj 1.1: Enabling edge2cloud computing continuum within each company.

This use case will deliver IoT solutions for Edge deployments with support for Cloud upstream data integration.

Obj 1.2: Enabling edge2cloud computing continuum between participating companies and their joint customer.

Information sharing is at the core of this use case. Asset tracking data must be shared between different stakeholders, and merged with ground support data to deliver alarm systems that can warn staff if they enter a dangerous area deep within an underground mine.

Obj 1.3: Validation of edge2cloud compute continuum at TRL6.

For the mining industry, testing is extremely important due to the harsh environments found in both underground and open pit mines. This use case will therefore involve multiple mining companies around the globe to identify suitable test sites with good conditions for trials. This includes rock mass that shows squeezing ground effects in a short time frame, and preferable seismic conditions as well.

UC Mapping with Project Innovations

Below is a list of use case 1.2's mappings towards COP-PILOT's innovation goals:

IA#1 – Application-aware IoT device and data management across collaborative domains:

Use case 1.2 will deliver innovation and novel technologies for IoT devices (asset tracking, ground support monitoring, alarms, seismic sensors, gateways, ...). Further, new data management solutions will be developed, and integration with Eclipse Arrowhead and ColonyOS will also be developed and integrated into the current eco-system.

IA#2 – Secure and programmable cross-domain resource and data service exposure:

Use case 1.2 will contribute with Eclipse Arrowhead systems and services to enable cross-domain data exchange using secure communication links. Furthermore, UC 1.2 will implement Eclipse Arrowhead compliant software to integrate with ThingWave's existing digital platform to allow information exchange with Eclipse Arrowhead and/or ColonyOS.

IA#3 – Ultra-scalable end-to-end service & infrastructure orchestration across diverse multi-tenant IoT-Edge-Core environments:

Use case 1.2 will develop software and system solutions for utilizing Eclipse Arrowhead for cross-domain data and information sharing. This includes using ColonyOS and Kubernetes for high availability solutions for on-prem installations and "Big data" applications.

IA#5 – Promotion of innovative cross-sector vertical services through large-scale pilots:

Use case 1.2 aims to perform several short and longer trials to obtain massive amounts of sensor data that can be used to develop AI models as well as use for testing and integration validation. This will require the development of efficient data models and services that promote information exchange between different COP-Pilot partners and stake holders.

Rationale for the Use of the COP-PILOT Platform

The COP Pilot integration platform aims to simply how vendors (such as ThingWave) can deploy their solutions onto customers' networks and thereby provide efficient, secure, and reliable on-prem system integration.

Challenges addressed

The challenges addressed from UC#1.2 are:

- Enable scalability of whole system, hardware, software and visualization. Need to enable 1000 sensor per ThingWave Gateway and better visualization tools to keep track of larger amounts of sensors.
- Integrated asset tracking and Mining4.0 by connecting ThingWave tags to smart rock bolts. Enable flexible visualization tools for the assets, as well as real time alert systems.
- Improved system integration functions using Arrowhead and/or ColonyOS.
- AI data processing and Edge computing to enable decision support software with regards to a large quantity of sensors and with regards to events, such as blasting or earthquakes, in a mine.

Expected outcomes

1. Integrated edge2cloud compute continuum based on Eclipse Arrowhead and ColonyOS.
2. Demonstration of business integration across participating companies supported by edge HPC.
3. Edge2cloud continuum security.

Key pain points

Some of the key pain points in the implementation of UC#1.2:

- Integration challenges.
- Diverse customer infrastructure.
- Integration with Edge and Cloud solutions.
- High maintenance and operational costs in on-prem deployments.
- High sensor installation costs.
- Hard to track assets underground.
- Advanced data processing requires heavy computational resources.
- Advanced IoT solutions on extremely restricted energy budget.
- Scalability challenges.
- Hard to find suitable mine test sites, with regards to ground support issue, seismicity, IT infrastructure and easy access.

UC Diagrams

TW UC overview diagram

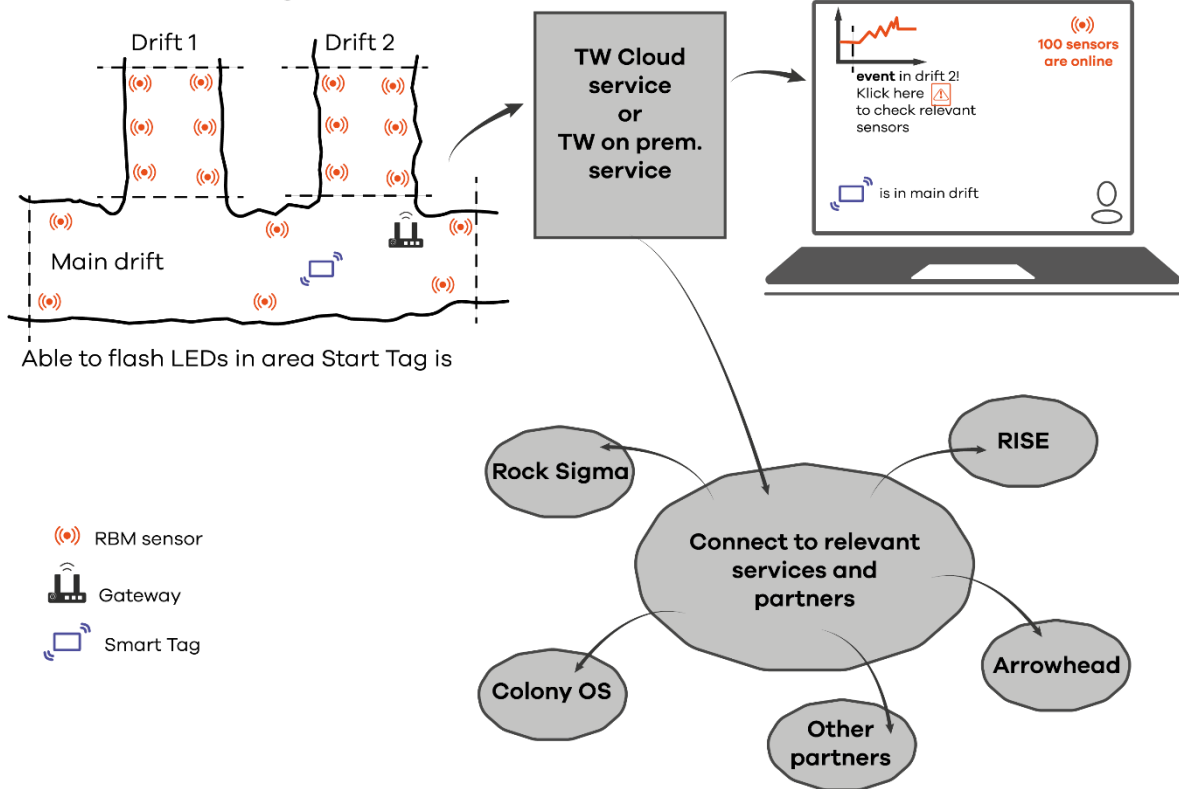


Figure 5.2 TAB use case overview diagram.

TW UC system diagram

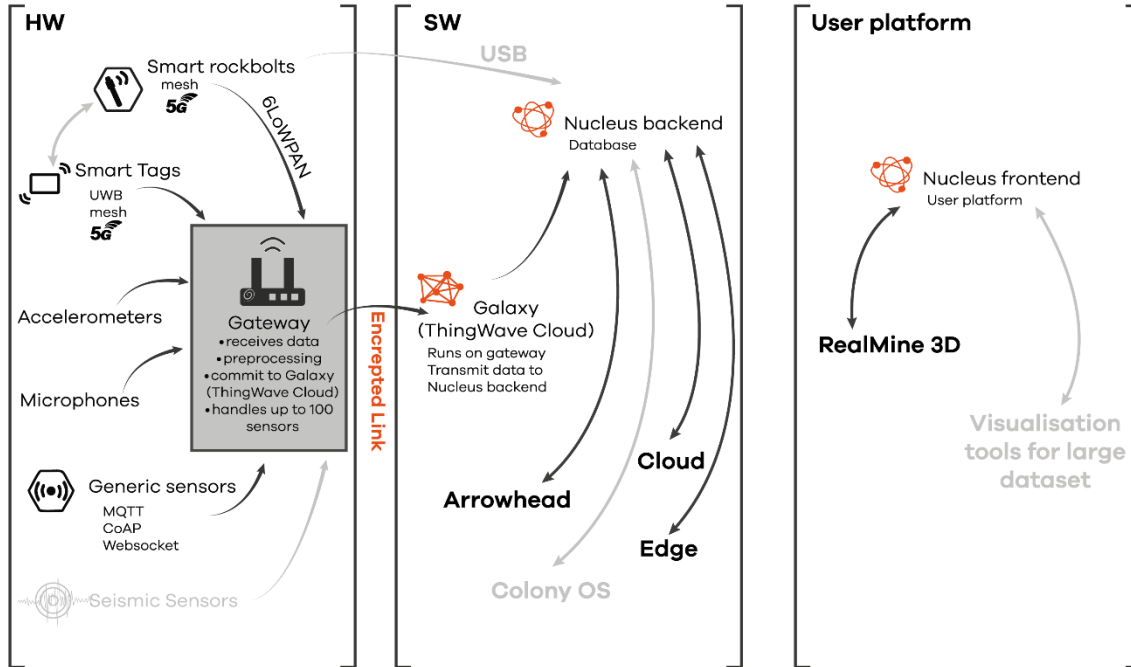


Figure 5.3 TAB use case system diagram.

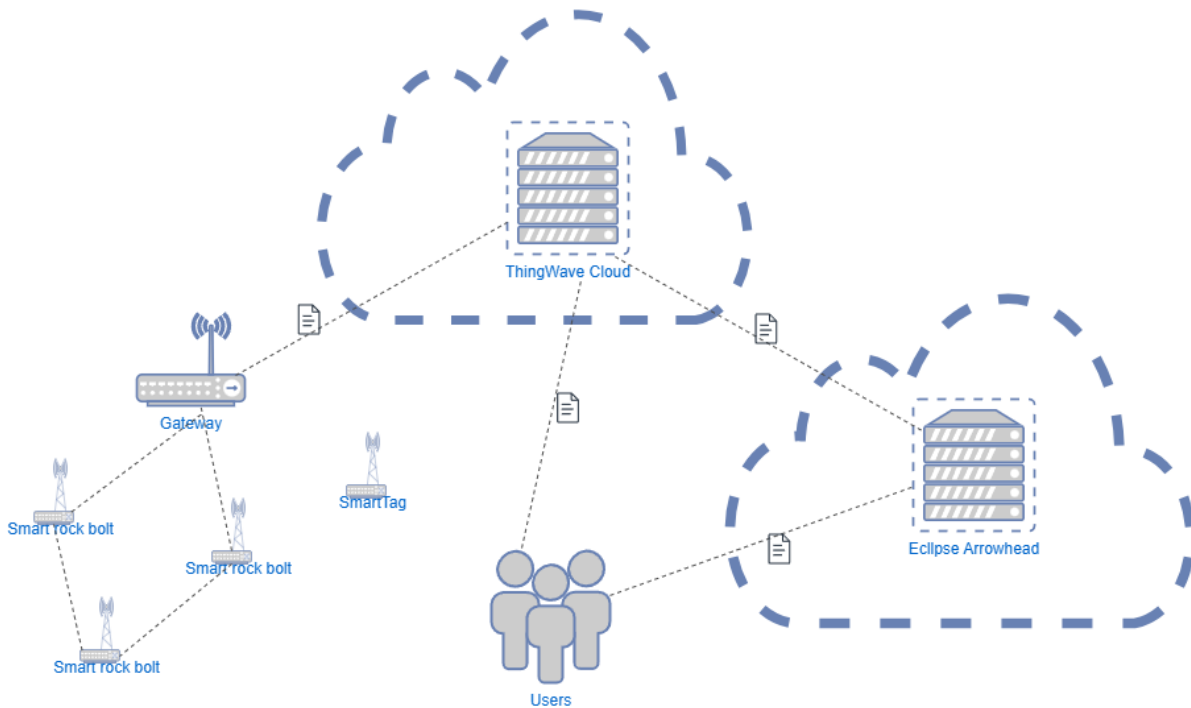


Figure 5.4 Use case architecture diagram

Requirements

Functional requirements

Table 5.8: Use Case functional requirements

Req. ID	Subject + Condition	Commitment	Action + Object + {Constraint and/or Value}
FR1	TAB DGS solution	Must	Support data stream bandwidth with regards to data reception performance of {10k packets per second}
FR2	TAB DGS solution	Must	Support alarm detection latency regarding time from sensor reading to user being alerted of {10s}
FR3	TAB DGS solution	Must	Enable a threshold of sensors connected to gateway {1000pcs}
FR4	TAB DGS solution	Must	Ensure a rock bolt rupture detection accuracy of {+-10% of bolt length}
FR5	TAB DGS solution	Must	Support fault identification time in RBM-sensor {≤10s}
FR6	TAB DGS solution	Must	Ensure a positional update rate for asset tracking {10s}
FR7	TAB DGS solution	Must	Integrate with proposed Cluster 1 ColonyOS/Arrowhead platform
FR8	TAB DGS solution	Must	Ensure proper data security both in platform authentication and in data transmission

Non-functional requirements

Table 5.8: Use Case non-functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
NFR1	TAB DGS solution	Shall ensure	High system availability {≥ 99.999%}
NFR2	TAB DGS solution	Shall support	Fast rock bolt installation time {300s}
NFR3	TAB DGS solution	Shall support	Integration between underground asset tracking and Mining 4.0 platform
NFR4	TAB DGS solution	Shall provide	Visualization of data from large number of sensors
NFR5	TAB DGS solution	Shall provide	Visualization of assets underground
NFR6	TAB DGS solution	Shall support	AI data processing algorithms and Edge computing

Business requirements

Sustainability business requirements

Table 5.10: Use Case sustainability requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
SR1	Fuel emission efficiency	Good to have	Reduce the amount of fuel emissions from doing daily or multiple-per-week manual human tunnel inspections using vehicles, by instead automatically deliver status reports from installed rock bolts	Deliver > 100 automatic rock bolt status reports per day
SR2	Asset lifecycle improvement	Compulsory	Prolong the functional lifetime of assets by accurately monitoring their locations	Increased total available area with tracking capabilities by > 15%

Societal business requirements

Table 5.11: Use Case societal requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
SC1	Worker safety	Good to have	Minimize the time spent by human workers in potentially dangerous area to perform manual tunnel inspections	Deliver > 100 automatic rock bolt status reports per day
SC2	Worker safety	Good to have	Continuously track the location of human workers in order to assess their risk in case of mining hazards	Ensure a positional update rate every 10 seconds
SC3	Worker safety	Good to have	Minimize the event reception delay, the time between events and when information is received to enable quicker decisions	Reduce event reception delay to < 60 seconds
SC4	Data privacy compliance	Compulsory	Ensure that any handled data is subject to mining	Any compliance audits passed successfully

			companies data restriction demands	
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Market business requirements

Table 5.12: Use Case market, or business, requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
BR1	Deployment cost efficiency and scalability	Compulsory	Reduce the cost of installing and configuring rock bolts	> 50% reduction of physical installation time, > 60% reduction in configuration time
BR2	Reduced cost of assets	Good to have	Improved asset monitoring reduces the number of lost asset incidents and thereby the cost associated with searching for lost assets as well as the cost for purchasing new	Reduced cost of assets - Qualitative assessment through interviews
BR3	Operational cost efficiency	Good to have	Greatly reduce the need for costly and time-consuming daily or multiple-per-week manual human tunnel inspection by automatically deliver status reports from installed rock bolts	Deliver > 100 automatic rock bolt status reports per day

ANNEX 3.C: UC - 1.3 CONDITION MONITORING AND PREDICTIVE MAINTENANCE IN MINING

Description

Undisrupted material flow and logistics of products is essential for mining operations, where there is limited or no storage in place to compensate for unplanned downtimes within the logistic chain. Belt Conveyors are in this context the arteries of the logistics chain where bulk material and refined products are forwarded to the next processing step or to the final delivery to the customer. In mining operation, ships or railway are usually the means of transport between plants and customers, where belt conveyors are the intermediate transportation mode.

Near real-time monitoring of conveyor belt operations reduces the risks for spontaneous severe damages to the belt. Such damages, like a belt rips, lead to unplanned stops with subsequent production loss of the industrial application caused by and interruption of the main material transport system. Relevant data to be provided to the platform/cloud infrastructure to enable data processing, analysis and review by automated systems (data science engines) as well as users.

The use-case therefore enables a more safe and reliable material transport in mining operations.

Short Description

Belt scrapers are traditionally used to remove material attached to the belt where the conveyor discharges the belt. The intrinsic function of the scraper is to clean the belt from material and has the effect that belt and other components in the conveyor have extended operational life. The scraper is also continuously in contact with the belt making it an ideal sensing device to measure changes in the belt surface.

In this use case (UC) the patented sensing technology Hosch-Iris Discover is applied to a conveyor belt, that monitors the belt surface using a unique displacement measurement technique. The displacement motion is then acquired from the sensing device and transmitted to the platform/cloud infrastructure to enable data processing, analysis and visualization to the user for decision making. Moreover, fully automated analytics systems using AI and ML to provide actionable insights to users. These insights are then used to make decisions on belt operation and maintenance.

Complete Description

Continuous material flow and logistics are crucial for mining operations, as there is little to no storage to manage unplanned downtimes. Belt conveyors serve as essential components in the logistics chain, transporting bulk materials and refined products between processing steps or final delivery. Near real-time monitoring of conveyor belt operations reduces the risk of severe damage, such as belt rips, which can cause unplanned stops and production losses.

The use-case aims to ensure safe and reliable material transport in mining operations. Belt scrapers clean the conveyor belt, extending its lifespan, and act as sensors to monitor changes in the belt surface. The Hosch-Iris Discover technology uses a patented sensing technique to measure belt displacement. This data is transmitted to a cloud platform for analysis and visualization, enabling decision-making regarding belt operation and maintenance through AI and ML-driven insights.

Current practice in the monitoring of conveyor belts is to install several guarding mechanisms that monitor the alignment of the belt and detect belt rips. Those mechanisms usually render an emergency stop of the conveyor when triggered. To complement these reactive mechanisms, the

complete conveyor with all its components, including the belt, is inspected on a regular basis to preventively identify issues, like damage to the belt. Those inspections usually lead to a stop in production as the belt can only be inspected during empty runs of the conveyor. Moreover, the inspection is not condition-based but time-based. In between inspections, there is no knowledge about degradation or damage which is progressing. Moreover, inspections are manual activities where a human visually inspects the belt surface as it passes by an inspection location. Human errors in the inspection are therefore common.

The proposed UC introduces an IoT device which enables condition monitoring of the belt 24/7 and during production at a low cost. Human inspections are thereby complemented by a condition monitoring scheme which detects new arising damages or issues and then assesses the degradation at those specific locations. Depending on the criticality level at the detection instances and the rate of the degradation and the criticality during the monitoring, operators and maintenance staff is warned or alerted. Subsequently, catastrophic damage or failure can be avoided.

Main actors and roles

Table 5.13 Main actors and roles

Actor name	Actor type	Actor Description and Role
Operator conveyor belt(s)	End user	Oversees the daily productive operation of the conveyor systems. Focused on uptime and undisturbed material flow. Uses UI and the visualization of processed data to gain insights of possible disruptions.
Maintenance engineer conveyor belt(s)	End user	Responsible for maintenance of conveyor system components. Focused on reducing scheduled downtime and preventing unscheduled downtime. Uses UI and the visualization of data to identify needs for and schedule maintenance activities.
Production Manager(s)	End user	Responsible for undisrupted production and possibly increasing efficiency of production. Uses UI and the visualization of processed data to gain an overview of the status of conveyor systems and potential disruptions of material flow/production.
Service engineer of Hosch-Iris Splaice	Operator	Service engineer for digital services. In charge of customer satisfaction and ensuring correct insights are provided by correctly configuring the system. Administration of Users, reviewing UI and receiving feedback from users for needed improvements or possible irregularities.
Commissioning engineer of Hosch-Iris Discover	Engineer	Commissioning engineer for hardware units. Oversees, supports or carries out the installation of hardware and sensor.

		<p>Ensures the system is functional after installation and collaborates with customer technicians. Ensures via UI that the data is transmitted reliably. Possibly carrying out maintenance or changing parts if necessary.</p>
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Ambition, Motivation and Objectives

Motivation

To provide decision support to users for an in-time operational intervention preventing or limiting belt damages and subsequent production losses, and to efficiently deploy solution at multiple conveyor belts and customers.

Ambition

To adapt and implement the condition monitoring solution alongside decision support, validate the provided actionable insights and operational interventions, and showcase a scalable deployment scheme.

UC Mapping with Project Objectives

- Obj#1.1: Enabling edge2cloud computing continuum within each company.
 - The ambition is to elevate their current edge2cloud computing architecture to a higher level of security and reliability
 - To improve the efficiency of the data storage and of the resources for data acquisition and transmission
- Obj#1.2: Enabling edge2cloud computing continuum between participating companies and their joint customer.
 - Going from a manual deployment process for the customers to an automated deployment of the solution after commissioning of the edge device
- Obj#1.3: Validation of edge2cloud compute continuum at TRL6.
 - Improved Hardware & Firmware for reliable and efficient Data collection and transmission, supporting scalability

UC Mapping with Project Innovations

- IA#1 – Application-aware IoT device and data management across collaborative domains:
 - New generation hardware to be deployed with improved performance regarding stability and efficiency. Notifications provided from device (application aware)

- IA#2 – Secure and programmable cross-domain resource and data service exposure:
 - Existing pilot application to be improved and applied in additional operation for use case and deployed in COP-PILOT environment.
- IA#3 – Ultra-scalable end-to-end service & infrastructure orchestration across diverse multi-tenant IoT-Edge-Core environments
 - Enables multi-unit and multi-customer deployment with geographic distribution around the globe.
- IA#4 – Innovation Area #4: Intelligent & automation tools for high-TRL vertical service onboarding and preservation:
 - Enables faster and more reliable deployment of the IoT and cloud integration.

Rationale for the Use of the COP-PILOT Platform

The vision of the COP Pilot platform holds the promise for Hosch and Predge to deploy their corporation product Splaice in an automated and scalable way to their customers and thereby providing efficient, secure, and reliable condition monitoring and predictive maintenance for the customers conveyor belts. It further enables the development and deployment of more stable, secure and efficient hardware for data collection and transmission.

Challenges addressed

The COP-PILOT approach is likely to aid in addressing the following challenges

- Provision of IoT Data in a suitable and performant protocol for close to real time processing
- Reliable data transmission technology to be applied
- Data security and secure decentralized access for services and users
- Scalable deployment for multiple units for one or multiple customers
- Automated updating of the UI and the AI for multiple points of interest

Expected outcomes

EO#1.2: Demonstration of business integration across participating companies supported by edge HPC.

EO#1.3: Edge2cloud continuum security.

In practical terms this can be expressed as

- Reliable data provision and processing

- Access to additional information generated by data provided (processed data)
- Seamless data sharing with customers and other authorized users

Key pain points

- Data security regulations of industrial operation
- Interoperability of cloud systems and infrastructure
- Performance of system in case large data volumes are generated and transmitted
- Deployment and management of multi-unit and multi-customer environments

UC Diagrams

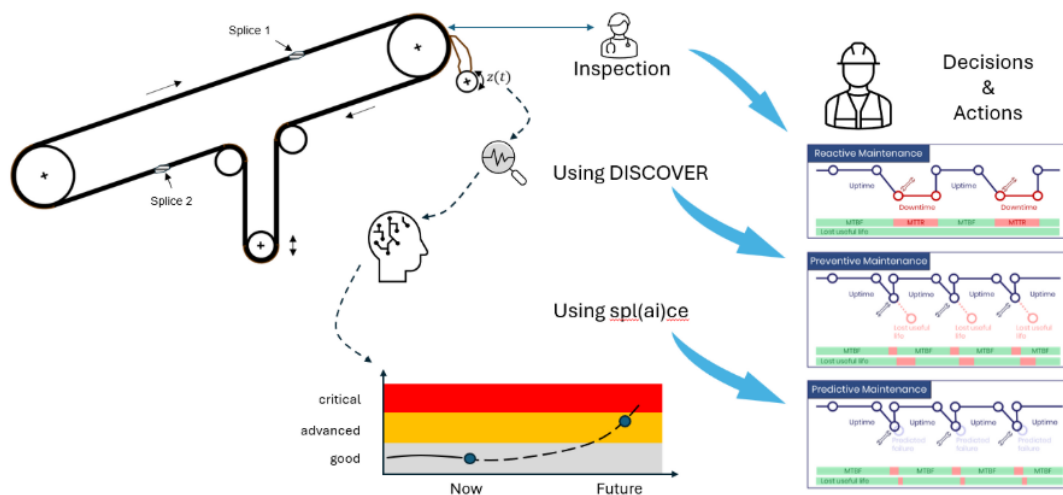


Figure 5.5 Use case overview diagram

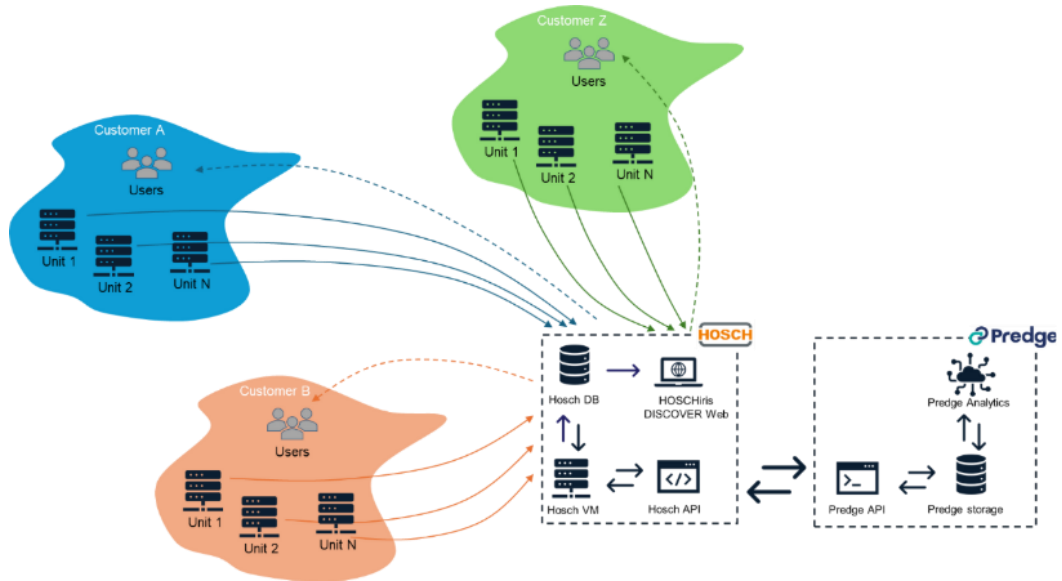


Figure 5.6 Use case system diagram

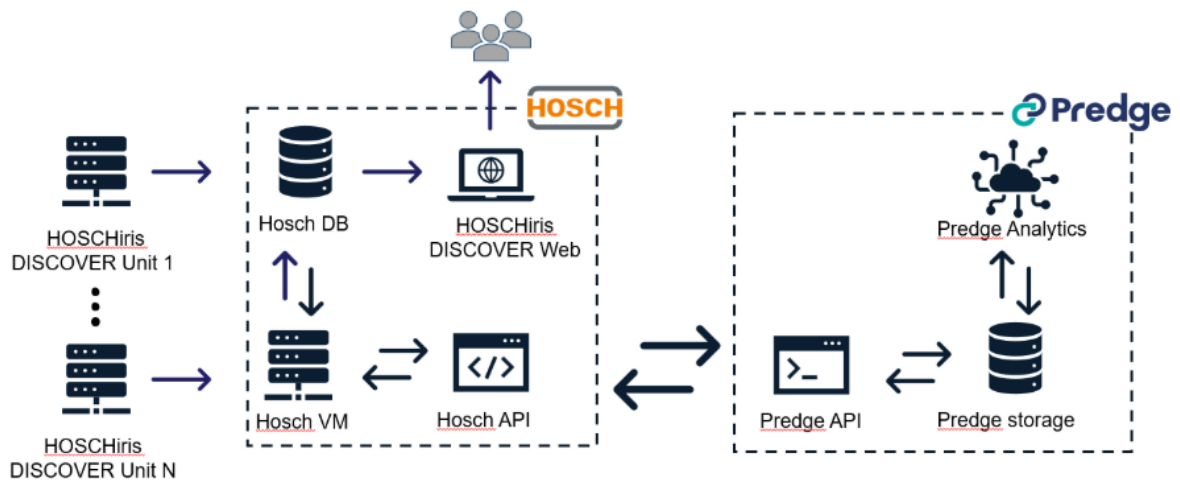


Figure 5.7 Use case architecture diagram

Requirements

Functional requirements

Table 5.14 Use Case functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
FR 1	Measurement system	Must	Acquire data on the scraper movement as it tracks the belt surface
FR 2	Data transmission	Must	Transmit the acquired measurements from the IoT device into the Hosch Iris cloud
FR 3	Data ingestion	Must	Transmitted data is ingested in adequate data storages for the different data types

FR 4	Data provisioning services	Must	Bidirectional services for provisioning of data-to-data consumers (customers, processing services, eco-system partners).
FR 5	Data processing services	Must	Processing of the consumed data for the generation of insights relating to belt condition and maintenance
FR 6	Decision support	Must	Visualization of acquired data and insights to end-users for the decision making. and reporting of actions

Non-functional requirements

Table 5.15 Use Case non-functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
NFR 1	Measurement system	Must	Provide data with a sufficiently high sample rate {1000 Hz}
NFR 2	Connectivity	Must	Minimal loss connectivity between IoT devices and cloud for each device {300 GB/month, 99.8% availability}
NFR 3	Data retention	Must	Data need to be stored for a predefined time period per device and customer {1 year}
NFR 4	Data provisioning and visualization	Must	Forward data streams to a data consumer with a limited delay {1 second}
NFR 5	Data processing	Must	Insights need to be generated within a certain time frame after a complete revolution of a conveyor belt {1 minute}

Business requirements

Sustainability business requirements

The use case does not have any sustainability business requirements.

Societal business requirements

Table 5.16 Use Case societal requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
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SC1	Improved worker safety	Compulsory	Improve worker safety by predicting and avoiding sudden potentially dangerous conveyor belt breakdowns.	Belt damage discovery at least 8 hours before condition becomes critical in > 90% of cases
SC2	Data privacy compliance	Compulsory	Ensure that any handled data is subject to mining companies data restriction demands	Any compliance audits passed successfully

Market business requirements

Table 5.17 Use Case market (business) requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
BR1	Maintenance predictability	Compulsory	Discover damages to conveyor belts before they become critical to avoid costly unplanned downtime	Belt damage discovery at least 8 hours before condition becomes critical in > 90% of cases
BR2	Deployment cost efficiency and scalability	Compulsory	Advanced automation and orchestration technology deploys, configures and scales computational resources efficiently, which reduces time and effort spent on managing IT infrastructure and platforms	Reduced installation and commissioning time by > 50%

ANNEX 3.D: UC - 1.4 IOT-EDGE-CLOUD-CONTINUUM FOR DIGITAL MINES

Description

UC1.4 develops and validates an edge-to-cloud computing continuum tailored for digital mining operations. A dedicated testbed at RISE's ICE Datacentre in Luleå will emulate realistic mining conditions, enabling experimentation with scalable data processing and resource management.

The use case integrates ColonyOS for federated orchestration, self-adaptive autoscaling, and automated resource provisioning, while Eclipse Arrowhead supports secure service discovery and interoperability between industrial systems. Together, these technologies demonstrate how distributed mining applications can operate efficiently across heterogeneous infrastructures, ensuring resilience, low latency, and optimized use of computing resources.

Short Description

UC1.4 establishes an experimental edge-to-cloud testbed for digital mines at RISE's ICE Datacentre in Luleå, emulating the conditions of underground operations. The use case integrates ColonyOS for federated orchestration and self-adaptive autoscaling, with Eclipse Arrowhead providing secure service discovery and system interoperability. The setup will demonstrate how mining applications can dynamically provision compute resources, maintain resilience under varying load, and enable real-time analytics across distributed industrial infrastructures.

Complete Description

UC1.4 aims to demonstrate how distributed computing resources can be orchestrated into a unified IoT-Edge-Cloud continuum supporting digital mining operations. The focus is on achieving reliable, low-latency data processing and adaptive scalability in environments that combine low-power IoT sensors, local edge nodes, and cloud-based analytics.

To support this, a dedicated testbed will be established at RISE's ICE Datacentre in Luleå, designed to emulate the conditions of underground mines. The testbed will provide an environment for validating scalable data pipelines, visual prototypes of digital mining applications, and dynamic resource provisioning across heterogeneous infrastructures.

Within this setup, ColonyOS provides the meta-operating system layer that enables federated orchestration, self-adaptive autoscaling, and automated resource provisioning across multiple computing domains. These mechanisms are being further developed through research at Luleå University of Technology (LTU). Complementing this, Eclipse Arrowhead is utilised and evaluated as an edge-level framework for secure service discovery and interoperability between industrial systems, ensuring that edge, on-premise, and cloud services can exchange data in a reliable manner.

UC1.4 connects the outcomes of the previous Cluster 1 use cases (UC#1.1-UC#1.3) into an integrated demonstration of the COP-PILOT edge-to-cloud architecture. It shows how advanced orchestration technologies can improve operational efficiency, resilience, and safety in mining by enabling distributed applications to react autonomously to changes in workload and environmental conditions. The results will provide a foundation for future large-scale pilots of digital mine operations and other industrial domains requiring robust edge-to-cloud computing.

Main actors and roles

Table 5.18 Main actors and roles

Actor name	Actor type	Actor Description and Role
LTU	Technology provider	ColonyOS and Eclipse Arrowhead expert.
RISE	Testbed provider	Edge infrastructure expert/provider.

Ambition, Motivation and Objectives

Motivation

The digital transformation in the mining industry demands a new type of computing platform that can operate seamlessly across heterogeneous edge, cloud, and on-premises environments. Current approaches rely on fragmented orchestration tools and vendor-specific platforms that hinder interoperability, increase costs, and require significant engineering effort. There is thus a need for an open, modular, and secure foundation provided by the COP-PILOT project that reduces complexity, enables local autonomy, and supports real-time, scalable data processing.

Ambition

Our ambition is to develop a unified, open, and service-oriented Edge-to-Cloud (E2C) continuum platform tailored for industrial environments. By leveraging the complementary capabilities of ColonyOS and Eclipse Arrowhead within the COP-PILOT architecture, we aim to streamline orchestration across heterogeneous systems, reduce integration complexity, and enhance local autonomy through secure, low-latency edge computing. This approach shifts engineering focus from low-level platform integration to high-value domain innovation, while ensuring scalability, resilience, and regulatory compliance in federated, real-world deployments.

UC Mapping with Project Objectives

The use case will directly contribute to the following objectives:

Obj#1.1: Enabling edge2cloud computing continuum within each company.

Obj#1.2: Enabling edge2cloud computing continuum between participating companies and their joint customer.

Obj#1.3: Validation of edge2cloud compute continuum at TRL6.

UC Mapping with Project Innovations

The use case contributes directly to the following COP-PILOT Innovation Areas:

- **IA#1 – Application-aware IoT device and data management across collaborative domains.**

By combining ColonyOS and Eclipse Arrowhead, the use case enables secure and interoperable IoT device and data management across distributed domains. Arrowhead provides structured, service-based integration for industrial devices, while ColonyOS delivers

platform-agnostic data synchronization and process orchestration across heterogeneous infrastructures. This open, modular approach reduces vendor lock-in and supports scalable, application-aware IoT deployments in industrial environments.

- **IA#2 – Secure and programmable cross-domain resource and data service exposure.** The integration adopts a layered approach: Arrowhead provides secure service discovery within local domains, while ColonyOS enables cross-domain orchestration and resource coordination. Together, they support trusted and programmable data exchange without direct coupling of orchestration layers.
- **IA#3 – Ultra-scalable end-to-end service and infrastructure orchestration across diverse multi-tenant IOT-Edge-Cloud environments.** The use case demonstrates scalable orchestration across heterogeneous edge-to-cloud infrastructures by applying a layered approach. ColonyOS provides meta-orchestration for dynamic workload placement and resource management across distributed domains, while Eclipse Arrowhead ensures secure and standardized service interaction within trusted local environments. Together, these frameworks enable coordinated operation of compute and data services in complex, multi-tenant industrial ecosystems.
- **IA#4 – Intelligent and automation tools for high-TRL vertical service onboarding and preservation.** Cluster 1 platform enables self-adaptive service and resource management through declarative process definitions and dynamic resource orchestration. The framework interfaces with the COP-PILOT Domain orchestration layer to enable zero-touch service deployment, monitoring, and lifecycle management.
- **IA#5 – Promotion of innovative cross-sector vertical services through large-scale pilots.** The modular design of the ColonyOS–Arrowhead platform enables reuse of orchestration patterns and service templates across sectors beyond mining, including logistics, manufacturing, and smart infrastructure. Integration with the COP-PILOT orchestration framework ensures interoperability and transferability of results across industrial domains, promoting cross-sector scalability and adoption

Rationale for the Use of the COP-PILOT Platform

The COP-PILOT platform aims to provide a scalable and secure orchestration environment to deploy and manage the ColonyOS–Arrowhead instances across distributed, multi-domain industrial use cases. It also enables a collaborative environment that facilitates sharing of data and services across different domains participating in the COP-PILOT project, including third-party users.

Challenges addressed

- Integration of sensor and data sources in other Cluster 1 pilot use cases (logistics, mines) (Arrowhead).
- Interoperability between different mining technology suppliers (Arrowhead).
- Real-time data collection from distributed sensor networks (Arrowhead, FIWARE).

- Ensuring interoperability and resilience of edge devices during data collection and ingestion (ColonyOS and Arrowhead).
- Enabling robust data analytics and compute resilience through orchestration across the E2C continuum (ColonyOS).
- Implementation of industrial-grade authentication and authorization mechanisms (x.509 certificates and blockchain-based systems) (ColonyOS and Arrowhead).
- Providing a verified and validated E2C platform that combines both service, compute and deployment orchestration.
- Reduce bandwidth requirements using distributed (Edge) compute resources by forming resilient E2C platform.

Expected outcomes

The use case will directly contribute to the following outcomes:

1. Integrated E2C compute continuum based on the COP-PILOT platform, including Eclipse Arrowhead and ColonyOS components.
2. Demonstration of business integration across participating companies supported by edge HPC.
3. Edge2cloud continuum security.

Key pain points

Mining companies and IT providers targeting the mining sector face increasing challenges in managing complex, distributed computing environments. Rising cloud costs, security and the demand for real-time processing are accelerating the shift toward local edge computing. However, the reliance on multiple platforms (both edge and cloud) introduces significant integration complexity, operational overhead, and fragmentation. A substantial portion of engineering resources must therefore be allocated to addressing low-level platform issues instead of delivering domain-specific value. Interoperability gaps between sensor systems further hinder deployment. Ensuring security and compliance across federated domains remains challenging. These factors limit the development of resilient, cost-efficient, and future-proof digital infrastructures for the mining industry.

UC Diagrams

This figure below illustrates the layered orchestration and deployment architecture used in UC1.4 for managing a digital mining environment using the COP-PILOT domain orchestrator (OpenSlice+FIWARE), Eclipse Arrowhead, and ColonyOS.

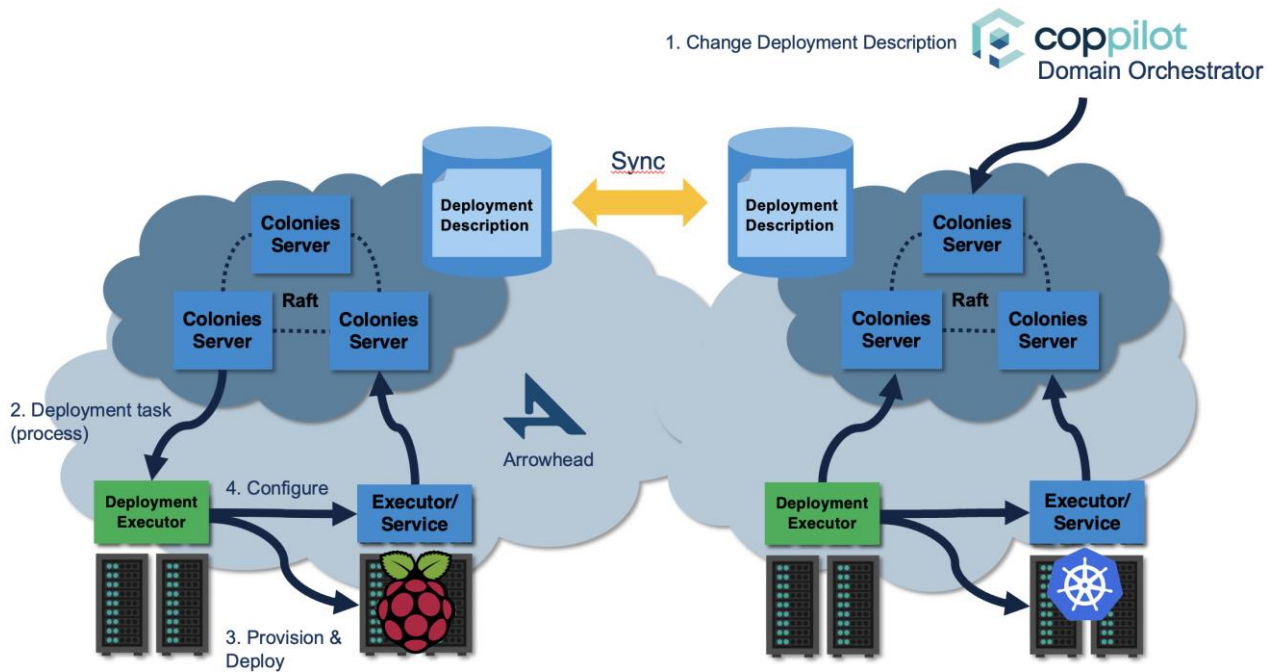


Figure 5.8: Deployment orchestration using ColonyOS integrated with COP-PILOT DomainOrch

At the edge device layer, sensors such as geophones (e.g., from Thingwave or Hosch) operate within Arrowhead-managed local environments, which provide secure service discovery and access control between industrial components.

Above this, ColonyOS functions as a meta-operating system that maintains a global view of desired versus current system state across the edge-to-cloud continuum. Using a controller architecture similar to Kubernetes, ColonyOS continuously reconciles configurations and workload distributions. When updates are required, it generates executable processes for deployment and configuration executors, which perform the necessary actions to align the system state with operational policies.

Through this federated architecture, Arrowhead contributes trusted service interoperability within local domains, while ColonyOS governs high-level orchestration, automated deployment, and runtime adaptation across domains. Together they establish a secure, scalable, and self-managing edge-to-cloud continuum supporting real-time analytics, seismic processing, and industrial operations within the COP-PILOT framework. This integrated architecture enables a scalable, secure, and interoperable computing continuum that supports real-time analytics applications (e.g., seismic compute engines), dynamic service management, and cross-domain collaboration within COP-PILOT.

Testbed

The UC#1.4 testbed also enables an emulated edge-to-cloud computing continuum designed to reproduce key characteristics of digital mining environments. It integrates simulated IoT devices, edge computing nodes, and cloud services connected through automated deployment and orchestration mechanisms.

Within this environment, data streams are generated to represent typical mining operations and processed dynamically across distributed computing layers. ColonyOS coordinates the deployment, configuration, and scaling of software components, ensuring consistency and resilience across the continuum.

This setup enables experimentation with self-adaptive orchestration, workload distribution, and resource management, providing a controlled environment for validating the scalability and interoperability of the COP-PILOT architecture in industrial contexts.

Requirements

Functional requirement Service Orchestration

Service Orchestration refers to the coordinated management, integration, and automation of distributed services and components to deliver reliable, end-to-end system functionality. In the context of UC#1.4, service orchestration is used to e.g. connect Thingwave sensors with RockSigma controllers, enabling real-time data exchange, control logic, and analytics across the Edge-to-Cloud (E2C) continuum.

Table 5.19 Service orchestration

Req. ID	Subject(+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
SFR1	Arrowhead	Investigate	Evaluate service registration, discovery, and orchestration mechanisms provided by Arrowhead's SOA-based framework.
SFR2	Secure Identity & Access Framework	Should	Implement secure authentication and access control across the E2C continuum using certificate-based models (e.g., Arrowhead x.509) and evaluate integration with decentralised identity frameworks (e.g., SPIFFE/SPIRE or Web3-based self-sovereign IDs).
SFR3	Arrowhead	Should	Explore federated sensor data access through Arrowhead's local trust zones ("local clouds") to enable secure data exchange between mine sites and subsystems.
SFR4	ColonyOS / Arrowhead	Must	Provide declarative meta-orchestration to define edge processing logic, including data filtering, transformation, and pre-processing before forwarding to cloud analytics.
SFR5	ColonyOS	Should	Support dynamic workload placement and automated recovery across edge and cloud nodes to maintain service continuity under variable compute or network conditions.

Functional requirements Compute Orchestration

Compute Orchestration refers to the automated deployment, scheduling, execution, and monitoring of computational workflows and services across distributed computing environments-ranging from IoT devices and edge nodes to cloud data centres. In UC#1.4, ColonyOS is responsible for coordinating and managing these resources across the Edge-to-Cloud continuum, ensuring resilience, security, observability, and policy-driven control.

Table 5.20 Functional requirements Compute Orchestration

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
OFR2	ColonyOS	Must	Secure authentication and access control blockchain credentials (Web3-style self-sovereign IDs).
OFR3	ColonyOS	Must	Execution of distributed computational workflows and services across IoT, edge, and cloud platforms using ColonyOS.
OFR6	ColonyOS	Must	Fault tolerance and process re-assignment, in case of failures.
OFR7	ColonyOS	Must	System-wide logs, metrics, and traces.
OFR9	ColonyOS	Must	Enable edge-local execution of compute-intensive tasks, such as real-time sensor analytics and filtering, to minimize cloud dependency and latency.
OFR9	ColonyOS	Must	Declarative meta-orchestration, defining policies and SLA requirements.

Functional requirements Deployment Orchestration

Deployment Orchestration refers to the automated provisioning, configuration, scaling, and lifecycle management of software components across E2C computing continuums. In UC#1.4, this includes deploying ColonyOS executors, Arrowhead services, and compute workloads dynamically across IoT devices, edge nodes, and cloud resources within the COP-PILOT platform. The orchestration must ensure resilience, resource efficiency, and environmental sustainability.

Table 5.21 Functional requirements Deployment Orchestration

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
DFR5	ColonyOS COP-PILOT platform	Must	Dynamic allocation of compute, memory, and storage resources across the E2C continuum.
DFR6	ColonyOS COP-PILOT platform	Must	Fault tolerance and re-deployment of ColonyOS executors in case of failures.
DFR7	ColonyOS COP-PILOT platform	Must	System-wide logs, metrics, and traces.
DFR8	ColonyOS COP-PILOT platform	Must	Indent-based description of deployment blueprints.
DFR10	ColonyOS COP-PILOT platform	Must	Automatic scaling of cloud and edge resources to reduce cloud costs and carbon emissions.

DFR11	COP-PILOT platform	Must	Automatically provision and setup ColonyOS + Arrowhead E2C continuum.
DFR12	ColonyOS COP-PILOT platform	Must	Implement state reconciliation logic, where autonomous agents monitor and enforce convergence between desired and actual system state across the continuum.

Non-functional requirements

Table 5.22 Non-functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
NFR1	ColonyOS-Arrowhead COP-PILOT	Shall ensure	System availability { $\geq 99.9\%$ }
NFR2	ColonyOS-Arrowhead COP-PILOT	Shall support	Secure data transmission (TLS) and encrypted storage (AES-256).
NRF2	ColonyOS-Arrowhead COP-PILOT	Shall preserve	System state consistency across failures {zero data loss for committed tasks}
NFR3	ColonyOS-Arrowhead COP-PILOT	Shall provide	Audit logs {configurable retention}

Business requirements

Sustainability business requirements

Table 5.23 Sustainability business requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
BR1	Reduced energy usage	Compulsory	Advanced automation and orchestration technology deploys, configures and scales computational resources efficiently. Data processing closer to data sources also lowers transmission overhead.	Reduced total business energy consumption - Qualitative assessment through interviews

Societal business requirements

Table 5.24 Societal business requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
SC2	Data privacy compliance	Compulsory	Ensure that any handled data is subject to mining companies data restriction demands	Any compliance audits passed successfully

Market business requirements

Table 5.25 Use Case market (business) requirements

Req. ID	Subject (+Condition)	Commitment	Action + Object + {Constraint and/or Value}	Quantifiable measures for assessment
BR4	Reduced IT-related costs	Compulsory	Advanced automation and orchestration technology deploys, configures and scales computational resources efficiently, which reduces time and effort spent on managing IT infrastructure and platforms	Reduced IT-related costs