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SERIES Y: GLOBAL INFORMATION
INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS,
NEXT-GENERATION NETWORKS, INTERNET OF
THINGS AND SMART CITIES

**ITU-T Y.3000 series – Use cases for autonomous
networks**

ITU-T Y-series Recommendations – Supplement 71

ITU-T



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Supplement 71 to ITU-T Y-series Recommendations

ITU-T Y.3000 series – Use cases for autonomous networks

Summary

Supplement 71 to ITU-T Y-series Recommendations discusses use cases for autonomous networks. The use cases are divided into two categories, and possible requirements, interactions among actors and possible key components are also discussed.

Various use cases are derived according to the key concepts behind autonomous networks of exploratory evolution, real-time responsive experimentation and dynamic adaptation to enable handling of hitherto unseen changes in network scenarios or inputs to reduce the human effort involved in managing the network.

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Supplement 71 to ITU-T Y-series Recommendations

ITU-T Y.3000 series – Use cases for autonomous networks

1 Scope

This Supplement discusses use cases for autonomous networks (ANs). The use cases are divided into two categories, and possible requirements, interactions among actors and possible key components are also discussed.

2 References

- [ITU-T Y.3115] Recommendation ITU-T Y.3115 (2022), *AI enabled cross-domain network architectural requirements and framework for future networks including IMT-2020*.
- [ITU-T Y.3172] Recommendation ITU-T Y.3172 (2019), *Architectural framework for machine learning in future networks including IMT-2020*.
- [ITU-T Y.3173] Recommendation ITU-T Y.3173 (2020), *Framework for evaluating intelligence levels of future networks including IMT-2020*.
- [ITU-T Y.3174] Recommendation ITU-T Y.3174 (2020), *Framework for data handling to enable machine learning in future networks including IMT-2020*.
- [ITU-T Y.3176] Recommendation ITU-T Y.3176 (2020), *Machine learning marketplace integration in future networks including IMT-2020*.
- [ITU-T Y.3178] Recommendation ITU-T Y.3178 (2021), *Functional framework of artificial intelligence-based network service provisioning in future networks including IMT-2020*.
- [ITU-T Y.3179] Recommendation ITU-T Y.3179 (2021), *Architectural framework for machine learning model serving in future networks including IMT-2020*.
- [ITU-T Y.Suppl. 55] ITU-T Supplement Y.Suppl. 55 (2019) ITU-T Y.3170-series – *Machine learning in future networks including IMT-2020: use cases*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following term defined elsewhere:

3.1.1 network service [b-ITU-T Y.3515]: A collection of network functions with a well specified behaviour.

NOTE – Examples of network services include content delivery networks (CDNs) and IP multimedia subsystem (IMS).

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

AF Application Function

AI	Artificial Intelligence
AN	Autonomous Networks
AoA	Angle of Arrival
API	Application Programming Interface
ASIC	Application-Specific Integrated Circuit
BS	Base Station
CAPEX	Capital Expenditure
CI/CD	Continuous Integration and Continuous Delivery
CL	Closed Loop
CLI	Command Line Interface
CN	Controller Node
CNF	Cloud Native Network Function
CNN	Convolutional Neural Network
CP	Control Plane
CSP	Communication Service Provider
CU	Centralized Unit
CUP	Common User Profile
DevOps	Development and Operations
DSL	Domain-Specific Language
DT	Digital Twin
DU	Distributed Unit
EBS	Exhaustive Beam Sweep
ER	Emergency Response
Ev	Evolution
Ex	Experimentation
E2AP	E2 Application Protocol
E2E	End to End
FEC	Forward Error Correction
FLAML	Fast and Lightweight Automated Machine Learning
GNN	Graph Neural Networks
GUI	Graphical User Interface
IA	Initial Access
IDSA	Inter-Domain Service Automation
KB	Knowledge Base
KPI	Key Performance Indicator
MANO	MANagement and Orchestration
MEC	Multi-Access Edge Computing

MIMO	Multiple Input Multiple Output
ML	Machine Learning
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
MOS	Mean Opinion Score
MVNO	Mobile Virtual Network Operator
NAO	Network Application Orchestrator
NF	Network Function
NFVO	Network Function Virtualization Orchestrator
NSSI	Network Slice Sub-net Instances
O	Open
OFDM	Orthogonal Frequency-Division Multiplexing
ONAP	Open Networking Automation Platform
Op	Operational
OPEX	Operational EXpenditure
O-RAN	Open Radio Access Network
OSS	Operational Support System
NACF	Network Access Control Function
nRT RIC	near Real Time Radio access network Intelligent Controller
PCF	Policy Control Function
PDU	Protocol Data Unit
PoC	Proof of Concept
QoE	Quality of Experience
QoS	Quality of Service
QPaaS	Quality of experience Prediction as-a-Service
RAN	Radio Access Network
RIC	Radio access network Intelligent Controller
RSRP	Reference Signal Received Power
RX	Receiver
SDK	Software Development Kit
SDN	Software Defined Networking
SINR	Signal-to-Interference-plus-Noise Ratio
SL	Supervised Learning
SLA	Service Level Agreement
SLAM	Simultaneous Localization And Mapping
SMF	Session Management Function
SNR	Signal-to-Noise Ratio

SoC	System-on-Chip
SRC	SouRCe
SS	Synchronization Signal
SSB	Synchronization Signal Block
SVM	Support Vector Machine
TOSCA	Topology and Orchestration Specification for Cloud Applications
TX	Transmitter
TXB	Transmit Beam
UL	UpLink
UP	User Plane
URLLC	Ultra-Reliable Low-Latency Communication
VNF	Virtual Network Function
ZSM	Zero-touch Service Management

5 Conventions

In this Supplement, in alignment with the conventions of [ITU-T Y.Suppl. 55], possible requirements which are derived from a given use case are classified as follows:

- The keywords "it is critical" indicate a requirement which would need to be fulfilled (e.g., by an implementation) and enabled to provide the benefits of the use case.
- The keywords "it is expected" indicate a specification which is important but not absolutely necessary to be fulfilled (e.g., by an implementation). Thus, this possible requirement would not need to be enabled to provide the complete benefits of the use case.
- The keywords "it is of added value" indicate a specification which can be optionally fulfilled (e.g., by an implementation), without implying any sense of importance regarding its fulfilment. Thus, this specification would not need to be enabled to provide the complete benefits of the use case.

6 Introduction

As the demand on and expectations of communication networks is growing, so are user subscriptions and new service expectations. Network operators must find new ways to address these expectations while at the same time controlling operational cost. ANs are those that possess the ability to monitor, operate, recover, heal, protect, optimize and reconfigure themselves in order to adapt to hitherto unseen changes in situations. These abilities are commonly known as the self-* properties. The impact of autonomy on the network touches on many areas including planning, security, audit, inventory, optimization, orchestration, and quality of experience (QoE). Hence, ANs form an important part of future networks not only to provide value-added features to the user, but also to reduce the management overheads for the network operator. The use cases discussed in this document are based on considerations for enhancing end-user experience, motivating autonomous behaviour in networks.

The main concepts behind ANs which are elaborated here are exploratory evolution, real-time responsive experimentation and dynamic adaptation. To study and analyse use cases along these concepts in networks, a basic building block called "controller" is introduced. Controllers are used in the use cases to further elaborate ANs and the key concepts required to enable them.

A controller is a system with workflows composed of modules, realizing or implementing specific functionalities in the network. A controller's modules can be designed independently of the network architecture, implemented and integrated into the network after verification.

A controller's modules may themselves be workflows, open loops or closed loops.

Examples of controllers are closed loops [ITU-T Y.3115] implemented as software modules that address functionalities such as monitoring, analysis and optimization.

Dynamic changes in network scenarios and states may arise in the network as detected or identified via monitoring of the underlay network. Many of these situations may be hitherto unknown or unseen in the network. The concept of exploratory evolution introduces the mechanisms and processes of exploration and evolution to adapt a controller in response to changes in the underlay network. These processes generate new controllers or update (evolve) existing controllers to respond to such changes and solve the situation or task at hand more appropriately.

The process of exploratory evolution may potentially reduce the role of the human engineer by exploring alternate techniques or "creative" solutions.

Controllers may be tested using testing tools, data generators or real data from the underlay network. Validation of controllers and their logic, using simulated and/or real data, may be done before the deployment of controllers in the network. A comparison of the results of exploratory evolution of controllers may result in the selection of the best variation of the solution or approach. This continuous process, based on monitoring and optimization of deployed controllers in the underlay network, is called real-time responsive experimentation.

Finally, the adapted and validated controllers are integrated at run time to underlay networks. Dynamic adaptation is the final concept in equipping the network with autonomy and the ability to handle new and hitherto unseen changes in network scenarios.

With consideration of the above concepts, an autonomous network is a network which can generate, adapt and integrate controllers at run time using network-specific information and can realize exploratory evolution, real-time responsive experimentation and dynamic adaptation. Hence, networks which are able to handle hitherto unseen changes in network scenarios or inputs, thereby reducing the human effort involved in managing the network, are termed ANs. The use cases analysed in this Supplement point to scenarios where the concepts of exploratory evolution, real-time responsive experimentation and dynamic adaptation can help to realize ANs.

This Supplement provides various types of use cases. These use cases either directly describe various autonomous behaviours or describe the applications that benefit from autonomous behaviours. For each use case, there may be various entities which are involved in different steps of the use case. Such entities, termed here as actors, interact with each other as part of the use case scenario, contributing to use case requirements. Actors may be implemented physically or virtually in the network realizing the use case. Analysis of use case requirements may suggest exemplar components which could realize the use case in the network.

NOTE 1 – The actors can be constituted of elements of different natures, including environment stakeholders such as operators and users, modules, domains and others.

This Supplement provides, where appropriate, actor-interaction diagrams and specific figures of exemplar components, which may help further analysis during later stages of standardization.

NOTE 2 – The components shown in the figures are exemplary in nature, pointing to a possible set of components which may be used in a realization of the use case. They are hereafter referred to as possible components.

The analysis of use cases includes the study of the relations to the concepts of exploratory evolution, real-time responsive experimentation and dynamic adaptation, as well as the derivation of possible requirements and their classification according to the conventions in clause 5.

NOTE 3 – From here on, for simplicity, the concepts of exploratory evolution, real-time responsive experimentation and dynamic adaptation are mentioned as, respectively, "evolution", "experimentation" and "adaptation".

7 Use cases and requirements

This clause describes use cases and their requirements and, where appropriate, actor-interaction diagrams and specific figures of possible components are provided. Use cases are classified into two categories. Category 1 (cat 1) describes scenarios related to the autonomous behaviours themselves. Cat 1 use cases may have requirements related to the components enabling the key concepts of exploratory evolution, real-time responsive experimentation and dynamic adaptation. On the other hand, category 2 (cat 2) describes scenarios related to applications of autonomous behaviours in the network. They may point to the ways in which possible components in the AN interact to enable benefits to the various stakeholders like operators and end users.

7.1 Import and export of knowledge in an autonomous network

<i>Use case ID</i>	AN-usecase-001
<i>Use case description</i>	<p>To satisfy the key concepts of ANs (evolution, experimentation and adaptation) while minimizing human intervention requires knowledge. This knowledge may include representation of data about the environment in which the autonomous system is operating, possible actions and consequences, key configuration options, possible measurement parameters and other elements of logic. This use case describes the scenarios where knowledge is accessed and used by the actors involved in the AN to realize the use case.</p> <p>General use case scenarios comprise the following steps:</p> <ol style="list-style-type: none"> 1) Knowledge is imported from outside or peer entities of the AN components 2) Knowledge is referred to internally in the AN components, e.g., for driving evolution, driving exploration, configuration of automation loops. 3) A report is generated for human consumption 4) Knowledge is stored and updated within the AN components 5) Knowledge is exported from the AN components to the outside or to peer entities.
<i>Use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>References</i>	[b-Clark], [b-AN2020], [b-Jimenez-Ruiz], [b-Myklebust], [b-Turing]

7.1.1 Use case requirements

Critical requirements

- AN-UC01-REQ-001: It is critical that the AN enable the exchange of knowledge between the different involved AN components.
- AN-UC01-REQ-002: It is critical that the AN enable the optimization of knowledge bases.

NOTE 1 – Examples of optimizations applied to the knowledge bases are access policies, granularity of storage, interconnection between various knowledge bases and relation between problems and solutions, addition of new knowledge.

- AN-UC01-REQ-003: It is critical that the AN enable the creation of reports on the use of knowledge bases for consumption by humans and machines.

NOTE 2 – Example of contents of reports are statistics on access of knowledge bases by various AN components as well as network services in the same or different administrative domains.

- AN-UC01-REQ-004: It is critical that the AN enable the exchange of knowledge between the involved AN components and other entities in the same administrative domain.

NOTE 3 – Other entities include AN components and network services.

- AN-UC01-REQ-005: It is critical that the AN use one or more knowledge bases for mapping one or more high level use case descriptions to the controller specification.

NOTE 4 – Controller specification may use languages such as TOSCA [b-TOSCA], whereas use case descriptions may be unstructured. The high-level use case description is to be converted to a structured controller specification. This process of "conversion" may utilize the help of humans (using GUIs) who can better understand unstructured information, and/or automated generation techniques.

Expected requirements

- AN-UC01-REQ-006: It is expected that the AN enable the exchange of knowledge between AN components and other entities in different administrative domains.

NOTE 5 – The entities in other administrative domains include AN components and network services.

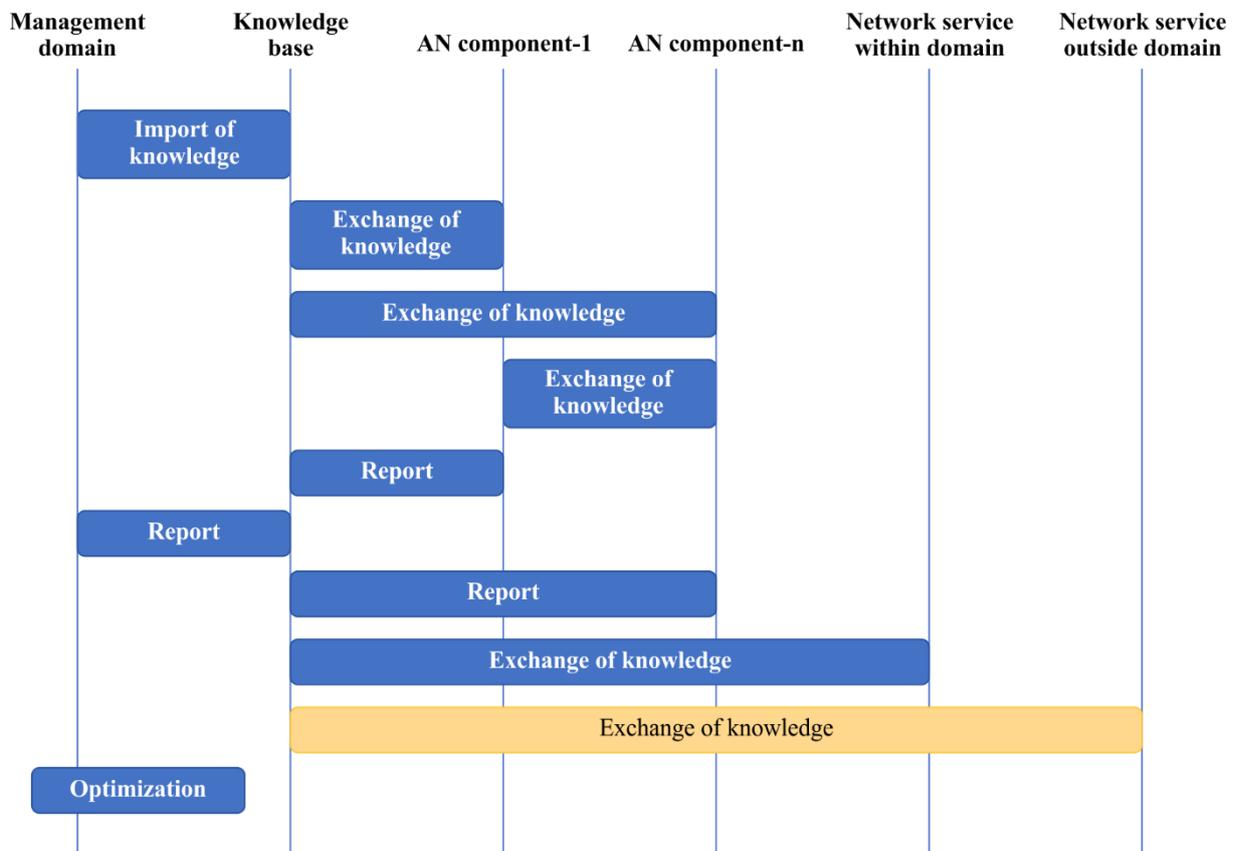
Added value requirements

- AN-UC01-REQ-007: It is of added value that automated generation techniques be used by the AN to produce controller specifications, using the stored controller descriptions and the knowledge base.

NOTE 6 – For example, a graph neural network (GNN) based recommendation engine may be used to help automatic generation techniques.

7.1.2 Actor interactions and possible components

In line with the use case description, Figure 1 illustrates the interactions between various actors for the access and use of knowledge in an autonomous network.



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Figure 1 – Actor interactions for access and use of knowledge in an autonomous network

NOTE 1 – Multiple AN components (1 to *n*) may be present in the system.

NOTE 2 – Actor interactions captured in Figure 1 may not reflect the strict time sequence of activities.

Figure 1 shows the possible interactions between various actors enabling this use case. However, while instantiating this use case in the network, various components may be necessary. Figure 2 shows a possible set of components related to the use case. The possible functions and services exposed are depicted using connectors in the figure. In an implementation instance, these could be either directly connected or accessed via service-based architectures. The exact nature, requirements and implementations related to the components and their interactions are for future study and not in the scope of this document.

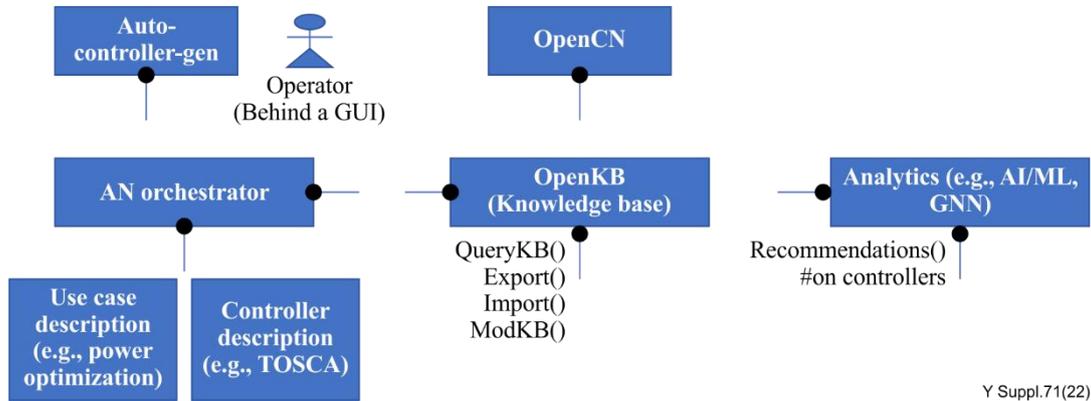


Figure 2 – Possible components related to the access and use of knowledge in autonomous network

Actors involved (Figure 1):

- Management domain: this actor includes entities in the network which configure, monitor and otherwise manage the AN components in the network.
- Knowledge base: this actor stores knowledge which may be queried, stored and updated by various AN components. This may be implemented in the form of an open knowledge base.
- Network services within domain: these actors are network services running within the same administrative domain of the AN. Similarly, there may be network services running outside the administrative domain of the AN.

Possible key components involved (Figure 2):

- AN orchestrator: this component manages the other AN components in the network.
- Autocontroller generator: this component may generate controllers.
- OpenCN: this component provides a repository of controllers.
- OpenKB: this component provides a repository to store knowledge.
- Analytics: this component provides analytics services (including prediction, inferences) for the AN.

7.2 Configuring and driving simulators from autonomous components in the network

<i>Use case ID</i>	FG-AN-usecase-002
<i>Use case description</i>	To explore and experiment with various autonomous behaviour scenarios, the AN component requires access to simulators. Simulators help evaluate the outcome of possible options without potential adverse fallouts in the real network. Long term study of simulation results by human researchers to understand the evolutionary needs of the network is also common. In this respect, the AN components need to interface with, configure and drive the different simulators.

<i>Use case ID</i>	FG-AN-usecase-002
	The following are related steps in this use case scenario: 1) The AN components decide the autonomous behaviour scenarios for exploration and experimentation. 2) The AN components interact with the AN sandbox to configure specific simulators which can perform the required experimentation. 3) The AN sandbox monitors the simulators and reports the completion of simulations. 4) The results are analysed by the AN components and further actions (such as updating the knowledge base) are taken.
<i>Use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>Reference</i>	[ITU-T Y.3172]

7.2.1 Use case requirements

Critical requirements

- AN-UC02-REQ-001: It is critical that AN components arrive at autonomous behaviour scenarios potentially usable for exploration and experimentation.

NOTE 1 – AN components may independently arrive at different autonomous behaviour scenarios usable for exploration and experimentation based on several factors such as the functionalities they implement, the current status of their knowledge, etc. For example, AN components may arrive at candidate strategies to be used for exploration and experimentation for access control. These strategies may be based on game theory approaches or combinatorial optimization approaches.

- AN-UC02-REQ-002: It is critical that AN components trigger experimentation in the AN sandbox.

NOTE 2 – AN components may independently trigger experimentation by configuring simulators in the AN sandbox.

- AN-UC02-REQ-003: It is critical that the AN sandbox collates and aggregates triggers for experimentation to form a coherent, experimentation pipeline, the execution of which is monitored and reported by the AN sandbox to the AN components.
- AN-UC02-REQ-004: It is critical that AN components analyse the reports from the AN sandbox while considering the steps in AN behaviour.

NOTE 3 – The steps in AN behaviour which depend on the analysis of reports from the AN sandbox include steps in evolution and update of knowledge.

7.2.2 Actor interactions and possible components

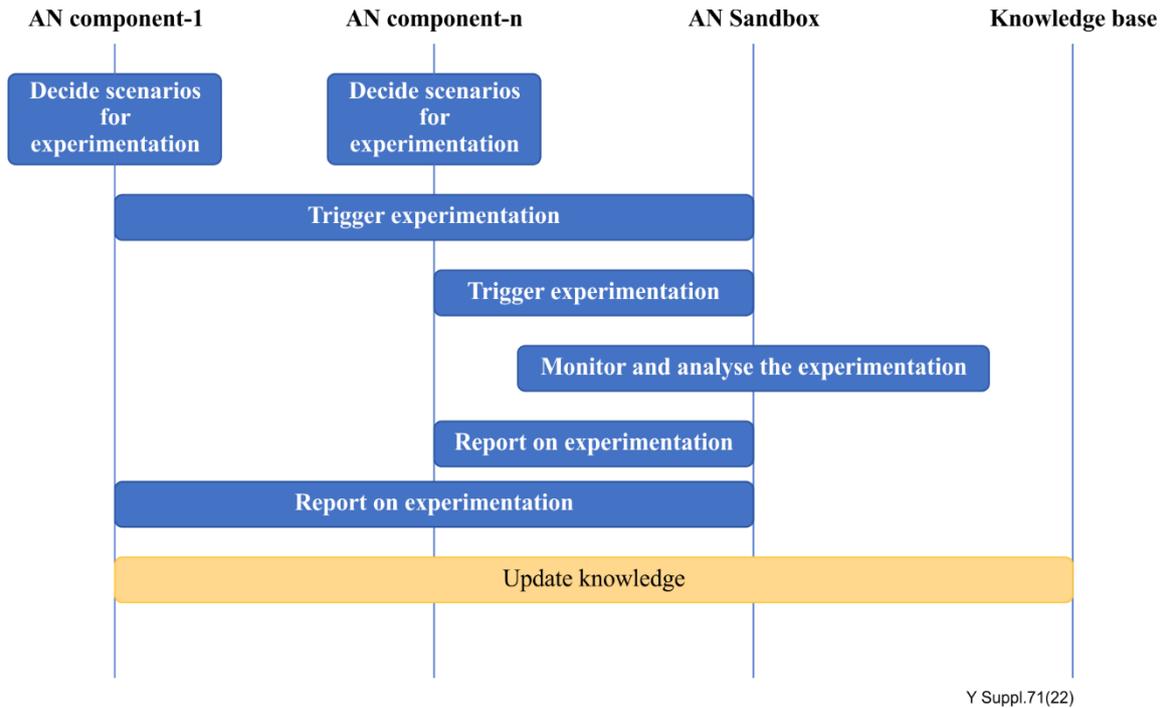


Figure 3 – Actor interactions for configuring and driving simulators from autonomous components in the network

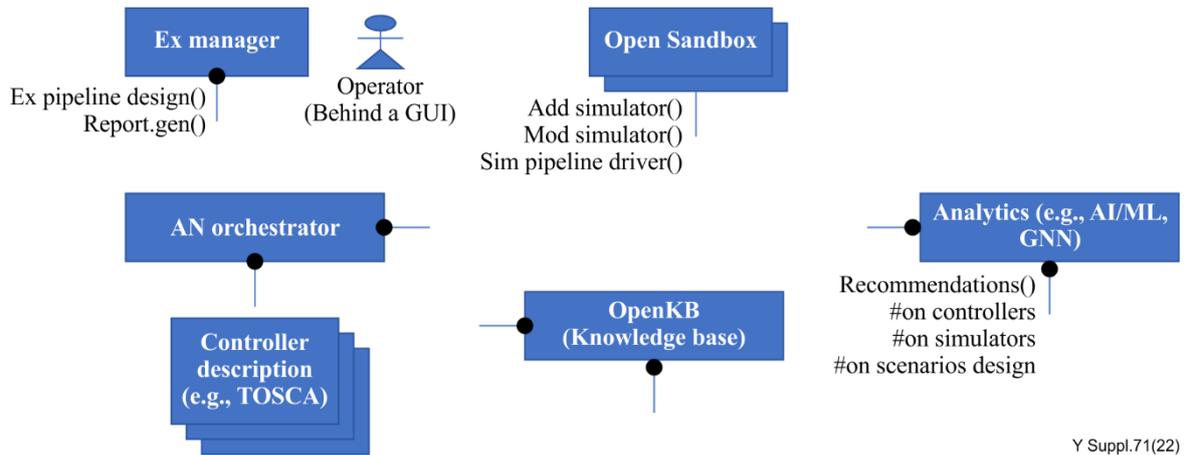


Figure 4 – Possible components related to configuring and driving simulators from autonomous components in the network

Actors involved (Figure 3):

- AN sandbox: this actor provides an experimentation platform for controllers. This allows testing and verification of controllers. This may be implemented in the form of an openly accessible sandbox.
- Knowledge base: this actor stores knowledge which may be queried, stored and updated by various AN components. This may be implemented in the form of an open knowledge base.

Possible key components involved (Figure 4):

- AN orchestrator: This component manages the other AN components in the network.
- Experimentation manager: This component manages the experimentation stage of controllers, including testing and verification.

- Analytics: This component provides analytics services (including prediction, inferences) for the AN.
- OpenKB: This component provides a repository to store knowledge.
- Open sandbox: This component provides an experimentation platform that allows testing and verification of controllers.

7.3 Peer-in-loop (including humans)

<i>Use case ID</i>	FG-AN-usecase-003
<i>Use case description</i>	To guide the autonomous behaviour, AN components require access to peers. Peers include humans and other autonomous entities. Exchange of information with peers helps in taking better decisions. In this respect, AN components need to interface with and exchange information with various other AN components and humans. The following are related steps in this use case scenario: 1) The AN components decide to take guidance from other autonomous entities (peers such as humans). 2) A message exchange with the peer is initiated. 3) The results of the exchange are analysed by the AN components and further actions (such as updating the knowledge base) are taken.
<i>Use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>Reference</i>	[ITU-T Y.3172]

7.3.1 Use case requirements

Critical requirements

- AN-UC03-REQ-001: It is critical that AN components enable synchronous or asynchronous interoperable exchange of feedback or information from peers regarding the decisions and choices related to the AN behaviour.

NOTE 1 – Peers may include humans and machines.

NOTE 2 – Feedback may include exchange of information regarding the AN behaviour such as evolution, experimentation and adaptation. Contents of the information exchanged may include capabilities and status of AN components, e.g., knowledge base, orchestration and simulators. The format used for information exchange is for further study.

7.3.2 Actor interactions and possible components

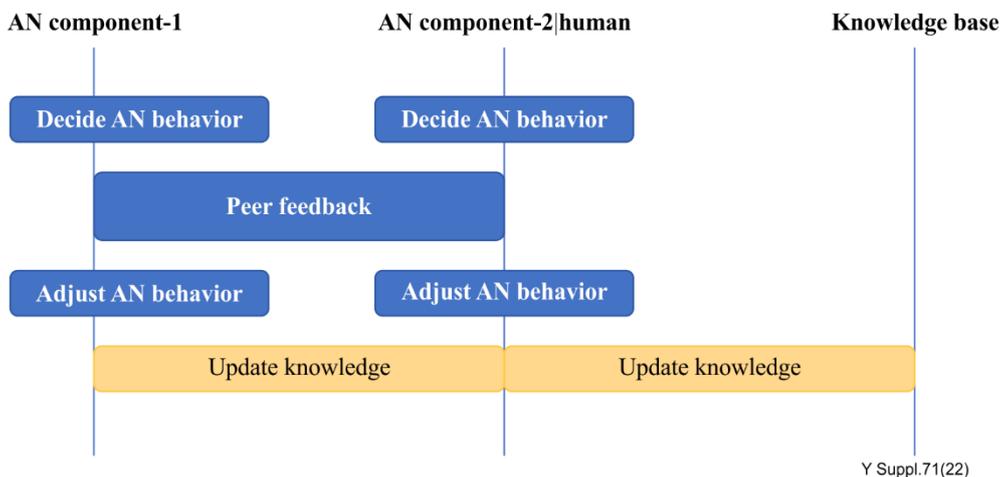


Figure 5 – Actor interactions for peer-in-loop (including humans)

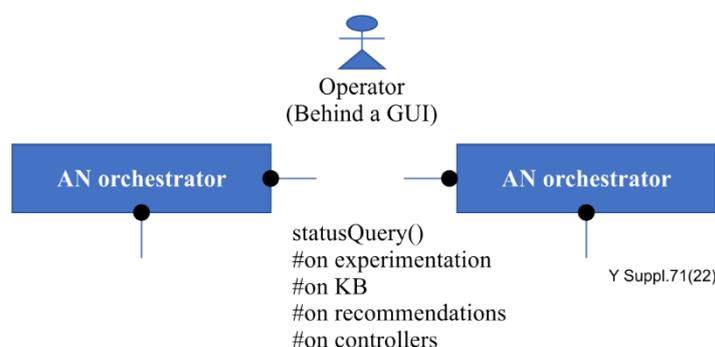


Figure 6 – Possible components related to peer-in-loop (including humans)

Actors involved (Figure 5):

Knowledge base: this actor stores knowledge which may be queried, stored and updated by various AN components. This may be implemented in the form of an open knowledge base.

Possible key components involved (Figure 6):

AN orchestrator: This component manages the other AN components in the network.

7.4 Configuring and driving automation loops from autonomous components in the network

<i>Use case ID</i>	FG-AN-usecase-004
<i>Use case description</i>	<p>There are different automation loops in various domains of the network already proposed by different standards bodies and industry bodies. To reflect the decisions of autonomous behaviour in the network, the AN components require access to automation loops. Automation loops help implement the decisions taken by the AN components in the network. Moreover, it is possible that automation loops provide valuable inputs for AN components to be considered for, say, further experimentation.</p> <p>In this respect, the AN components need to interface with, configure and drive the different automation loops.</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) The AN components decide the configurations of automation loops. 2) The AN components interact with the automation loops to configure specific scenarios which can perform the required automation. 3) The automation loops monitor the automation and report the status of automation. 4) The results are analysed by the AN components and further actions (such as updating the knowledge base) are taken. <p>NOTE – An example of configuring automation loops is to select and provision the type of machine learning (ML) model to be used for domain-specific analytics.</p>
<i>Use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>Reference</i>	[ITU-T Y.3173]

7.4.1 Use case requirements

Critical requirements

- AN-UC04-REQ-001: It is critical that AN components decide the type of closed loops and manage the closed loops.

NOTE 1 – AN components may decide the type and structure of closed loops based on their analysis of reports, monitoring and other information exchanges. Management of closed loops may include instantiating, deletion, updating and other operations on closed loops.

- AN-UC04-REQ-002: It is critical that AN components consider the capability and flexibility offered by closed loops to configure them to perform specific automation tasks.
- AN-UC04-REQ-003: It is critical that closed loops monitor the specific parameters of automation tasks and report them to the AN components.

NOTE 2 – Specific parameters of automation tasks may include data input to automation, analytics used in the closed loop, actions taken as part of automation, failures and error logs.

- AN-UC04-REQ-004: It is critical that AN components consider the reports from closed loops while deciding the AN behaviour.

NOTE 3 – Examples of AN behaviour are evolution, experimentation and adaptation.

7.4.2 Actor interactions and possible components

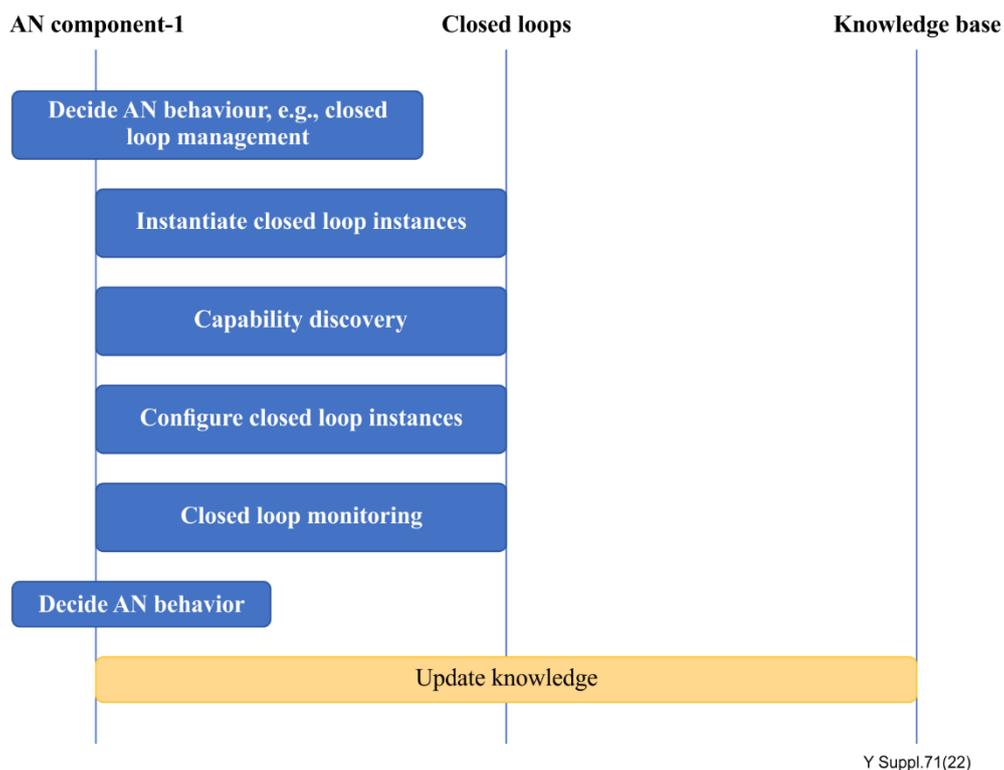


Figure 7 – Actor interactions for configuring and driving automation loops from autonomous components in the network

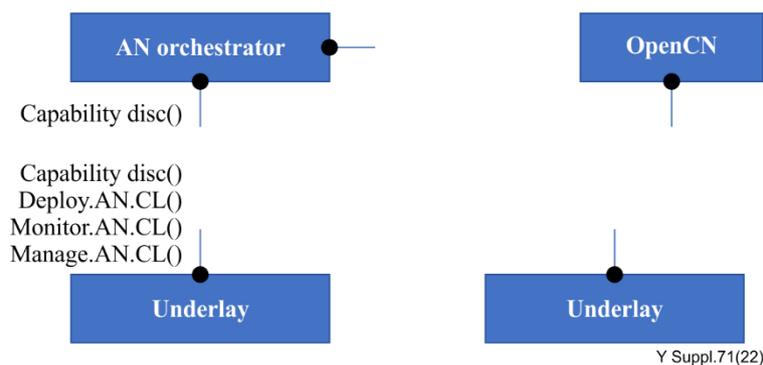


Figure 8 – Possible components related to configuring and driving automation loops from autonomous components in the network

Actors involved (Figure 7):

Knowledge base: This actor stores knowledge which may be queried, stored and updated by various AN components. This may be implemented in the form of an open knowledge base.

Possible key components involved (Figure 8):

- AN orchestrator: This component manages the other AN components in the network.
- OpenCN: This component provides a repository of controllers.

7.5 Domain analytics services for E2E service management

<i>Use case ID</i>	FG-AN-usecase-005
<i>Use case description</i>	<p>Interoperability with components of external frameworks which provide domain analytics and predictions could assist ANs in rapidly integrating with existing network components and reuse functionality which already exists in the network. This use case introduces a scenario where there are already such frameworks deployed in the network and autonomous network components are required to consume services provided by such frameworks.</p> <p>NOTE – For example, [b-ETSI GS ZSM 002] (section 6.5.3.2) describes the domain analytics services which provide domain-specific insights and generate domain-specific predictions based on data collected by domain data collection services and other data.</p> <p>The following are related steps in this use case scenario taking ZSM [b-ETSI GS ZSM 002] as a reference of an external framework.</p> <p>The AN components act as a ZSM service consumer.</p> <ol style="list-style-type: none"> 1) ZSM framework components act as a provider for closed loop (CL) management and other domain and cross domain services (including analytics) to the AN components. 2) Discovery of ZSM services is carried out by the AN components. 3) Each ZSM service performs the end to end (E2E)service management based on the interaction with the AN components. <ol style="list-style-type: none"> a) Examples of interactions are: managing subscriptions, configuring analytics, request analysis results, etc. b) Other examples in the context of zero-touch provisioning, workflow-based automation, provisioning and management of workflows are mentioned in clause 7.5 in [b-FGAN-O-013-R1].
<i>Use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>Reference</i>	[b-ETSI GS ZSM 002]

7.5.1 H3Use case requirements

Critical requirements

- AN-UC05-REQ-001: It is critical that AN support discovery and consumption of the services provided by different types of CL service automation frameworks.

NOTE – Examples of different types of CL service automation frameworks are ETSI ZSM [b-ETSI GS ZSM 002] and FRINX machine [b-FGAN-O-013-R1]. Examples of actions taken by ANs after the consumption of services provided by CL service automation frameworks are managing subscriptions, configuring analytics, request analysis results, etc.

7.5.2 Actor interactions and possible components

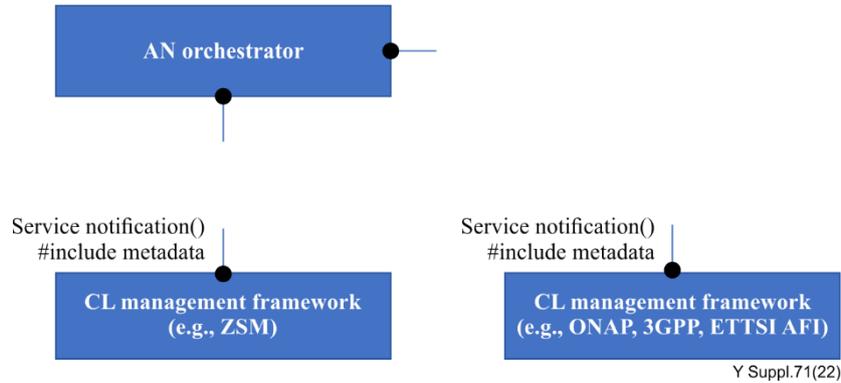


Figure 9 – Possible components related to domain analytics services for E2E service management

Possible key components involved (Figure 9):

- AN orchestrator: This component manages the other AN components in the network.
- CL management frameworks: Closed loop management frameworks e.g., provided by ETSI ZSM, manage CLs in networks.

7.6 Automation and intelligent operation, maintenance and management (OAM) of radio network

<i>Use case ID</i>	FG-AN-usecase-006
<i>Description</i>	<p>Dynamic radio environment, network structure, user behaviour and user distribution drive the network needs to be monitored and optimized continually. Currently, discovering problems, analysing root causes and then formulating solutions for the radio networks consumes a lot of experts' time and labour. Therefore, artificial intelligence (AI) and big data technology is necessary to achieve full process automation and intelligent management of wireless network.</p> <p>Some examples of autonomous management, applicable to the operation, maintenance and management (OAM) of the wireless network, are real-time monitoring of data quality, quasi-real-time diagnosis, root cause analysis, recommended solutions and evaluation of impacts of recommended solutions in the radio network.</p> <ul style="list-style-type: none"> • Real-time monitoring of data quality: There is a need to collect real-time data from the IMT-advanced and IMT-2020 integrated network management, then to compare the consistency of the number of network elements from the collected data, and to achieve data quality monitoring and warning through a visualization panel. • Quasi-real-time diagnosis of abnormal condition in cells: Using several categories of KPI performance indicators, an ML algorithm, e.g., support vector machine (SVM) [b-Cortes], is used to diagnose network elements in these categories of scenarios, such as residential and colleges, on a daily/weekly basis, and distribute them to frontline managers. • Root cause analysis and recommended solutions: Through collecting tens of thousands of expert experiences, radio network knowledge bases have been established through knowledge

<i>Use case ID</i>	FG-AN-usecase-006
	<p>graphs to develop intelligent recommendation algorithms and search engines, and to directly provide reasons and recommend solutions for each network element with abnormal condition to first-line experts, thus reducing the troubleshooting time and error rate.</p> <ul style="list-style-type: none"> • Evaluation of processing effects: Through a mature evaluation system, the effectiveness of the solution to each abnormal condition is evaluated after the implementation, and then the knowledge base and recommendation algorithm are optimized, and the intelligence level of the entire process is continuously improved.
<i>Category</i>	Category 1 – Use case for autonomous behaviour
<i>Reference</i>	None

7.6.1 Use case requirements

Critical requirements

- AN-UC06-REQ-001: It is critical that the AN enable the discovery of problems in underlay networks, the analysis of root cause and the formulation of solutions.

NOTE 1 – Examples of autonomous management, applicable to the OAM of a wireless network are real-time monitoring of data quality, quasi-real-time diagnosis, root cause analysis, recommendation of solutions and evaluation of impacts of recommended solutions in the radio network.

- AN-UC06-REQ-002: It is critical that the AN enable data quality, monitoring and visualization.

NOTE 2 – Data quality may need real-time monitoring, evaluation with respect to the knowledge base, and reporting may be done using an online GUI or a report to human. Data quality may be useful to analytics services.

- AN-UC06-REQ-003: It is critical that the AN enable the capturing and use of the knowledge from domain experts including use of AI/ML mechanisms for the recommendation of solutions based on root cause analysis.

NOTE 3 – An example of a representation format of knowledge is knowledge graphs.

Expected requirements

- AN-UC06-REQ-004: It is expected that the AN use AI and big data technologies to achieve full process automation and intelligent management of networks.

Added value requirements

- AN-UC06-REQ-005: It is of added value that the AN monitor varied sets of KPIs to identify faults.
- AN-UC06-REQ-006: It is of added value that AN solutions may be monitored, optimized and continuously improved.

NOTE 4 – The OpenKB [b-FGAN-O-013-R1] and recommendation algorithms are examples of AN solutions that may be optimized.

7.6.2 Actor interactions and possible components

None.

7.7 Intelligent energy saving for data centres

<i>Use case ID</i>	FG-AN-usecase-007
<i>Description</i>	The rapid growth of mobile Internet, cloud computing and other business is driving the need for large-scale data centres. Data centres consume large

<i>Use case ID</i>	FG-AN-usecase-007
	amounts of energy to run and maintain their cooling system and facilities, servers and other devices. Traditional methods cannot efficiently reduce the energy costs of data centres. Therefore, AI mechanisms are introduced to analyse the monitoring data and adjust the configurations automatically. Intelligent energy saving solutions include a series of autonomous behaviours, such as automatic data acquisition, AI-based energy consumption modelling and inference, facility parameter control policy decision, facility adjustment action implementation, energy saving result evaluation and continuous control policy optimization.
<i>Category</i>	Category 2 – Application of autonomous behaviour
<i>Reference</i>	None

7.7.1 Use case requirements

Critical requirements

- AN-UC07-REQ-001: It is critical that the AN support data acquisition, representation, analysis of collected data and adaptation of configurations in underlay networks such as data centres.

NOTE 1 – Data acquisition and data representations may use industry standards. Analysis may use ML techniques. Adaptations may use the underlay network's specific APIs. Adaptations may be arrived at using controllers or workflows or CLs.

Expected requirements

- AN-UC07-REQ-002: It is expected that the AN support representation, autonomous analysis and continuous optimization of policies.

NOTE 2 – Policies may be related to domain-specific workflows and decisions, e.g., to energy usage in data centres.

7.7.2 Actor interactions and possible components

None.

7.8 Autonomous massive MIMO

<i>Use case ID</i>	FG-AN-usecase-008
<i>Use case description</i>	<p>Massive multiple input multiple output (MIMO) is a key technology in IMT-2020 which can effectively improve the vertical coverage and system capacity in complex scenarios by using a large-scale antenna array and three-dimensional beamforming.</p> <p>Compared with traditional antenna, there are more dimensions of parameters to adjust for a massive MIMO large-scale antenna array, including horizontal lobe width, vertical lobe width, azimuth, dip angle and beam number. Each dimension can be finely adjusted by setting a reasonable step size and theoretically there may be tens of thousands possible combination of antenna parameter weights in a cell. Therefore, manual optimization and adjustment based on scenario/service changes can be very difficult in consideration of multicell coordination.</p> <p>The autonomous massive MIMO use case is about helping operators quickly converge and achieve optimal adjustment of antenna parameters with AI capabilities of multidimensional analysis and prediction. The general workflow is: the IMT-2020 base station collects position information from user equipment (UE) and sends it to the network management system, which then calculates the distribution of UE and finds the optimal weight</p>

<i>Use case ID</i>	FG-AN-usecase-008
	combination with ML algorithms based on the target RSRP/SINR distribution in the current scenario, so as to maximize the utilization of system capacity and guarantee the user experience.
<i>Use case category</i>	Cat 2: application of autonomous behaviour
<i>Reference</i>	None

7.8.1 Use case requirements

Critical requirements

- AN-UC08-REQ-001: It is critical that the AN support the identification of parameters which can be optimized, including ML parameters, based on the use case.

NOTE 1 – An example of the use case is parameter optimization for a massive MIMO large-scale antenna array, including horizontal lobe width, vertical lobe width, azimuth, dip angle and beam number.

- AN-UC08-REQ-002: It is critical that the AN support the identification of data which can be collected to analyse and infer, based on the use case.

NOTE 2 – Examples of data are the distribution of UE, the target RSRP/SINR distribution in the current scenario.

- AN-UC08-REQ-003: It is critical that the AN support identification of KPIs which need to be optimized.

NOTE 3 – Examples of KPIs are system capacity and QoE.

- AN-UC08-REQ-004: It is critical that the AN support optimization of KPIs in distributed deployments which require multicell coordination.

7.8.2 Actor interactions and possible components

None.

7.9 Network resource allocation for emergency management based on closed loop analysis

<i>Use case ID</i>	FG-AN-usecase-9
<i>Use case description</i>	<p>Telecommunication systems are a critical pillar of emergency management. A set of hierarchical AI/ML based CLs could be used to intelligently deploy and manage slice for emergency responders in the affected area. A higher CL in the operational support system (OSS) can be used for detecting which area is affected by the emergency and deploy a slice for emergency responders to that area. It can then set a resource arbitration policy for the lower CL in RAN. The lower loop can use this policy to intelligently share RAN resources between the public and emergency responder slice. It can also intelligently manage ML pipelines across the edge and emergency responder devices by using split AI/ML models or offloading of inference tasks from the devices to the edge.</p> <p>NOTE 1 – An instance of open RAN architecture is explained in [b-O-RAN.WG1.O-RAN-Arch], including near-RT RICs and non-RT RICs which host applications designed to run with different latency requirements (e.g., xApps and rApps). The applications may be implemented independent of the RIC implementations and may be provided by any third party.</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) The mobile network operator (MNO) may instruct the OSS to detect a certain set of emergencies and provide connectivity to emergency responders according to a predefined SLA. <p>NOTE 2 – For example, this input may be provided using an operator intent.</p>

<i>Use case ID</i>	FG-AN-usecase-9
	<p>2) The OSS might deploy a CL to achieve this. It might collect data from sources such as network analytics data, social media scraping, input from emergency responders etc.</p> <p>NOTE 3 – For example, such inputs may be provided from near real time radio access network intelligent controllers (nRT-RICs) or other NFs in the network.</p> <p>3) The OSS might use AI/ML models to detect emergencies and deploy emergency response (ER) slices to the location. It might also create a high level strategy/policy to reallocate resources among the slices.</p> <p>NOTE 4 – Such CLs may be hosted in non-RT RICs and may be used for predictive resource allocations to specific edge locations based on predicted needs, which in turn based on the detected emergency.</p> <p>NOTE 5 – The policy to reallocate resources may depend, among other things, on the type of emergency e.g., natural disaster, earthquake, law and order situation, traffic accident, etc.</p> <p>4) The RAN domain might use this high-level strategy/policy and possibly other inputs from emergency responders to create a CL to arbitrate resources among RAN network slice sub-net instances (NSSI).</p> <p>NOTE 6 – Such CLs may be hosted nearer to the edge, e.g., nRT-RIC. The policy input from the higher loop may indicate, among other things, the different sources of data for the lower loop.</p> <p>5) The RAN domain CL might also decide to offload inference tasks from ER devices to the edge or use a split AI/ML model to run inference tasks on the edge and ER device. This decision might be taken based on available network and compute resources.</p> <p>NOTE 7 – Some layers of the AI/ML model may be hosted in the wearable devices of the emergency responders, which will help in, say, locating persons under distress using various inputs.</p> <p>Relation with autonomous behaviour:</p> <ol style="list-style-type: none"> 1) Workflows for the CLs are independent of each other. The only interaction between CLs is via high level intents over the inter-loop interface. 2) CLs can create new CLs in other network domains without human intervention. 3) Although loops are deployed in a hierarchical fashion, each loop has the ability to evolve independently. It can use different models and ML pipelines as required. Each loop may move up or down the autonomy levels as defined in [ITU-T Y.3173]. 4) CLs have ability to split and provision AI/ML models to other CLs in an automated fashion. 5) By making CLs in the edge domain autonomous, the use case also enables lower orchestration delays and better privacy and flexibility for verticals (e.g., industrial campus networks). 6) Higher loops can use historical knowledge available to them to optimize and generalize lower loops using high-level intent. This increases the efficiency of lower loops while preserving their autonomy. (e.g., the higher loop might know certain kind of ML models are good for cyclone emergency management based on previous cyclones.) <p>NOTE 8 – This use case might be well-aligned with the use case "Composable, hierarchical closed loops" in [b-FGAN-O-013-R1] and others cited above.</p>
<i>Use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>Reference</i>	[b-ETSI GS ZSM 001]

7.9.1 Use case requirements

Critical requirements

- AN-UC09-REQ-001: It is critical that the AN allow interaction between CLs via high level intents.

NOTE 1 – CLs may create new CLs in other network domains without human intervention.

- AN-UC09-REQ-002: It is critical that the AN allow each CL to evolve independently, using different analytical, optimization mechanisms including ML models and ML pipelines as required.

NOTE 2 – Each CL may move up or down the autonomy levels as defined in [ITU-T Y.3173]

Expected requirements

- AN-UC09-REQ-003: It is expected that CLs have the ability to provision or recommend AI/ML models to other CLs in automated fashion.
- AN-UC09-REQ-004: It is expected that CLs in the edge domain may be autonomous, in order to enable lower orchestration delay and better privacy and flexibility for verticals (e.g., industrial campus networks).
- AN-UC09-REQ-005: It is expected that higher CLs use the knowledge base available to them to optimize and generalize lower CLs using high-level intent.

NOTE 3 –This increases the efficiency of lower CLs while preserving their autonomy. (e.g., the higher loop might know certain kind of ML models are good for cyclone emergency management based on previous cyclones.)

7.9.2 Actor interactions and possible components

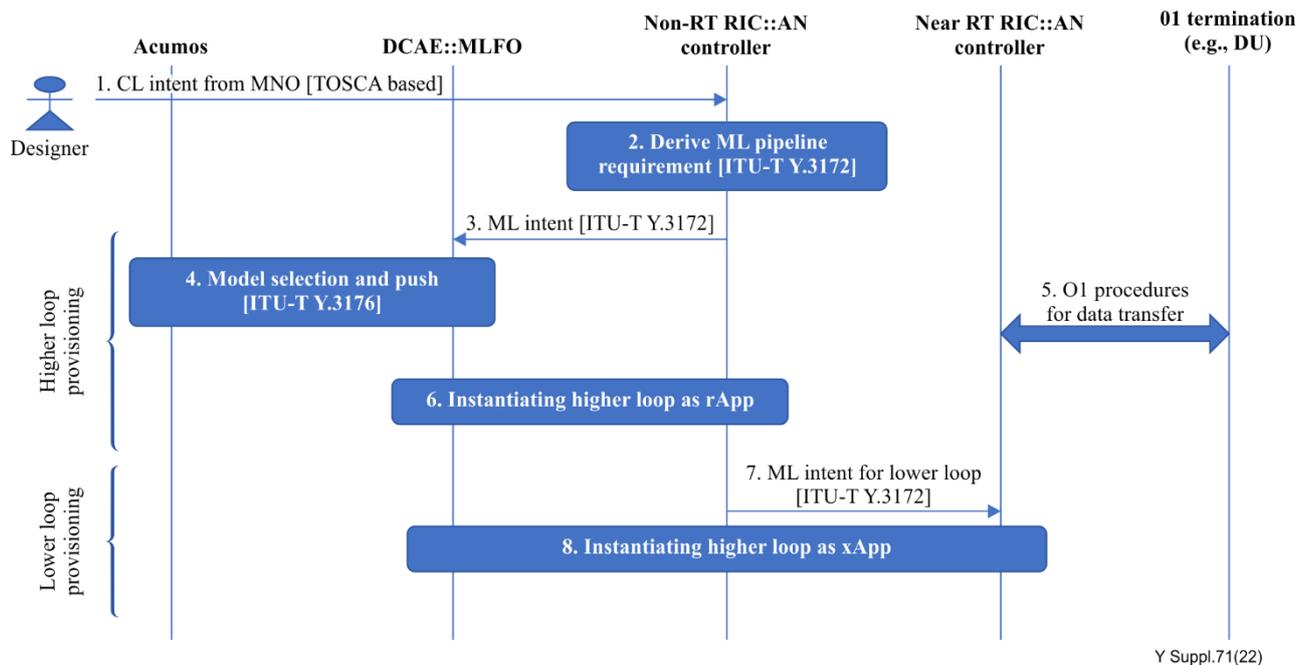


Figure 10 – Actor interactions for network resource allocation for emergency management based on closed loop analysis

NOTE 1 – Create a high-level abstract model for CLs, and then create declarative policies for that high-level model that express the "intent" of creating ML pipelines. The components ("nodes") of the high-level service are decomposed into more concrete services (possibly recursively). Declarative policies must be "translated" into more concrete declarative policies on the decomposed services in conjunction. For example, "non-RT" level service may impose certain CL requirements on a RIC that implements the ML pipeline. "nRT" level service may impose some other CL requirements on a RIC that implements that ML pipeline. This recursive

decomposition coupled with recursive policy mapping happens all the way down until service components can be realized on the available resources. At that point, the low-level declarative policies must be translated somehow into imperative policies (e.g., if jitter exceeds a certain threshold, re-prioritize the traffic associated with the service).

NOTE 2 – "Imperative" policies use the "event/condition/action" pattern, vs declarative policies that use a "capabilities/context/constraints" pattern. Declarative policies are more suitable for top-level "intent" statements, but they need to be translated (by the orchestrator) into corresponding "imperative" policies in order to be actionable. The "propagation" and "escalation" of intents: the "event/condition/action" statements are the control loops being referred to that make sure that service components comply with desired behaviour at all times. By coupling "event/condition/action" control loops with TOSCA's substitution mapping feature, these control loops become "cascading", i.e., they can propagate down from high-level abstract "intent" statements to low-level device reconfigurations, and they can escalate back up if necessary.

NOTE 3 – The events are generated (using notifications) by nodes in the service topology model. The conditions are evaluated based on attribute values of nodes in the service topology model. The actions are performed on the service topology model first, and then propagated to the external world (the "resources").

7.10 Inter-domain service automation (IDSA) – for microfinance

<i>Use case ID</i>	FG-AN-usecase-010
<i>Use case description</i>	<p>Microfinance applications may be hosted by non-experts in IMT-2020 or any form of cloud/ICT technologies. The end-user requirements are domain-specific, e.g., loan management, banking account/ledger management etc. The main stakeholders who are enterprises (e.g., banks) may be knowledgeable and would like to focus only on their business workflows (rather than on cloud/ICT technologies). The underlying cloud infrastructure (for that matter, the application design) and the network infrastructure (IMT-2020 and beyond) is immaterial to a bank/finance manager.</p> <p>However, from a technology perspective, the following objectives are desired to be achieved:</p> <ol style="list-style-type: none"> 1) Give the best end-user experience: e.g., reduced downtime for services, reduced latencies for services, security and data privacy, intelligent services, by exploiting the best cloud service deployment for the microfinance application, e.g., edge, load balancing, secure messaging across multicloud, hybrid-cloud, AI/ML services via distributed cloud. 2) Insulate the end-user from complexities of migration between generations of communication technologies: by providing interoperable, standard, backwards compatible networking abstraction technologies. The integrating service lifecycle management pipeline provides agility to service development and testing. 3) Mitigate the risk of increased integration service costs: by using open source technologies, standards, benchmarking, automating in test beds. 4) Automate: reducing human involvement reduces training costs for banks and operational costs in networks and brings other benefits such as intelligent fault isolation without depending on third party service providers. <p>NOTE – DevOps [b-ISO/IEC 23167] [b-ITU-T Y.3515], CI/CD [b-ITU-T Y.3525] are examples of service lifecycle management pipelines.</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Intent-based cloud service specification. 2) Processing of intent and development, validation in sandbox/testbed. Testbed components (e.g., simulators, data models) are selected based on intent. 3) Evaluation and analysis of test results based on key parameter indice (KPI) specifications in the intent. 4) Derivation of optimal configuration, cloud service deployment, management and orchestration.

<i>Use case ID</i>	FG-AN-usecase-010
	5) Intent-based network service deployment, management and orchestration. 6) Single "cockpit" for monitoring services. 7) Autonomous, intelligence-guided, technology-agnostic migration of services from one version of underlying technology to another and migrating applications from edge to fog. 8) Reports from various parts of the underlying technologies provided to humans in regular or event based intervals.
<i>Notes on use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>References</i>	[b-ISO/IEC 23167], [b-ITU-T Y.3515], [b-ITU-T Y.3525]

7.10.1 Use case requirements

Critical requirements

- AN-UC10-REQ-001: It is critical that the AN consider inputs from the industry vertical solution provider regarding the required service characteristics, using an intent-based mechanism, while deciding the development and deployment options for industry vertical applications and network services.

NOTE 1 – The AN can autonomously decide the best possible development and deployment option for network services which can support the verticals. This has to be based on the requirements of the applications [ITU-T Y.3178]. For example, for banking applications, service characteristics may include latency on banking transactions, mean time between service failures, level of privacy of each field in the customer profile. Examples of deployment options may include edge, core cloud, enterprise network and using specific hardware.

- AN-UC10-REQ-002: It is critical that the AN abstract the management (creation, deletion and update) of the industry vertical applications and network services from the industry vertical solution provider.

NOTE 2 – Underlying domain orchestration, network-specific technologies and APIs are abstracted by AN towards the industry vertical solution provider. For example, banking applications may be hosted as web applications (on popular web frameworks with or without an accompanying mobile component), enterprise applications (e.g., J2EE based). They may be instantiated as cloud-native applications, may use distributed architecture across private/public clouds etc. Service management infrastructure supporting the applications may include brokers, workflow managers and schedulers. Irrespective of such deployment and management variance, AN provides abstracted interfaces to verticals which hide such complexities.

- AN-UC10-REQ-003: It is critical that the AN validate any changes to the application and network services in a sandbox environment before applying it in the network.

NOTE 3 – Autonomous behaviour may result in automated creation, deletion and update of applications and/or network services. The impact of such modified applications and/or network services has to be studied before they are applied in the network. This may be done by using a testbed or sandbox with simulators or even a digital-twin-based environment. Specific emphasis may be applied on maintaining compatibility of the modifications with the applications and network services in the network.

- AN-UC10-REQ-004: It is critical that the AN continuously monitor the application and network services in the network.

NOTE 4 – Monitoring may be done to find erroneous behaviour, faults, gaps in architecture, design, bugs, etc. Monitoring may identify the gaps in end-to-end service implementations with respect to changing intents of the verticals. Thus, monitoring may also be used to find the need for evolution in underlying network domains.

- AN-UC10-REQ-005: It is critical that the AN produce regular and asynchronous reports for human consumption.

NOTE 5 – Reports to humans may summarize all monitored values, analysis, decision points and explanations for such decisions by the AN.

Expected requirements

- AN-UC10-REQ-006: It is expected that the AN provide automated triggers to service the lifecycle management pipeline for management (creation, deletion and update) of application and network services.

NOTE 6 – DevOps [b-ISO/IEC TS 23167], [b-ITU-T Y.3515], CI/CD [b-ITU-T Y.3525] are examples of service lifecycle management pipelines.

NOTE 7 – As part of management of applications, AN may analyse the gaps, faults and issues in the current design and implementation of an end-to-end service. Mitigation of such issues may be triggered to the DevOps pipeline. However, the level of automation of the solution may depend on the capabilities of the DevOps pipeline.

- AN-UC10-REQ-007: It is expected that the AN configuration include the set of reference points which may be used for the integration into end-to-end network services and applications.

NOTE 8 – Even though an AN exposes abstracted interfaces for application management to verticals, to achieve the integration of network services, the AN may use open interfaces or closed black boxes. The availability of open interfaces and corresponding components is to be made known to the AN via configurations. Such configurations may be dynamically changing based on the availability of new components and interfaces.

- AN-UC10-REQ-008: It is expected that the AN propose "recipes" of network services and applications which may satisfy a particular intent from the vertical.

NOTE 9 – Recipes may include a combination of existing application components, network service components, corresponding configuration options, etc.

- AN-UC10-REQ-009: It is expected that the AN be updated at runtime by the underlying domain orchestration about the supported set of reference points in the domain and the available set of network service and application components, which may be used for integration into end-to-end network services and applications.

NOTE 10 – Runtime changes, triggered by the operator or third parties in the underlying domains are made aware to the AN. Such updates may be abstracted and passed by the AN to the verticals, where relevant, for information or policy decisions.

Added value requirements

- AN-UC10-REQ-010: It is of added value that the AN propose a modified "recipe" of network services and applications which may bridge a gap, fix a fault or solve issues in the current design and implementation of end-to-end services.

NOTE 11 – A modified recipe may be based on the analysis of gaps, issues or faults encountered while monitoring network services and applications.

7.10.2 Actor interactions and possible components

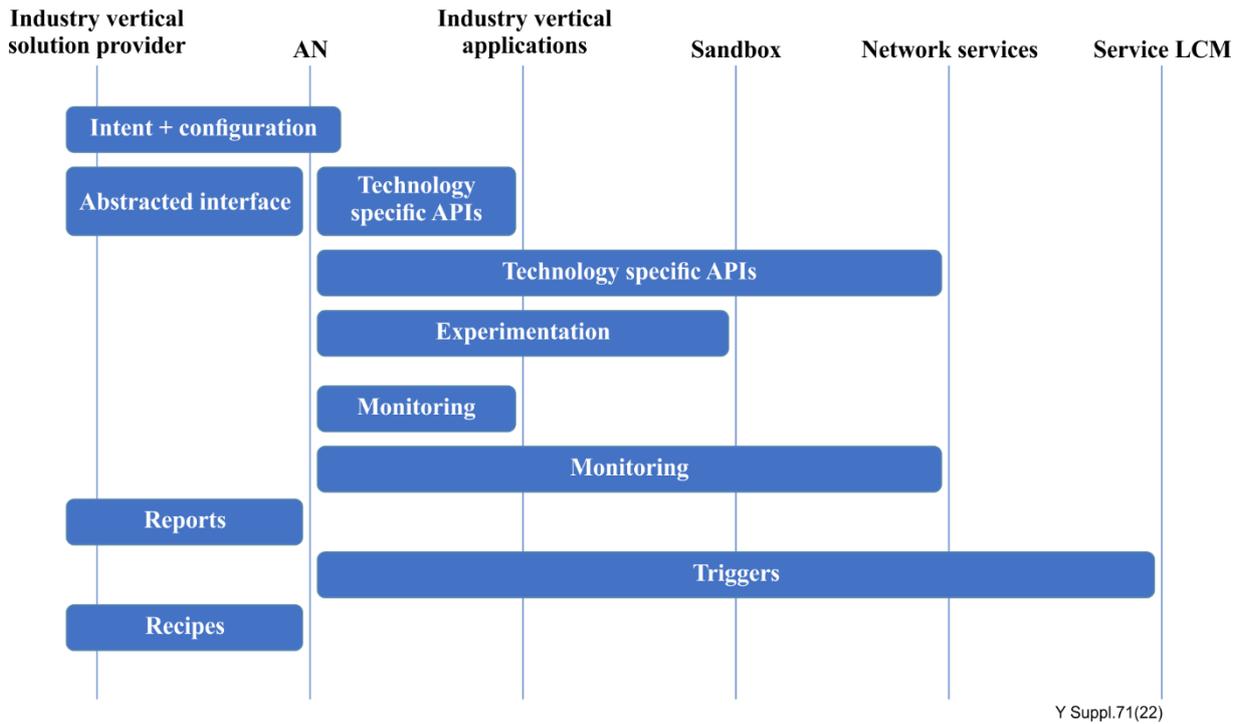


Figure 11 – Actor interactions for inter-domain service automation (IDSA) – for microfinance

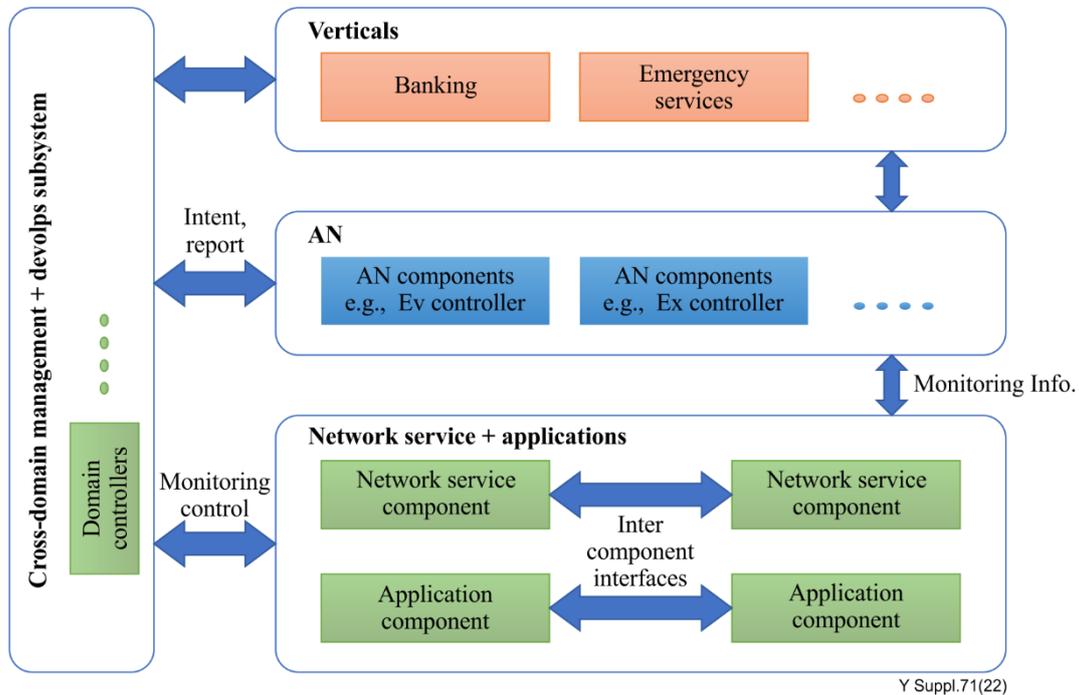


Figure 12 – Possible components related to inter-domain service automation

Actors involved (Figure 11):

- Industry vertical solution provider: this actor provides vertical related services which in turn use network services in the underlay network. For example, an autonomous transport service which relies upon low latency services provided by 5G.

- **Sandbox:** This actor provides an experimentation platform for controllers. This allows the testing and verification of controllers. This may be implemented in the form of an openly accessible sandbox.

Possible key components involved (Figure 12):

- **Network services and applications:** includes services and applications deployed in the network, including their interfaces.
- **Verticals:** Includes applications used by end users e.g., banking and emergency services.
- **Domain controllers:** part of the management subsystem, provides monitoring, configurations and supports reporting by various other components in the network.
- **Ev controller:** Evolution controller.
- **Ex controller:** Experimentation controller.

7.11 Autonomous vertical-driven edge service and middle-mile connectivity for rural financial inclusion (FI)

<i>Use case ID</i>	FG-AN-usecase-011
<i>Use case description</i>	<p>Digital financial inclusion (FI) in many geographies is limited because of the lack of network availability and low reliability of connection. Frequently, bank branches have to fall back on costly and complex connectivity through satellites. Other than the capital and operational aspects, the bank staff also need to handle the link failover and maintenance activities in case of issues. Furthermore, such solutions do not allow local community to utilize the network.</p> <p>Autonomous last hop connectivity both through IMT-Advanced/IMT-2020 as well as other non-3GPP heterogeneous networks needs to be seamlessly enabled to operate in an affordable manner. The solution is likely to provide the following benefits:</p> <ol style="list-style-type: none"> 1) Based on the requirements from the verticals, connectivity for rural finance (FI) sites independent of network providers or large telcos. 2) Allowing the connectivity to be shared with the local community to ensure a better return on investments. 3) Edge computing and related infrastructure can enable more compelling deployments for digital FI as well as other verticals (e.g., short-term telecommute/interviews etc.). 4) Automated operations and security audits: reducing human involvement in maintaining and running the edge or last hop reduces training costs for banks, operational costs in networks and brings other benefits such as intelligent fault isolation without depending on third party service providers, continuous audit of deployed solution for security, etc. <p>The following are related subsystems and associated steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Deploy micro-servers/nano-data-centres for the edge. 2) Enable heterogeneous network connectivity. 3) Autonomous, intelligence-guided handling of alignment or interference or mobility related challenges for various last hop approaches. 4) Automate onboarding of community users and community specific apps, their billing/payments etc. 5) Single "cockpit" for monitoring the services and health of infra to local-bank-staff/managed-service-provider. 6) Reports from various parts of the underlying technologies are provided to humans in regular intervals or event based. This includes sharing of usage details with authorized management systems, These reports may be used for tracking the usage at a granular level, mapped to the vertical and the tracking

<i>Use case ID</i>	FG-AN-usecase-011
	the corresponding benefits from the infrastructure, e.g., for the purpose of extending subsidies to such infrastructure.
<i>Notes on use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>Reference</i>	None

7.11.1 Use case requirements

Critical requirements

- AN-UC11-REQ-001: It is critical that the AN utilize heterogeneous network connectivity options at the edge in the last mile, including the commissioning, provisioning, configuration, integration, maintenance and optimization, in a seamless, real-time and easy-to-use manner.

NOTE 1 – Especially in rural settings the technology of choice may vary considerably depending on various factors such as availability of technology, ease of deployment, low power consumption, etc. Currently, in such deployments, it invariably rests upon the industry vertical solution provider to also take on the responsibility of integrating and maintaining these varied last-mile connectivity options. It is important that the AN bring together various such technologies under one umbrella, at the edge, to provide seamless integration and maintenance. Some of the operations in the lifecycle of the last-mile connectivity may need real-time interventions, some of it may need deep domain expertise and some of it may require training – all of which may not be possible in certain rural settings.

- AN-UC11-REQ-002: It is critical that the AN enable sharing of the various network connectivity options at the edge across the community-driven industry vertical applications.

NOTE 2 – With an emphasis on providing maximum connectivity and application services to the local community, the best available option for connectivity is to be chosen, if needed, dynamically.

- AN-UC11-REQ-003: It is critical that the AN enable onboarding of industry vertical applications at run time.

NOTE 3 – Evolution of needs in a local community may result in changing application requirements.

- AN-UC11-REQ-004: It is critical that the AN enable common, open, interoperable, adaptable mechanisms for managing end users, based on the needs of the local community.

NOTE 4 – Onboarding, billing, problem resolutions and other end-user management functions need to be agnostic and community-driven at the edge. Based on the use cases, the mechanisms for end-user management have to adapt. For example, for low-mobility rural areas, a relevant tariff plan needs to be offered.

- AN-UC11-REQ-005: It is critical that the AN enable a single window of monitoring the heterogeneous underlying technologies.

NOTE 5 – The complexities of monitoring, administering and maintaining the underlying technologies need to be hidden from the industry vertical solution provider as well as the local communities.

7.11.2 Actor interactions and possible components

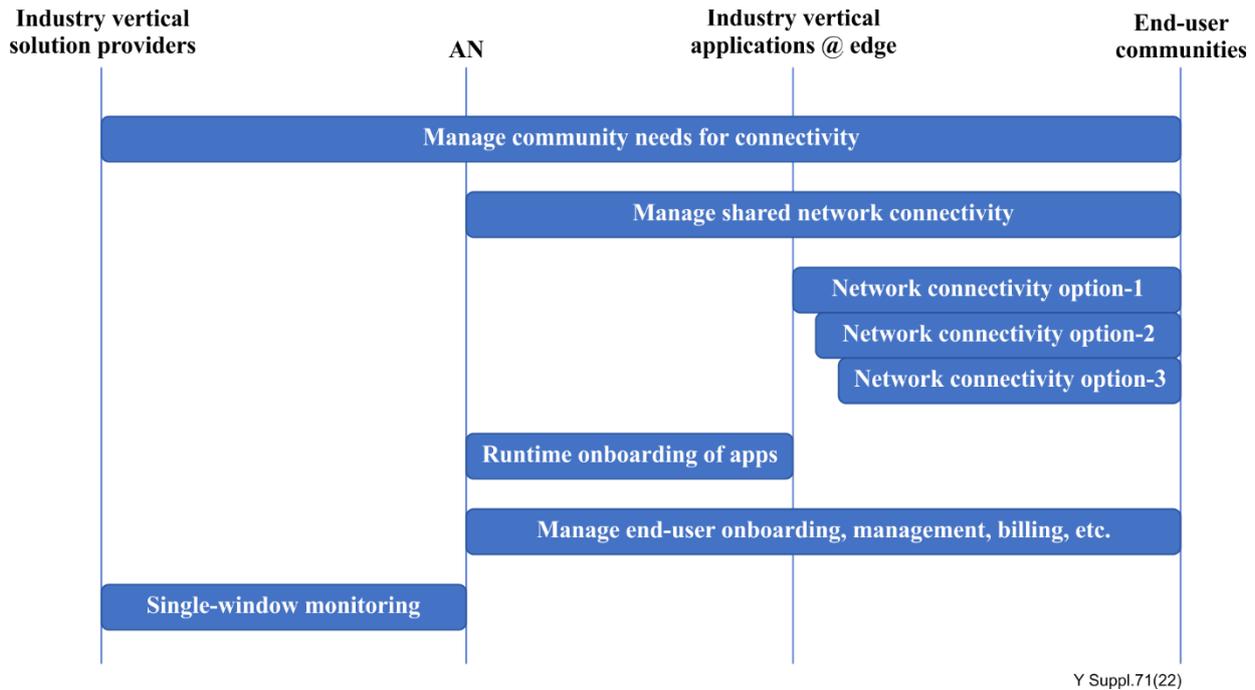


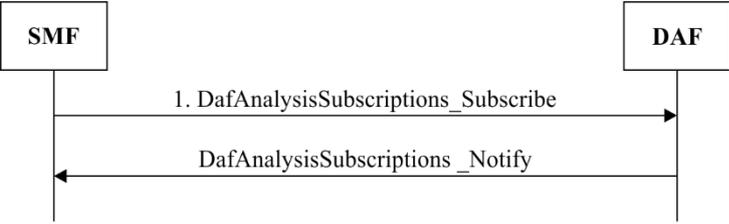
Figure 13 – Actor interactions in the autonomous vertical-driven edge service

Actors involved (Figure 13):

- Industry vertical solution provider: this actor provides vertical related services which in turn use network services in the underlay network, e.g., autonomous transport service which rely upon low latency services provided by 5G.
- End-user communities: this actor represents a set of end users in a specific geographic location, with specific connectivity requirements.

7.12 Signalling flows for autonomous IMT-2020 network

<i>Use case ID</i>	FG-AN-usecase-012
<i>Use case description</i>	<p>Data analysis function (DAF) is introduced in the IMT-2020 network [b-ITU-T Y.3104]. The signalling flow between DAF and other network functions (NFs) (e.g., session management function (SMF), policy control function (PCF), network access control function (NACF) and application function (AF) describes data collection and analysis result providing.</p> <p>The procedure in Figure 14 is used by DAF to collect data on event(s) related to SMF by invoking the SmfEventSubscription service.</p> <p style="text-align: right;">Y Suppl.71(22)</p> <p>Figure 14 – Signalling flow for data collection from SMF</p> <p>1) The DAF subscribes to or unsubscribes from a (set of) events (e.g., UE IP address, UP path change, protocol data unit (PDU) session</p>

<i>Use case ID</i>	FG-AN-usecase-012
	<p>establishment/release, etc.) by invoking the SmfEventSubscription_Subscribe service operation.</p> <p>2) The SMF notifies the DAF (e.g., with the event report) by invoking the SmfEventSubscription_Notify service operation.</p> <p>The procedure in Figure 15 is used by NF service consumers (e.g., SMF) to request analytics information from DAF by invoking the DafAnalysis_Request service.</p>  <p style="text-align: right;"><small>Y Suppl.71(22)</small></p> <p>Figure 15 – Signalling flow for analytics subscribe/unsubscribe from DAF</p> <p>1) SMF subscribes to or unsubscribe from a (set of) data analytic events by invoking the DafAnalysisSubscriptions_Subscribe service operation. Subscription requirements of data analytic events may include load information of UPF.</p> <p>2) The DAF notifies the SMF about analysis events by invoking the DafAnalysisSubscriptions_Notify service operation.</p>
<i>Use case category</i>	Cat 1: autonomous behaviour in IMT-2020 network
<i>Reference</i>	[b-ITU-TQ.5024]

7.12.1 Use case requirements

Critical requirements

- AN-UC012-REQ-001: It is critical that the AN enable flexible provisioning and subscription of analysis parameters in NFs.

NOTE – Examples of analysis parameters are events, notifications, corresponding information and event handing controllers. NFs may dynamically provision or subscribe to controllers and corresponding parameters.

7.12.2 Actor interactions and possible components

None.

7.13 Plug/play of network instance

<i>Use case ID</i>	FG-AN-usecase-013
<i>Use case description</i>	<p>Benefits of open architecture approach include:</p> <ul style="list-style-type: none"> – Reducing capital expenditure (CAPEX) through a prosperous multivendor ecosystem with scale economics. However, more the number of interfaces, the greater the effort in integration. This needs to be mitigated using automation. – Enabling a rich application space using hierarchical controllers. The hierarchical control loops with varying time criticalities (<10 ms (at edge), <1 s (at near edge) < multisecond (at orchestrator)) were discussed in [b-FGAN-O-013-R1]. However, provisioning of applications at various levels and corresponding coordination with capabilities of the NFs is a challenge. <p>In this context, the use case "plug/play of network instance" in open architecture is introduced.</p> <p>NOTE – The network instance can be a network resource, a network function, a network slice and network services [b-ETSI GS ZSM 001].</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Addition of sources (SRCs) [ITU-T Y.3172]: the network instance is plugged into the network. Data collection functions supported by this new SRC are analysed. 2) Bottom-up bootstrapping of infrastructure layer (using cloud orchestration), network as a service (NaaS, using open networking automation platform (ONAP)), services layer (using service orchestration), based on these new SRCs. <p>OR</p> <p>Top-down bootstrapping of apps, services, NaaS, infrastructure, based on these new SRCs.</p>
<i>Use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>References</i>	[b-FGAN-O-013-R1], [b-ETSI GS ZSM 001], [ITU-T Y.3172]

7.13.1 Use case requirements

Critical requirements

- AN-UC013-REQ-001: It is critical that the AN enable the plug and play of NFs in the underlay network and subsequent seamless participation of such NFs in the AN functions.

NOTE – Examples of AN functions are creation and hosting of controllers. Plug and play may be executed by manual or autonomous mechanisms.

7.13.2 Actor interactions and possible components

None.

7.14 Generative adversarial sandbox (or hybrid closed loops)

<i>Use case ID</i>	FG-AN-usecase-014
<i>Use case description</i>	<p>In addition to open interfaces between various RAN components, a rich ecosystem of simulators is evolving. This allows implementation of various "hybrid" CLs – part of the CL (e.g., data generation) is implemented in simulators whereas rest of the CL (e.g., analysis and action) are implemented in another part of the test network using real network functions (NF).</p> <p>This use case introduces the "generative adversarial sandbox" (or "hybrid CLs").</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Based on the inputs from the NF (e.g., data from SRC) and existing CLs, simulator configurations and capabilities are autonomously scripted. 2) Hybrid CLs are autonomously composed – with parts of the CL in real NF and parts of it in simulators. 3) Similar to the process for generative adversarial Networks, hybrid CLs are evaluated and tested using a two-part network – one with simulated and another real NFs. 4) The results are analysed and ranked.
<i>Use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>Reference</i>	None

7.14.1 Use case requirements

Critical requirements

- AN-UC014-REQ-001: It is critical that the AN enable creation of hybrid CLs with parts of the CLs hosted in real NFs as against other parts of it in simulated NFs.

NOTE 1 – Examples of parts of CLs are modules which generate data, modules which implement domain-specific functions, modules which provide APIs for implementation of adapting decisions from controllers.

- AN-UC014-REQ-002: It is critical that the AN enable testing and validation of CLs using the parts of CLs hosted in simulated NFs.

NOTE 2 – Examples of such testing are robustness related test scenarios, security and vulnerability testing scenarios.

7.14.2 Actor interactions and possible components

None.

7.15 Open, integrated, log analysis

<i>Use case ID</i>	FG-AN-usecase-015
<i>Use case description</i>	<p>Fault prediction and isolation based on log analysis is an important existing use case. Logs are generally implemented in unstructured text with no standard formats. With a disaggregated network service implementation, correlating logs from various vendors becomes a challenge. This complicates the fault prediction and fault isolation algorithms based on unstructured data from logs.</p> <p>This use case introduces "open, integrated, log analysis".</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Collection of logs from various open interfaces and NFs. 2) Correlation and analysis of the collected logs, across various open interfaces and NFs. 3) Identification of optimization mechanisms based on log analysis.

<i>Use case ID</i>	FG-AN-usecase-015
<i>Use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>Reference</i>	None

7.15.1 Use case requirements

Critical requirements

- AN-UC015-REQ-001: It is critical that the AN enable correlation and identification of relevant logs, their access using open interfaces, analysis and resulting optimization of underlay networks to apply specific adaptations.

7.15.2 Actor interactions and possible components

None.

7.16 Composeable, hierarchical closed loops

<i>Use case ID</i>	FG-AN-usecase-016
<i>Use case description</i>	<p>There are different automation loops in different levels of the architecture. High level use cases (such as log-analysis-based fault prediction) require access to capabilities of various network instances. This in turn may be provided by multiple vendors or open source providers. Thus, the provisioning and management of CLs should be driven hierarchically.</p> <p>This use case introduces "composeable, hierarchical CLs".</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Declarative specifications decide the high-level aspects of CLs. 2) They are in turn correlated with declarative specifications for network services. 3) These are then used to generate detailed declarative specifications for CLs in different parts of the network. 4) Orchestrators at various levels generate commands to provision and manage the CLs based on these generated declarative specifications. 5) The declarative specifications and/or CL components may be stored/updated for regeneration of CLs at any point of time.
<i>Use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>Reference</i>	None

7.16.1 Use case requirements

Critical requirements

- AN-UC016-REQ-001: It is critical that the AN enable composition of hierarchical CLs using declarative specifications.
- AN-UC016-REQ-002: It is critical that the AN enable derivation of controllers at various levels of the network.
- AN-UC016-REQ-003: It is critical that the AN enable management of declarative specifications of controllers.

NOTE – Management operations on declarative specifications may include creation, storage, update, delete, etc.

7.16.2 Actor interactions and possible components

None.

7.17 Quality of experience (QoE) prediction as-a-service (QPaaS)

<i>Use case ID</i>	FG-AN-usecase-017
<i>Use case description</i>	<p>Intelligent and autonomous troubleshooting is a crucial enabler for the current IMT-2020 and networks beyond. Autonomous troubleshooting is challenging for several reasons, one of which is the availability of a wide range of applications that future networks will support.</p> <p>Traditionally, the methods to gain insight into the delivered quality of service and user experience have been controlled laboratory experiments, where users' opinions have been collected. The results are then reported in mean opinion scores (MOS), corresponding to the average of users' views. These methods are often referred to as subjective quality assessment, and there are standardized methods for conducting them.</p> <p>In this use case, an application or network service (NS) provider uses a QoE-prediction-as-a-service (QPaaS) autonomous system to conduct and follow-up QoE measurement and prediction.</p> <p>Firstly, the autonomous system conducts subjective tests to measure user experience of participating users. The locations and specifications of which users are selected and how the users' responses affect the QoE depend on the application and is learned by the autonomous system. The autonomous system also measures relevant user parameters to map user opinions and application KPIs.</p> <p>Secondly, the autonomous system follows applicable network KPIs and map network and application KPIs.</p> <p>Thirdly, based on this mapping, the autonomous system enables the application provider to predict the QoE of its users based on network KPIs regardless of their participation. The autonomous system continuously (or periodically) improves the prediction accuracy by random subjective tests or user behaviour analysis.</p> <p>Related steps in this use case scenario are:</p> <ul style="list-style-type: none"> • Application or NS provider demands and deploys a QPaaS from a third-party server. <ul style="list-style-type: none"> ○ Application or NS provider provides a mechanism to collect/use user feedback and network metrics. • Identify a method of measurement for QoE: <ul style="list-style-type: none"> ○ Perform subjective tests, e.g., video streaming, two-way communications, etc. User opinions are elicited on a scale of 1–5 or thumbs up/down. ○ Perform user behaviour analysis, e.g., gaming, augmented reality/virtual reality (AR/VR), driver assistance, etc. In a group of gamers connected via various communication service providers (CSPs), if the gamers from a particular CSP face delays or a specific cell site (geographic area) is facing latency, the gaming scores and avatar behaviour itself leave enough clues on the QoE. Similarly, on AR/VR, the level of engagement/interaction, or in assisted driving, the level of coordination between vehicles, can be measured. • The QPaaS server collects/processes network and application KPIs. • The QPaaS server determines a mapping between application KPIs and application QoE metric (MOS) using (supervised) machine learning. <ul style="list-style-type: none"> ○ This mapping may be used by the application server for future objective testing of user QoE. • The QPaaS server collects/processes relevant NS KPIs and forms a mapping between network KPI and application KPI (or MOS) using (supervised) machine learning. <ul style="list-style-type: none"> ○ The NS provider may use this mapping for future objective testing of network performance given the application.

<i>Use case ID</i>	FG-AN-usecase-017
	<ul style="list-style-type: none"> Perform periodic verification with subjective tests/user feedback, and improve learning based on the results. <p>Due to various applications, QoE measurement and prediction is a significant issue in future networks. The network should be able to autonomously perform QoE measurement and mapping of network KPI to QoE metrics.</p> <p>NOTE – As applications and NSs evolve, so do their corresponding KPIs and the mappings (user satisfaction parameters, to application KPIs and to network KPIs). See related open issues below which handles information exchange between evolving applications and NS and QPaaS.</p>
<i>Notes on use case category</i>	Cat 2: describes a scenario related to the application of autonomous behaviour in the network.
<i>References</i>	[b-Jahromi], [b-Pierucci], [b-Bouraqia], [b-Liu]

7.17.1 Use case requirements

Critical requirements

- AN-UC017-REQ-001: It is critical that the AN use both subjective information from users and QoE information derived and analysed from network services to arrive at the application QoE metric.

NOTE 1 – Subjective information from users may include user opinions and subject measures e.g., opinions on a scale of 1–5 or thumbs up/down about a streamed video. Examples of QoE information derived and analysed from network services are the level of engagement/interaction in an online game, and analysis of gaming scores and avatar behaviour.

- AN-UC017-REQ-002: It is critical that the AN learn and update the process of information collection from users and derivation from network services.

NOTE 2 – For example, the parameters collected, the mechanisms for collecting and the sample set for collection may be learned and updated. Also, the mapping between the application QoE metric and the information collected from users and derived from network services may evolve over a period of analysis.

NOTE 3 – The mapping between the application QoE metric and the information collected from users and derived from network services may be modelled using AI/ML techniques.

- AN-UC017-REQ-003: It is critical that the AN evolve and update the mapping between the application QoE metric, network KPIs and application KPIs.

NOTE 4 – The process of evolution and adaptation may be triggered by application feature additions, network service updates or user device updates.

Expected requirements

- AN-UC017-REQ-004: It is expected that the AN enable the plugin of QoE prediction algorithms.

NOTE 5 – QoE prediction algorithms may be integrated based on abstract APIs exposed from the AN, which are agnostic to the type of application and the specific underlying network technology.

7.17.2 Actor interactions and possible components

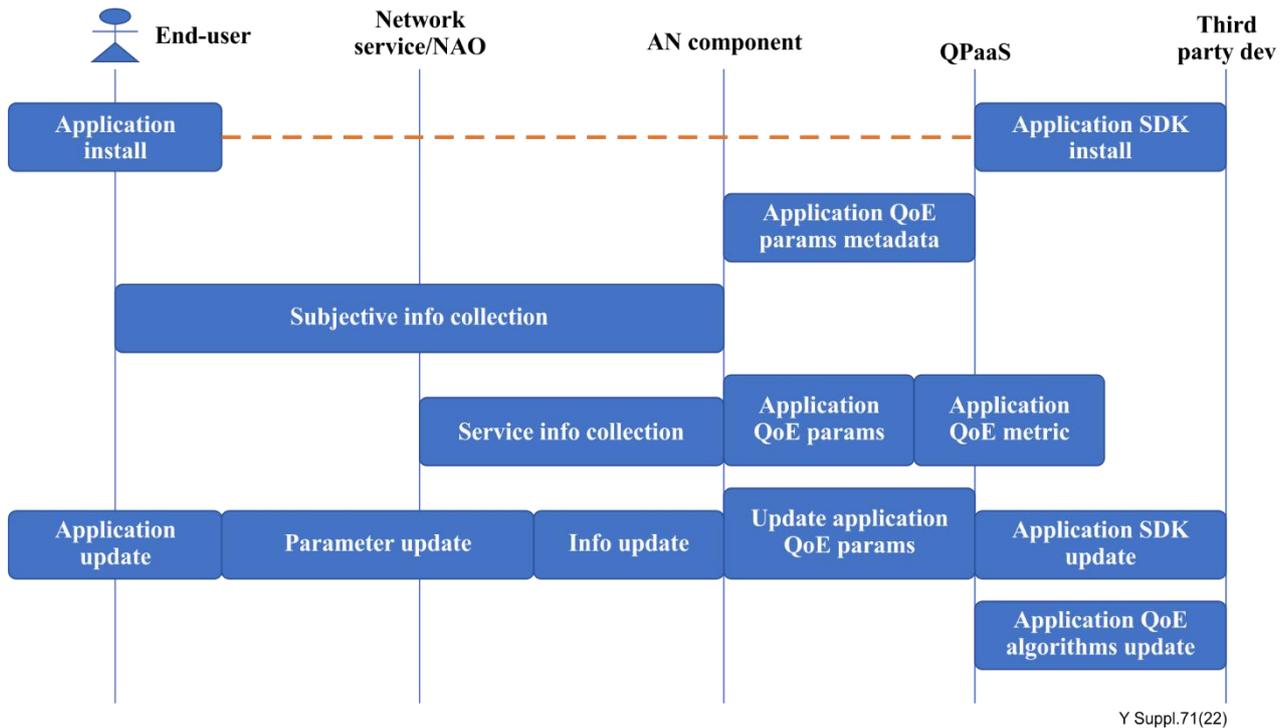


Figure 16 – Actor interactions for quality of experience (QoE) prediction as-a-service (QPaaS)

Actors involved (Figure 16):

QPaaS: QoE-prediction-as-a-service is an actor which provides a platform to host third-party applications which can predict the QoE experienced by end users while using a specific application.

7.18 Autonomy applied to content delivery networks (CDN)

<i>Use case ID</i>	FG-AN-usecase-18
<i>Use case description</i>	<p>[b-FGAN-O-013-R1] introduced autonomous content delivery networks (CDN), especially looking at a few key aspects of CDN and what makes them unique, focusing on several of their properties and approaches that can leverage to increase their autonomy. With increasing bandwidth of networks, proliferation in the connected devices, increasing demand of content (e.g., live video, cloud gaming, 360 video), build-your-own approach to CDN enabled by cloud services, cloud based CDNs are attractive but bring several challenges. However, caching based on data analysis remains unsolved while CDN providers struggle to provide rich content at high QoE.</p> <p>[b-FGAN-O-013-R1] called out specific aspects that need programmability-routing, caching and eviction. Importance of logging and metrics were called out on request/response metadata, timing information and internal logic decisions. Current implementations of CLs for managing CDN are simplistic, e.g., standard autoscaling in the context of CDN, increasing the stream-per-node approach by hardware beef-up (better compute, more cores, more memory, L1 cache, networking including PCIe 4.0, cryptographic acceleration).</p> <p>The following considerations are important to note in the context of autonomous CDNs:</p> <p>1) Metric for success: CDN usually define their success based on whether they can serve the user traffic. But this has a cyclic effect because the ability to attract</p>

<i>Use case ID</i>	FG-AN-usecase-18
	<p>traffic depends on how well CDNs process the traffic they currently have. The challenging part is the metric used to judge the CDN.</p> <p>NOTE – For example:</p> <ol style="list-style-type: none"> a) Incorporating the current number of requests into the score would be useful. b) If there is anonymized access to user QoE data, how fast the page loaded, this would be a useful metric. c) Another option is to measure the response time from the CDN (usually abridged to the hit ratio). d) Include other overlays in the measurement e.g., control planes, service management, tiered storage design. e) Going beyond autoscaling to healing, load balancing and edge compute, concurrency. <ol style="list-style-type: none"> 2) Adapting the possible caching strategies (needed especially for memory intensive contents which require large memory in CDN): <ol style="list-style-type: none"> a) based on the treatment of various type of content and CDN use cases in the cache. e.g., live video that is cached for a brief period of time, VoD, live transcoding b) To reduce the time to live (TTL) to avoid keeping infrequently popular objects in cache. <ol style="list-style-type: none"> i) bypass the cache for large objects, or for certain classes of users, or particular extensions. ii) use the disk, or explicitly forbid it. iii) take advantage of flexibility provided by virtual cache. 3) Decoupling the components helps standardization: <ol style="list-style-type: none"> a) Open-caching is pushing to provide a subset of metrics. b) Perhaps an opportunity to derive "upstream" gaps in standards and lead an open source proof of concept (PoC). c) Study of an open, interoperable CDN components – e.g., caching, transcoding, analytics which can help independent evolution of the CDN pipeline, while taking advantage of the work in other bodies e.g., encode/decode, AI, graphics, and hardware evolution e.g., compute/mem/network/acceleration. d) Similarly, take advantage of the software deployment trajectory towards cloud native. <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Outer loop: Represent the "QoS/QoE requirements" in an intent, deployment considerations (e.g., hardware, cloud) are to be captured in the intent. Software/CDN pipeline considerations are to be captured here too. 2) Based on analysis, derive the cache policy, action: autoscaling/traffic routeing, geographical location (e.g., edge), and decide storage configurations, APIs and concurrency mechanisms. 3) Experiment to determine a good combo of KPIs, data measurement, policies, action areas (e.g., scaling, positioning). 4) Inner loop: Adapt the CDN and corresponding configurations based on the above, with tangible, demonstrable benefits in QoE. 5) Feedback to intent evolution – to step 1 above.
<i>Notes on use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>Reference</i>	[b-FGAN-O-013-R1]

7.18.1 Use case requirements

Critical requirements

- AN-UC018-REQ-001: It is critical that the AN enable representation of QoS/QoE requirements in an intent, and additionally deployment considerations (e.g., hardware, cloud) and software/CDN pipeline considerations are to be captured in the intent.
- AN-UC018-REQ-002: It is critical that the AN enable adaptations based on analysis.
- AN-UC018-REQ-003: It is critical that the AN enable experiments to determine a good combination of KPIs, data measurement, policies, action areas (e.g., scaling, positioning).
- AN-UC018-REQ-004: It is critical that the AN enable the tracing of adaptations on configurations to tangible, demonstrable benefits in QoE.
- AN-UC018-REQ-005: It is critical that the AN enable feedback to intent evolution.

NOTE – Feedback may include parameters for representation in the intent, additional deployment considerations and adaptations.

7.18.2 Actor interactions and possible components

None.

7.19 Analysis-driven evolution in virtualized RAN based on DevOps

<i>Use case ID</i>	FG-AN-usecase-19
<i>Use case description</i>	<p>Open radio access network (O-RAN) architectures allow disaggregated evolution of RAN components. Programmability and interfaces exposed by RAN components in O-RANs allow developers the opportunity to create applications (e.g., xApps) based on data from the RAN.</p> <p>In parallel, development methodologies such as DevOps are being applied to enable the rapid introduction of services to networks.</p> <p>At the same time, technology evolution to the next generation of networks is in progress.</p> <p>This use case links the dev and ops cycle on one side to the programmability offered by new RAN architectures such as O-RAN.</p> <p>An analysis of RAN services and applications (e.g., data, messages, interfaces, logs from xApps and rApps) can provide valuable information regarding software evolution and technology evolution and deployment evolution.</p> <p>NOTE – [b- O-RAN.WG3.E2GAP] defines an interface, E2, connecting the near-RT RIC and one or more O-CU-CPs, one or more O-CU-UPs, one or more O-DUs and one or more O-eNBs. The E2 node is a logical node terminating the E2 interface. The E2 enables a direct association between the xApp and RAN functionality.</p> <p>The following are related steps in this use case scenario (with O-RAN as example architecture [b-O-RAN.WG1.O-RAN-Arch]):</p> <ol style="list-style-type: none"> 1) Analysis of heterogeneous RAN components, corresponding splits, capabilities, deployment options and interfaces, and data models (e.g., E2 nodes and E2AP support). 2) Analyse the information in the near real time RAN intelligent controller (nRT RIC) 3) Discover the capabilities of various RAN nodes and instantiate (potentially cloud-native versions of) applications (e.g., xApps) based on RIC software development kits (SDKs). 4) Provision and analyse the CLs at near real time RIC.

	<p>5) In correlation with the non-RT RIC, analyse the DevOps cycle at the near real time RIC to provision new types of cloud native network functions (CNFs) in the near real time RIC and new types of E2 nodes (or new capability needs in E2 nodes).</p> <p>6) In the non-RT RIC, analyse the DevOps cycles of near-RT RIC, new capability needs of E2 nodes, arrive at new use cases (e.g., limitations of the current network with respect to user experience and the corresponding reasons).</p> <p>This use case is related to the evolution and experimentation aspects. It takes advantage of the increased data gathered from the RAN via the open interfaces and the DevOps style of RIC application development to automate specific aspects of the evolution process.</p>
<i>Notes on use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>References</i>	[b-DISH-AWS], [b-ONF], [b-O-RAN.WG1.O-RAN-Arch], [b-O-RAN.WG3.E2GAP]

7.19.1 Use case requirements

Critical requirements

- AN-UC019-REQ-001: It is critical that the AN enable the analysis of heterogeneous RAN components, corresponding splits, capabilities, deployment options and interfaces, and data models

NOTE 1 – For example, E2 nodes and E2AP support.

- AN-UC019-REQ-002: It is critical that the AN enable the discovery of the capabilities of various RAN nodes and the instantiation of (potentially cloud-native versions of) applications.

NOTE 2 – Examples of applications are xApps.

- AN-UC019-REQ-003: It is critical that the AN enable the provisioning and analysis of CLs at near real time locations.

NOTE 3 – Near real time RIC is an example of a near real time location.

- AN-UC019-REQ-004: It is critical that the AN, in correlation with the orchestrator, analyse the DevOps cycle at near real time locations to provision new types of NFs in the near real time locations

NOTE 4 – Further examples of new types of NF are new types of E2 nodes (or new capability needs in E2 nodes).

7.19.2 Actor interactions and possible components

None.

7.20 Evolving edge applications for verticals using private 5G

<i>Use case ID</i>	FG-AN-usecase-20
<i>Use case description</i>	<p>Vertical network applications such as corrosion detection and intruder detection need to be enabled at the edge using AI/ML.</p> <p>These applications enable inspection and surveillance services for critical industrial infrastructures. However, multidomain (core and edge) E2E deployment of applications, on demand, is needed to achieve the required performance for these applications. In this context, the 5G orchestration platform allows distributed deployment of applications, especially in exploiting the capabilities at an edge environment. This allows network</p>

<i>Use case ID</i>	FG-AN-usecase-20
	<p>operators to manage the unique KPIs of services at edge sites without exposing the network architecture.</p> <p>By providing an environment to develop and deploy edge applications, to serve specific needs of verticals, network operators are able to create an ecosystem for value creation, especially for domain-focussed small businesses.</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Enterprises deploy private 5G network slices at the edge. 2) The applications and KPIs are analysed at the edge. 3) Network management and optimization approaches are triggered based on this analysis. 4) Tailor-made applications which are specifically tuned for the needs of the enterprise are offered to the enterprise. <p>NOTE – This aligns with the concept of NetApps and the network application orchestrator (NAO) [b-FGAN-O-013-R1], decoupling the network operations logic from service provider logic and providing clear business roles.</p> <ol style="list-style-type: none"> 5) The process facilitates experimentation and evaluation of candidate solutions. 6) Edge network evolution and adaptation is triggered based on the analysis. <p>This use case is related to the evolution and experimentation aspects. It takes advantage of the increased deployment flexibility provided by private 5G networks. Edge-core information exchange is used to trigger experimentation and adaptation of the edge.</p> <p>There is also an expectation of alignment with domain-specific experiments and matching KPIs based on innovations in the verticals.</p>
<i>Notes on use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>References</i>	[b-FGAN-O-013-R1]

7.20.1 Use case requirements

Critical requirements

- AN-UC020-REQ-001: It is critical that the AN interface with network application orchestration platforms at the edge to provide both local, vertical-specific real-time analytics as well as non-real-time analytics.

NOTE 1 – Network application orchestration platforms may coordinate with edge analytics and edge service management to abstract the edge network architecture to the AN. Analytics may be made available for remote access (e.g., away from the edge).

- AN-UC020-REQ-002: It is critical that the AN provide network management and optimization, as well as application management and optimization services to application orchestration platforms at the edge.

NOTE 2 – While network management and optimization provide specific inputs to the edge about the network architecture, application management and optimization services may provide specific inputs on placement, functionalities and other aspects of applications.

Expected requirements

- AN-UC020-REQ-003: It is expected that the AN provide tailor-made recipes for application management and optimization specific to verticals deployed at the edge.

NOTE 3 – These recipes may be the result of offline, generalized analytics at the AN. These recipes may be considered by NAO while designing, developing and deploying applications at the edge.

Added value requirements

- AN-UC020-REQ-004: It is of added value that the AN consider input from NAO, and continuously optimize the tailor-made recipes for application management and optimization specific to verticals deployed at the edge.

NOTE 4 – The input from NAO may be agnostic to the details of network architecture or user details at the edge. This would further enhance the privacy and security of the system.

7.20.2 Actor interactions and possible components

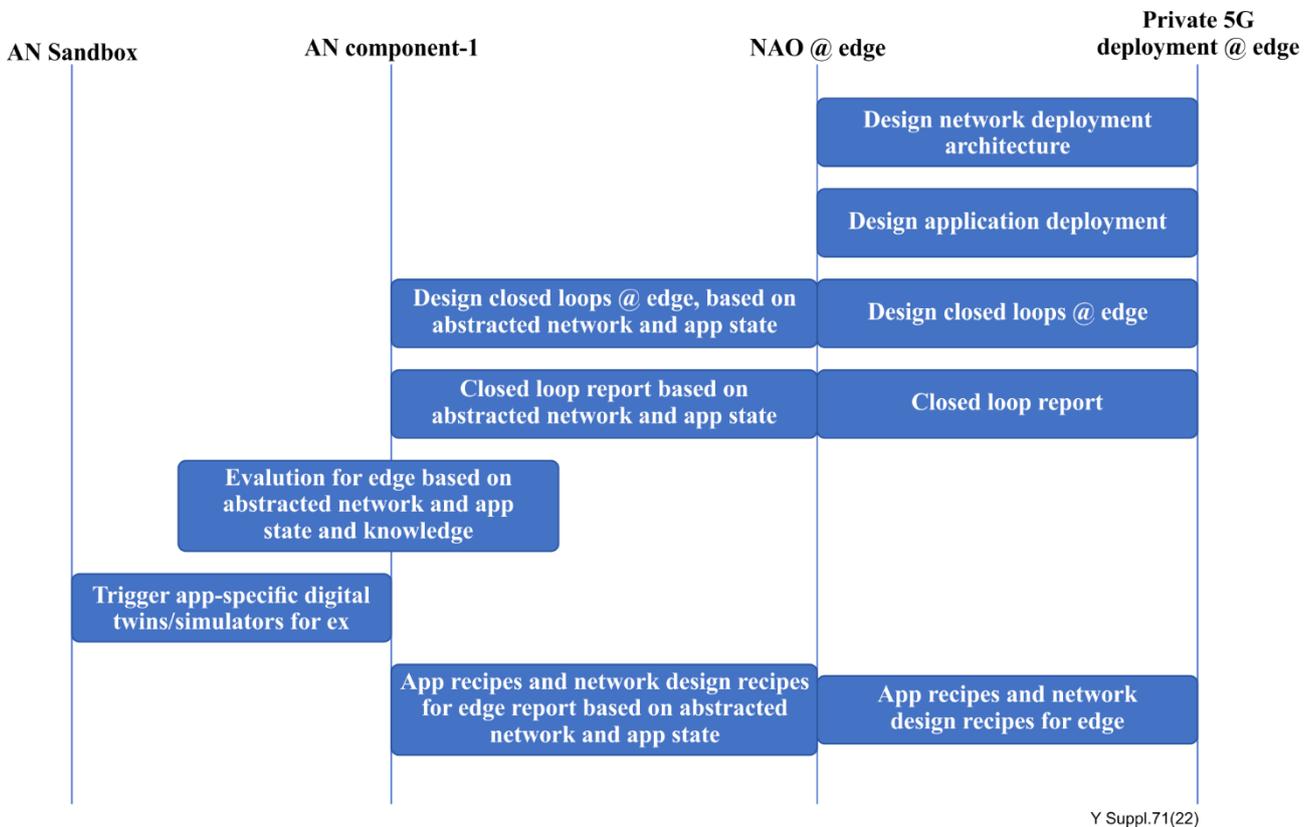


Figure 17 – Actor interactions for evolving edge applications for verticals using private 5G

Actors involved (Figure 17):

NAO@edge: This is an actor which manages the network application and orchestrates their lifecycle at the edge locations.

7.21 Experimentation and "fire drills" for public safety networks

<i>Use case ID</i>	FG-AN-usecase-21
<i>Use case description</i>	<p>ER and public safety need resilient, on-demand network setup and management. This will require inputs from verticals including emergency responders. Experimentation and trial runs may be mandated in certain regions.</p> <p>Based on the new technologies used in evolving the networks, there are different ways of deploying public safety networks. To validate the readiness of such networks, experiments need to be designed, even for the rare scenarios. In fact, for public safety networks, the design of rare scenarios is more important than the "sunny-day" success scenarios.</p> <p>It is also important that the experimentation matches step with the evolution of technologies used for implementing the public safety networks.</p>

<i>Use case ID</i>	FG-AN-usecase-21
	<p>The following are related steps in this use case scenario:</p> <ul style="list-style-type: none"> – Step 0: Continuous analysis of external inputs and creation of strategies for experiments (experiments are equivalent to "fire drills"). – Step 1: CLs are formed in sandboxes, "fire drills" are conducted and analysed. – Step-2: Based on the "success" or failure of the rare scenarios, network optimization may be triggered. <p>This use case is related to the evolution and experimentation aspects. It applies a principle similar to the generative adversarial network (GAN) for experimenting, validating the preparedness of public safety networks.</p>
<i>Notes on use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>Reference</i>	None

7.21.1 Use case requirements

Critical requirements

- AN-UC021-REQ-001: It is critical that the AN enable continuous analysis of external inputs and creation of strategies for experiments.
- AN-UC021-REQ-002: It is critical that the AN enable CL formation in sandboxes, where specific tests can be conducted and analysed on those CLs.
- AN-UC021-REQ-003: It is critical that the AN trigger network optimizations based on the "success" or "failure" of rare scenarios in sandboxes.

7.21.2 Actor interactions and possible components

None.

7.22 Machine learning for network automation

<i>Use case ID</i>	FG-AN-usecase-22
<i>Use case description</i>	<p>[b-FGAN-O-013-R1] introduces ML-enabled network automation and the required "tailoring" of ML apps for networks.</p> <p>[b-FGAN-O-013-R1] calls out specific aspects that need consideration in network while applying ML: requirements from each domain and specificities (time, data and error) of each domain. Reference architecture is discussed including a ML orchestration layer. Considerations for algorithm design including trade-offs are discussed.</p> <p>The concept of "sub-problems" in networks and the limited role of ML is also discussed. The challenge in mix-match of data with ML (with respect to security, location, interoperability, etc) is discussed. A potentially top-down approach to service optimization is discussed.</p> <p>The following are the additional considerations in this use case:</p> <ol style="list-style-type: none"> 1) Domain-specific characteristics (called "specificities" in [b-FGAN-O-013-R1]) may not be known beforehand to the solution designer, especially given the loosely coupled architecture of future networks and ML. 2) In addition to domain specificities, service-based specificities may also be important. Even in case of multidomain services, specificities could be captured per domain, E2E, at service level. So when new tenants are added, a way to dynamically capture their specificities plus the domains with their corresponding specificities, is needed.

<i>Use case ID</i>	FG-AN-usecase-22
	<p>3) Agile dev and deployments in future networks may need dynamic discovery of trade-offs per service. Considering the service life cycle as day-0 (design), day-1 (deployment), day-2 (monitor), day-3 (optimization), day-4 (redesign) and day-5 (evolution), feedback loops are important to enable rapid development and reduce time to market for new services.</p> <p>4) Runtime discovery of "sub-problems"</p> <p>The following are related steps in this use case scenario:</p> <p>1) ML pipelines configure policies in the network based on the network QoS feedback.</p> <p>2) Service metrics and related policies are provisioned in the ML pipelines based on the monitoring and analysis of errors.</p> <p>3) Service redesign and optimization is triggered based on "sub-problems" and "specificities" discovered.</p> <p>4) Network/domain specificities are tracked and, similarly, optimization problems are tracked. These are input to the service evolution.</p>
<i>Notes on use case category</i>	Cat 2: Describes a scenario related to application of autonomous behaviour in the network.
<i>References</i>	[b-FGAN-O-013-R1], [ITU-T Y.3172]

7.22.1 Use case requirements

Critical requirements

- AN-UC022-REQ-001: It is critical that the AN enable, in case of multidomain services, specificities per domain, E2E.

NOTE 1 – This includes a way to dynamically, autonomously capture their specificities plus the domains with their corresponding specificities.

- AN-UC022-REQ-002: It is critical that the AN enable agile dev and deployments in future networks' dynamic discovery of trade-offs per service.

NOTE 2 – Considering the service life cycle as day-0 (design), day-1 (deployment), day-2 (monitor), day-3 (optimization), day-4 (redesign), day-5 (evolution), feedback loops are important to enable rapid development and reduce time to market for new services.

- AN-UC022-REQ-003: It is critical that the AN enable runtime discovery of "sub-problems".

7.22.2 Actor interactions and possible components

None.

7.23 Autonomous agents (with varied competence) in networks

<i>Use case ID</i>	FG-AN-usecase-23
<i>Use case description</i>	<p>[b-FGAN-O-013-R1] introduces autonomous systems in hostile environments. Estimation and judgement of competence as key criteria for determining the right level of autonomy is the focus. Levels of autonomy for unmanned systems are introduced, especially ranging from "sub-functions" to single functions to single system to teams. A framework for robot autonomy is discussed with corresponding guidelines. Based on these, the characteristics for operations in hostile environments are listed.</p> <p>[b-FGAN-O-013-R1] calls out the requirements for operations with autonomous systems. Relation between the needed level of autonomy depending on environment and type of task in contrast to capabilities of the system in combination with policies. Systems should provide the best possible support and hence the autonomy level has to be adjusted such that humans only have to</p>

<i>Use case ID</i>	FG-AN-usecase-23
	<p>intervene when it is necessary and makes sense. Due to dynamics during missions in hostile environments, the systems have to adapt their autonomy level at run time (or humans have to adapt it) according to the situation and the corresponding requirements. The existing stage levels of autonomy have to be extended by the ability of switching the level in run time (judgement by design vs judgement in run time).</p> <p>A simple workflow scheme for autonomy with varying autonomy levels is discussed. This includes task specification by human and task understanding, feasibility check, task planning, and task execution by system. Request for support to human and control by human can be to any of these workflow steps. Monitoring of performance levels by humans and learning by the system are added steps.</p> <p>Autonomy level and dependency on competence are discussed. Competence analysis as a weighted function of capabilities needed, capabilities existing, existing options for actions and existing constraints is described.</p> <p>The following are the additional considerations in this use case:</p> <ol style="list-style-type: none"> 1) Taking telco service design, development, deployment and operations (ops) as an example – the levels of autonomy may be applied as follows: <ol style="list-style-type: none"> a) Service design is done by designers (100% designer interaction, no ops interaction). b) Existing SDKs and application programming interfaces (APIs) are exercised to create applications (e.g., rApps or xApps) – (high level designer interaction, high code but low ops interaction). c) Configuration of existing or new services in real-time environments (e.g., distributed unit (DU) – mid level designer interaction, high ops involvement). d) Service deployment and QoE measurement in customer premises (e.g., VoD – no code, low designer interaction, collaborative, high ops involvement). <p>Thus, it may be relevant to consider the nature of the task in addition to the type of environment, e.g., for the ops engineers the design phase is a "difficult environment" (due to low involvement) and for the service designers the customer premises is a "difficult environment" (due to constraints in site visits).</p> <p>Thus, it may be relevant to consider a multiagent system where the agents have varied competences (capabilities, options for actions and constraints).</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Problem detected in the network: e.g., video performance degradation for customers, agents collect debug data. analysis agents with matching capabilities are deployed at the nRT RIC and triggered to analyse the data. 2) Fault isolation: example of steps in the scenario are in CU, DU, user plane and control plane, collaborative analysis is used to pin-point the cause of failure. This may involve multiagent team communication to carry out the steps in the workflow described in [b-FGAN-O-013-R1]. 3) Fault correction: example of steps in the scenario are parameter configuration, service upgrade or software re-configuration. 4) Analysis of task performance by agents: example of steps in the scenario are collaborative analysis being used to collect data from the agents, including where human interactions were needed. 5) Trigger creation of new agents with new capabilities: example of steps in the scenario are location and capabilities being selected based on the next higher level of autonomy to reduce human interaction in this scenario.

<i>Use case ID</i>	FG-AN-usecase-23
<i>Notes on use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>References</i>	[b-Beyerer], [b-Hesse], [b-FGAN-O-013-R1]

7.23.1 Use case requirements

Critical requirements

- AN-UC023-REQ-001: It is critical that the AN enable, autonomous agents to collect debug data.

NOTE 1 – For example, analysis agents with matching capabilities are deployed at the nRT RIC and triggered to analyse the data.

- AN-UC023-REQ-002: It is critical that the AN enable fault isolation (e.g., in CU, DU, user plane, control plane) using collaborative analysis to pin-point the cause of failure.

NOTE 2 – This may involve multiagent team communication carry out the steps in the workflow.

- AN-UC023-REQ-003: It is critical that the AN enable fault correction (e.g., parameter configuration) using service upgrade or software reconfigurations.
- AN-UC023-REQ-004: It is critical that the AN enable analysis of task performance by agents.

NOTE 3 – Collaborative analysis is used to collect data from the agents – including where the human interactions were needed.

- AN-UC023-REQ-005: It is critical that the AN enable creation of new agents with new capabilities.

NOTE 4 – Example location and capabilities are selected based on the next higher level of autonomy to reduce human interaction in this scenario.

7.23.2 Actor interactions and possible components

None.

7.24 Automated, adaptive acceleration for AI @ edge

<i>Use case ID</i>	FG-AN-usecase-24
<i>Use case description</i>	<p>[b-FGAN-O-013-R1] introduces spatial architectures which scale performance and resources to meet application requirements and scaling to fit into available resources – in the context of DNN. It also discussed that reduced precision can be highly effective to reach communication requirements. Spatial architectures can exploit custom arithmetic at a greater degree. Further, it discussed topologies fully co-designed for hardware architecture, where the circuit is the DNN [b-Umuroglu]. The parameters of deep neural network (DNN) (lookup table (LUT) contents) are adjusted while iterating on the training dataset until accuracy is achieved.</p> <p>[b-FGAN-O-013-R1] shows the results (with an example of intrusion detection) that spatial processing, customized arithmetic and learned circuits can help scale to communication throughput and latency requirements.</p> <p>[b-FGAN-O-013-R1] also talks about [b-Blott] and providing tools and platforms for exploration of DNN compute architectures. ML engineers can create specialized hardware architectures on an field programmable gate arrays (FPGA) with spatial architectures and custom precision. Design and runtime software tools (e.g., FINN) for DNN to FPGA development starting with training or learning reduced precision DNNs, using open neural network</p>

<i>Use case ID</i>	FG-AN-usecase-24
	<p>exchange (ONNX) based intermediate representation, perform optimization on this intermediate representation, to create a DNN hardware IP, was discussed. Thus, it may be relevant to consider the following aspects for this specific use case:</p> <ol style="list-style-type: none"> 1) AI-enabled applications are increasingly being deployed at the edge. Low latency, low power consumption and small footprint are considerations for AI applications at the edge. Accelerated, AI-enabled applications at the edge are important enablers for future networks. 2) As AI technology evolves, AI models evolve, the acceleration platform must also be adaptable and at the same time satisfying the requirements above. Also, reduced time to market, development time and cost to reach production readiness are important factors influencing deployment decisions by network operators. A fully customized circuit board developed for each application may not fit this bill. 3) Solutions that are pluggable into a larger edge application, providing both the flexibility of a custom implementation with ease-of-use and reduced time to market of an off-the-shelf solution, are needed. 4) Adaptive computing includes hardware that can be highly optimized for specific applications, such as FPGAs. In addition to FPGAs, new types of adaptive hardware such as adaptive System-on-Chip (SoC), which contains FPGA fabric, coupled with one or more embedded CPU subsystems, have been introduced recently. 5) Prebuilt platforms and APIs and software tools enable full customization of the adaptive hardware, enabling even more flexibility and optimization. This can be used to design highly flexible yet efficient systems at the edge. 6) Exploiting the development and adoption of standards in interface and protocols at the edge, different AI-enabled edge applications can use similar hardware components. <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Given an AI/ML model layered architecture, the following considerations need to be applied: (a) concurrency in the processing of layers; (b) fragmentation/buffering between layers vs offloading of layers into compute; (c) precision vs performance and energy efficiency. 2) Given the specific goals and constraints of the AI/ML model, consider the trade-off between the complexity of the target platform architecture and precision to explore the model architecture and layer compositions. 3) Transformation of an AI/ML model, going through the process of intermediate representation, optimization, hardware implementation, evaluation and back to training/modelling. 4) Derive feedback for hardware adaptation and design.
<i>Notes on use case category</i>	Cat 2: Describes a scenario related to application of autonomous behaviour in the network.
<i>References</i>	[b-Blott], [b-Xilinx], [b-Umuroglu], [b-SCALE-Sim], [b-FGAN-O-013-R1]

7.24.1 Use case requirements

Critical requirements

- AN-UC024-REQ-001: It is critical that the AN enable analysis of concurrency in processing of layers in a DNN, fragmentation/buffering between layers vs offloading of layers into compute and analysis of precision vs performance and energy efficiency.

- AN-UC024-REQ-002: It is critical that the AN consider the trade-off between the complexity of the target platform architecture and precision to explore the ML model architecture and layer compositions.
- AN-UC024-REQ-003: It is critical that ANs enable a bidirectional pipeline to support the transformation of AI/ML models encompassing specification, optimization, implementation, evaluation and deployment.A
- AN-UC024-REQ-004: It is critical that the AN derive feedback for hardware adaptation and design.

7.24.2 Actor interactions and possible components

None.

7.25 Assistive networks: Adaptation of communication system based on changing user accessibility needs

<i>Use case ID</i>	FG-AN-usecase-25
<i>Use case description</i>	<p>For both disabled and able-bodied people, as accessibility requirements evolve, adaptations need to be applied on the network, device and user profiles to align with the changing needs of the user.</p> <p>The scope of assistive technologies needs to be broadened to "assistive networks". Assistive networks can be thought of as E2E network slices that include assistive, adaptive and rehabilitative connectivity for persons with specific needs. They also include the automated mechanisms used in selecting, locating, using and customizing the networks. Assistive networks promote greater independence by enabling people to connect to devices and network more autonomously.</p> <p>Environmental models exist for surroundings but building on top of such environment models to adapt the connectivity to the user with specific requirements is the need of the hour.</p> <p>User model and simulations are needed to provide inputs to the AN.</p> <p>The development of standard definitions is needed for application model, assistive network, context modelling, environmental model and common user profile, metadata, simulation and virtual instance in the context of the AN.</p> <p>Individualization needs to be added as an important dimension of the AN for future networks.</p> <p>Reuse of common user profile (CUP) to automate the collection, analysis and adaptation of the network and applications is proposed here.</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Environment model, including the network environment, is built for the user. For example, radio propagation models, signal strengths with respect areas and mobility prediction models. 2) The user model is accessed and updated. An example of user specific constraints is that a user inside a car wearing seat belt has limited mobility within the car. Similar examples are elderly people and children, and persons with acute needs in an emergency. 3) Simulations are used (offline and/or real time) to determine the changes and adaptations needed in the network to satisfy the needs of the user. For example, digital twins which include environment simulations and user specific criteria may be used. 4) Adaptations are applied to the network and the context. For example, drone based coverage, reconfigurable intelligent surface (RIS) configurations or beam configurations to provide better coverage may be provided.

<i>Use case ID</i>	FG-AN-usecase-25
	5) Generalizations and evolutions are studied for applicability in a larger context. For example, continuous update of models, transfer of model parameters across domains for easy learning, evolution of network simulators and context for new encountered scenarios. This use case is related to adding environment sensing and adaptation to include inclusivity in the evolution and experimentation aspects.
<i>Notes on use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>References</i>	[b-Biswas], [b-AVA-1], [b-AVA-2], [b-ISO/IEC 24756], [b-ISO 9241-129], [b-KUKA]

7.25.1 Use case requirements

Critical requirements

- AN-UC025-REQ-001: It is critical that the AN enable the creation and representation of an environment model including the network environment for a user with assistive needs.

NOTE 1 – For example, radio propagation models, signal strengths with respect areas, mobility prediction models.

- AN-UC025-REQ-002: It is critical that the AN enable updating of the user model.

NOTE 2 – For example, user specific constraints, user inside a car wearing seat belt has limited mobility within the car. Similar examples are elderly people and children, and persons with acute needs in an emergency.

- AN-UC025-REQ-003: It is critical that the AN enable simulations (offline and/or real time) to determine the changes and adaptations needed in the network to satisfy the needs of the user.

NOTE 3 – An example is digital twins which include environment simulations and user specific criteria.

- AN-UC025-REQ-004: It is critical that the AN enable adaptations applied to the network and the context.

NOTE 4 – For example, drone based coverage may be provided or RIS configurations or beam configurations may be used to provide better coverage.

- AN-UC025-REQ-005: It is critical that the AN enable generalizations and evolutions which are studied for applicability in a larger context.

NOTE 5 – Examples are continuous update of models, transfer of model parameters across domains for easy learning, evolution of network simulators and context for new encountered scenarios.

7.25.2 Actor interactions and possible components

None.

7.26 Ev-as-a-service: Achieving zero-touch evolution in a delegated autonomy case

<i>Use case ID</i>	FG-AN-usecase-26
<i>Use case description</i>	Some usage scenarios assume a multidomain architecture. Each domain may have its own orchestrator. NOTE 1 – An example in FG-AN-usecase-20, NAO is mentioned. Management and orchestration (MANO) / network function virtualization orchestrator (NFVO) is used in the network function virtualization (NFV) domain; the service orchestrator may be used similar to ONAP in the communication domain. – CLs are assumed in each domain, managed by the corresponding orchestrators.

<i>Use case ID</i>	FG-AN-usecase-26
	<ul style="list-style-type: none"> – (For the purposes of this use case), it is assumed that each CL enables autonomous behaviour in that domain for specific use cases e.g., resource scaling based on load. <p>NOTE 2 – The autonomous behaviour enabled by use case specific CLs and managed by domain orchestrators can be extended to any number of management domains.</p> <ul style="list-style-type: none"> – Current frameworks [ITU-T Y.3172], [ITU-T Y.3179], [b-ETSI GS ZSM 002] assume offline development and provisioning of services which form the CLs. For example, AI/ML model training based on data from the network, followed by model serving in the network. – This use case introduces an evolution (Ev) function which analyses the inputs from the CLs (and other context information in the domain orchestrator) to trigger the creation of new services which can cater to the evolving needs of the domains. – The triggers may be input to DevOps pipeline. This may result in creation of new framework services or new applications or new virtual network functions (VNFs) or new configurations or new AI/ML models, etc. – These may then be tested and evaluated in an experimental setup (e.g., digital twins, sandbox, etc) and deployed in corresponding domains using the domain orchestrators. <p>In summary, the use case aims to monitor, identify the need for ev, generate a new function to support this need and "(re-)inject" that function through the DevOps pipeline into the CLs. Note that this may require multidomain coordination to modify the CLs and may be challenging from an implementation perspective. Implementation may depend on the capabilities provided by the underlying CL frameworks e.g., zero- touch service management (ZSM).</p> <p>Levels of "mutation" of CL:</p> <p>There can be a spectrum of adaptation changes to the CL:</p> <ol style="list-style-type: none"> a) No adaptation at all – same input to the CL, always leads to the same output. b) Limited adaptation – CL improves utility over time, so same input may not lead to the same output (after improvement). c) Full-fledged evolution, involving development and injection of new functions. <p>The capability of underlying CL frameworks may be a factor in deciding the level of adaptation possible in the AN.</p> <p>Division of responsibility between the controller and the CL:</p> <ol style="list-style-type: none"> 1) "Unintelligent" vs "intelligent" CLs: unintelligent CL may allow full reconfigurations and re-injections of functions which may allow overall mutation of its functionality over time. However, an "intelligent" closed loop may use its intelligence to limit external influence by the controller. In any case, the domain orchestrator should know the mutation capabilities of the CL. In a case in which limitations to adaptations are encountered, the CL (or domain orchestrator) should be able to escalate the requirement to higher domains. 2) The timescale of Ev has to be agreed between the CL and the orchestrator. <p>The following are related (example) steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Enterprise/vertical provides intent for application/service 2) A corresponding slice is created by NAO. 3) Corresponding resources are allocated by NFV MANO 4) NSaaS may be instantiated using ONAP/SO.

<i>Use case ID</i>	FG-AN-usecase-26
	<p>5) Use case specific CLs are instantiated in each domain e.g., power optimization, interference management, resource utilization, self-x.</p> <p>6) Ev as a service is instantiated in the zero-touch framework.</p> <p>7) Based on the analysis of inputs from use case specific CLs and domain orchestrators, Ev triggers configurations, updates, service instantiation, new CLs and even new service development (using triggers to devops pipeline).</p> <p>8) After testing and validation, such updates are reflected in the domains and use case specific CLs.</p> <p>This use case proposes an Ev-as-a-service scenario in relation to zero-touch frameworks.</p>
<i>Notes on use case category</i>	Cat 2: describes a scenario related to the application of autonomous behaviour in the network.
<i>References</i>	[b-ETSI GS ZSM 001], [b-ETSI GS ZSM 002], [b-ETSI GR ZSM 009-3], [b-Ciavaglia-1], [b-ETSI GS ZSM 013], [ITU-T Y.3172], [ITU-T Y.3179]

7.26.1 Use case requirements

Critical requirements

- AN-UC026-REQ-001: It is critical that the evolution function (Ev) in the AN analyses the inputs from domain-specific CLs (and other context information in the domain orchestrator) to trigger the management (creation, update and delete) of network services which may in turn participate in the CLs.

NOTE 1 – The management (creation, update and delete) of network services, over a number of iterations, may result in evolution.

- AN-UC026-REQ-002: It is critical that modifications to network services and applications be tested and evaluated in an experimental setup and deployed in corresponding domains using the domain orchestrators.

NOTE 2 – Examples of experimental setups used for the testing and evaluation of network services and applications are digital twins, sandbox, etc.

Expected requirements

- AN-UC026-REQ-003: It is expected that management of network services, applications, VNFs, configurations or AI/ML models be done at runtime in coordination with DevOps pipelines.
- AN-UC026-REQ-004: It is expected that domain-specific CLs allow management of network services or applications or VNFs or configurations or AI/ML models in coordination with AN components.

NOTE 3 – There can be a spectrum of adaptation changes (levels of "mutation") of network services:

- No adaptation at all.
- Limited adaptation – improves utility over time.
- Full-fledged evolution, involving development and injection of new functions.

The capability of underlying CL frameworks may be a factor in deciding the level of evolution and adaptation possible in the AN.

Added value requirements

- AN-UC026-REQ-005: It is of added value that the Ev function in the AN act as consumer of mutation functions provided by underlying service management frameworks and in turn provide an evolution service to underlying service management frameworks.

NOTE 4 – An example of a service management framework is ETSI ZSM [b-ETSI GS ZSM 001].

7.26.2 Actor interactions and possible components

None.

7.27 Experimentation as a service: Digital twins as platforms for experimentation

<i>Use case ID</i>	FG-AN-usecase-27
<i>Use case description</i>	<p>[b-FGAN-O-013-R1] described a digital twin (DT) as a representation of a physical and/ or logical object. The contribution proposed to build digital twins of computer network infrastructures. Some examples of the (hypothetical) questions which could be answered using DTs were listed as: Which is the best network upgrade given a budget? Which is the best link upgrade to accommodate a new customer? What is the method to support a new customer SLA with the current network capacity? etc.</p> <p>The impact of DTs in network planning and upgrading, troubleshooting and performance analysis, and what-if analysis were described in [b-FGAN-O-013-R1]. This makes DTs a perfect environment for experimentation in the context of ANs.</p> <p>[b-FGAN-O-013-R1] took the approach of using neural networks (NNs) to build DTs. The approach using graph neural network (GNN) [b-Scarselli] was described. It generalizes to unseen topologies, routings and traffics. The specific example of RouteNet [b-Rusek-2] was described. RouteNet can generalize to unseen topologies, routings and traffic matrices.</p> <p>DRL plus GNN looks to be a promising technique for real-time network optimization and was introduced in [b-FGAN-O-013-R1].</p> <p>The AN aims to remove the human from the control loop. This poses hard challenges to offer 100% guarantees once the AN products have been deployed in networks. In order to achieve mature solutions for AN control, it will be essential for AN vendors to validate in advance that their products will operate successfully in the target customer networks, before they are actually deployed. A DT can be used to estimate accurately the resulting network performance of an experimentation approach and the effect after applying the actions produced by the AN, thus determining what network scenarios are well-supported by the product. After a comprehensive validation test, the vendor can apply the adaptations to the network.</p> <p>The following are examples of scenarios in this use case:</p> <p>Scenario-1: preparation of DT: import network configurations (including CLs) into DT. This sets the stage for preparation of simulations in the DT.</p> <p>Scenario-2: trigger of DT for simulations: update of network configurations in DT (if any, by engineer), followed by simulations in DT and generation of asynchronous events. These events are consumed by the AN engine and may in turn result in experimental configurations/updates from the AN engine towards the DT. This cycle may continue based on the sequence of simulations and scenarios in the DT. The validation of KPIs in the DT as a result of experimentation and adaptations by the AN engine is an important step.</p> <p>Scenario-3: trigger of AN engine by operator: update of network policy/configurations by engineer, which triggers the AN engine to corresponding experiments or configurations towards the DT. Experimentation may be configured in the DT and corresponding events and KPIs may be used to evaluate the result of the experimentation. This may result in selecting the best possible sequence of actions or adaptations towards the network. The validation of the AN engine's actions is an important step here.</p> <p>Scenario-4: trigger based on evolution: Other triggers for experiments in AN engine may include inputs from evolution functionality. Experimentation and</p>

<i>Use case ID</i>	FG-AN-usecase-27
	<p>the evaluation of actions or adaptations towards the network are same as stated above.</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Import environment into DT, trigger simulations in DT and validate the results, especially the use case specific CLs. 2) AN-triggered experiments and adaptations are tested using corresponding simulator settings in the DT and evaluating the impact in simulations. <p>This use case is related to the concept of experimentation.</p>
<i>Notes on use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>References</i>	[b-Rusek-1], [b-Rusek-2], [b-Almasan], [b-FGAN-O-013-R1]

7.27.1 Use case requirements

Critical requirements

- AN-UC027-REQ-001: It is critical that the AN enable the import of the simulation environment into the DT, trigger simulations in the DT and validate the results, especially the use case specific CLs.
- AN-UC027-REQ-002: It is critical that the AN-triggered experiments and adaptations be tested using corresponding simulator settings in DT and that the impact in simulated environment is evaluated.

7.27.2 Actor interactions and possible components

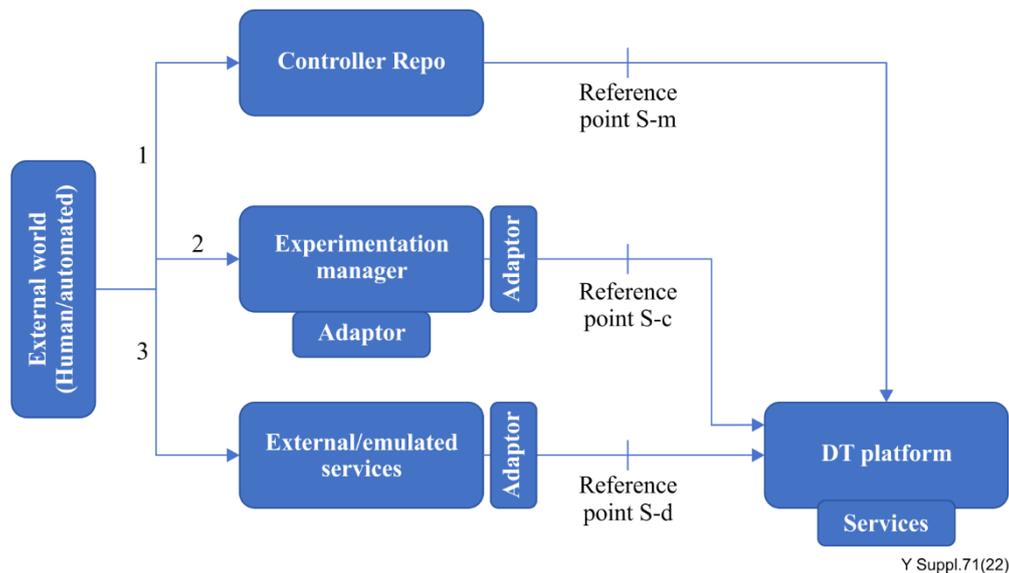


Figure 18 – Possible components for experimentation as a service

Possible key components involved (Figure 18):

- Experimentation manager: This is a component which manages the experimentation stage of controllers, including testing and verification.
- DT platform: This component provides a DT platform that allows testing and verification of controllers.
- Controller repo: This component provides a repository of controllers.

7.28 Evolution from scenario-specific, explicit coordination to coordination-free interoperability (achieved using data-driven approaches)

<i>Use case ID</i>	FG-AN-usecase-28
<i>Use case description</i>	<p>Deep learning is being used to address challenging problems in wireless communications such as modulation recognition, radio fingerprinting and many other scenarios. The advantages of this approach include the capability to address a wide range of scenarios for which it is difficult to devise a mathematical model (e.g., channel estimation, beam management for future networks).</p> <p>Existing solutions mostly rely on explicit coordination between the TX and RX, introducing problems of interoperability and necessity for standards. Such signalling messages eat into the costly spectrum and complicate protocol design.</p> <p>A data-driven approach based on NN is an alternative to achieve coordination-free interoperability.</p> <p>An example scenario for the use case is as follows: Millimetre wave (mmWave) communication with large antenna arrays is a promising technique to enable extremely high data rates. Because of their highly directional transmissions, radios operating at millimetre wave (mmWave) frequencies need to perform beam management to establish and maintain reliable mmWave links. The TX and RX need to coordinate to select the beam pair that yields the highest beamforming gain.</p> <p>Currently 5G NR defines the stages of exhaustive beam sweep (EBS) as: initial access (IA) and beam tracking. For both IA and beam tracking, the 3rd Generation Partnership Project (3GPP) NR standard for 5G communications utilizes synchronization signal blocks (SSBs) [b-3GPP 36.331].</p> <p>Beam management for the IA procedure in 3GPP NR involves:</p> <ol style="list-style-type: none"> 1) Beam sweep: The base station transmits directional synchronization signals (SSs) to cover all the transmit beams (TXBs) of a certain codebook. Each beam is swept with an SSB, which is a group of 4 orthogonal frequency-division multiplexing (OFDM) symbols and 240 subcarriers in frequency. 2) Beam measurement: The UE itself, if configured for directional reception, performs a directional scan, measuring the quality of each beam pair. 3) Beam decision: The UE selects the beam to be used to perform IA. 4) Beam reporting: During the next SSB in the selected direction, the UE acquires information on the time and frequency resources in which the base station will be in receive mode for the random access message using the same TXB. <p>Receiver can associate signal-to-noise ratio (SNR) levels to beams without explicit coordination with the transmitter using a pilotless estimation technique. The RX infers the angle of arrival (AoA) and the TXB by passively eavesdropping on data transmissions to other users in the network. This is enabled by leveraging a data-driven approach based on convolutional neural networks (CNNs) to achieve coordination-free beam management in mmWave networks based on a unique "signature" of the beam from the impairments. This method infers the AoA of the beam and the actual beam being used by the transmitter through waveform-level deep learning on ongoing transmissions between the TX to other receivers. Experimentation is achieved by a experimental data collection campaign with two software-defined radio testbeds, and by using multiple antennas, codebooks, gains and locations, and includes three different AoAs and multiple TX and RX locations.</p> <p>Evaluation criteria include an upper bound on the expected search time of the proposed algorithm. The proposed technique reduces latency by up to seven</p>

<i>Use case ID</i>	FG-AN-usecase-28
	<p>times with respect to the 5G NR initial beam sweep in a default configuration and with a 12-beam codebook.</p> <p>The following are related steps in this use case scenario:</p> <ol style="list-style-type: none"> 1) Based on the analysis of data from the network, reference points are selected by evolution where data-driven NN based approaches can be applied to reduce signalling. Evolution should cherry-pick the reference points which have the best trade-offs in terms of benefits (e.g., spectral efficiency, latency, etc) as against the cost of training. Evolution should also help in understanding the experimentation approaches to follow. 2) Based on the scenario under study (for evolution), the experimentation is setup and data sources are provisioned and ML pipelines are setup [ITU-T Y.3172]. 3) Based on the evaluation of the AI/ML models in the sandbox, they are injected into the NFs. 4) Control and data flows are modified according to the evolved network.
<i>Notes on use case category</i>	Cat 1: Describes a scenario related to core autonomous behaviour itself.
<i>References</i>	[b-O'Shea-1], [b-O'Shea-2], [b-Jagannath], [b-Mao], [b-AI4Good-1], [b-AI4Good-2], [b-AI4Good-3]

7.28.1 Use case requirements

Critical requirements

- AN-UC028-REQ-001: It is critical that the AN enable a selection of reference points based on evolution where data-driven NN based approaches can be applied to reduce signalling.

NOTE – Evolution should cherry-pick the reference points which have the best trade-offs in terms of benefits (e.g., spectral efficiency, latency) as against the cost of training. Evolution should also help in understanding the experimentation approaches to follow.

- AN-UC028-REQ-002: It is critical that the AN enable, based on the scenario under study (for evolution), experimentation setup and data sources provisioning and ML pipeline setup [ITU-T Y.3172].
- AN-UC028-REQ-003: It is critical that the AN enable the injection of ML models into the NFs, based on the evaluation of the AI/ML models in the sandbox.
- AN-UC028-REQ-004: It is critical that the AN enable the modification of control and data flows according to the evolved network.

7.28.2 Actor interactions and possible components

None.

7.29 Intelligent maintenance assistance system

<i>Use case ID</i>	FG-AN-usecase-029
<i>Use case description</i>	<p>The intelligent maintenance assistance system is an intelligent service system for network operation and maintenance. The system combines AI algorithms and AR capabilities to provide intelligent assistance for the front line staff of operators in aspects of network operation and maintenance.</p> <p>The system includes the backstage support system and AR glasses app. The backstage support system is deployed in cloud servers in the form of a microservice, and is connected with the network management system of operators to exchange data. The AR glasses app is used for staff's on-site work.</p> <p>The backstage support system provides the following functions:</p>

<i>Use case ID</i>	FG-AN-usecase-029
	<p>1) AI algorithms and AR capabilities for the system. Developers can also use these algorithms to develop applications.</p> <ol style="list-style-type: none"> a) AI algorithms include bar /QR code recognition, OCR and device port recognition. b) AR capabilities include image recognition and tracking, 3D object recognition and tracking, visual simultaneous localization and mapping (SLAM). <p>2) The data management function can help implement equipment data transmission, storage and management, including that of network resource data, equipment status data and equipment operation data.</p> <p>3) The system management function includes user management, authority management, system operation management, parameter configuration and other functions to ensure the stable and reliable operation of the system.</p> <p>The AR glasses app provides the following functions:</p> <ol style="list-style-type: none"> 1) Information collection: Staff can collect pictures through the camera of AR glasses and upload them to the backstage support system. The AI algorithms in the backstage support system can recognize the collected pictures and save the recognition results. Here, the staff can collect the text information of the labels of devices to supplement and update the information in the backstage support system. 2) Data visualization: The data managed in the backstage support system can be displayed on the AR glasses. This function can provide the display of alarm information, base station information, equipment information, electricity consumption and network status, to assist the network operation and maintenance of staff. 3) Remote guidance of experts. Through the camera of AR glasses, experts can understand the situation of the work site and provide remote guidance. <p>The steps in this use case are as below:</p> <ol style="list-style-type: none"> 1) Using AR glasses (and other external sensors), collect data about the environment, which include equipment label, port and electricity consumption. This step may include bar/QR code recognition, OCR and device port recognition. 2) AI-based cognition analysis, perception visualization and other analysis algorithms are applied on the collected data to create a virtual model of planning and design corresponding to the real environment to assist network designers. This step may include the application of image recognition and tracking, 3D object recognition and tracking, and visual SLAM. 3) This model is then used in conjunction with real data for maintenance and optimization by an intelligence maintenance assistance system. This step may involve query of the virtual model, analysis of real alarms and cell data, along with the virtual model, to create intelligence assistance for frontline workers. This step may use network data management, system management and core algorithms for the whole system. The output from this step may include 3D models which can be rendered in AR glasses, AI processed network information for display and real-time remote guidance information. 4) As the network services evolve and new NFs (virtual or physical) are plugged in, the following evolution steps are applied: <ol style="list-style-type: none"> a) AR app is updated to collect new data, including new equipment data and new sensors and new environment information. b) backstage support system is updated with new data management systems, core algorithms, etc 5) Periodic or asynchronous reports are produced for human consumption regarding the operation of intelligent maintenance assistant system.

<i>Use case ID</i>	FG-AN-usecase-029
	6) An SDK may be exposed to 3rd party developers who may develop new applications to analyse the AR-collected data. This may in turn help operators to provide new value-added applications in the intelligent maintenance assistant system.
<i>Notes on use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>Reference</i>	None

7.29.1 Use case requirements

Critical requirements

- AN-UC029-REQ-001: It is critical that the AN enable collection of environment data related to network operation and maintenance using automated techniques such as augmented reality (AR) glasses.
- AN-UC029-REQ-002: It is critical that the AN enable analysis of environment data related to network operation and maintenance using cloud and AI techniques.
- AN-UC029-REQ-003: It is critical that the AN provide intelligent assistance, rendered using automated techniques such as AR for network operation and maintenance.

NOTE 1 – The intelligent assistance may be produced using analysis by AI/ML on the collected data from AR.

- AN-UC029-REQ-004: It is critical that the AN update the data collection mechanisms and data analysis mechanisms along with the result rendering mechanisms based on the analysis by AI/ML on the collected data from AR and the evolution of the underlay networks.
- AN-UC029-REQ-005: It is critical that the AN provide periodic and/or asynchronous updates to humans about the operation of the intelligent assistant system.

Expected requirements

- AN-UC029-REQ-006: It is expected that the AN enable exposure of programming capabilities to third party developers for creation of novel applications which can help automated operation and maintenance of the network, including evolution and adaptation of NFs.

NOTE 2 – Such novel applications may analyse the data collected using AR, suggest new data collection mechanisms based on gaps in collected data, suggest new analytical methods or suggest new targets for application of analysis.

7.29.2 Actor interactions and possible components

None.

7.30 Demand forecasting and live service migration methods in edge computing systems

<i>Use case ID</i>	FG-AN-usecase-030
<i>Use case description</i>	Virtualization and cloudification of services have enabled automation, flexible placement and programmability to network topology. The efficiency of service delivery can be significantly improved using these techniques. However, there are significant challenges to host ultra-reliable low-latency communication (URLLC) and massive machine type communications (mMTC) services in 5G, in centralized topologies. Monitoring of networks by telco operators has revealed that network topology is not static and load is not uniform over a long service time. This use case describes a dynamic network topology and service placement using a genetic algorithm to analyse and predict services. In addition, efficient forecasting and live migration methods of service are introduced as an application to edge

<i>Use case ID</i>	FG-AN-usecase-030
	<p>computing systems. This approach can enable the intelligent allocation of operator equipment resources for providing flexible and efficient topologies. Simulation based analysis of results has proved that network equipment efficiency can significantly be increased by these techniques.</p> <p>The optimization of the mobile edge computing network performance for a service by addressing the service placement problem is described below.</p> <p>"Match-making" and analytics service is hosted by REX platform [b-AI4Good-4], exposed as APIs to third party service providers. Services (e.g., gaming) can now utilize the resources at the edge efficiently. Edge network reports the resource status (and other metadata) to the REX platform via the "RExclient" deployed at the edge [b-FGAN-O-013-R1]. Third party service provider interfaces with the REX platform via "RExclient" deployed at the service provider [b-FGAN-O-013-R1] for service deployment at the edge.</p> <p>In addition, the following extensions are proposed:</p> <ul style="list-style-type: none"> – REX platform will host "composition" service for controllers (CLs). – Edge networks will expose APIs to deploy and manage controllers. – REX platform will analyse the requirements from applications and manage the composition service towards the edge networks. – The sub/pub mechanism described in [b-FGAN-O-013-R1] is extended to include controller metadata. <ul style="list-style-type: none"> 1) Registration of multi-access edge computing (MEC) on the platform will include controller capabilities. 2) Pub MEC status information to the platform will include controller status. 3) Service provider subscribed to this platform receives information about available MECs along with the controllers. <p>1) Connection, discovery and capability exchange (info exchange) between the hosted (prediction) service and clients (e.g., REX server and client) on the network operator side (edge) and the (application) service providers on the ISP side.</p> <p>2) Data (including traffic characteristics and controller metadata) are measured and analysed to predict the resource utilization and automation at the edge.</p> <p>3) Placement of services, migration and composition of corresponding controllers are managed by REX platform.</p>
<i>Notes on use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>References</i>	[b-AI4Good-4], [b-FGAN-O-013-R1]

7.30.1 Use case requirements

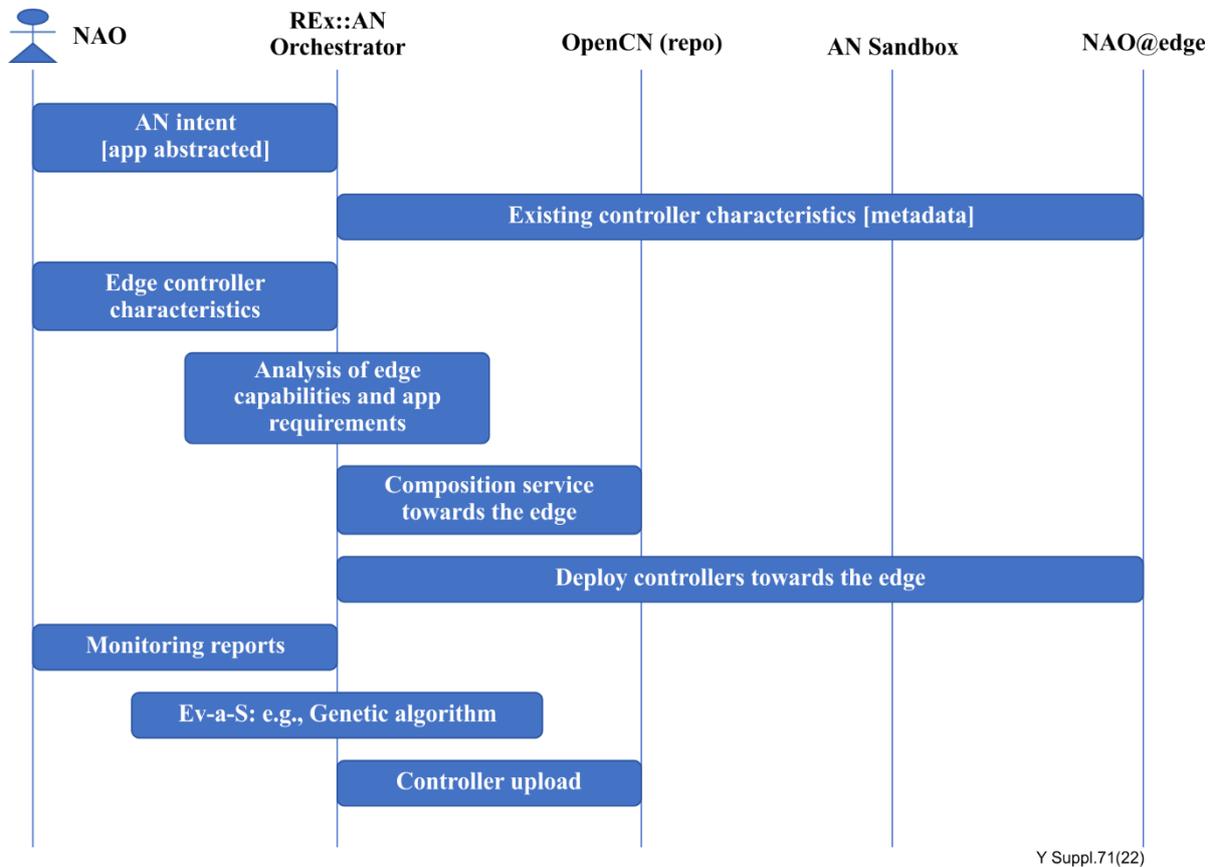
Critical requirements

- AN-UC030-REQ-001: It is critical that the AN integrate with edge networks that will expose APIs to deploy and manage controllers.
- AN-UC030-REQ-002: It is critical that the AN enable analysis of the requirements from applications and manage the composition service towards the edge networks.
- AN-UC030-REQ-003: It is critical that the AN enable a sub/pub mechanism including controller metadata.

NOTE – Thus, registration of MEC on the platform will include controller capabilities. Pub MEC status information to the platform will include controller status. A service provider subscribed to this platform receives information about available MECs along with the controllers.

- AN-UC030-REQ-004: It is critical that the AN enable connection, discovery and capability exchange (info exchange) between the hosted (prediction) service and clients on the network operator side (edge) and the (application) service providers on the ISP side.
- AN-UC030-REQ-005: It is critical that placement of services, migration and composition of corresponding controllers are managed by domain-specific orchestrators.

7.30.2 Actor interactions and possible components



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Figure 19 – Actor interactions for demand forecasting and live service migration

Actors involved (Figure 19):

- NAO: This is an actor which manages the network application and orchestrates their lifecycle.
- REx::AN orchestrator: This actor is an implementation of an AN orchestrator that manages controllers in the network using the REx platform.
- OpenCN: This actor stores the controllers.
- AN sandbox: This actor provides an experimentation platform for controllers. This allows the testing and verification of controllers. This may be implemented in the form of an openly accessible sandbox.
- NAO@edge: This is an actor which manages the network application and orchestrates their lifecycle at the edge locations.

7.31 OpenCN: An open repository of intents for controllers and modules

<i>Use case ID</i>	FG-AN-usecase-031
<i>Use case description</i>	<p>As controllers/CLs evolve to solve practical problems in the networks, this use case aims to provide a baseline repository (called OpenCN) of intents for different forms of controllers. As in the case of various opensource repositories and AI/ML marketplaces, an open repository will form a baseline for reusable controllers and provide components for composing and chaining together controllers. In addition, open repo will increase trust in controllers.</p> <p>Metadata related to controllers which describe the controllers and related modules would enable discovery and other related services such as subscription/publication of new controllers. Metadata also allows the specification of guidelines for integrating controllers with service-x and underlay networks.</p> <p>Not only does the baseline intents allow stakeholders to reuse, extend and interoperate controller implementations, it also allows the development of an ecosystem of services around it – providing customizations (adaptations), integrations (post-experimentations) and, finally, evolutions.</p> <p>NOTE- It is possible to integrate OpenCN with CL frameworks e.g., ETSI ZSM [b-ETSI GS ZSM 002].</p> <p>Steps in the use case are as follows:</p> <ul style="list-style-type: none"> – Initial version of controllers are formed from intent or composition from modules (by evolution controllers). – These may be stored in the repo labelled as "untested" or candidate controllers. – Experimentation (Ex) manager pulls the candidates from the repo and (uses AN sandbox to) evaluate and test and compare the controllers. – Evolution (Ev) manager uses the open repo to pull and apply ev strategies – Operational (Op) controllers are stored in the open repo and pulled and deployed in underlay networks by various CL automation frameworks. <p>NOTE – Standardized intent formats may be used for storing controllers.</p>
<i>Notes on use case category</i>	Cat 1: Describes a scenario related to core autonomous behaviour itself.
<i>Reference</i>	None

7.31.1 Use case requirements

Critical requirements

- AN-UC031-REQ-001: It is critical that the AN enable storage of controllers in an open repository.

NOTE – Experimentation (Ex) manager pulls the candidates from the repo and (uses AN sandbox to) evaluate and test and compare the controllers. Evolution (Ev) manager uses the open repo to pull and apply ev strategies. Operational (Op) controllers are stored in the open repo and pulled and deployed in underlay networks by various CL automation frameworks.

7.31.2 Actor interactions and possible components

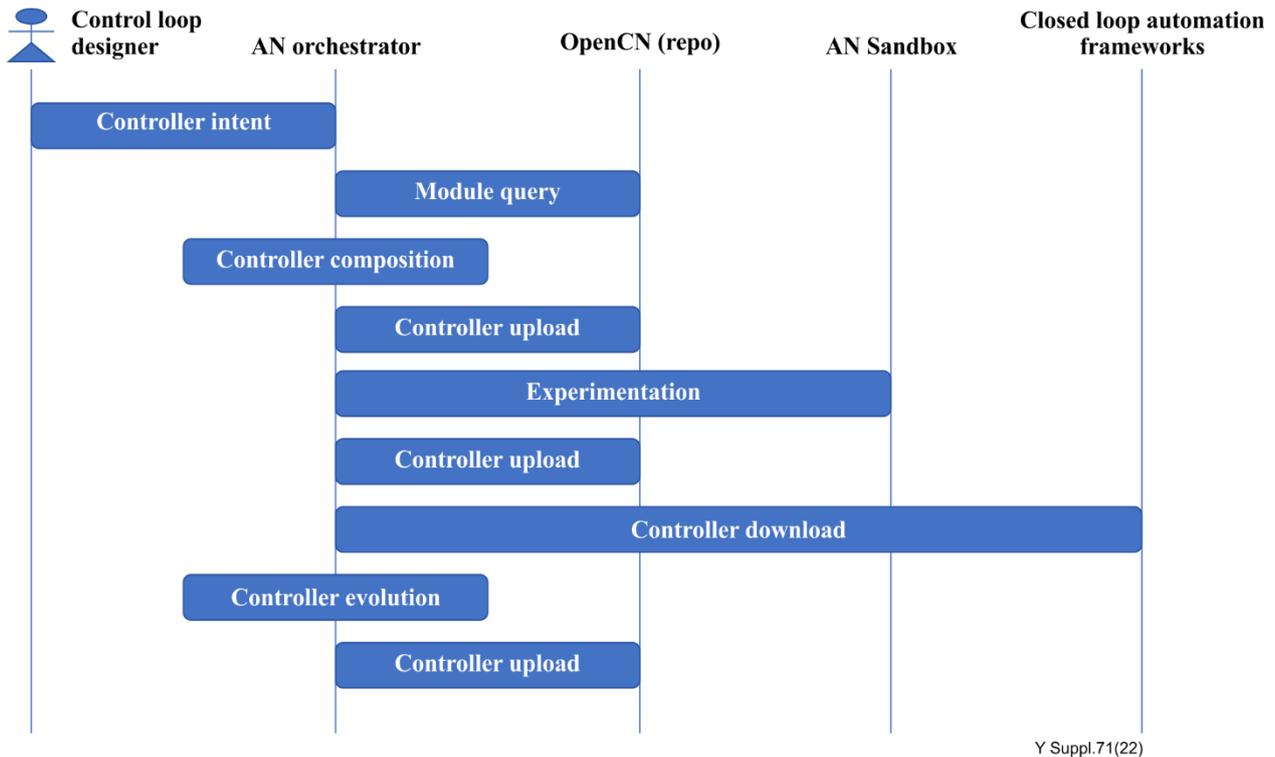


Figure 20 – Actor interactions for open repository of intents

Actors involved (Figure 20):

- Control loop designer: This actor designs a control loop. The actor can be a human or a machine.
- AN Orchestrator: This actor manages the other AN components in the network.
- OpenCN: This actor stores the controllers.
- AN sandbox: This actor provides an experimentation platform for controllers. This allows testing and verification of controllers. This may be implemented in the form of an openly accessible sandbox.
- CL automation frameworks: This actor manages CLs in the networks.

7.32 AI-enabled game theory-based mechanism for resource allocation

<i>Use case ID</i>	FG-AN-usecase-032
<i>Use case description</i>	<p>With the advent of the Internet of Things, a large number of devices may be trying to connect to the network. The macro base station may be capacity limited to serve these devices. An alternative is device to device communication, but the complexity of algorithms and privacy concerns are limiting factors here. Another option is deploying small base stations known as small cells and each small cell trying to serve a set of users.</p> <p>Microcell, metro cell, pico cell and femtocells are collectively known as small cells and networks containing all these base stations are termed as "heterogeneous networks". To optimize the use of bandwidth, co-channel deployment mechanisms are assumed, i.e., macro cell and small cells will share the same set of sub-channels. Transmission among small cells may cause interference not only among them but also to the macro cell users. Hence, efficient resource allocation</p>

<i>Use case ID</i>	FG-AN-usecase-032
	<p>algorithms are considered to mitigate interference among them so as to satisfy QoS constraints of all the devices/users.</p> <p>Distributed algorithms may be needed to mitigate the interference since there may not be coordination (e.g., X2 interface [b-3GPP 36.420]) among the small cells.</p> <p>In this scenario, distributed resource allocation (subchannel allocation and power allocation to each subchannel) are proposed so as to satisfy QoS requirements of all the devices.</p> <p>NOTE – a game-theory-based model is proposed and to reach equilibrium points both traditional based algorithms such as ML algorithms are proposed.</p> <p>Story-1 for the use case: In an enterprise deployment of small cell, say in a factory floor, low latency is required for certain UE, e.g., robotic arms or self-guided vehicles as in Industry 4.0 use cases. Macro cell coverage is limited in such indoor factory floors and interference is a problem. Resource allocation for low-latency UE in the presence of interference and low coverage by macro is the problem addressed in this "story".</p> <ul style="list-style-type: none"> • Co-existence of UE that requires low latency service and that do not require low latency service: <ul style="list-style-type: none"> ○ Each small cell can allocate certain channels (power has to be allocated via game theory) to UE that requires low latency (high priority basis) and for other UE it can allocate channel and power by playing the game model. ○ Power allocation is based on UE rate requirements. • Serving UE that all requires low latency: <ul style="list-style-type: none"> ○ The small cell that serves these users can act as a leader and other cells can act as a follower. ○ Here priority will go to the leader and after allocation of resource by this cell, all others will allocate resources accordingly by playing the Stackelberg game model [b-Sankar-2]. • Given the measurements such as channel gains observed by a user on a particular subchannel along with interference plus noise on that channel, it is needed to allocate channel and power per subchannel so as to satisfy user requirements (e.g., rate, low latency). <ul style="list-style-type: none"> ○ Here channel allocation matrix and power per subchannel (known as Nash Equilibrium-NE point [b-Sankar-1]) has to be computed iteratively via game theory approach. Three different kind of algorithms such as traditional optimized algorithms, reinforcement learning algorithms and genetic algorithms, are used. ○ Comparison of the above algorithms for better usage. ○ Once a data set that consists of various measurements-channel gains, interference plus noise, set of sub-channels, user per cell, user requirements along with NE point has been created, the supervised learning (SL) model can be trained (this model sits at the small base stations (BSs) to obtain subchannel allocation and power per subchannel depends on the local measurements along with other inputs at each small BS). ○ Compare the output from SL with traditional methods. • Supposing there are multiple users try to access the channel at a particular time and resources are scarce, then it will be necessary to schedule the users into different frame durations (msec). For this, an auctioning mechanism is considered to schedule the user in a particular time slot. The utility for each auction is a function of user requirements such as rate and latency. • Once the user scheduling is performed, then channel and power per channel according to the algorithm described above, are determined.

<i>Use case ID</i>	FG-AN-usecase-032
	<ul style="list-style-type: none"> In the above procedure both time domain and frequency domain scheduling are performed separately. <p>Story-2: surveillance videos – high uplink (UL) rate is required for cameras – macro cell coverage and interference is problem. Allocation for rate-required UE in the presence of interference and low coverage by macro. Priority allocation for UL intensive UE to achieve QoS.</p> <p>Story-3: power constrained wearables and privacy – user specific data cannot be exposed to a third party and to perform analytics, no data should be taken out of the trust zone (enterprise or private network). All AI/ML, analytics etc needs to be carried out within the private network.</p> <p>The steps in the use case (related to autonomy) are:</p> <ol style="list-style-type: none"> 1) Controllers are formed based on, e.g., intents and/or evolution (Ev) to optimize resource allocation with various considerations including latency, throughput or privacy preserving analytics. 2) Modelling of inter-controller interaction using game theory: "Players" in the game would be the equivalence classes of controllers. "Players" may be selected from the evolvable population. 3) (Initial) strategies/gains/payoffs are defined and initialized for each equivalence class and game is modelled. 4) Players [controllers] can be cooperating or non-cooperating. They may participate in the game based on trust. 5) Modelling of strategies/gains/payoff for each player (controller) may change based on Ev. 6) Use experimentation (Ex) to study the model (strategies/gains) which is evolved, and the elements of trust in this game can be studied. The strategies for maximizing the gains can also be investigated, either by cooperation or non-cooperation. 7) Adaptations to be applied to the controllers are arrived at – in the form of changes to strategies, gains/payoffs and trust. Formation of new "players" may be part of adaptation. 8) Outer loop: Collect the data from the set of solutions, train the AI/ML model and infer the equilibrium from the new input data using trained model.
<i>Notes on use case category</i>	Cat 1: Describes a scenario related to core autonomous behaviour itself.
<i>References</i>	[b-Sankar-1], [b-Sankar-2], [b-Ahmad], [b-Al-Turjman], [b-Ciavaglia-2]

7.32.1 Use case requirements

Critical requirements

- AN-UC032-REQ-001: It is critical that the AN enable characterization of controllers using metadata, which may be updated dynamically based on monitoring of the controllers.

NOTE 1 – The metadata associated with controllers would be used for modelling controllers as players. Example – the CLs aiming to optimize transmit power and those intending to optimize coverage may be modelled as players in a game.

Expected requirements

- AN-UC032-REQ-002: It is expected that the AN enable experimentation with various gaming strategies, payoffs and equilibria with controllers as players.

NOTE 2 – Experimentation may be conducted in the sandbox and coordinated e.g., by an experimentation manager, and may result in analysis of strategies, payoffs and equilibria.

- AN-UC032-REQ-003: It is expected that the AN enable classification of controllers with respect to their trustability.

NOTE 3 – Parameters related to the measurement of trust as applied to controllers and the methods of classification may be out of the scope of this particular use case.

- AN-UC032-REQ-004: It is expected that the AN enable analysis of experimentation results with AI/ML based techniques.

NOTE 4 – Learnings from AI/ML may be used in optimizing gaming strategies, payoffs and equilibria.

- AN-UC032-REQ-005: It is expected that the AN enable adaptation of controllers with new strategies.

NOTE 5 – Learnings from AI/ML may be used in optimizing gaming strategies, payoffs and equilibria.

- AN-UC032-REQ-006: It is expected that the AN enable derivation and application of different combinations of game theory mechanisms such as auction theory based on the use case specification.

NOTE 6 – Use case specification may be captured and formalized in the form of intent. Derivation of game theory mechanisms such as auctioneer may use human or automated mechanisms. Application or integration of such mechanisms in underlay networks may use specific architecture and interface considerations as in open RAN.

7.32.2 Actor interactions and possible components

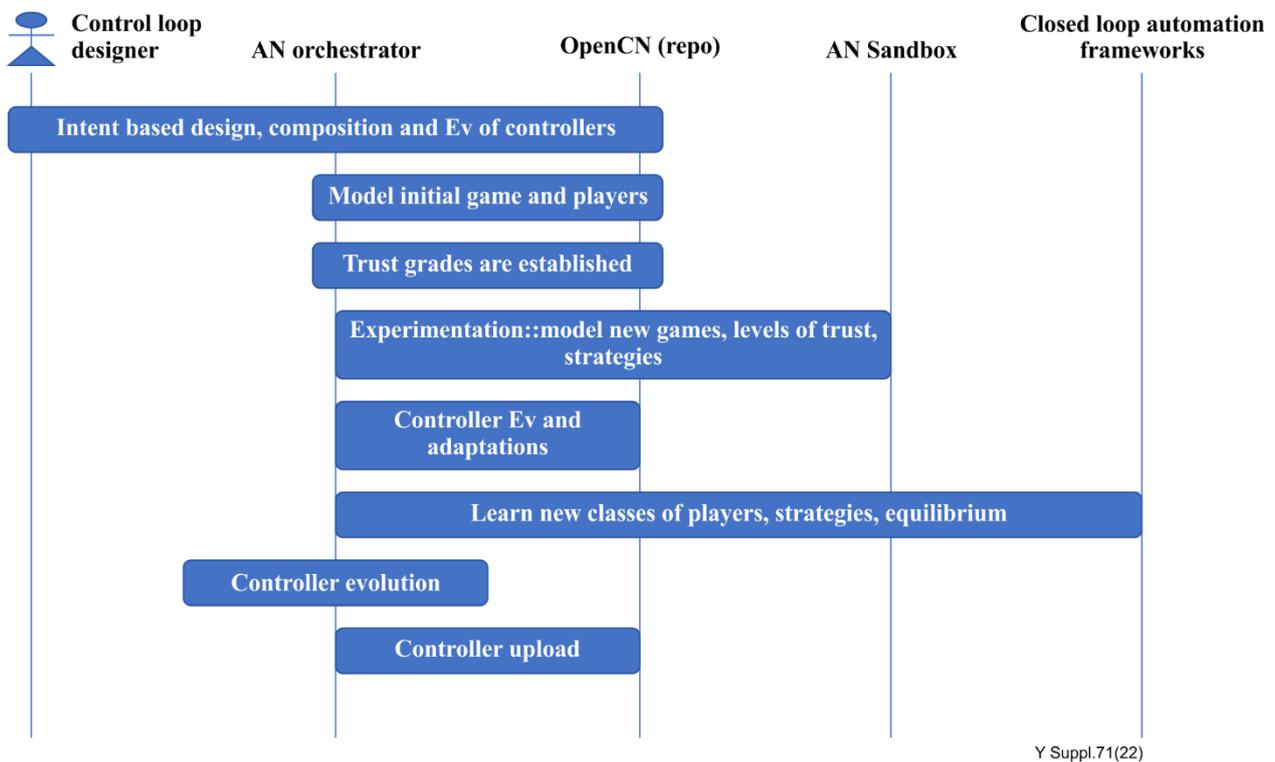
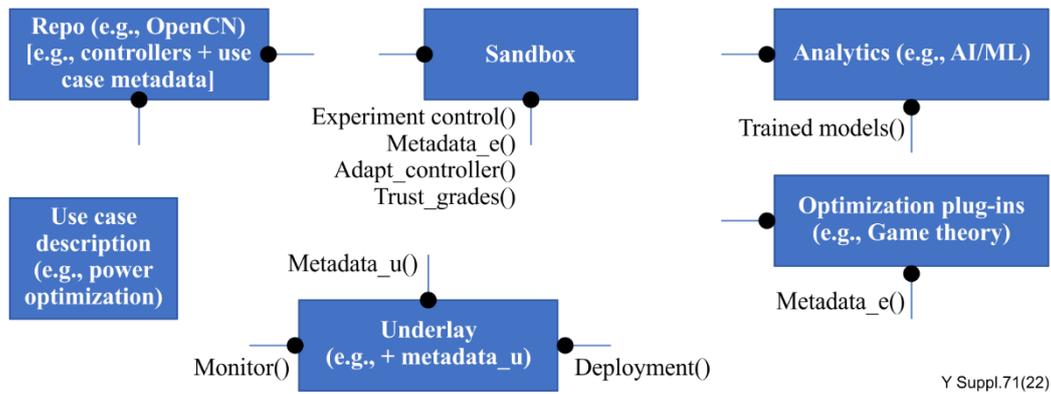


Figure 21 – Actor interactions for AI-enabled game-theory-based resource allocation



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Figure 22 – Possible components related to AI-enabled game theory-based resource allocation

Actors involved (Figure 21):

- Control loop designer: This actor designs a control loop. The actor can be a human or a machine.
- AN orchestrator: This actor manages the other AN components in the network.
- OpenCN: This actor stores the controllers.
- AN sandbox: This actor provides an experimentation platform for controllers. This allows testing and verification of controllers. This may be implemented in the form of an openly accessible sandbox.
- CL automation frameworks: This actor manages CLs in the networks.

Possible key components involved (Figure 22):

- Repo: This component provides a repository of controllers.
- Sandbox: This component provides an experimentation platform that allows testing and verification of controllers.
- Analytics: This component provides analytics services (including prediction, inferences) for the AN.
- Optimization plug-ins: This component provides plug-ins which implement specific optimization algorithms on top of basic schemes. For example, game-theory-based mechanisms for resource allocation.

7.33 Service automation using workflows

<i>Use case ID</i>	FG-AN-usecase-033
<i>Use case description</i>	<p>Network automation scenarios in future networks include large scale automation of management of network devices, services and retrieval of operational state data from a network. User specific workflows, along with modularized tasks, are one of the mechanisms to achieve this automation.</p> <p>Combined with an interworking of NETCONF [b-IETF RFC 6241] and OpenConfig YANG models [b-Openconfig], vendor native models, and the command line interface (CLI), use-specific, customized solutions can be created and dockerized containers can be designed and tested.</p> <p>The workflows are defined using a JSON based domain-specific language (DSL) by wiring a set of tasks together. The tasks are either control tasks (fork, conditional, etc.) or application tasks (e.g., encoding a file) that are executed on a remote device. Atomic tasks are chained together into more complex workflows.</p> <p>NOTE 1 – The FRINX machine [b-FRINX-1] distribution comes pre-loaded with a number of standardized workflows.</p>

<i>Use case ID</i>	FG-AN-usecase-033
	<p>Steps in this use case are as follows:</p> <p>Step-1: Create or compose workflow: Operations or functions on workflows: In addition to creating, the workflow designer can also</p> <ul style="list-style-type: none"> – edit a workflow; – delete a workflow. <p>These operations may be achieved using a workflow manager. This may include an API-based-interface or a GUI-based interface. A graphical user interface may be used to create, edit or run workflows and monitor any open tasks. The GUI may also help with explainability.</p> <p>NOTE 2 – This would help to on-board new services (e.g., in underlay networks) and view their status.</p> <p>NOTE 3 – The composing step (from the GUI) may produce output in a generic form (e.g., TOSCA or YANG) and translating this representation of workflows into deployable instances can use a generic and can take different types of inputs and produce different types of outputs.</p> <p>Step-2: Store in resource database: workflow specification and execution data are stored in a resource database.</p> <p>Step-3: Link tasks: A task corresponds to a worker utilized in the workflow. Tasks in the workflow may receive input parameters and the execution logic of the task may be implemented in python functions called worker. Worker tasks may be registered in the main python file "main.py" in the same directory where the worker was created.</p> <p>NOTE 4 – All workers to be used in the FRINX machine must be included in this file.</p> <p>Step-5: Deploy workflows: Workflows may be deployed on simulated underlay networks and their performance and benchmarking may be tested and monitored. Workflows may also be deployed on real underlay networks once their performance in the experimentation is satisfactory.</p> <p>Step-6: Monitor: The following service states may be mapped to workflows:</p> <ul style="list-style-type: none"> – Experimental state: Workflows which are deployed in the sandbox are in experimental state. In combination with simulators, these are tested and experimented upon. – Evolutionary state: workflows which are in Ev state are selected for evolution, and based on Ev strategies, various experiments may be designed for them. – Deployed state: Workflows which are in deployed state are in combination with service-x and acting upon real underlay networks. They may be monitored for performance and other parameters. – In the context of the use case, controllers (CLs) are represented as workflows. Modules are modelled as tasks. – Controller specification and module specifications are created using the designer, sanity checked and stored in the resource db. – Workflow manager is used to visualize the controllers, monitor and analyse. – Deploy will link service-x with controllers
<i>Notes on use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>References</i>	[b-FRINX-1], [b-FRINX-2], [b-TIP 5G]

7.33.1 Use case requirements

- AN-UC033-REQ-001: It is critical that the AN enable creation of controllers in a generic format agnostic to the type and characteristics of the underlay network.

NOTE 1 – The generic format may not include deployment specific details. This allows design time flexibility and abstraction.

- AN-UC033-REQ-002: It is critical that the AN enable translation of controller specifications from generic format to include underlay network-specific details.

NOTE 2 – The translation of controller specifications may include, for example, steps such as replacing and augmenting abstracted parameters with underlay network-specific parameters and other such customizations.

- AN-UC033-REQ-003: It is critical that the AN enable storage of generic and underlay network-specific representation of controllers in a repository.

Expected requirements

- AN-UC033-REQ-004: It is expected that the AN enable different implementations of translation from generic to underlay network-specific representation of controllers.

NOTE 3 – Workflow managers which implement the translation may be provided by different vendors.

- AN-UC033-REQ-005: It is expected that the AN enable storage of different classes of controllers in a repository.

NOTE 4 – Examples of different classes of controllers are (a) initial representation of controllers, (b) those which are experimented with corresponding metadata (results), and (c) those which are deployed with corresponding metadata (from monitoring).

7.33.2 Actor interactions and possible components

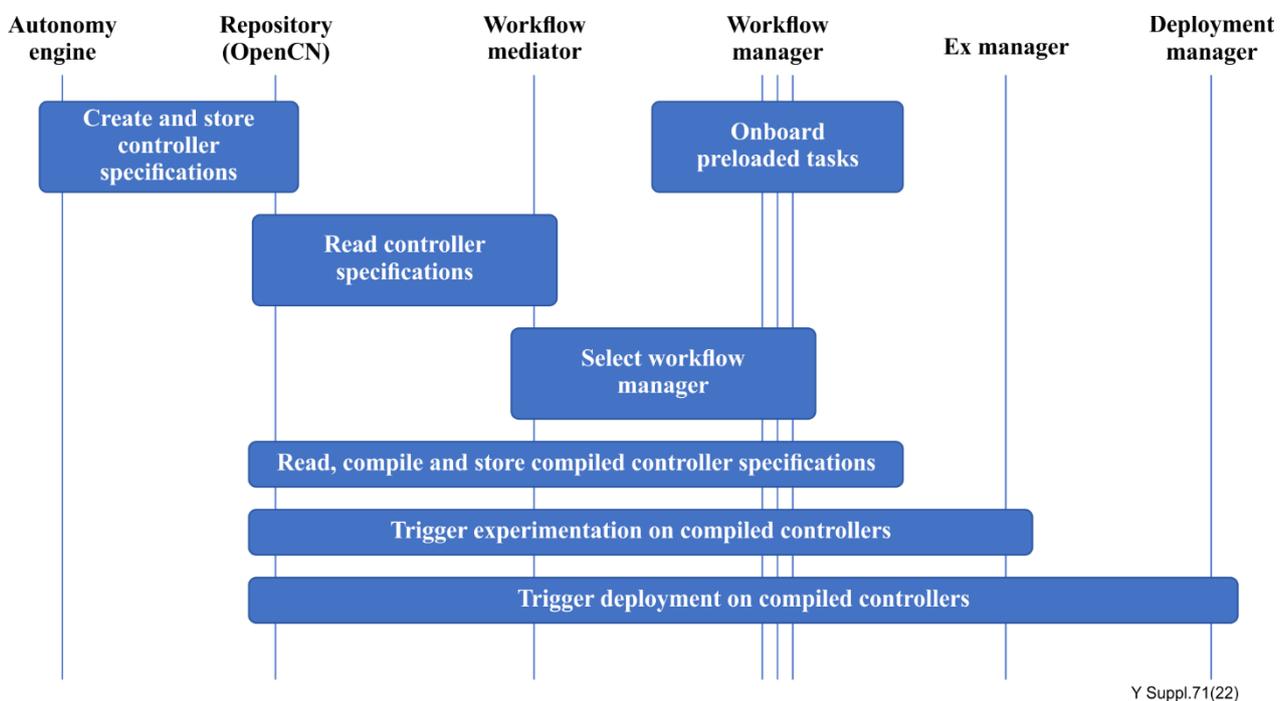


Figure 23 – Actor interactions for service automation using workflows

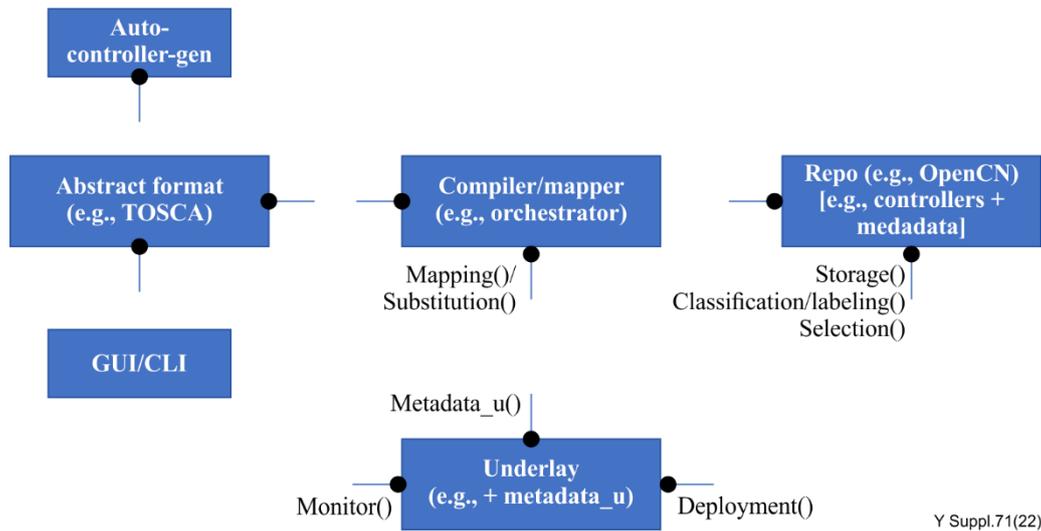


Figure 24 – Possible components related to service automation using workflows

Actors involved (Figure 23):

- Workflow mediator: This actor is responsible for enabling the creation of controllers in a generic format agnostic and interacting with workflow managers adapting them to the type and characteristics of the underlay network.
- Workflow manager: This actor creates workflows from existing or newly created tasks and further triggers the validation and deployment of workflows in different types of underlay networks.
- Deployment manager: This actor deploys the workflows in underlay networks.

Possible key components involved (Figure 24):

- Auto-controller-gen: This component is responsible for generating controllers that are automated or assisting humans. This component may use inputs from the knowledge base, controller repositories and recommendation systems to generate controllers.
- Abstract format: A declarative format which allows the representation of the design of controllers while abstracting the deployment details. The adaptations for specific underlay networks are applied at a later stage than the design stage.
- Graphical user interface (GUI) or CLI: A graphical front end which allows a better experience for human users who are designing and managing controllers.
- Compiler or mapper: This component parses the controllers, validates the syntax as well as appropriately maps the abstracted notations and subcomponents to their respective underlay network-specific detailed representations.

7.34 Disaggregation and placement of in-network programs

<i>Use case ID</i>	FG-AN-usecase-034
<i>Use case description</i>	Concepts and tools based on the overarching vision of software-defined networking (SDN) such as host based (packet processing), middleboxes, NFV, OpenFlow and configurable flow tables, and Programmable switch application-specific integrated circuits (ASICs) are well known. Support for the P4 Language consortium [b-ONF P4] has grown over time and it has been central to enabling dataplane programmability. In-network programs applications such as forward error correction (FEC), traffic compression, encapsulation/decapsulation, etc are typical applications in dataplanes. However, the current programming paradigms map dataplane programs 1:1 to devices and resource dedicated to the program,

<i>Use case ID</i>	FG-AN-usecase-034
	<p>executing on a single target, limiting to the scope of "programmability of the network" and hence creating a mismatch with the overarching vision of SDN. Toolsets which decompose dataplane programs into a suitable mix of dataplanes are needed. Flightplan [b-Flightplan] is an example of such a toolset which helps splitting a P4 program into a set of cooperating P4 programs and maps them to run as a distributed system formed of several, possibly heterogeneous, dataplanes.</p> <p>Steps in this use case are as follows:</p> <p>Scenario A: "loosely coupled" integration of Flightplan with AN.</p> <p>Step-1: Given a controller specification, selection of "in-network controllers", e.g., dataplane programs, is made by the selection controller.</p> <p>Step-2: Flightplan helps in segmenting, planning and allocation/mapping to devices.</p> <p>Step-3: Underlay networks may use other toolsets, e.g., FRINX machine, or form ZSM managed domains, and/or host their own ways of achieving the above-mentioned integration of controllers in their service domains. This forms the "application" (or deployment) side of the controller lifecycle.</p> <p>Scenario B: "tightly coupled" integration of Flightplan with AN.</p> <p>Step-1: Flightplan may interface and "collaborate" with an AN orchestrator (or different controllers in the AN domain) to achieve the following:</p> <ol style="list-style-type: none"> segmentation of dataplane programs-based factors known to AN e.g., resource needs or overall E2E controller deployments across different domains like ZSM or FRINX. Diagnose and debug and analyse various "possibilities" for solutions. hand-over control between various dataplanes. placement of controllers. analysis of performance KPIs. <p>Step-2: Recommend, possibly evolutionary, changes to controllers based on Flightplan's analysis of constraints and KPIs.</p>
<i>Notes on use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>References</i>	[b-Flightplan]

7.34.1 Use case requirements

- AN-UC034-REQ-001: It is critical that the AN support both loosely coupled and tightly coupled integration mechanisms with underlay networks.

NOTE 1 – For example, underlay networks may integrate workflow management mechanisms such as FRINX, CL automation frameworks such as ETSI ZSM, and in-network dataplane program management mechanisms such as Flightplan. An example of loosely coupled integration is passing down intents from the AN to Flightplan (which further analyses it to derive a program profile). Examples of tightly coupled integration is the exchange of granular information e.g., current resource allocation status, current KPIs monitored, and providing control and visibility over placement of controllers in devices.

NOTE 2 – Loosely coupled integration allows for more autonomy in the underlay network.

- AN-UC034-REQ-002: It is critical that underlay networks support loosely coupled integration mechanisms with the AN.
- AN-UC034-REQ-003: It is critical that the AN support discovery of capability with respect to the level of integration provided by the underlay network.
- AN-UC034-REQ-004: It is critical that the AN decide the "application" and deployment of controllers to various underlay networks based on the E2E requirements of the use case.
- AN-UC034-REQ-005: It is expected that underlay networks support tightly coupled integration mechanisms with the AN.

7.34.2 Actor interactions and possible components

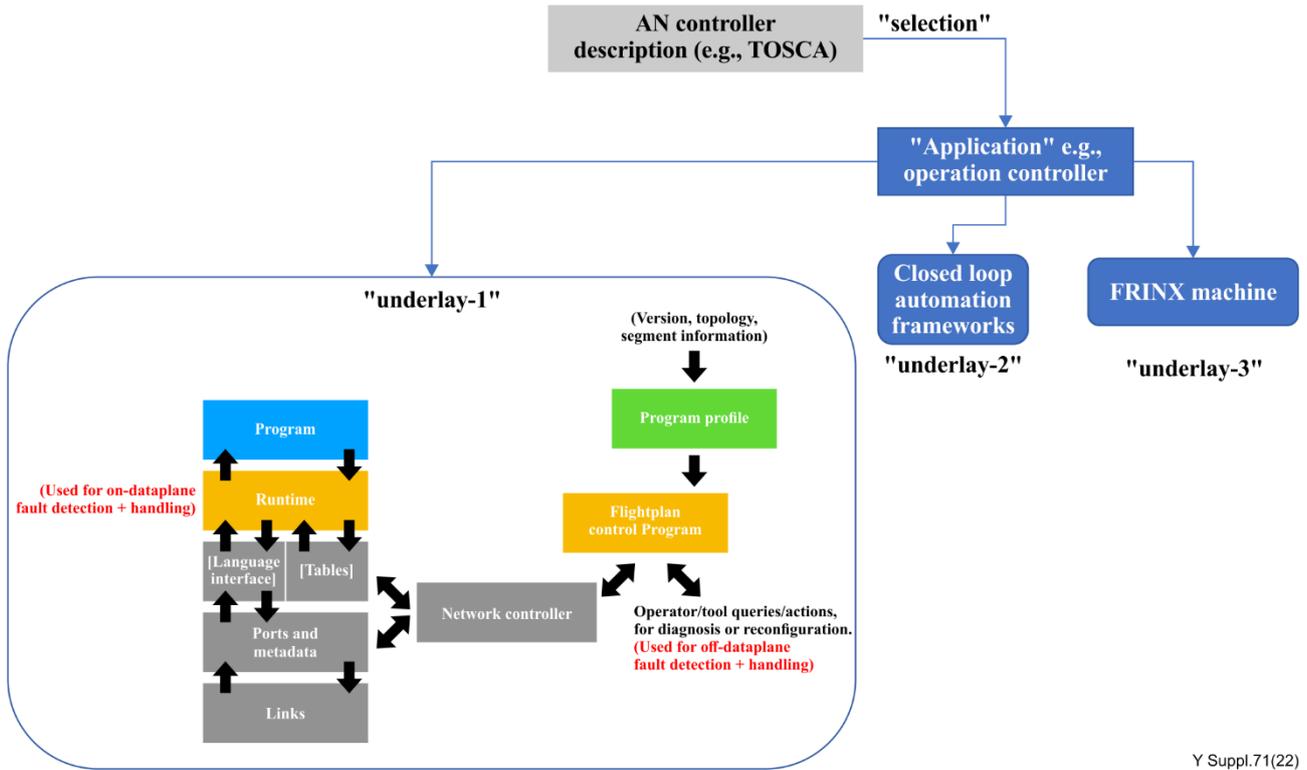


Figure 25 – Actor interactions for disaggregation and placement of in-network programs

Actors involved (Figure 25):

- Underlay-1: An instance of an underlay network, which implements the disaggregation and placement of in-network programs.
- Underlay-2: An instance of an underlay network which implements CL automation frameworks.
- Underlay-3: An instance of an underlay network which implements workflow orchestration, e.g., FRINX machine.
- Application: This actor interacts with underlay networks to instantiate and operate the controllers in the various underlay networks, for example, an operation controller which uses APIs exposed by various underlay networks.
- AN controller: This actor selects the underlay network to deploy the controllers per the use case description.

7.35 A fast and lightweight autoML library (FLAML)

<i>Use case ID</i>	FG-AN-usecase-035
<i>Use case description</i>	<p>Currently, selecting learners and hyper parameters for each learner is a tedious and manual task. Fast and lightweight automated machine learning (FLAML) [b-FLAML] is a lightweight Python library that finds accurate machine learning models automatically, efficiently and economically.</p> <p>FLAML leverages the structure of the search space to choose a search order optimized for both cost and error. For example, the system tends to propose cheap configurations at the beginning stage of the search, but quickly moves to configurations with high model complexity and large sample size when needed in the later stage of the search.</p>

<i>Use case ID</i>	FG-AN-usecase-035
	<p>FLAML integrates several simple but effective search strategies into an adaptive system.</p> <p>FLAML:</p> <ol style="list-style-type: none"> 1) Can optimize with low latency; 2) Can handle large datasets; 3) Is not restricted to fixed set of configs; 4) Can easily add new/custom learners; 5) Can cold start. <p>Some of the optimizations done are related to:</p> <ol style="list-style-type: none"> 1) The trials experimentation to be invoked; 2) The order to invoke the trials. <p>Some of the proposed properties of optimizations in FLAML are:</p> <ol style="list-style-type: none"> 1) Suitable sample size; 2) Resample; 3) Fair chance; 4) Optimal trial. <p>Steps related to use case:</p> <ol style="list-style-type: none"> 1) Overall use case for autonomous network is specified in the intent to AN. 2) The requirements for ML use case and hence ML intents are derived from the overall use case. 3) Based on the knowledge base or on human guidance, the AN configures FLAML with the ML intent. 4) It is left to FLAML to select the learner, carry out trials, and adapt/optimize the ML model's parameters. 5) It is left to FLAML to tightly or loosely couple with the AN domain, to utilize its experimentation manager, analytics or sandbox or knowledge base (KB).
<i>Notes on use case category</i>	Cat 1: describes a scenario related to core autonomous behaviour itself.
<i>References</i>	[b-Wang-1], [b-FLAML], [b-Microsoft], [b-Wu-1], [b-Wu-2]

7.35.1 Use case requirements

- AN-UC035-REQ-001: It is critical that the AN enable capturing of the overall use case in an AN intent and the derivation of requirements for ML use case and hence ML intents from the overall use case.
- AN-UC035-REQ-002: It is critical that, based on the KB or on human guidance, the AN configure ML optimization tools with the ML intent.

NOTE – FLAML is an example of an ML optimization tool. It is left to FLAML to select the learner, carry out trials, and adapt/optimize the ML model's parameters.

- AN-UC035-REQ-003: It is critical that based on the capabilities of the ML optimization tool, the AN tightly or loosely couples with the tool, to utilize its experimentation manager, analytics or sandbox or KB.

7.35.2 Actor interactions and possible components

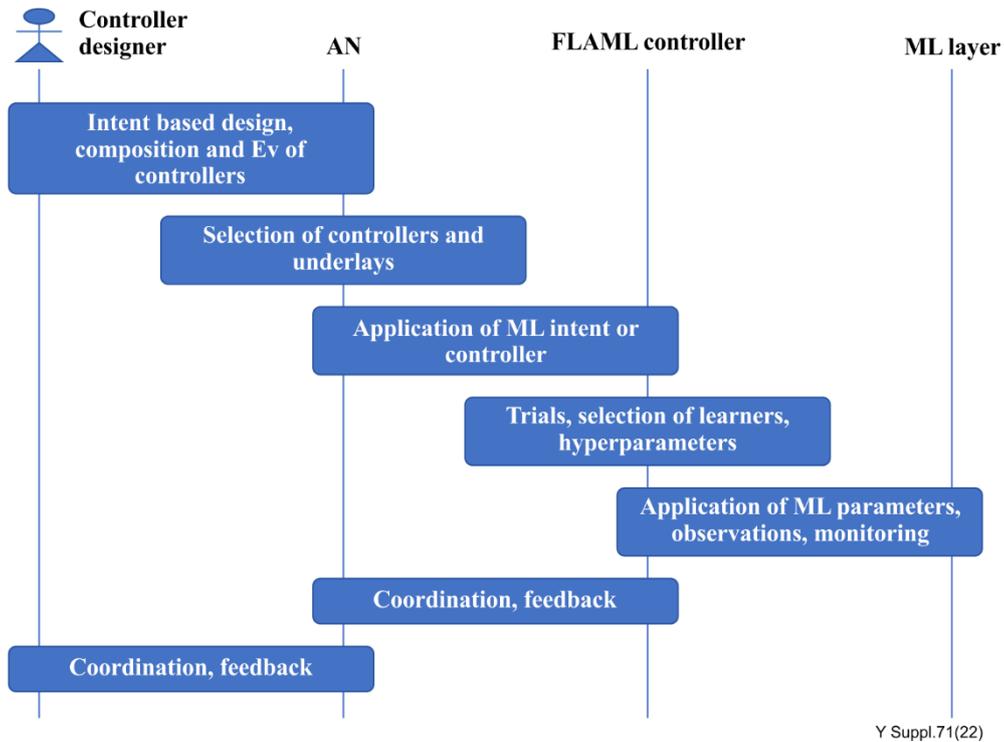


Figure 26 – Actor interactions for FLAML

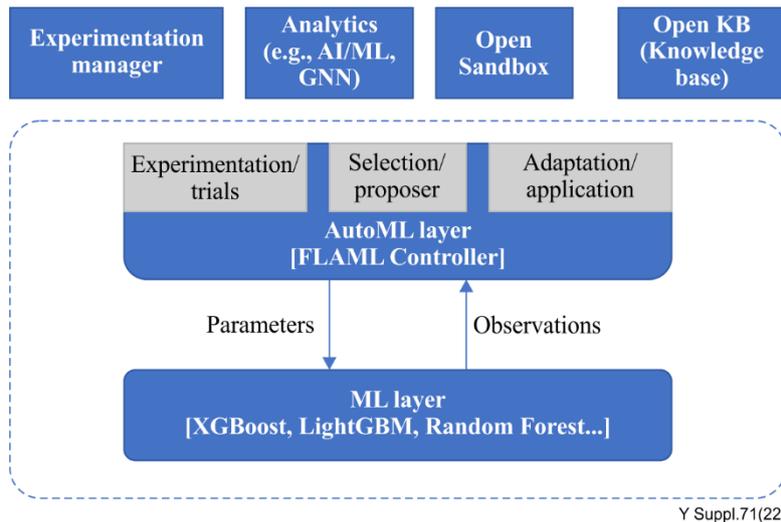


Figure 27 – Possible components for FLAML (adapted from [b-FLAML])

Actors involved (Figure 26):

- FLAML controller: This actor interacts with ML underlay networks to monitor and optimize the ML models.
- ML layer: This actor is the ML underlay network hosting various types of ML models.

7.36 Connected AI (CAI) testbed: Testbed for 5G connected artificial intelligence on virtualized networks

<i>Use case ID</i>	FG-AN-usecase-036
<i>Use case description</i>	<p>5G testbeds are an important alternative to simulators and many have been recently described, emphasizing aspects such as cloud functionalities, management and orchestration. This use case describes the connected AI testbed, which is a 5G mobile network testbed with a virtualized and orchestrated structure using containers, which focuses on integration to AI applications.</p> <p>Two use cases are described, one for RAN slicing and another for the placement of VNFs according to application requirements. The focus is on the application of AI to RAN and the transport network, including fronthaul and backhaul.</p> <p>The SDN and RAN controllers work as information sources about the network. They also work as agents to dynamically change the mobile and the computer network. An AI agent performs different actions in the testbed according to the application, using the information provided by the SDN and RAN controllers to train and execute in test stage its NNs. The ML workloads are orchestrated along the cluster to provide the AI agent processes.</p> <p>Steps related to the use case:</p> <ol style="list-style-type: none"> 1) The overall use case for the autonomous network is specified in the intent to the AN. 2) The requirements for the AI agent and hence the ML intents are derived from the overall use case. 3) Based on the KB or on human guidance, the AN configures the AI agent with the ML intent. 4) It is left to the AI agent to select the model, and optimize the ML model's parameters. 5) It is left to the AI agent to tightly or loosely couple with the AN domain, to utilize its experimentation manager, analytics or sandbox or KB.
<i>Notes on use case category</i>	Cat 2: describes a scenario related to the application of autonomous behaviour in the network.
<i>Reference</i>	[b-Nahum]

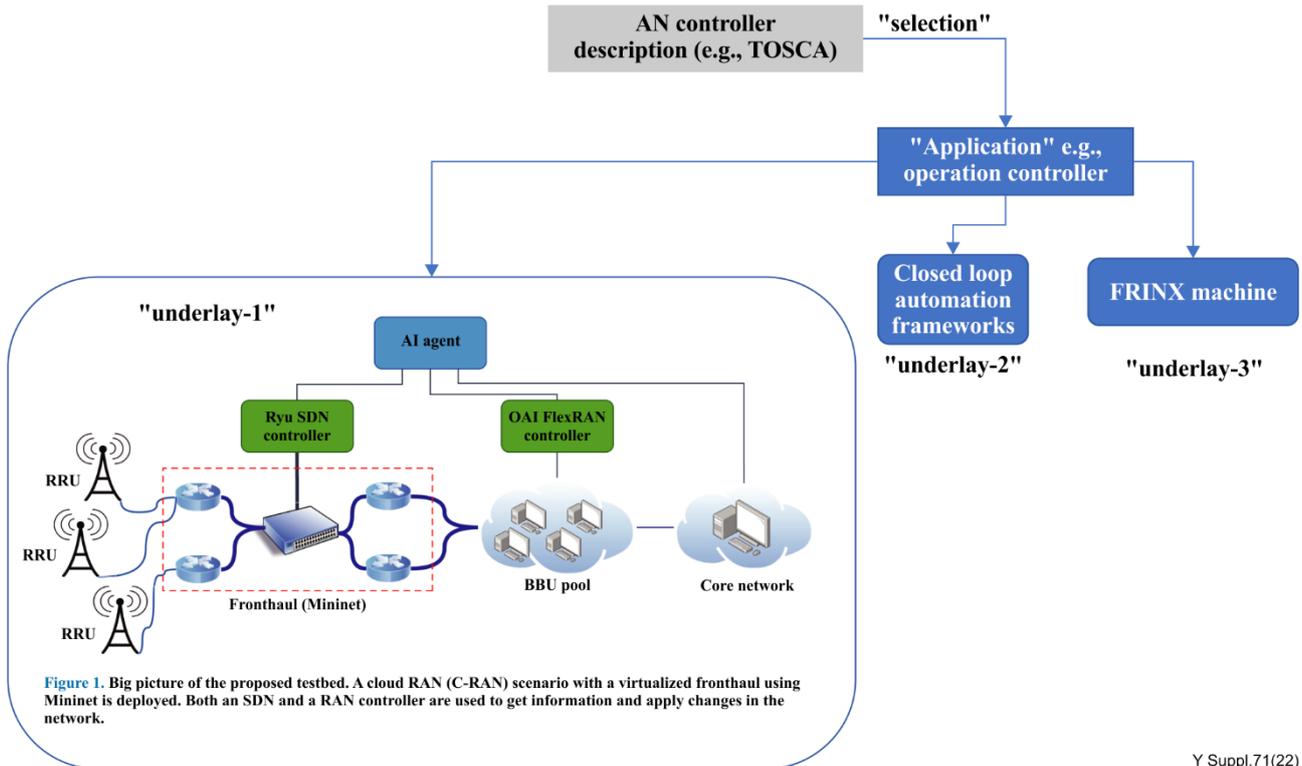
7.36.1 Use case requirements

- AN-UC036-REQ-001: it is critical that, based on the KB or human guidance, the AN configure AI agents.

NOTE – AI agents may in turn select the model and optimize the ML model's parameters in the ML pipeline to be deployed in the underlay network.

- AN-UC036-REQ-002: it is critical that based on the capabilities of the AI agent, the AN tightly or loosely couple with the AI agent, to utilize its experimentation manager, analytics or sandbox or KB.

7.36.2 Actor interactions and possible components



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Figure 28 – Actor interactions for the connected AI (CAI) testbed

Actors involved (Figure 28):

- Underlay-1: An instance of an underlay network, which implements a 5G mobile network testbed with a virtualized and orchestrated structure using containers, focusing on integration to AI applications.
- Underlay-2: An instance of an underlay network which implements CL automation frameworks.
- Underlay-3: An instance of an underlay network which implements workflow orchestration e.g., FRINX machine.
- Application: This actor interacts with underlay networks to instantiate and operate the controllers in the various underlay networks. For example, an operation controller which uses APIs exposed by various underlay networks.
- AN controller: This actor selects the underlay network to deploy the controllers per the use case description.

7.37 Negotiated boundaries in AN for seamless network sharing

<i>Use case ID</i>	FG-AN-usecase-037
<i>Use case description</i>	<p>It is possible that various networks are operated and deployed by operators in shared settings. The operators or interested parties such as mobile virtual network operators (MVNOs) share the network for various reasons such as reducing CAPEX and operational expenditure (OPEX) (reduce TCO in general) and providing coverage for the users.</p> <p>There are some underlying arrangements for sharing the network such as RAN sharing, spectrum sharing, and core network and transport network sharing. These arrangements are governed by the agreement between the interested parties. The</p>

<i>Use case ID</i>	FG-AN-usecase-037
	<p>arrangements could possibly be network slicing, 3GPP based network sharing or some custom vendor solution. The arrangements are rigid and not flexible because of a prior agreement between the parties. The prior agreement creates a boundary between the operators, and any change in the boundary requires a revisit to the agreement.</p> <p>NOTE – Forming new agreements with different operators, withdrawing the existing agreement, and changing service level agreements (SLA) are examples of changes in boundaries between operators.</p> <p>From the AN perspective, the strict boundary is a roadblock towards autonomy. The boundaries are required to be flexible and scale in and out dynamically without involving any central authority (here an operator/human). The AN decides the scaling of boundaries(in/out) based on the requirement. The control loops, intent or some prediction algorithm can generate requirements for the action of the AN. The AN is required to adapt and provide the associated management such as policing, billing and other configured elements related to the shared arrangement between the interested parties. The AN is required to have the capability to negotiate the boundaries through the adapted agreements between the interested parties. The negotiation of boundaries means the AN can independently change the agreements in runtime.</p> <p>The following describes an example of load balancing:</p> <ol style="list-style-type: none"> 1) Consider a scenario of base stations deployed by different operators in a single coverage area. 2) The base station is loaded, and there is a need to balance the load for providing the users with the desired quality of service. 3) In the case of a non-AN, the base station can balance the load to different operator base stations. However, it can only scale out to the predefined operators in the agreement, and those base stations can also be loaded. To scale out to the other base stations, it needs an operator (human) in the loop who then completes the sharing agreement and provision arrangements. 4) In an AN case, the base station can identify the requirement to load balance the users to other base stations. The AN acts independently to adapt the agreement and scale its coverage via other base stations with reduced intervention of the operator (human). The AN provisions the associated agreements dynamically per the requirement.
<i>Use case category</i>	Cat 2: Describes a scenario related to application of autonomous behaviour in the network.
<i>Reference</i>	None

7.37.1 Use case requirements

Critical requirements

- AN-UC037-REQ-001: It is critical that autonomous networks support seamless autonomous behaviour in the case of underlay networks that support scaling across shared resource pools and across administrative domains.

NOTE 1 – Examples of seamless autonomous behaviour may include inclusion (or exclusion) of new controllers or CLs or services or devices into the scaled AN domain.

NOTE 2 – Examples of shared resource pools are CPU cores, memory, RAN resources such as spectrum frequencies, or network resources such as ports.

NOTE 3 – Examples of administrative domains are base stations, transport network or core NFs which are owned, maintained and operated by different network operators.

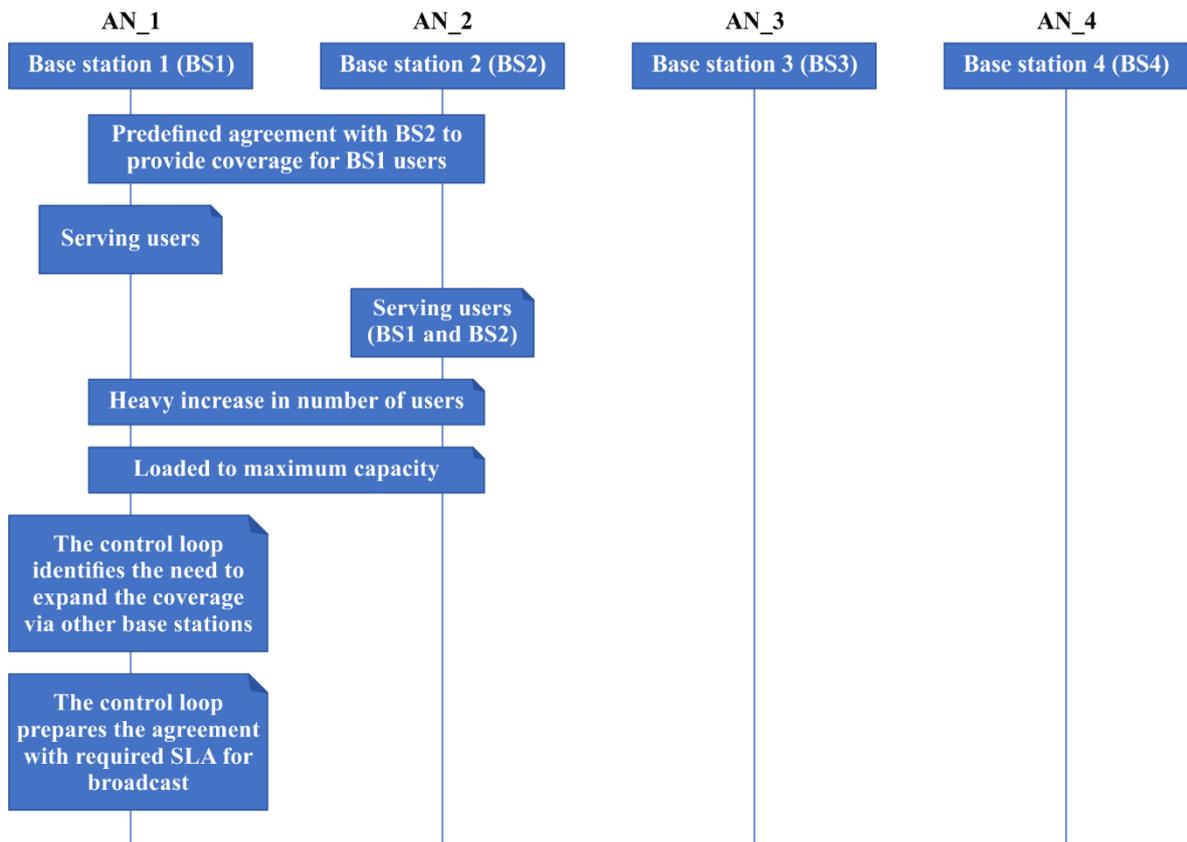
Expected requirements

- AN-UC037-REQ-002: It is expected that autonomous networks reuse existing mechanisms for the dynamic management of agreements between different administrative domains of network operators to achieve seamless autonomous behaviour in case of underlay networks that support scaling across shared resource pools and across administrative domains.

NOTE 4 – Examples of existing mechanisms for dynamic management of agreements are blockchain mechanisms or smart contracts.

7.37.2 Actor interactions and possible components

Figure 29 and Figure 30 depict the scenarios of dynamic changes in base station load in terms of number of served users (Figure 29) and the corresponding network sharing and SLA negotiations (Figure 30).



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Figure 29 – Actor interactions for negotiated boundaries in AN for seamless network sharing

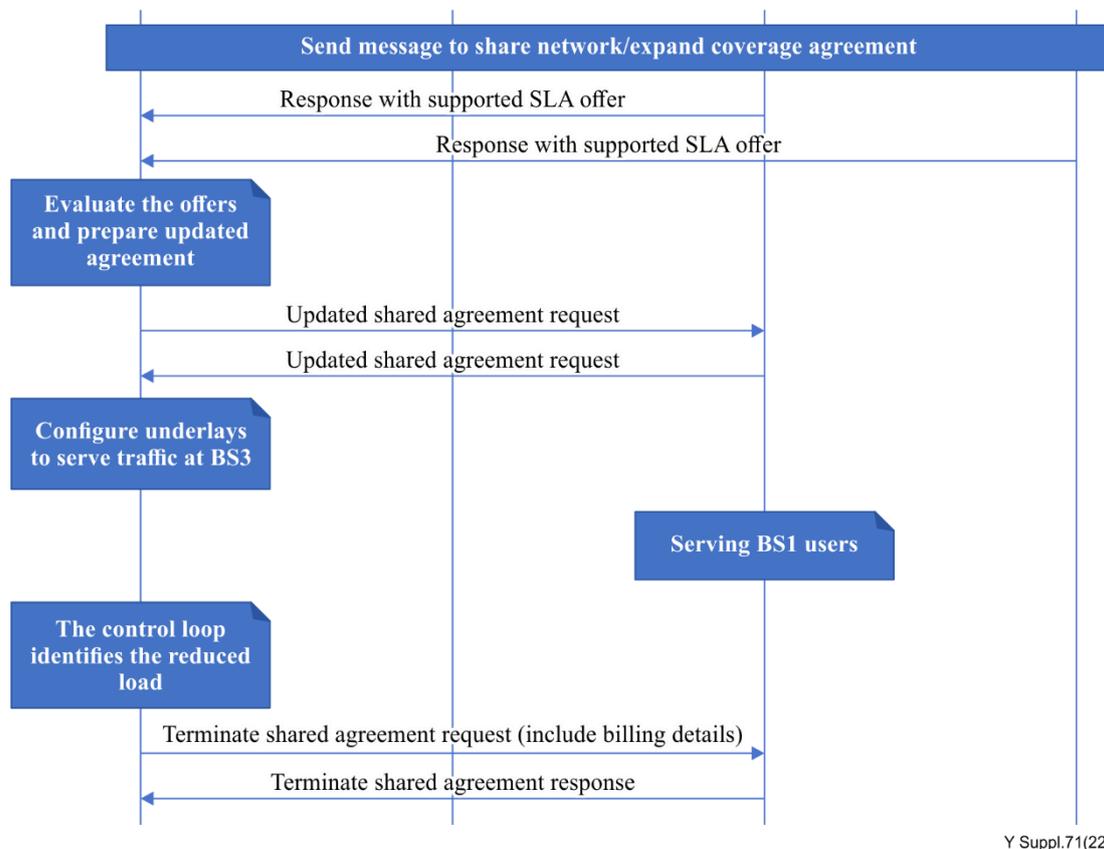


Figure 30 – Actor interactions for negotiated boundaries in AN for seamless network sharing

Actors involved (Figure 30):

- Base station: An actor which provides connectivity to UE and hosts controllers to monitor and optimize the service load (in terms of number of users served).

7.38 AN enabled end-to-end supply chain

<i>Use case ID</i>	FG-AN-usecase-038
<i>Use case description</i>	<p>Currently, the supply chain for the networks is highly operator dependent. The operator drives the choice of equipment, procurement, testing and deployment. Planning tools can help to automate the deployment process.</p> <p>Modern advancements include deploying drones for the inspection and monitoring of deployed base stations [b-Sharma]. Such inspection by drones is a step towards automation and autonomy. Mission critical applications require the on-demand deployment of the network, with rapid deployment. The supply chain's end-to-end orchestration stage helps in the deployment of network equipment, virtual or physical, which brings the network equipment to up and running stage. In an ultra-dense deployment world, the scale of equipment in numbers is very large and hence creates challenges for an operator to manage millions of items of equipment deployed in different geographies. This brings to the fore the importance of ANs supported by an end-to-end orchestrated supply chain.</p> <p>In this use case, end-to-end orchestration of the supply chain is studied in the AN context. There is a need to delegate the control from the operator to AN and remove the dependency of the operator. The AN can act independently and decide the orchestration of the supply chain per the requirements. All physical operations such as power-up of equipment and cabling would need human intervention, but the AN can certainly schedule those events, notify required teams and monitor</p>

<i>Use case ID</i>	FG-AN-usecase-038
	<p>progress. Furthermore, the AN exposes interfaces for operators or orchestrators to feed the vendor lists, equipment lists for bootstrapping and update process. The AN drives the end-to-end supply chain orchestration with minimal intervention by the operator in run time.</p> <p>The following describes an example:</p> <ol style="list-style-type: none"> 1) The operator feeds the list of vendors or procurement of equipment in AN. It is similar to the source of the image in the docker file. Over a period of time, the AN could learn which equipment came from which vendor and rate the vendors based on the performance of their equipment. 2) The AN identifies the need to provision network equipment for various reasons such as replacement for faulty equipment, expansion of the network's capacity, new sites, upgrade and emergency deployment. 3) The AN understands the need, possibly through some optimization algorithm, direct requirement through intents, other orchestration mechanisms or prediction-based control loops. 4) The AN drives the supply chain by procuring, testing the equipment and finally deploying the equipment. The testing requires operator intervention for physical activities. The AN runs the automated test procedures and tallies the results to decide the deployment of equipment. 5) The AN configures the underlying equipment and newly deployed equipment for integration to go live.
<i>Use case category</i>	Cat 2: Describes a scenario related to application of autonomous behaviour in the network.
<i>Reference</i>	[b-Sharma]

7.38.1 Use case requirements

Critical requirements

- AN-UC038-REQ-001: It is critical that autonomous networks support the interface towards and orchestration of software and hardware inventory management systems in underlay networks.
- AN-UC038-REQ-002: It is critical that autonomous networks support interface towards respective teams (human or bot) or the operations centre of the software and hardware components/equipment/systems.

NOTE – Examples of the orchestration of inventory management systems are representing and triggering addition, deletion and changes in the inventory. The benefits of such orchestration mechanisms may include the proactive and rapid adaptation of controllers and predictive management of supply chains.

7.38.2 Actor interactions and possible components

Figure 31 and Figure 32 depict scenarios of monitoring equipment carried out in the network (Figure 31), and corresponding trigger of inventory management system and deployment and validations (Figure 32).

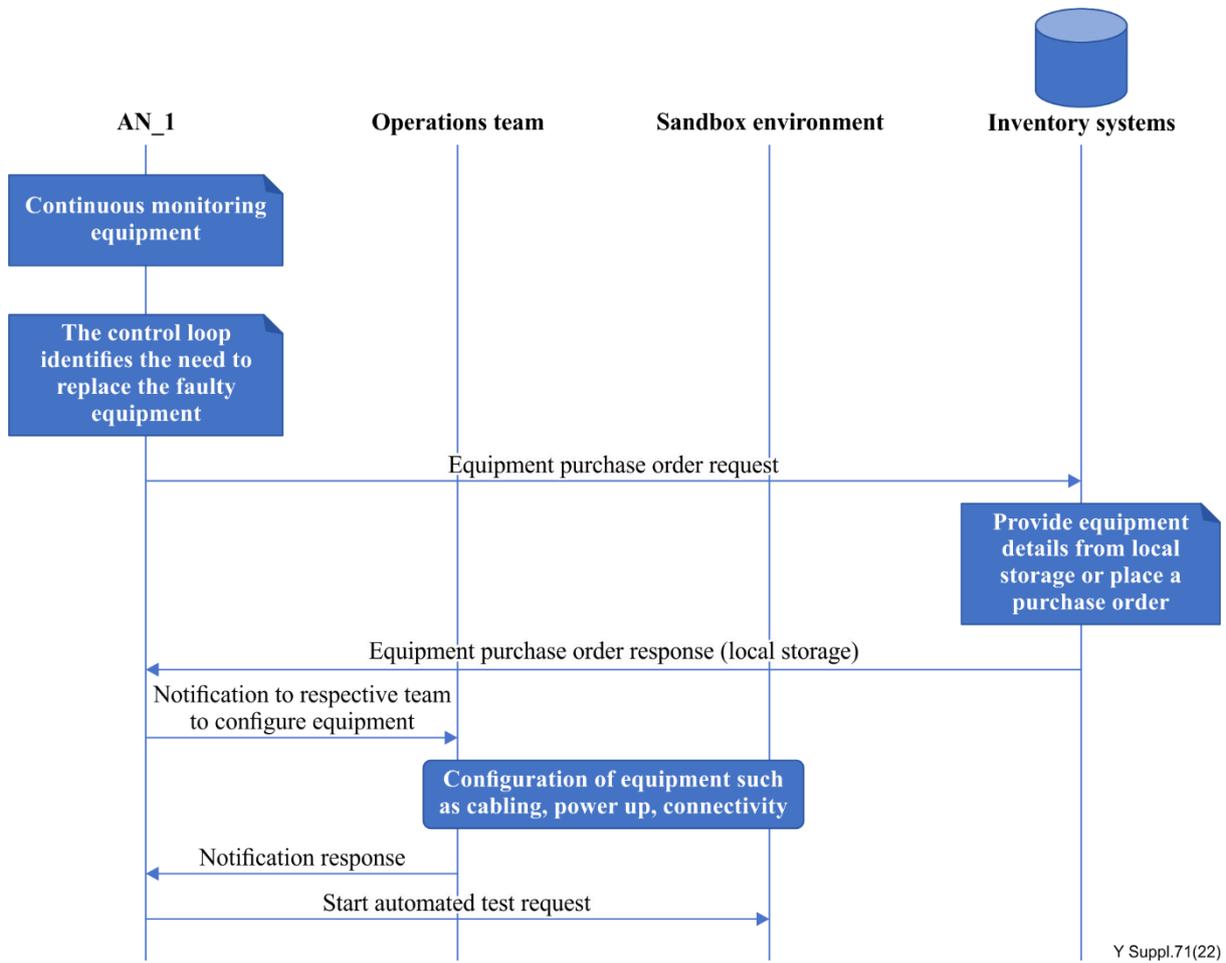


Figure 31 – Actor interactions for an AN enabled end-to-end supply chain

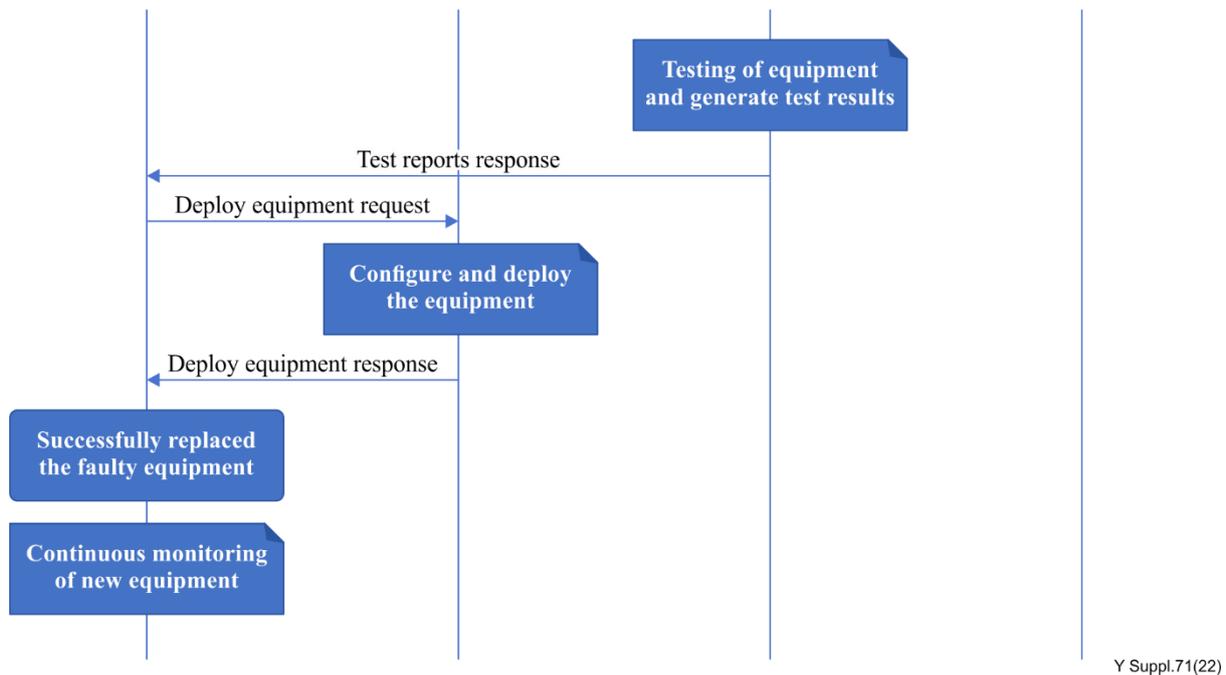


Figure 32 – Actor interactions for an AN enabled end-to-end supply chain

Actors involved (Figure 31, Figure 32):

- AN_1: An actor or set of actors which provides autonomous network capabilities.

- Operations team: An actor which provides management and operations for equipment and other inventory in the underlay network.
- Inventory systems: An actor which stores and provides the list and details of equipment used in the underlay network.

7.39 Towards openness in AN

<i>Use case ID</i>	FG-AN-usecase-039
<i>Use case description</i>	<p>Future networks include the heterogeneous AN and control loops are an essential part of AN. There could be various control loops deployed at various endpoints in a heterogeneous AN. The various endpoints could be the edge, cloud, devices such as switches, routers, user terminals and customer premises equipment; in general, a control loop could possibly be found in every item of network equipment.</p> <p>Different vendors develop various control loops for delivering specific functionality of the AN, focusing on improving cost, efficiency, performance and scalability factors. Single vendor solutions which develop the entire AN are rare. Most solutions would incorporate a plug and play design. In such a scenario, there is a need for the AN to adopt an open design for inclusiveness.</p> <p>Inclusive design helps the AN to plug any control loop from any vendor based on its requirement. The AN acts independently without involving any central authority to include the third-party control loops. To enable such inclusive design, the AN is required to expose an interface to integrate control loops. The interface requires metadata about control loops. The AN independently manages the lifecycle of the control loops. The AN requires the capability to test and configure the control loops. The vendors would use such an interface to develop the application (control loop), knowing that it will help integrate their application. Such a design helps the ecosystem to provide innovative solutions.</p> <p>This use case realization includes a control loop application store, where vendors can publish their control loops, and any AN can use it as a repository for control loops. A vendor does not need to publish the control loop in the application store. AN can fetch the control loop from the required location defined in the system.</p> <p>The following describes an example:</p> <ol style="list-style-type: none"> 1) AN identifies the need to deploy a control loop for a particular service or update the existing control (may be evolutionary). 2) Based on the requirement, the AN searches for the control loop either in the application store or at a preconfigured location. 3) The AN downloads the control loop, tests it in a sandbox environment and configures it. The configuration provides control loops providing access to resources. The resources could be data, storage, network, placement or security. 4) Once configured, the AN deploys the control loop and continuously monitors its performance. 5) The AN also configures the SLA and billing settings for the vendor.
<i>Use case category</i>	Cat 2: Describes a scenario related to the application of autonomous behaviour in the network.
<i>Reference</i>	None

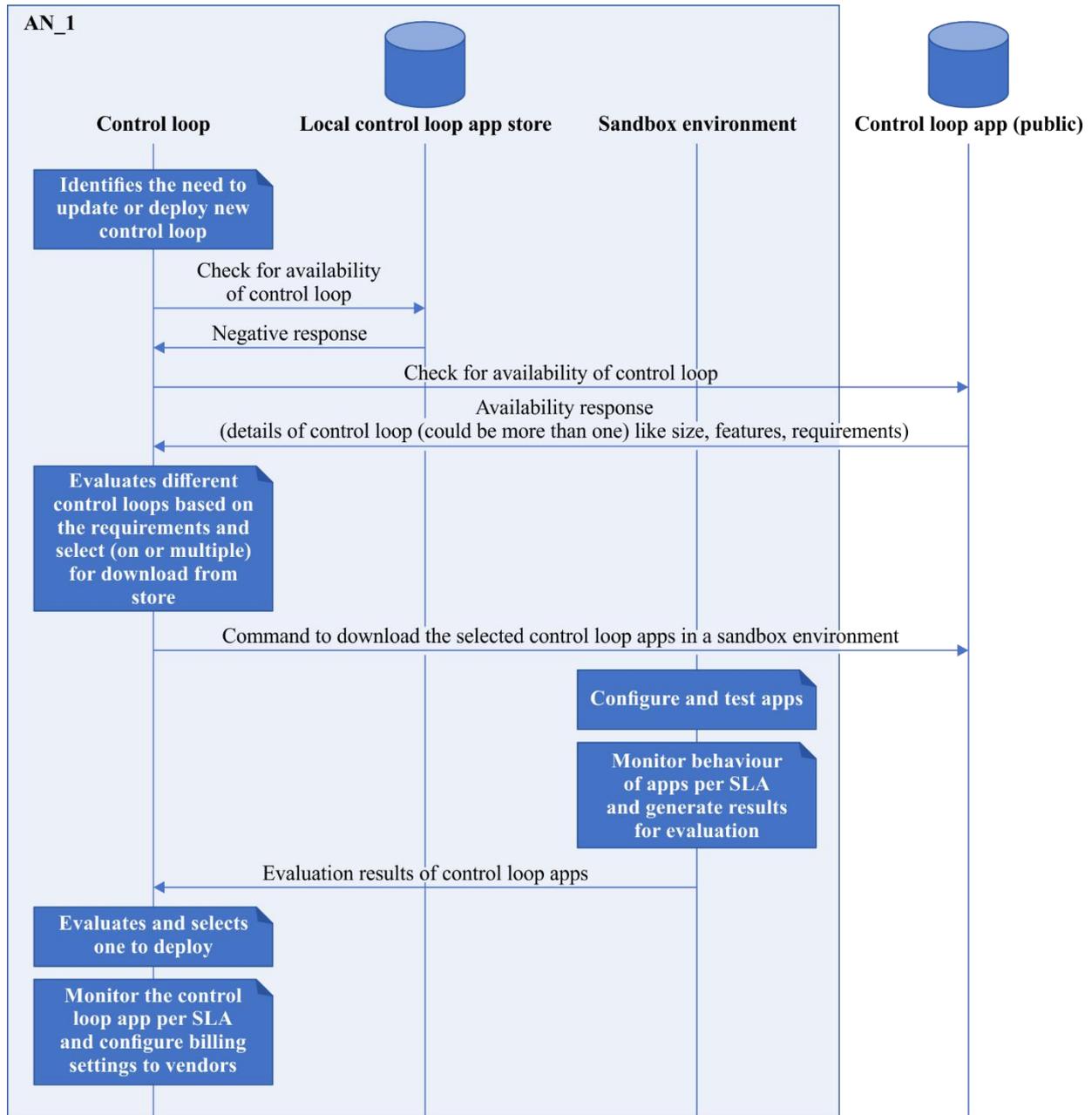
7.39.1 Use case requirements

Critical requirements

- AN-UC039-REQ-001: It is critical that ANs support identifying the need for a control loop and enable the selection, evaluation, integration and monitoring of control loops in different underlay networks.

NOTE – The AN may use metadata based selection of control loops from open repositories. Evaluation of control loops may be done using sandboxes. The control loops are local (internal) or third-party developed.

7.39.2 Actor interactions and possible components



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Figure 33 – Actor interactions for openness in the AN

Actors involved (Figure 32, Figure 33):

- Control loop: An actor which provides an instance of the controller.
- Local control loop app store: An actor which provides a local instance of openCN in a specific operator underlay network.
- Inventory systems: An actor which provides a public instance of openCN which may serve multiple operators' underlay networks.

7.40 Awareness in AN

<i>Use case ID</i>	FG-AN-usecase-040
<i>Use case description</i>	<p>There are heterogeneous networks (HetNet) with networks such as RAN, core, and the transport and convergence of wireless and wireline of different technologies. The evolution of HetNet technologies would comprise control loops in the journey towards the AN. Multiple control loops from different vendors and operators surround the AN at any given location or endpoint in such a HetNet scenario. The AN needs to be aware of the surrounding control loops or other ANs in general. It could be for various reasons such as collaboration, coordination, security, training machine learning model, split learning or offload. The AN must have an interface to communicate and interact with other control loops in a different AN and control loops within the AN. The interface is required to enable other control loops to be autonomous, discover each other and communicate directly with other control loops without involving any centralized entity. The control loops within the AN may have a centralized entity, but communication with the external control loop is without a centralized entity. The AN is self-sufficient to act independently.</p> <p>Consider the following example of usage of interface:</p> <ol style="list-style-type: none"> 1) The discovery of nearby control loops and ANs is available at edge nodes. 2) An edge node AN_1 entity is running some application and because of heavy burst load in the requests, it runs short of compute and storage to maintain the desired quality of service. 3) The AN_1 node identifies the problem based on the feedback, monitoring or any logic/algorithm. It seeks out help in the form of collaboration to offload the requests using the interface. 4) Another AN edge node AN_2 responds with its capability and SLA parameters. The AN_1 evaluates and decide to offload the requests to AN_2. 5) AN_1 and AN_2 use the interface to configure the routing and policy to divert the traffic to AN_2 and initiate the offload process. 6) AN_1 uses the interface to release all the resources and bill the usage per the SLA once the load reduces.
<i>Use case category</i>	Cat 2: describes a scenario related to application of autonomous behaviour in the network.
<i>Reference</i>	None

7.40.1 Use case requirements

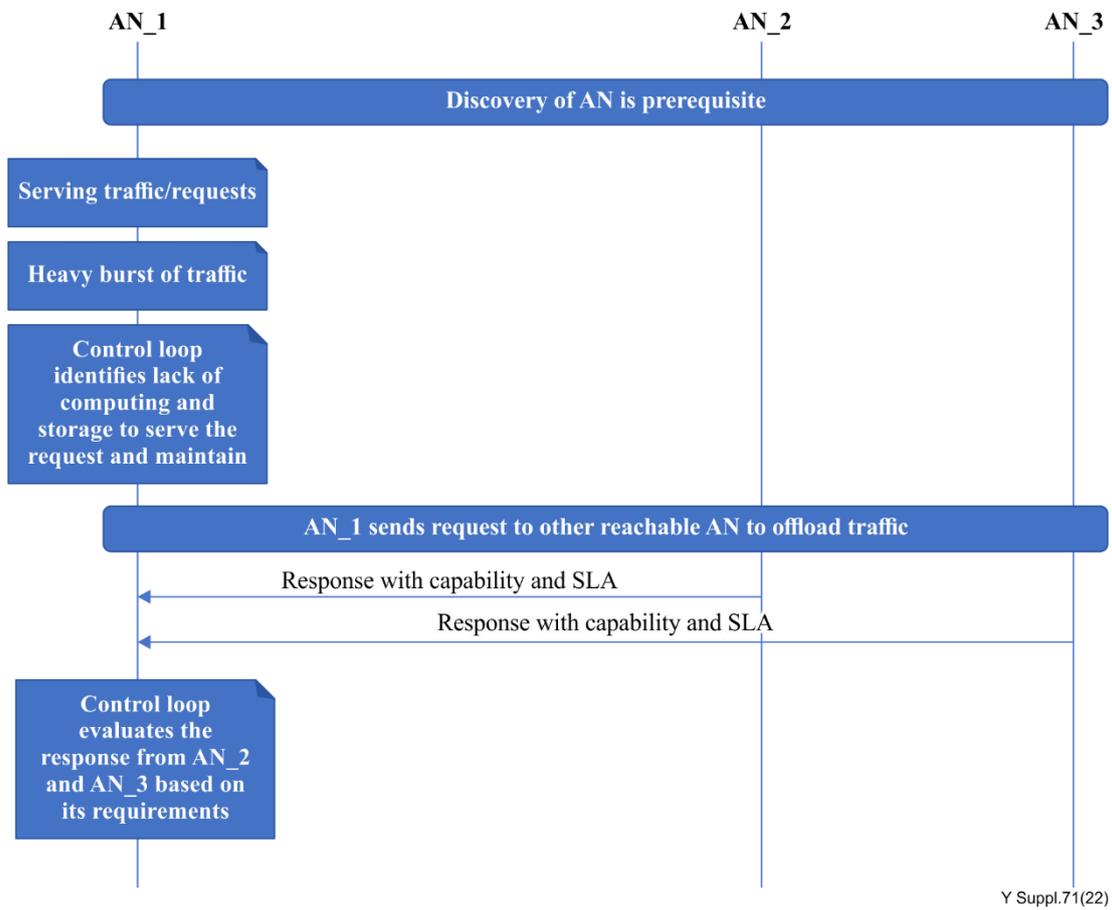
Critical requirements

- AN-UC040-REQ-001: It is critical that autonomous networks support peer interaction between different controller instances.

NOTE – Examples of peer interaction are capability discovery and exchange and resource pooling. Peer interaction may be achieved without involving a centralized entity.

7.40.2 Actor interactions and possible components

Figure 34 and Figure 35 depict the scenarios of monitoring of traffic load done in the network (Figure 34) and dynamic offload with corresponding configurations and reconfigurations (Figure 35).



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Figure 34 – Actor interactions for awareness in the AN

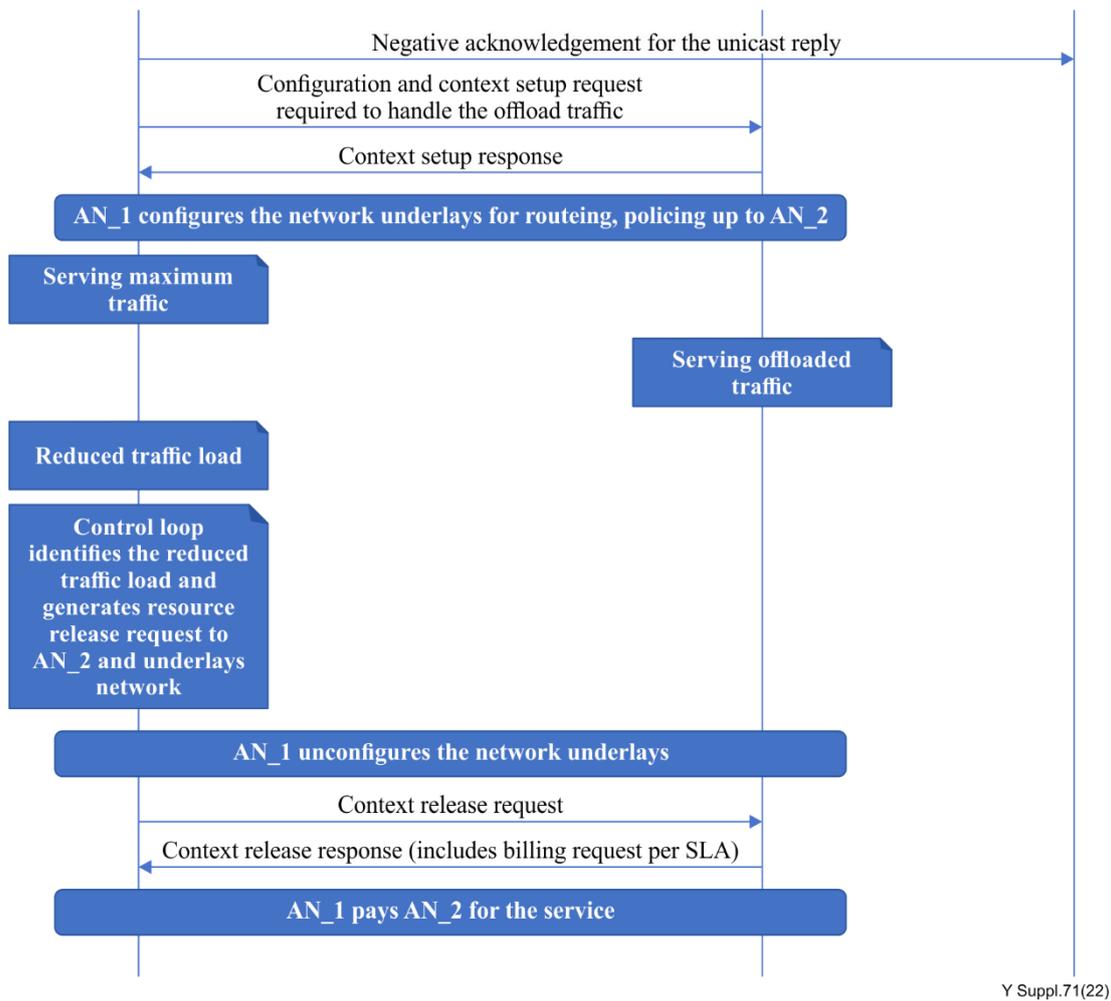


Figure 35 – Actor interactions for awareness in the AN

Actors involved (Figure 34, Figure 35):

AN_1, AN_2 and other ANs are actors which serve traffic requests and host controllers which optimize the traffic load by making offload decisions to other ANs based on capability and SLA negotiations.

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