O-RAN.WG11.TR.Threat-Modeling.O-R004-v05.00

Technical Report

O-RAN Work Group 11 (Security Work Group)

O-RAN Security Threat Modeling and Risk Assessment

O-RAN ALLIANCE e.V., Buschkauler Weg 27, 53347 Alfter, Germany
Register of Associations, Bonn VR 11238, VAT ID DE321720189

Contents

List of figures

List of tables

Intellectual Property Rights (IPR)

This Intellectual Property Rights Policy (“IPR Policy”) will apply to documents or code developed by the O-RAN ALLIANCE for the purpose of describing key components of a Radio Access Network and their interconnections and performance, including in particular, but not limited to, the functions, behaviors, and requirements for systems, subsystems, software modules, and hardware modules, and the details of the interfaces and APIs that interconnect these components to each other or to external systems and components as well as future amendments or revisions thereto, if any. Except as otherwise defined, all capitalized terms will have the meaning defined for them in the O-RAN Constitution

Foreword

This Technical Report (TR) has been produced by O-RAN Alliance.

The content of the present document is subject to continuing work within O-RAN and may change following formal O-RAN approval. Should the O-RAN Alliance modify the contents of the present document, it will be re-released by O-RAN with an identifying change of version date and an increase in version number as follows:

version xx.yy.zz

where:

xx: the first digit-group is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc. (the initial approved document will have xx=01). Always 2 digits with leading zero if needed.

yy: the second digit-group is incremented when editorial only changes have been incorporated in the document. Always 2 digits with leading zero if needed.

zz: the third digit-group included only in working versions of the document indicating incremental changes during the editing process. External versions never include the third digit-group. Always 2 digits with leading zero if needed.

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the O-RAN Drafting Rules (Verbal forms for the expression of provisions).

"**must**" and "**must not**" are **NOT** allowed in O-RAN deliverables except when used in direct citation.

1 Scope

The contents of the present document are subject to continuing work within O-RAN and may change following formal O-RAN approval. Should the O-RAN Alliance modify the contents of the present document, it will be re-released by O-RAN with an identifying change of version date and an increase in version number as follows:

version xx.yy.zz

where:

xx: the first digit-group is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc. (the initial approved document will have xx=01). Always 2 digits with leading zero if needed.

yy: the second digit-group is incremented when editorial only changes have been incorporated in the document. Always 2 digits with leading zero if needed.

zz: the third digit-group included only in working versions of the document indicating incremental changes during the editing process. External versions never include the third digit-group. Always 2 digits with leading zero if needed.

This technical report describes the O-RAN Security Threat Modeling and Risk Assessment. It identifies assets to be protected, analyzes the O-RAN components for vulnerabilities, examines potential threats associated with those vulnerabilities, provides security principles which stakeholders should adress when building a secure end-to-end O-RAN system and assesses the risks of the identified threats based on impact and likelihood factors.

NOTE: The present document is transformed from a Technical Specification (TS) to a Technical Report (TR) as it doesn’t containe normartive requirements. Instead, it is an informative document that serves as a vital resource for understanding the potential risks within O-RAN and defining appropriate requirement/controls to mitigate them effectively.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies. In the case of a reference to a 3GPP document, a non-specific reference implicitly refers to the latest version of that document in Release 18, or the latest 3GPP release prior to Release 18 that includes that document.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, O-RAN cannot guarantee their long-term validity.

[i.1] 3GPP TR 21.905: Vocabulary for 3GPP Specifications

[i.2] 3GPP TS 33.511: Security Assurance Specification (SCAS) for the next generation Node B (gNodeB) network product class

[i.3] 3GPP TS 33.501: Security architecture and procedures for 5G system

[i.4] 3GPP TR 33.926: Security Assurance Specification (SCAS) threats and critical assets in 3GPP network product classes

[i.5] 3GPP TS 33.117: Catalogue of general security assurance requirements

[i.6] ORAN ALLIANCE TS “O-RAN Architecture Description”

[i.7] ISO 27005: Information security, cybersecurity and privacy protection — Guidance on managing information security risks

[i.8] O-RAN ALLIANCE TS “Near-RT RIC Architecture”

[i.9] O-RAN ALLIANCE TS “O-RAN Acceleration Abstraction Layer General Aspects and Principles”

[i.10] O-RAN ALLIANCE: “O-RAN WG4 “Control, User and Synchronization Plane Specification” [i.11] O-RAN ALLIANCE TR “Cloud Architecture and Deployment Scenarios for O-RAN Virtualized RAN”

[i.12] ERICSSON ‘Security Considerations of Open RAN’ whitepaper and slides.

[i.13] NIST Special Publication 800-154 2 Guide to Data-Centric System Threat Modeling

[i.14] Resource Allocation Scheme in 5G Network Slices

[i.15] 3GPP TR 33.818: “Security Assurance Methodology (SECAM) and Security Assurance Specification (SCAS) for 3GPP virtualized network products”.

[i.16] Fraunhofer AISEC - threat analysis of container-as-a-service for network function virtualization

[i.17] Ecology-Based DoS Attack in Cognitive Radio Networks

[i.18] AN ARCHITECTURAL RISK ANALYSIS OF MACHINE LEARNING SYSTEMS: Toward More Secure Machine Learning

[i.19] 5G Americas Whitepaper October 2018 “The Evolution of Security in 5G”

[i.20] 3GPP TR 33.845: Study on security aspects of the 5G Service Based Architecture (SBA)

[i.21] OWASP API Security Top 10

[i.22] MITRE ATT&CK containers matrix

[i.23] 3GPP TR 33.848: Study on security impacts of virtualisation

[i.24] Graz University of Technology (2018), Meltdown and Specter

[i.25] O-RAN ALLIANCE TS: "Near-Real-time RAN Intelligent Controller and E2 interface; E2 General Aspects and Principles"

[i.26] NIST Special Publication 800-207, “Zero Trust Architecture,” https://csrc.nist.gov/publications/detail/sp/800-207/final

[i.27] O-RAN ALLIANCE TS: "Management Plane Specification".

[i.28] CWE-524, "Use of Cache Containing Sensitive Information", https://cwe.mitre.org/data/definitions/524.html

[i.29] CAPEC-204, “Lifting Sensitive Data Embedded in Cache”, https://capec.mitre.org/data/definitions/204.html

[i.30] Infiltrating Corporate Intranet Like NSA, https://i.blackhat.com/USA-19/Wednesday/us-19-Tsai-Infiltrating-Corporate-Intranet-Like-NSA.pdf

[i.31] Output Integrity Attack, https://owasp.org/www-project-machine-learning-security-top-10/docs/ML09_2023-Output_Integrity_Attack

[i.32] ENISA: “Securing Machine Learning Algorithms”; https://www.enisa.europa.eu/publications/securing-machine-learning-algorithms

[i.33] OWASP Top 10 Machine Learning Security risks, 2023 https://owasp.org/www-project-machine-learning-security-top-10/

[i.34] O-RAN ALLIANCE TS: “O2dms Interface Specification: Kubernetes Native API Profile for Containerized NFs”

[i.35] NIST Glossary, NIST Computer Resource Center, Glossary | CSRC (nist.gov)

3 Definition of terms, symbols and abbreviations

3.1 Definition of terms

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [i.1], O-RAN [i.6], [i.9], [i.11] and the following apply:

Attack: The realization of some specific threat that impacts the confidentiality, integrity, accountability, or availability of a resource. [adapted from i.35]

Attack surface: The set of points on the boundary of a system, a system component, or an environment where an attacker can try to enter, cause an effect on, or extract data from, that system, component, or environment. [i.35]

O-Cloud instance ID: The O-Cloud instance ID is a unique identifier assigned to components within the O-Cloud platform, including VMs, pods, containers, nodes, and compute pools (i.e., a cluster in Kubernetes). This ensures uniqueness across the entire O-Cloud environment, irrespective of the component type. For instance, a VM, a pod, a container, a node, and a cluster will each have a distinct O-Cloud instance ID within the platform, ensuring that there is no ambiguity in identification.

Radio jamming is the deliberate jamming, blocking or creating interference with authorized wireless network. A radio jammer is a transmitter that tunes to the same frequency as the opponents' receiving equipment and with the same type of modulation, with enough power to override any signal at the receiver.

Radio Sniffing technique helps to decode all sorts of essential network configuration details easily with low-cost software radios. Sniffing information can aid attackers in optimizing and crafting attacks.

Risk: A measure of the extent to which an entity is threatened by a potential circumstance or event, and typically a function of: (i) the adverse impacts that would arise if the circumstance or event occurs; and (ii) the likelihood of occurrence. Information system-related security risks arise from the loss of confidentiality, integrity, or availability of information or information systems and reflect the potential adverse impacts to organizational operations (including mission, functions, image, or reputation), organizational assets, individuals, and other organizations. [i.35]

Risk mitigation: Prioritizing, evaluating, and implementing the appropriate risk-reducing controls/countermeasures recommended from the risk management process. [i.35]

RF spoofing refers to transmitting a fake signal meant to pretence as an actual signal.

Security controls: Actions, devices, procedures, techniques, or other measures that reduce the vulnerability of an information system. [i.35]

Technical controls: The security controls for an information system that are primarily implemented and executed by the information system through mechanisms contained in the hardware, software, or firmware components of the system. [i.35]. Also referred to as 'Security Controls' and 'Controls' in O-RAN.

Threat: Any circumstance or event with the potential to adversely impact organizational operations (including mission, functions, image, or reputation), organizational assets, or individuals through an information system via unauthorized access, destruction, disclosure, modification of information, and/or denial of service. Also, the potential for a threat-source to successfully exploit a particular information system vulnerability. [i.35]

Vulnerability: Weakness in a system, system security procedures, internal controls, or implementation that could be exploited or triggered by a threat. [i.35]

Y1: An interface over which RAN analytics services are exposed by the Near-RT RIC to be consumed by Y1 consumers.

Y1 consumers: A role played by entities within or outside of the PLMN trust domain that consumes the Y1 services produced by the Near-RT RIC.

3.2 Symbols

For the purposes of the present document, the symbols apply: none

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 and the following apply:

AAL	Acceleration Abstraction Layer
AALI	Acceleration Abstraction Layer Interface
AALI-C	Acceleration Abstraction Layer Interface-Common
AALI-C-App	Acceleration Abstraction Layer Interface-Common-Application
AALI-C-Mgmt	Acceleration Abstraction Layer Interface-Common-Management
AALI-P	Acceleration Abstraction Layer Interface-Profile
AI/ML	Artificial Intelligence/Machine Learning
DL	Down Link

DoS	Denial of Service
eNB	eNodeB (applies to LTE)
FH	Front haul
FTP	File Transfer Protocol
FTPS	File Transfer Protocol Secure
GM	Grand Master
gNB	gNodeB (applies to NR)
IPSEC	Internet Protocol Security
KPI	Key Performance Indicator
KQI	Key Quality Indicator
L1	Layer 1
LAA	Licensed-Assisted Access
LBT	Listen Before Talk
LLS	Lower Layer Split
MIMO	Multiple Input, Multiple Output
MITM	Man In The Middle
MNO	Mobile Network Operator
NETCONF	Network Configuration Protocol
NF	Network Function
NFV	Network Function Virtualisation
NR-U	New Radio Unlicensed
O-DU	O-RAN Distributed Unit
O-RU	O-RAN Radio Unit
PDCP	Packet Data Convergence Protocol
PDSCH	Physical Downlink Shared Channel
PUSCH	Physical Uplink Shared Channel
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PTP	Precision Timing Protocol
QoE	Quality of Experience
RBAC	Role-based Access Control
RIC	O-RAN RAN Intelligent Controller
RU	Radio Unit
SDN	Software Defined Network
SINR	Signal-to-Interference-plus-Noise Ratio
SMO	Service Management and Orchestration
SSH	Secure Shell
T-TC	Telecom Transparent Clock
TC	Transparent Clock
TLS	Transport Layer Security
UAV	Unmanned Aerial Vehicle
UL	Up Link
V2X	Vehicle to Everything
VM	Virtual machine

VNF	Virtualised Network Function
ZT	Zero Trust
ZTA	Zero Trust Architecture

4 Overview

4.1 Objective and structure

O-RAN architecture [i.6] differs significantly from the architecture of 3GPP RAN. It involves introducing new components, interfaces, and technologies, which give rise to new actors (stakeholders) and enable novel business models. Consequently, the attack surface expands considerably, and we anticipate that O-RAN design and deployment will present numerous security challenges and associated risks. These challenges primarily stem from various factors, such as the inclusion of O-RAN specific interfaces and components, the utilization of virtualization/containerization techniques, the incorporation of open-source code, and the capability to support AI/ML models, among other considerations.

Additionally, the O-RAN architecture is being developed using zero trust (ZT) and zero trust architecture (ZTA) principles as described in the NIST Zero Trust Architecture Special Publication [i.26]. Zero trust is an evolving set of cybersecurity paradigms that move defenses from static, network-based perimeters to focus on users, assets, and resources. Zero trust assumes there is no implicit trust granted to assets or user accounts based solely on their physical or network location (i.e., local area networks versus the internet) or based on asset ownership (enterprise or personally owned). Zero trust also assumes that an adversary can always be in the network. According to the publication [i.26], zero trust is based on the following tenets that can be adapted to the O-RAN architecture. Full descriptions of each tenet can be found in [i.26].

- [ZT-1] All data sources and computing services are considered resources.
- [ZT-2] All communication is secured regardless of network location.
- [ZT-3] Access to individual enterprise resources is granted on a per-session basis.
- [ZT-4] Access to resources is determined by dynamic policy—including the observable state of client identity, application/service, and the requesting asset—and may include other behavioral and environmental attributes.
- [ZT-5] The enterprise monitors and measures the integrity and security posture of all owned and associated assets. No asset is inherently trusted.
- [ZT-6] All resource authentication and authorization are dynamic and strictly enforced before access is allowed.
- [ZT-7] The enterprise collects as much information as possible about the current state of assets, network infrastructure and communications and uses it to improve its security posture.

Therefore, the security analysis and the threat model for O-RAN must be carefully studied and relevant assets/stakeholders/vulnerabilities/threats/requirements/countermeasures/recommendations must be identified to reduce risk exposure, mitigate any harmful effects, and drive to a ZTA.

The material presented in this analysis aims at supporting various O-RAN stakeholders understanding the relevant threats resulting to an exposure of O-RAN assets by exploiting the vulnerabilities.

The objective is to give a comprehensive and high-level view on how security is organized in O-RAN system. In this document, we assume that 3GPP security requirements are met. Unless explicitly stated, features relate to O-RAN specifications.

This analysis is consolidated from various relevant sources, including main 5G standardization documents and telecommunication best practices (e.g., 3GPP, ETSI, NIST, ENISA).

The first main part outlines the main stockholder roles involved in managing and using O-RAN system. Further, it addresses the prerequisites and assumptions needed to securely implement and run O-RAN systems. It also identifies the list of critical assets to be protected in integrity, availability, confidentiality, replay and authenticity.

The second main part addresses the threat model. It identifies the threat agents, determines the threat surface, identifies vulnerabilities, and lists the threats for each O-RAN component or interface. For each threat, the description, threatened asset(s), vulnerabilities, threat agents and affected components are given.

The third main part describes the security principles to be achieved to counter the identified threats. In addition, it illustrates the coverage between threats and security principles.

The fourth main part is the risk assessment of the identified threats in terms of severity and likelihood.

NOTE 1: The present documentfocuses only on the components, interfaces and protocols specified by O-RAN alliance. Components, interfaces and protocols specified by 3GPP are only referenced where needed but are not within the scope of this specific O-RAN security analysis.

NOTE 2: The present document is a working document with the need to update the content on a regular basis following the risk evaluation.

NOTE 3: In this document, the term NF (Network Function) is used to designate either VNF (Virtual Network Function), CNF (Cloud-native Network Function) or PNF (Physical Network Function).

NOTE 4: Terms “Containers” and “Virtual Machines” are used interchangeably in this document as the implementation of O-RAN SW components could either be container-based, VM-based or hybrid (Containers and VMs together).

4.2 Methodology

The methodology adopted in this document is based on the standard ISO 27005 [i.7] which provide a detailed and flexible structure to release a risk assessment.

The methodology followed in this document comprises three stages:

1) Identification

   a. **Identify stakeholders:** First, we need to identify the stakeholders involved in the implementation, management, operation and maintenance of the O-RAN system. Roles and responsibilities of each stakeholder are given.

   b. **Define assumptions:** The list of minimum prerequisites and assumptions need to be defined for the operational environment (not under the control of the O-RAN system) required to successfully operate the O-RAN system.

   c. **Identify assets:** First, we need to locate relevant assets the O-RAN system hold and give details about the type (Data, component, etc.), the security properties (CIA) at rest and in transit and location.

   d. **Identify threats:** We need to identify the relevant threats associated with the new O-RAN components, interfaces and technologies. In addition, the threat surface and agents are given.

   e. **Identify vulnerabilities:** O-RAN system may have weaknesses in its new O-RAN components, interfaces and technologies which need to be identified.

   f. **Define security principles:** We need to define security principles to be achieved in order to reduce risk exposure.

   g. **Elaborate and refine security principles:** Each security principle needs to be detailed and refined into requirements, recommendations and countermeasures.

   h. **Identify existing/ongoing countermeasures:** We need to identify all of O-RAN existing/ongoing controls and to take into account the protection provided by these controls before applying any new ones.

2) Risk assessment

The value for *Risk* is defined by the following equation:

Risk = (the probability of a threat exploiting a vulnerability) x (total impact of the vulnerability being exploited)

3) Risk treatment

    a. Now that we know the level of risk that each threat poses, we need to decide how we'll treat them. There are four options:

        i. **Modify the risk** by implementing a control to reduce the likelihood of it occurring.

        ii. **Avoid the risk** by ceasing any activity that creates it. This response is appropriate if the risk is too big to manage with a security control.

        iii. **Share the risk** with a third party. There are two ways: by outsourcing the security efforts to another organization or by purchasing cyber insurance to ensure the funds to respond appropriately in the event of a disaster.

        iv. **Retain the risk**. This means that the organization accepts the risk and believes that the cost of treating it is greater than the damage that it would cause.

4.3 Document Scope

This clause comprises the architecture in the scope of the security analysis. The architecture includes the list of O-RAN components, interfaces and protocols manipulating critical assets and implementing security functions.

4.3.1 Scope regarding architecture

As specified in [i.6], the logical architecture of O-RAN includes the following components, interfaces and protocols:

O-RAN components:

- Network functions and applications
    - Service Management and Orchestration (SMO)
    - Non-RT RIC and rApps
    - Near-RT RIC and xApps
    - O-CU-CP/UP
    - O-DU
    - O-RU
    - O-eNB
- Cloud computing platform
    - O-Cloud comprising a collection of physical infrastructure nodes that meet O-RAN requirements to host the relevant O-RAN functions (such as Near-RT RIC, O-CU-CP, O-CU-UP, and O-DU), the supporting software components (such as Operating System, Virtual Machine Monitor, Container Runtime, etc.) and the appropriate management and orchestration functions.

O-RAN specific interfaces:

- A1 Interface between Non-RT RIC and Near-RT RIC to enable policy-driven guidance of Near-RT RIC applications/functions, and support AI/ML workflow.
- O1 Interface connecting the SMO to the Near-RT RIC, one or more O-CU-CPs, one or more O-CU-UPs, and one or more O-DUs.
- O2 Interface between the SMO and the O-Cloud.
- E2 Interface 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.
- Open Fronthaul CUS-Plane Interface between O-RU and O-DU.

- Open Fronthaul M-Plane Interface between O-RU and O-DU as well as between O-RU and SMO.
- Y1 Interface over which RAN analytics services exposed by the Near-RT RIC to be consumed by Y1 consumers.

Relevant Protocols used by O-RAN system for enforcing security:

- TLS
  - Should be used to protect the traffic between the O-RAN system and other network elements. It establishes a secure channel and provides CIA (Confidentiality, Integrity, Authenticity) features.
  - Should be used in O1 interface for NETCONF over TLS and JSON/REST over TLS
  - Should be used in A1 interface
- SSH
  - Should be used in O1 interface and Fronthaul M-Plane for NETCONF over SSH
- IPSEC
  - Should be used to protect E2 traffic
- FTP and FTPS
  - Should be used to protect file transfers over O1 and Fronthaul M-Plane interfaces
- PTP (Precision Timing Protocol, IEEE 1588-2019)

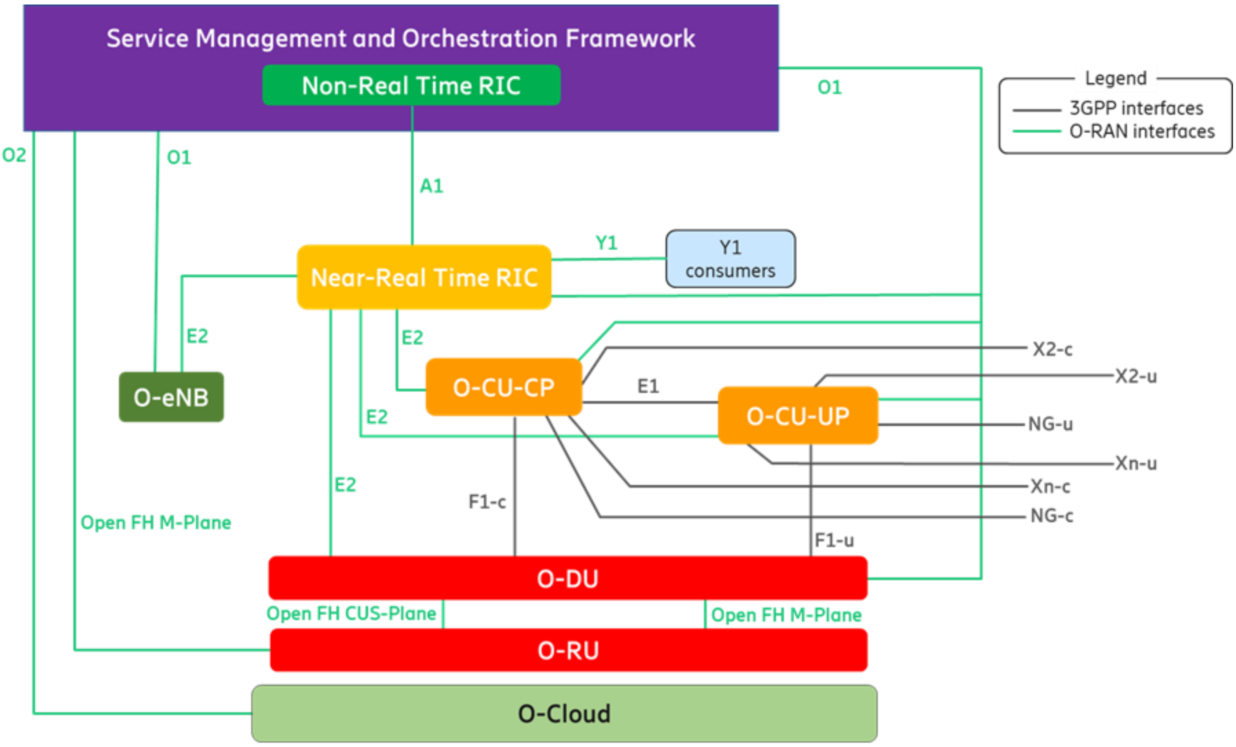


Figure 4-1 : Logical Architecture of O-RAN system [i.6]

4.3.2 Out of scope components

The following components are not in the perimeter of the O-RAN system defined by the alliance; therefore, they are considered out of scope of this study:

- 3GPP interfaces are already studied and maintained by 3GPP,
- UE,
- MEC,
- Core,

- Antennas.

5 Statement of compatibility with 3GPP

This chapter gives the statement of compatibility with 3GPP/SCAS security Assets, Threats and Requirements. The statement of compatibility shows that 3GPP Assets/Threats/Requirements are applicable and that there is no conflict affecting the security of O-RAN components.

5.1 Assets and Threats

Table 5-1 : Statement of compatibility with 3GPP – Assets and Threats

3GPP/SCAS document reference/clause	Description	Applicable to O-RAN	Rationale
TR 33.926 [i.4], clauses 5 and 6	It describes the generic assets and threats of 3GPP network products	Yes	Since these assets/threats are for generic 3GPP (virtualized) network products, they are also applicable to O-RAN. It means that there is no need to repeat those assets/threats in this document.
TR 33.818 [i.15], clause 5.2.4	It describes the generic assets, threats and requirements of 3GPP/ETSI NFV virtualized network products.	Yes	
TR 33.848 [i.23], clause 5	It considers the consequences of virtualization on 3GPP architectures, in order to identify threats and subsequent security requirements relating to ETSI-defined interfaces and Security functional requirements related to Virtualization layer, hardware and resource isolation.	Yes	

In addition, the assets/threats related to the additional specific O-RAN interfaces and components are considered. As a result, clauses 6.3 and 7.4 elaborates the O-RAN specific assets and threats respectively.

5.2 Security requirements

Table 5-2 : Statement of compatibility with 3GPP – Security requirements

3GPP/SCAS document reference/clause	Description	Applicable to O-RAN	Rationale
TS 33.117 [i.5], clauses 4.3 and, 4.42	It describes the general approach taken towards security functional requirements deriving from 3GPP specifications and the corresponding test cases, independent of a specific network product class.	Yes	Since these requirements are for generic 3GPP (virtualized) network products, they are to be fulfilled by O-RAN. It means that there is no need to repeat those requirements in this document.
TR 33.818 [i.14], clauses 5.2.5 and 5.3	It describes the generic assets, threats and requirements of 3GPP/ETSI NFV virtualized network products.	Yes	
TR 33.848 [i.23], clause 5	It considers the consequences of virtualization on 3GPP architectures, in order to identify threats and subsequent security requirements relating to ETSI-defined interfaces and	Yes	

	Security functional requirements related to Virtualization layer, hardware and resource isolation.		
TS 33.501 [i.3]	It describes the security architecture and procedures for 5G system including gNodeB	Yes	
TS 33.511 [i.2]	It describes the security requirements for the next generation Node B (gNodeB) network product class	Yes	

In addition, O-RAN also needs to consider the security requirements related to the additional specific O-RAN interfaces and components. As a result, clause 8 focus on the O-RAN security principles.

6 Roles-Assumptions-Assets

6.1 Stakeholders roles and responsibilities

The main stakeholders managing and using the O-RAN system are the following:

Table 6-1 : Roles and responsibilities

Role	Description
Mobile Network Operator (MNO)	Who offers network services and has a license to operate in allocated spectrum.
Orchestrator	Who is in charge of operating and orchestrating the O-RAN services. The MNO could be the orchestrator.
HW/ Network vendor	Who is in charge of: • Providing the network infrastructure including servers to run SDN controller, switches, routers, gateways, radio hardware, etc. • Installation, maintenance or replacement of the hardware/network device • Providing capability and procedures to securely configure the hardware/network device • Providing capability for the hardware/network device to generate log events • Providing capability for log files to be sent to an externalized log analysis system provided by the MNO • Providing a process for users, including security researchers, to submit bug reports (e.g., using an issue tracker or a mailing list) • Testing according to 3GPP and O-RAN test plans. Testing should include security tests of the device and its interfaces • Setting up a vulnerability management process of monitoring, identifying, evaluating, treating and reporting on security vulnerabilities in the hardware/network device including firmware • Maintenance of the firmware that includes providing patches for bugs and vulnerabilities

HW/ Network administrator	Who is in charge of: • Configuration of the hardware/network device • Enabling collection of log events • Collection and analysis of log events generated by the hardware/network device • Deploying firmware patches in compliance with HW/ Network vendors deployment guidance • Monitoring, identifying and notifying HW/ Network vendors on discovered vulnerabilities • Regular testing of hardware/network configuration The MNO could be the HW/ Network administrator.
NF vendor	Who is in charge of: • Developing and providing NFs (e.g. VNF, CNF, PNF) for Near-RT RIC, O-CU-CP, O-CU-UP, O-DU, etc. • Providing capability and procedures to securely configure the NF • Setting up a vulnerability management process of monitoring, identifying, evaluating, treating and reporting on security vulnerabilities in the NF • Setting up a patch development, testing and delivery processes • Maintenance of the NF that includes providing patches for bugs and vulnerabilities • Providing capability for NF to generate log events • Providing capability for log files to be sent to an externalized log analysis system provided by the MNO • Testing according to 3GPP and O-RAN test plans. Testing should include security tests of the NF and its interface • Providing a process for users, including security researchers, to submit bug reports (e.g., using an issue tracker or a mailing list)
NF administrator	Who is in charge of: • Deploying patches in compliance with NF vendors deployment guidance • Monitoring, identifying and notifying NF vendors on discovered vulnerabilities • Securely configuring the NF • Regular testing of the NF configuration • Enabling collection of log events • Analyzing log events generated by the software The MNO could be the NF administrator.
Virtualization/Containerization hardware infrastructure provider	Who is in charge of: • Provides virtualized/containerized infrastructure comprising computing resources (e.g., from computing platforms), storage and network. • Providing capability to securely configure the virtualization/containerization hardware infrastructure

	• Setting up a vulnerability management process of monitoring, identifying, evaluating, treating and reporting on security vulnerabilities in the virtualization/containerization hardware infrastructure • Maintenance of the security of hardware infrastructure • Providing capability for the hardware infrastructure to generate log events • Providing capability for log files to be sent to an externalized log analysis system provided by the MNO • Providing a process for users, including security researchers, to submit bug reports (e.g., using an issue tracker or a mailing list)
Virtualization/Containerization hardware infrastructure administrator	Who is in charge of: • Deploying the Virtualization/Containerization hardware infrastructure in compliance with providers deployment guidance • Monitoring, identifying and notifying Virtualization/Containerization hardware infrastructure providers on discovered vulnerabilities • Securely configuring the Virtualization/Containerization hardware infrastructure • Regular testing of the Virtualization/Containerization hardware infrastructure configuration • Enabling collection of log events • Analyzing log events generated by the Virtualization/Containerization hardware infrastructure The MNO could be the Virtualization/Containerization hardware infrastructure administrator.
Virtualization/Containerization software infrastructure provider	Who is in charge of: • Provides virtualized/containerized infrastructure services and designs, builds, and operates virtualization/containerization infrastructure(s). The infrastructure comprises software of compute nodes such as hypervisors, host operating systems, and container run-time systems. • Providing capability to securely configure the virtualization/containerization software infrastructure • Setting up a vulnerability management process of monitoring, identifying, evaluating, treating and reporting on security vulnerabilities in the virtualization/containerization software infrastructure • Setting up a patch development, testing and delivery processes • Maintenance of the software infrastructure that includes providing patches for bugs and vulnerabilities • Providing capability for the software infrastructure to generate log events • Providing capability for log files to be sent to an externalized log analysis system provided by the MNO • Providing a process for users, including security researchers, to submit bug reports (e.g., using an issue tracker or a mailing list)
Virtualization/Containerization software infrastructure administrator	Who is in charge of: • Deploying patches in compliance with Virtualization/Containerization software infrastructure providers deployment guidance • Monitoring, identifying and notifying Virtualization/Containerization software infrastructure providers of discovered vulnerabilities

	• Securely configuring the Virtualization/Containerization software infrastructure • Regular testing of the Virtualization/Containerization software infrastructure configuration • Enabling collection of log events • Analyzing log events generated by the Virtualization/Containerization software infrastructure The MNO could be the Virtualization/Containerization software infrastructure administrator.
System integrator	Who is in charge of: • Appropriately integrating O-RAN HW and SW components. SW components are integrated, in most cases remotely. • Ensuring that those components function together as expected • Securely configuring (system level) the O-RAN system • Testing patches after deployment to ensure that they don't break other parts of O-RAN system or even expose new vulnerabilities The MNO could be the integrator.
System tester	Tester of the O-RAN system to ensure quality, security, functionality and performance. The MNO could be the system tester.
Other administrators	Identity Admin: • Manages (Add, Modify, Delete) administrator accounts • Configures general settings for administrator accounts (password policy, etc.) RBAC Admin • Generates RBAC policies and permissions on admin access System Admin • Monitors network traffic for any suspicious activity • Performs risk assessment and defends against zero-day malware • Audits the O-RAN system • Triggers the update of O-RAN components on the latest security patches • Runs regular backups • Regularly performs analysis of log data PKI Admin • Manage and secure private keys and certificates

NOTE 1: The operation, administration and orchestration of the O-RAN system can be split across multiple companies or roles.

NOTE 2: A trust management mechanism becomes crucially important to realize trustworthy collaboration among the O-RAN stakeholders.

6.2 Assumptions and prerequisites

This section contains the list of minimum prerequisites and assumptions for equipment, software vendors, users and the physical environment to successfully operate the O-RAN system.

- The operational environment of the O-RAN system provides reliable timestamps for the generation of audit records, etc.

- Administrators, integrators, operators and orchestrators are trustworthy, and trained such that they are capable of securely managing the O-RAN system and following the instructions provided by O-RAN Alliance as well as the provided guidance by vendors and service providers.

- Log files, secrets and credentials stored in external systems and related to O-RAN are protected. They are access controlled so only privileged users have access to those secrets/credentials.

6.3 Critical assets

The following table gives the list of critical assets to be protected within the O-RAN system.

An asset in this context may encompass data, interface or component deemed valuable for the O-RAN system. A component is defined as an O-RAN network function or architectural element.

Here's an explanation of each column, along with guidance on how to fill out the table:

- **Asset ID:** It identifies each asset uniquely. It helps in cataloging and referencing specific assets systematically.
- **Asset Description:** A brief description of what the asset is, including its purpose, contents, and any relevant attributes.
- **Component**: It specifies the O-RAN element(s) the asset is associated with, such as O-DU, O-RU, SMO, etc. This clarifies the asset's location within the O-RAN architecture.
- **Interface**: It indicates the interface through which the asset communicates or interacts with other elements. This could be internal interfaces or external interfaces.

NOTE: Assets can either be confined to a component (for those not shared with other O-RAN elements) or be present within a component and also transmitted to other O-RAN elements over interfaces. The way in which the 'Component' and 'Interface' columns are filled out will vary based on these situations.

- **When**: It is a categorization of the asset's state in terms of its lifecycle or operational phase, like "at rest" or "in transit". It is used to indicate when certain protection levels should be applied.
    - **When (At rest):** Marks with an 'x' if the asset needs protection while it is at rest (stored and not actively being used or transmitted).
    - **When (In transit):** Marks with an 'x' if the asset needs protection during transit (being transmitted or moved).
- **Protection level (Confidentiality, Integrity, Availability, Replay, Authenticity)**: These columns specify the type of protection or security measure required for the asset. An 'x' in any of these sub-columns indicates a need for measures to ensure:
    - **Confidentiality:** The asset should be accessible only to authorized entities.
    - **Integrity:** The asset should be protected from unauthorized changes.
    - **Availability:** The asset should be accessible to authorized entities when needed.
    - **Replay:** Protection against replay attacks, ensuring that repeated or delayed transmissions are identified and prevented.
    - **Authenticity:** The asset should be verifiable as genuine.

Instructions for completing the table:

- **Asset ID**: Assign a unique identifier to each asset.

- **Asset Description**: Provide a detailed description of the asset, including its nature, purpose, and any other relevant details.

- **Component**: Specify the component associated with the asset, if applicable.
- **Interface**: Indicate the interface(s) related to the asset.
- **When (At rest/In transit)**: Mark with an 'x' if the asset requires protection either at rest or in transit.
- **Protection level**: Mark with an 'x' in the appropriate sub-columns to indicate the types of protection required for the asset.

The categories "Data" and "Components" are defined as follows:

- **Data:** It refers to the information that is processed, stored, and transmitted through the O-RAN architecture.
- **Components:** It involves the physical (Hardware), logical and virtual (Software) parts of the O-RAN system.

Table 6-2 : Critical assets

Asset ID	Asset Description	Component	Interface	When		Protection Level				
				At rest	In transit	Confidentiality	Integrity	Availability	Replay	Authenticity
	Data & Interfaces									
ASSET-D-01	Critical S-Plane data such as: - Data flow for synchronization and timing information between nodes - PTP (e.g. ANNOUNCE message) transported over Fronthaul that interconnects multiple O-RUs and O-DUs. - Timing configuration (LLS C1, C2, C3, C4) and topology	O-DU, O-RU	Fronthaul CUS-Plane		x		x		x	x
				x			x	x		
ASSET-D-02	Critical Management-Plane data transported over the Fronthaul interface such as: maintenance and monitoring signals, data collected related to O-RU operations, logs (troubleshooting, trace)	O-DU, O-RU, SMO	Fronthaul M-Plane		x	x	x		x	x
				x		x	x	x		
ASSET-D-03	Critical Management-Plane data transported over the O1 interface such as: - Observables (events and counters) and network status provided over O1 to non-RT RIC from Near-RT RIC, O-CU and O-DU. - The non-RT RIC uses the O1 observables (Feedback on the fulfilment of A1 policies in the near-RT RIC) to continuously evaluate the impact of the A1 policies towards fulfillment of the RAN Intent. - Managed Element Telemetry to monitor the application behavior (from O-Cloud).	Near-RT RIC, Non-RT RIC, O-CU, O-DU, SMO	O1		x	x	x		x	x
				x		x	x	x		
ASSET-D-04	Critical C-Plane data such as: - Scheduling information, FFT size, CP length, Subcarrier spacing, UL PRACH scheduling - DL and UL Beamforming commands (e.g., beam index) and scheduling - LBT Configuration parameters such as lbtHandle, lbtDeferFactor, lbtBackoffCounter, lbtOffset, MCOT, lbtMode, sfnSf, lbtCWconfig_H, lbtCWconfig_T, lbtTrafficClass. - LBT DL indication parameters such as lbtHandle, lbtResult, initialPartialSFs, bufferError, lbtCWR_Result	O-DU, O-RU	Fronthaul CUS-Plane		x	x	x		x	x
				x			x	x		
ASSET-D-05	Critical Fronthaul U-Plane data such as:	O-DU, O-RU			x		x		x	x

Asset ID	Asset Description	Component	Interface	When		Protection Level				
				At rest	In transit	Confidentiality	Integrity	Availability	Replay	Authenticity
	- User data (i.e. DNS, PUSCH, PDSCH, etc.), - Control channel data (PDCCH, PUCCH, etc.), - I/Q samples, PRACH-related information, eCPRI, and O-RAN headers - MAC CEs (Control Elements)		Fronthaul CUS-Plane	x			x	x		
ASSET-D-06	Reference signals, synchronization signal and channels in downlink and uplink between O-RU and UE	O-RU	Radio		x	x	x		x	x
ASSET-D-07	A1 policies that are provided to the near-RT RIC over the A1 interface to guide the RAN performance towards the overall goal expressed in RAN Intent. The A1 policies are declarative policies that contain statements on policy objectives and policy resources applicable to UEs and cells. A1 policies are created, modified and deleted by the non-RT RIC.	Near-RT RIC, Non-RT RIC	A1		x	x	x			x
ASSET-D-08	A1 Enrichment Information that is collected or derived at SMO/non-RT RIC either from non-network data sources or from network functions themselves and provided over the A1 interface to be utilized by near-RT RIC, e.g. an ML model, to improve its performance. Discovery and request of A1 Enrichment Information from near-RT RIC to non-RT RIC External Enrichment Information that is provided by an O-RAN external information source to near-RT RIC over A1	Near-RT RIC, Non-RT RIC	A1		x	x	x			x
ASSET-D-09	Data transported over the E2 interface such as: - Near real-time information (e.g. UE basis, 2Cell basis). - The persistent configuration used by the near-RT RIC to control the RAN. - Identifiers of E2 nodes. - xApp-related messages. - Control signaling information. - Policies used by the Near-RT RIC to monitor, suspend/stop, override or control the behavior of E2 node.	O-DU, O-CU, Near-RT RIC	E2		x	x	x		x	x

Asset ID	Asset Description	Component	Interface	When		Protection Level				
				At rest	In transit	Confidentiality	Integrity	Availability	Replay	Authenticity
	- NEAR-RT RIC services messages (REPORT, INSERT, CONTROL and POLICY). - Interface Management messages (E2 Setup, E2 Reset, E2 Node Configuration Update, Reporting of General Error Situations). - Near-RT RIC Service Update messages.									
ASSET-D-10	Database holding data from xApp applications and E2 Node	Near-RT RIC	-	x		x	x	x		x
ASSET-D-11	E2 Node data (e.g. configuration information (cell configuration, supported slices, PLMNs, etc.), network measurements, context information, etc.)	E2 nodes	-	x			x	x		
ASSET-D-12	It consists of • The Physical Infrastructure (O-Cloud Node Identifier, Pool Identifier, Pool Location Identifier, and Use Identifier) used to create the O-Cloud, • The logical Clouds which it provides as interfaces for deployments, and the inventory of deployments (deployment ID and descriptor) on the cloud • O-Cloud ID, IP address, IMS address, the IP address endpoint or url of the SMO and any necessary security keys or passwords for communication using O2 • DMS capabilities • O-Cloud (IMS): List of All Resource Pools in the O-Cloud, Attributes of a specific O-Cloud, List of all resources of an O-Cloud Pool, Attributes of each O-Cloud Resource, List of all DMS • **O-Cloud (DMS): List of Locations Supported For a given location the Capabilities supported (e.g. Descriptor types, Technology types, Accelerator types), For a given location the Capacity of the location, For a given location the Availability of the location**	SMO, O-CLOUD	O2, O-CLOUD internal interfaces	x	x	x	x	x	x	x
ASSET-D-13	It includes: - Telemetry information of O-Cloud deployments in the network for analyzing the O-Cloud's state and health, and for delivering on service monitoring goals. It consists of fault, performance and configuration data:	SMO, O-CLOUD	O2, O-CLOUD internal interfaces	x	x	x	x	x	x	x

Asset ID	Asset Description	Component	Interface	When		Protection Level				
				At rest	In transit	Confidentiality	Integrity	Availability	Replay	Authenticity
	- Deployment Telemetry to monitor the number of deployment instances an O-Cloud has at that moment and how many were expected, how the on-progress deployment is going, and health checks. Additional Deployment Telemetry metrics like CPU, network, and memory usage can also be collected. - - Infrastructure Telemetry to monitor the health of the O-Cloud Infrastructure components. Network Operations are interested in discovering if all the components in the O-Cloud Infrastructure are working properly and at what capacity, how many deployments are running on each node, and the resource utilization of the O-Cloud Infrastructure.									
ASSET-D-14	O-Cloud Provisioning information (Affinity, Anti-Affinity, Quorum Diversity Rules, capabilities, capacity and availability) O-Cloud software management information: catalog of authorized software and its version, list of authorized VNF/CNF, VNF/CNF description files	SMO, O-CLOUD	O2, O-CLOUD internal interfaces		x	x	x		x	x
ASSET-D-15	Package: O-RAN Cloudified Network Function Software Image including the underlying software executable image, image properties/metadata such as descriptors, image signature(s), LCM scripts, data files, SoftwareImageId, Vendor, and version, secrets, configuration files. Application data: Subscriber data, Policy data, UE context, etc. NF location, time clock NF instance: Application software, guest OS, host OS, Libs, instance identity, crypto keys, namespaces, virtual resources instance states, physical hardware, etc.	O-CLOUD	-	x			x	x		
ASSET-D-16	X.509 certificates in O-RAN network such as those used for SMO, O-CU-CP, O-CU-UP, O-DU, O-RU, Near-RT RIC, Non-RT RIC, O-CLOUD, NetCONF (O1, Fronthaul)	All	O1, Fronthaul, O2, E2, A1	x			x	x		x
ASSET-D-17	Security private keys in O-RAN network such as those used for SMO, O-CU-CP, O-CU-UP, O-DU, O-RU, Near-RT RIC, Non-RT RIC, O-CLOUD, NetCONF (O1, Fronthaul)), for authentication, encryption, signing (e.g. for TLS and similar protocols, image signing)	All	O1, Fronthaul, O2, E2, A1	x		x	x	x		x
ASSET-D-18	O-RAN components associated and configuration data, such as: - Software version information, identifier, IP address, port number, network layer parameters, time of request, previous behavior, etc.	All	-	x		x	x	x		

Asset ID	Asset Description	Component	Interface	When		Protection Level				
				At rest	In transit	Confidentiality	Integrity	Availability	Replay	Authenticity
	- The security related parameters (such audit records, lists of algorithms which are allowed for usage, file management, hash values, etc.).									
ASSET-D-19	Cryptographic keys: KgNB, KRRC-enc, KRRC-int, KUP-int, and KUP-enc (Hierarchy of cryptographic key derived from Anchor Key. (as defined in ETSI TS 133 501 clause 6.2.)	O-CU	-	x		x	x	x		
ASSET-D-20	Credentials (Administrators): account information and passwords on SMO, O-CU-CP, O-CU-UP, O-DU, O-RU, Near-RT RIC, Non-RT RIC, O-Cloud used in O-RAN network	All		x		x	x	x		
ASSET-D-21	3GPP application related data such as subscription data, session data, call control related information etc.	O-CU		x	x	x	x	x	x	x
ASSET-D-22	Inter- and intra-slice UE priority [i.14]	O-CU, O-DU	-	x	x		x	x		
ASSET-D-23	Patches for vulnerable SW components	All	-		x		x	x		x
ASSET-D-24	NETCONF Configuration Access Control Model datastores	All		x		x	x	x		x
ASSET-D-25	Training or test data and associated labels: data sets collected externally or internally from the Near-RT RIC, O-CU and O-DU and passed to the ML training hosts in a ML system.	Near-RT RIC, Non-RT RIC, xAPPs, rAPPs	A1, O1, E2		x	x	x		x	x
				x		x	x	x		x
ASSET-D-26	The trained ML model which includes the configured hyperparameters, inference algorithm, and learned parameters.	Near-RT RIC, Non-RT RIC, xAPPs, rAPPs		x		x	x	x		
ASSET-D-27	The ML prediction results built into the model (e.g. expected outcomes)	Near-RT RIC, Non-RT RIC, xAPPs, rAPPs				x	x	x		
ASSET-D-28	The behavior of the ML system including tasks for data collection, data wrangling, pipeline management, model retraining, and model deployment.	Near-RT RIC, Non-RT RIC, xAPPs, rAPPs		At runtime		x	x	x		
ASSET-D-29	Security event log files generated by O-RAN components	All		x	x		x	x		x
ASSET-D-30	O-RAN specific several UE IDs	Near-RT RIC, Non-RT RIC, SMO	A1, E2, O1		x	x	x		x	x
				x		x	x	x		
ASSET-D-31	Security telemetry from the NFV system for detecting threats and anomalies	All	O2, O-CLOUD	x	x	x	x	x	x	x

Asset ID	Asset Description	Component	Interface	When		Protection Level				
				At rest	In transit	Confidentiality	Integrity	Availability	Replay	Authenticity
			internal interfaces							
ASSET-D-32	Cryptographic keys used during secure boot, for encryption/decryption, etc.	All	-	x		x	x	x		
ASSET-D-33	Data transported over the AALI-C-Mgmt interface		AALI-C-Mgmt		x	x	x		x	x
ASSET-D-34	Data transported over the AALI-C-App & AALI-P interfaces		AALI-C-App & AALI-P		x		x		x	x
ASSET-D-35	Data transported over the vendor specific interface		vendor specific interface		x		x			x
ASSET-D-36	AAL profiles	AAL		x			x	x		
ASSET-D-37	AAL-LPU	AAL		x			x	x		
ASSET-D-38	Stored AAL data (e.g., logs, configuration data)	AAL		x			x	x		
ASSET-D-39	xAppID	Near-RT RIC, xApps		x	x		x			
ASSET-D-40	ML models that have not been trained yet, i.e., Initial Models and their associated learning algorithm.	Non-RT RIC, Near-RT RIC, SMO		x	x		x	x		
Components (logical, virtual, physical)										
ASSET-C-01	Logical module: Service Management and Orchestration (SMO)			x			x	x		x
ASSET-C-02	Near-RT RIC software			x			x	x		x
ASSET-C-03	O-CU-CP software			x			x	x		x
ASSET-C-04	O-CU-UP software			x			x	x		x
ASSET-C-05	O-DU software			x			x	x		x
ASSET-C-06	O-RU software			x			x	x		x
ASSET-C-07	O-eNB			x			x	x		x

Asset ID	Asset Description	Component	Interface	When		Protection Level				
				At rest	In transit	Confidentiality	Integrity	Availability	Replay	Authenticity
ASSET-C-08	O-Cloud			x			x	x		x
ASSET-C-09	xApps			x			x	x		x
ASSET-C-10	rApps			x			x	x		x
ASSET-C-11	Non-RT RIC software			x			x	x		x
ASSET-C-12	ML components deploying machine learning such as: ML training and interference hosts, ML applications (xAPPS, rAPPs)			x			x	x		x
ASSET-C-12	PNF NF equipment			x			x	x		x
ASSET-C-13	A1 termination				x	x	x	x		x
ASSET-C-14	A1 interface, including protocol stack				x	x	x	x	x	x
ASSET-C-15	R1 termination				x	x	x	x		x
ASSET-C-16	R1 interface, including protocol stack				x	x	x	x	x	x
ASSET-C-17	SMO Framework/Platform	x						x		x
ASSET-C-18	SMO Functions	x						x		X
ASSET-C-19	R1 Service Exposure Functions	x						x		x
ASSET-C-20	A1 Functions	x						x		x
ASSET-C-21	Data Management and Exposure Functions	x						x		x
ASSET-C-22	O1, including protocol stack		x		x	x	x	x	x	x
ASSET-C-23	O2, including protocol stack		x		x	x	x	x	x	x
ASSET-C-24	OFH M-Plane, including protocol stack		x		x	x	x	x	x	x
ASSET-C-25	OFH CUS-Plane, including protocol stack		x		x	x	x	x	x	x
ASSET-C_26	External interfaces		x		x	x	x	x	x	x
ASSET-C_27	External interfaces termination at SMO Framework/Platform		x		x	x	x	x		x

Asset ID	Asset Description	Component	Interface	When		Protection Level				
				At rest	In transit	Confidentiality	Integrity	Availability	Replay	Authenticity
ASSET-C-28	External interfaces termination at Non-RT RIC Framework		x		x	x	x	x		x
ASSET-C-29	AAL software including software, libraries, drivers, etc.	AAL		x			x	x		
ASSET-C-30	The hardware accelerator device firmware	Hardware accelerator device		x			x	x		
ASSET-C-31	Shared O-RU	x				x	x	x		x
ASSET-C-32	O-RU Host	x				x	x	x		x
ASSET-C-33	O-RU Tenant (Shared Resource Operator)	x				x	x	x		x
ASSET-C-34	O-DU Host	x				x	x	x		x
ASSET-C-35	O-DU Tenant (Shared Resource Operator)	x				x	x	x		x
ASSET-C-36	O-CU Host, includes O-CU-CP and O-CU-UP software	x				x	x	x		x
ASSET-C-37	O-CU Tenant (Shared Resource Operator), includes O-CU-CP and O-CU-UP software	x				x	x	x		x
ASSET-C-38	SMO Host	x				x	x	x		x
ASSET-C-39	SMO Tenant (Shared Resource Operator)	x				x	x	x		x
ASSET-C-40	E2 interface, including protocol stack		x		x	x	x	x	x	x
ASSET-C-41	E2 Functions	x						x		x
ASSET-C-42	Y1 interface, including protocol stack		x		x	x	x	x	x	x
ASSET-C-43	Y1 Functions	x						x		x
ASSET-C-44	Service Management and Exposure (SME)	x				x	x	x		x
ASSET-C-45	Data Management and Exposure (DME)	x				x	x	x		x
ASSET-C-46	Topology Exposure and Inventory Management (TE&IM)	x				x	x	x		x
ASSET-C-47	rApp Management	x				x	x	x		x
ASSET-C-48	R1 Services	x				x	x	x		x

Asset ID	Asset Description	Component	Interface	When		Protection Level				
				At rest	In transit	Confidentiality	Integrity	Availability	Replay	Authenticity
ASSET-C-49	Network Function Orchestrator (NFO)	x				x	x	x		x
ASSET-C-50	Federated O-Cloud Orchestration and Management (FOCOM)	x				x	x	x		x
ASSET-C-51	RAN NF Fault Management (FM)	x				x	x	x		x
ASSET-C-52	RAN NF Configuration Management (CM)	x				x	x	x		x
ASSET-C-53	RAN NF Performance Management (PM)	x				x	x	x		x
ASSET-C-54	A1 Enrichment Information Management	x				x	x	x		x
ASSET-C-55	A1 Policy Management	x				x	x	x		x
ASSET-C-56	A1 E1 Management	x				x	x	x		x
ASSET-C-57	SW Package Onboarding	x				x	x	x		x
ASSET-C-58	Service Orchestration	x				x	x	x		x
ASSET-C-59	Service Assurance	x				x	x	x		x
ASSET-C-60	RAN Analytics	x				x	x	x		x
ASSET-C-61	AI/ML Workflow	x				x	x	x		X
ASSET-C-62	SMOS Communication		x		x	x	x	x	x	x

7 Threat model

7.1 Threat surface

The O-RAN architecture [i.6] introduces new functions and interfaces. The introduction of additional interfaces and nodes, and the decoupling of hardware and software, expands the threat and attack surface of the network. For the purposes of this document, threat surfaces are divided into six (6) main groups:

- Additional functions: SMO, Non-Real-Time RIC, Near-Real-Time RIC
- Additional open interfaces: A1, E2, O1, O2, Open Fronthaul
- Modified architecture: Lower Layer Split (LLS) 7-2x
- Decoupling increases threat to Trust Chain
- Containerization and Virtualization: Disaggregation of software and hardware
- Exposure to public exploits may be increased due to use of Open Source Code

The following entry points are considered:

- API between planes which facilitate the propagation of threats
- Threats coming from inside the O-RAN system
- Threats coming from outside the O-RAN system

7.2 Threat agent

For the purposes of this document, threat agents are categorized as follows:

- Cyber-criminals: Represents individuals who commits cybercrimes, where he/she makes use of the computer either as a tool or as a target or as both.
- Insiders: Represents malicious attacks perpetrated on a network or computer system by a person with authorized system access.
- Hacktivists: Represents actors that perform cyber-attacks to achieve political or social gains.
- Cyber-terrorists: Represents actors that their sole aim of violence against clandestine agents and subnational groups through the compromise of O-RAN infrastructures.
- Script kiddies: Represents actors that do not poses deep technical expertise or resources to perform sophisticated attacks.
- Nation-State: actors aggressively target and gain persistent access to public and private sector networks to compromise, steal, change, or destroy information.

7.3 Potential vulnerabilities

This document addresses the following potential security vulnerabilities that are exploitable through attacks against Confidentiality, Integrity, and Availability:

- O-RAN specific vulnerabilities

  - Unauthorized access to O-DU, O-CU-CP, O-CU-UP and RU to degrade RAN performance or execute broader network attack (Availability)
  - Unprotected synchronization and control plane traffic on Open Fronthaul Interface (Integrity and Availability)
  - Disable over-the-air ciphers for eavesdropping (Confidentiality)
  - Near-RT RIC conflicts with O-gNB (Availability)
  - x/rApps conflicts (Availability)
  - x/rApps access to network and subscriber data (Confidentiality)
  - Unprotected management interface (Confidentiality, Integrity, Availability)
  - CP UL or DL messages can be injected for attack on UP (Availability)
- General vulnerabilities
  - Decoupling of functions without hardware root of trust and software trust chain (Integrity)
  - Exposure to public exploits from use of Open Source code (Confidentiality, Integrity, Availability)
  - Misconfiguration, poor isolation or insufficient access management in the O-Cloud platform (Confidentiality, Integrity, Availability)

7.4 Threats

7.4.0 Threat Structure

The threat analysis is carried out using a well-defined structure to present each threat case and simplify the risk analysis associated with each threat. The following table is the template used to present the threat characteristics:

Threat ID	**Unique identification per Threat (e.g. T-XX-01)**
Threat title	Title of the threat
Threat description	Description of the Threat
Threat type	Spoofing Tampering Repudiation Information disclosure Denial of Service Elevation of Privilege
Vulnerabilities	What vulnerabilities are related to the threat?
Impact type	Authenticity Integrity Non-repudiation Confidentiality Availability

Affected Assets	Authorization
	Impacted Asset(s) (Data & Component)

For identifying threat types, we are using STRIDE, which categories threats into six distinct types:

1. S - Spoofing identity. An application or program can masquerade as another to gain advantages not typically allowed for that program.
2. T - Tampering with data. This involves the malicious modification of data, including making unauthorized changes to a database and alteration of data as it flows between computers.
3. R - Repudiation. A user or program refuses the authenticity of a good or reasonable command or action.
4. I - Information disclosure. This involves the exposure of information to individuals with unauthorized access to it. For example, users gain the ability to read a file that they normally would not have been granted access to, or an intruder can read data in transit between computers.
5. D - Denial of service. These attacks deny service to valid users, such as making a website unavailable or unusable by flooding it with illegitimate requests to keep legitimate users without access.
6. E - Elevation of privileges. An unauthorized user gains privileged rights to access previously not granted to compromise or destroy the system, such as a change in membership.

STRIDE maps different threat types to their corresponding impacts on system security, as shown in the following table:

Threat types	**Impact types**
Spoofing	Authenticity
Tampering	Integrity
Repudiation	Non-repudiability
Information disclosure	Confidentiality
Denial of Service	Availability
Elevation of Privilege	Authorization

7.4.1 Threats against O-RAN system

7.4.1.1 Common among O-RAN components

The O-RAN system architecture introduces the following common threats among its components:

Threat ID	**T-O-RAN-01**
Threat title	An attacker exploits insecure designs or lack of adoption in O-RAN components
Threat description	Unauthenticated/unauthorized access to O-RAN components could possibly be achieved via the different O-RAN interfaces, depending upon the design of the hardware-software O-RAN system and how different functions are segregated within the O-RAN system. O-RAN components might be vulnerable if: • Outdated component from the lack of update or patch management, • Poorly design architecture, • Missing appropriate security hardening, • Unnecessary or insecure function/protocol/component.

	An attacker could, in such case, either inject malwares and/or manipulate existing software, harm the O-RAN components, create a performance issue by manipulation of parameters, or reconfigure the O-RAN components and disable the security features with the purpose of eavesdropping or wiretapping on various CUS & M planes, reaching northbound systems, attack broader network to cause denial-of-service, steal unprotected private keys, certificates, hash values, or other type of breaches. In addition, O-RAN components could be software providing network functions, so they are likely to be vulnerable to software flaws: it could be possible to bypass firewall restrictions or to take advantage of a buffer overflow to execute arbitrary commands, etc.

Threat ID	**T-O-RAN-02**
Threat title	An attacker exploits misconfigured or poorly configured O-RAN components
Threat description	Unauthenticated/unauthorized access to O-RAN components could possibly be achieved via the different O-RAN interfaces, depending upon the configuration of the hardware-software O-RAN system. O-RAN components might be vulnerable if: • Errors from the lack of configuration change management, • Misconfigured or poorly configured O-RAN components, • Improperly configured permissions, • Unnecessary features are enabled (e.g. unnecessary ports, services, accounts, or privileges), • Default accounts and their passwords still enabled and unchanged, • Security features are disabled or not configured securely. An attacker could, in such case, either inject malwares and/or manipulate existing software, harm the O-RAN components, create a performance issue by manipulation of parameters, or reconfigure the O-RAN components and disable the security features with the purpose of eavesdropping or wiretapping on various CUS & M planes, reaching northbound systems, attack broader network to cause denial-of-service, steal unprotected private keys, certificates, hash values, or other type of breaches.

Threat ID	**T-O-RAN-03**
Threat title	Attacks from the internet exploit weak authentication and access control to penetrate O-RAN network boundary
Threat description	Web servers serving O-RAN functional and management services should provide adequate protection. An attacker that have access to the uncontrolled O-RAN network could: • Bypass the information flow control policy implemented by the firewall, • And/or attack O-RAN components in the trusted networks by taking advantage of particularities and errors in the design and implementation of the network protocols (IP, TCP, UDP, application protocols), • Use of incorrect or exceeded TCP sequence numbers, • Perform brute force attacks on FTP passwords, • Use of improper HTTP user sessions, • Etc. The effects of such attacks may include: • An intrusion, meaning unauthorized access to O-RAN components, • Blocking, flooding or restarting an O-RAN component causing a denial of service,

	• Flooding of network equipment, causing a denial of service, • Etc.

Threat ID	**T-O-RAN-04**
Threat title	An attacker attempts to jam the airlink signal through IoT devices
Threat description	DDoS attacks on O-RAN systems: The 5G evolution means billions of things, collectively referred to as IoT, will be using the 5G O-RAN. Thus, IoT could increase the risk of O-RAN resource overload by way of DDoS attacks. Attackers create a botnet army by infecting many (millions/billions) IoT devices with a “remote-reboot” malware. Attackers instruct the malware to reboot all devices in a specific or targeted 5G coverage area at the same time.

Threat ID	**T-O-RAN-05**
Threat title	An attacker penetrates and compromises the O-RAN system through the open O-RAN’s Fronthaul, O1, O2, A1, and E2
Threat description	O-RAN’s Fronthaul, O1, O2, A1, and E2 management interfaces are the new open interfaces that allow software programmability of RAN. These interfaces may not be secured to industry best practices. O-RAN components might be vulnerable if: • Improper or missing authentication and authorization processes, • Improper or missing ciphering and integrity checks of sensitive data exchanged over O-RAN interfaces, • Improper or missing replay protection of sensitive data exchanged over O-RAN interfaces, • Improper prevention of key reuse, • Improper implementation, • Improperly validate inputs, respond to error conditions in both the submitted data as well as out of sequence protocol steps. An attacker could, in such case, cause denial-of-service, data tampering or information disclosure, etc. **NOTE**: O-RAN interfaces allow use of TLS or SSH. Industry best practices mandate the use of TLS (v1.2 or higher) or SSH certificate-based authentication. An implementation that implements TLS version lower than 1.2 or a SSH password authentication, may become the key source of vulnerability that a malicious code will exploit to compromise the O-RAN system.

Threat ID	**T-O-RAN-06**
Threat title	An attacker exploits insufficient/improper mechanisms for authentication and authorization to compromise O-RAN components
Threat description	O-RAN management and orchestration should not be used without appropriate authentication and authorization and authorization checks. O-RAN components might be vulnerable if: • Unauthenticated access to O-RAN functions, • Improper authentication mechanisms, • Use of Predefined/ default accounts, • Weak or missing password policy, • Lack of mutual authentication to O-RAN components and interfaces,

	• Failure to block consecutive failed login attempts, • Improper authorization and access control policy. An attacker could, in such case, either inject malwares and/or manipulate existing software, harm the O-RAN components, create a performance issue by manipulation of parameters, or reconfigure the O-RAN components and disable the security features with the purpose of eavesdropping or wiretapping on various CUS & M planes, reaching northbound systems, attack broader network to cause denial-of-service, steal unprotected private keys, certificates, hash values, or other type of breaches.

Threat ID	**T-O-RAN-07**
Threat title	An attacker compromises O-RAN monitoring mechanisms and log files integrity and availability
Threat description	Improper / missing controls for protection of security event log files generated by O-RAN components and the lack of security events logged together with a unique system reference (e.g. host name, IP or MAC address) and the exact time the incident occurred do not allow a correct and rapid audit in case of security incident occurrence. Security restoration is delayed. Compromise of availability and integrity of security event log files could conduct to delays, wrong audit results, delays in security restoration, threats persistence.

Threat ID	**T-O-RAN-08**
Threat title	An attacker compromises O-RAN data integrity, confidentiality and traceability
Threat description	O-RAN components may not be secured to industry best practices. Adequate security controls are needed for protecting sensitive data stored, processed and transferred by O-RAN components. O-RAN components might be vulnerable if: • Improper or missing ciphering of sensitive data in storage or in transfer, • Improper or missing integrity mechanisms to protect sensitive data in storage or in transfer, • Presence of active function(s) that reveal confidential internal data in the clear to administrators. Such functions could be, for example, local or remote OAM CLI or GUI, logging messages, alarms, configuration file exports etc. • No traceability (logging) of access to personal data. An attacker could, in such case, cause denial-of-service, data tampering, information disclosure, spoofing identity, elevation of privilege, etc.

Threat ID	**T-O-RAN-09**
Threat title	An attacker compromises O-RAN components integrity and availability
Threat description	Overload situation could appear in the case of DoS attack or increased traffic. Inability to deal with such events affects availability of information or security functionalities of O-RAN components. O-RAN components may boot from unauthorized memory devices. Inability to deal with such events affects integrity of information or security functionalities of O-RAN components. Insufficient assurance of O-RAN software package integrity could affect CIA of data, services, hardware and policies during installation or upgrade phases for O-RAN components. An attacker could, in such case, cause denial-of-service, data tampering, information disclosure, spoofing identity, etc.

Threat ID	**T-O-RAN-10**
Threat title	Inconsistent Log Format Impeding Effective Attack Detection

Threat description	In the given scenario, the network operates with various devices and systems that generate logs in different formats. The lack of a standardized, common log format hinders the network operator's ability to aggregate and analyse logs centrally. This fragmentation creates blind spots and significantly delays the detection of attacks, as correlating events across disparate systems becomes challenging. An attacker can exploit this vulnerability by conducting attacks that leave traces across multiple systems, knowing that the lack of a centralized logging system will complicate the timely detection and response to the threat.
Threat type	Spoofing, Tampering, Repudiation, Information Disclosure, Denial of service, Elevation of privilege
Impact type	Authentication, Integrity, Non-repudiation, Confidentiality, Availability, Authorization
Affected Assets	all

7.4.1.2 Threats against the Open Fronthaul interface and M-S-C-U planes

The LLS architecture and the fronthaul interface introduce the following threats:

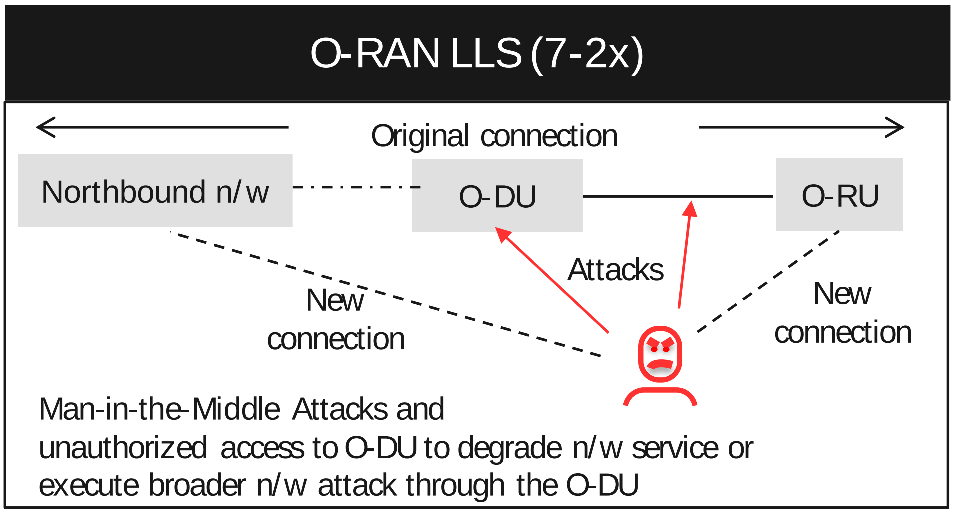

O-RAN LLS (7-2x)
Original connection
Northbound n/w
O-DU
O-RU
Attacks
New connection
New connection
Man-in-the-Middle Attacks and unauthorized access to O-DU to degrade n/w service or execute broader n/w attack through the O-DU

Figure 7-1 : Threats and Vulnerabilities for O-RAN LLS 7-2x

Threat ID	**T-FRHAUL-01**
Threat title	An attacker penetrates O-DU and beyond through O-RU or the Fronthaul interface to access or modify sensitive information [i.12]
Threat description	When having two different vendors, the O-RU and the O-DU needs to be managed as different entities and may have heterogeneous security levels. Instead, the O-DU will have to bridge the management traffic between the management system and the O-RU. Hence, the bridged traffic becomes a possible attack vector in this split architecture, allowing an attacker to potentially access or modify sensitive information.
Threat type	Information disclosure, Tampering
Vulnerabilities	Heterogeneous security levels between O-RU and O-DU provided by different vendors
Impact type	Confidentiality, Integrity
Affected Assets	Critical S-Plane data [ASSET-D-01], Critical Management-Plane data [ASSET-D-02], Critical C-Plane data [ASSET-D-04], Critical Fronthaul U-Plane data [ASSET-D-05]

Threat ID	**T-FRHAUL-01A**

Threat title	An attacker penetrates O-DU and beyond through O-RU or the Fronthaul interface to impersonate a legitimate system or user [i.12]
Threat description	When having two different vendors, the O-RU and the O-DU need to be managed as different entities and may have heterogeneous security levels. Instead, the O-DU will have to bridge the management traffic between the management system and the O-RU. Hence, an attacker could potentially exploit the bridging mechanism to impersonate a legitimate system or user, allowing them to access the northbound systems beyond the O-DU through the Open Fronthaul interface.
Threat type	Spoofing
Vulnerabilities	Heterogeneous security levels between O-RU and O-DU provided by different vendors
Impact type	Authenticity
Affected Assets	Critical S-Plane data [ASSET-D-01], Critical Management-Plane data [ASSET-D-02], Critical C-Plane data [ASSET-D-04], Critical Fronthaul U-Plane data [ASSET-D-05]

Threat ID	**T-FRHAUL-02**
Threat title	Unauthorized access to Open Fronthaul Ethernet L1 physical layer interface(s) to obtain protected information
Threat description	The Open Fronthaul Ethernet L1 physical interface comprises one or more coaxial cables, twisted pairs, or optical fibers. Each end of the Open Fronthaul Ethernet L1 physical interface comprises a physical connection (colloquially known as an Ethernet Port) to physical O-RAN network elements, e.g., O-DU, O-RU, etc. Unauthorized access to the Open Fronthaul Ethernet L1 physical layer interface (cables and connections) provides a means to launch attacks on the availability, integrity, and confidentiality of the Open Fronthaul system. Potential loss of confidentiality on the Open Fronthaul interface can occur from one or more of the following threats: • An unauthorized device on the Ethernet L1 Interface has access to U-Plane traffic on the Open Fronthaul Interface. • An unauthorized device on the Ethernet L1 Interface has access to S-Plane traffic on the Open Fronthaul Interface. • An unauthorized device on the Ethernet L1 Interface has access to C-Plane traffic on the Open Fronthaul Interface. • An unauthorized device on the Ethernet L1 Interface has access to M-Plane traffic on the Open Fronthaul Interface.
Threat type	Information disclosure
Vulnerabilities	Lack of authentication and access control to the Open Front Haul Ethernet L1 physical layer interface
Impact type	Confidentiality
Affected Assets	Critical S-Plane data [ASSET-D-01], Critical Management-Plane data [ASSET-D-02], Critical C-Plane data [ASSET-D-04], Critical Fronthaul U-Plane data [ASSET-D-05]

Threat ID	**T-FRHAUL-03**
Threat title	Unauthorized access to Open Fronthaul Ethernet L1 physical layer interface(s) to disrupt services

Threat description	The Open Fronthaul Ethernet L1 physical interface comprises one or more coaxial cables, twisted pairs, or optical fibers. Each end of the Open Fronthaul Ethernet L1 physical interface comprises a physical connection (colloquially known as an Ethernet Port) to physical O-RAN network elements, e.g., O-DU, O-RU, etc. Unauthorized access to the Open Fronthaul Ethernet L1 physical layer interface (cables and connections) provides a means to launch attacks on the availability, integrity, and confidentiality of the Open Fronthaul system. Potential loss of availability on the Open Fronthaul interface can occur from one or more of the following threats: • An unauthorized device on the Ethernet L1 Interface can flood the L1 interface with unintended network traffic causing disruption or degradation of authorized network elements on the Open Fronthaul interface. • An unauthorized device on the Ethernet L1 Interface can send Ethernet- L2 messages to authorized network devices causing disruption, denial, or degradation of the Open Fronthaul interface. • An attacker (person) gains access to the Open Fronthaul Ethernet L1 interface(s) and denies the Open Fronthaul services by disabling a physical connection to a network element either by removing an Ethernet port connection or cutting the physical interface (coaxial cable, twisted pair, or optical fiber).
Threat type	Denial of Service
Vulnerabilities	Lack of authentication and access control to the Open Front Haul Ethernet L1 physical layer interface
Impact type	Availability
Affected Assets	Critical S-Plane data [ASSET-D-01], Critical Management-Plane data [ASSET-D-02], Critical C-Plane data [ASSET-D-04], Critical Fronthaul U-Plane data [ASSET-D-05]

Threat ID	**T-MPLANE-01**
Threat title	An attacker attempts to intercept the Fronthaul (MITM) over M Plane to obtain protected information
Threat description	The High bit rate Fronthaul interface imposes strict performance requirements ((bandwidth, latency, fronthaul transport link length, etc.) that limit the use of some security features, due to the increased processing delay. This opens the risk of passive wiretapping over the fronthaul interface to intercept the M plane.
Threat type	Information disclosure
Vulnerabilities	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements
Impact type	Confidentiality
Affected Assets	Critical Management-Plane data [ASSET-D-02], Critical Management-Plane data transported over the O1 interface [ASSET-D-03]

Threat ID	**T-MPLANE-02**
Threat title	An attacker attempts to intercept the Fronthaul (MITM) over M Plane to alter m-plane data
Threat description	The High bit rate Fronthaul interface imposes strict performance requirements ((bandwidth, latency, fronthaul transport link length, etc.) that limit the use of some security features, due to the increased processing delay. This opens the risk of Man-in-the-Middle (MITM) attacks over the fronthaul interface to intercept and modify the M plane.
Threat type	Tampering

Vulnerabilities	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements
Impact type	Integrity
Affected Assets	Critical Management-Plane data [ASSET-D-02], Critical Management-Plane data transported over the O1 interface [ASSET-D-03]

Threat ID	**T-MPLANE-03**
Threat title	An attacker attempts to intercept the Fronthaul (MITM) over M Plane to disrupt services
Threat description	The High bit rate Fronthaul interface imposes strict performance requirements ((bandwidth, latency, fronthaul transport link length, etc.) that limit the use of some security features, due to the increased processing delay. This opens the risk of an Attacker to launch a Denial of Service (DoS) attack over the fronthaul interface to disrupt the M plane
Threat type	Denial of Service
Vulnerabilities	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements
Impact type	Availability
Affected Assets	Critical Management-Plane data [ASSET-D-02], Critical Management-Plane data transported over the O1 interface [ASSET-D-03]

Threat ID	**T-SPLANE-01**
Threat title	DoS attack against a Master clock
Threat description	A denial of service (DoS) attack towards a Master clock of the timing network used by the open Fronthaul to maintain the availability and accuracy of the Master clock. An attacker can attack a master clock by sending an excessive number of time protocol packets or impersonate a legitimate clock, a slave, or an intermediate clock, by sending malicious messages to the master, thus degrading the victim's performance. The attacker may be residing either within the attacked network (insider) or on an external network connected to the attacked network. This attack results in a situation where the clock service is interrupted completely, or the timing protocol is operational, but slaves are being provided inaccurate timing information due the degraded performance of the Master clock. This clock service disruption or degradation in the accuracy of time may cause DoS to applications on all the RUs that rely on accurate time, potentially bringing down the cell. A cell outage caused by misaligned time, may further impact performance in connected neighbouring cells.
Threat type	Denial of Service
Vulnerabilities	- Improper process to monitor and manage the performance of the Master clock - ANNOUNCE messages can be sent publicly in clear text
Impact type	Availability
Affected Assets	Critical S-Plane data [ASSET-D-01]

Threat ID	**T-SPLANE-02**

Threat title	Impersonation of a Master clock (Spoofing) within a PTP network with a fake ANNOUNCE message
Threat description	An attacker within the PTP network can impersonate the master clock's grandmasterIdentity value and propose himself as a grandmaster candidate by sending fake ANNOUNCE messages declaring him to be the best clock in the network. The attacker may be residing either within the attacked network (insider) or on an external network connected to the attacked network. This attack results in a situation where the attacker clock becomes a GM, PTP is operational, all clocks are synchronized, but the malicious GM provides intentionally inaccurate timing information. This degradation in the accuracy of time may cause DoS to applications on all the RUs that rely on accurate time, potentially bringing down the cell. A cell outage caused by misaligned time, may further impact performance in connected neighbouring cells.
Threat type	Denial of Service
Vulnerabilities	- Inaccurate timing information - Improper synchronization between clocks - ANNOUNCE messages can be sent publicly in clear text
Impact type	Availability
Affected Assets	Critical S-Plane data [ASSET-D-01]

Threat ID	**T-SPLANE-03**
Threat title	A Rogue PTP Instance wanting to be a Grand Master
Threat description	An attacker can propose himself as a grandmaster candidate by sending manipulated/malicious ANNOUNCE messages declaring him to be the best clock in the network. The attacker causes other nodes in the network to believe it is a legitimate master. The attacker is internal to the attacked PTP network and could launch this attack by either modification of in-flight protocol packets or injecting fake ANNOUNCE messages to the PTP network. It is assumed that an MITM attacker has physical access to a segment of the network or has gained control of one of the nodes in the network. This attack results in a situation where the time protocol is operational, but slaves are being provided intentionally inaccurate timing information. This degradation in the accuracy of time may cause DoS to applications on all the RUs that rely on accurate time, potentially bringing down the cell. A cell outage caused by misaligned time, may further impact performance in connected neighbouring cells.
Threat type	Denial of Service
Vulnerabilities	- Inaccurate timing information - Improper synchronization between clocks - ANNOUNCE messages can be sent publicly in clear text
Impact type	Availability
Affected Assets	Critical S-Plane data [ASSET-D-01]

Threat ID	**T-SPLANE-04**
Threat title	Selective interception and removal of PTP timing packets
Threat description	An attacker can position himself in such way that allows him to intercept and remove valid synchronization packets. This leads to clock synchronization errors of all clocks downstream or makes them go into free-running mode.

	Attacks may be launched close to the GM by tapping the egress line of an active GM clock. This impacts a larger set of slaves who depend on this GM for timing synchronization. Attacks may also target a one or more slaves. This is done by tapping the ingress line of a particular slave(s). The impact is confined to the targeted slaves. Alternatively, a MiTM attacker can reside in an intermediate node such as TCs, routers and switches to launch this attack. The attacker has physical access to a node of the PTP n/w or has gained full control of one device in the network. This requires additional capability to tap the h/w where PTP timing is implemented. Selective interception and removal can impact timing packets and cause clock degradation in attacked nodes. Removing all packets or random packets may push the clocks in attacked nodes into free running mode This attack results in a situation where the time protocol is operational, but slaves are being provided intentionally inaccurate timing information. This degradation in the accuracy of time may cause DoS to applications on all the RUs that rely on accurate time, potentially bringing down the cell. A cell outage caused by misaligned time, may further impact performance in connected neighbouring cells.
Threat type	Denial of Service
Vulnerabilities	- Inaccurate timing information - Improper synchronization between clocks - ANNOUNCE messages can be sent publicly in clear text
Impact type	Availability
Affected Assets	Critical S-Plane data [ASSET-D-01]

Threat ID	**T-SPLANE-05**
Threat title	Packet delay manipulation attack
Threat description	IEEE 1588 requires symmetric delays between GM and slaves. In packet delay manipulation attacks, the attacker is positioned such a way that allows him to delay the transmission of legitimate time synchronization protocol packets to the intended destination. An attacker launches this attack by either tapping the transmission network or by taking control of an intermediate nodes such as routers, switches and T-TCs. This attack results in a situation where the time protocol is operational, but slaves are being provided intentionally inaccurate timing information. This degradation in the accuracy of time may cause DoS to applications on all the RUs that rely on accurate time, potentially bringing down the cell. A cell outage caused by misaligned time, may further impact performance in connected neighbouring cells.
Threat type	Denial of Service
Vulnerabilities	- Inaccurate timing information - Improper synchronization between clocks - ANNOUNCE messages can be sent publicly in clear text
Impact type	Availability
Affected Assets	Critical S-Plane data [ASSET-D-01]

Threat ID	**T-CPLANE-01**
Threat title	Spoofing of DL C-plane messages
Threat description	The lack of authentication could allow an adversary to inject their own DL C-plane messages that falsely claim to be from the associated O-DU. As a result, it would block the O-RU from processing the corresponding U-Plane packets, leading to temporary DoS. (Dropping the entire DL C-plane messages achieves the same goal).
Threat type	Denial of Service
Vulnerabilities	Lack of authentication could allow an adversary to inject DL C-plane messages
Impact type	Availability
Affected Assets	Critical C-Plane data [ASSET-D-04]

Threat ID	**T-CPLANE-02**
Threat title	Spoofing of UL C-plane messages
Threat description	The lack of authentication could allow an adversary to inject their own UL C-plane messages that falsely claim to be from the associated O-DU. As a result, temporarily limited cell performance (or even DoS) on cells served by the O-RU and in addition a consequential DoS threat to all O-RUs served by that O-DU will exist. (Dropping the entire UL C-plane messages achieves the same goal).
Threat type	Denial of Service
Vulnerabilities	Lack of authentication could allow an adversary to inject UL C-plane messages
Impact type	Availability
Affected Assets	Critical C-Plane data [ASSET-D-04]

Threat ID	**T-UPLANE-01**
Threat title	An attacker attempts to intercept the Fronthaul (MITM) over U-Plane to obtain user data
Threat description	The High bit rate Fronthaul interface impose strict performance requirements ((bandwidth, latency, fronthaul transport link length, etc.) that limit the use of some security features, due to the increased processing delay. This opens the risk of Man-in-the-Middle (MITM) attacks over the fronthaul interface to intercept the U-Plane. For the transported U-Plane data an attacker could potentially do threats, such as passive wiretapping and intercept sensitive information. 3GPP defines UP integrity protection algorithms in their specifications but many of the OEMs have not implemented them because of impact on the user experience (e.g. download and upload data throughputs). Enabling UP integrity protection requires considerable compute resources and adds overhead that directly impacts the maximum throughputs that can be measured on the user device. The integrity protection is enabled on the Control Plane messages but that still leaves the user’s data traffic vulnerable because the Control Plane and User Plane are segregated. For example, the lack of UP integrity could enable an attacker to intercept user data.
Threat type	Information disclosure
Vulnerabilities	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements

Impact type	Confidentiality
Affected Assets	Critical Fronthaul U-Plane data [ASSET-D-05]

Threat ID	**T-UPLANE-02**
Threat title	An attacker attempts to intercept the Fronthaul (MITM) over U-Plane to modify u-plane data
Threat description	The High bit rate Fronthaul interface impose strict performance requirements ((bandwidth, latency, fronthaul transport link length, etc.) that limit the use of some security features, due to the increased processing delay. This opens the risk of Man-in-the-Middle (MITM) attacks over the fronthaul interface to intercept the U-Plane. For the transported U-Plane data an attacker could potentially manipulate the data, such as modifying or altering the contents. 3GPP defines UP integrity protection algorithms in their specifications but many of the OEMs have not implemented them because of impact on the user experience (e.g. download and upload data throughputs). Enabling UP integrity protection requires considerable compute resources and adds overhead that directly impacts the maximum throughputs that can be measured on the user device. The integrity protection is enabled on the Control Plane messages but that still leaves the user's data traffic vulnerable because the Control Plane and User Plane are segregated. For example, the lack of UP integrity could enable a rogue base station to manipulate the user data messages (i.e. DNS) and redirect a user to a malicious website.
Threat type	Tampering
Vulnerabilities	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements
Impact type	Integrity
Affected Assets	Critical Fronthaul U-Plane data [ASSET-D-05]

Threat ID	**T-UPLANE-03**
Threat title	An attacker attempts to intercept the Fronthaul (MITM) over U-Plane to disrupt services
Threat description	The High bit rate Fronthaul interface impose strict performance requirements ((bandwidth, latency, fronthaul transport link length, etc.) that limit the use of some security features, due to the increased processing delay. This opens the risk of Man-in-the-Middle (MITM) attacks over the fronthaul interface to disrupt the U-Plane. For the transported U-Plane data an attacker could potentially launch a Denial of Service (DoS) attack, overwhelming the fronthaul interface and impacting the performance and availability of the service. 3GPP defines UP integrity protection algorithms in their specifications but many of the OEMs have not implemented them because of impact on the user experience (e.g. download and upload data throughputs). Enabling UP integrity protection requires considerable compute resources and adds overhead that directly impacts the maximum throughputs that can be measured on the user device. The lack of UP integrity could enable an attacker to launch a DoS attack on the fronthaul interface, causing service disruption and impacting user experience.
Threat type	Denial of Service
Vulnerabilities	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements
Impact type	Availability
Affected Assets	Critical Fronthaul U-Plane data [ASSET-D-05]

Threat ID	**T-UPLANE-04**
Threat title	Spoofing and unauthorized access of U-Plane data packets
Threat description	The lack of authentication and authorization mechanisms could allow an adversary to spoof a legitimate O-DU or O-RU. Once spoofed, the attacker could tamper with or inject their own U-plane data packets, falsely masquerading as those from the legitimate O-DU or O-RU. This could lead to the processing of altered or corrupted data, degrading service quality, or even causing a Denial of Service (DoS).
Threat type	Spoofing, Elevation of privilege
Vulnerabilities	Lack of authentication, and authorization protection for U-Plane data packets
Impact type	Authenticity, Authorization
Affected Asset	Critical Fronthaul U-Plane data [ASSET-D-05]

7.4.1.3 Threats against O-RU

7.4.1.3.1 Generic threats

The O-RU introduces the following threats:

Threat ID	**T-ORU-01**
Threat title	An attacker stands up a false base station attack by attacking an O-RU
Threat description	A false base station attack occurs when an attacker masquerades as a legitimate mobile network to facilitate a Man-in-The-Middle (MiTM) attack between a subscriber's user equipment (UE) and the mobile network. There are three attack scenarios on an O-RU that enable an attacker to realize a false base station attack: 1. Hijack fronthaul to realize a false base station attack: Attacker disables an operational O-RU's access to the open fronthaul, plugs a false base station system into the operational O-RU's fronthaul interface, and launches a false base station attack with the O-RU providing the air interface. 2. Recruit a standalone O-RU to realize a false base station attack: The stand-alone O-RU is an O-RU that is not operational but is available to an attacker to incorporate into a false base station system. The attacker plugs a false base station system into the standalone O-RU's fronthaul interface and launches a false base station attack with the O-RU providing the air interface. 3. Gain unauthorized physical access to O-RU to realize a false base station attack: An attacker gains access to external and internal components of an O-RU (other than the open fronthaul interface), connects the O-RU under attack to a false base station system, and launches a false base station attack with the O-RU providing the air interface. Successful attacks may cause: a) For a subscriber's UE in attack scenarios 1, 2, and 3: the false base stations, also known as SUPI/5G-GUTI catchers, retrieves a subscriber identity by forcing a UE to attach to the false base station systems. This opens the door to subscriber identity interception/disclosure and unauthorized subscriber tracking attacks. These attacks include stealing subscriber information, tampering with transmitted information, tracking subscribers, and compromising subscriber privacy. b) For the operator network: in attack scenario 1, the attacker removes the operational O-RU from providing service to UEs in the coverage area served by the operational O-RU. c) For operators and vendors in attack scenarios 1, 2, and 3, the attacker recruits legitimate operator/vendor equipment for the purpose of creating a false base station attack on subscribers, possibly harming the reputation of the operator and vendor whose O-RU was used in the attack. **NOTE**: The false base station threat has existed since GSM networks and continued to evolve and persist with the evolution of mobile networks. 5G networks are expected to introduce several security enhancements over 4G

	and legacy networks. Despite these security enhancements, 5G networks could still be a target of false base station attacks [i.19].

7.4.1.3.2 Centralized user management for the O-RU related threats

Threat ID	T-O-RU-02
Threat title	An attacker leverages the lack of traceability with shared user accounts
Threat description	O-RU can be contacted via various controllers for example the SMO and/or the O-DU. This can lead to multiple users on these entities connecting to possibly the few shared local user accounts on the O-RU. O-RU components might be vulnerable if: • Identical local user accounts are shared across entities (e.g: SMO, O-DU) for concurrent access

Threat ID	T-O-RU-03
Threat title	An attacker manipulates initial provisioning information
Threat description	Before the O-RU centralized user management feature is activated the initial provisioning information containing for example the IP address of the centralized authentication and authorization server needs to be configured in the O-RU. The provisioning information could be in the Software Configuration server for example and transfers the information to the O-RU O-RU components might be vulnerable if: • Initial provisioning information from the Software configuration server could be manipulated to point to another server rather than the centralized authentication and authorization server.

Threat ID	T-O-RU-04
Threat title	An attacker compromises O-RU user information, data integrity, confidentiality towards an external centralized authentication and authorization server
Threat description	O-RU can connect to a external centralized authentication and authorization server. The local users on the O-RU should be minimized and the centralized users should be maximized. Also credentials should be transferred between the O-RU and the centralized authentication and authorization and should be secure. The centralized authentication and authorization should also store the credentials of the centralized users in a secure manner O-RU components might be vulnerable if: • O-RU credentials including account information and passwords could be mismanaged, misclassifying O-RU users between centralized and local users which could defeat the purpose of central authentication, authorization and administration • Data in plain text between the O-RU and centralized Authentication and authorization server could be manipulated • O-RU related credentials can be manipulated if not stored securely in the centralised server

7.4.1.4 Threats against Near-RT RIC

Near-Real-Time (RT) RIC introduces the following threats:

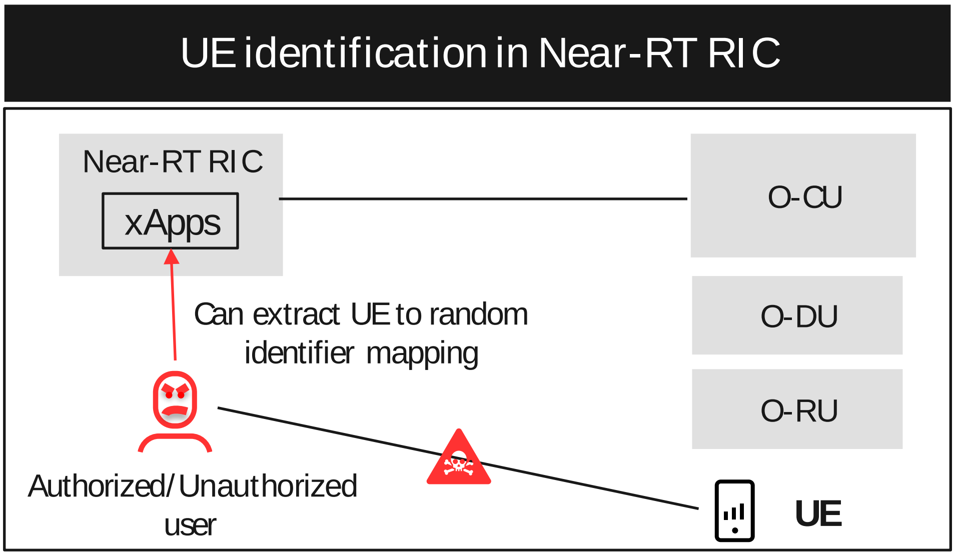

UE identification in Near-RT RIC
Near-RT RIC
xApps
Can extract UE to random identifier mapping
Authorized/Unauthorized user
O-CU
O-DU
O-RU
UE

Figure 7-2 : UE Identification in Near-RT-RIC

Threat ID	**T-NEAR-RT-01**
Threat title	Malicious xApps can exploit UE identification, track UE location and change UE priority [i.12]
Threat description	xApps in the Near-RT RIC have the capability to manipulate behaviour of a certain cell, a group of UEs, and a specific UE. A malfunctioning or unavailable root of trust could potentially cause issues on the network and compromise RAN performance, privacy, etc. For example, the xApp could track a certain subscriber or impact service for a subscriber or a dedicated area. In addition, an xApp can receive order via A1 to control a certain UE and if a malfunctioning xApp receives an order to prioritize this UE, then the owner of the malfunctioning xApp knows a VIP that they want to track is in a certain area. With this command exposure, the attacker can obtain a rough location of a very important person and change the order from prioritize to deprioritize for a UE. Further, E2 interface exposes UE identification that can be exploited by a malicious xApp. As the E2 interface (similar to A1 interface) can point out a certain UE in the network, this will create a correlation between the randomized (anonymized) UE identities between the RAN nodes. For example, a xApp can potentially be used as a “sniffer” for UE identification. The additional challenge for the Near-RT RIC / E2 compared to the Non-RT RIC / A1 is that more frequent signalling is expected over the E2 interface to enable near-real-time operation. Therefore, the UE identifier will be exchanged more frequently over the E2 than over the A1.
Threat type	Information disclosure, Denial of Service
Vulnerabilities	Malicious xApps may be used to gain access to UE identification location and priority
Impact type	Confidentiality, Availability
Affected Assets	3GPP application related data [ASSET-D-21], Inter- and intra-slice UE priority [ASSET-D-22], Near-RT RIC SW [ASSET-C-02], xApps [ASSET-C-09], E2 Functions [ASSET-C-41], Y1 Functions [ASSET-C-43]

Threat ID	**T-NEAR-RT-02**
Threat title	Risk of a malicious xApp on Near-RT RIC obtaining protected information
Threat description	The security threats associated with the onboarding and deployment of malicious xApps include: • Malicious xApps attaining unauthorized access to the Near-RT RIC and E2 Nodes • Malicious xApps abusing radio network information and control capabilities over RAN functions • Malicious xApp exploiting UE identification, tracking UE location and changing UE slice priority

Threat type	Information disclosure, Elevation of Privilege
Vulnerabilities	Improper or missing authentication and authorization of xApps
Impact type	Confidentiality, Authorization
Affected Assets	Database holding data from xApp applications and E2 Node [ASSET-D-10], E2 Node data [ASSET-D-11], 3GPP application related data [ASSET-D-21], Inter- and intra-slice UE priority [ASSET-D-22]

Threat ID	**T-NEAR-RT-02A**
Threat title	Risk of a malicious xApp on Near-RT RIC impacting service availability
Threat description	The security threats associated with the onboarding and deployment of malicious xApps include: • Malicious xApp impacting service for a subscriber or a dedicated area
Threat type	Denial of Service
Vulnerabilities	Improper or missing authentication and authorization of xApps
Impact type	Availability
Affected Assets	Database holding data from xApp applications and E2 Node [ASSET-D-10], E2 Node data [ASSET-D-11], 3GPP application related data [ASSET-D-21], Inter- and intra-slice UE priority [ASSET-D-22]

Threat ID	**T-NEAR-RT-03**
Threat title	Attackers exploit non authenticated, weakly or incorrectly authenticated Near-RT RIC APIs to obtain protected information
Threat description	Not mutually authenticating xApps and Near-RT RIC platform APIs could potentially allow attackers to perform the following type of attacks [i.20]: - Operating malicious xApp claiming to be genuine in order to request certain services (theft of services) or information (data leakage) - Man in the middle attacks between a genuine xApp and a Near-RT RIC platform API - Querying network or UE information from a compromised xApp to Near-RT RIC platform (e.g. database via SDL API), thereby leaking potentially sensitive data about network and/or UE (potential privacy issues) - Subscribing a malicious xApp to services provided by the Near-RT RIC platform, such as API-related events notifications, discovery of APIs, E2SM, etc. The use of weak credentials in the process of API authentication can compromise the overall system. The user/password combination isn't considered safe, not only for password related attacks (e.g., brute-force), but also it would represent a high risk to allow xApps, especially 3rd party xApps, to store the user/password combo. This approach would extend the attack surface into xApps side. As a reference, OWASP API Security Top 10 report [i.21] indicates that authentication mechanisms are often implemented incorrectly, allowing attackers to compromise authentication tokens or to exploit implementation flaws to assume other user's identities temporarily or permanently. Compromising system's ability to identify the client/user, compromises API security overall.
Threat type	Information disclosure, Spoofing
Vulnerabilities	Non authenticated, weakly or incorrectly authenticated Near-RT RIC APIs
Impact type	Confidentiality, Authenticity
Affected Assets	Data transported over the E2 interface [ASSET-D-09], Database holding data from xApp applications and E2 Node [ASSET-D-10], E2 Node data [ASSET-D-11], Credentials (Administrators) [ASSET-D-20], 3GPP application related data [ASSET-D-21], Inter- and intra-slice UE priority [ASSET-D-22],

	Training or test data and associated labels [ASSET-D-25], The trained ML model [ASSET-D-26], Security event log files [ASSET-D-29], O-RAN specific several UE IDs [ASSET-D-30], Near-RT-RIC SW [ASSET-C-02], xApps [ASSET-C-09], E2 Functions [ASSET-C-41], Y1 Functions [ASSET-C-43]

Threat ID	**T-NEAR-RT-03A**
Threat title	Attackers exploit non authenticated, weakly or incorrectly authenticated Near-RT RIC APIs for MiTM attacks
Threat description	Not mutually authenticating xApps and Near-RT RIC platform APIs could potentially allow attackers to perform the following type of attack [i.20]: - Man in the middle attacks between a genuine xApp and a Near-RT RIC platform API The use of weak credentials in the process of API authentication can compromise the overall system. The user/password combination isn't considered safe, not only for password related attacks (e.g., brute-force), but also it would represent a high risk to allow xApps, especially 3rd party xApps, to store the user/password combo. This approach would extend the attack surface into xApps side. As a reference, OWASP API Security Top 10 report [i.21] indicates that authentication mechanisms are often implemented incorrectly, allowing attackers to compromise authentication tokens or to exploit implementation flaws to assume other user's identities temporarily or permanently. Compromising system's ability to identify the client/user, compromises API security overall.
Threat type	Tampering
Vulnerabilities	Non authenticated, weakly or incorrectly authenticated Near-RT RIC APIs
Impact type	Integrity
Affected Assets	Data transported over the E2 interface [ASSET-D-09], Database holding data from xApp applications and E2 Node [ASSET-D-10], E2 Node data [ASSET-D-11], Credentials (Administrators) [ASSET-D-20], 3GPP application related data [ASSET-D-21], Inter- and intra-slice UE priority [ASSET-D-22], Training or test data and associated labels [ASSET-D-25], The trained ML model [ASSET-D-26], Security event log files [ASSET-D-29], O-RAN specific several UE IDs [ASSET-D-30], Near-RT-RIC SW [ASSET-C-02], xApps [ASSET-C-09], E2 Functions [ASSET-C-41], Y1 Functions [ASSET-C-43]

Threat ID	**T-NEAR-RT-04**
Threat title	Attackers exploit non authorized Near-RT RIC APIs to access resources and services which they are not entitled to use, to obtain protected information.
Threat description	If the API consumers are not authorized by the API producers, attackers (e.g, malicious xApps) would potentially be able to perform the following types of attacks: - Abuse and/or theft of services or information (data leakage), requesting and successfully obtaining them from the platform, e.g, in order to extract potentially sensitive information from the network and/or UEs As a reference, OWASP API Security Top 10 report [i.21] indicates that 'Broken Object Level Authorization' has been the most common and impactful attack on APIs. Even if the application implements a proper infrastructure for authorization checks, developers might forget to use these checks before accessing a sensitive

	object. Unauthorized access can result in data disclosure to unauthorized parties, data loss, or data manipulation. In the actual context of Near-RT RIC [i.8], the platform as API producer is responsible to specify those rights/privileges for the platform services as resources to the xApps as consumers. In general, an xApp should only have the required set of permissions to perform the actions for which they are authorized, and no more. **NOTE**: The investigation of services for which the API producer is the xApp is for further study
Threat type	Information disclosure, Elevation of Privilege
Vulnerabilities	Non-authorized RT RIC APIs
Impact type	Confidentiality, Authorization
Affected Assets	Data transported over the E2 interface [ASSET-D-09], Database holding data from xApp applications and E2 Node [ASSET-D-10], E2 Node data [ASSET-D-11], Credentials (Administrators) [ASSET-D-20], 3GPP application related data [ASSET-D-21], Inter- and intra-slice UE priority [ASSET-D-22], Training or test data and associated labels [ASSET-D-25], The trained ML model [ASSET-D-26], Security event log files [ASSET-D-29], O-RAN specific several UE IDs [ASSET-D-30], Near-RT-RIC SW [ASSET-C-02], xApps [ASSET-C-09], E2 Functions [ASSET-C-41], Y1 Functions [ASSET-C-43]

Threat ID	**T-NEAR-RT-04A**
Threat title	Attackers exploit non authorized Near-RT RIC APIs to access resources and services which they are not entitled to use, to disrupt services.
Threat description	If the API consumers are not authorized by the API producers, attackers (e.g, malicious xApps) would potentially be able to perform the following types of attacks: - Negatively impacting the network performance due to malicious policies over E2 Nodes - Flooding the platform with resource demanding operations that may lead to a Denial of Service attack As a reference, OWASP API Security Top 10 report [i.21] indicates that 'Broken Object Level Authorization' has been the most common and impactful attack on APIs. Even if the application implements a proper infrastructure for authorization checks, developers might forget to use these checks before accessing a sensitive object. Unauthorized access can result in data disclosure to unauthorized parties, data loss, or data manipulation. In the actual context of Near-RT RIC [i.8], the platform as API producer is responsible to specify those rights/privileges for the platform services as resources to the xApps as consumers. In general, an xApp should only have the required set of permissions to perform the actions for which they are authorized, and no more. **NOTE**: The investigation of services for which the API producer is the xApp is for further study
Threat type	Denial of Service
Vulnerabilities	Non-authorized RT RIC APIs
Impact type	Availability
Affected Assets	Data transported over the E2 interface [ASSET-D-09], Database holding data from xApp applications and E2 Node [ASSET-D-10], E2 Node data [ASSET-D-11], Credentials (Administrators) [ASSET-D-20], 3GPP application related data [ASSET-D-21], Inter- and intra-slice UE priority [ASSET-D-22], Training or test data and associated labels [ASSET-D-25],

	The trained ML model [ASSET-D-26], Security event log files [ASSET-D-29], O-RAN specific several UE IDs [ASSET-D-30], Near-RT-RIC SW [ASSET-C-02], xApps [ASSET-C-09], E2 Functions [ASSET-C-41], Y1 Functions [ASSET-C-43]

Threat ID	**T-NEAR-RT-05**
Threat title	Attackers exploit non uniquely identified xApps using a trusted xAppID to access resources and services which they are not entitled to use.
Threat description	Not uniquely identifying xApps using a trusted xAppID potentially entails certain threats and potential attacks: - A non-unique xAppID might cause misidentification of an xApp, possibly allowing a potentially malicious xApp to request certain services (theft of services), information (data leakage), or alter existing information - A malicious xApp might use the xAppID assigned to a legitimate xApp to request services or information from Near-RT RIC platform - A non-unique xApp ID could make it impossible to accurately assign actions to the correct xApp - A non-unique xApp ID could make it difficult to recognize that a malicious xApp is in the environment
Threat type	Information disclosure, Elevation of Privilege
Vulnerabilities	Not uniquely identifying xApps using a trusted xAppID
Impact type	Confidentiality, Authorization
Affected Assets	xAppID [ASSET-D-39], Near-RT-RIC SW [ASSET-C-02], xApps [ASSET-C-09]

7.4.1.5 Threats against Non-RT RIC

Threats against Non-RT RIC include:

Threat ID	**T-NONRTRIC-01**
Threat title	An attacker penetrates the Non-RT RIC to cause a denial of service or degrade the performance
Threat description	An attacker penetrates the Non-RT RIC through the SMO and attempts to trigger a Denial of Service or degrade the performance of non-RT RIC so that non-RT RIC would not be liable for ensuring: • The monitoring or tracing of the network to understand the effect of the A1 policy on performance in Near-RT RIC • The update of A1 policy • The exposure and secure delivery of A1 Enrichment Information to near-RT RIC • The setup of access control rules and the selection of which Enrichment Information ID (EiId) are exposed to a near-RT RIC

Threat ID	T-NONRTRIC-02
Threat title	UE tracking in the Non-RT RIC
Threat description	An attacker gains access to the Non-RT RIC through the SMO for UE tracking.

Threat ID	**T- NONRTRIC-03**
Threat title	Data Corruption/Modification
Threat description	An attacker gains access to the Non-RT RIC through the SMO to cause Data Corruption/Modification.

Threat ID	**T-NONRTRIC-04**
Threat title	Attacker exploits non-uniquely identified rApp instances
Threat description	An attacker can exploit non-uniquely identified rApp instances using a trusted rAppID to gain unauthorized access to services and data. Potential threats and attacks include: - A non-unique rAppID might cause misidentification of an rApp instance, possibly allowing a potentially malicious rApp instance to request certain services (theft of services), information (data leakage), or alter existing information - A malicious rApp instance might use the rAppID assigned to a legitimate rApp instance to request access to R1 services or data - A non-unique rApp ID could make it impossible to accurately assign actions to the correct rApp instance - A non-unique rApp ID could make it difficult to recognize that a malicious rApp instance is in the environment

7.4.1.6 Threats against xApps

xApps introduce the following threats:

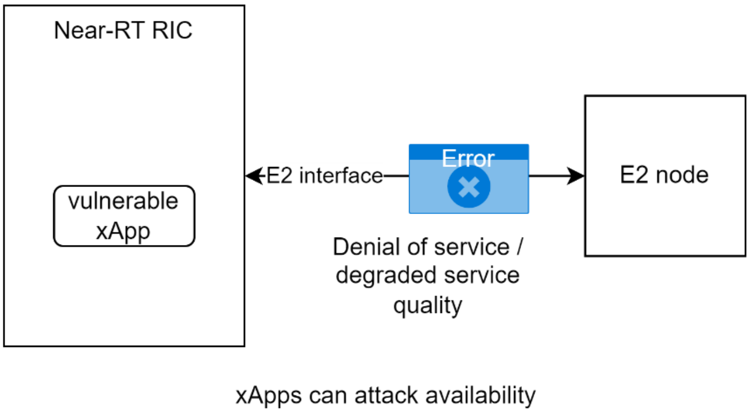

Near-RT RIC
vulnerable xApp
E2 interface
Error
E2 node
Denial of service / degraded service quality
xApps can attack availability

Figure 7-3 : Near-RT-RIC and xApps conflict with E2 node

Threat ID	**T-xApp-01**
Threat title	An attacker exploits xApps vulnerabilities and misconfiguration to alter data transmitted over A1 or E2 interfaces.
Threat description	Vulnerabilities can potentially exist in any xApp if it stems from an untrusted or unmaintained source. If attackers can find an exploitable xApp, they can alter data transmitted over A1 or E2 interfaces, potentially disrupting the normal functioning of the Near-RT RIC. The actual consequences may vary. For example, an attacker may gain the ability to alter data transmitted over A1 or E2 interfaces, extract sensitive information, etc. Malicious xApps can manipulate the behaviour of the Near-RT RIC, allowing attackers to alter data and impact the performance of the network service.

Threat type	Tampering
Vulnerabilities	xApp stems from an untrusted or unmaintained source
Impact type	Authenticity
Affected Assets	O-CU-CP software [ASSET-C-03], O-eNB [ASSET-C-07], O-Cloud [ASSET-C-08], xApps [ASSET-C-09], rApps [ASSET-C-10]

Threat ID	**T-xApp-01A**
Threat title	An attacker exploits xApps vulnerabilities and misconfiguration to extract sensitive information.
Threat description	Vulnerabilities can potentially exist in any xApp if it stems from an untrusted or unmaintained source. If attackers can find exploitable xApp, they can extract sensitive information, potentially gaining access to confidential data. The actual consequences may vary. For example, an attacker may extract sensitive information about network configuration, user data, or other confidential information. Malicious xApps can be used to extract sensitive information, allowing attackers to gain unauthorized access to sensitive data and potentially compromise the security of the Near-RT RIC.
Threat type	Information Disclosure
Vulnerabilities	xApp stems from an untrusted or unmaintained source
Impact type	Confidentiality
Affected Assets	O-CU-CP software [ASSET-C-03], O-DU software [ASSET-C-05], O-eNB [ASSET-C-07], O-Cloud [ASSET-C-08], xApps [ASSET-C-09], rApps [ASSET-C-10]

Threat ID	**T-xApp-01B**
Threat title	An attacker exploits xApps vulnerabilities and misconfiguration to disrupt Near-RT RIC functions
Threat description	Vulnerabilities can potentially exist in any xApp if it stems from an untrusted or unmaintained source. If attackers can find exploitable xApp, they can disrupt the normal functioning of the Near-RT RIC, potentially causing a denial of service. The actual consequences may vary. For example, an attacker may cause performance degradation, service interruptions, or complete unavailability of the Near-RT RIC. Malicious xApps can be used to impact Near-RT RIC functions, allowing attackers to disrupt the normal functioning of the network service and potentially cause a denial of service.
Threat type	Denial of Service
Vulnerabilities	xApp stems from an untrusted or unmaintained source
Impact type	Availability
Affected Assets	O-CU-CP software [ASSET-C-03], O-DU software [ASSET-C-05], O-eNB [ASSET-C-07], O-Cloud [ASSET-C-08], xApps [ASSET-C-09], rApps [ASSET-C-10]

Threat ID	**T-xApp-01C**
Threat title	An attacker exploits xApps vulnerabilities and misconfiguration to gain unauthorized control over Near-RT RIC

Threat description	Vulnerabilities can potentially exist in any xApp if it stems from an untrusted or unmaintained source. If attackers can find exploitable xApp, they can gain unauthorized control over another xApp or the whole Near-RT RIC, potentially allowing them to perform actions that would normally be restricted. The actual consequences may vary. For example, an attacker may gain the ability to manipulate the behaviour of a certain cell, a group of UEs, or a specific UE, or even take control of the entire Near-RT RIC. Malicious xApps can be used to elevate the attacker's privileges, allowing them to perform unauthorized actions and gain control over the Near-RT RIC, potentially leading to a complete compromise of the system.
Threat type	Elevation of Privilege
Vulnerabilities	xApp stems from an untrusted or unmaintained source
Impact type	Authorization
Affected Assets	O-CU-CP software [ASSET-C-03], O-DU software [ASSET-C-05], O-eNB [ASSET-C-07], O-Cloud [ASSET-C-08], xApps [ASSET-C-09], rApps [ASSET-C-10]

Threat ID	**T-xApp-02**
Threat title	Conflicting xApps impact O-RAN system functions to degrade performance or create a DoS [i.12]
Threat description	Conflicting xApps impact O-RAN system functions such as mobility management, admission controls, bandwidth management and load balancing for the purpose of performance degradation. There is no clear functional split between the Near-RT RIC and the O-gNB. The functional split depends on the available xApps and the capabilities exposed by the O-gNB. This creates possible conflicts between the decisions taken by the Near-RT RIC and the O-gNB that could lead to instability in the network, which introduces vulnerabilities that could be exploited by threat actors. For example, a threat actor can utilize a malicious xApp that intentionally triggers RRM decisions conflicting with the O-gNB internal decisions to create denial of service.
Threat type	Denial of Service
Vulnerabilities	xApps may be misconfigured or compromised Failing or misconfigured authentication and authorization in xApp
Impact type	Availability
Affected Assets	O-CU-CP software [ASSET-C-03], O-DU software [ASSET-C-05], O-eNB [ASSET-C-07], O-Cloud [ASSET-C-08], xApps [ASSET-C-09], rApps [ASSET-C-10]

Threat ID	**T-xApp-03**
Threat title	An attacker compromises xApp isolation
Threat description	An attacker can exploit weaknesses and vulnerabilities to compromise xApp isolation and to break out of xApp confinement. For example, attacker can use the underlying system vulnerabilities to easily breach isolation and confinement. Adversary can use side effects resulting from a shared resource usage to deduce information from co-hosted xApps. Gaining unauthorized access to the underlying system provides new opportunities to exploit vulnerabilities in other xApps or O-RAN components to intercept and spoof network traffic, to degrade services (DoS), etc.

Threat ID	**T-xApp-04**
Threat title	False or malicious A1 policies from the Non-RT RIC inform behavior of xApps to trigger a DoS, affect performance, or locate a subscriber.

Threat description	Unauthorized access to the Non-RT RIC enables the creation of 'false policies' that can be issued to the Near-RT RIC for enforcement. Existing Near-RT RIC policies could also be modified to achieve a false policy. False policies passed to the Near-RT RIC would be persistent until they were modified or deleted by the Non-RT RIC or the Near-RT RIC power cycles. False policies can be created to have numerous impacts to the normal performance of the RAN. A single false A1 policy can target a specific UE, groups of UEs, or an entire cell. A false policy could influence the Near-RT RIC to configure the O-DU and O-RU functions to support Denial of Service (DoS) attacks by using feedback data to degrade RAN performance. False policies could also be used for the purpose of locating a subscriber or group of subscribers. In this case, the false policy would cause the Near-RT RIC to isolate a subscriber in the O-CU. The Near-RT RIC could also use MIMO beamforming in the O-DU and O-RU to isolate a user onto a single beam. The data feedback from the RAN can include UE location or trajectory information from GPS data. The subscriber location would be attained from access to the Non-RT RIC in the SMO function. The Near-RT RIC is capable of steering traffic to achieve optimal QoS or QoE performance. A false policy could notionally cause the Near-RT RIC to steer user data to isolate the data in order to facilitate a cyber-attack.

7.4.1.7 Threats against rApps

Threats against rApps include:

Threat ID	**T-rAPP-01**
Threat title	Conflicting rApps unintentionally or maliciously impact O-RAN system functions to degrade performance or trigger a DoS
Threat description	rApps in the Non-RT RIC can be provided by different vendors. For example, one vendor can provide the rApp for Carrier license scheduling and another vendor provide the rApp for energy saving, etc. This creates the risk that different rApps will take conflicting decisions at the same instance in time for the same user. Such conflicts between rApps include: • Direct conflicts: different rApps request change for the same parameter. • Indirect conflicts: different rApps request change to different parameters that will create opposite effects. • Implicit conflicts: different rApps request change to different parameters that are not creating any obvious opposite effect but result in an overall network performance degradation, instabilities, etc. These conflicts are difficult to mitigate since dependencies are impossible to observe.

Threat ID	**T-rAPP-02**
Threat title	An attacker exploits rApp vulnerabilities
Threat description	Vulnerabilities can potentially exist in any rApp. If attackers can find exploitable rApp, they can potentially force a data breach, disrupt the offered network service. and take over another rApp or the non-RT RIC. The actual consequences may vary. For example, an attacker may gain the ability to alter data transmitted over A1 interface, extract sensitive information, etc.

Threat ID	**T-rAPP-03**
Threat title	An attacker exploits rApps misconfiguration
Threat description	Security misconfiguration, such as open ports or enabled unused protocols, can potentially exist in an rApp. If attackers can find exploitable rApp, they can disrupt the offered network service and potentially take over another rApp or the whole non-RT RIC.

	The actual consequences may vary. For example, an attacker may gain the ability to alter data transmitted over A1 interface, extract sensitive information, etc.

Threat ID	**T-rAPP-04**
Threat title	An attacker bypasses authentication and authorization
Threat description	An Attacker can exploit an rApp that has weak or misconfigured authentication and authorization to gain access to the rApp and pose as a tenant.

Threat ID	**T-rAPP-05**
Threat title	An attacker deploys and exploits malicious rApp
Threat description	An untrusted source may intentionally provide a malicious rApp. A trusted source may have a backdoor intentionally inserted in the rApp. If attackers can find exploitable rApp, they can disrupt the offered network service and potentially take over another rApp or the whole non-RT RIC. Malicious rApps could impact non-RT RIC functions such as AI/ML model training, A1 policy management, Enrichment information management, Network Configuration Optimization in the purpose of performance degradation, DoS, enrichment data sniffing (UE location, trajectory, navigation information, GPS data, etc.), etc.

Threat ID	**T-rAPP-06**
Threat title	An attacker bypasses authentication and authorization using an injection attack
Threat description	It is possible that an attacker to submit requests without prior authentication and authorization by executing an injection attack to manipulate configurations, access logs, perform remote code execution, etc.

Threat ID	**T-rAPP-07**
Threat title	rApp exploits services
Threat description	A malicious rApp or a trusted but compromised rApp can exploit services across the R1 interface

7.4.1.8 Threats against PNF

Threat ID	**T-PNF-01**
Threat title	An attacker compromises a PNF to launch attacks against VNFs/CNFs
Threat description	A lack of security policies to protect mixed PNF-VNF/CNF deployments could be used to perform attacks against VNFs/CNFs, potentially taking advantage of legacy security used by PNFs and not provided by the virtualization/containerization layer. Attackers could use insecure interfaces as injection points and for launching the attacks. Attackers could leverage lack of authentication, integrity check mechanisms to tamper software updates to PNFs.
Threat Type	Information Disclosure, Tampering
Vulnerabilities	Vulnerabilities in a PNF deployed in a PNF-VNF/CNF deployments.
Impact Type	Confidentiality, Integrity

Affected Assets	All

Threat ID	**T-PNF-01A**
Threat title	An attacker compromises a PNF to launch Denial of Service attacks against VNFs/CNFs
Threat description	A lack of security policies to protect mixed PNF-VNF/CNF deployments could be used to perform attacks against VNFs/CNFs, potentially taking advantage of legacy security used by PNFs and not provided by the virtualization/containerization layer. The attacks on VNF/CNF could lead to denial of service of the VNF/CNF services and function to its dependent functions/elements.
Threat Type	Denial of Service
Vulnerabilities	Vulnerabilities in a PNF deployed in a PNF-VNF/CNF deployments.
Impact Type	Availability
Affected Assets	All

7.4.1.9 Threats against R1 interface

The R1 interface facilitates inter-connection between rApps and Non-RT RIC framework supplied by different vendors, and provides a level of abstraction between rApps and Non-RT RIC framework/SMO that can be the consumers and or producers of R1 services.

Threat ID	**T-R1-01**
Threat title	An attacker gains unauthorized access to R1 services
Threat description	“Service management and exposure services Producer” determines whether the Service Producer is authorized to produce the service. An attacker can perform a spoofing attack to gain unauthorized access to R1 services.

Threat ID	**T-R1-02**
Threat title	Attacker modifies Service Heartbeat message to cause Denial of Service
Threat description	Attacker can exploit the Service Heartbeat on the R1 by modifying or inserting heartbeat messages to cause denial of service

Threat ID	**T-R1-03**
Threat title	Malicious actor bypasses authentication to Request Data
Threat description	Attacker can exploit password-based authentication on the R1 to request unauthorized data. Weak password management can easily be exploited. (Certificate-based mutual authentication using TLS and PKI X.509 certificates is recommended).

Threat ID	**T-R1-04**
Threat title	An attacker bypasses authorization to discover data
Threat description	“Data registration and discovery service producer” determines whether the Data Producer is authorized to produce the data types. An attacker can perform a spoofing attack to bypass authorization to discover available data.

Threat ID	**T-R1-05**
Threat title	An attacker gains unauthorized access to data
Threat description	An attacker can perform a spoofing attack to exploit the Data request and subscription service for the purpose to gain unauthorized access to data.

Threat ID	**T-R1-06**
Threat title	An attacker modifies a Data Request
Threat description	Data Consumers consume the “Data request and subscription service” to request data instances or subscribe to them. An attacker can modify a request to force the consumer to receive a different data set then that intended. Without checks, the received data could be processed, leading to erroneous decisions or triggers.

Threat ID	**T-R1-07**
Threat title	A malicious actor snoops Data Delivery to the Data Consumer
Threat description	Data delivery messages relate to a particular data request or subscription. The data can be delivered to the Data Consumer in different ways, including: • as part of the payload of a data delivery message, • as a data stream, • from e.g., a REST endpoint, a message bus or object store location. An attacker can perform snooping, injection, or modification attacks in the Delivery of Data process.

7.4.1.10 Threats against A1 interface

The A1 interface enables the Non-RT RIC function to provide policy-based guidance, ML model management and enrichment information to the Near-RT RIC function for RAN optimization. The Non-RT RIC can provide enrichment information over the A1 interface to support the policy enforcement in the Near-RT RIC. The A1 interface is used for discovery, request and delivery of A1 Enrichment Information and discovery of External Enrichment Information.

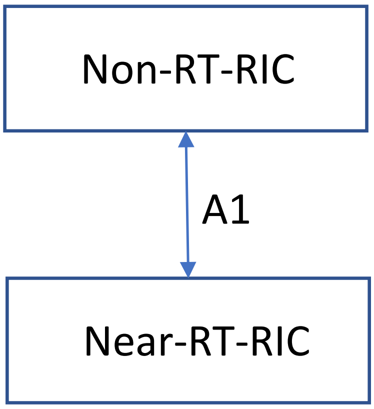


Figure 7-4 : A1 interface between the Non-RT RIC and the Near-RT RIC

Threat ID	**T-A1-01**
Threat title	Untrusted peering between Non-RT-RIC and Near-RT-RIC

Threat description	Malicious Non-RT-RIC peers with a Near-RT-RIC over the A1 interface, or a malicious Near-RT-RIC peers with a Non-RT-RIC over the A1 interface, due to weak mutual authentication.

Threat ID	**T-A1-02**
Threat title	Malicious function or application monitors messaging across A1 interface
Threat description	Internal threat actor can gain access to the messaging across the A1 interface for a MiTM attack to read policy.

Threat ID	**T-A1-03**
Threat title	Malicious function or application modifies messaging across A1 interface
Threat description	Internal threat actor can gain access to the messaging across the A1 interface for a MiTM attack to modify or inject policy. This can result in the Near-RT RIC receiving malicious policy.

Threat ID	**T-A1-04**
Threat title	Unauthorized access to Non-RT-RIC- or Near-RT-RIC- resources
Threat description	A malicious actor accesses Near-RT-RIC resources or Non-RT-RIC resources over the A1 interface, due to weak service consumer authorization.
Threat type	Elevation of Privilege
Impact type	Authorization
Affected Asset	A1 policies [ASSET-D-07], A1 Enrichment Information [ASSET-D-08]

7.4.1.11 Threats against application life cycle

Threat ID	**T-AppLCM-01**
Threat title	Compromise of App/VNF/CNF update package integrity prior to onboarding
Threat description	Attackers gains access to the SMO to modify the App/VNF/CNF update package to enable a malicious application.
Threat type	Tampering; Denial of Service
Impact type	Integrity; Availability
Affected Asset	ASSET-D-15: App/VNF/CNF software package

Threat ID	**T-AppLCM-02**
Threat title	Compromise of App/VNF/CNF update image integrity during instantiation
Threat description	Attacker gains access to the O-Cloud platform to modify the App/VNF/CNF update image to enable a malicious application.
Threat type	Tampering; Denial of Service
Impact type	Integrity; Availability

Affected Asset	ASSET-D-15: App/VNF/CNF software package

Threat ID	**T-AppLCM-03**
Threat title	Downgrade attack to vulnerable application version
Threat description	A software version downgrade attack is a form of attack on a system that makes it abandon a more recent version of a software package in favor of an older, possibly vulnerable, version. Malicious actor downgrades an application to enable exploitation of application vulnerabilities.
Threat type	Denial of Service; Tampering
Impact type	Availability; Integrity
Affected Asset	ASSET-D-15: App/VNF/CNF software package

Threat ID	**T-AppLCM-04**
Threat title	Attacker exploits missing or improperly defined elements of application’s SecurityDescriptor
Threat description	Proper and comprehensive definition of the App/VNF/CNF package SecurityDescriptor helps ensure elements of security needed for the App/VNF/CNF package are present. If attackers can find missing or improperly defined elements of an App/VNF/CNF package SecurityDescriptor, they can exploit that to gain unauthorized access to data and services.
Threat type	Elevation of Privilege; Denial of Service
Impact type	Authorization; Availability
Affected Asset	ASSET-D-15: App/VNF/CNF software package

Threat ID	**T-AppLCM-05**
Threat title	Malicious actor modifies application’s SecurityDescriptor
Threat description	Malicious actor modifies fields of an App/VNF/CNF package SecurityDescriptor to change security elements of the App/VNF/CNF, which could include information on encryption, algorithms, key requirements, firewall rules, etc. An attacker can modify the SecurityDescriptor to cause service disruption and gain unauthorized access to data and services.
Threat type	Tampering; Elevation of Privilege; Denial of Service
Impact type	Integrity; Authorization; Availability
Affected Asset	ASSET-D-15: App/VNF/CNF software package

Threat ID	**T-AppLCM-06**
Threat title	Improper decommissioning of application
Threat description	The improper decommissioning of an application can lead to excessive or conflicting resource usage, accidental deletion of pertinent data (such as application data, cryptographic keys, etc.), and misallocation of resources to a malicious application. Credentials or other trust relationships may not be revoked or removed, which leaves an exposure.

Threat type	Denial of Service, Information Disclosure
Impact type	Availability, Confidentiality
Affected Asset	ASSET-C-02: Near-RT RIC software, ASSET-C-11: Non-RT RIC software, ASSET-C-09: xApps, ASSET-C-10: rApps, ASSET-C-03: O-CU-CP software, ASSET-C-04: O-CU-UP software, ASSET-C-05: O-DU software

Threat ID	**T-AppLCM-07**
Threat title	Improper deletion of application sensitive data
Threat description	Adversary can gain access to sensitive data and secrets if an application's data is not securely deleted. This can include access to secure artifacts such as certificates and keys.
Threat type	Information Disclosure
Impact type	Confidentiality
Affected Asset	ASSET-D-16: X.509 certificates, ASSET-D-17: Private keys, ASSET-D-32: Cryptographic keys used during secure boot

7.4.1.12 Threats against E2 interface

E2 is a logical interface connecting the Near-RT RIC with an E2 Node as defined in [i.25]. The E2 functions are grouped into the following categories:

- Near-RT RIC Services
- Near-RT RIC support functions

Threat ID	T-E2-01
Threat title	Untrusted Near-RT-RIC and/or E2 Nodes
Threat description	A malicious E2 Node communicates with a Near-RT-RIC over the E2 interface, or a malicious Near-RT-RIC communicates with an E2 Node over the E2 interface, due to weak mutual authentication.

Threat ID	T-E2-02
Threat title	Malicious actor monitors messaging across E2 interface
Threat description	Threat actor can gain access to the messaging across the E2 interface for a MiTM attack to read messages.

Threat ID	T-E2-03
Threat title	Malicious actor modifies messaging across E2 interface
Threat description	Threat actor can gain access to the messaging across the E2 interface for a MiTM attack to modify or inject messages. This can result in the Near-RT RIC and/or the E2 Nodes receiving malicious messages.

7.4.1.13 Threats against Y1 interface

The Near-RT RIC provides RAN analytics information (RAI) services via Y1 service interface. These services can be consumed by Y1 consumers by subscribing to or requesting the RAN analytics information via the Y1 service interface. Y1 consumers may be Application Functions (AFs) which are within an O-RAN trusted domain. AFs outside the O-

RAN trusted domain may use Y1 services, too. Further details are available in the O-RAN Architecture Description [i.6], clauses 5.1 and 5.4.18.

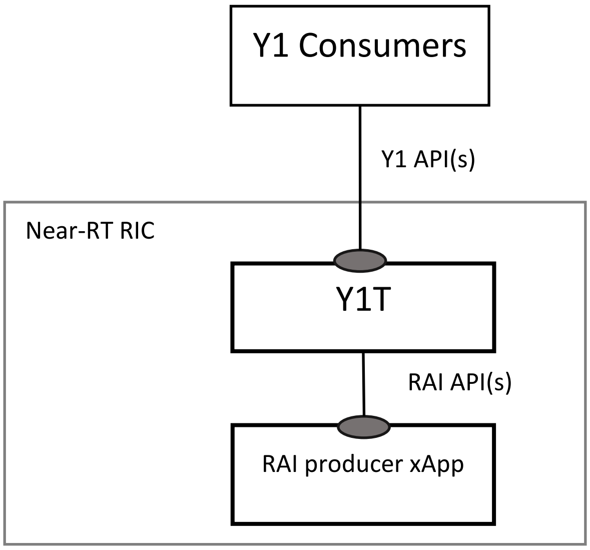


Figure 7-5 : RAN analytics information (RAI) services via Y1 service interface

Malicious Y1 consumers may use their access through the Y1 interface with the intent of accessing, manipulating or negatively impacting the privacy of subscribers, the RAN or the core network.

Threat ID	T-Y1-01
Threat title	Untrusted Near-RT-RIC and Y1 consumers
Threat description	A Malicious Y1 consumer communicates with a Near-RT-RIC over the Y1 interface, or a malicious Near-RT-RIC communicates with a Y1 consumer over the Y1 interface, due to weak mutual authentication.

Threat ID	T-Y1-02
Threat title	Malicious actor monitors messaging across Y1 interface
Threat description	Threat actor can gain access to the messaging across the Y1 interface for a MiTM attack to read messages.

Threat ID	T-Y1-03
Threat title	Malicious actor modifies messaging across Y1 interface
Threat description	Threat actor can gain access to the messaging across the Y1 interface for a MiTM attack to modify or inject messages. This can result in the Near-RT RIC and/or the Y1 consumers receiving malicious messages.

7.4.2 Threats against O-CLOUD

Virtualization and containerization technologies in O-RAN introduce the following relevant threats:

7.4.2.1 Generic Threats

Threat ID	T-GEN-01
Threat title	Software flaw attack
Threat description	Code of host OS, Hypervisor/Container Engine and VNF/CNF can include flaws that an attacker can exploit if they are present. As O-RAN software components relies on opensource software, opensource libraries, 3rd party components. Vulnerability in any of these software components likely to allow attacker to exploit O-CLOUD environment. This could lead attacker to carry out to malicious activities, such as: • Compromise of the underlying VM/Container • Exploit host access via Escape to Host • Take advantage of weak identity and access management policies to attempt to elevate privileges • Execute adversary-controlled code • Enable an adversary to move from a virtualized environment, such as within a virtual machine or container, onto the underlying host
Threat type	Spoofing, Tampering, Information disclosure, Elevation of Privilege
Impact type	Authenticity, Integrity, Confidentiality, Authorization
Affected Asset	Host OS, Hypervisor/Container Engine and VNFs/CNFs (Near RT RIC, O-CU, O-DU)

Threat ID	T-GEN-02
Threat title	Malicious access to exposed services using valid accounts
Threat description	Access to valid accounts to use the O-Cloud services is often a requirement, which could be obtained through credential pharming or by obtaining the credentials from users after compromising the network. Adversaries may obtain and abuse credentials of existing accounts as a means of gaining initial access, persistence, privilege escalation, or defense evasion. Compromised credentials may be used to bypass access controls placed on various resources on O-Cloud. Compromised credentials may also grant an adversary increased privilege to specific O-Cloud services or access to restricted areas of the O-Cloud network. Access may be also gained through an exposed service that doesn't require authentication. In containerized environments, this may include an exposed Docker API, Kubernetes API server, kubelet, or web application such as the Kubernetes dashboard.
Threat type	Spoofing, Tampering, Information disclosure, Elevation of Privilege
Impact type	Authenticity, Integrity, Confidentiality, Authorization
Affected Asset	Host OS, Hypervisor/Container Engine and VNFs/CNFs (Near RT RIC, O-CU, O-DU)

Threat ID	T-GEN-03
Threat title	Untrust binding between the different O-Cloud layers
Threat description	One major challenge in virtualized architectures and especially in O-Cloud is to prove that a particular VM/Container runs on top of a specific Hypervisor/Container Engine. More specifically, it is necessary to assure that a trusted VM/Container is executed on a particular trusted Hypervisor/Container Engine, whereas the Hypervisor/Container Engine's trust state relies on an attestation that considers the entire corresponding hard and software stack. More precisely, this includes all hardware chips, firmware, OS and Hypervisor/Container Engine components that are relevant for the Hypervisor/Container Engine's trust state determination. If it is not possible to establish a correlation between VM/Container and Hypervisor/Container Engine, an attacker is able to make use of a trusted VM/Container that runs on top of an untrusted

	Hypervisor/Container Engine and it would be impossible to detect any interference made by the malicious Hypervisor/Container Engine, e.g. intercepting communication, replacing strong or using weak cryptographic keys, etc. Similarly, trustworthiness in the service-layer might only be established if there is a mechanism to determine that only trusted VNFs/CNFs, w.r.t trusted VM/Container's, are running on specific trusted Hypervisors/Container Engines that are part of the service-provisioning-chain.
Threat type	Tampering, Information disclosure
Impact type	Integrity, Confidentiality
Affected Asset	Host OS, Hypervisor/Container Engine and VNFs/CNFs (Near RT RIC, O-CU, O-DU)

Threat ID	T-GEN-04
Threat title	Lack of Authentication & Authorization in interfaces between O-Cloud components
Threat description	O-Cloud deploys CNF applications as containers in a cluster of physical nodes which may be spanned across geographical locations. Owing to the Service Based Architecture of CNFs, this introduces several service endpoints communicating across each other over the network (container to container, container to cloud infrastructure component) and it is fairly difficult to distinguish between a service terminating an external interface and a service exposing only an internal interface. Multi-tenant deployments and deployments in public cloud also require the CNF applications to run alongside unknown entities. In such deployment scenarios, CNF service endpoints with no authentication/weak authentication expose risk of attack that can impact the availability of service and the CNF. Lack of proper authentication in interfaces exposed by CNF services, introduces threats of lateral movement where a compromised container/rogue container • can compromise the availability of internal service by bringing down the internal service and perform lateral movement of attack by exploiting the availability of other such services • can compromise the confidentiality of the internal service by extracting critical application data
Threat type	Information disclosure, Denial of Service
Impact type	Availability, Confidentiality
Affected Asset	Host OS, Hypervisor/Container Engine and VNFs/CNFs (Near RT RIC, O-CU, O-DU)

Threat ID	T-GEN-05
Threat title	Unsecured credentials and keys
Threat description	Adversaries may search compromised O-RAN NFs, VL, orchestration layer or hardware to find and obtain insecurely stored credentials. These credentials can be stored and/or misplaced in many locations on the O-cloud platform, including plaintext files (e.g. Bash History), operating system or application-specific repositories (e.g. Credentials in Registry), or other specialized files/artifacts (e.g. Private Keys) [i.22]. **Bash History**: Adversaries may search the bash command history on compromised systems for insecurely stored credentials. **Credentials in registry**: Adversaries may search the Registry on compromised systems for insecurely stored credentials. **Private Keys**: Adversaries may search for private key certificate files on compromised systems for insecurely stored credentials. Private cryptographic keys and certificates are used for authentication, encryption/decryption, and digital signatures; Common key and certificate file extensions include: .key, .pgp, .gpg, .ppk., .p12, .pem, .pfx, .cer, .p7b, .asc.

	Adversary tools have been discovered that search compromised systems for file extensions relating to cryptographic keys and certificates.
Threat type	Tampering, Information disclosure, and Elevation of privilege
Impact type	Integrity, Confidentiality, Authorization
Affected Asset	Private keys and credentials

Threat ID	T-GEN-06
Threat title	Sensitive application data cache exploitation
Threat description	Most of the applications use data that is sensitive in nature which needs to be secured. And it is common for these applications to cache such sensitive data, after retrieving the data from a secure storage. This caching occurs in various forms: within application memory, in persistent file systems, or in ephemeral file systems (For example, non-persistent container file system). For a VNF, the application can cache the sensitive data in its memory which is non-persistent (erased when the application ceases to exist) or in the persistent virtual machine file system. For a CNF, the application can store the sensitive data in its memory which is non-persistent (erased when the application/microservice ceases to exist) or in the non-persistent container file system, or in the persistent host file system, provided the application has the necessary privileges to access host file system. The sensitive data components that are cached by applications could be of different types which are used as authentication keys, session keys, passwords, tokens, etc. The storage of sensitive data in the application cache is used to improve performance of the applications and keeping the sensitive information readily available to the applications for faster initialization, re-initialization or recovery. An example of faster recovery/re-initialization is a scenario where a TLS client establishes a TLS session with a server and stores the client certificate and corresponding private key in the application cache. If the TLS session is terminated unexpectedly (For example, due to network error conditions), the TLS client uses the cached client certificates and private key for recovering / re-establishing the TLS session, instead of retrieving the information from a more secure, but slower, storage solution. While leveraging application cache is indispensable for significant performance gains, it also presents a notable security risk [i.28], [i.29]. The sensitive data stored in application cache would be a primary target from attackers/threat actors [i.30], who can exploit this information to penetrate deeper into O-RAN network functions. To counter this threat, a “Defense in depth” approach is essential. This approach encompasses multiple security layers designed to mitigate risks associated with application caches, focusing on strong encryption, strict access management and anomaly detection to protect sensitive data effectively.
Threat type	Tampering, Information disclosure
Impact type	Integrity, Confidentiality
Affected Asset	Certificates, private keys, credentials and other application specific sensitive data

7.4.2.2 Threats concerning VMs/Containers

Threat ID	T-VM-C-01
Threat title	Abuse of a privileged VM/Container
Threat description	It’s possible to run VMs/Containers with unintended configurations. Such misconfigurations can help the adversaries to compromise even strongest of VM/Container isolation measures. Such misconfigurations scenarios include: • A VMs/Containers can be configured to have more privileges than what is actually required (e.g. settings that give it unnecessary, and perhaps unplanned, privileges). For example, an attacker with access to such a container, can use it to gain higher privileges on host, perform un-authorized operations and get to anything that the host, or any of the containers running on that host, can reach. • A VMs/Containers have unintended read/write access to a directory on host filesystem. This could allow an attacker to perform unauthorized modifications to the contents, create symbolic links to any directories or files not directly exposed by the hostPath, install SSH keys, read secrets mounted to the host, and take other malicious actions.
Threat type	Spoofing, Tampering, Information disclosure, Denial of Service and Elevation of privilege
Impact type	Authenticity, Integrity, Confidentiality, Availability and Authorization
Affected Asset	Host OS, Hypervisor/Container Engine and VNFs/CNFs (Near RT RIC, O-CU, O-DU)

Threat ID	T-VM-C-02
Threat title	VM/Container escape attack
Threat description	VNF/CNF deployed on the same physical machine as tenants share the same host kernel and host OS resources. Lack of strong isolation between the VMs/Containers and the host allows for a potential risk of a rogue VM/Container escaping the VM/Container confinement and impacting other co-hosted VMs/Containers. In others, an attacker may deploy a new malicious VM/Container configured without network rules, user limitations, etc. to bypass existing defenses within O-Cloud infrastructure. Attacker deploys malicious VM/Container to escapes the host (Hypervisor/Container Engine/Host OS) and reaches the server’s hardware, then the malicious VM/Container can gain root access to the whole server where it resides. This gives the malicious VM/Container full control on all the VMs/Containers hosted on the same hacked server. This could allow an attacker to undermine the confidentiality, integrity and/or availability of VNFs/CNFs resources. Containers can be deployed by various means, such as via Docker's create and start APIs or via a web application such as the Kubernetes dashboard or Kubeflow. Adversaries may deploy containers based on retrieved or built malicious images or from benign images that download and execute malicious payloads at runtime. When a malicious VM/Container escapes isolation, it can gain full control over the underlying host and cause any of the below serious threats: • Attacker would gain the ability to mount attacks on the host or compromise the host functionalities • Compromise the confidentiality & integrity of co-hosted VMs/Containers and tenants • Launch DDOS attacks on co-hosted VMs/Containers and host services thereby degrading their performance • Introduce new vulnerabilities in host to be used for future attacks • Lack of network segmentation could potentially expose other VMs/Containers in the environment to attack. An example of this could be reconnaissance, exploitation and subsequent lateral movement to another host within the cluster.
Threat type	Spoofing, Tampering, Information disclosure, Denial of Service and Elevation of privilege
Impact type	Authenticity, Integrity, Confidentiality, Availability and Authorization
Affected Asset	Host OS, Hypervisor/Container Engine and VNFs/CNFs (Near RT RIC, O-CU, O-DU)

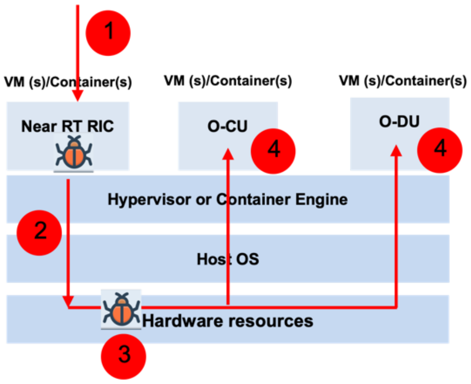


Figure 7-6 : Illustration of the VM/Container escape attack

Threat ID	T-VM-C-03
Threat title	VM/Container data theft
Threat description	The VNF/CNF remotely stores sensitive data (e.g. passwords, private keys, subscription data, logs) on the logical volume that the IMS/DMS allocates to the VNF/CNF. An attacker can retrieve/manipulate these data if they have been stored in an insecure way (e.g. clear text, unsalted hashes) or a malware is installed on the logical volume that the VIM allocates to the VNF/CNF. Container example: Adversaries may attempt to discover containers and other resources that are available locally within O-Cloud. Other resources may include images, deployments, pods, nodes, and other information such as the status of a cluster. These resources can be viewed within web applications such as the Kubernetes dashboard or can be queried via the Docker and Kubernetes APIs. In Docker, logs may leak information about the environment, such as the environment’s configuration, which services are available, and what cloud provider the victim may be utilizing. The discovery of these resources may inform an adversary’s next steps in the environment, such as how to perform lateral movement and which methods to utilize for execution.
Threat type	Tampering, Information disclosure
Impact type	Integrity, Confidentiality
Affected Asset	Images, environment’s configuration, and other information such as the status of a cluster

Threat ID	T-VM-C-04
Threat title	VM/Container migration attacks
Threat description	The attacks that exploit VM/Container migration can be divided into two subcategories based on the target plane: 1. **Control Plane Attacks**: These attacks target the module that is responsible for handling the migration process on a server which is called the migration module that is found in the host. By exploiting a bug in the migration module software, the attacker can hack the server and take full control over the migration module. This gives the attacker the ability to launch malicious activities including the following: a. **Migration Flooding**: The attacker moves all the VMs/Containers that are hosted on the hacked server to a victim server that does not have enough resource capacity to host all the moved VMs/Containers. This causes a denial of service for the VNFs/CNFs running in the VMs/Containers of the victim server as there will not be enough resources to satisfy the demands of all the hosted VMs/Containers leading into VM/Container performance degradation and VM/Container crashes. b. **False Resource Advertising**: The hacked server claims that it has a large resource slack (a large amount of free resources). This attracts other servers to off-load some of their VMs/Containers to the hacked server so that the O-Cloud workload gets distributed over the O-Cloud servers. After moving VMs/Containers from other servers to the hacked server, the attacker can exploit other vulnerabilities to break into the offloaded

	VMs/Containers as now these VMs/Containers are placed on a server that is under the control of the attacker. 2. **Data Plane Attacks**: These constitute the second type of VM/Container migration attacks and those attacks target the network links over which the VM/Container is moved from a server to another. Such data plane attacks include the MitM where an attacker sniffs the packets that are exchanged between the source and destination servers and reads the migrated memory pages. The attacker can monitor and/or modify the received packets while continuing to forward them to victim VM/Container resides so that the victim does not detect that any malicious activity is going on.
Threat type	Tampering, Information disclosure, Denial of Service
Impact type	Integrity, Confidentiality, Availability
Affected Asset	VNFs/CNFs (Near RT RIC, O-CU, O-DU)

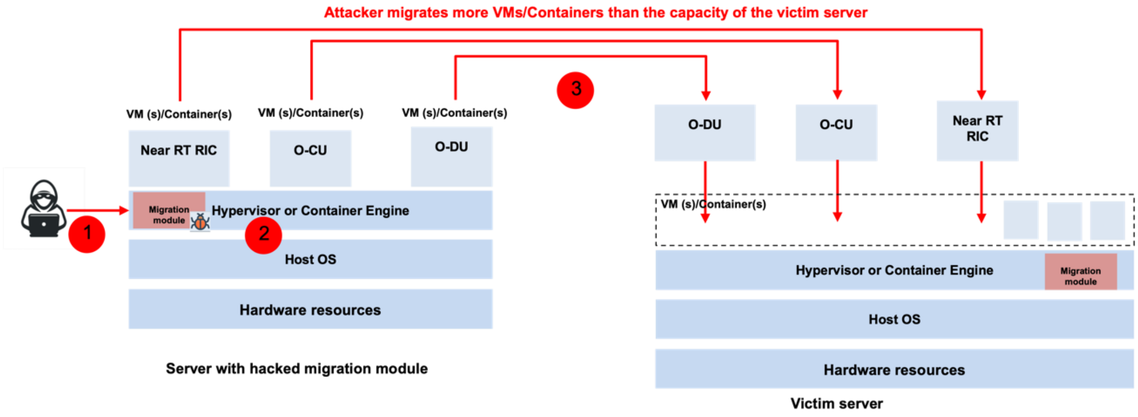


Figure 7-7 : Illustration of the migration flooding attack

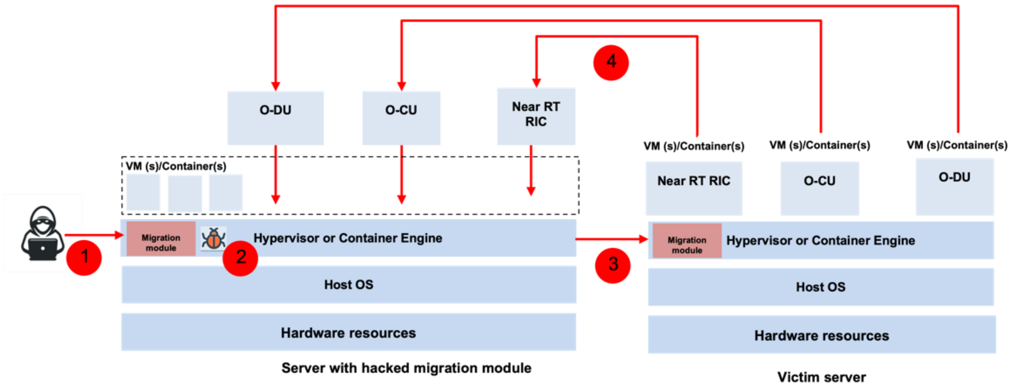


Figure 7-8 : Illustration of the false resource advertising attack

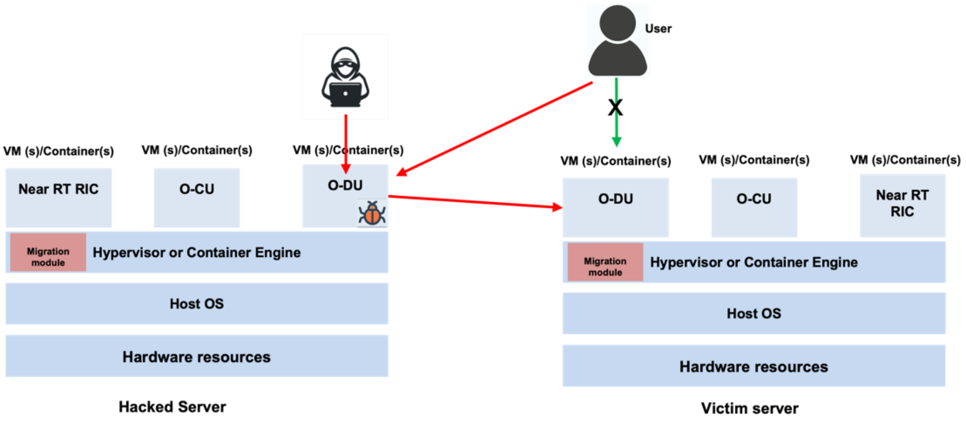


Figure 7-9 : Illustration of the migration MITM attack

Threat ID	T-VM-C-05
Threat title	Changing virtualization resource without authorization
Threat description	IMS/DMS which manage the Virtualization layer is responsible for assigning virtualized resource as requested. There are several ways to cause a DoS attack for the VNFs/CNFs: • If IMS/DMS are compromised or the O2 interface is not securely protected, an attacker who compromised the IMS/DMS or breached the O2 interface can change the virtualized resource used by a VNF/CNF by manipulating the allocation of virtualized resource. For example, when an instantiated VNF/CNF is running, adversaries having access to a compromised IMS/DMS or adversaries breaching the insecure O2 interface can misguide the Virtualization layer to reduce the resource of or delete a VM/Container on which a VNF/CNF is running. This can result in the reliability, availability or even illegal termination of a VNF/CNF and hence the denial of service. • Hardware resource configuration and state information (e.g. events) exchange is performed through O2 interface. If the IMS is compromised or the O2 interface is not securely protected, an attacker who compromised the IMS or breached the O2 interface can tamper the hardware configuration and state information so that the virtualized resource supported by the hardware layer becomes unreliable. For example, adversaries having access to a compromised IMS or adversaries breaching the insecure O2 interface can misguide the O-Cloud platform to detach a hardware accelerator from a VNF/CNF. • Adversaries having access to a compromised virtualization layer can change the virtualization resource used by the instantiated VNF/CNF without authorization, • A malicious VM/Container deployed for one instance of a VNF/CNF on a host can illegally occupy the resources of the instantiated VNF/CNF deployed on the same host, resulting in resource limitation of the instantiated VNF/CNF In this type of attacks, the extra allocation of resources for the malicious VM/Container comes at the expense of the other VMs/Containers that share the same server as the malicious VM/Container, where these victim VMs/Containers get allocated less share of resources than what they should actually obtain, which in turn degrades their performance.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	Host OS, Hypervisor/Container Engine and VNFs/CNFs (Near RT RIC, O-CU, O-DU)

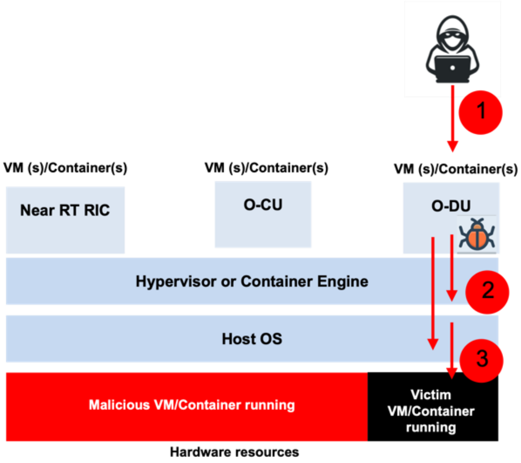


Figure 7-10 : Illustration of the Theft-of-Service/DoS Attack

Threat ID	T-VM-C-06
Threat title	Failed or incomplete VNF/CNF termination or releasing of resources
Threat description	A malicious VNF/CNF is instantiated in the O-Cloud infrastructure to access data not erased from a terminated VNF/CNF or any VNF/CNF that has released resources. Data could include application data, cryptographic keys... Abuse of resources allocation in the O-Cloud infrastructure to allocate to a malicious VNF/CNF the virtual resources released from a terminated VNF/CNF or from a VNF/CNF that has released resources after a move or a scaling process. Inclusion of concealed software in the O-Cloud infrastructure to prevent the deletion/erasure of data and states of the VNF/CNF that has been terminated.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Asset	Sensitive data (e.g. passwords, private keys, subscription data, logs), VNFs/CNFs (Near RT RIC, O-CU, O-DU) software and data

7.4.2.3 Threats concerning VM/Container images

Threat ID	T-IMG-01
Threat title	VM/Container images tampering
Threat description	An attacker can inject malicious code or tamper the information inside the unprotected image during on boarding. Then after the instantiation of the VNF/CNF, the tampered code can cause DoS, information stealing, frauds and so on. There are several attacks categories belonging to this threat. Such attacks include: • Build machine attacks: If an attacker can modify or influence the way a VM/Container image is built, they could insert malicious code that will subsequently get run in the production environment. • Supply chain attacks: Once the VM/Container image is built, it gets stored in a registry, and it gets retrieved or “pulled” from the registry at the point where it’s going to be run. An attacker who can replace an image or modify an image between build and deployment could run arbitrary code on your deployment.
Threat type	Tampering, Information disclosure

Impact type	Integrity, Confidentiality
Affected Asset	VM/Container images

Threat ID	T-IMG-02
Threat title	Insecure channels with images repository
Threat description	Images often contain sensitive components like an organization's proprietary software, and embedded secrets and administrator credentials. If connections to registries are performed over insecure channels, man-in-the-middle attacks could intercept network traffic and therefore the contents integrity and confidentiality of images may be compromised. There is also an increased risk of man-in-the-middle attacks that could intercept network traffic intended for registries and steal developer or administrator credentials within that traffic. Thus, could be used to provide fraudulent or outdated images to orchestrators, etc.
Threat type	Tampering, Information disclosure
Impact type	Integrity, Confidentiality
Affected Asset	VMs/Containers images

Threat ID	T-IMG-03
Threat title	Secrets disclosure in VM/Container images
Threat description	There are scenarios which benefit from including configuration and secrets, such as passwords or credentials in VNFs/CNFs images. For e.g. VMs/Containers require to be able to connect to other VMs/Containers within the deployment as well as with external entities. All these connections need to be authenticated and secured. One way of achieving this is to provide the requisite secrets or keys to the VMs/Containers which allow them to authenticate, be authenticated, secure the communication channel and signature. A common but in-secure means of providing secrets to the VMs/Containers is by packaging the secrets or the keys with the image itself. There is the risk that the same can be extracted, read or manipulated before the VM/Container is deployed and the secret used. With a long supply chain, VM/Container images are vulnerable to outside scrutiny. With VM/Container images containing secrets or keys, this becomes a serious threat vector. Adversaries can extract them by obtaining a copy of the image and they can be potentially shared with third parties for illicit gain. • Secrets embedded within a VM/Container image can be stolen. • Secrets embedded within a VM/Container image can be modified Compromised private keys and algorithms used for image signing due to poor key protection/management/design could undermine the security of image signing process.
Threat type	Spoofing, Tampering, Information disclosure
Impact type	Authenticity, Integrity, Confidentiality
Affected Asset	VM/Container images

Threat ID	T-IMG-04
Threat title	Build image on VL
Threat description	Adversaries may build a VM/Container image directly on the VL to bypass defenses that monitor for the retrieval of malicious images from a registry. Container example: A remote build request may be sent to the Docker API that includes a Dockerfile that pulls a vanilla base image, such as alpine, from a public or local registry and then builds a custom image upon it. An adversary may take advantage of that build API to build a custom image on the host that includes malware downloaded from their C2 server, and they then may deploy container using that custom image.

	If the base image is pulled from a public registry, defenses will likely not detect the image as malicious since it’s a vanilla image. If the base image already resides in a local registry, the pull may be considered even less suspicious since the image is already in the environment.
Threat type	Spoofing, Tampering, Information disclosure, Denial of Service and Elevation of privilege
Impact type	Authenticity, Integrity, Confidentiality, Availability and Authorization
Affected Asset	VM/Container images

7.4.2.4 Threats concerning the virtualization layer (Host OS-Hypervisor/Container engine)

Threat ID	T-VL-01
Threat title	VM/Container hyperjacking attack
Threat description	VMs/Containers run on host machines, and it is needed to ensure that those hosts (Hypervisor/Container Engine/Host OS- are not running vulnerable code (for example, old versions of components with known vulnerabilities). Hyperjacking is an attack in which adversaries gain control over the host of a server or install a malicious Hypervisor/Container Engine/Host OS and exploit that to run malicious applications on the VM/Container that run on top of the host. This would enable the attacker to control all the VMs/Containers running on the host. Hyperjacking involves installing a malicious, fake the Hypervisor/Container Engine/Host OS that can manage the entire server system. If the attacker gains access to the Hypervisor/Container Engine/Host OS, everything that is connected to that server can be manipulated. The Hypervisor/Container Engine/Host OS represents a single point of failure when it comes to the security and protection of sensitive information. For a hyperjacking attack to succeed, an attacker would have to take control of the Hypervisor/Container Engine/Host OS by the following methods: • Injecting a rogue Hypervisor/Container Engine or Host OS beneath the original hypervisor or on top of an existing Hypervisor/Container Engine/Host OS • Directly obtaining control of the original Hypervisor/Container Engine or Host OS • Running a rogue hypervisor on top of an existing hypervisor
Threat type	Spoofing, Tampering, Information disclosure, Denial of Service and Elevation of privilege
Impact type	Authenticity, Integrity, Confidentiality, Availability and Authorization
Affected Asset	Host OS, Hypervisor/Container Engine and VNFs/CNFs (Near RT RIC, O-CU, O-DU)

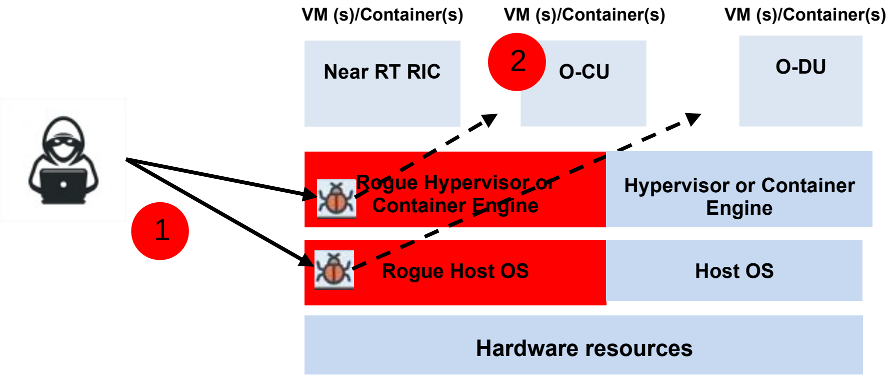


Figure 7-11 : Illustration of the VM/Container hyperjacking attack

Threat ID	T-VL-02
Threat title	Boot tampering
Threat description	The bootloader of the virtualization layer (Host OS, Hypervisor, Container Engine) for VNF/CNF may be maliciously tampered by an attacker, e.g. the attacker compromises hypervisor or host OS to tamper the bootloader of guest OS (in case of VM) or Container. In a O-Cloud environment any failure during the boot sequence can result in a number of situations that need to be handled by the NFO/FOCOM: • failure of the physical machine to start at all • physical machine entering a safe-mode • physical machine continuing boot regardless of the integrity measurements
Threat type	Tampering
Impact type	Integrity
Affected Asset	Host OS, Hypervisor/Container Engine and VNFs/CNFs (Near RT RIC, O-CU, O-DU)

Threat ID	T-VL-03
Threat title	Attack internal network services
Threat description	In addition to attacking the network between containers, adversaries can also attack supporting services such as DNS service, which is only reachable from within the cluster network. The highly distributed nature of containers requires shared services for example for coordination and service discovery. An attacker can target these services to degrade services. For example, a denial-of-service against the service discovery infrastructure could prevent O-Cloud to react to changing resource requirements properly. Thus, O-Cloud may no longer be able to scale appropriately to sudden demand spikes [i.16].
Threat type	Denial of Service
Impact type	Availability
Affected Asset	Software components at runtime and their associated data

7.4.2.5 Threats concerning O-Cloud interfaces

7.4.2.5.1 O2 interface

Two main interfaces are defined in O-RAN WG6 specification and identified as critical assets of O-Cloud, i.e. interfaces O2 between O-Cloud and SMO. The threats on these interfaces are as follows.

Threat ID	T-O2-01
Threat title	MitM attacks on O2 interface between O-Cloud and SMO
Threat description	If the interface O2 interface is not protected, an attacker can attack all the requests/responses sent between the O-Cloud and the SMO (FOCOM and NFO). For example, the attacker can tamper/alter/disclose requests and services (See 'Critical services' in 2.3) sent over O2 between O-Cloud and SMO, hence the virtualized resource or relevant status information is not as requested. This affects the normal operation of the O-Cloud, and even causes DoS attacks, information leakage.

	An attacker can tamper the specific assignment of virtualized resources to cause resource assignment errors or an attacker can intercept virtualized resources state information leading to information disclosure. An attacker can compromise IMS to tamper with the hardware state information (e.g. deleting hardware alarm information) to affect the hardware's operation or to result in information disclosure (e.g. an attacker can get the hardware configuration from the compromised IMS. Then, the attacker can attack the hardware according to the configuration such as CPU type, memory size etc.). An attacker can also tamper or intercept the hardware resource configuration and state information if the configuration and state information are transmitted using an insecure protocol on the O2 interface.
Threat type	Tampering, Information disclosure, Denial of Service
Impact type	Integrity, Confidentiality, Availability
Affected Asset	Telemetry, provisioning, logs, software management, performance information

7.4.2.5.2 O-Cloud API

Threat ID	T-OCAPI-01
Threat title	MitM attacks on O-Cloud interface between VNFs/CNFs and the virtualization layer
Threat description	An attacker can attack an instantiated VNF/CNF through a compromised virtualization layer. For example, cryptographic keys or other security critical data of an instantiated VNF/CNF could be stolen by an attacker with access to the virtualization layer, or the virtualized resource provided by the Virtualization layer to the instantiated VNF/CNF can be manipulated or the bootloader of Guest OS (in case of VM) or Container of an instantiated VNF/CNF can be tampered by an attacker via a compromised virtualization layer.
Threat type	Tampering, Information disclosure, Denial of Service
Impact type	Integrity, Confidentiality, Availability
Affected Asset	Host OS, Hypervisor/Container Engine and VNFs/CNFs (Near RT RIC, O-CU, O-DU)

7.4.2.6 Threats concerning hardware resources

Threat ID	T-HW-01
Threat title	Cross VM/Container side channel attacks
Threat description	In a typical cross-VM/Container side channel attack scenario, an adversary places a malicious VM/Container co-resident to the target VM/Container so that they share the same hardware resources. Then, the attacker extracts useful information such as cryptographic keys from the target VM/Container to use them for traffic eavesdropping and man-in-the-middle attacks. Through the side channel attack, an attacker sharing the same cache as the victim can monitor the cache access behavior of the victim. For example, the attacker is able to monitor cache timing information by measuring the execution of different operations on the victim's VM/Container. Generally, the attacker exploits timings in the shared high-level cache memory. However, power consumption or electromagnetic leaks can also be used as a vector to launch side channel attacks. In the virtual environment, prior to the cross-VM/Container side channel attack, the attacker needs to identify the target VM/Container's location and place a malicious VM/Container co-resident with the target. Later, that attacker may use the maliciously placed VM/Container to extract information from the target VM/Container with the side channel attack. Hardware vulnerabilities in processors can also have a large impact on O-Cloud security. Flaws in chip design can result in the compromise of tenant information in the cloud through side-channel attacks [i.24].

Threat type	Tampering, Information disclosure, Denial of Service
Impact type	Integrity, Confidentiality, Availability
Affected Asset	Sensitive data (e.g. passwords, private keys, subscription data, logs), VNFs/CNFs (Near RT RIC, O-CU, O-DU) related data

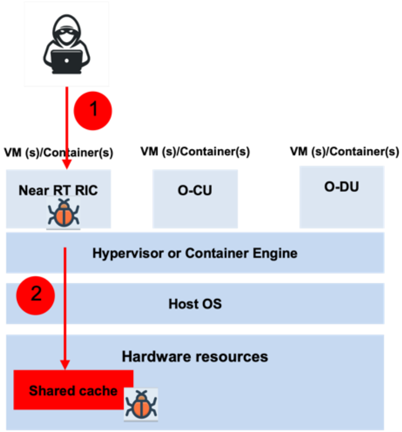


Figure 7-12 : Illustration of a cross VM/Container side channel attack

Threat ID	T-HW-02
Threat title	MitM attacks on the interface between virtualization layer and hardware
Threat description	An attacker can utilize the vulnerabilities of hardware (e.g. Meltdown and Specter of CPU in host) to attack virtualization layer and/or VNFs/CNFs through this interface, resulting in tampering, information disclosure or DoS.
Threat type	Tampering, Information disclosure, Denial of Service
Impact type	Integrity, Confidentiality, Availability
Affected Asset	All assets

7.4.2.7 Threats concerning O-Cloud management (SMO, NFO, FOCOM)

Threat ID	T-ADMIN-01
Threat title	Denial of service against NFO/FOCOM
Threat description	A denial-of-service attack against the NFO/FOCOM can interfere with the ability of operators to control and maintain their deployments. This can lead to the inability to react to changing resource requirements. In addition, the NFO/FOCOM is the external API to interact with the O-Cloud platform. Thus, other services may become inaccessible as well. For example, operators may be unable to retrieve logs, telemetry data. An attacker could use this opportunity to hide additional attacks on VM/Container instances. In addition, an attacker on the NFO/FOCOM could prevents the O-Cloud software update (VNFs/CNFs, VL) to exploit a known security flaw in the O-Cloud software.
Threat type	Denial of Service
Impact type	Availability

Affected Asset	VM/Container images, VNF/CNF, host OS, Hypervisor/Container Engine software

Threat ID	T-ADMIN-02
Threat title	Abuse a O-Cloud administration service
Threat description	Usually, the SMO including NFO/FOCOM is exposed to the tenant in a web front-end or REST API. In case these interfaces contain software vulnerabilities or implement authentication and authorization insufficiently, an adversary would be able to gain access to the VM/Container management and pose as a tenant. It is also possible that an adversary gains the ability to submit requests without prior authentication and authorization. The NFO/FOCOM interfaces encompasses a great deal of privileges because anyone gaining sufficient access is able to deploy new instances and disrupt existing O-Cloud services. It may also be possible for an adversary to submit compromised VM/Container images that unsuspecting tenants then use to initiate O-Cloud services. Moreover, adversaries can use the same access to extract business data, configuration data, user data and possibly credentials. For example, they may be able to create backups of VM/Container instances or they can export VM/Container images. The impact of compromised credentials is exacerbated by the fact that weak and insufficient safeguarding of credentials is recognized as one of the top threats in cloud computing [38]. Container example: Adversaries may abuse a container administration service to execute commands within a container. A container administration service such as the Docker daemon, the Kubernetes API server, or the kubelet may allow remote management of containers within an environment. Container example: In Docker, adversaries may specify an entrypoint during container deployment that executes a script or command, or they may use a command such as *docker exec* to execute a command within a running container. In Kubernetes, if an adversary has sufficient permissions, they may gain remote execution in a container in the cluster via interaction with the Kubernetes API server, the kubelet, or by running a command such as *kubectl exec*.
Threat type	Tampering, Information disclosure, Denial of Service and Elevation of privilege
Impact type	Integrity, Confidentiality, Availability, Authorization
Affected Asset	VNF/CNF, host OS, Hypervisor/Container Engine software and related information

7.4.2.8 Threats concerning Acceleration Abstraction Layer (AAL)

Threat ID	T-AAL-01
Threat title	Attacker exploits insecure API to gain access to hardware accelerator resources
Threat description	Insecure AAL API allows an attacker to tamper the requests/responses sent between the AAL components, the O-Cloud platform and O-RAN APPs/VNFs/CNFs. For example, the attacker can tamper requests and services sent over AALI-C-Mgnt between IMS and the hardware accelerator manager, hence capability of the hardware accelerator device, fault information, logs, performance information and others are not as requested. This affects the normal operation of the O-Cloud, and even causes tampering. An attacker can tamper application (e.g. O-DU) requests sent over AALI-C-App to an AAL implementation for allocation of buffers. This affects the normal operation of the applications, and even causes tampering. An attacker can tamper application (e.g. O-DU) requests sent over AALI-P for configuring and managing the AAL-LPU(s). This affects the normal operation of the applications, and even causes tampering.
Threat type	Tampering
Impact type	Integrity

Affected Asset	Data in transit AALI-C-App & AALI-P interfaces, Data in transit vendor specific interface, AAL profiles, AAL-LPUs, Stored AAL data, AAL software, Device firmware

Threat ID	T-AAL-02
Threat title	Internal Overload DoS attack targeting AAL services
Threat description	Overload situation could appear in the case of DoS attack or increased traffic on AAL interfaces. Inability to mitigate traffic volumetric attacks on AAL affects availability of AAL data and services. DoS attacks on the AALI-C interface affect the different services provided by the hardware accelerator manager and the transport abstraction framework. DoS attacks on the AALI-P interface affect the configuration and management of AAL-LPU (Acceleration Abstraction Layer Logical Processing Unit) by an application (e.g. O-DU) in addition to acceleration functionality.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	AAL profiles, AAL-LPUs, Stored AAL data, AAL software, Device firmware

Threat ID	T-AAL-03
Threat title	Fail to clear resources
Threat description	Fail to clear accelerator resources after a process termination. This causes an information leakage and incorrect results for computations. Further, failure to release accelerator resources may prevent other processes from running. This threat is relevant to accelerator resources either inside the hardware accelerator device (internal memories, registers, cache) or in the O-Cloud memories used by accelerators.
Threat type	Information disclosure, Denial of service
Impact type	Confidentiality, Availability
Affected Asset	AAL profiles, AAL-LPUs, Stored AAL data, AAL software, Device firmware

Threat ID	T-AAL-04
Threat title	HAM compromise
Threat description	A malicious actor can gain access to HAM to gain unauthorized access and control of the hardware accelerator device. This can result in the disruption of services (DoS) and tampering of accelerator components, such as firmware, drivers which can cause the accelerator to behave abnormally or crash altogether.
Threat type	Tampering, Denial of service
Impact type	Integrity, Availability
Affected Asset	Data in transit AALI-C-App & AALI-P interfaces, Data in transit vendor specific interface, AAL profiles, AAL-LPUs, Stored AAL data, AAL software, Device firmware

Threat ID	T-AAL-05
Threat title	Malicious memory accesses
Threat description	AAL that allows one process running on the hardware accelerator device to access memory owned by another process running on the hardware accelerator device can leak information (impact on confidentiality). Similarly, AAL allowing concurrently executing processes to write to one another's memory may have correctness errors (impact on integrity). If multiple processes are running concurrently and one is allowed to dominate accelerator resources, the other may suffer from degraded performance. For example, if one process can evict all cache entries belonging to the other, the victim will suffer performance penalties (impact on availability).
Threat type	Information disclosure, Tampering, Denial of service
Impact type	Confidentiality, Integrity, Availability
Affected Asset	AAL profiles, AAL-LPUs, Stored AAL data, AAL software, Device firmware

Threat ID	T-AAL-06
Threat title	Firmware attacks
Threat description	Hardware accelerators often have their own firmware, which can be targeted by attackers. This could include modifying the firmware to introduce vulnerabilities (e.g., malware) or installing a malicious firmware to extract/modify sensitive information or execute unauthorized actions (e.g., control the device remotely).
Threat type	Information disclosure, Tampering
Impact type	Confidentiality, Integrity
Affected Asset	AAL profiles, AAL-LPUs, Stored AAL data, AAL software, Device firmware

7.4.2.9 Threats concerning O-Cloud instance ID

Threat ID	T-O-CLOUD-ID-01
Threat title	ID reuse in O-Cloud's object lifecycle
Threat description	In O-Cloud, objects such as Containers, Pods, Nodes, and Services are identified by their IDs within a given compute pool (e.g., cluster in Kubernetes). When an object is deleted, its ID becomes available for reuse. This means that a new object can be created with the same ID as a previously deleted object. If an object gets deleted but all its associated data isn't properly isolated or cleaned, the ID, if reused, could lead to unintended data associations or leaks. Potential consequences: • Data Residue: A new object, reusing an ID, may inherit residual data or configurations from its predecessor, leading to potential misconfigurations and incorrect data associations. This can result in sensitive data exposure. • Data Overwrite: Automated processes unaware of the deletion and subsequent recreation might mistakenly write or read data from the new object, thinking it's the old one.

	• Monitoring Ambiguities: Monitoring tools might combine metrics from the old and new objects, resulting in confusing data. • Operational Disruptions: The new object might operate based on the residual configurations of the old object, potentially leading to system inefficiencies or failures.
Threat type	Tampering, Information disclosure
Impact type	Integrity, Confidentiality
Affected Asset	O-Cloud Provisioning information, Software components at runtime and their associated data, Security event logs

Threat ID	T-O-CLOUD-ID-02
Threat title	Node redundancy in O-Cloud deployments
Threat description	Nodes in O-Cloud often represent physical or virtual machines. If a machine fails and is replaced without deleting its corresponding Node object, and the new machine is given the same ID or the hostname, O-Cloud might treat the new machine as if it were the original. Potential consequences: • Resource Mismatch: The new host might have different resources (CPU, memory, storage) than the old one, leading to scheduling issues or resource constraints. • Stale Data: The new node might inherit data or configurations from the old node, leading to potential security or operational risks. • Network Issues: Network configurations or IP address assignments might be inconsistent or conflicting.
Threat type	Spoofing, Tampering, Information disclosure, Denial of Service
Impact type	Authenticity, Integrity, Confidentiality, Availability
Affected Asset	O-Cloud Provisioning information, Software components at runtime and their associated data, Security event logs

Threat ID	T-O-CLOUD-ID-03
Threat title	O-Cloud ID mismanagement
Threat description	IDs are crucial for uniquely identifying objects within the O-Cloud. Mismanagement occurs when these IDs are not properly assigned, tracked, or validated, leading to potential overlaps or inconsistencies. Potential consequences: • ID Collision: Due to system glitches or bugs, two distinct objects could inadvertently be allocated the same ID. Such an occurrence is termed an ID collision. This can result in operations meant for one object inadvertently affecting the other. • Resource Overwrite: If two objects share the same ID, updates or modifications intended for one might overwrite the data of the other, leading to data inconsistencies or loss.

	• ID-Based Permissions: Many security protocols and access controls in O-Cloud can be tied to object IDs. If an attacker can predict, guess, or manipulate the ID generation process, they might gain unauthorized access to resources. • Log Merging: Monitoring tools and logging systems use IDs to track events and operations related to specific objects. If two objects share an ID, their logs might get merged, making it challenging to trace events back to their source. • RBAC Anomalies: Role-Based Access Control (RBAC) regulations attached to specific object IDs could unintentionally approve or restrict access to the novel object due to misidentification.
Threat type	Spoofing, Tampering, Information Disclosure, Repudiation, Elevation of Privilege, Denial of Service
Impact type	Authenticity, Integrity, Non-repudiability, Confidentiality, Availability, Authorization
Affected Asset	O-Cloud Provisioning information, Software components at runtime and their associated data, Security event logs

7.4.2.10 Threats concerning time synchronization

Threat ID	T-TS-01
Threat title	Time synchronization disruption in O-Cloud
Threat description	Disruption or manipulation of the time synchronization process within the O-Cloud can lead to severe security and operational issues. An attacker may target the time synchronization mechanisms to alter time settings across O-Cloud nodes, leading to: • **Impersonation of time synchronization server:** An attacker may impersonate a legitimate time synchronization server, tricking nodes into accepting incorrect time data. This can cause nodes to synchronize with a malicious time source, leading to widespread time discrepancies. • **Data integrity loss:** Inconsistent timestamps can corrupt logs and audit trails within the O-Cloud, making it difficult to trace and analyze security events accurately. • **Operational disruption:** Time-sensitive operations within the O-Cloud may be disrupted, leading to data loss and service outages. • **Authentication and authorization bypass:** Many security mechanisms in the O-Cloud rely on accurate time. Disrupted time synchronization can undermine token expiration, certificate validity, and other time-based access controls, potentially allowing unauthorized access to O-Cloud resources. **EXAMPLE:** Time-sensitive operations such as automated backups, scheduled tasks (e.g., resource scaling, patch management), and certificate renewals. NOTE: This threat is linked to the operation of CronJob resources as described in clause 4.3.1.1.6 of the O-RAN specification [i.34]. Any disruption or manipulation of the time synchronization process can severely impact scheduled operations managed by CronJobs within the O-Cloud.
Threat type	Spoofing, Tampering, Denial of Service and Elevation of privilege
Vulnerabilities	Insecure time synchronization protocols Insufficient authentication mechanisms and access controls for the time synchronization settings

	Misconfiguration of time synchronization settings on O-Cloud nodes
Impact type	Authenticity, Integrity, Availability and Authorization
Affected Asset	Log and audit trails O-Cloud time synchronization settings

7.4.3 Threats to open source code

Open source introduces the following threats:

Threat ID	**T-OPENSRC-01**
Threat title	Developers use SW components with known vulnerabilities and untrusted libraries that can be exploited by an attacker through a backdoor attack
Threat description	The O-RAN Software Community is a Linux Foundation project, supported and funded by O-RAN to lead the implementation of the O-RAN specifications in Open Source. Industry has recognized that Open Source code introduces security risks. Open Source vulnerabilities are publicly available on the National Vulnerability Database (NVD). While this is intended for developers to disclose vulnerabilities, it is also used by hackers to exploit those vulnerabilities. Vulnerabilities frequently propagate as developers re-use free open source code enabling backdoors to attacks. There have been notable vulnerabilities from downloading open source libraries and dependencies, as well as supply chain risks when downloading Open Source code from untrusted repositories. Some O-RAN vendors and operators may not have accurate inventories of open-source software dependencies used by their different applications, or a process to receive and manage notifications concerning discovered vulnerabilities or available patches from the community supporting the open-source. Some O-RAN vendors may not have a lack of consistent Supply Chain traceability and security, and a lack of coding best practices conflicts with Security-by-Design principles. Developers may use modules with known vulnerabilities and untrusted libraries that can be exploited by an attacker through a backdoor attack. Attackers can exploit a vulnerability on the open source code and infects a hypervisor, operating system, VM or container with a malware.

Threat ID	**T-OPENSRC-02**
Threat title	A trusted developer intentionally inserts a backdoor into an open source code O-RAN component
Threat description	A trusted developer intentionally inserts a backdoor by injecting a few lines of malicious code into an open source code component to be used within the O-RAN system. A software project team picks up and uses the infected open source code and the development team's tools for vetting and testing the component do not detect the malicious code. Unknowingly they have introduced a vulnerability into their O-RAN software code. The vulnerability has gone undetected and the threat actor is able to compromise the software through the inserted vulnerability. The resulting effect on the O-RAN system can take a variety of forms, from being annoying to impacting system performance (DoS) to the loss of sensitive data.

7.4.4 Physical Threats

Threat ID	**T-PHYS-01**
Threat title	An intruder into a site gains physical access to O-RAN components to cause damage or access sensitive data

Threat description	Physical attacks on the O-RAN deployment that stores or processes keys, user plane data, control plane data and management data in cleartext. O-RAN physical components might be vulnerable if: • Improper physical security protection of data centers, PNFs, operation areas, etc. • Improper protection to power outages (power supply) • Improper protection against environmental disasters • Improper maintenance and monitoring of hardware parameters • Hardware backdoor Attackers try to modify the O-RAN components settings and configurations via local access. Physical access to O-RAN components thanks to unsecured management ports and consoles (such as JTAG, serial consoles or dedicated management ports), relaxed administrator credentials management, unsecured HW and SW configuration/management could allow an attacker to inject malwares and/or manipulate existing software, steal unprotected private keys, certificates, hash values, disable security features, create a performance issue by manipulation of parameters with the purpose of eavesdropping or wiretapping on various CUS & M planes, reaching the network beyond the O-RAN or with the purpose of gaining access to the O-RAN components, denial of service, intrusion and replay attacks or other type of breaches.

Threat ID	**T-PHYS-02**
Threat title	An intruder into the exchange over the Fronthaul cable network attempts to gain electronic access to cause damage or access sensitive data
Threat description	O-RU and O-DU may be located at different premises and connected through a cable network to support the fronthaul link. Attackers can gain access to, or control over, data traffic through breaching terminals in the cable landing sites (O-RU or O-DU).

7.4.5 Threats against 5G radio networks

Threats against 5G radio networks include:

Threat ID	**T-RADIO-01**
Threat title	Disruption through radio Jamming, Sniffing and Spoofing
Threat description	Like for any wireless technology, disruption through radio jamming is possible by analyzing the physical downlink and uplink control channels and signals. 5G radio network is vulnerable to: • Jamming Vulnerability of Reference Signals • Jamming Vulnerability of Synchronization Signal • Jamming Vulnerability of the PBCH • Sniffing and Spoofing Vulnerability of the PBCH • Jamming Vulnerability of PDCCH • Jamming Vulnerability of Physical Uplink Control Channel • Jamming Vulnerability of Physical Random-Access Channel **NOTE 1**: The O-RAN OEMs need to develop new intelligence that can proactively alert the operator when this attack is initiated so that the operator can take appropriate actions to mitigate. **NOTE 2**: In the scenario of RF spoofing, the UE needs to be able to validate the legitimacy of the O-RU as being one owned and operated by the operator. 3GPP has proposed in a study to use Digital Signatures to mitigate this threat but there has been no agreement on this to date. The O-RAN OEMs need to develop new

	intelligence that can proactively alert the operator when this attack is initiated so that the operator can take appropriate actions to mitigate.

Threat ID	**T-RADIO-02**
Threat title	DoS attacks on cognitive radio networks [i.17]
Threat description	Cognitive radio (CR) technology, which is designed to enhance spectrum utilization, depends on the success of opportunistic access, where unlicensed secondary users (SUs) exploit spectrum void unoccupied by primary users (PUs) for transmissions. To realize DoS attacks, malicious users (MUs) target the critical functionalities for CR ecosystems, including spectrum sensing, agile radio, and light-handed regulation since once these functionalities fail, SUs are not able to communicate effectively. For example, MUs can directly jam the victim by injecting interference or deceive SUs into believing that there is a PU by emulating the signal characteristics of the PU, thereby evacuating the occupied spectrum. Moreover, the liability rule is vulnerable to the selfish and greedy users aiming to maximize their own private benefits. Since complying with the rule results in less transmission opportunities, such SUs may not want to invest efforts to follow the rule and thus will transmit simultaneously with Pus.

7.4.6 Threats against AI/ML system

7.4.6.1 Introduction

This section provides the relevant threats against the AI/ML system implemented in O-RAN architecture.

7.4.6.2 Input Manipulation Attacks

Threat ID	T-AIML-IM-1
Threat title	Training Data Control
Threat description	An adversary takes control of a subset of the training data by inserting or modifying training samples.
Threat type	Tampering
Vulnerabilities	Vulnerabilities in data sources, vulnerabilities in training database
Impact type	Integrity
Affected Assets	Training or test data: data sets collected externally or internally from the Near-RT RIC, O-CU and O-DU and passed to the ML training hosts in a ML system. [ASSET-D-25] The trained ML model [ASSET-D-26], The ML prediction results built into the model [ASSET-D-27], The behaviour of the ML system [ASSET-D-28].

Threat ID	T-AIML-IM-2
Threat title	Testing Data Control
Threat description	An adversary adds perturbations to testing samples at model deployment time to generate adversarial examples or in backdoor poisoning attacks
Threat type	Tampering
Vulnerabilities	Vulnerabilities in data sources, vulnerabilities in training database
Impact type	Integrity
Affected Assets	Training or test data: data sets collected externalyexternally or internally from the Near-RT RIC, O-CU and O-DU and passed to the ML training hosts in a ML system. [ASSET-D-25] The trained ML model [ASSET-D-26], The ML prediction results built into the model [ASSET-D-27], The behaviour of the ML system [ASSET-D-28].

Threat ID	T-AIML-IM-3
Threat title	Label Manipulation
Threat description	An adversary may intentionally mis-assign labels to training data.
Threat type	Tampering
Vulnerabilities	Vulnerabilities in data sources, vulnerabilities in training database
Impact type	Integrity

Affected Assets	Training or test data: data sets collected externally or internally from the Near-RT RIC, O-CU and O-DU and passed to the ML training hosts in a ML system. [ASSET-D-25] The trained ML model [ASSET-D-26], The ML prediction results built into the model [ASSET-D-27], The behaviour of the ML system [ASSET-D-28].

Threat ID	T-AIML-IM-4
Threat title	AI/ML Query Exploitation
Threat description	An adversary may submit queries to the model and receive predictions (either labels or model confidences) and confidential data.
Threat type	Information Disclosure
Vulnerabilities	Vulnerabilities in data sources, vulnerabilities in training database, vulnerabilities in AI/ML APIs
Impact type	Confidentiality
Affected Assets	The trained ML model [ASSET-D-26], The ML prediction results built into the model [ASSET-D-27], The behaviour of the ML system [ASSET-D-28].

7.4.6.3 Data poisoning attacks

Threat ID	T-AIML-DP-01
Threat title	Black-box Data Poisoning
Threat description	An attacker in possession of a compromised data-source can inject poisoned data which can be consumed by AI/ML for training. For such an attack, the attacker does not need to know any details of the AI/ML algorithm, or the parameters being used. Knowledge of inputs and outputs of AI/ML is sufficient to launch such attacks.
Threat type	Tampering
Impact type	Integrity
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps), Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-DP-02
Threat title	Grey-box Data Poisoning
Threat description	An attacker being able to query the database which stores the training data, and/or streaming data used for online ML models, and/or AI/ML models may be able to get more details about the AI/ML algorithms being used and parameters configured if any. This can help the attacker to launch an attack which can poison the training data in a manner that would affect that particular algorithm or its parameters the most.
Threat type	Tampering
Impact type	Integrity
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps), Near-RT-RIC SW, Non-RT-RIC SW, O1 interface for streaming data, A1 interface, E2 interface for streaming data

Threat ID	T-AIML-DP-03
Threat title	White-box Data Poisoning
Threat description	An attacker having full knowledge of the AI/ML algorithm being used, the configurable parameters like thresholds, hyper-parameters, etc. can launch a data poisoning attack in a manner which can modify the behaviour of AI/ML algorithm with slow poisoning and can make it very challenging to detect such attacks.
Threat type	Tampering
Impact type	Integrity
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps), Near-RT-RIC SW, Non-RT-RIC SW, O1 interface for streaming data, A1 interface, E2 interface for streaming data

7.4.6.4 Membership Inference Attacks

Threat ID	T-AIML-MEI-01
Threat title	Information Access – Membership Inference
Threat description	An attacker possesses different levels of information on the model architecture, training parameters, training data, and relation between the output to the input. Based on the level of information access, the membership information attack (MIA) can be Black-box MIA, or Gray-box MIA or White-box MIA.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Assets	The trained ML model which includes the configured hyperparameters, inference algorithm, and learned parameters. Near-RT RIC software, Non-RT RIC software.

Threat ID	T-AIML-MEI-02
Threat title	Inference Technique – Membership Inference
Threat description	An attacker by applying different analysis methods tries to infer input to output relation. Some of the attack types are Decision threshold analysis, Gradient-based analysis, Distance-based analysis. In Decision threshold analysis, the subtle changes in input's relation to the model's output confidence score is observed. In Gradient-based analysis techniques such as back propagation is used to analyse input to output variation. In Distance-based analysis the distance between model's output for different inputs in multi-dimensional space is used.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Assets	The trained ML model which includes the configured hyperparameters, inference algorithm, and learned parameters. Near-RT RIC software, Non-RT RIC software.

Threat ID	T-AIML-MEI-03
Threat title	Target based – Membership Inference
Threat description	In a target-based membership attack the attacker would like to understand whether specific individual data or data of a group of individuals are involved in the training set. The attack types are known as Individual membership inference attack, Group membership inference attack, respectively. In Individual membership inference attack, the attacker tries to determine if a specific user information is included in the training data. In Group membership inference attack, the attacker tries to determine behaviour of individuals and group them based on available data.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Assets	The trained ML model which includes the configured hyperparameters, inference algorithm, and learned parameters. Near-RT RIC software, Non-RT RIC software.

7.4.6.5 Model Stealing

Threat ID	T-AIML-ME-01
Threat title	Intellectual Property Theft
Threat description	Stolen models can lead to the theft of intellectual property, allowing attackers to replicate the model's functionality without incurring the associated development costs. If a competitor gains unauthorized access to a trained model, it can undermine the original developer's competitive advantage by using the model for similar or competing purposes.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-ME-02
Threat title	Data Privacy Violations
Threat description	The stolen model may contain sensitive information embedded within its learned parameters. This can result in privacy breaches, especially if the model was trained on sensitive or personal data.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-ME-03
Threat title	Adversarial Attacks with Stolen Models
Threat description	Attackers may exploit the extracted model to craft adversarial examples (to mount an evasion attack) or launch targeted attacks against the system that initially deployed the model, using obtained knowledge about possible vulnerabilities.
Threat type	Tampering
Impact type	Integrity
Affected Assets	Database holding data from xApp applications and E2 Node [ASSET-D-10], Training or test data sets collected externally or internally [ASSET-D-25], Trained ML model [ASSET-D-26], Near-RT-RIC SW [ASSET-C-02], Non-RT-RIC SW [ASSET-C-11]

7.4.6.6 Model Inversion Threats

Threat ID	T-AIML-MOI-01
Threat title	Black-box Model Inversion
Threat description	An attacker has access to the model’s input-output pairs allowing them to input data and receive predictions. The attacker generates inputs, analyzes the model's outputs, and iteratively refines the inputs based on the obtained information. This process continues until the attacker is able to approximate the original training data. The attacker has no knowledge of the model's architecture, parameters, or the training data.
Threat type	Information Disclosure
Vulnerabilities	Model is overfitted, model may have memorized specific training examples, model API not properly protected
Impact type	Disclosure of sensitive/proprietary data
Affected Assets	Database holding data from xApp applications and E2 Node [ASSET-D-10], Training or test data sets collected externally or internally [ASSET-D-25], Trained ML model [ASSET-D-26] The ML prediction results built into the model [ASSET-D-27] The behavior of the ML system including tasks for data collection, data wrangling, pipeline management, model retraining, and model deployment. [ASSET-D-28]

Threat ID	T-AIML-MOI-02
Threat title	White-box Model Inversion
Threat description	An attacker has access to the AI model, including its architecture, parameters (such as weights and biases), and possibly partial knowledge of the training data. This information allows the attacker to exploit the inner workings of the model more effectively and reconstruct the original training data with higher accuracy. In this scenario, the attacker can use gradient-based optimization techniques to maximize the model's confidence in the target label or class, ultimately converging to a close approximation of the target data point.
Threat type	Information Disclosure
Vulnerabilities	Model is not protected, training data is not protected, model is overfitted, model may have memorized specific training examples, model API not protected
Impact type	Disclosure of sensitive/proprietary data
Affected Assets	Database holding data from xApp applications and E2 Node [ASSET-D-10], Training or test data sets collected externally or internally [ASSET-D-25], Trained ML model [ASSET-D-26] The ML prediction results built into the model [ASSET-D-27] The behavior of the ML system including tasks for data collection, data wrangling, pipeline management, model retraining, and model deployment. [ASSET-D-28]

7.4.6.7 AI Supply Chain Attacks

Threat ID	T-AIML-SC-01
Threat title	Poisoning via Supply Chain
Threat description	Adversaries may corrupt or manipulate training datasets to cause the AI model to learn incorrect associations or make biased predictions. This can lead to degraded performance, wrong decisions, or even backdoors in the final system.
Threat type	Tampering, Denial of Service

Impact type	Integrity, Availability
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-SC-02
Threat title	Model Tampering
Threat description	Attackers might inject malicious code or logic into the AI model itself during training or deployment. This could allow them to gain control over the target system, steal sensitive data, or force the AI system to produce incorrect results on demand.
Threat type	Tampering, Information disclosure
Impact type	Integrity, Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-SC-03
Threat title	Backdoor via Supply Chain
Threat description	In these attacks, a seemingly benign AI model is infected with malicious code that remains dormant until it receives a specific trigger. At this point, the attacker can remotely activate the backdoor and use it to compromise the target system or exfiltrate data.
Threat type	Tampering, Information disclosure
Impact type	Integrity, Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-SC-04
Threat title	Hardware Tampering
Threat description	Malicious actors may also focus on manipulating the hardware used for AI processing, such as GPUs, ASICs, or FPGAs. By introducing backdoors or vulnerabilities in these components, attackers can compromise the confidentiality, integrity, and availability of AI systems even if the software and data are secure.
Threat type	Tampering, Information disclosure
Impact type	Integrity, Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-SC-05
Threat title	Insecure Maintenance APIs
Threat description	Many AI services are exposed through APIs, for example for deployment and maintenance, that can be abused by attackers to launch supply chain attacks. If these APIs are not properly secured, they can be used to inject malicious code or exfiltrate sensitive information from the target system.
Threat type	Tampering, Information disclosure
Impact type	Integrity, Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-SC-06
Threat title	Third-party Libraries and Dependencies

Threat description	AI systems often rely on third-party libraries and open-source components which might contain vulnerabilities or backdoors that attackers can exploit. Insecure software supply chains increase the risk of such attacks.
Threat type	Tampering, Information disclosure
Impact type	Integrity, Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW

7.4.6.8 Output Integrity Attack

Threat ID	T-AIML-OI-01
Threat title	Denial of Service Impacting Output Integrity
Threat description	The AI/ML output can be manipulated to contain values that are incorrect or out of range. This can lead to service degradation, partial failure or total failure of the O-RAN element that is consuming this output and lead to denial of service to other O-RAN elements or subscribers.
Threat type	Denial of service
Impact type	Availability
Affected Assets	Training or test data sets collected externally or internally, Trained ML model, ML prediction results, A1 policies, E2 node data, Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-OI-02
Threat title	Subscriber QoE Change
Threat description	The AI/ML output can be manipulated to contain values which can influence the configuration or policies being used by the O-RAN elements. This can lead to a behavior of O-RAN network elements where a subscriber or a group of subscribers is treated unfairly or with a preference.
Threat type	Tampering
Impact type	Integrity
Affected Assets	Training or test data sets collected externally or internally, Trained ML model , ML prediction results ,Data transported over the O1 interface,A1 policies, E2 node data,Near-RT-RIC SW, Non-RT-RIC SW .

7.4.6.9 Model Poisoning

Threat ID	T-AIML-MP-01
Threat title	Model Parameter Poisoning
Threat description	The adversary has access to the parameters file of a trained model. The parameters file is altered to change the model's predictions to achieve the goals of the adversary.
Threat type	Tampering
Vulnerabilities	• Insufficient access controls to the model's parameters [i.33] • Inadequate monitoring and logging of model's activity [i.32] • Lack of control for poisoning in model [i.32] • Weak access protection mechanisms for ML model components [i.32]
Impact type	Integrity
Affected Assets	[ASSET-D-26] Trained ML model. [ASSET-C-12] ML components deploying machine learning (xApps, rApps). [ASSET-D-27] The ML prediction results built into the model (e.g. expected outcomes).

Threat ID	T-AIML-MP-02
Threat title	Inference Algorithm Poisoning
Threat description	The adversary has access to the code of a trained model. The inference algorithm is altered to change the model's predictions to achieve the goals of the adversary.
Threat type	Tampering
Vulnerabilities	• Insufficient access controls to the model's code [i.33] • Inadequate monitoring and logging of model's activity [i.32] • Lack of code integrity checking • Weak access protection mechanisms for ML model components [i.32]
Impact type	Integrity
Affected Assets	[ASSET-D-26] Trained ML model. [ASSET-D-27] The ML prediction results built into the model (e.g. expected outcomes).

Threat ID	T-AIML-MP-03
Threat title	Learning Algorithm Poisoning
Threat description	The adversary has access to the code of an untrained model. The learning algorithm is altered to cause the model to make incorrect predictions.
Threat type	Tampering
Vulnerabilities	• Insufficient access controls to the model's code [i.33] • Inadequate monitoring and logging of model's activity [i.32] • Weak access protection mechanisms for ML model components [i.32] • Lack of code integrity checking
Impact type	Integrity
Affected Assets	[ASSET-C-12] ML components deploying machine learning (xApps, rApps).

Threat ID	T-AIML-MP-04
Threat title	Model Control
Threat description	An adversary takes control of the model parameters by either generating a Trojan trigger and inserting it in the model or by sending malicious local model updates in federated learning
Threat type	Tampering
Vulnerabilities	Vulnerabilities in ML model storage, vulnerabilities in ML model transfer
Impact type	Integrity
Affected Assets	ML components deploying machine learning [ASSET-C-12] The trained ML model [ASSET-D-26], The ML prediction results built into the model [ASSET-D-27], The behavior of the ML system [ASSET-D-28].

7.4.6.10 Model Skewing Attacks

Threat ID	T-AIML-MS-01
Threat title	Data Manipulation for Model Skewing
Threat description	The attacker manipulates the data involved in the training of the model. The attacker modifies/injects the training data with modified data, or modifies the labels associated with the training data, resulting in learnt model behaviour to be changed. The impacted models have reduced accuracy / biased trained models, thereby the ability to make correct predications is compromised, or the output is biased. The model skewing attacks can significantly impact the operation of networks causing service disruptions, reputational damage, and financial losses.
Threat type	Tampering, (Applicable Threats T-SMO-11, T-SMO-12, T-SMO-31, t_rApps_05)
Impact type	Integrity, and use-case specific impacts on O-RAN network.
Affected Assets	Trained ML model, ML Prediction Results, ML system

Threat ID	T-AIML-MS-02
Threat title	Feedback Manipulation for Model Skewing
Threat description	The attacker manipulates the feedback mechanisms used by the AI/ML for continuous improvement during deployment. The attack can significantly impact the operation of networks causing service disruptions, reputational damage, and financial losses.
Threat type	Tampering, (Applicable Threats T-SMO-11, T-SMO-12, T-SMO-31, t_rApps_05)

Impact type	Integrity, and use-case specific impacts on O-RAN network.
Affected Assets	Trained ML model, ML Prediction Results, ML system

7.4.6.11 Transfer Learning Attack

Threat ID	T-AIML-TL-01
Threat title	Data Poisoning for Transfer Learning
Threat description	Attackers can poison the source model's training data by injecting malicious samples, which get propagated into the target model during transfer learning, causing misclassification or unintended behaviour in the latter.
Threat type	Tampering
Impact type	Integrity
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps), Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-TL-02
Threat title	Model Stealing for Transfer Learning
Threat description	By using a series of carefully crafted queries to the source model, attackers can extract sensitive information about its architecture and parameters, which they can then use to build a similar model for malicious purposes.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps), Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-TL-03
Threat title	Adversarial Examples
Threat description	Attackers can create input samples that fool both the source and target models, even if these inputs are visually or semantically similar to benign ones. These adversarial examples can be used to bypass security systems or cause misclassifications in critical applications like self-driving cars or healthcare.
Threat type	Tampering
Impact type	Integrity
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	T-AIML-TL-04
Threat title	Backdoor for Transfer Learning
Threat description	Attackers can embed hidden malicious functionality into the source model, which remains dormant until triggered by specific input patterns. When the trojans are transferred to the target model, they can cause unexpected behaviour or leak sensitive information.
Threat type	Tampering, Information disclosure
Impact type	Authenticity, Integrity, Availability, Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps), Near-RT-RIC SW, Non-RT-RIC SW

7.4.6.12 AI Energy-Latency Attack

Threat ID	T-AIML-EL-01
Threat title	Model Extraction
Threat description	By monitoring the energy and latency patterns, an attacker might deduce the structure of the neural network, including the types of layers, their sequence, and possibly hyperparameters.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node [ASSET-D-10], Trained ML model [ASSET-D-26], Near-RT-RIC SW [ASSET-C-02], Non-RT-RIC SW [ASSET-C-11], AAL software [ASSET-C-29], Hardware accelerator device firmware [ASSET-C-30]

Threat ID	T-AIML-EL-02
Threat title	Data Inference
Threat description	Observing the energy and latency signatures of different computations could allow an attacker to make inferences about the input data, potentially leading to privacy breaches, especially if the data is sensitive.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Assets	Database holding data from xApp applications and E2 Node [ASSET-D-10], Near-RT-RIC SW [ASSET-C-02], Non-RT-RIC SW [ASSET-C-11], AAL software [ASSET-C-29], Hardware accelerator device firmware [ASSET-C-30]

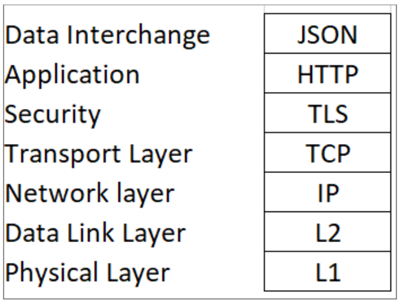
Threat ID	T-AIML-EL-03
Threat title	Denial of Service via Side Channels
Threat description	An attacker could exploit these side channels to craft inputs that maximize energy consumption or computation time, leading to a denial of service by overloading the system or draining battery life.
Threat type	Denial of service
Vulnerabilities	Vulnerabilities in data sources
Impact type	Availability
Affected Assets	Database holding data from xApp applications and E2 Node [ASSET-D-10], Trained ML model [ASSET-D-26], Near-RT-RIC SW [ASSET-C-02], Non-RT-RIC SW [ASSET-C-11], AAL software [ASSET-C-29], Hardware accelerator device firmware [ASSET-C-30]

7.4.6.13 Evasion attack

Threat ID	T-AIML-EV-01
Threat title	Grey-box based Data Evasion
Threat description	Possibility to tamper with the input to AI ML application during the inference phase in the Near-RT RIC or Non-RT RIC (model, model parameters, etc.) for example the model's gradient
Threat type	Tampering
Impact type	Integrity
Affected Assets	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, Near-RT-RIC SW, Non-RT-RIC SW

7.4.7 Protocol Stack Threats

The A1 and R1 interfaces use the REST protocol stack shown in the figure below. The transport network layer is built on IP transport. TCP provides the communication service at the transport layer. HTTP is the application-level protocol used providing reliable transport of messages. TLS provides secure HTTP connections for secure transport of messages. The application layer protocol is based on a RESTful approach with transfer of JSON formatted policy statements. Each of these protocols has known vulnerabilities that can be exploited by a malicious actor.



Data Interchange	JSON
Application	HTTP
Security	TLS
Transport Layer	TCP
Network layer	IP
Data Link Layer	L2
Physical Layer	L1

Figure 7-13 : REST Protocol Stack for the A1 and R1 Interfaces

Threat ID	**T-ProtocolStack-01**
Threat title	REST API Exploits
Threat description	REST API common attacks include injection, cross site scripting, and DoS attacks that can exploit common vulnerabilities if proper controls are not used to protect against vulnerabilities.

Threat ID	**T-ProtocolStack-02**
Threat title	REST API – Broken Object Level Authorization
Threat description	The REST API can be exploited to expose object identifiers without proper authorization checks.

Threat ID	**T-ProtocolStack-03**
Threat title	JSON Exploits
Threat description	JSON attacks include injection, deserialization, web token, and cross site scripting attacks that can exploit common vulnerabilities if proper controls are not used to protect against vulnerabilities.

Threat ID	**T-ProtocolStack-04**
Threat title	HTTP Exploits
Threat description	DDoS attacks include HTTP GET Flood, Garbage Flood, and Reverse Bandwidth Floods. Other well known HTTP attacks include injection attacks, such as Cross-Site Scripting (XSS) and SQL injection.

Threat ID	**T-ProtocolStack-05**

Threat title	TCP Volumetric DDoS
Threat description	TCP DDoS attacks include TCP SYN Flood, ACK Flood, and RST Flood.

7.4.8 SMO Threats

7.4.8.1 General SMO Threats

Threat ID	**T-SMO-01**
Threat title	External attacker exploits authentication weakness on SMO
Threat description	An external attacker can exploit the improper/missing authentication weakness on SMO functions. If the authentication of O-RAN subjects on A1, O1, O2, and External interfaces on SMO is not supported or not properly implemented, those interfaces without proper credentials could be exploited to gain access to the SMO.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	SMO

Threat ID	**T-SMO-02**
Threat title	External attacker exploits authorization weakness on SMO
Threat description	An external attacker can exploit the improper/missing authorization weakness on SMO functions. A malicious external entity on A1, O1, O2, and External interfaces without authorization or with an incorrect access token may invoke the SMO functions. The data at rest related to that function will be leaked to the attacker. In addition, an attacker can be able to perform certain actions, e.g. disclose O-RAN sensitive information or alter O-RAN components.
Threat type	Elevation of Privilege, Information Disclosure
Impact type	Authorization. Confidentiality
Affected Asset	SMO

Threat ID	**T-SMO-03**
Threat title	External Overload DoS attack targeted at SMO
Threat description	Overload situation could appear in the case of DoS attack or increased traffic on externally facing interfaces. Inability to mitigate traffic volumetric attacks on an external interface affects availability of SMO data and functions.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	SMO

Threat ID	**T-SMO-04**
Threat title	Internal attacker exploits authentication weakness on a SMO function

Threat description	An internal attacker can exploit the improper/missing authentication weakness on SMO functions. If the authentication of internal interfaces (e.g. Internal Message Bus and R1) on SMO is not supported or not properly implemented, those interfaces without credentials could exploited to gain access to the SMO.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	SMO

Threat ID	**T-SMO-05**
Threat title	Internal attacker exploits authorization weakness on a SMO function
Threat description	An internal attacker can exploit the improper/missing authorization weakness on SMO functions. Malicious internal entities without authorization or with an incorrect access token may invoke the SMO functions. The data at rest related to these functions will be leaked to the attacker. In addition, an attacker can be able to perform certain actions, e.g. disclose O-RAN sensitive information or alter O-RAN components.
Threat type	Elevation of Privilege, Information Disclosure
Impact type	Authorization
Affected Asset	SMO

Threat ID	**T-SMO-06**
Threat title	Internal Overload DoS attack targeted at SMO functions
Threat description	Overload situation could appear in the case of DoS attack or increased traffic on internal SMO interfaces. Inability to mitigate traffic volumetric attacks on an external interface affects availability of SMO data and functions.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	SMO

Threat ID	**T-SMO-07**
Threat title	Internal DoS attack disables internal SMO function(s) or process(es)
Threat description	Internal malicious actor exploits a vulnerability or escalates privilege to execute a DoS attack by disabling one or more SMO processes or functions. Inability to detect and report such events affects availability of SMO functions.
Threat type	Denial of Service, Escalation of Privilege
Impact type	Availability
Affected Asset	SMO

Threat ID	**T-SMO-08**
Threat title	Attacker exploits insecure API to gain access to SMO
Threat description	An insecure API may allow access to a system for an attacker to conduct remote code execution or an advanced persistent threat

Threat type	Tampering, Information Disclosure, Escalation of Privilege
Impact type	Integrity, Confidentiality, Authorization
Affected Asset	SMO

Threat ID	**T-SMO-09**
Threat title	Sensitive data in transit is exposed to an internal attacker
Threat description	Unprotected data transferred between internal SMO functions is disclosed to an internal threat actor
Threat type	Information Disclosure
Impact type	Confidentiality
Affected Asset	SMO

Threat ID	**T-SMO-10**
Threat title	Sensitive data at rest is exposed to an internal attacker
Threat description	Unprotected data stored on the SMO is disclosed to an internal threat actor that has gain authorized access through privilege escalation
Threat type	Information Disclosure
Impact type	Confidentiality
Affected Asset	SMO

Threat ID	**T-SMO-11**
Threat title	AI/ML poisoning by internal attacker
Threat description	Internal attacker gains authorized access exploited to poison AI/ML training data,or the AI/ML models, stored in the SMO to influence insights.
Threat type	Tampering
Impact type	Integrity
Affected Asset	SMO

Threat ID	**T-SMO-12**
Threat title	AI/ML exposure on external entity
Threat description	An external attacker can gain access to external entities to view or modify sensitive data AI/ML data, or models, transferred between the external function and SMO via external interfaces(e.g., EI, Human-Machine, A1, O1)
Threat type	Information disclosure, Tampering
Impact type	Confidentiality, Integrity
Affected Asset	SMO

Threat ID	**T-SMO-13**
Threat title	Malicious actor views local logs
Threat description	Malicious actor accesses locally stored logs in the SMO to perform reconnaissance to collect sensitive or private information.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Asset	SMO

Threat ID	**T-SMO-14**
Threat title	Malicious actor modifies local log entries
Threat description	Malicious actor accesses locally stored logs in the SMO to modify entries to hide presence or cause confusion.
Threat type	Tampering
Impact type	Integrity
Affected Asset	SMO

Threat ID	**T-SMO-15**
Threat title	Malicious actor deletes local log entries
Threat description	Malicious actor accesses locally stored logs in the SMO to delete entries to hide presence or cause confusion.
Threat type	Tampering
Impact type	Integrity
Affected Asset	SMO

Threat ID	**T-SMO-16**
Threat title	Malicious actor intercepts exports of local logs
Threat description	Malicious actor gains access to an external interface to intercept data in transit as logs are transferred from the SMO to a remote server/external entity.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Asset	SMO

Threat ID	**T-SMO-17**
Threat title	Malicious external actor gains unauthorized access to logs
Threat description	Malicious external actor gains unauthorized access to stored logs to view, modify, and delete
Threat type	Elevation of Privilege

Impact type	Confidentiality
Affected Asset	SMO

Threat ID	**T-SMO-18**
Threat title	Malicious internal actor gains authorized access to logs
Threat description	Malicious internal actor gains authorized access to stored logs to view, modify, and delete.
Threat type	Elevation of Privilege
Impact type	Authorization
Affected Asset	SMO

7.4.8.2 SMO Threats at O2 interface

Threat ID	**T-SMO-19**
Threat title	Internal attacker exploits O2 interface to view data in transit between SMO and O-Cloud
Threat description	If the O2 interface is not properly confidentiality protected, an internal attacker can perform a man-in-the-middle attack to view data in transit.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Asset	O2 interface

Threat ID	**T-SMO-20**
Threat title	Internal attacker exploits O2 interface to modify data in transit between SMO and O-Cloud
Threat description	If the O2 interface is not properly integrity protected, an internal attacker can perform a man-in-the-middle attack to modify data in transit.
Threat type	Tampering
Impact type	Integrity
Affected Asset	O2 interface

Threat ID	**T-SMO-21**
Threat title	Internal attacker uses O2 interface via SMO to exploit API vulnerability to gain access to O-Cloud infrastructure
Threat description	If the O2 interface uses an API with a known vulnerability that is not properly protected or patched, an attacker can exploit it to gain access to the O-Cloud infrastructure from the SMO.
Threat type	Spoofing
Impact type	Authenticity

Affected Asset	O-Cloud

Threat ID	**T-SMO-22**
Threat title	Internal attacker floods O2 interface via SMO to cause DDoS on O-Cloud infrastructure
Threat description	If the O2 interface is not protected, an internal attacker on the SMO can flood the O2 interface to overload the O-Cloud. This can prevent legitimate messages from reaching the O-Cloud or cause heavy processing at the O-Cloud, resulting in performance degradation.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	O-Cloud

Threat ID	**T-SMO-23**
Threat title	External attacker uses O2 interface via O-Cloud to exploit API vulnerability to gain access to SMO
Threat description	If the O2 interface uses an API with a known vulnerability that is not properly protected or patched, an attacker can exploit it to gain access to the SMO from the O-Cloud infrastructure.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	SMO

Threat ID	**T-SMO-24**
Threat title	External attacker floods O2 interface via O-Cloud to cause DDoS on SMO
Threat description	If the O2 interface is not protected, an external attacker in the O-Cloud can flood the O2 interface to overload the SMO. This can prevent legitimate messages from reaching the SMO or cause heavy processing at the SMO, resulting in performance degradation or outage of the SMO.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	SMO

Threat ID	**T-SMO-25**
Threat title	External attacker uses O2 interface via O-Cloud to gain authorized access to sensitive data-at-rest at the SMO
Threat description	If the SMO is not protected, an external attacker at the O-Cloud can use the O2 interface to gain authorized access to the SMO to view data-at-rest.
Threat type	Elevation of Privilege
Impact type	Authorization
Affected Asset	SMO

7.4.8.3 SMO Threats at External interfaces

Threat ID	**T-SMO-26**
Threat title	External attacker exploits External interface to view data in transit between SMO and external service
Threat description	If an External interface is not properly confidentiality protected, an external attacker can perform a man-in-the-middle attack to view data in transit.
Threat type	Information disclosure
Impact type	Confidentiality
Affected Asset	External interface

Threat ID	**T-SMO-27**
Threat title	External attacker exploits External interface to modify data in transit between SMO and external service
Threat description	If an External interface is not properly integrity protected, an external attacker can perform a man-in-the-middle attack to modify data in transit.
Threat type	Tampering
Impact type	Integrity
Affected Asset	External interface

Threat ID	**T-SMO-28**
Threat title	External attacker uses External interface to exploit API vulnerability to gain access to SMO
Threat description	If an External interface uses an API with a known vulnerability that is not properly protected or patched, an attacker can exploit it to gain access to the SMO.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	SMO

Threat ID	**T-SMO-29**
Threat title	External attacker floods External interface to cause DDoS at SMO
Threat description	If the External interface is not protected, an external attacker can flood an External interface to overload the SMO. This can prevent legitimate messages and data from reaching the SMO or cause heavy processing at the SMO, resulting in performance degradation or outage of the SMO.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	SMO

Threat ID	**T-SMO-30**
Threat title	External attacker uses External interface to gain access to sensitive data-at-rest at the SMO

Threat description	If the SMO is not protected, an external attacker can use the External interface to gain authorized access to the SMO to view data-at-rest.
Threat type	Elevation of Privilege
Impact type	Authorization
Affected Asset	SMO

Threat ID	**T-SMO-31**
Threat title	External attacker poisons External AI/ML data to corrupt SMO
Threat description	External data sources may be outside the control of the stakeholder(s) responsible for the O-RAN deployment. The stakeholder for an External data source could fail to provide proper security controls to protect data consumed by the SMO. If an external attacker were to gain access to AI/ML data, it could be corrupted and then be used at the SMO.
Threat type	Tampering
Impact type	Integrity
Affected Asset	SMO

Threat ID	**T-SMO-32**
Threat title	External attacker poisons External Enrichment Information data sources to corrupt SMO
Threat description	External data sources may be outside the control of the stakeholder(s) responsible for the O-RAN deployment. The stakeholder for an External data source could fail to provide proper security controls to protect data consumed by the SMO. If an external attacker were to gain access to External Enrichment Information, it could be corrupted and then be used at the SMO.
Threat type	Tampering
Impact type	Integrity
Affected Asset	SMO

7.4.9 Threats against Shared O-RU

Threat Analysis tables are provided for each of the identified Shared O-RU threats in the clauses below. The Shared O-RU Threats are classified into 6 threat groups:

- Lateral Movement Between Network Functions
- Physical Port Access Threats
- Data Access Threats
- Availability Threats
- Configuration Threats
- Resiliency Threats

Use of the term “MNO Tenant” or “Tenant” refers to a “Shared Resource Operator (SRO)” as defined in [i.27].

7.4.9.1 Lateral Movement Between Network Functions

This clause provides threat analysis tables for threats to access between Shared O-RU network functions.

Threat ID	T-SharedORU-01
Threat title	O-DU Tenant accesses O-DU Host
Threat description	The O-DU Tenant accesses the O-DU Host through the Shared O-RU. Weak authentication can be exploited by a tenant to move laterally across the deployment.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-DU Host

Threat ID	T-SharedORU-02
Threat title	O-DU Host accesses O-DU Tenant
Threat description	The O-DU Host accesses the O-DU Tenant through the Shared O-RU. Weak authentication can be exploited by a host to move laterally across the deployment.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-DU Tenant

Threat ID	T-SharedORU-03
Threat title	O-DU Tenant accesses O-DU Tenant
Threat description	An O-DU Tenant accesses another O-DU Tenant through the Shared O-RU supporting multiple tenants. Weak authentication can be exploited by a tenant to move laterally across the deployment.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-DU Tenant

Threat ID	T-SharedORU-04
Threat title	Password Attack on OFH M-Plane
Threat description	Use of single-factor authentication with password on the Open Fronthaul M-Plane can be exploited by an internal malicious actor to gain access to the Shared O-RU. The attack can be a brute-force attack or stolen password. There is increased risk of password attack in a multi-tenant environment. The internal malicious actor may be the Host MNO, a Tenant MNO, or a 3rd-party. [i.9]
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	Shared O-RU, O-DU Host, O-DU Tenant

Threat ID	T-SharedORU-05
Threat title	Untrusted peering to O-DU
Threat description	Attacker exploits weak authentication on the O-DU to establish a session with a malicious app masquerading as a Shared O-RU. From the O-DU, a malicious actor can move laterally across Shared O-RUs and northbound to the O-CU and SMO.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-DU Host, O-DU Tenant

Threat ID	T-SharedORU-06
Threat title	Untrusted peering to the Shared O-RU
Threat description	Attacker exploits weak authentication on the Shared O-RU to establish session with a malicious app masquerading as a O-DU Host or O-DU Tenant
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-07
Threat title	Untrusted peering to the SMO
Threat description	Attacker exploits weak authentication on the SMO to establish session with a malicious app masquerading as a Shared O-RU.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	SMO Host, SMO Tenant

Threat ID	T-SharedORU-08
Threat title	SMO Tenant accesses SMO Host
Threat description	The SMO Tenant accesses the SMO Host through the Shared O-RU. Weak authentication can be exploited by a tenant to move laterally across the deployment.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	SMO Host

Threat ID	T-SharedORU-09
Threat title	SMO Host accesses SMO Tenant
Threat description	The SMO Host accesses the SMO Tenant through the Shared O-RU. Weak authentication can be exploited by a host to move laterally across the deployment.

Threat type	Spoofing
Impact type	Authenticity
Affected Asset	SMO Tenant

Threat ID	T-SharedORU-10
Threat title	O-DU Host accesses O-CU Tenant
Threat description	The O-DU Host accesses the O-CU Tenant through the Shared O-RU. Weak authentication can be exploited by a host to move laterally across the deployment.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-CU Tenant

Threat ID	T-SharedORU-11
Threat title	O-DU Tenant accesses O-CU Host
Threat description	The O-DU Tenant accesses the O-CU Host through the Shared O-RU. Weak authentication can be exploited by a host to move laterally across the deployment.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-CU Host

Threat ID	T-SharedORU-12
Threat title	O-DU Tenant accesses O-CU Tenant
Threat description	The O-DU Tenant accesses another O-CU Tenant through the Shared O-RU supporting multiple tenants. Weak authentication can be exploited by a host to move laterally across the deployment.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-CU Tenant

Threat ID	T-SharedORU-13
Threat title	SMO Host accesses O-CU Tenant
Threat description	The SMO Host accesses the O-CU Tenant through the Shared O-RU. Weak authentication can be exploited by a host to move laterally across the deployment.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-CU Tenant

Threat ID	T-SharedORU-14
Threat title	SMO Tenant accesses O-CU Host
Threat description	The SMO Tenant accesses the O-CU Host through the Shared O-RU. Weak authentication can be exploited by a host to move laterally across the deployment.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-CU Host

7.4.9.2 Physical Port Access Threats

This clause provides threat analysis tables for physical port access threats to Shared O-RU.

Threat ID	T-SharedORU-15
Threat title	Physical port access to Shared O-RU Host/Tenant
Threat description	A host, tenant, or third-party gains physical port connectivity to the Shared O-RU. With this physical access the actor exploits weak physical layer authentication to gain access to the Shared O-RU.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-16
Threat title	Physical port access to O-DU Host/Tenant
Threat description	A host, tenant, or third-party gains physical port connectivity to a O-DU Host or O-DU Tenant. With this physical access the actor exploits weak physical layer authentication to gain access to the O-DU.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-DU Host, O-DU Tenant

Threat ID	T-SharedORU-17
Threat title	Physical port access to O-CU Host/Tenant
Threat description	A host, tenant, or third-party gains physical port connectivity to a O-CU Host or O-CU Tenant. With this physical access the actor exploits weak physical layer authentication to gain access to the O-CU.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-CU Host, O-CU Tenant

Threat ID	T-SharedORU-18
Threat title	Malicious User Login Attempt to SMO Host/Tenant
Threat description	The attacker attempts to access the SMO Host or SMO tenant though a management interface. The attacker may be an internal or external actor. Weak account management and/or authentication can be exploited to gain access to move laterally across the deployment for nefarious purposes such as reconnaissance or damage.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	SMO Host, SMO Tenant

Threat ID	T-SharedORU-19
Threat title	Malicious User Login Attempt to O-CU Host/Tenant
Threat description	The attacker attempts to access the O-CU Host or O-CU Tenant though a management interface. The attacker may be an internal or external actor. Weak account management and/or authentication can be exploited to gain access to move laterally across the deployment for nefarious purposes such as reconnaissance or damage.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-CU Host, O-CU Tenant

Threat ID	T-SharedORU-20
Threat title	Malicious User Login Attempt to O-DU Host/Tenant
Threat description	The attacker attempts to access the O-DU Host or O-DU Tenant though a management interface. The attacker may be an internal or external actor. Weak account management and/or authentication can be exploited to gain access to move laterally across the deployment for nefarious purposes such as reconnaissance or damage.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	O-DU Host, O-DU Tenant

Threat ID	T-SharedORU-21
Threat title	Malicious User Login Attempt to Shared O-RU Host/Tenant
Threat description	The attacker attempts to access the O-RU Host or O-RU Tenant though a management interface. The attacker may be an internal or external actor. Weak account management and/or authentication can be exploited to gain access to move laterally across the deployment for nefarious purposes such as reconnaissance or damage.
Threat type	Spoofing
Impact type	Authenticity
Affected Asset	Shared O-RU

7.4.9.3 Data Access Threats

This clause provides threat analysis tables for threats to Shared O-RU data access.

Threat ID	T-SharedORU-22
Threat title	Unauthorized internal threat actor gains access to data in Shared O-RU
Threat description	Malicious internal threat actor exploits compromised credentials or weak or misconfigured authorization to gain access to view or modify sensitive data-at-rest or data-in-use in the Shared O-RU.
Threat type	Elevation of Privilege
Impact type	Authorization
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-23
Threat title	Unauthorized external threat actor gains access to data in Shared O-RU
Threat description	Malicious external threat actor exploits compromised credentials or weak or misconfigured authorization to gain access to view or modify sensitive data-at-rest or data-in-use in the Shared O-RU.
Threat type	Elevation of Privilege
Impact type	Authorization
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-24
Threat title	Data exposure at Shared O-RU
Threat description	Data-at-rest on the Shared O-RU is exposed to a tenant. Attacker exploits weak confidentiality protection to view data owned by the MNO Host or a MNO Tenant.
Threat type	Information Disclosure
Impact type	Confidentiality
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-25
Threat title	Shared O-RU data exposure at SMO
Threat description	Data-at-rest on the SMO related to a Shared O-RU is exposed to an unauthorized tenant / SMO user. Attacker exploits weak confidentiality protection to view data owned by the MNO Host or a MNO Tenant of a shared O-RU.
Threat type	Information Disclosure
Impact type	Confidentiality
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-26

Threat title	Shared O-RU data exposure at O-DU
Threat description	Data-at-rest on the O-DU related to a Shared O-RU is exposed to an unauthorized tenant. Attacker exploits weak confidentiality protection to view data owned by the MNO Host or a MNO Tenant of a shared O-RU.
Threat type	Information Disclosure
Impact type	Confidentiality
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-27
Threat title	Exposed data in transit between Shared O-RU and O-DU Host/Tenant
Threat description	Data-in-transit between the Shared O-RU and an O-DU Host or O-DU Tenant could be exposed to another MNO or malicious threat actor. Weak confidentiality protection of data-in-transit allows the host, tenant, or actor to view intercepted data owned by the MNO Host or a MNO Tenant.
Threat type	Information Disclosure
Impact type	Confidentiality
Affected Asset	Shared O-RU, M-Plane, CUS-Plane

Threat ID	T-SharedORU-28
Threat title	Exposed data in transit between Shared O-RU and SMO Host/Tenant
Threat description	Data-in-transit between the Shared O-RU and a SMO Host or SMO Tenant could be exposed to another MNO or malicious threat actor. Weak confidentiality protection of data-in-transit allows the host, tenant, or actor to view intercepted data owned by the MNO Host or a MNO Tenant.
Threat type	Information Disclosure
Impact type	Confidentiality
Affected Asset	Shared O-RU, O1

Threat ID	T-SharedORU-43
Threat title	Eavesdropping of unprotected CUSM-plane data within shared O-RU
Threat description	The SMO assigns the role of Host and MNO SRO(s). The tenant maliciously or intended is obtaining access to transport protocol stack and is therefore able to eavesdrop sensitive data from neighbor tenants and the host. The tenant may have capability for sniffing/capturing of CUSM-plane data.
Threat type	Information Disclosure
Impact type	Confidentiality
Affected Asset	Shared O-RU

7.4.9.4 Availability Threats

This clause provides threat analysis tables for availability threats to Shared O-RU.

Threat ID	T-SharedORU-29

Threat title	Modify/Delete OFH C-Plane messages
Threat description	A Host MNO, Tenant MNO, or 3rd-party, modifies or deletes control plane messages on the OFH C-Plane between the Shared O-RU and Host O-DU or Tenant O-DU. This type of integrity attack can also result in an availability attack.
Threat type	Tampering
Impact type	Integrity, Availability
Affected Asset	Shared O-RU, O-DU Host, O-DU Tenant, CUS-Plane

Threat ID	T-SharedORU-30
Threat title	Clock hijacking on OFH S-Plane
Threat description	A Host MNO, Tenant MNO, or 3rd-party takes the role of Grand Master clock on the S-Plane to degrade performance on the U-Plane. This type of authorization exploit can also result in an availability attack.
Threat type	Elevation of Privilege
Impact type	Authorization, Availability
Affected Asset	Shared O-RU, O-DU Host, O-DU Tenant, CUS-Plane

Threat ID	T-SharedORU-31
Threat title	Parameter conflicts at Shared O-RU
Threat description	O-DU Host and O-DU Tenants may force conflicting parameter settings at the Shared O-RU that can degrade performance or cause an outage.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-32
Threat title	Volumetric DDoS attack from O-DU targeting Shared O-RU
Threat description	An O-DU Host or O-DU Tenant maliciously or unintentionally sends a high-rate of malformed, mis-sequenced, invalid, or valid packets over the Open Fronthaul interface to the Shared O-RU. This kind of attack can cause a Denial of Service on the Shared O-RU.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	Shared O-RU, M-Plane, CUS-Plane

Threat ID	T-SharedORU-33
Threat title	Volumetric DDoS attack from SMO targeting Shared O-RU
Threat description	The SMO Host maliciously or unintentionally sends a high-rate of malformed, mis-sequenced, invalid, or valid packets over the Open Fronthaul interface to the Shared O-RU. This kind of attack can cause a Denial of Service on the Shared O-RU.

Threat type	Denial of Service
Impact type	Availability
Affected Asset	Shared O-RU, O1

Threat ID	T-SharedORU-34
Threat title	Volumetric DDoS attack targeting O-DU
Threat description	Shared O-RU maliciously or unintentionally sends a high-rate of malformed, mis-sequenced, invalid, or valid packets over the Open Fronthaul interface to the O-DU Host or O-DU Tenant. This kind of attack can cause a Denial of Service on the O-DU.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	O-DU Host, O-DU Tenant, CUS-Plane, M-Plane

Threat ID	T-SharedORU-35
Threat title	Shared O-RU initialization hijacking by DHCP compromise
Threat description	Shared O-RU bootup and initialization sequence depends on parameters passed to it via DHCP options. An attacker can compromise DHCP server and use it to hijack the O-RU and prevent Shared O-RU from reaching carrier-active state. This kind of attack can cause a Denial of Service on the shared O-RU.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-36
Threat title	Shared O-RU M-plane hijacking by DNS compromise
Threat description	Shared O-RU M-plane initialization depends on DNS, if FQDN is returned as the NETCONF controller of shared O-RU during its initialization. The name resolution of FQDN can be manipulated by an attacker using a compromised DNS server and prevent Shared O-RU from reaching carrier-active state due to unavailability of carrier configuration. This kind of attack can cause a Denial of Service on the shared O-RU.
Threat type	Denial of Service
Impact type	Availability
Affected Asset	Shared O-RU

7.4.9.5 Configuration Threats

This clause provides threat analysis tables for configuration threats to Shared O-RU.

Threat ID	T-SharedORU-37
Threat title	Misconfiguration of MNO Host Role

Threat description	The SMO assigns the role of MNO Host and MNO SRO(s). The assignment of Host role to the wrong SRO can expose data. A threat actor could exploit an incorrectly assigned role of Host to control function of the Shared O-RU
Threat type	Information Disclosure, Denial of Service
Impact type	Confidentiality, Availability
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-38
Threat title	Incorrect Assignment of Spectrum Resources
Threat description	Shared O-RU is responsible for assignment and control of spectrum resources, including component carrier and frequencies within a carrier. Tenant access to the wrong resources, due to malicious intent or could be exploited to gain access to information.
Threat type	Spoofing
Impact type	Authentication
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-39
Threat title	Chain of Trust in a Multi-Tenant Environment
Threat description	The Chain of Trust is a certificate-based chain used to authenticate an entity. The Chain of Trust is established by validating the hardware and software for the entity up to the root certificate as the trust anchor. The Shared O-RU mutually authenticates O-DU Hosts and O-DU Tenants. Certificates from O-DU tenants must be validated as trustworthy. Malicious actors can exploit untrustworthy certificates to gain access to the Shared O-RU.
Threat type	Spoofing
Impact type	Authentication
Affected Asset	Shared O-RU, O-DU Host, O-DU Tenant, O-CU Host, O-CU Tenant, SMO Host, SMO Tenant

Threat ID	T-SharedORU-40
Threat title	Hijack of MNO Host Role
Threat description	The SMO assigns the role of MNO Host and MNO SRO(s). A tenant may maliciously or unintentionally obtain the host role. The elevation of privilege would enable the tenant, acting as host, to have authorized access on the Shared O-RU to sensitive data, credentials, and system privileges.
Threat type	Elevation of Privilege
Impact type	Authorization
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-41
Threat title	Not Released Host Role (Host Role resume)

Threat description	The SMO assigns the role of Host and MNO SRO(s). The tenant maliciously or intended is obtaining the host role, and implicit has obtained elevated privileges which could be used to drive wrong things, like obtaining of sensitive data and/or driving DoS. The tenant is not releasing the host role and/or the tenant is reusing known sensitive information and is driving wrong things. How to avoid that a tenant who has become once in his/her life a host is obtaining information that could be misused now and in the future.
Threat type	Elevation of Privilege
Impact type	Authorization
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-42
Threat title	Misuse of "sudo" privileges
Threat description	The SMO assigns the role of Host and MNO SRO(s). The tenant maliciously or intended is obtaining the host role, and implicit has obtained elevated privileges which could be used to drive wrong things, like obtaining of sensitive data and/or driving DoS. How to avoid that any of the tenants can misuse the "sudo" privileges. This includes the default credentials of a shared O-RU.
Threat type	Elevation of Privilege
Impact type	Authorization
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-55
Threat title	Set Incorrect Array-Carrier configuration on O-DU (Standby)
Threat description	Threat actor spoofs SMO to set or modify the pre-configured array-carrier configuration on the O-DU in Standby state.
Threat type	Spoofing
Impact type	Authentication
Affected Asset	O-DU, O1 interface

Threat ID	T-SharedORU-56
Threat title	Modify Array-Carrier pre-configuration on Shared O-RU
Threat description	Threat actor can gain access to Shared O-RU to modify its pre-configured array-carrier
Threat type	Elevation of Privilege
Impact type	Authorization
Affected Asset	Shared O-RU

Threat ID	T-SharedORU-57
Threat title	Modify/Inject M-Plane messages with Array-Carrier configuration

Threat description	Threat actor Modifies/Injects M-Plane messages with Array-Carrier configuration sent to the Shared O-RU.
Threat type	Tampering
Impact type	Integrity
Affected Asset	Shared O-RU, M-Plane

7.4.9.6 Resiliency Threats

This clause provides threat analysis tables for threats introduced by the O-DU Resiliency use case.

Threat ID	T-SharedORU-52
Threat title	Thrashing O-DU Failovers
Threat description	Threat actor spoofs SMO to cause O-DU-1 and O-DU-2 to thrash between Active state and Standby state
Threat type	Spoofing
Impact type	Authentication
Affected Asset	O-DU, O1 interface

Threat ID	T-SharedORU-53
Threat title	Dual (Dueling) Active O-DUs
Threat description	Threat actor spoofs SMO to cause O-DU-1 and O-DU-2 to both be in Active state.
Threat type	Spoofing
Impact type	Authentication
Affected Asset	O-DU, O1 interface

Threat ID	T-SharedORU-54
Threat title	Modify/Inject O1 messages at the SMO
Threat description	Threat actor spoofs O-DU to modify, inject, flood O1 messages to the SMO to prevent SMO detection of O-DU failure.
Threat type	Tampering
Impact type	Integrity
Affected Asset	SMO, O1 interface

7.5 Coverage matrix of threats

From the above threats, a threat inventory is developed to provide a mapping between threats, vulnerabilities and assets. For the purposes of this document, threats have been grouped into two categories:

1. ‘O-RAN specific’ comprises threats directly relating to O-RAN components and interfaces

2. ‘General’ covers threats relating to physical, open source, virtualization, IoT and radio aspects

The threat inventory provides details of each individual threat: threat agents, vulnerabilities, threatened assets and affected components.

Table 7-1 : O-RAN Threat Inventory

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
O-RAN specific threats					
T-O-RAN-01	An attacker exploits insecure designs or lack of adaption in O-RAN components	All	• Outdated component from the lack of update or patch management • Poorly design architecture • Missing appropriate security hardening • Unnecessary or insecure function/protocol/component	All	All
T-O-RAN-02	An attacker exploits misconfigured or poorly configured O-RAN components	All	• Errors from the lack of configuration change management • Misconfigured or poorly configured O-RAN components • Improperly configured permissions • Unnecessary features are enabled (e.g. unnecessary ports, services, accounts, or privileges) • Default accounts and their passwords still enabled and unchanged • Security features are disabled or not configured securely	All	All
T-O-RAN-03	Attacks from the internet to penetrate O-RAN network boundary	All	Errors in the design and implementation of the network protocols (HTTP, P, TCP, UDP, application protocols)	All	All
T-O-RAN-04	An attacker attempts to jam the airlink signal through IoT devices	All	Failure to address overload situations	ASSET-D-06, ASSET-D-18	O-RU, airlink with UE, O-DU
T-O-RAN-05	An attacker penetrates and compromises the O-RAN system through the open O-RAN's Fronthaul, O1, O2, A1, and E2	All	• Improper or missing authentication and authorization processes • Improper or missing ciphering and integrity checks of sensitive data exchanged over O-RAN interfaces • Improper or missing replay protection of sensitive data exchanged over O-RAN interfaces • Improper prevention of key reuse	All	rApps, xApps, O-RU, O-DU, O-CU, Near-RT RIC, Non-RT RIC
T-O-RAN-06	An attacker exploits insufficient/improper mechanisms for authentication and authorization to compromise O-RAN components	All	• Unauthenticated access to O-RAN functions • Improper authentication mechanisms • Use of Predefined/ default accounts • Weak or missing password policy • Lack of mutual authentication to O-RAN components and interfaces • Failure to block consecutive failed login attempts • Improper authorization and access control policy	All	All
T-O-RAN-07	An attacker compromises O-RAN monitoring mechanisms and log files integrity and availability	All	• Lack of security event logging • Insufficient protection of log files	ASSET-D-29	All
T-O-RAN-08	An attacker compromises O-RAN data integrity, confidentiality and traceability	All	• Improper or missing ciphering of sensitive data in storage or in transfer • Improper or missing integrity mechanisms to protect sensitive data in storage or in transfer • Presence of active function(s) that reveal confidential internal data • No traceability (logging) of access to personal data	ASSET-D-01 to ASSET-D-29	All
T-O-RAN-09	An attacker compromises O-RAN components integrity and availability	All	• Improper handling of overload situations • Unrestricted boot memory devices • Lack of / improper mechanisms for Network Product software package integrity validation	ASSET-C-01 to ASSET-C-12	All

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-O-RAN-10	Inconsistent Log Format Impeding Effective Attack Detection	All	• Lack of Centralized Log Management: Without a centralized system to collect and analyse logs, it's difficult to correlate events across different systems, which can obscure the detection of attack patterns. • Lack of Log Standardization: Different systems generating logs in various formats can lead to inconsistencies in the data, making it difficult to aggregate and analyse logs effectively. • Limited Log Analysis Capabilities: Even with centralized logs, if the analysis tools or processes are not up to the task, potential threats may still go undetected. • Inconsistent Time Synchronization: Without synchronized time across systems, it becomes challenging to correlate log entries accurately, which is crucial for tracking attackers' movements and actions.	All	All
T-FRHAUL-01	An attacker penetrates O-DU and beyond through O-RU or the Fronthaul interface to access or modify sensitive information	All	Heterogeneous security levels between O-RU and O-DU provided by different vendors	ASSET-D-01, ASSET-D-02, ASSET-D-04, ASSET-D-05	rApps, xApps, O-RU, O-DU, O-CU, Near-RT RIC, Non-RT RIC
T-FRHAUL-01A	An attacker penetrates O-DU and beyond through O-RU or the Fronthaul interface to impersonate a legitimate system or user	All	Heterogeneous security levels between O-RU and O-DU provided by different vendors	ASSET-D-01, ASSET-D-02, ASSET-D-04, ASSET-D-05	rApps, xApps, O-RU, O-DU, O-CU, Near-RT RIC, Non-RT RIC
T-FRHAUL-02	Unauthorized access to Open Front Haul Ethernet L1 physical layer interface(s) to obtain protected information	All	Lack of authentication and access control to the Open Front Haul Ethernet L1 physical layer interface	ASSET-D-01, ASSET-D-02, ASSET-D-04, ASSET-D-05	rApps, xApps, O-RU, O-DU, O-CU, Near-RT RIC, Non-RT RIC
T-FRHAUL-03	Unauthorized access to Open Front Haul Ethernet L1 physical layer interface(s) to disrupt services	All	Lack of authentication and access control to the Open Front Haul Ethernet L1 physical layer interface	ASSET-D-01, ASSET-D-02, ASSET-D-04, ASSET-D-05	rApps, xApps, O-RU, O-DU, O-CU, Near-RT RIC, Non-RT RIC
T-MPLANE-01	An attacker attempts to intercept the Fronthaul (MITM) over M Plane to obtain protected information	All	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements	ASSET-D-02, ASSET-D-03	Near-RT RIC, Non-RT RIC, O-CU, O-DU, SMO
T-MPLANE-02	An attacker attempts to intercept the Fronthaul (MITM) over M Plane to alter m-plane data	All	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements	ASSET-D-02, ASSET-D-03	Near-RT RIC, Non-RT RIC, O-CU, O-DU, SMO
T-MPLANE-03	An attacker attempts to intercept the Fronthaul (MITM) over M Plane to disrupt services	All	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements	ASSET-D-02, ASSET-D-03	Near-RT RIC, Non-RT RIC, O-CU, O-DU, SMO
T-SPLANE-01	DoS attack against a Master clock	All	• Improper process to monitor and manage the performance of the Master clock • ANNOUNCE messages can be sent publicly in clear text	ASSET-D-01	O-DU, O-RU
T-SPLANE-02	Impersonation of a Master clock (Spoofing) within a PTP network with a fake ANNOUNCE message	All	• Inaccurate timing information • Improper synchronization between clocks • ANNOUNCE messages can be sent publicly in clear text	ASSET-D-01	O-DU, O-RU
T-SPLANE-03	A Rogue PTP Instance wanting to be a Grand Master	All	• Inaccurate timing information • Improper synchronization between clocks • ANNOUNCE messages can be sent publicly in clear text	ASSET-D-01	O-DU, O-RU
T-SPLANE-04	Selective interception and removal of PTP timing packets	All	• Inaccurate timing information • Improper synchronization between clocks • ANNOUNCE messages can be sent publicly in clear text	ASSET-D-01	O-DU, O-RU

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-SPLANE-05	Packet delay manipulation attack	All	• Inaccurate timing information • Improper synchronization between clocks • ANNOUNCE messages can be sent publicly in clear text	ASSET-D-01	O-DU, O-RU
T-CPLANE-01	Spoofing of DL C-plane messages	All	Lack of authentication could allow an adversary to inject DL C-plane messages	ASSET-D-04	O-DU, O-RU
T-CPLANE-02	Spoofing of UL C-plane messages	All	Lack of authentication could allow an adversary to inject UL C-plane messages	ASSET-D-04	O-DU, O-RU
T-UPLANE-01	An attacker attempts to intercept the Fronthaul (MITM) over U-Plane to obtain user data	All	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements	ASSET-D-05	O-DU, O-RU
T-UPLANE-02	An attacker attempts to intercept the Fronthaul (MITM) over U-Plane to modify u-plane data	All	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements	ASSET-D-05	O-DU, O-RU
T-UPLANE-03	An attacker attempts to intercept the Fronthaul (MITM) over U-Plane to disrupt services	All	Lack of sufficient security measures in the Fronthaul due to the negative impact on the performance requirements	ASSET-D-05	O-DU, O-RU
T-UPLANE-04	Spoofing and unauthorized access of U-Plane data packets	All	Lack of authentication, and authorization protection for U-Plane data packets	ASSET-D-05	O-DU, O-RU
T-ORU-01	An attacker stands up a false base station attack by attacking an O-RU	All	False O-RUs	ASSET-D-01, ASSET-D-02, ASSET-D-03, ASSET-D-04, ASSET-D-05, ASSET-D-06	O-RU
T-O-RU-02	An attacker leverages the lack of traceability with shared user accounts	All	• Identical local user accounts are shared across entities(eg:SMO, O-DU) for concurrent access	ASSET-D-18 ASSET-D-20	ASSET-C-06
T-O-RU-03	An attacker manipulates initial provisioning information	All	• Initial provisioning information from the Software configuration server could be manipulated to point to another server rather than the centralized authentication and authorization server	ASSET-D-18 ASSET-D-20	ASSET-C-06
T-O-RU-04	An attacker compromises O-RU user information, data integrity, confidentiality towards an external centralized authentication and authorization server	All	• O-RU credentials including account information and passwords could be mismanaged, misclassifying O-RU users between centralized and local users which could defeat the purpose of central authentication, authorization and administration • Data in plain text between the O-RU and centralized Authentication and authorization server could be manipulated • O-RU related credentials can be manipulated if not stored securely	ASSET-D-20	ASSET-C-06 ASSET-C-26
T-NEAR-RT-01	Malicious Apps can exploit UE identification, track UE location and change UE priority	All	Malicious xApps may be used to gain access to UE identification location and priority	ASSET-D-21, ASSET-D-22, ASSET-C-02, ASSET-C-09, ASSET-C-41, ASSET-C-43	Near-RT RIC, xApps, E2 Functions, Y1 Functions
T-NEAR-RT-02	Risk of a malicious xApp on Near-RT RIC to obtain protected information	All	Improper or missing authentication and authorization of xApps	ASSET-D-10, ASSET D-11, ASSET D-21, ASSET-D-22	Near-RT RIC, UE, xApps
T-NEAR-RT-02A	Risk of a malicious xApp on Near-RT RIC impacting service availability	All	Improper or missing authentication and authorization of xApps	ASSET-D-10, ASSET D-11, ASSET D-21, ASSET-D-22	Near-RT RIC, UE, xApps
T-NEAR-RT-03	Attackers exploit non authenticated, weakly or incorrectly authenticated Near-RT RIC APIs to obtain protected information	All	Non authenticated, weakly or incorrectly authenticated Near-RT RIC APIs	ASSET-D-09, ASSET-D-10, ASSET D-11, ASSET D-20, ASSET-D-21, ASSET-D-25, ASSET-D-26, ASSET-D-29, ASSET-D-30, ASSET-C-02, ASSET-C-09, ASSET-C-41, ASSET-C-43	Near-RT RIC, UE, xApps
T-NEAR-RT-03A	Attackers exploit non authenticated, weakly or incorrectly authenticated Near-RT RIC APIs for MiTM attacks	All	Non authenticated, weakly or incorrectly authenticated Near-RT RIC APIs	ASSET-D-09, ASSET-D-10, ASSET D-11, ASSET D-20, ASSET-D-21, ASSET-D-25,	Near-RT RIC, UE, xApps

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
				ASSET-D-26, ASSET-D-29, ASSET-D-30, ASSET-C-02, ASSET-C-09, ASSET-C-41, ASSET-C-43	
T-NEAR-RT-04	Attackers exploit non authorized Near-RT RIC APIs to access resources and services which they are not entitled to use, to obtain protected information.	All	Non-authorized RT RIC APIs	ASSET-D-09, ASSET-D-10, ASSET D-11, ASSET D-20, ASSET-D-21, ASSET-D-25, ASSET-D-26, ASSET-D-29, ASSET-D-30, ASSET-C-02, ASSET-C-09, ASSET-C-41, ASSET-C-43	Near-RT RIC, UE, xApps
T-NEAR-RT-04A	Attackers exploit non authorized Near-RT RIC APIs to access resources and services which they are not entitled to use, to disrupt services.	All	Non-authorized RT RIC APIs	ASSET-D-09, ASSET-D-10, ASSET D-11, ASSET D-20, ASSET-D-21, ASSET-D-25, ASSET-D-26, ASSET-D-29, ASSET-D-30, ASSET-C-02, ASSET-C-09, ASSET-C-41, ASSET-C-43	Near-RT RIC, UE, xApps
T-NEAR-RT-05	Attackers exploit non uniquely identified xApps using a trusted xAppID to access resources and services which they are not entitled to use.	All	Not uniquely identifying xApps using a trusted xAppID	ASSET-D-39, ASSET-C-02, ASSET-C-09	Near-RT RIC, xApps
T-NONRTRIC-01	An attacker gains access to the Non-RT RIC through the SMO to cause a denial of service or degrade the performance of the Non-RT-RIC	All	Improper or missing authentication and authorization processes on the Non-RT RIC or SMO	ASSET-D-03, ASSET-D-07, ASSET-D-08, ASSET-C-11	Non-RT RIC, rApps
T-NONRTRIC-02	An attacker gains access to the Non-RT RIC through the SMO for UE tracking	All	Malicious rApps may be used to gain access to UE identification	ASSET-D-21, ASSET-D-22, ASSET-C-11	Non-RT RIC, rApps, UE
T-NONRTRIC-03	An attacker gains access to the Non-RT RIC through the SMO to cause Data Corruption/Modification	All	Improper or missing authentication and authorization processes on the Non-RT RIC or SMO	ASSET-C-11	Non-RT RIC
T-NONRTRIC-04	An attacker exploits non uniquely identified rApp instances using a trusted rAppID to access R1 services and data which they are not entitled to use	All	Not uniquely identifying rApp instances using a trusted rAppID	ASSET-C-10, ASSET-C-11	Non-RT RIC, rApps
T-xAPP-01	An attacker exploits xApps vulnerabilities and misconfiguration to alter data transmitted over A1 or E2 interfaces.	All	xApp stems from an untrusted or unmaintained source	ASSET-C-03, ASSET-C-05, ASSET-C-07, ASSET-C-08, ASSET-C-09, ASSET-C-10	O-CU, Near-RT RIC, xApps
T-xAPP-01A	An attacker exploits xApps vulnerabilities and misconfiguration to extract sensitive information.	All	xApp stems from an untrusted or unmaintained source	ASSET-C-03, ASSET-C-05 ASSET-C-07, ASSET-C-08, ASSET-C-09, ASSET-C-10	O-CU, Near-RT RIC, xApps
T-xAPP-01B	An attacker exploits xApps vulnerabilities and misconfiguration to disrupt Near-RT RIC functions	All	xApp stems from an untrusted or unmaintained source	ASSET-C-03, ASSET-C-05, ASSET-C-07, ASSET-C-08, ASSET-C-09, ASSET-C-10	O-CU, Near-RT RIC, xApps
T-xAPP-01C	An attacker exploits xApps vulnerabilities and misconfiguration to gain unauthorized control over Near-RT RIC	All	xApp stems from an untrusted or unmaintained source	ASSET-C-03, ASSET-C-07, ASSET-C-08, ASSET-C-09, ASSET-C-10	O-CU, Near-RT RIC, xApps

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-xAPP-02	Conflicting xApps impact O-RAN system functions to degrade performance or create a DoS [i.12]	All	• xApps may be misconfigured or compromised • Failing or misconfigured authentication and authorization in xApp	ASSET-C-03, ASSET-C-05, ASSET-C-07, ASSET-C-08, ASSET-C-09, ASSET-C-10	O-CU, Near-RT RIC, xApps
T-xAPP-03	An attacker compromises xApp isolation	All	Vulnerabilities in the underlying system hosting xApps	ASSET-C-03, ASSET-C-07, ASSET-C-08, ASSET-C-09, ASSET-C-10	O-CU, Near-RT RIC, xApps
T-xApp-04	False or malicious A1 policies modify behavior of xApps	All	xApp functionality exploited by malicious A1 policies	ASSET-D-07, ASSET-D-11, ASSET-C-09	O-CU, O-DU, Near-RT RIC, xApps
T-rAPP-01	Conflicting rApps impact O-RAN system functions to degrade performance or trigger a DoS	All	rApp stems from an untrusted or unmaintained source	ASSET-C-10	rApps, Non-RT RIC
T-rAPP-02	An attacker exploits rApp vulnerability for data breach or denial of service	All	rApp management is exposed to the tenant in a web front-end or REST API. These interfaces may contain software vulnerabilities or implement authentication and authorization insufficiently.	ASSET-C-10	rApps, Non-RT RIC
T-rAPP-03	An attacker exploits rApps misconfiguration	All	Vulnerabilities in the underlying system hosting rApps	ASSET-C-10	rApps, Non-RT RIC
T-rAPP-04	An attacker bypasses authentication and authorization	All	• rApps may be misconfigured or compromised • Failing or misconfigured authentication and authorization in rApp	ASSET-C-10	rApps, Non-RT RIC
T-rAPP-05	An attacker deploys and exploits malicious rApp	All	• rApps may be misconfigured or compromised • Failing or misconfigured authentication and authorization in rApp	ASSET-C-10	rApps, Non-RT RIC
T-rAPP-06	An attacker bypasses authentication and authorization using an injection attack	All	• rApps may be misconfigured or compromised • Failing or misconfigured authentication and authorization in rApp	ASSET-C-10	rApps, Non-RT RIC
T-rAPP-07	rApp exploits services	All	• rApps may be misconfigured or compromised • Failing or misconfigured authentication and authorization in rApp	ASSET-C-10	rApps, Non-RT RIC
T-PNF-01	An attacker compromises a PNF to launch attacks against VNFs/CNFs	All	Vulnerabilities in a PNF deployed in a PNF-VNF/CNF deployments.	All	All
T-PNF-01A	An attacker compromises a PNF to launch Denial of Service attacks against VNFs/CNFs	All	Vulnerabilities in a PNF deployed in a PNF-VNF/CNF deployments.	All	All
T-SMO-01	External attacker exploits authentication weakness on SMO	All	Missing or improperly configured authentication	ASSET-C-11, ASSET-C-17	Non-RT RIC, SMO Framework
T-SMO-02	External attacker exploits authorization weakness on SMO	All	Missing or improperly configured authorization	ASSET-C-11, ASSET-C-17	Non-RT RIC, SMO Framework
T-SMO-03	External Overload DoS attack targeted at SMO	All	Lack of overload protection and rate-limiting	ASSET-C-11, ASSET-C-17	Non-RT RIC, SMO Framework
T-SMO-04	Internal attacker exploits authentication weakness on a SMO function	All	Missing or improperly configured authentication	ASSET-C-11, ASSET-C-17, ASSET-C-18, ASSET-C-19, ASSET-C-20, ASSET-C_21	All
T-SMO-05	Internal attacker exploits authorization weakness on a SMO function	All	Missing or improperly configured authorization	ASSET-C-11, ASSET-C-17, ASSET-C-18, ASSET-C-19, ASSET-C-20, ASSET-C_21	All
T-SMO-06	Internal Overload DoS attack targeted at SMO functions	All	Lack of overload protection and rate-limiting	ASSET-C-11, ASSET-C-17, ASSET-C-18, ASSET-C-19, ASSET-C-20, ASSET-C_21	All

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-SMO-07	Internal DoS attack disables internal SMO function(s) or process(es)	All	Privilege escalation or improperly configured authorization	ASSET-C-11, ASSET-C-17, ASSET-C-18, ASSET-C-19, ASSET-C-20, ASSET-C_21	All
T-SMO-08	Attacker exploits insecure API to gain access to SMO	All	API vulnerability	ASSET-C-11, ASSET-C-17, ASSET-C-18, ASSET-C-19, ASSET-C-20, ASSET-C_21	All
T-SMO-09	Sensitive data in transit is exposed to an internal attacker	All	Missing or weak confidentiality protection of data in transit	ASSET-C-11, ASSET-C-17, ASSET-C-18, ASSET-C-19, ASSET-C-20, ASSET-C_21	All
T-SMO-10	Sensitive data at rest is exposed to an internal attacker	All	Missing or weak confidentiality protection of data at rest	ASSET-C-11, ASSET-C-17, ASSET-C-18, ASSET-C-19, ASSET-C-20, ASSET-C_21	All
T-SMO-11	AI/ML poisoning by internal attacker	All	Missing integrity protection of data at rest	ASSET-C-11, ASSET-C-17	Non-RT RIC, SMO Froamework
T-SMO-12	AI/ML exposure on external entity	All	Missing or weak confidentiality protection of data at rest	ASSET-C-11, ASSET-C-17	Non-RT RIC, SMO Framework
T-SMO-13	Malicious actor views local logs	All	Missing or weak confidentiality protection of data at rest	ASSET-C-17, ASSET-C-18	SMO Framework, SMO Functions
T-SMO-14	Malicious actor modifies local log entries	All	Missing integrity protection of data at rest	ASSET-C-17, ASSET-C-18	SMO Framework, SMO Functions
T-SMO-15	Malicious actor deletes local logs	All	Missing integrity protection of data at rest	ASSET-C-17, ASSET-C-18	SMO Framework, SMO Functions
T-SMO-16	Malicious actor intercepts exports of local logs	All	Missing or weak confidentiality protection of data in transit	ASSET-C-17, ASSET-C_18, ASSET-C-26	SMO Framework, SMO Functions, External interfaces
T-SMO-17	Malicious external actor gains unauthorized access to logs	All	Missing or improperly configured authorization	ASSET-C-17, ASSET-C-18	SMO Framework, SMO Functions
T-SMO-18	Malicious internal actor gains authorized access to logs	All	Missing or improperly configured authorization	ASSET-C-17, ASSET-C-18	SMO Framework, SMO Functions
T-SMO-19	Internal attacker exploits O2 interface to view data in transit between SMO and O-Cloud	All	Missing or weak confidentiality protection of data in transit	ASSET-C_08, ASSET-C-17, ASSET-C-23	O-Cloud, SMO, O2 interface
T-SMO-20	Internal attacker exploits O2 interface to modify data in transit between SMO and O-Cloud	All	Missing integrity checking for data in transit	ASSET-C_08, ASSET-C-17, ASSET-C-23	O-Cloud, SMO, O2 interface
T-SMO-21	Internal attacker uses O2 interface via SMO to exploit API vulnerability to gain access to O-Cloud infrastructure	All	API vulnerability	ASSET-C_08, ASSET-C-17, ASSET-C-23	O-Cloud, SMO, O2 interface
T-SMO-22	Internal attacker floods O2 interface via SMO to cause DDoS on O-Cloud infrastructure	All	Lack of overload protection and rate-limiting	ASSET-C-08, ASSET-C-17, ASSET-C-23	O-Cloud, SMO, O2 interface
T-SMO-23	External attacker uses O2 interface via O-Cloud to exploit API vulnerability to gain access to SMO	All	API vulnerability	ASSET-C_08, ASSET-C-17, ASSET-C-23	O-Cloud, SMO, O2 interface
T-SMO-24	External attacker floods O2 interface via O-Cloud to cause DDoS on SMO	All	Lack of overload protection and rate-limiting	ASSET-C_08, ASSET-C-17, ASSET-C-23	O-Cloud, SMO, O2 interface
T-SMO-25	External attacker uses O2 interface via O-Cloud to gain authorized access to sensitive data-at-rest at the SMO	All	Missing or improperly configured authorization	ASSET-C_08, ASSET-C-17, ASSET-C-23	O-Cloud, SMO, O2 interface

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-SMO-26	External attacker exploits External interface to view data in transit between SMO and external service	All	Missing or weak confidentiality protection of data in transit	ASSET-C_11, ASSET-C-17, ASSET-C-26	Non-RT RIC, SMO, External interfaces
T-SMO-27	External attacker exploits External interface to modify data in transit between SMO and external service	All	Missing integrity checking for data in transit	ASSET-C_11, ASSET-C-17, ASSET-C-26	Non-RT RIC, SMO, External interfaces
T-SMO-28	External attacker uses External interface to exploit API vulnerability to gain access to SMO	All	API vulnerability	ASSET-C_11, ASSET-C-17, ASSET-C-26	Non-RT RIC, SMO, External interfaces
T-SMO-29	External attacker floods External interface to cause DDoS at SMO	All	Lack of overload protection and rate-limiting	ASSET-C_11, ASSET-C-17, ASSET-C-26, ASSET-C_27, ASSET-C-28	All
T-SMO-30	External attacker uses External interface to gain access to sensitive data-at-rest at the SMO	All	Missing or improperly configured authorization	ASSET-C_11, ASSET-C-17, ASSET-C-26	Non-RT RIC, SMO, External interfaces
T-SMO-31	External attacker poisons External AI/ML data to corrupt SMO	All	Missing integrity checking for data at rest	ASSET-C_11, ASSET-C-17, ASSET-C-26	Non-RT RIC, SMO, External interfaces
T-SMO-32	External attacker poisons External Enrichment Information data sources to corrupt SMO	All	Missing integrity checking for data at rest	ASSET-C_11, ASSET-C-17, ASSET-C-26	Non-RT RIC, SMO, External interfaces
T-R1-01	A malicious actor gains unauthorized access to R1 services	All	weak mutual authentication	ASSET-C-16	R1 interface
T-R1-02	Attacker modifies Service Heartbeat message to cause Denial of Service	All	weak mutual authentication	ASSET-C-16	R1 interface
T-R1-03	Malicious actor bypasses authentication to Request Data	All	weak mutual authentication	ASSET-C-16	R1 interface
T-R1-04	Malicious actor bypasses authorization to Discover Data	All	weak mutual authentication	ASSET-C-16	R1 interface
T-R1-05	A malicious actor gains unauthorized access to data	All	weak mutual authentication	ASSET-C-16	R1 interface
T-R1-06	Malicious actor modifies a Data Request	All	weak mutual authentication	ASSET-C-16	R1 interface
T-R1-07	Malicious actor compromises Data Delivery to the Data Consumer	All	weak mutual authentication	ASSET-C-16	R1 interface
T-A1-01	Untrusted peering between Non-RT-RIC and Near-RT-RIC	All	weak mutual authentication	ASSET-C-14	A1 interface
T-A1-02	Malicious function or application monitors messaging across A1 interface	All	weak mutual authentication	ASSET-C-14	A1 interface
T-A1-03	Malicious function or application modifies messaging across A1 interface	All	weak mutual authentication	ASSET-C-14	A1 interface
T-A1-04	Unauthorized access to Non-RT-RIC- or Near-RT-RIC- resources	All	weak service consumer authorization	ASSET-D-07, ASSET-D-08	A1 interface
T-AppLCM-01	Compromise of App/VNF/CNF update package integrity during onboarding	All	Lack of integrity verification	ASSET-D-15	Apps/VNFs/CNFs
T-AppLCM-02	Compromise of App/VNF/CNF update image integrity during instantiation	All	Lack of integrity verification	ASSET-D-15	Apps/VNFs/CNFs images
T-AppLCM-03	Downgrade attack to vulnerable application version	All	Lack of integrity verification	ASSET-D-15	Apps/VNFs/CNFs
T-AppLCM-04	Attacker exploits missing or improperly defined elements of application's SecurityDescriptor	All	Misconfiguration	ASSET-D-15	Apps/VNFs/CNFs

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-AppLCM-05	Malicious actor modifies application's SecurityDescriptor	All	Lack of authentication, lack of integrity verification	ASSET-D-15	Apps/VNFs/CNFs
T-AppLCM-06	Improper decommissioning of application	All	Improper release of resources and secrets	ASSET-D-15	Apps/VNFs/CNFs
T-AppLCM-07	Improper deletion of application sensitive data	All	Missing or weak confidentiality protection	ASSET-D-16, ASSET-D-17, ASSET-D-32	Apps/VNFs/CNFs
T-SharedORU-01	O-DU Tenant accesses O-DU Host	All	Weak authentication can be exploited by a tenant to move laterally across the deployment.	ASSET-C-34	O-DU Host
T-SharedORU-02	O-DU Host accesses O-DU Tenant	All	Weak authentication can be exploited by a host to move laterally across the deployment.	ASSET-C-35	O-DU Tenant
T-SharedORU-03	O-DU Tenant accesses O-DU Tenant	All	Weak authentication can be exploited by a tenant to move laterally across the deployment.	ASSET-C-35	O-DU Tenant
T-SharedORU-04	Password Attack on OFH M-Plane	All	The attack can be a brute-force attack or stolen password. There is increased risk of password attack in a multi-tenant environment.	ASSET-C-31, ASSET-C-34, ASSET-C-35	Shared O-RU, O-DU Host, O-DU Tenant
T-SharedORU-05	Untrusted peering to O-DU	All	Attacker exploits weak authentication on the O-DU to establish a session with a malicious app masquerading as a Shared O-RU. From the O-DU, a malicious actor can move laterally.	ASSET-C-34, ASSET-C-35	O-DU Host, O-DU Tenant
T-SharedORU-06	Untrusted peering to the Shared O-RU	All	Weak authentication can be exploited to establish session with a malicious app masquerading as a O-DU Host or O-DU Tenant	ASSET-C-31	Shared O-RU
T-SharedORU-07	Untrusted peering to the SMO	All	Weak authentication on the SMO can be exploited to establish session with a malicious app masquerading as a Shared O-RU.	ASSET-C-31	Shared O-RU
T-SharedORU-08	SMO Tenant accesses SMO Host	All	Weak authentication can be exploited by a tenant to move laterally across the deployment.	ASSET-C-38	SMO Host
T-SharedORU-09	SMO Host accesses SMO Tenant	All	Weak authentication can be exploited by a tenant to move laterally across the deployment.	ASSET-C-39	SMO Tenant
T-SharedORU-10	O-DU Host accesses O-CU Tenant	All	Weak authentication can be exploited by a tenant to move laterally across the deployment.	ASSET-C-37	O-CU Tenant
T-SharedORU-11	O-DU Tenant accesses O-CU Host	All	Weak authentication can be exploited by a tenant to move laterally across the deployment.	ASSET-C-36	O-CU Host
T-SharedORU-12	O-DU Tenant accesses O-CU Tenant	All	Weak authentication can be exploited by a tenant to move laterally across the deployment.	ASSET-C-37	O-CU Tenant
T-SharedORU-13	SMO Host accesses O-CU Tenant	All	Weak authentication can be exploited by a tenant to move laterally across the deployment.	ASSET-C-37	O-CU Tenant
T-SharedORU-14	SMO Tenant accesses O-CU Host	All	Weak authentication can be exploited by a tenant to move laterally across the deployment.	ASSET-C-36	O-CU Host

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-SharedORU-15	Physical port access to Shared O-RU Host/Tenant	All	Weak physical layer authentication can be exploited to gain access.	ASSET-C-31	Shared O-RU
T-SharedORU-16	Physical port access to O-DU Host/Tenant	All	Weak physical layer authentication can be exploited to gain access.	ASSET-C-34, ASSET-C-35	O-DU Host, O-DU Tenant
T-SharedORU-17	Physical port access to O-CU Host/Tenant	All	Weak physical layer authentication can be exploited to gain access.	ASSET-C-36, ASSET-C-37	O-CU Host, O-CU Tenant
T-SharedORU-18	Malicious User Login Attempt to SMO Host/Tenant	All	Weak account management and/or authentication can be exploited to gain access.	ASSET-C-38, ASSET-C-39	SMO Host, SMO Tenant
T-SharedORU-19	Malicious User Login Attempt to O-CU Host/Tenant	All	Weak account management and/or authentication can be exploited to gain access	ASSET-C-36, ASSET-C-37	O-CU Host, O-CU Tenant
T-SharedORU-20	Malicious User Login Attempt to O-DU Host/Tenant	All	Weak account management and/or authentication can be exploited to gain access	ASSET-C-32, ASSET-C-33	O-DU Host, O-DU Tenant
T-SharedORU-21	Malicious User Login Attempt to Shared O-RU Host/Tenant	All	Weak account management and/or authentication can be exploited to gain access	**ASSET-C-31**	Shared O-RU
T-SharedORU-22	Unauthorized internal threat actor gains access to data in Shared O-RU	All	Compromised credentials or weak or misconfigured authorization to gain access to view or modify sensitive data	**ASSET-C-31**	Shared O-RU
T-SharedORU-23	Unauthorized external threat actor gains access to data in Shared O-RU	All	Compromised credentials or weak or misconfigured authorization to gain access to view or modify sensitive data	**ASSET-C-31**	Shared O-RU
T-SharedORU-24	Data exposure at Shared O-RU	All	Weak confidentiality protection exploited to view sensitive data	**ASSET-C-31**	Shared O-RU
T-SharedORU-25	Shared O-RU data exposure at SMO	All	Weak confidentiality protection exploited to view sensitive data	**ASSET-C-31**	Shared O-RU
T-SharedORU-26	Shared O-RU data exposure at O-DU	All	Weak confidentiality protection exploited to view sensitive data	**ASSET-C-31**	Shared O-RU
T-SharedORU-27	Exposed data in transit between Shared O-RU and O-DU Host/Tenant	All	Weak confidentiality protection exploited to view sensitive data	**ASSET-C-31, ASSET-C-24, ASSET-C-25**	Shared O-RU, M-Plane, CUS-Plane
T-SharedORU-28	Exposed data in transit between Shared O-RU and SMO Host/Tenant	All	Weak confidentiality protection exploited to view sensitive data	**ASSET-C-31, ASSET-C-22**	Shared O-RU, O1
T-SharedORU-29	Modify/Delete OFH C-Plane messages	All	Weak integrity protection exploited to modify or delete control messages	**ASSET-C-31, ASSET-C_34, ASSET-C-35, ASSET-C-25**	Shared O-RU, O-DU Host, O-DU Tenant, CUS-Plane
T-SharedORU-30	Clock hijacking on OFH S-Plane	All	Weak authorization exploit can also result in spoofing of the Grand Master clock for an availability attack	**ASSET-C-31, ASSET-C_34, ASSET-C-35, ASSET-C-25**	Shared O-RU, O-DU Host, O-DU Tenant, CUS-Plane

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-SharedORU-31	Parameter conflicts at Shared O-RU	All	Conflicting parameter settings degrade performance or cause an outage.	**ASSET-C-31**	Shared O-RU
T-SharedORU-32	Volumetric DDoS attack from O-DU targeting Shared O-RU	All	High-rate of malformed, mis-sequenced, invalid, or valid packets to cause a Denial of Service	**ASSET-C-31, ASSET-C-24, ASSET-C-25**	Shared O-RU, M-Plane, CUS-Plane
T-SharedORU-33	Volumetric DDoS attack from SMO targeting Shared O-RU	All	High-rate of malformed, mis-sequenced, invalid, or valid packets to cause a Denial of Service	**ASSET-C-31, ASSET-C-22**	Shared O-RU, O1
T-SharedORU-34	Volumetric DDoS attack targeting O-DU	All	High-rate of malformed, mis-sequenced, invalid, or valid packets to cause a Denial of Service	**ASSET-C_34, ASSET-C-35, ASSET-C-24, ASSET-C-25**	O-DU Host, O-DU Tenant, M-Plane, CUS-Plane
T-SharedORU-35	Shared O-RU initialization hijacking by DHCP compromise	All	Compromise DHCP server and use it to prevent Shared O-RU from reaching carrier-active state causing a Denial of Service	**ASSET-C-31**	Shared O-RU
T-SharedORU-36	Shared O-RU M-plane hijacking by DNS compromise	All	The name resolution of FQDN can be manipulated by an attacker using a compromised DNS server and prevent Shared O-RU from reaching carrier-active state causing a Denial of Service	**ASSET-C-31**	Shared O-RU
T-SharedORU-37	Misconfiguration of MNO Host Role	All	A threat actor could exploit an incorrectly assigned role of Host to control function of the Shared O-RU	**ASSET-C-31**	Shared O-RU
T-SharedORU-38	Incorrect Assignment of Spectrum Resources	All	Tenant access to the wrong resources, due to malicious intent or could be exploited to gain access to information.	**ASSET-C-31**	Shared O-RU
T-SharedORU-39	Chain of Trust in a Multi-Tenant Environment	All	Untrustworthy certificates can be exploited to gain access to the Shared O-RU	**ASSET-C-31, ASSET-C-34, ASSET-C-35, ASSET-C-36, ASSET-C_37, ASSET-C-38, ASSET-C-39**	Shared O-RU, O-DU Host, O-DU Tenant, O-CU Host, O-CU Tenant, SMO Host, SMO Tenant
T-SharedORU-40	Hijack of MNO Host Role	All	Elevation of privilege enables the tenant, acting as host, to have authorized access to sensitive data, credentials, and system privileges	**ASSET-C-31**	Shared O-RU
T-SharedORU-41	Not Released Host Role (Host Role resume)	All	Elevation of privilege enables the tenant, acting as host, to have authorized access to sensitive data, credentials, and system privileges	**ASSET-C-31**	Shared O-RU
T-SharedORU-42	Misuse of “sudo” privileges	All	Elevation of privilege enables the tenant, acting as host, to have authorized access to sensitive data, credentials, and system privileges	**ASSET-C-31**	Shared O-RU
T-SharedORU-43	Eavesdropping of unprotected CUSM-plane data within shared O-RU	All	Eavesdrop sensitive data between neighbor tenants and the host	**ASSET-C-31**	Shared O-RU
T-SharedORU-44 through T-SharedORU-51 are Void					
T-SharedORU-52	Thrashing O-DU Failovers	All	Threat actor spoofs SMO to cause O-DU-1 and O-DU-2 to thrash between Active state and Standby state	**ASSET-C-34, ASSET-C-22**	O-DU, O1
T-SharedORU-53	Dual (Dueling) Active O-DUs	All	Threat actor spoofs SMO to cause O-DU-1 and O-DU-2 to both be in Active state.	**ASSET-C-34, ASSET-C-22**	O-DU, O1

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-SharedORU-54	Modify/Inject O1 messages at the SMO	All	Threat actor spoofs O-DU to modify, inject, flood O1 messages to the SMO to prevent SMO detection of O-DU failure.	**ASSET-C-38, ASSET-C-22**	SMO, O1
T-SharedORU-55	Set Incorrect Array-Carrier configuration on O-DU (Standby)	All	Threat actor spoofs SMO to set or modify the pre-configured array-carrier configuration on the O-DU in Standby state.	**ASSET-C-34, ASSET-C-22**	O-DU, O1
T-SharedORU-56	Modify Array-Carrier pre-configuration on Shared O-RU	All	Threat actor can gain access to Shared O-RU to modify its pre-configured array-carrier	**ASSET-C-31**	Shared O-RU
T-SharedORU-57	Modify/Inject M-Plane messages with Array-Carrier configuration	All	Threat actor Modifies/Injects M-Plane messages with Array-Carrier configuration sent to the Shared O-RU.	**ASSET-C-31, ASSET-C-24**	Shared O-RU, M-Plane
			General threats		
T-GEN-01	Software flaw attack	All	Vulnerable code exploits, Design Weakness	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-GEN-02	Malicious access to exposed services using valid accounts	All	Lack of authentication	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-GEN-03	Untrust binding between the different O-Cloud layers	All	Lack of integrity verification during boot or runtime	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-GEN-04	Lack of Authentication & Authorization in interfaces between O-Cloud components	All	Lack of authentication, Insecure interfaces	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs, O2
T-GEN-05	Unsecured credentials and keys	All	Insecure O-Cloud APIs, Lack of integrity verification during boot or runtime	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud
T-GEN-06	Sensitive application data cache exploitation	All	Sensitive information disclosure, Privilege escalation in Applications	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-VM-C-01	Abuse of a privileged VM/Container	All	Misconfiguration or Insecure VM/Container configurations	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-VM-C-02	VM/Container escape attack	All	Shared tenancy vulnerabilities (multitenant environment), Lack of strong VM/Container isolation, lack of authentication, Insecure networking, Unrestricted communication between VMs/Containers	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-VM-C-03	VM/Container data theft	All	Lack of authentication, insecure data storage	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-VM-C-04	VM/Container migration attacks	All	Host misconfiguration, lack of authentication, memory pages copied in clear, vulnerable code exploits	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-VM-C-05	Changing virtualization resource without authorization	All	Insecure O1/O2 interfaces, Lack of authentication/access control on IMS/DMS	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-VM-C-06	Failed or incomplete VNF/CNF termination or releasing of resources	All	Lack of authentication, misconfigurations (VNF/CNF, Host OS, Hypervisor/Container Engine)	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-IMG-01	VM/Container images tampering	All	Compromised VM/Container images (Build machine attacks, Supply chain attacks) at rest, lack of authentication, misconfiguration or Insecure VM/Container images configurations	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs images
T-IMG-02	Insecure channels with images repository	All	Compromised VM/Container images in transit	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs images

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-IMG-03	Secrets disclosure in VM/Container images	All	Secret exposure in VNF/CNF images	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs images
T-IMG-04	Build image on VL	All	Host misconfiguration, lack of authentication	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs images
T-VL-01	VM/Container hyperjacking attack	All	Host misconfiguration, lack of authentication	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-VL-02	Boot tampering	All	Host misconfigurations, lack of authentication	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-VL-03	Attack internal network services	All	Insecure O-Cloud APIs, Lack of authentication	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud
T-O2-01	MitM attacks on O2 interface between O-Cloud and SMO	All	Insecure O2 interface, lack authentication	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O2
T-OCAPI-01	MitM attacks on O-Cloud interface between VNFs/CNFs and the virtualization layer	All	Insecure O-Cloud APIs, lack of authentication	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs
T-HW-01	Cross VM/Container side channel attacks	All	Flaws in chip design, use of shared hardware, Lack of isolation, lack of authentication	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud, Apps/VNFs/CNFs

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-HW-02	MitM attacks on the interface between virtualization layer and hardware	All	Insecure interfaces between HW and VL layers, lack of authentication, misconfiguration	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	O-Cloud
T-ADMIN-01	Denial of service against NFO/FOCOM	All	Lack of authentication, vulnerable code exploits, design weakness, insecure O2 interface	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	NFO/FOCOM, O-Cloud, Apps/VNFs/CNFs
T-ADMIN-02	Abuse a O-Cloud administration service	All	Lack of authentication, secret exposure (insufficient safeguarding of credentials), vulnerable code exploits, design weakness	ASSET-D-12, ASSET-D-13, ASSET-D-14, ASSET-D-15, ASSET-D-16, ASSET-D-17, ASSET-D-18, ASSET-D-19, ASSET-D-20, ASSET-D-29, ASSET-D-31, ASSET-D-32	NFO/FOCOM, O-Cloud, Apps/VNFs/CNFs
T-AAL-01	Attacker exploits insecure API to gain access to hardware accelerator resources	All	Insecure AAL APIs and interfaces Lack authentication and authorization	ASSET-D-33 to ASSET-D-38	ASSET-C-29, ASSET-C-30
T-AAL-02	Internal Overload DoS attack targeting AAL services	All	Insecure AAL APIs and interfaces Lack authentication and authorization	ASSET-D-33 to ASSET-D-38	ASSET-C-29, ASSET-C-30
T-AAL-03	Fail to clear resources	All	Insecure AAL APIs Flaws in AAL design Lack of secure deletion of data after process termination	ASSET-D-33 to ASSET-D-38	ASSET-C-29, ASSET-C-30
T-AAL-04	HAM compromise	All	Insecure HAM APIs Flaws in HAM design Lack of access control	ASSET-D-33 to ASSET-D-38	ASSET-C-29, ASSET-C-30
T-AAL-05	Malicious memory accesses	All	Insecure AAL APIs Flaws in AAL design Unrestricted memory access Lack of access control	ASSET-D-33 to ASSET-D-38	ASSET-C-29, ASSET-C-30
T-AAL-06	Firmware attacks	All	Weak accelerator design	ASSET-D-33 to ASSET-D-38	ASSET-C-29, ASSET-C-30

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
			Misconfiguration Insecure AAL/HAM APIs		
T-O-CLOUD-ID-01	ID reuse in O-Cloud's object lifecycle	All	Insufficient data cleanup Weak isolation mechanisms Inadequate monitoring and Logging Lack of ID randomization Inefficient access controls No Timestamping or Versioning Lack of notification mechanisms	ASSET-D-14, ASSET-D-15, ASSET-D-18, ASSET-D-29	ASSET-C-08
T-O-CLOUD-ID-02	Node redundancy in O-Cloud deployments	All	Inadequate decommissioning procedures Weak identity management Insufficient data cleanup No state verification Lack of Resource Auditing Lack of notification mechanisms Inadequate monitoring and Logging	ASSET-D-14, ASSET-D-15, ASSET-D-18, ASSET-D-29	ASSET-C-08
T-O-CLOUD-ID-03	O-Cloud ID mismanagement	All	Predictable ID Generation Lack of ID validation Inefficient synchronization No ID revocation mechanism Inadequate access controls Lack of Namespace Segregation	ASSET-D-14, ASSET-D-15, ASSET-D-18, ASSET-D-29	ASSET-C-08
T-OPENSRC-01	Developers use SW components with known vulnerabilities and untrusted libraries that can be exploited by an attacker through a backdoor attack	All	• Inaccurate inventories of open-source software • Lack of consistent Supply Chain traceability and security • Lack of coding best practices • Modules with known vulnerabilities and untrusted libraries	All	All

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-OPENSRC-02	A trusted developer intentionally inserts a backdoor into an open source code O-RAN component	All	Bugs in open source software caused by mistakes and human error	All	All
T-PHYS-01	An intruder into a site gains physical access to O-RAN components to cause damage or access sensitive data	All except Script kiddies	• Improper physical security protection of data centres, PNFs, operation areas, etc. • Improper protection to power outages (power supply) • Improper protection against environmental disasters • Improper maintenance and monitoring of hardware parameters • Hardware backdoor	All	All
T-PHYS-02	An intruder into the exchange over the Fronthaul cable network attempts to gain electronic access to cause damage or access sensitive data	All except Script kiddies	Physical access to the open Fronthaul cable network	ASSET-D-01, ASSET-D-02, ASSET-D-04, ASSET-D-05	O-RU, O-DU
T-RADIO-01	Disruption through radio jamming, sniffing and spoofing	All except Script kiddies	Weakness of wireless cellular communications	ASSET-D-06	UE, O-RU, O-DU
T-RADIO-02	DoS attacks on cognitive radio networks	All except Script kiddies	Weakness of wireless cellular communications	ASSET-D-06	UE, O-RU, O-DU
T-AIML-IM-1	Training Data Control	All	Vulnerabilities in data sources, vulnerabilities in training database	ASSET-D-25, ASSET-D-26, ASSET-D-27, ASSET-D-28	Near-RT RIC, Non-RT RIC, xAPPs, rApps
T-AIML-IM-2	Testing Data Control	All	Vulnerabilities in data sources, vulnerabilities in training database	ASSET-D-25, ASSET-D-26, ASSET-D-27, ASSET-D-28	Near-RT RIC, Non-RT RIC, xAPPs, rApps
T-AIML-IM-3	Label Manipulation	All	Vulnerabilities in data sources, vulnerabilities in training database	ASSET-D-25, ASSET-D-26, ASSET-D-27, ASSET-D-28	Near-RT RIC, Non-RT RIC, xAPPs, rApps
T-AIML-IM-4	AI/ML Query Exploitation	All	Vulnerabilities in data sources, vulnerabilities in training database, vulnerabilities in AI/ML APIs	ASSET-D-26, ASSET-D-27, ASSET-D-28	Near-RT RIC, Non-RT RIC, xAPPs, rApps
T-AIML-DP-01	Black-box Data Poisoning	All	Vulnerabilities in data sources, vulnerabilities in training database	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-12, ASSET-C-02, ASSET-C-11	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, xApps, rApps, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-DP-02	Grey-box Data Poisoning	All	Vulnerabilities in data sources, vulnerabilities in data transport, vulnerabilities in training database	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-12, ASSET-C-02, ASSET-C-11, ASSET-C-22, ASSET-C-14, ASSET-C-40	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, xApps, rApps, Near-RT-RIC SW, Non-RT-RIC SW, O1 interface for streaming data, A1 interface, E2 interface for streaming data
T-AIML-DP-03	White-box Data Poisoning	All	Vulnerabilities in data sources, vulnerabilities in training database	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-12,	Database holding data from xApp applications and E2 Node, Training

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
				ASSET-C-02, ASSET-C-11, ASSET-C-22, ASSET-C-14, ASSET-C-40	or test data sets collected externally or internally, Trained ML model, xApps, rApps, Near-RT-RIC SW, Non-RT-RIC SW, O1 interface for streaming data, A1 interface, E2 interface for streaming data
T-AIML-MEI-01	Information Access - Membership Inference	All	Vulnerabilities in data sources, vulnerabilities in training database	ASSET-D-26, ASSET-C-02, ASSET-C-11	Trained ML model, xApps, rApps, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-MEI-02	Inference Technique - Membership Inference	All	Vulnerabilities in data sources, vulnerabilities in training database	ASSET-D-26, ASSET-C-02, ASSET-C-11	Trained ML model, xApps, rApps, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-MEI-03	Target based - Membership Inference	All	Vulnerabilities in data sources, vulnerabilities in training database	ASSET-D-26, ASSET-C-02, ASSET-C-11	Trained ML model, xApps, rApps, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-ME-01	Intellectual Property Theft	All	Vulnerabilities in data sources, vulnerabilities in training database, vulnerabilities in ML model storage, vulnerabilities in ML model transfer	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11	Database holding data from xApp applications and E2, Training or test data sets collected externally or internally, Trained ML model, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-ME-02	Data Privacy Violations	All	Vulnerabilities in data sources, vulnerabilities in training database, vulnerabilities in ML model storage, vulnerabilities in ML model transfer	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11	Database holding data from xApp applications and E2, Training or test data sets collected externally or internally, Trained ML model, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-ME-03	Adversarial Attacks with Stolen Models	All	Vulnerabilities in data sources, vulnerabilities in training database, vulnerabilities in ML model storage, vulnerabilities in ML model transfer	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11	Database holding data from xApp applications and E2, Training or test data sets collected externally or internally, Trained ML model, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-MOI-01	Black-box Model Inversion	All	Model is overfitted, model may have memorized specific training examples, model API not properly protected	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-D-27	Near-RT RIC, Non-RT RIC, xAPPs, rApps
T-AIML-MOI-02	White-box Model Inversion	All	Model is not protected, training data is not protected, model is overfitted, model may have memorized specific training examples, model API not protected	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-D-27, ASSET-D-28	Near-RT RIC, Non-RT RIC, xAPPs, rApps

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-AIML-SC-01	Data Poisoning via Supply Chain	All	Vulnerabilities in data sources, vulnerabilities in training database, vulnerabilities in ML model transfer	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-12	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-SC-02	Model Tampering	All	Vulnerabilities in ML model transfer	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-12	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-SC-03	Backdoor via Supply Chain	All	Vulnerabilities in ML model transfer	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-12	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-SC-04	Hardware Tampering	All	Vulnerabilities in the AI processing HW	ASSET-D-10, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-12	Database holding data from xApp applications and E2 Node, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-SC-05	Insecure Maintenance APIs	All	Vulnerabilities in the ML maintenance APIs	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-12	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
					(xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-SC-06	Third-party Libraries and Dependencies	All	Vulnerabilities in the ML- related SW	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-12	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-OI-01	Denial of Service Impacting Output Integrity	All	Vulnerabilities in data sources, vulnerabilities in training database, vulnerabilities in ML model storage, vulnerabilities in ML model transfer	ASSET-D-25,ASSET-D-26, ASSET-D-27, ASSET-D-07,ASSET-C-12, ASSET-C-02, ASSET-C-11	Training or test data sets collected externally or internally, Trained ML model, ML prediction results,A1 policies,E2 node data, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-OI-02	Subscriber QoE Change	All	Vulnerabilities in data sources, vulnerabilities in training database, vulnerabilities in ML model storage, vulnerabilities in ML model transfer.	ASSET-D-25, ASSET-D-26, ASSET-D-27, ASSET-D-07, ASSET-D-11,ASSET-C-02, ASSET-C-02, ASSET-C-11	Training or test data sets collected externally or internally, Trained ML model , ML prediction results ,Data transported over the O1 interface,A1 policies, E2 node data, Near-RT-RIC SW, Non-RT-RIC SW .
T-AIML-MP-01	Model Parameter Poisoning	All	• Insufficient access controls to the model's parameters [i.33] • Inadequate monitoring and logging of model's activity [i.32] • Lack of control for poisoning in model [i.32] • Weak access protection mechanisms for ML model components [i.32]	[ASSET-D-26], [ASSET-C-12], [ASSET-D-27]	Near-RT RIC, Non-RT RIC, O-CU, O-DU, xApps, rApps
T-AIML-MP-02	Inference Algorithm Poisoning	All	• Insufficient access controls to the model's code [i.33] • Inadequate monitoring and logging of model's activity [i.32] • Lack of code integrity checking • Weak access protection mechanisms for ML model components [i.32]	[ASSET-D-26], [ASSET-D-27]	Near-RT RIC, Non-RT RIC, O-CU, O-DU, xApps, rApps
T-AIML-MP-03	Learning Algorithm Poisoning	All	• Insufficient access controls to the model's code [i.33] • Inadequate monitoring and logging of model's activity [i.32] • Weak access protection mechanisms for ML model components [i.32] • Lack of code integrity checking	[ASSET-C-12]	Near-RT RIC, Non-RT RIC, xApps, rApps
T-AIML-MP-04	Model Control	All	Vulnerabilities in ML model storage, vulnerabilities in ML model transfer	ASSET-D-12, ASSET-D-26, ASSET-D-27, ASSET-D-28	Near-RT RIC, Non-RT RIC, xAPPs, rApps

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-AIML-MS-01	Data Manipulation for Model Skewing	All	Vulnerabilities in (i) training data validation, (ii) less robust model training against cyber-attacks, (iii) less model performance monitoring for monitoring of suspicious activity	ASSET-D-26, ASSET-D-27, ASSET-D-28	Trained ML model, xApps, rApps, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-MS-02	Feedback Manipulation for Model Skewing	All	Vulnerabilities in (i) less secure feedback mechanisms to prevent manipulation, (ii) less robust model training against cyber-attacks, (iii) less model performance monitoring for monitoring of suspicious activity	ASSET-D-26, ASSET-D-27, ASSET-D-28	Trained ML model, xApps, rApps, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-TL-01	Data Poisoning for Transfer Learning	All	Vulnerabilities in data sources, Vulnerabilities in training database	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-12	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-TL-02	Model Stealing for Transfer Learning	All	Vulnerabilities in data sources, Vulnerabilities in training database, Vulnerabilities in ML model storage, Vulnerabilities in ML model transfer	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-12	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-TL-03	Adversarial Examples	All	Vulnerabilities in data sources, Vulnerabilities in training database, Vulnerabilities in ML model storage, Vulnerabilities in ML model transfer	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, Near-RT-RIC SW, Non-RT-RIC SW
T-AIML-TL-04	Backdoor for Tranfer Learning	All	Vulnerabilities in ML model transfer	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-12	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, ML components deploying machine learning (xApps, rApps),Near-RT-RIC SW, Non-RT-RIC SW

Threat ID	Threat title	Threat agent	Vulnerability	Threatened Asset	Affected Components
T-AIML-EL-01	Model Extraction	All	Vulnerabilities in data sources	ASSET-D-10, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-29, ASSET-30	Database holding data from xApp applications and E2 Node, Trained ML model, Near-RT-RIC SW, Non-RT-RIC SW, AAL software, Hardware accelerator device firmware
T-AIML-EL-02	Data Inference	All	Vulnerabilities in data sources	ASSET-D-10, ASSET-C-02, ASSET-C-11, ASSET-C-29, ASSET-30	Database holding data from xApp applications and E2 Node, Near-RT-RIC SW, Non-RT-RIC SW, AAL software, Hardware accelerator device firmware
T-AIML-EL-03	Denial of Service via Side Channels	All	Vulnerabilities in data sources	ASSET-D-10, ASSET-D-26, ASSET-C-02, ASSET-C-11, ASSET-C-29, ASSET-30	Database holding data from xApp applications and E2 Node, Trained ML model, Near-RT-RIC SW, Non-RT-RIC SW, AAL software, Hardware accelerator device firmware
T-AIML-EV-01	Grey-box based Data Evasion	All	Vulnerabilities in the input APIs of the AI ML model application Vulnerabilities in the source of input data used by AI ML for inferences	ASSET-D-10, ASSET-D-25, ASSET-D-26, ASSET-C-02, ASSET-C-11	Database holding data from xApp applications and E2 Node, Training or test data sets collected externally or internally, Trained ML model, Near-RT-RIC SW, Non-RT-RIC
T-E2-01	Untrusted Near-RT-RIC and E2 Nodes	All	weak mutual authentication	ASSET-C-40	E2 interface
T-E2-02	Malicious actor monitors messaging across E2 interface	All	Missing or weak confidentiality protection	ASSET-C-40	E2 interface
T-E3-03	Malicious actor modifies messaging across E2 interface	All	Lack of integrity verification	ASSET-C-40	E2 interface
T-Y1-01	Untrusted Near-RT-RIC and Y1 consumers	All	weak mutual authentication	ASSET-C-42	Y1interface
T-Y1-02	Malicious actor monitors messaging across Y1 interface	All	Missing or weak confidentiality protection	ASSET-C-42	Y1 interface
T-Y1-03	Malicious actor modifies messaging across Y1 interface	All	Lack of integrity verification	ASSET-C-42	Y1 interface

1

8 Security principles

This clause elucidates security principles that an O-RAN system should achieve. They provide high level and abstract statement of the intended solution to countering potential Threats. Each security principle references applicable ZT tenets.

8.1 Principles (SP)

8.1.1 SP-AUTH Mutual Authentication

- Mutual authentication SHOULD be established to allow the O-RAN system verifying who performs what, thus possible to detect fake base stations, unauthorized or malicious components, malicious applications and malicious users/administrators.
- ZT Tenets: ZT-1, ZT-2, ZT-3, ZT-4, ZT-6

8.1.2 SP-ACC Access Control

- The O-RAN system SHOULD forbid unauthorized administrators or components to access O-RAN resources or services anytime and anywhere. Access controls are required for:
  - Network Access Controls for filtering unauthorized/unexpected traffic in the O-RAN components over their interfaces.
  - Access controls to restrict access to component configurations.
  - Access controls for hardware to maintain the trust chain.
- ZT Tenets: ZT-1, ZT-3, ZT-4, ZT-6

8.1.3 SP-CRYPTO Secure cryptographic, key management and PKI

- Well-known, standardized, secure and unbroken cryptographic schemes and protocols SHOULD be used. Proprietary schemes and protocols SHOULD be avoided.
- A secure key management of O-RAN keys (KgNB, KRRC-enc, KRRC-int, KUP-int, and KUP-enc, ksn) SHOULD be implemented to manage all the steps of key lifecycle: key generation using an appropriate level of entropy from a reliable source, secure key storage, key rotation and revocation, secure key destruction, etc.
- Reliable PKI for authentication and data encryption SHOULD be used. Public CAs SHOULD be supported. The certificates SHOULD be issued by a trusted or rooted Certificate Authority (CA). The CA implements the Certificate Policy which specifies the rules and policies about who may or may not receive a Certificate. Relying parties can access the Certificate Policy to determine what validation/verification checks were performed prior to certificate issuance.
- Each O-RU SHOULD be configured with lists of algorithms which are allowed for usage. There SHOULD be one list for integrity algorithms, and one for ciphering algorithms. These lists SHOULD be ordered according to a priority decided by the operator.
- ZT Tenets: ZT-2, ZT-4

8.1.4 SP-TCOMM Trusted Communication

- Integrity, confidentiality, availability, authenticity and replay protection of resources SHOULD be ensured in transit (see ‘Critical Assets’, clause 6.3) over O-RAN interfaces.
- ZT Tenets: ZT-1, ZT-2

8.1.5 SP-SS Secure storage

- Integrity, confidentiality, availability protection of O-RAN resources SHOULD be ensured at rest (see ‘Critical Assets’, clause 6.3).
- ZT Tenets: ZT-1, ZT-2, ZT-4, ZT-5, ZT-6

8.1.6 SP-SB Secure boot and self-configuration

- O-RAN components SHOULD secure their firmware and configuration to provide the opportunity for trust to be extended higher in the software stack. Verified platform firmware can, in turn, verify the operating system (OS) boot loader, which can then verify other software components all the way up to the OS itself, the hypervisor or container runtime layers and O-RAN components. The transitive trust SHOULD be consistent with the concept of the chain of trust (CoT)-a method where each piece of code in the boot process measures and checks the signature of the next stage of the boot process before the software boots.
- The secure boot process, signature verification and self-configuration SHOULD be securely implemented for all O-RAN components to authenticate them before loading.
- ZT Tenets: ZT-1, ZT-3, ZT-4, ZT-5

8.1.7 SP-UPDT Secure Update

- A secure update management process SHOULD be implemented for introducing a new component or software change into the O-RAN system. The process SHOULD consider the ability to update the cryptographic algorithms and to adapt to upcoming O-RAN security challenges. A timely update cycles if vulnerabilities are discovered SHOULD be in place.
- ZT Tenets: ZT-1, ZT-5, ZT-7

8.1.8 SP-RECO Recoverability & Backup

- A recoverability process to recovery in case of denial of service SHOULD be implemented. An approach for detecting and mitigating DoS attacks SHOULD be in place.
- O-RAN vendors SHOULD define a recovery plan that resets the O-RAN components to a trustworthy state in case of a malfunction or an attack (e.g. DoS).
- Backup systems SHOULD be in place to allow data or component on the O-RAN to be secured. Backup systems SHOULD ensure a suitable level of data or component availability and reliability.
- ZT Tenets: ZT-1, ZT-5, ZT6, ZT-7

8.1.9 SP-OPNS Security management of risks in open-source components

- Vendors using open-source code SHOULD enhance its security by applying industry coding best practices. It is recommended that vendors practice a higher level of due diligence for exposure to public exploits when using Open-Source code.
- A Software Bill of Materials (SBOM) SHOULD be maintained to track which open-source components are in use and where.
- Security Analysis (Audit, vulnerability scan, etc.) SHOULD be performed to ensure all identified components are free of security vulnerabilities.
- A proper policy and process SHOULD be in place for identifying and patching known issues with the open-source components. Open-source software components SHOULD be kept up to date and patched.
- ZT Tenets: ZT-1, ZT-4, ZT-5, ZT-6, ZT-7

8.1.10 SP-ASSU Security Assurance

- Mobile networks are classified as critical infrastructure making security assurance especially more than relevant:
    - Vendors SHOULD ensure and prove that its software or hardware meets 3GPP Security Assurance Specifications (SCAS).
    - Vendors SHOULD ensure and prove that its software or hardware fulfils O-RAN security tests, requirements and recommendations provided by O-RAN alliance.
    - Vendors SHOULD ensure and prove that their software or hardware meets the needs of many national and international cybersecurity regulations, such as the Cyber Act, GDPR, etc.
    - Vendors SHOULD provide risk assessment, secure code review, penetration testing, vulnerability analysis and hardening guidelines for their O-RAN components.
- ZT Tenets: ZT-1, ZT-5, ZT-7

8.1.11 SP-PRV Privacy

- In O-RAN, the privacy of end users SHOULD be considered. The privacy of end users can be divided into data privacy, identity privacy and personal information privacy. Most Communication services are to gather data and personal information around end users, which may reveal information sensitive to their privacy. Adversaries would further extract more personal information about end users, such as UE priority, location information, trajectory, and preference.
- ZT Tenets: ZT-1, ZT-2, ZT-3, ZT-4, ZT-5, ZT-6, ZT-7

8.1.12 SP-SLC Continuous security development, testing, logging, monitoring and vulnerability handling

- Continuous development and continuous integration (CD/CI) with continuous regression testing and software security auditing SHOULD be implemented.
- Relevant activities events SHOULD be logged and logs collected SHOULD be analyzed in real time for the identification of potential security attacks and for security auditing.
- Continuous monitoring SHOULD be implemented to verify that the wanted security state is maintained throughout the lifecycle of deployed O-RAN components.
- Vulnerability management SHOULD be in place with intelligence to continuously track, identify and remediate vulnerable applications. Vendors SHOULD keep track of any new vulnerabilities discovered and is ready to act on customer product security incidents and reported security issues affecting O-RAN components.
- ZT Tenets: ZT-1, ZT-4, ZT-5, ZT-6, ZT-7

8.1.13 SP-ISO Robust Isolation

- In a multi-vendor environment, intra-domain host isolation SHOULD be enforced. In the same host, VMs, CNs, virtualization/container layer, CPU, storage, and network security isolation of resources SHOULD be ensured by implementing system security orchestration, segmentation, lifecycle management, time scheduling, monitoring and audit on the management, signaling, control and data planes, and the execution of virtualized O-RAN components.
- ZT Tenets: ZT-1, ZT-2, ZT-3, ZT-4, ZT-5, ZT-7

8.1.14 SP-PHY Physical security

- The O-RAN system SHOULD be located at physically secure environment in a way that minimizes the risk of resource theft and destruction. It SHOULD support secure storage of sensitive data (cryptographic keys and configuration data), execution of sensitive functions (encryption/decryption, authentication), and execution of boot and update processes.

- Special attention SHOULD be paid to the site intrusion and physical access threats against O-RU sites. Consequently O-RU equipment SHOULD disable all unnecessary physical and logical ports, protocols and interfaces. In addition, secure physical connections to O-RU for O&M operations SHOULD be implemented (e.g. secure laptop with secure credentials).

- ZT Tenets: ZT-1, ZT-2, ZT-3, ZT-4, ZT-5, ZT-6, ZT-7

8.1.15 SP-CLD Secure cloud computing and virtualization

- Defense methods SHOULD be implemented: virtual machine-based intrusion detection, virtual machine-based isolation, virtual machine-based kernel protection, virtual machine-based access control, and virtual machine-based trusted computing.

- ZT Tenets: ZT-1, ZT-2, ZT-3, ZT-4, ZT-5, ZT-6, ZT-7

8.1.16 SP-ROB Robustness

- The O-RAN system SHOULD not only ensure the robustness of software or hardware resources, but also guarantee the robustness of the cognitive radio channel for meeting the QoS of communication services required by users. In some scenarios, the robustness of spectrum sensing SHOULD be enhanced when some sensing nodes (e.g., O-RU) easily malfunction. Robustness is an essential consideration for overcoming the security threats caused by jamming, DoS or DDoS attacks.

- ZT Tenets: ZT-1, ZT-2, ZT-3, ZT-5, ZT-6, ZT-7

8.1.17 SP-IDM O-Cloud ID secure management

- To counter threats associated with ID reuse, mismanagement, and redundancy, the O-Cloud should employ robust strategies for ID generation, validation, and lifecycle management. Properly managed IDs reduce risks of data inconsistencies, unauthorized access, and operational inefficiencies.

- ZT Tenets: ZT-1, ZT-3, ZT-4, ZT-5, ZT-6, ZT-7

8.2 Coverage Threats - Security principles

The table below illustrates how threats are covered by security principles. It outlines the list of security principles contributing to counter threats.

Table 8-1 : Coverage Security principles-Threats (1/4)

SP	Threats																																		
	T-O-RAN-01	T-O-RAN-02	T-O-RAN-03	T-O-RAN-04	T-O-RAN-05	T-O-RAN-06	T-O-RAN-07	T-O-RAN-08	T-O-RAN-09	T-FRHAUL-01	T-FRHAUL-01A	T-FRHAUL-02	T-FRHAUL-03	T-MPLANE-01	T-MPLANE-02	T-MPLANE-03	T-SPLANE-01	T-SPLANE-02	T-SPLANE-03	T-SPLANE-04	T-SPLANE-05	T-CPLANE-01	T-CPLANE-02	T-UPLANE-01	T-UPLANE-02	T-UPLANE-03	T-UPLANE-04	T-ORU-01	T-NEAR-RT-01	T-NEAR-RT-02	T-NEAR-RT-02A	T-NEAR-RT-03	T-NEAR-RT-03A	T-NEAR-RT-04	T-NEAR-RT-04A	T-NEAR-RT-05
SP-AUTH			x			x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x
SP-ACC			x			x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x	x	x	x	
SP-CRYPTO		x	x		x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x
SP-TCOMM					x			x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x	x	x	
SP-SS							x	x																x	x	x	x					x	x	x	x	
SP-SB		x																											x	x	x					x
SP-UPDT	x																													x	x					x
SP-RECO				x					x																											
SP-OPNS									x																				x	x	x					x
SP-ASSU	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x	x	x	x					x
SP-PRV								x																					x	x	x	x	x	x	x	x
SP-SLC	x						x		x																				x	x	x					x
SP-ISO		x																											x	x	x					x
SP-PHY									x																			x								
SP-CLD																													x	x	x					x
SP-ROB				x																																

Table 8-2 : Coverage Security principles-Threats (2/4)

SP	Threats																				
	T-NONRTRIC-01	T-NONRTRIC-02	T-NONRTRIC-03	T-xAPP-01	T-xAPP-01A	T-xAPP-01B	T-xAPP-01C	T-xAPP-02	T-xAPP-03	T-xAPP-04	T-rAPP-01	T-rAPP-02	T-rAPP-03	T-rAPP-04	T-rAPP-05	T-rAPP-06	T-rAPP-07	T-PNF-01	T-PNF-01A	T-SMO-01	T-SMO-02	T-SMO-03
SP-AUTH	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x			x		
SP-ACC	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	
SP-CRYPTO	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x					
SP-TCOMM										x												
SP-SS																						
SP-SB		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
SP-UPDT				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SP-RECO				x	x	x	x	x	x	x	x	x	x	x	x	x	x					x
SP-OPNS		x	x																			
SP-ASSU	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SP-PRV		x	x							x												
SP-SLC	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SP-ISO		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					
SP-PHY																		x	x			
SP-CLD		x	x	x	x	x	x	x	x		x	x	x	x	x	x	x					
SP-ROB																						

Table 8-3 : Coverage Security principles-Threats (3/4)

SP	Threats																																											
	T-GEN-01	T-GEN-02	T-GEN-03	T-GEN-04	T-GEN-05	T-GEN-06	T-VM-C-01	T-VM-C-02	T-VM-C-03	T-VM-C-04	T-VM-C-05	T-VM-C-06	T-IMG-01	T-IMG-02	T-IMG-03	T-IMG-04	T-VL-01	T-VL-02	T-VL-03	T-O2-01	T-OCAPI-01	T-HW-01	T-HW-02	T-ADMIN-01	T-ADMIN-02	T-AAL-01	T-AAL-02	T-AAL-03	T-AAL-04	T-AAL-05	T-AAL-06	T-O-CLOUD-ID-01	T-O-CLOUD-ID-02	T-O-CLOUD-ID-03	T-OPENSRC-01	T-OPENSRC-02	T-PHYS-01	T-PHYS-02	T-RADIO-01	T-RADIO-02	T-AIML-DP-01	T-AIML-DP-02	T-AIML-DP-03
SP-AUTH	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x										x	x	x
SP-ACC	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x										x	x	x
SP-CRYPTO	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x																x	x	x
SP-TCOMM																																											
SP-SS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x												
SP-SB	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x										x	x	x
SP-UPDT	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x					x	x	x
SP-RECO	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x										x	x	x
SP-OPNS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x										x	x							
SP-ASSU	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x
SP-PRV																																											
SP-SLC	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x					x	x	x

SP-ISO	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x										x	x	x
SP-PHY																																					x	x					
SP-CLD	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x										x	x	x
SP-ROB																																							x	x			
SP-IDM																																x	x	x									

Table 8-4 : Coverage Security principles-Threats (4/4)

SP	Threats																																									
	T-AIML-MEI-01	T-AIML-MEI-02	T-AIML-MEI-03	T-AIML-ME-01	T-AIML-ME-02	T-AIML-ME-03	T-AIML-IM-1	T-AIML-IM-2	T-AIML-IM-3	T-AIML-IM-4	T-AIML-MOI-01	T-AIML-MOI-02	T-AIML-SC-01	T-AIML-SC-02	T-AIML-SC-03	T-AIML-SC-04	T-AIML-SC-05	T-AIML-SC-06	T-AIML-OI-01	T-AILML-OI-02	T-AIML-MP-01	T-AIML-MP-02	T-AIML-MP-03	T-AIML-MP-04	T-AIML-MS-01	T-AIML-MS-02	T-AIML-TL-01	T-AIML-TL-02	T-AIML-TL-03	T-AIML-TL-04	T-AIML-EL-01	T-AIML-EL-02	T-AIML-EL-03	T-AIML-EV-01	T-O-RAN-10	T-TS-01	T-A1-04						
SP-AUTH	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x							
SP-ACC	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x						
SP-CRYPTO	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x							
SP-TCOMM																																				x							
SP-SS	x	x	x				x	x	x										x	x	x	x	x	x	x	x																	
SP-SB	x	x	x	x	x	x							x	x	x	x	x	x	x	x					x	x	x	x	x	x	x	x	x	x		x							
SP-UPDT	x	x	x	x	x	x							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									
SP-RECO	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x							

SP-OPNS										x									x		x	x	x	x																			
SP-ASSU	x	x	x	x	x	x				x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									
SP-PRV	x	x	x				x	x	x	x	x	x									x	x	x	x	x	x																	
SP-SLC	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							
SP-ISO	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x							
SP-PHY																																											
SP-CLD	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x									
SP-ROB																																											
SP-IDM											x	x																															

9 Risk assessment

After identifying the list of assets, threats and vulnerabilities, the next step is the risk assessment. The main concepts of risk assessment are illustrated in the following figure.

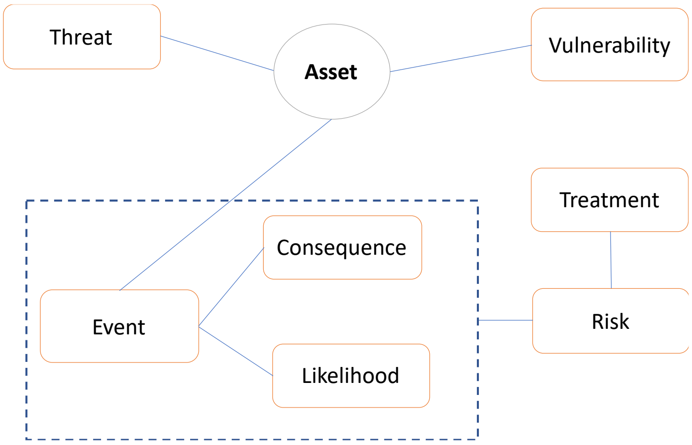


Figure 9-1 : Main concepts of risk assessment

The criticality of the identified threats in clause 7.4 were assessed based on the severity (consequence) and the likelihood of occurrence. Indications of severity level for each threat are given whether they are considered as high, medium, or low. This severity is a global perception of the risk based on its impacts. In practice, it varies strongly depending on the use cases and deployment/configuration models of the O-RAN system.

Moreover, the type of loss (availability, integrity and/ or confidentiality) has been assessed for each threat.

9.1 Determination of severity level process

The process followed to determine the severity level resulting from threats that successfully exploit vulnerabilities is based on Table 9-1 which includes the definition in terms of Privacy, Confidentiality, Integrity, Availability of the three severity levels ‘Low’, ‘Medium’ and ‘High’ shown here as green, yellow and red.

Table 9-1 defines what “low,” “medium” and “high” means.

The severity of an impact is expressed as follows:

- Level of impact for various threats on the properties Privacy, Confidentiality, Integrity, and Availability
- Scale of impact, depending on the number of affected O-RUs and /or O-DUs.
- Scale of impact depending on the Clock Model and Synchronization Topology configurations LLS-C1, LLS-C2, LLS-C3 and LLS-C4 [i.10].
- Adverse impacts depending on whether or not existing requirments and controls are already defined in the O-RAN requirments specifications.

Table 9-1 : Severity rating

Severity level	Privacy	Confidentiality	Integrity	Availability	Number of affected O-RUs/O-DUs (Only for Threats on O-RU, O-DU, FH interface)	Clock Model and Synchronization Topology configurations (only for Threats on S-PLANE)	Adverse impacts

Low	Disclosure of personal data which, with aggregation or processing, is unlikely to reveal unique subscriber's identity.	Disclosure of information for internal use. No specific impact on its disclosure	Minor/Unnoticeable effect on system behavior/output	Brief Interruption in operations. (Estimated in secs/mins/hours)	One O-DU is affected with its related O-RU	DoS attacks on LLS-C2 DoS attacks on LLS-C4	Already existing requirements and controls are defined in the O-RAN specifications to prevent, or at least significantly impede, the vulnerability from being exercised. Existing requirements and controls are only efficient to protect from both internal and external threats.
Medium	Disclosure of personal data (according to GDPR) which CAN be processed or aggregated to uniquely identify subscribers. **NOTE**: Personal data in GDPR means any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.	Disclosure of privileged information Access credentials/ configuration data, etc.	Alteration of some system functionality and features/output.	Short-term Interruption in operations. (Estimated in hours/Days)	One O-DU is affected with its related multiple O-RUs	DoS attacks on LLS-C1	Already existing requirements and controls are defined in the O-RAN specifications to prevent, or at least significantly impede, the vulnerability from being exercised. Existing requirements and controls are only efficient to protect from external threats.
High	Disclosure of sensitive personal data (GDPR special category). **NOTE**: Special data category in GDPR: data revealing racial or ethnic origin, political opinions, religious or philosophical beliefs, or trade union membership, and the processing of genetic data,	Disclosure of high value information, trade secrets, IP, mission critical data, master-keys, etc.	Complete change in normal System functioning	Prolonged interruption of operations. (Estimated in days/Weeks)	Several O-DUs and O-RUs are affected	DoS attacks on LLS-C3	No existing requirements and controls in the ORAN specifications yet to protect from internal and/or external threats

	biometric data for uniquely identifying a natural person, data concerning health or data concerning a natural person’s sex life or sexual orientation.						

NOTE 1: The severity level depends on the number of affected RUs and O-DUs. The severity level is consequently 'Low' in case of one affected O-RU, 'Medium' in case of one affected O-DU with its related multiple O-RUs, and 'High' for multiple affected O-DUs-O-RUs. Operators conducting a full risk analysis according to this report should conduct a use case-based analysis taking into account the likelihood and the real deployment of the O-RAN system.

NOTE 2:

Configuration LLS-C1

In LLS-C1, the network timing is distributed from O-DU to O-RU via direct connection between O-DU site and O-RU site. O-DU is acting as a master and directly synchronizes O-RU.

- DoS attacks against the master clock: There are two scenarios:
    1. Scenario 1: One O-RU is served by O-DU, therefore only one O-RU is affected. Consequently, the severity level is ‘Low’.
    2. Scenario 2: Multiple O-RUs are served by O-DU, therefore all those O-RUs are affected as the connection between O-DU and O-RU is point-to-point. Consequently, the severity level is ‘Low’.

Configuration LLS-C2

In LLS-C2, the network timing is distributed from O-DU to O-RU between O-DU sites and O-RU sites. One or more Ethernet switches are allowed in the fronthaul network. O-DU acting as master to distribute network timing toward O-RU.

- DoS attacks against the master clock within the O-DU may affect one or multiple O-RUs. In this configuration, a neighbor O-DU could act a backup and play the role of a master to distribute network timing to all the RUs belonging to the affected O-DU by reconfiguring the network of switches. Consequently, the severity level is ‘Low’.

Configuration LLS-C3

Frequency and time distribution is made by the fronthaul network itself (not by the O-DU). One or more PRTC/T-GM are implemented in the fronthaul network to distribute network timing toward O-DU and O-RU.

- DoS attacks against the master clock within the fronthaul network may affect multiple O-DUs with their related O-RUs. Consequently, the severity level is ‘High’.

Configuration LLS-C4

Local PRTC timing that provides time synchronization to the O-RU (it could be embedded in the O-RU).

- DoS attacks against the master clock may affect only one O-RU. Consequently, the severity level is ‘Low’.

According to what we described in the here above two notes, T-SPLANE-01 has been split in Table 9-4 according to the Clock Model and Synchronization Topology configurations C1, C2, C3, and C4.

NOTE: Adverse impacts: This factor depends on the normative O-RAN security requirements in the security requirements specification. For a threat without any requirement in front of it, the adverse impacts level is High. It is Medium or Low for a threat with related security requirements (see column ‘Assupltions’) helping in reducing its impact.

9.2 Determination of likelihood level process

The process followed to determine the likelihood level resulting from threats that successfully exploit vulnerabilities is based on Table 9-2 which includes the relevant factors that are considered. For each factor, three levels ‘Low’, ‘Medium’ and ‘High’ are shown in Table 9-2 as green, yellow and red.

Table 9-2 defines what “low,” “medium” and “high” means.

The likelihood level is expressed by four factors as follows:

- Adverse impacts: This factor depends on the existing normative O-RAN security requirements and controls. For example, the level is high in case no available O-RAN security requirements and controls in the O-RAN security specifications. In the risk assessment Table 9-4 in the column ‘Assumptions’, some of the agreed security controls by the O-RAN alliance have been stated for some threats as arguments for justifying the likelihood levels ‘Low’ or ‘Medium. This means that the likelihood level is estimated at Low’ or ‘Medium’, provided that the security controls are in place.

  NOTE: This factor is used to determine the likelihood level for the most categories of threats. It is also used as a relevant factor for severity for some categories of threats, in particular the O-Cloud threats category.

- Threat event initiation: This factor takes into consideration the capabilities that attackers possess and the potential entry points to exploit a vulnerability and initiate an attack. For example, it is high if an attack can be initiated from internet or untrusted network.

- Exposure: This factor is related to the number of external interfaces and/or services that are exposed to an attacker.

- Zero Trust Approach: Likelihood scoring considers a zero-trust architecture which protects against internal threat actors. Likelihood scores are higher for a zero-trust architecture (ZTA) because internal threats should be considered in addition to external threats. In a ZTA it cannot be assumed that perimeter defense is sufficient. As a result, scored Likelihood = Medium, at a minimum. Reconnaissance type attacks can be scored Likelihood = High while damaging/availability attacks can be scored Likelihood = Medium. The reason is that threat actors are less likely to perform damaging attacks that are quickly and easily detected. Advanced Persistent Threats (APTs) typically move laterally in anonymous fashion to prevent detection while providing reconnaissance (see O-RAN.SFG.Non-RT-RIC-Security-TR-v01.00).

Table 9-2 : Likelihood rating

Scale	Factors	Measure of Likelihood
High	Adverse impacts	No existing requirements and controls in the ORAN specifications yet to protect from internal and/or external threats
	Threat event initiation	Attack can be launched from the internet or untrusted network
	Exposure	System has a large amount of exposed interfaces (e.g. ORAN interfaces, multiple O-DU, multiple O-RU, multi administrators/customers)
	ZTA	Reconnaissance type attacks
	Open-source/COTS support	• No vulnerability handling and patch management in place: Several CVE have already been discovered; no regular patches provided to fix the detected vulnerabilities • Use of open-source module not supported by a broader community • Use of non popular COTS product
Medium	Adverse impacts	Already existing requirements and controls are defined in the O-RAN specifications to prevent, or at least significantly impede, the vulnerability from being exercised. Existing requirements and controls are only efficient to protect from external threats.
	Threat event initiation	Malicious user needs to have direct access to the target system
	Exposure	System has a medium amount of exposed interfaces (e.g. ORAN interfaces, one O-DU, multiple O-RU)

	ZTA	**Damaging/availability type attacks**
	Open-source/COTS support	• **Vulnerability handling and patch management in place but not efficient: Several CVE have already been discovered; no timely patches provided to fix the discovered vulnerabilities** • **Use of open-source module moderately supported by a broader community**
Low	**Adverse impacts**	**Already existing requirements and controls are defined in the O-RAN specifications to prevent, or at least significantly impede, the vulnerability from being exercised. Existing requirements and controls are only efficient to protect from both internal and external threats.**
	Threat event initiation	**The malicious user needs to have administrative or elevated privileges in the target system (external having internal privileges or internal having internal privileges)**
	Exposure	**Slightly exposed to external systems (e.g. one O-DU, one O-RU) (least privilege approach)**
	ZTA	**Perimeter defenses are sufficient. No potential for internal threats**
	Open-source/COTS support	• **Component supporting open-source module: a broader community is investing in** • **COTS modules are popular and widely used in critical infrastructure**

9.3 Evaluation of the risks process

The following risk assessment matrix is used to assess the risk score. The matrix takes as input two estimated qualitative inputs: (i) likelihood and (ii) the severity. One axis representing the probability of a risk scenario occurring and the other representing the damage it will cause (Severity). In the middle, you have scores based on their combined totals.
Using this formula RISK= Severity x Likelihood by a simple multiply the severity and likelihood scores to obtain the final risk score as shown in Table 9-3.

For example, if the estimated likelihood of a threat is low and the corresponding severity is high, then the risk is medium.

Table 9-3 : Risk assessment matrix

Severity	3-High	3-Medium	6-High	9-High
	2-Medium	2-Low	4-Medium	6-High
	1-Low	1-Low	2-Low	3-Medium
		1-Low	2-Medium	3-High

Likelihood

9.4 Risk assessment output

The following is the risk assessment output table which illustrates the different threats along with their impacts, the type of loss, the perceived severity/likelihood levels and the risk scoring.

1 Table 9-4 : Risk Assessment
2

THREAT ID	RISK DESCRIPTION	IMPACT DESCRIPTION	CIA	SEVERITY LEVEL	Likelihood LEVEL	Applied factors	Rationale	Considered Assumptions	Risk Score
T-O-RAN-01(NEAR RT RIC)	An attacker exploits insecure designs or lack of adoption of security controls (e.g. hardening) in O-RAN components causing: - Loss of service - Privacy issues - Performance issues in the system in O-RAN components	Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data	C, I, A	High	High	• Exposure (High): A1, O1, E2, xApps, rApps • Adverse impacts (High)	O-Cloud security hardening requirements have not been specified yet and it is unclear whether the industry practices sufficiently cover the threats outlined. O-RAN Alliance has specified security for O-RAN interfaces at the transport layers thereby mitigating access to O-RAN functions through the interfaces. The O-RAN Alliance has not yet specified security for protecting the platforms that host the O-RAN functions from physical or remote access.		High
T-O-RAN-01 (Non RT RIC + SMO)	An attacker exploits insecure designs or lack of adoption of security controls (e.g. hardening) in O-RAN components causing: - Loss of service - Privacy issues - Performance issues in the system in O-RAN components	Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data	C, I, A	High	High	• Exposure (High): A1, O1, O2, rApps • Adverse impacts (High)	O-Cloud security hardening requirements have not been specified yet and it is unclear whether the industry practices sufficiently cover the threats outlined. O-RAN Alliance has specified security for O-RAN interfaces at the transport layers thereby mitigating access to O-RAN functions through the interfaces. The O-RAN Alliance has not yet specified security for protecting the platforms that host the O-RAN functions from physical or remote access.		High

T-O-RAN-01 (O-CU)	An attacker exploits insecure designs or lack of adoption of security controls (e.g. hardening) in O-RAN components causing: - Loss of service - Privacy issues - Performance issues in the system in O-RAN components	Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data	C, I, A	High	High	• Exposure (High): O1, E2, administration interfaces • Adverse impacts (High)	O-Cloud security hardening requirements have not been specified yet and it is unclear whether the industry practices sufficiently cover the threats outlined. O-RAN Alliance has specified security for O-RAN interfaces at the transport layers thereby mitigating access to O-RAN functions through the interfaces. The O-RAN Alliance has not yet specified security for protecting the platforms that host the O-RAN functions from physical or remote access.		High
T-O-RAN-01 (O-DU)	An attacker exploits insecure designs or lack of adoption of security controls (e.g. hardening) in O-RAN components causing: - Loss of service - Privacy issues - Performance issues in the system in O-RAN components	Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data	C, I, A	High	High	• Exposure (High): E2, O1, FH • Adverse impacts (High)	O-Cloud security hardening requirements have not been specified yet and it is unclear whether the industry practices sufficiently cover the threats outlined. O-RAN Alliance has specified security for O-RAN interfaces at the transport layers thereby mitigating access to O-RAN functions through the interfaces. The O-RAN Alliance has not yet specified security for protecting the platforms that host the O-RAN functions from physical or remote access.		High
T-O-RAN-01 (O-RU)	An attacker exploits insecure designs or lack of adoption of security controls (e.g. hardening) in O-RAN components causing: - Loss of service - Privacy issues - Performance issues in the system in O-RAN components	Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data	C, I, A	High	High	• Exposure (High): FH, O1, physical • Adverse impacts (High)	O-Cloud security hardening requirements have not been specified yet and it is unclear whether the industry practices sufficiently cover the threats outlined. O-RAN Alliance has specified security for O-RAN interfaces at the transport layers thereby mitigating access to O-RAN functions through the interfaces. The O-RAN Alliance has not yet specified security for protecting the platforms that host the O-RAN		High

							functions from physical or remote access.		
T-O-RAN-02	An attacker exploits misconfigured or poorly configured O-RAN components causing: - Loss of service - Privacy issues - Performance issues in the system	Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data	C, I, A	High	High	• Threat event initiation (High) • Adverse impacts (High)	O-Cloud security hardening requirements have not been specified yet and it is unclear whether the industry practices sufficiently cover the threats outlined.		High
T-O-RAN-03	Attacks from the internet exploit weak authentication and access control to penetrate O-RAN network boundary, causing: - Flooding of the network - loss of service, performance issues - Unauthorized access to ORAN components	Denial of service for component access and/or function/service offered; Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data;	C, I, A	High	Medium	• Threat event initiation (High) • Adverse impacts (Medium)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for xApps yet. This attack to be performed requires multiple steps to be achieved by an attacker.	The O-RAN network elements should not be exposed to untrusted/ internet end points without network access control.	High
T-O-RAN-04	An attacker attempts to flooding the airlink signal (legitimate communications) through IoT devices causing: - Loss of service	Denial of service for component access and/or function/service offered	A	Medium	High	• Threat event initiation (High) • Adverse impacts (High)	O-RAN Alliance has not specified yet any security measures on flooding attacks through IoT devices.		High
T-O-RAN-05	An attacker penetrates and compromises the O-RAN system through the open O-RAN's Fronthaul, O1, O2, A1, and E2	Data tampering and information disclosure; Denial of service from within for component access and/or function/service offered; Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data;	C, I, A	High	Medium	• Threat event initiation (Medium) • Adverse impacts (Medium)	Existing controls are in place (moderately satisfactory), Malicious user needs to have direct (physical) access to the target system		High

T-O-RAN-06	An attacker exploits insufficient/improper mechanisms for authentication and authorization to compromise O-RAN components	Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data	C, I, A	High	High	• Threat event initiation (High) • Adverse impacts (Medium)	Existing controls are in place (moderately satisfactory), Attack can be launched from the internet or untrusted network	Authentication procedures are in place	High
T-O-RAN-07	An attacker compromises O-RAN monitoring mechanisms and log files integrity and availability	Compromise of availability and integrity of security event log files could conduct to delays, wrong audit results, delays in security restoration, threats persistence.	I, A	Medium	Medium	• Threat event initiation (Medium) • Adverse impacts (Medium)	Existing controls are in place (moderately satisfactory), Malicious user needs to have administrative or elevated privileges in the target system. It is a likely scenario after initial compromise of network elements.	Authentication procedures , patch management regular programmed update, vulnerability handling/regular scanning, SBOM are in place	Medium
T-O-RAN-08	An attacker compromises O-RAN data integrity, confidentiality and traceability	An attacker could, in such case, data tampering, information disclosure, spoofing identity, elevation of privilege, etc.	C, I	Medium	Medium	• Threat event initiation (Medium) • Adverse impacts (Medium)	Existing controls are in place (moderately satisfactory). Likely scenario after initial compromise of network elements with local data storage.	Protection at rest (e.g. HSM) is in place (operator decision),	Medium
T-O-RAN-09	An attacker compromises O-RAN components integrity and availability	An attacker could, in such case, cause denial-of-service, data tampering, information disclosure, spoofing identity, etc.	I, A	High	Medium	• Threat event initiation (Medium) • Adverse impacts (Medium)	Existing controls are in place (moderately satisfactory), Malicious user needs to have direct access to the target system		High
T-ORAN-10	A successful attack could: -compromise confidentiality, integrity and availability due to the prolonged undetected presence of an attacker in the network	confidentiality, integrity, availability	CIA	High	High	• Impact on confidentiality, integrity and availability (High) • Threat event initiation (High)	- Impact on confidentiality, integrity, and availability (High): fragmented logs lead to undetected breaches, tampering, and delayed responses, causing significant data loss, integrity issues, and system disruptions. - Threat event initiation (High): Adversary behaviour generally goes undiscovered.		High
T-FRHAUL-01	An attacker penetrates O-DU and beyond through O-RU (bidding-down attack)	Data tampering and information disclosure;	C, I	High	Medium	• Threat event initiation (Medium) • Adverse impacts (Medium) • Exposure (Medium)	System has an amount of exposed interfaces: multiple O-DU, multiple O-RU, FH interface. It is a possible attack, however needs physical access and sophistication to execute		High

T-FRHAUL-01A	An attacker penetrates O-DU and beyond through O-RU (bidding-down attack)	Spoofing	C, I	High	Medium	• Threat event initiation (Medium) • Adverse impacts (Medium) • Exposure (Medium)	System has an amount of exposed interfaces: multiple O-DU, multiple O-RU, FH interface. It is a possible attack, however needs physical access and sophistication to execute		High
T-FRHAUL-02	Unauthorized access to the Open Front Haul Ethernet L1 physical layer interface (cables and connections)	It provides a means to launch attacks on the confidentiality of the Open Front Haul system.	C	High	Low	• Threat event initiation (Low) • Adverse impacts (High)	It is a possible attack, however needs physical access and sophistication to execute		Medium
T-FRHAUL-03	Unauthorized access to the Open Front Haul Ethernet L1 physical layer interface (cables and connections)	It provides a means to launch attacks on the availability of the Open Front Haul system.	A	High	Low	• Threat event initiation (Low) • Adverse impacts (High)	It is a possible attack, however needs physical access and sophistication to execute		Medium
T-MPLANE-01	An attacker attempts to intercept the Fronthaul (MITM) over M Plane to obtain protected information	Passive wiretapping	C	Medium	Low	• Threat event initiation (Low) • Adverse impacts (Medium)	It is a possible attack, however needs physical access and sophistication to execute	TLS with PKI is supported, it is up to MNO, the likelihood is low provided that MNOs use TLS over the M-Plane	Low
T-MPLANE-02	An attacker attempts to intercept the Fronthaul (MITM) over M Plane to alter m-plane data	Intercepting and modifying of the M plane messages.	I	Medium	Low	• Threat event initiation (Low) • Adverse impacts (Medium)	It is a possible attack, however needs physical access and sophistication to execute	TLS with PKI is supported, it is up to MNO, the likelihood is low provided that MNOs use TLS over the M-Plane	Low
T-MPLANE-03	An attacker attempts to intercept the Fronthaul (MITM) over M Plane to disrupt services	Denial of service	A	Medium	Low	• Threat event initiation (Low) • Adverse impacts (Medium)	It is a possible attack, however needs physical access and sophistication to execute	TLS with PKI is supported, it is up to MNO, the likelihood is low provided that MNOs use TLS over the M-Plane	Low
T-SPLANE-01-C1 (one O-RU scenario)	DoS attack on an O-DU acting as master to distribute network timing toward O-RU based on point-to-point connection in LLS-C1. In this scenario, only one O-RU is connected to O-DU,	This attack may cause performance degradation or interruption of services to only one O-RU that rely on accurate time from the affected O-DU. The severity level is consequently 'Low'.	A	Low	Low	• Exposure (Low) • Threat event initiation (Medium)	Slightly exposed to external systems: one O-RU. It is a possible attack, however needs physical access and sophistication to execute	Access control on the CUSM-Plane that mitigates unauthorized access by an insider are in place. 802.1x	Low

	therefore only that O-RU is affected.							protocol is supported it can reduce the likelihood of this attack.	
T-SPLANE-01-C1 (multiple O-RUs scenario)	DoS attack on an O-DU acting as master to distribute network timing toward O-RU based on point-to-point connection in LLS-C1. In this scenario, multiple O-RUs are connected to O-DU, therefore those O-RUs are affected.	This attack may cause performance degradation or interruption of services to all the RUs that rely on accurate time from the affected O-DU. The severity level is consequently 'Medium'.	A	Medium	Medium	• Exposure (Medium) • Threat event initiation (Medium)	System has a medium amount of exposed interfaces: multiple O-RUs. It is possible attack, however needs physical access and sophistication to execute		Medium
T-SPLANE-01-C2	DoS attack on an O-DU acting as master to distribute network timing toward O-RU in LLS-C2. One or more Ethernet switches are allowed between the central site (hosting O-DUs) and the remote sites (hosting O-RUs).	This attack may cause performance degradation or interruption of services to all the RUs that rely on accurate time from the affected O-DU. In this configuration, a neighbor O-DU could act a backup and play the role of a master to distribute network timing to all the RUs belonging to the affected O-DU by reconfiguring the network of switches. The severity level is consequently 'Low'.	A	Low	Medium	• Exposure (Medium) • Threat event initiation (Medium)	System has a medium amount of exposed interfaces. It is a possible attack, however needs physical access and sophistication to execute	Access control on the CUSM-Plane that mitigates unauthorized access by an insider are in place. 802.1x protocol is supported it can reduce the likelihood of this attack.	Low
T-SPLANE-01-C3	DoS attack against a Master clock in the LLS-C3 configuration	In this configuration, the frequency and timing distribution is made by the fronthaul network (not by O-DU). DoS attack against a master clock may cause performance degradation or interruption of services to all the RUs and DUs that rely on accurate time from the affected master clock in the fronthaul network. The severity level is consequently 'High'.	A	High	Medium	• Exposure (Medium) • Threat event initiation (Medium)	System has a medium amount of exposed interfaces. It is a possible attack, however needs physical access and sophistication to execute		High
T-SPLANE-01-C4	DoS attack against a Master clock in the LLS-C4 configuration	In this configuration, the time source could be locally embedded in the RU itself. DoS attack in the time source may cause performance degradation or interruption of services to only one O-RU where the time source is embedded. The severity level is consequently 'Low'.	A	Low	Low	• Exposure (Low) • Threat event initiation (Medium)	Slightly exposed to external systems: one O-RU. It is a possible attack, however needs physical access and sophistication to execute	Access control on the CUSM-Plane that mitigates unauthorized access by an insider are in place. 802.1x protocol is supported it can reduce the likelihood of this attack.	Low

T-SPLANE-02	Impersonation of a Master clock (Spoofing) within a PTP network with a fake ANNOUNCE messages	Degradation in the accuracy of time may cause DoS to applications on all the RUs that rely on accurate time, potentially bringing down the cell. A cell outage caused by misaligned time, may further impact performance in connected neighboring cells.	A	High	Low	• Threat event initiation (Medium) • Adverse impacts (Low)	Existing controls are in place to prevent, or at least significantly impede, the vulnerability from being exercised. It is a possible attack, however needs physical access and sophistication to execute	Access control on the CUSM-Plane that mitigates unauthorized access by an insider are in place. 802.1x protocol is supported it can reduce the likelihood of this attack.	Medium
T-SPLANE-03	A Rogue PTP Instance wanting to be a Grand Master by sending manipulated/malicious ANNOUNCE messages declaring him to be the best clock in the network	Degradation in the accuracy of time may cause DoS to applications on all the RUs that rely on accurate time, potentially bringing down the cell. A cell outage caused by misaligned time, may further impact performance in connected neighboring cells.	A	High	Low	• Threat event initiation (Medium) • Adverse impacts (Low)	Existing controls are in place to prevent, or at least significantly impede, the vulnerability from being exercised. It is a possible attack, however needs physical access and sophistication to execute	Access control on the CUSM-Plane that mitigates unauthorized access by an insider are in place. 802.1x protocol is supported it can reduce the likelihood of this attack.	Medium
T-SPLANE-04	Selective interception and removal of PTP timing packets	Clock degradation in attacked nodes. Removing all packets or random packets may push the clocks in attacked nodes into free running mode. Degradation in the accuracy of time may cause DoS to applications on all the RUs that rely on accurate time, potentially bringing down the cell. A cell outage caused by misaligned time, may further impact performance in connected neighboring cells.	A	High	Low	• Threat event initiation (Medium) • Adverse impacts (Low)	Existing controls are in place to prevent, or at least significantly impede, the vulnerability from being exercised. It is a possible attack, however needs physical access and sophistication to execute	Access control on the CUSM-Plane that mitigates unauthorized access by an insider are in place. 802.1x protocol is supported it can reduce the likelihood of this attack.	Medium
T-SPLANE-05	Packet delay manipulation attack	Degradation in the accuracy of time may cause DoS to applications on all the RUs that rely on accurate time, potentially bringing down the cell. A cell outage caused by misaligned time, may further impact performance in connected neighboring cells.	A	High	Medium	• Threat event initiation (Medium) • Adverse impacts (Medium)	Existing controls are in place to prevent (moderately satisfactory). It is a possible attack, however needs physical access and sophistication to execute	802.1x protocol is supported it can reduce the likelihood of this attack.	High

T-CPLANE-01	Spoofing of DL C-plane messages	The lack of authentication could allow an adversary to inject own DL C-plane messages that falsely claiming to be from the associated O-DU. As a result, it would block the O-RU to process the corresponding U-Plane packets, leading to temporarily DoS. (dropping the entire DL C-plane messages would achieve same goal)	A	Medium	Low	• Threat event initiation (Medium) • Adverse impacts (Low)	Existing controls are in place to prevent, or at least significantly impede, the vulnerability from being exercised. It is a possible attack, however needs physical access and sophistication to execute	802.1x at the ethernet level ensures authentication and authorization for communication over FH interface, not sure that this control reduce the risk of spoofing of c-plane at a low level. Mitigations related to monitoring and configuration of network nodes are in place	Low
T-CPLANE-02	Spoofing of UL C-plane messages	The lack of authentication could allow an adversary to inject own UL C-plane messages that falsely claiming to be from the associated O-DU. As a result, temporarily limited cell performance (or even DoS) on cells served by the O-RU and in addition a consequential threat to all O-RUs parented to that O-DU might exist. (dropping the entire UL C-plane messages would achieve same goal)	A	Medium	Low	• Threat event initiation (Medium) • Adverse impacts (Low)	Existing controls are in place to prevent, or at least significantly impede, the vulnerability from being exercised. It is a possible attack, however, needs physical access and sophistication to execute	802.1x at the ethernet level ensures authentication and authorization for communication over FH interface, not sure that this control reduce the risk of spoofing of c-plane at a low level. Mitigations related to monitoring and configuration of network nodes are in place	Low
T-UPLANE-01	An attacker attempts to intercept the Fronthaul (MITM) over U Plane to obtain user data (PDCP protocol is used)	For the transported U-Plane data an attacker could potentially do threats, such as passive wiretapping, but would need to break PDCP Security prior to any content access.	C	Medium	Low	• Threat event initiation (Low) • Adverse impacts (Medium)	Existing controls are in place to prevent, or at least significantly impede, the vulnerability from being exercised. It is a possible attack, however, needs physical access and sophistication to execute	802.1x protocol is supported it can reduce the likelihood of this attack.	Low
T-UPLANE-02	An attacker attempts to intercept the Fronthaul (MITM) over U Plane to	For the transported U-Plane data an attacker could potentially do threats, such as passive	I	Medium	Low	• Threat event initiation (Low)	Existing controls are in place to prevent, or at least significantly impede, the vulnerability from	802.1x protocol is supported it can reduce the	Low

	modify u-plane data (PDCP protocol is used)	wiretapping, but would need to break PDCP Security prior to any content access.				• Adverse impacts (Medium)	being exercised. It is a possible attack, however, needs physical access and sophistication to execute	likelihood of this attack.	
T-UPLANE-03	An attacker attempts to intercept the Fronthaul (MITM) over U Plane to disrupt services (PDCP protocol is used)	For the transported U-Plane data an attacker could potentially do threats, such as passive wiretapping, but would need to break PDCP Security prior to any content access.	A	Medium	Low	• Threat event initiation (Low) • Adverse impacts (Medium)	Existing controls are in place to prevent, or at least significantly impede, the vulnerability from being exercised. It is a possible attack, however, needs physical access and sophistication to execute	802.1x protocol is supported it can reduce the likelihood of this attack.	Low
T-UPLANE-04	Spoofing and unauthorized access of U-Plane data packets	An attacker could degrade service quality, disrupt legitimate data flow, and potentially cause a DoS.	NA	Medium	Low	• Threat event initiation (Low) • Adverse impacts (Medium)	Existing controls are in place to prevent, or at least significantly impede, the vulnerability from being exercised. It is a possible attack, however, needs physical access and sophistication to execute	802.1x protocol is supported it can reduce the likelihood of this attack.	Low
T-ORU-01-a	An attacker stands up a rogue O-RU (standalone) - a false base station	This opens the door to subscriber's identity interception/disclosure and unauthorized user tracking attacks (privacy breach).	C, I	High	Medium	• Threat event initiation (Medium) • Adverse impacts (Medium)	Existing controls are in place to prevent (moderately satisfactory). It is a possible attack, however needs physical access and sophistication to execute	Security measures already defined by 3GPP, monitoring/detection mechanisms of a rogue ORU are in place	High
T-ORU-01-b	An attacker stands up a rogue O-RU attacking O-DU and beyond (core network)	It provides a means to launch attacks on the availability, integrity, and confidentiality of the Open Front Haul system, ODUs and beyond in the core network.	C, I	High	Low	• Threat event initiation (Medium) • Adverse impacts (Low)	Existing controls are in place to prevent, or at least significantly impede, the vulnerability from being exercised. It is a possible attack, however needs physical access and sophistication to execute	802.1x protocol is supported it can reduce the likelihood of this attack.	Medium
T-NEAR-RT-01	Malicious xApps can exploit UE identification, track UE location and change UE priority	An xApp can receive order via A1 to control a certain UE and if a malfunctioning xApp receives an order to prioritize this UE, then the owner of the malfunctioning xApp knows a VIP that they want to track in a certain area. With this command exposure, the attacker can obtain a rough location of a very important person and change the order from prioritize to deprioritize for a UE; Interception of UE identifier	C, I	High	High	• Threat event initiation (High) • Adverse impacts (High) • Exposure (High)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC. Further, there is no testing framework in place for xApps yet.		High
T-NEAR-RT-02	Risk of a malicious xApp on Near-RT RIC to obtain protected information	Deployment of malicious xApps may allow unauthorized access to E2 Nodes, abuse of radio network information, or exploit UE identification and location.	C, I	High	High	• Threat event initiation (High) • Exposure (High)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC. Further, there is no testing framework in place for xApps yet.		High

T-NEAR-RT-02A	Risk of a malicious xApp on Near-RT RIC impacting service availability	Deployment of malicious xApps may allow impacting service or exploit slice priority.	A	High	High	• Threat event initiation (High) • Adverse impacts (High)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC. Further, there is no testing framework in place for xApps yet.		High
T-NEAR-RT-03	Near-RT RIC APIs can be compromised and manipulated due to lack, incorrect or weak authentication mechanism	Near-RT RIC data around services and UEs can be eavesdropped.	C	High	High	• Threat event initiation (High) • Exposure (High)	O-RAN Alliance has not specified yet any Near-RT RIC APIs measures.		High
T-NEAR-RT-03A	Near-RT RIC APIs can be compromised and manipulated due to lack, incorrect or weak authentication mechanism	Unauthenticated APIs can be manipulated causing services disruptions in RAN network	A	High	High	• Threat event initiation (High) • Adverse impacts (High)	O-RAN Alliance has not specified yet any Near-RT RIC APIs measures.		High
T-NEAR-RT-04	Resources and services provided by Near-RT RIC platform and xApps via APIs can be abused and/or misused	Near-RT RIC data around services and UEs can be eavesdropped by xApps without proper permissions.	C	High	High	• Threat event initiation (High) • Adverse impacts (High) • Exposure (High)	O-RAN Alliance has not specified yet any Near-RT RIC APIs measures.		High
T-NEAR-RT-04A	Resources and services provided by Near-RT RIC platform and xApps via APIs can be abused and/or misused	Abuse of resources and misuse of services can produce disruptions and/or outages in the network.	A	High	High	• Threat event initiation (High) • Adverse impacts (High) • Exposure (High)	O-RAN Alliance has not specified yet any Near-RT RIC APIs measures.		High

T-NEAR-RT-05	Risk of deployment of a malicious, non-uniquely identified xApps using a trusted xAppID to access resources and services which they are not entitled to use.	theft of services, data leakage	C, I	High	High	• Threat event initiation (High) • Exposure (High)	O-RAN Alliance has not specified yet any xApp security measures around the xAppID yet.		High
T-NONRTRIC-01	An attacker gains access to the Non-RT RIC through the SMO to cause a denial of service or degrade the performance of the Non-RT-RIC	Non-RT RIC would not be able to: •monitor or trace the network to understand the effect of policy on performance in Near-RT RIC •update A1 policy •provide exposure and secure delivery of A1 Enrichment Information to Near-RT RIC •setup access control rules and the selection of which Enrichment Information ID (EiId) is exposed to a near-RT RIC	A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any security measures around the authentication and access control to the Non RT-RIC.		High
T-NONRTRIC-02	An attacker gains access to the Non-RT RIC through the SMO for UE tracking	Attacker has access to sensitive data and is able to track a UE	C	High	High	• ZTA (High) • Adverse impacts (High)	O-RAN Alliance has not specified yet any security measures around the authentication and access control to the Non RT-RIC.		High
T-NONRTRIC-03	An attacker gains access to the Non-RT RIC through the SMO to cause Data Corruption/Modification	A malicious actor who gains unauthorized access to the Non-RT-RIC can modify policy to pass a “False Policy” to the Near-RT-RIC to degrade performance or cause an outage.	C	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any security measures around the authentication and access control to the Non RT-RIC.		High
T-xAPP-01	An attacker exploits xApps vulnerabilities and misconfiguration to alter data transmitted over A1 or E2 interfaces.	If attackers can find exploitable xApp, they can disrupt the offered network service and potentially take over another xApp or the whole Near-RT RIC. The actual consequences may vary. For example, an attacker may gain the ability to alter data transmitted over A1 or E2 interfaces, extract sensitive information, etc.	I	High	High	• Threat event initiation (High) • Adverse impacts (High) • Exposure (High)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for xApps yet.		High
T-xAPP-01A	An attacker exploits xApps vulnerabilities and misconfiguration to extract sensitive information.	If attackers can find exploitable xApp, they can disrupt the offered network service and potentially take over another xApp or the whole Near-RT RIC. The actual consequences may vary. For example, an attacker may gain the ability to alter data transmitted over A1 or E2 interfaces, extract sensitive information, etc.	C	High	High	• Threat event initiation (High) • Adverse impacts (High) • Exposure (High)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for xApps yet.		High

T-xAPP-01B	An attacker exploits xApps vulnerabilities and misconfiguration to disrupt Near-RT RIC functions	If attackers can find exploitable xApp, they can disrupt the offered network service and potentially take over another xApp or the whole Near-RT RIC. The actual consequences may vary. For example, an attacker may gain the ability to alter data transmitted over A1 or E2 interfaces, extract sensitive information, etc.	A	High	High	• Threat event initiation (High) • Adverse impacts (High) • Exposure (High)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for xApps yet.		High
T-xAPP-01C	An attacker exploits xApps vulnerabilities and misconfiguration to gain unauthorized control over Near-RT RIC	If attackers can find exploitable xApp, they can disrupt the offered network service and potentially take over another xApp or the whole Near-RT RIC. The actual consequences may vary. For example, an attacker may gain the ability to alter data transmitted over A1 or E2 interfaces, extract sensitive information, etc.	C, I, A	High	High	• Threat event initiation (High) • Adverse impacts (High) • Exposure (High)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for xApps yet.		High
T-xAPP-02	Conflicting xApps impact O-RAN system functions to degrade performance or trigger a DoS	An attacker can utilize a malicious xApp that intentionally triggers RRM decisions conflicting with the O-gNB internal decisions to create denial of service or performance degradation.	A	High	Medium	• Threat event initiation (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for xApps yet.		High
T-xAPP-03	An attacker compromises xApp isolation	Gaining unauthorized access to the underlying system provides new opportunities to exploit vulnerabilities in other xApps or O-RAN components to intercept and spoof network traffic, to degrade services (DoS), etc.	C, I, A	High	Medium	• Threat event initiation (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for xApps yet.		High
T-xApp-04	False or malicious A1 policies modify behavior of xApps	A malicious A1 policy can exploit xApp functionality to trigger a DoS, affect performance, or locate a subscriber.	I, A	High	Medium	• Threat event initiation (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any xApp security measures around the Onboarding onto SMO and deployment onto Near RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for xApps yet. This attack to be performed requires multiple steps to be achieved by an attacker.		High

T-rAPP-01	Conflicting rApps impact O-RAN system functions to degrade performance or trigger a DoS	rApps in the Non-RT RIC performing different functions can be provided by different vendors. This creates the risk that different rApps will take conflicting decisions to set conflicting policies. This can result in performance degradation or outage.	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any rApp security measures around the Onboarding onto SMO and deployment onto Non RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for rApps yet.		High
T-rAPP-02	An attacker exploits rApp vulnerability for data breach or denial of service	Vulnerabilities can potentially exist in any rApp. If attackers can find exploitable rApp, they can disrupt the offered network service and potentially take over another rApp or the non-RT RIC. The consequences may vary. For example, an attacker may gain the ability to alter data transmitted over A1 interface, extract sensitive information, etc.	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any rApp security measures around the Onboarding onto SMO and deployment onto Non RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for rApps yet.		High
T-rAPP-03	An attacker exploits rApps misconfiguration	Security misconfiguration, such as open ports or enabled unused protocols, can potentially exist in an rApp. If attackers can find exploitable rApp, they can disrupt the offered network service and potentially take over another rApp or the whole non-RT RIC. The actual consequences may vary. For example, an attacker may gain the ability to alter data transmitted over A1 interface, extract sensitive information, etc.	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any rApp security measures around the Onboarding onto SMO and deployment onto Non RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for rApps yet.		High
T-rAPP-04	An attacker bypasses authentication and authorization	An Attacker can exploit an rApp that has weak or misconfigured authentication and authorization to gain access to the rApp and pose as a tenant.	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any rApp security measures around the Onboarding onto SMO and deployment onto Non RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for rApps yet.		High

T-rAPP-05	An attacker deploys and exploits malicious rApp	An untrusted source may intentionally provide a malicious rApp. A trusted source may have a backdoor intentionally inserted in the rApp. If attackers can find exploitable rApp, they can disrupt the offered network service and potentially take over another rApp or the whole Non-RT RIC. Malicious rApps could impact Non-RT RIC functions such as AI/ML model training, A1 policy management, Enrichment information management, Network Configuration Optimization in the purpose of performance degradation, DoS,	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any rApp security measures around the Onboarding onto SMO and deployment onto Non RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for rApps yet.		High
T-rAPP-06	An attacker bypasses authentication and authorization using an injection attack	It is possible that an attacker to submit requests without prior authentication and authorization by executing an injection attack to manipulate configurations, access logs, perform remote code execution, etc.	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any rApp security measures around the Onboarding onto SMO and deployment onto Non RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for rApps yet.		High
T-rAPP-07	rApp exploits services	A malicious rApp or a trusted but compromised rApp can exploit services such as O1 services across the R1 interface	A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any rApp security measures around the Onboarding onto SMO and deployment onto Non RT-RIC, authentication and access control, secure configuration, etc. Further, there is no testing framework in place for rApps yet.		High

T-PNF-01	An attacker compromises a PNF to launch attacks against VNFs/CNFs	Data tampering and information disclosure; Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data;	C, I	High	Medium	• Threat event initiation (Medium) • Adverse impacts (Medium)	This is a likely attack but may need physical access to the PNF.		High
T-PNF-01A	An attacker compromises a PNF to launch Denial of Service attacks against VNFs/CNFs	Denial of service from within for component access and/or function/service offered	A	High	Medium	• Threat event initiation (Medium) • Adverse impacts (Medium)	This is a likely attack but may need physical access to the PNF.		High
T-SMO-01	An attacker can exploit the misconfigured/poorly implemented authentication mechanism on SMO functions	The data stored in the SMO may be exposed/manipulated to an attacker.	C, I	High	High	• ZTA (High) • Threat event initiation (High)	O-RAN Alliance has not specified yet any SMO security measures around authentication, access control, secure configuration, etc.		High
T-SMO-02	An attacker can exploit the misconfigured/poorly implemented authorization on SMO functions	An attacker can be able to perform certain actions, e.g. disclose O-RAN sensitive information or alter O-RAN components.	C, I, A	High	High	• ZTA (High) • Threat event initiation (High)	O-RAN Alliance has not specified yet any SMO security measures around authentication, access control, secure configuration, etc.		High
T-SMO-03	Overload DoS attacks at SMO	Inability to deal with such events affects availability of SMO data and functions.	A	Medium	Medium	• ZTA (Medium) • Threat event initiation (High)	O-RAN Alliance has not specified yet any SMO security measures around authentication, access control, secure configuration, etc.		Medium
T-OPENSRC-01	Developers use SW components with known vulnerabilities and untrusted libraries that can be exploited by an attacker through a backdoor attack	Attackers can exploit a vulnerability on the open source code and infects a hypervisor, operating system, VM or container with a malware.	C, I, A	High	High	Open-source/COTS support (High)	Vulnerability handling and patch management are not yet defined by O-RAN Alliance. Several CVE have already been discovered on open source software.		High

T-OPENSRC-02	A trusted developer intentionally inserts a backdoor into an open source code O-RAN component.	Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data;	C, I, A	High	Medium	Open-source/COTS support (High)	Vulnerability handling and patch management are not yet defined by O-RAN Alliance. Several CVE have already been discovered on open source software.		High
T-PHYS-01	An intruder into a site gains physical access to O-RAN components to cause damage or access sensitive data	Data tampering and information disclosure; Denial of service from within for component access and/or function/service offered; Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data;	C, I, A	High	Medium	Exposure (Medium)	O-RAN system has many external interfaces. Different O-Cloud deployment models can be used to implement O-RAN. Several scenarios to implement O-RUs and O-DUs are supported by O-RAN.		High
T-PHYS-02	An intruder into the exchange over the Fronthaul cable network attempts to gain electronic access to cause damage or access sensitive data	Data tampering and information disclosure; Denial of service from within for component access and/or function/service offered; Unauthenticated/unauthorized access of the O_RAN component leads to compromised performance and/or function/service, lateral attack towards other O-RAN system component(s) from inside, and loss/stolen/tampering of sensitive data;	C, I, A	High	Medium	Exposure (Medium)	O-RAN system has many external interfaces. Different O-Cloud deployment models can be used to implement O-RAN. Several scenarios to implement O-RUs and O-DUs are supported by O-RAN.		High
T-RADIO-01	Disruption through radio Jamming , Sniffing and Spoofing	Service disruption and information exposure	C, I, A	High	High	Exposure (High)	These attacks are common and not specific to O-RAN. They are likely to occur, hence they need more investigation and consideration. Mitigations to reduce these types of attacks should be defined by O-RAN Alliance.		High
T-RADIO-02	DoS attacks on cognitive radio networks	Service disruption	A	Medium	High	Exposure (High)	These attacks are common and not specific to O-RAN. They are likely to occur, hence they need more investigation and consideration. Mitigations to reduce these types of attacks should be defined by O-RAN Alliance.		High

T-R1-01	A malicious actor gains unauthorized access to R1 services	"Service management and exposure services Producer" determines whether the Service Producer is authorized to produce the service. An attacker can perform a spoofing attack to gain unauthorized access to R1 services.	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any R1 security measures.		High
T-R1-02	Attacker modifies Service Heartbeat message to cause Denial of Service	Attacker can exploit the Service Heartbeat on the R1 by modifying or inserting heartbeat messages to cause denial of service	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any R1 security measures.		High
T-R1-03	Malicious actor bypasses authentication to Request Data	Attacker can exploit password-based authentication on the R1 to request unauthorized data. Weak password management can easily be exploited. (Certificate-based mutual authentication using TLS and PKI X.509 certificates is recommended).	C, I, A	High	High	• ZTA (High) • Adverse impacts (High)	O-RAN Alliance has not specified yet any R1 security measures.		High
T-R1-04	Malicious actor bypasses authorization to Discover Data	"Data registration and discovery service producer" determines whether the Data Producer is authorized to produce the data types. An attacker can perform a spoofing attack to discover available data.	C, I, A	High	High	• ZTA (High) • Adverse impacts (High)	O-RAN Alliance has not specified yet any R1 security measures.		High
T-R1-05	A malicious actor gains unauthorized access to data	An attacker can perform a spoofing attack to exploit the Data request and subscription service for the purpose to gain unauthorized access to data.	C, I, A	High	High	• ZTA (High) • Adverse impacts (High)	O-RAN Alliance has not specified yet any R1 security measures.		High
T-R1-06	Malicious actor modifies a Data Request	Data Consumers consume the "Data request and subscription service" to request data instances or subscribe to them. An attacker can modify a request to force the consumer to receive a different data set then that intended. Without checks, the received data could be processed, leading to erroneous decisions or triggers.	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any R1 security measures.		High
T-R1-07	Malicious actor snoops Data Delivery to the Data Consumer	Data delivery messages relate to a particular data request or subscription. The data can be delivered to the Data Consumer in different ways, including:	A	High	High	• ZTA (High) • Adverse impacts (High)	O-RAN Alliance has not specified yet any R1 security measures.		High

		• as part of the payload of a data delivery message, • as a data stream, • from e.g., a REST endpoint, a message bus or object store location. An attacker can perform snooping, injection, or modification attacks in the Delivery of Data process.							
T-A1-01	Untrusted peering between Non-RT-RIC and Near-RT-RIC	Malicious Non-RT-RIC peers with a Near-RT-RIC over the A1 interface, or a malicious Near-RT-RIC peers with a Non-RT-RIC over the A1 interface, due to weak mutual authentication.	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any A1 security measures.		High
T-A1-02	Malicious function or application monitors messaging across A1 interface	Attacker gains access to A1 messaging for reconnaissance	C, I, A	High	High	• ZTA (High) • Adverse impacts (High)	O-RAN Alliance has not specified yet any A1 security measures.		High
T-A1-03	Malicious function or application modifies messaging across A1 interface	Internal threat actor can gain access to the messaging across the A1 interface for a MiTM attack to modify or inject policy. This can result in the Near-RT RIC receiving malicious policy.	C, I, A	High	Medium	• ZTA (Medium) • Adverse impacts (High)	O-RAN Alliance has not specified yet any A1 security measures.		High
T-A1-04	Unauthorized access to Non-RT-RIC- or Near-RT-RIC- resources	A malicious actor can gain access to Near-RT-RIC resources or Non-RT-RIC resources over the A1 interface.	C, I, A	High	High	• ZTA (High) • Threat event initiation (High)	ZTA: ease of performing reconnaissance attacks without immediate detection Threat event initiation: simple to execute for sophisticated inside actors		High
T-GEN-01-a	A successful attack could: - Compromise the deployed VNF/CNF	Spoofing, Tampering, Information disclosure, Elevation of Privilege	C, I	Medium	High	• Adverse impacts (Medium), • ZTA (High)	Adverse impacts (Medium) - Only one VNF/CNF might be affected, Existing requirements and controls are defined in the O-RAN specifications that may impede successful exercise of the vulnerability. ZTA (High): Reconnaissance and availability type attacks	SBOM requirements REQ-SEC-SYS-1	High
T-GEN-01-b	A successful attack could: - Deployment of malicious VM/Container (Lack of isolation) - Exploit host access to escape the host and reach hardware server then the malicious VM/Container can gain root access to the whole server where it resides	Spoofing, Tampering, Information disclosure, Elevation of Privilege	C, I	High	High	• Adverse impacts (High), • ZTA (High)	Adverse impacts (High) - Multiple VNFs/CNFs might be affected ZTA (High): Reconnaissance and availability type attacks	SBOM requirements REQ-SEC-SYS-1	High
T-GEN-02	A successful attack could: - Bypass access controls placed on various	Spoofing, Tampering, Information disclosure, Elevation of Privilege	C, I	Medium	High	• Adverse impacts (Medium), • ZTA (High)	Adverse impacts (Medium) - Requirements are in place for user authentication and authorization	REQ-SEC-PASS-1	High

	resources on O-Cloud - Gain increased privilege to specific O-Cloud services - Access to restricted areas of the O-Cloud network						ZTA (High): Reconnaissance type attacks	REQ-SEC-OCLOUD-1 REQ-SEC-OCLOUD-2	
T-GEN-03-a	A successful attack could: - Make use of a untrusted VM/Container that runs on top of a trusted Hypervisor/Container Engine	Tampering, Information disclosure	C, I	Medium	High	• Adverse impacts (Medium), • ZTA (High)	Adverse impacts (Medium) - Only one VNF/CNF might be affected ZTA (High): Reconnaissance type attacks		High
T-GEN-03-b	A successful attack could: - Make use of a trusted VM/Container that runs on top of an untrusted Hypervisor/Container Engine to intercept communication, replace strong or use weak cryptographic keys, etc.	Tampering, Information disclosure	C, I	High	High	• Adverse impacts (High), • ZTA (High)	Adverse impacts (High) - Multiple VNFs/CNFs might be affected ZTA (High): Reconnaissance and availability type attacks		High
T-GEN-03-C	A successful attack could: - Make use of a trusted VM/Container that runs on top of a trusted Hypervisor/Container Engine that runs on top of an untrusted hardware to intercept communication, replace strong or use weak cryptographic keys, etc.	Tampering, Information disclosure	C, I	High	High	• Adverse impacts (High), • ZTA (High)	Adverse impacts (High) - Multiple VNFs/CNFs might be affected ZTA (High): Reconnaissance and availability type attacks		High
T-GEN-04	A successful attack could: - Compromise the availability of O-Cloud services - Compromise the confidentiality/integrity of O-Cloud services by extracting/modifying critical application data	Information disclosure, Denial of Service	C, A	High	High	• Adverse impacts (High), • ZTA (High)	Adverse impacts (High) – No existing controls for interfaces in O-Cloud ZTA (High): Reconnaissance and availability type attacks		High
T-GEN-05 (a)	A successful attack could: - view insecurely stored credentials and cryptographic materials	Information disclosure, Elevation of Privilege	C	Medium	High	Adverse impacts (Medium), ZTA (High)	Adverse impacts (Medium) – Requirements are defined for sensitive data protection in the O-RAN security specifications ZTA (High): Reconnaissance type attacks	REQ-SEC-OCLOUD-SS-1 REQ-SEC-OCLOUD-SS-2 REQ-SEC-OCLOUD-SS-3	High

								SEC-CTL-OCLOUD-SS-1 SEC-CTL-OCLOUD-SS-2 SEC-CTL-OCLOUD-SS-3	
T-GEN-05 (b)	A successful attack could: - modify insecurely stored credentials and cryptographic materials	Tampering, Elevation of Privilege	I	Medium	Medium	Adverse impacts (Medium), ZTA (Medium)	Adverse impacts (Medium) – Requirements are defined for sensitive data protection in the O-RAN security specifications ZTA (Medium): Integrity type attacks	REQ-SEC-OCLOUD-SS-1 REQ-SEC-OCLOUD-SS-2 REQ-SEC-OCLOUD-SS-3 SEC-CTL-OCLOUD-SS-1 SEC-CTL-OCLOUD-SS-2 SEC-CTL-OCLOUD-SS-3	Medium
T-GEN-06	A successful attack could: - Gain access to the sensitive information - Escalate privileges in Applications	Information disclosure, Elevation of Privilege	C	Medium	Medium	Adverse impacts (Medium), ZTA (High)	Adverse impacts (Medium) – Requirements are defined for sensitive data protection in the O-RAN security specifications ZTA (High): Reconnaissance type attacks		Medium
T-VM-C-01	A successful attack could: - Compromise VM/Container isolation measures - Gain higher privileges on host or any of the containers running on that host - Perform unauthorized modifications to the contents of host filesystem e.g. install SSH keys, read secrets mounted to the host, and take other malicious actions	Spoofing, Tampering, Information disclosure, Denial of Service and Elevation of privilege	C, I, A	High	High	• Adverse impacts (High), • ZTA (High)	Adverse impacts (High) – No existing requirements ZTA (High): Reconnaissance and availability type attacks		High
T-VM-C-02	A successful attack could: - Deploy a new malicious VM/Container configured without network rules, user limitations, etc. to bypass existing defenses within O-Cloud infrastructure - Compromise the confidentiality & integrity of co-hosted VMs/Containers and	Spoofing, Tampering, Information disclosure, Denial of Service and Elevation of privilege	C, I, A	High	Medium	• Adverse impacts (High), • ZTA (Medium)	Adverse impacts (High) – No existing requirements ZTA (Medium) - Availability type attacks		High

	tenants - Launch DDOS attacks on co-hosted VMs/Containers and host services thereby degrading their performance								
T-VM-C-03	A successful attack could: - Retrieve/manipulate VNF/CNF sensitive data (e.g. passwords, private keys, subscription data, logs)	Tampering, Information disclosure	C, I	High	High	• Adverse impacts (High), • ZTA (High)	Adverse impacts (High) – No existing requirements ZTA (High): Reconnaissance type attacks		High
T-VM-C-04-a	A successful attack could: - Cause migration Flooding: VM/Container performance degradation and VM/Container crashes	Tampering, Information disclosure, Denial of Service	C, I, A	High	Medium	• Adverse impacts (High), • ZTA (Medium)	Adverse impacts (High) – No existing requirements ZTA (Medium): Availability type attacks		High
T-VM-C-04-b	"A successful attack could: - Sniff the packets that are exchanged between the source and destination servers - Read the migrated memory pages - Monitor and/or modify the received packets while continuing to forward them to victim VM/Container"	Tampering, Information disclosure, Denial of Service	C, I, A	High	High	• Adverse impacts (High), • ZTA (High)	Adverse impacts (High) – No existing requirements ZTA (High): Reconnaissance type attacks		High
T-VM-C-05	A successful attack could: - Misguide the Virtualization layer to reduce the resource of or delete a VM/Container on which a VNF/CNF is running. This can result in the reliability, availability or even illegal termination of a VNF/CNF and hence the denial of service - Misguide the O-Cloud platform to detach a hardware accelerator from a VNF/CNF	Denial of Service	A	High	Medium	• Adverse impacts (High), • ZTA (Medium)	Adverse impacts (High) – No existing requirements ZTA (Medium): Availability type attacks		High

T-VM-C-06	A successful attack could: - Access to data not erased from a terminated VNF/CNF or any VNF/CNF that has released resources	Information disclosure	C	High	High	• Adverse impacts (High), • ZTA (High)	Adverse impacts (High) – No existing requirements ZTA (High): Reconnaissance and availability type attacks		High
T-IMG-01	A successful attack could: - Insert malicious code that will subsequently get run in the production environment	Tampering, Information disclosure	C, I	Medium	High	• Adverse impacts (Medium), • ZTA (High)	Adverse impacts (Medium) – Requirements are defined for image protection in the O-RAN security specifications ZTA (High): Reconnaissance and availability type attacks	REQ-SEC-ALM-PKG-1 to REQ-SEC-ALM-PKG-15 SEC-CTL-ALM-PKG-1 to SEC-CTL-ALM-PKG-4	High
T-IMG-02	A successful attack could: - Intercept network traffic intended for registries and steal developer or administrator credentials within that traffic. Thus, could be used to provide fraudulent or outdated images to orchestrators, etc.	Tampering, Information disclosure	C, I	Medium	High	• Adverse impacts (Medium), • ZTA (High)	Adverse impacts (Medium) – Requirements are defined for image protection in the O-RAN security specifications ZTA (High): Reconnaissance and availability type attacks	REQ-SEC-ALM-PKG-1 to REQ-SEC-ALM-PKG-15 SEC-CTL-ALM-PKG-1 to SEC-CTL-ALM-PKG-4	High
T-IMG-03	A successful attack could: - Secrets embedded within a VM/Container image can be stolen - Secrets embedded within a VM/Container image can be modified	Spoofing, Tampering, Information disclosure	C, I	Medium	High	• Adverse impacts (Medium), • ZTA (High)	Adverse impacts (Medium) – Requirements are defined for image protection in the O-RAN security specifications ZTA (High): Reconnaissance and availability type attacks	REQ-SEC-ALM-PKG-1 to REQ-SEC-ALM-PKG-15 SEC-CTL-ALM-PKG-1 to SEC-CTL-ALM-PKG-4	High
T-IMG-04	A successful attack could: - Build a custom image on the host that includes malware and then may deploy container using that custom image	Spoofing, Tampering, Information disclosure, Denial of Service and Elevation of privilege	C, I, A	Medium	High	• Adverse impacts (Medium), • ZTA (High)	Adverse impacts (Medium) – Requirements are defined for image protection in the O-RAN security specifications ZTA (High): Reconnaissance and availability type attacks	REQ-SEC-ALM-PKG-1 to REQ-SEC-ALM-PKG-15 SEC-CTL-ALM-PKG-1 to SEC-CTL-ALM-PKG-4	High
T-VL-01	A successful attack could: - Gain control over the host of a server or install a malicious Hypervisor/Container Engine/Host OS and	Spoofing, Tampering, Information disclosure, Denial of Service and Elevation of privilege	C, I, A	High	High	• Adverse impacts (High), • ZTA (High)	Adverse impacts (High) - No existing requirements ZTA(High) - Reconnaissance and availability type of attacks		High

	exploit that to run malicious applications on the VM/Container that run on top of the host. This would enable the attacker to control all the VMs/Containers running on the host.								
T-VL-02	A successful attack could cause: - Failure of the physical machine to start at all - Physical machine entering a safe-mode - Physical machine continuing boot regardless of the integrity measurements	Tampering	I	High	Medium	• Adverse impacts (High), • ZTA (Medium)	Adverse Impact (High) - No existing requirements ZTA(Medium) - Availability type attacks		High
T-VL-03	A successful attack could: - cause denial-of-service against the service discovery infrastructure to prevent O-Cloud to react to changing resource requirements properly	Denial of Service	A	Medium	Medium	Adverse impacts (Medium), ZTA (Medium)	Adverse impacts (Medium) – Requirements are defined for O-Cloud authentication and authorization in the O-RAN security specifications. ZTA (Medium): Availability type attacks	REQ-SEC-OCLOUD-O2dms-1 REQ-SEC-OCLOUD-O2dms-2 REQ-SEC-OCLOUD-O2dms-3 REQ-SEC-OCLOUD-O2dms-4 REQ-SEC-OCLOUD-O2ims-1 REQ-SEC-OCLOUD-O2ims-2 REQ-SEC-OCLOUD-O2ims-3 REQ-SEC-OCLOUD-O2ims-4 REQ-SEC-O-CLOUD-NotifAPI-1 REQ-SEC-O-CLOUD-NotifAPI-2 SEC-CTL-O-CLOUD-INTERFACE-1 SEC-CTL-O-CLOUD-INTERFACE-2 SEC-CTL-O-CLOUD-INTERFACE-3	Medium

								REQ-SEC-OCLOUD-ISO-1 REQ-SEC-OCLOUD-ISO-2 REQ-SEC-OCLOUD-ISO-3 REQ-SEC-OCLOUD-ISO-4	
T-O2-01	A successful attack could: - Tamper/alter/disclose requests and services sent over O2 between O-Cloud and SMO, hence the virtualized resource or relevant status information is not as requested - Affect the normal operation of the O-Cloud, and even causes DoS attacks, information leakage.	Tampering, Information disclosure, Denial of Service	C, I, A	Low	High	• Adverse impacts (Low), • ZTA (High)	Adverse impacts (Low) – Requirements are defined for the protection of O2 interface in the O-RAN security specifications ZTA (High): Reconnaissance and availability type attacks	REQ-SEC-O2-1 SEC-CTL-O2-2 REQ-SEC-DOS-1	Medium
T-OCAPI-01	A successful attack could: - Cryptographic keys or other security critical data of an instantiated VNF/CNF could be stolen by an attacker with access to the virtualization layer - The virtualized resource provided by the Virtualization layer to the instantiated VNF/CNF can be manipulated	Tampering, Information disclosure, Denial of Service	C, I, A	Low	High	• Adverse impacts (Low), • ZTA (High)	Adverse impacts (Low) – Requirements are defined for the protection of O-Cloud API in the O-RAN security specifications ZTA (High): Reconnaissance and availability type attacks	REQ-SEC-O2-1 SEC-CTL-O2-2 REQ-SEC-DOS-1	Medium
T-HW-01	A successful attack could: - Maliciously placed VM/Container extracts information from the target VM/Container with the side channel attack	Tampering, Information disclosure, Denial of Service	C, I, A	High	High	• Adverse impacts (High), • ZTA (High)	Adverse Impact (High) - No existing requirements ZTA (High): Reconnaissance and availability type attacks		High
T-HW-02	A successful attack could: - Extract useful information such as cryptographic keys from the target VM/Container to use them for traffic eavesdropping and man-in-the-middle attacks.	Tampering, Information disclosure, Denial of Service	C, I, A	High	High	• Adverse impacts (High), • ZTA (High)	Adverse Impact (High) - No existing requirements ZTA (High): Reconnaissance and availability type attacks		High

T-AAL-01	A successful attack could: - tamper the requests/responses sent between the AAL components, the O-Cloud platform and O-RAN APPs/VNFs/CNFs	Tampering	I	High	Medium	Adverse impacts (Medium), ZTA (High)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications ZTA (Medium): Integrity type attacks		High
T-AAL-02	A successful attack could: - cause DoS attack or increased traffic on AAL interfaces	Denial of Service	A	High	Medium	Adverse impacts (Medium), ZTA (High)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications ZTA (Medium): Availability type attacks		High
T-AAL-03 (a)	Fail to clear resources	Information disclosure	C	High	High	Adverse impacts (High), ZTA (High)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications ZTA (High): reconnaissance type attacks		High
T-AAL-03 (b)	Fail to clear resources	Denial of service	A	High	Medium	Adverse impacts (High), ZTA (Medium)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications ZTA (Medium): Availability type attacks		High
T-AAL-04 (a)	HAM compromise	Tampering	I	High	Medium	Adverse impacts (High), ZTA (Medium)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications ZTA (Medium): Integrity type attacks		High
T-AAL-04 (b)	HAM compromise	Denial of service	A	High	Medium	Adverse impacts (High), ZTA (Medium)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications ZTA (Medium): Availability type attacks		High
T-AAL-05 (a)	Malicious memory accesses	Information disclosure	C	High	High	Adverse impacts (High), ZTA (High)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications ZTA (High): reconnaissance type attacks		High
T-AAL-05 (b)	Malicious memory accesses	Tampering	I	High	Medium	Adverse impacts (High), ZTA (Medium)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications ZTA (Medium): Integrity type attacks		High
T-AAL-05 (c)	Malicious memory accesses	Denial of service	A	High	Medium	Adverse impacts (High), ZTA (Medium)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications ZTA (Medium): Availability type attacks		High
T-AAL-06 (a)	Software attacks	Information disclosure	C	High	High	Adverse impacts (High), ZTA (High)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications		High

							ZTA (High): reconnaissance type attacks		
T-AAL-06 (b)	Software attacks	Tampering	I	High	Medium	Adverse impacts (High), ZTA (Medium)	Adverse impacts (High) – Not security requirements yet for AAL in O-RAN security specifications ZTA (Medium): Integrity type attacks		High
T-O-CLOUD-ID-01	In the O-Cloud environment, the reuse of IDs from deleted objects for new objects can lead to unintended data associations, leaks, and operational disruptions.	Tampering, Information disclosure	C, I	High	High	Adverse impacts (High), ZTA (High)	Adverse impacts (High) – Not security requirements yet for O-Cloud ID in O-RAN security specifications ZTA (High): reconnaissance and integrity type attacks		High
T-O-CLOUD-ID-02	In O-Cloud deployments, replacing failed machines without proper management of their corresponding Node objects can lead to resource mismatches, stale data inheritance, and network inconsistencies.	Spoofing, Tampering, Information disclosure, Denial of Service	C, I, A	High	High	Adverse impacts (High), ZTA (High)	Adverse impacts (High) – Not security requirements yet for O-Cloud ID in O-RAN security specifications ZTA (High): reconnaissance, integrity, and availability type attacks		High
T-O-CLOUD-ID-03	In the O-Cloud environment, improper management of object IDs can lead to overlaps, inconsistencies, unauthorized access, and operational disruptions.	Spoofing, Tampering, Information Disclosure, Repudiation, Elevation of Privilege, Denial of Service	C, I, A	High	High	Adverse impacts (High), ZTA (High)	Adverse impacts (High) – Not security requirements yet for O-Cloud ID in O-RAN security specifications ZTA (High): reconnaissance, integrity, and availability type attacks		High
T-ADMIN-01	A successful attack could: - Lead to the inability to react to changing resource requirements - Operators may be unable to retrieve logs, telemetry data - Prevents the O-Cloud software update (VNFs/CNFs, VL) to exploit a known security flaw in the O-Cloud software	Denial of Service	A	Medium	Medium	• Adverse impacts (Medium), • ZTA (Medium)	Adverse impacts (Medium) – Requirements are defined for the protection against DoS attacks and for the protection of O-Cloud API and O2 interface in the O-RAN security specifications ZTA (Medium): Availability type attacks	REQ-SEC-DOS-1	Medium
T-ADMIN-02	A successful attack could: - Deploy new instances and disrupt existing O-Cloud services - Submit compromised VM/Container images that unsuspecting tenants then use to initiate O-Cloud services - Extract business data,	Tampering, Information disclosure, Denial of Service and Elevation of privilege	C, I, A	Medium	High	• Adverse impacts (High), • ZTA (High)	Adverse impacts (Medium) – Requirements are defined for the protection of O-Cloud API and O2 interface in the O-RAN security specifications ZTA (High): Reconnaissance and availability type attacks	REQ-SEC-PASS-1 REQ-SEC-O2-1 SEC-CTL-O2-2 REQ-SEC-DOS-1	High

	configuration data, user data and possibly credentials - Create backups of VM/Container instances or export VM/Container images								
T-AIML-IM-1	A successful attack could: - Take alter a subset of the training data by inserting or modifying training samples	Integrity	I	High	Low	• Impact on integrity (High) • Threat event initiation (low)	• Impact on integrity: Bad training data will cause the model to behave incorrectly • Threat event initiation: needs high sophistication to execute		Medium
T-AIML-IM-2	A successful attack could: - generate adversarial examples in the model	Tampering	I	High	Low	• Impact on integrity (High) • Threat event initiation (low)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation: needs high sophistication to execute		Medium
T-AIML-IM-3	A successful attack could: - mis-assign labels to training data	Tampering	I	High	Low	• Impact on integrity (High) • Threat event initiation (low)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation: needs high sophistication to execute		Medium
T-AIML-IM-4	A successful attack could: - allow an adversary to submit queries to the model and receive predictions (either labels or model confidences) and confidential data	Confidentiality	C	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	• Impact on confidentiality: major change in normal AI/ML functioning • Threat event initiation: needs high sophistication to execute		Medium
T-AIML-DP-01	A successful attack could: -inject poisoned data which can be consumed by AI/ML for training.	Tampering	I	High	Medium	• Impact on integrity (High) • Threat event initiation (Medium)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation: needs sophistication to execute		High
T-AIML-DP-02	A successful attack could: -enable the attacker to get more details about the AI/ML algorithms being used and parameters configured if any	Tampering	I	High	Medium	• Impact on integrity (High) • Threat event initiation (Medium)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation: needs sophistication to execute		High
T-AIML-DP-03	A successful attack could: - enable the attacker to modify the behaviour of AI/ML algorithm with slow poisoning	Tampering	I	High	Medium	• Impact on integrity (High) • Threat event initiation (Medium)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation: needs sophistication to execute		High
T-AIML-MEI-01	A successful attack based on level of information available to attacker can	Information Disclosure	C	High	Medium	• Impact on confidentiality (High)	• Impact on confidentiality: Knowledge of information used in training gets exposed		High

	result in disclosing specific individual’s data used in training the model					• Threat event initiation (Medium)	• Threat event initiation needs sophistication to execute		
T-AIML-MEI-02	A successful attack based on analysis methods used by the attacker can result in disclosing specific individual’s data used in training the model	Information Disclosure	C	High	Medium	• Impact on confidentiality (High) • Threat event initiation (Medium)	• Impact on confidentiality: Knowledge of information used in training gets exposed • Threat event initiation needs sophistication to execute		High
T-AIML-MEI-03	A successful target based attack can result in disclosing specific individual’s data or a group's data used in training the model	Information Disclosure	C	High	Medium	• Impact on confidentiality (High) • Threat event initiation (Medium)	• Impact on confidentiality: Knowledge of information used in training gets exposed • Threat event initiation needs sophistication to execute		High
T-AIML-ME-01	A successful attack could: -Cause theft of intellectual property -Undermine the original developer's competitive advantage	Confidentiality	C	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	• Impact on confidentiality: Disclosure of high value information • Threat event initiation: needs high sophistication to execute		Medium
T-AIML-ME-02	A successful attack could: -Cause privacy breaches	Confidentiality	C	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	• Impact on confidentiality: Disclosure of high value information • Threat event initiation: needs high sophistication to execute		Medium
T-AIML-ME-03	A successful attack could: -allow adversarial attacks -allow targeted attacks	Tampering	I	High	Low	• Impact on integrity (High) • Threat event initiation (low)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation: needs high sophistication to execute		Medium
T-AIML-MOI-01	A successful attack could: - Cause disclosure of sensitive/proprietary data	Confidentiality	C	High	Medium	• Impact on confidentiality (High) • Threat event initiation (medium)	• Impact on confidentiality: Disclosure of high value information • Threat event initiation: needs medium sophistication to execute		High
T-AIML-MOI-02	A successful attack could: - allow an attacker to reconstruct the original training data with higher accuracy	Confidentiality	C	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	• Impact on confidentiality: major change in normal AI/ML functioning • Threat event initiation: needs high sophistication to execute		Medium
T-AIML-SC-01	A successful attack could: -corrupt or manipulate training datasets - cause degraded performance, wrong decisions, or even	Tampering, Denial of Service	IA	High	Medium	• Impact on confidentiality (High) • Threat event initiation (Medium)	needs sophistication to execute		High

	backdoors in the final system								
T-AIML-SC-02	A successful attack could: -inject malicious code or logic into the AI model itself during training or deployment	Tampering, Confidentiality	CI	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	needs high sophistication to execute		Medium
T-AIML-SC-03	A successful attack could: -infect the model with malicious code that remains dormant until it receives a specific trigger	Tampering, Confidentiality	CI	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	needs high sophistication to execute		Medium
T-AIML-SC-04	A successful attack could: -manipulate the hardware used for AI processing, such as GPUs, ASICs, or FPGAs	Tampering, Confidentiality	CI	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	needs high sophistication to execute		Medium
T-AIML-SC-05	A successful attack could: -inject malicious code or exfiltrate sensitive information from the target system.	Tampering, Confidentiality	CI	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	needs high sophistication to execute		Medium
T-AIML-SC-06	A successful attack could: -insert vulnerabilities or backdoors that attackers can exploit	Tampering, Confidentiality	CI	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	needs high sophistication to execute		Medium
T-AIML-OI-01	A successful attack could cause : - service disruption of the O-RAN elements that are using configuration / policies derived from the manipulated output of a model .	Denial of Service	A	High	Medium	• Impact on Availability (High) • Adverse impacts (Medium)	• Impact on Availability (High): Prolonged interruption of operations. • Adverse impacts (Medium) – O-RAN Alliance has specified security for O-RAN interfaces at the transport layers thereby mitigating access to O-RAN functions through the interfaces. The O-RAN Alliance has not yet specified security for regarding the Training or test data sets collected externally or internally, Trained ML model , ML prediction results .		High
T-AIML-OI-02	AI/ML models are used to perform QoE optimization and QoE based traffic steering in O-RAN [i.14]. A	Tampering	I	High	Medium	• Impact on Integrity (High) • Adverse impacts (Medium)	• Impact on Integrity (High): Major change in normal AI/ML system functioning. • Adverse impacts (Medium) – O-RAN Alliance has specified		High

	carefully crafted manipulation of the output of AI/ML model can be used to degrade the QoE of a subscriber or a group of subscribers.						security for O-RAN interfaces at the transport layers thereby mitigating access to O-RAN functions through the interfaces. The O-RAN Alliance has not yet specified security for regarding the Training or test data sets collected externally or internally, Trained ML model , ML prediction results .		
T-AIML-MP-01	A successful attack can change the parameters file which will cause the model to make incorrect predictions.	Tampering	I	High	Medium	• Impact on integrity (High) • Threat event initiation (Medium)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation needs sophistication to execute		High
T-AIML-MP-02	A successful attack can change the inference algorithm which will cause the model to make incorrect predictions.	Tampering	I	High	Medium	• Impact on integrity (High) • Threat event initiation (Medium)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation needs sophistication to execute		High
T-AIML-MP-03	A successful attack can change the learning algorithm which will cause the model to make incorrect predictions.	Tampering	I	High	Medium	• Impact on integrity (High) • Threat event initiation (Medium)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation needs sophistication to execute		High
T-AIML-MP-04	A successful attack could: - create a Trojan trigger in the model -send malicious local model updates in federated learning	Integrity	I	High	Low	• Impact on integrity (High) • Threat event initiation (low)	• Impact on integrity: Disclosure of high value information • Threat event initiation: needs high sophistication to execute		Medium
T-AIML-MS-01	A successful attack could: modify data which can result in a skewed trained model resulting in incorrect ML output	Tampering	I	High	Medium	• Impact on integrity (High) • Threat event initiation (Medium)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation needs sophistication to execute		High
T-AIML-MS-02	A successful attack could: manipulate the feedback mechanism used by AI/ML for continuous improvement during deployment, which can be result in a skewed trained model resulting in incorrect ML output	Tampering	I	High	Medium	• Impact on integrity (High) • Threat event initiation (Medium)	• Impact on integrity: major change in normal AI/ML functioning • Threat event initiation needs sophistication to execute		High

T-AIML-TL-01	A successful attack could: -corrupt or manipulate training datasets - cause degraded performance, wrong decisions, or even backdoors in the final system	Tampering	I	High	Medium	• Impact on integrity (High) • Threat event initiation (Medium)	needs sophistication to execute		High
T-AIML-TL-02	A successful attack could: - extract sensitive information about its architecture and parameters	Confidentiality	C	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	needs high sophistication to execute		Medium
T-AIML-TL-03	A successful attack could: - bypass security systems or cause misclassifications in critical applications like self-driving cars or healthcare.	Tampering	I	High	Low	• Impact on integrity (High) • Threat event initiation (low)	needs high sophistication to execute		Medium
T-AIML-TL-04	A successful attack could: -infect the model with malicious code that remains dormant until it receives a specific trigger	Tampering, Confidentiality	CI	High	Low	• Impact on confidentiality and integrity (High) • Threat event initiation (low)	needs high sophistication to execute		Medium
T-AIML-EL-01	A successful attack could: - deduce the structure of the neural network, including the types of layers, their sequence, and possibly hyperparameters	Confidentiality	C	High	Low	• Impact on confidentiality (High) • Threat event initiation (Low)	needs high sophistication to execute		Medium
T-AIML-EL-02	A successful attack could: - make inferences about the input data, potentially leading to privacy breaches, especially if the data is sensitive	Confidentiality	C	High	Low	• Impact on confidentiality (High) • Threat event initiation (low)	needs high sophistication to execute		Medium
T-AIML-EL-03	A successful attack could: - maximize energy consumption or computation time, leading to a denial of service by overloading	Denial of Service	A	High	Low	• Impact on availability (High) • Threat event initiation (low)	needs high sophistication to execute		Medium

	the system or draining battery life.								
T-AIML-EV-01	A successful attack could: - Compromise Authentication Systems tricking AI/ML systems into granting access to unauthorized users - Undermine Integrity of Data by tricking AI/ML systems into drawing incorrect conclusions	Tampering	I	High	Medium	• Impact on integrity (High) • Threat event initiation (Medium)	needs sophistication to execute		High
T-TS-01	Disruption or manipulation of the time synchronization process within the O-Cloud environment can lead to severe security and operational issues.	An attacker may target the time synchronization mechanisms to alter time settings across nodes, leading to data integrity loss, authentication and authorization bypass, and operational disruption.	I, A	High	Medium	Impact of Integrity and Availability (High) Threat Event Initiation (Medium)	Impact of Integrity and Availability (High): due to potential widespread operational and security impacts, including data integrity loss and operational disruptions affecting multiple nodes. Threat Event Initiation (Medium): it requires elevated privileges to modify time synchronization settings.		High

Annex: Change history/Change request (history)

Date	Revision	Description
2024.12.06	05.00	Final version 05.00
2024.12.04	04.00.04	Update according to received notes from November train review
2024.12.03	04.00.03	Update according to received notes from November train review
2024.12.02	04.00.02	Update according to received notes from November train review
2024.11.25	04.00.01	Integration of CRs: • NOK CRs: CR0181, CR0187, CR0190, CR0201, CR0203, CR0206, CR0207, CR0208, CR0210 • NEC CRs: CR0027, CR0029 • WG11 CRs: CR0048, CR0050 • ERI CR: CR0153
2024.07.26	04.00	Final version 04.00
2024.07.24	03.00.03	Update according to received notes from July train review
2024.07.23	03.00.02	Update according to received notes from July train review
2024.07.10	03.00.01	Implemented CRs: NOK CR0155, NOK CR0142, NOK CR0160, NOK CR0161, NOK CR0162, NOK CR0167, NOK CR0170, NOK CR0171, NOK CR0172, NEC CR0018, NEC CR0023, WG11 CR 0035, WG11 CR 0044, ATT CR 0022, ATT CR 0044, RMI CR 0020, RMI CR 0027, MTR CR 0096
2024.03.27	03.00	Final version 03.00
2024.03.19	02.00.02	Addressed editorial notes
2024.03.15	02.00.01	Implemented CRs ERI CR0103, MTR CR0081, SYM CR0040, NEC CR0007, NEC CR0011, WG11 CR0029
2023.11.22	02.00	Final version 02.00
2023.11.21	01.00.02	Update according to received notes from November train review
2023.11.03	01.00.01	Implemented CRs WG11 CR0015, MTR CR0004
2019.01.31	01.00	Final version 01.00
2019.01.24	00.00.02	Implemented CRs ERI-0011, NOK-0032 and DCM-0008
2019.01.22	00.00.01	Create initial O-RAN version, with change-marks from previous content.