Intent Based Networking in 5G Slicing Life-cycle Management and Orchestration

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Intent Based Networking in 5G Slicing Life-cycle Management and Orchestration

- **Acknowledgement**
  - This overview and analysis is compiled and structured, based on several **public documents such as**: conference proceedings, studies (overviews, tutorials, research papers), standards, projects, etc. (see specific references in the text and the Reference list).
  - **The selection and structure of this material belongs to the author.**
  - **Notes:**
    - Given the extension of the topics, this **presentation is limited to a high-level overview only**, mainly on concepts and architectural aspects.
    - The presentation takes as an example the utilization of IBN approach in 5G slicing life-cycle management and orchestration.

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Intent Based Networking in 5G Slicing Life-cycle Management and Orchestration

- **Motivation of this talk**
  - **Current state in networks and services**
    - **Increased complexity** (challenges: integration of cloud/edge computing and networking technologies, 5G, 6G, .. big data, large range of services, …)
    - **Driving forces for extension of IT&C technologies :** IoT, smart cities, industry, governance, health systems IoV/automotive, safety/ emergency-oriented systems, environment, entertainment, etc.
  - **Orchestration, management, and control in networks and services** became increasingly complex
    - **Need for**
      - **automation, adaptability, intelligence, programmability, flexibility, sustainability**
    - Appropriate technologies have been developed (> 2000)
      - **Softwarization/virtualization, Policy Based Management, Cognitive and autonomic management, Intent Based networking (IBN)**
      - Artificial Intelligence /Machine Learning (Ai/ML) – can offer a strong support for the above

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1. Introduction

- **Current state in networks and services**

  - **Increased complexity** (challenges: integration of cloud/edge computing and networking technologies, big data, …)
  - **IT&C driving forces:** IoT, smart cities, industry, governance, IoV/automotive needs, safety/emergency-oriented systems, energy saving, green technologies, entertainment, environment preservation, etc.

  - **Example: 5G mobility-capable networks**
    - high bandwidth, large range of services, large communities of users/terminals (e.g., IoT), inter-operability with clouds
    - dedicated - logical separated slices**-** customized for various business demands, programmability through softwarization, virtualization, open sources and open interfaces that allow access for third parties

  - **Orchestration, Management and Control (OMC) for 5G Multi-x** (**x= tenant, operator, provider, domain** E2E) → **– need enhanced concepts and methods and technologies**

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2. Network and services management issues and technologies

2.1 FCAPS classical management functions

- **F- Failure** detection (classically- based on monitoring) and repairing
- **C- Configuration** of the entities (physical, logical)
- **A - Accounting** of resource usage (who, what, when, how much)
- **P- Performance** evaluation (including enforcement and checking Service Level Agreements fulfillment)
- **S - Security** – protection of the system

FCAPS –tasks that can be supported by cognitive and ML techniques – examples

- **Failure Prevention**
  - **Proactive fault prediction and mitigation**
    - predict upcoming failures
    - identify the root cause of the predicted fault and select the mitigation steps
    - Problem: existing ML-based localization approaches: still poor scalability for the high-dimensional device-log-attributes, even in moderate-size networks → dimensionality reduction is needed

2. Network and services management issues and technologies

FCAPS –tasks that can be supported by cognitive and ML techniques – examples (cont'd**)**

- **Fault Management in Cloud and Virtualized Environments**
  - The multi-tenancy, E2E, multi-domain in cloud/NFV environment raises the complexity and dimensions of the fault space in a network
  - ML (e.g., DeepNNs) can **model complex multi-dimensional state spaces-** -- > used to predict and locate faults
  - Any **automated mitigation** within a Virtual Network (VN)/slice should not affect other coexisting VNs
    - ML (in particular- **Reinforcement Learning** combined **with DeepNNs**) can learn to optimize mitigation steps

Adapted from : Sara Ayoubi, et.al., Machine Learning for Cognitive Network Management, IEEE Comm.Magazine , January 2018, pp.158-165

2. Network and services management issues and technologies

FCAPS –tasks that can be supported by cognitive and ML techniques – examples (cont'd**)**

- **Performance Management**
  - **Adaptive Probing**
    - Large number of devices, parameters, small time intervals to log data → high overhead produced by measurement traffic
    - **Regression,** mostly based on time series data – usable for prediction
    - Solution: adjusting the probing rates, to lower the measuring traffic overhead, while minimizing performance degradation and providing high prediction accuracy
- **Detecting Patterns of Degradation**
  - detecting the characteristic degradation patterns before the quality drops below an acceptable level
  - elastic resource (re)allocation to accommodate dynamic user demands – goal: performance optimization and high resource utilization
  - however, performance prediction for autonomic tuning of the network behavior is still a research challenge

Adapted from : Sara Ayoubi, et.al., Machine Learning for Cognitive Network Management, IEEE Comm.Magazine , January 2018, pp.158-165

2. Network and services management needs

- **FCAPS – tasks that can be supported by ML techniques – examples** (cont'd)
- **Configuration Management:**

  - **Mapping** *High-Level Requirements* to *Low-Level Configurations*:
    - There is still a gap between high-level services requirements and low-level configurations (e.g., resources to be provisioned)
    - RL techniques can be applied
    - The reward for selecting a configuration setting of a given network element can be seen as the utility indication of that particular setting in delivering the high-level requirements under a given network condition

  - **Configuration and Verification**
    - Configuration changes (e.g., access control lists, routing tables) should comply with high-level requirements and not adversely affect the expected network behavior
    - Interest exists in applying DL-aided verification, code correction, and theorem proving

Adapted from: Sara Ayoubi, et.al., Machine Learning for Cognitive Network Management, IEEE Comm.Magazine , January 2018, pp.158-165

2. Network and services management issues and technologies

2.2 Specific classes of problems in network and service management

- extension of the classical FCAPS
- many of them can benefit from AI/ML support

▪**Spectrum management in 5G, 6G**

▪**Traffic management and control**

- ▪Traffic **classification:** labeled and unlabeled traffic traces (payload-based; host-behaviour based, flow feature based)
- ▪Traffic **prediction:** synthetic and real traffic traces with flow statistics; link load and traffic volume prediction in ISP networks; early flow-size prediction and elephant flow detection

▪**Congestion control:** packet loss classification; queue management; congestion window control (for TCP); collect experience from network simulator

▪**Resource management**

- ▪ admission control; resource reservation and allocation (e.g., for slices (RAN, Core network, Cloud), VNFs, etc.)- in multi-domain multi-operator and multi-tenant contexts; adaptive and automatic re-allocation of resources to meet dynamic needs; synthetic workload with different patterns can be used for training the AI/ML machines

2. Network and services management issues and technologies

2.2 Specific classes of problems in network and service management (cont'd)

- **Fault magement:** prediction; detection; localizing the faults; automated mitigation
- **Network transport management and control**
  - routing strategy; load balancing; QoS assurance with different levels of guarantees for real-time streams; route monitoring; E2E path bandwidth availability prediction and checking; trraffic patterns labeling with routing paths computed by routing protocols; decentralized/ centralized/mixed routing
- **QoS and QoE management:** QoE optimization; Session quality information; QoS/QoE correlation; QoS prediction under QoS impairment; QoS prediction for media-oriented communications
- **Performance prediction:** datasets with quality measurements – e.g. from public CDNs; throughput prediction (datasets of HTTP throughput measurement)
- **Network protection: i**ntrusion detection (misuse-based, anomaly-based); anomaly detection; hybrid intrusion detection
- **Mobile networks:** network-level mobile data analysis; mobility patterns analysis, user localization, mobile networks applications
- **Internet of Things (IoT) specific**
- **Wireless sensor networks**

2. Network and services management issues and technologies

2.3 Policy Based Management (PBN) concepts

- **PBM** -separates the rules that govern the behavior of a system from the system functionality; it increases the management flexibility
  - PBM is an **imperative management paradigm**
  - **PBM applied to networks: PBNM**
- Today there exist several management architectures such as: ***SLA-driven, Business-driven, autonomous, adaptive, and self-* management***

- **Policy:** a **set of rules** used to manage and control the changing and/or maintaining of the state of one or more managed objects
  - It is defined at a higher level of abstraction, involving a canonical model of systems and devices to which the policy is to be applied
  - definition of a rule : ***[if.. then ... actions]*** structure
    - an ***event* occurrence** will trigger a rule if a ***set of conditions*** are valid and, a ***set of actions*** are carried out
    - It specify *what* to be done, *when* and in *which circumstance*
- PBNM offers simple **control loops**, allowing autonomic behavior: ***self-**** management properties, (* = ***configuration, healing, optimization, protection****)* *(CHOP)* –in a similar way as in autonomic managed systems.

See: J. Strassner, "Policy-Based Network Management", Elsevier.", 2003.

2.3 Policy and Policy Based Management (PBNM) concepts (cont'd)

- A **policy agent on a controller** or the device subsequently "renders" the policy, i.e., translates the canonical model into a *device-specific representation*
- The policy definition is de-coupled from policy instantiation and policy enforcement
- Usually the **policies are pushed (**by a **controller)** onto devices where they are rendered and enforced; the controller deploys policies across the network and monitors their proper operation
- However, PBM can also include a **pull- component ;** the decision regarding actions to be taken is delegated to a **Policy Decision Point (PDP),** which:
  - can reside outside the managed device itself
  - typically, has global visibility on context where to make policy decisions
  - usually gets the policies from a **Policy Data Base**
- Whenever a network device observes an event, it asks the PDP for a decision
  - then, the device carries out the decision as returned by the PDP;
  - the device "enforces" the policy acting as a PEP (**Policy Enforcement Point)**
- Either way, PBNM architectures typically involve a central component from which policies are deployed across the network and/or policy decisions served.

2. Network and services management issues and technologies

2.4 Cognitive Management concepts

- **Cognitive network management**
  - recent trend using **AI/ML** and in particular to develop **self-x capabilities**
  - (-x= -aware, -configuring, -optimization, -healing and -protecting systems)

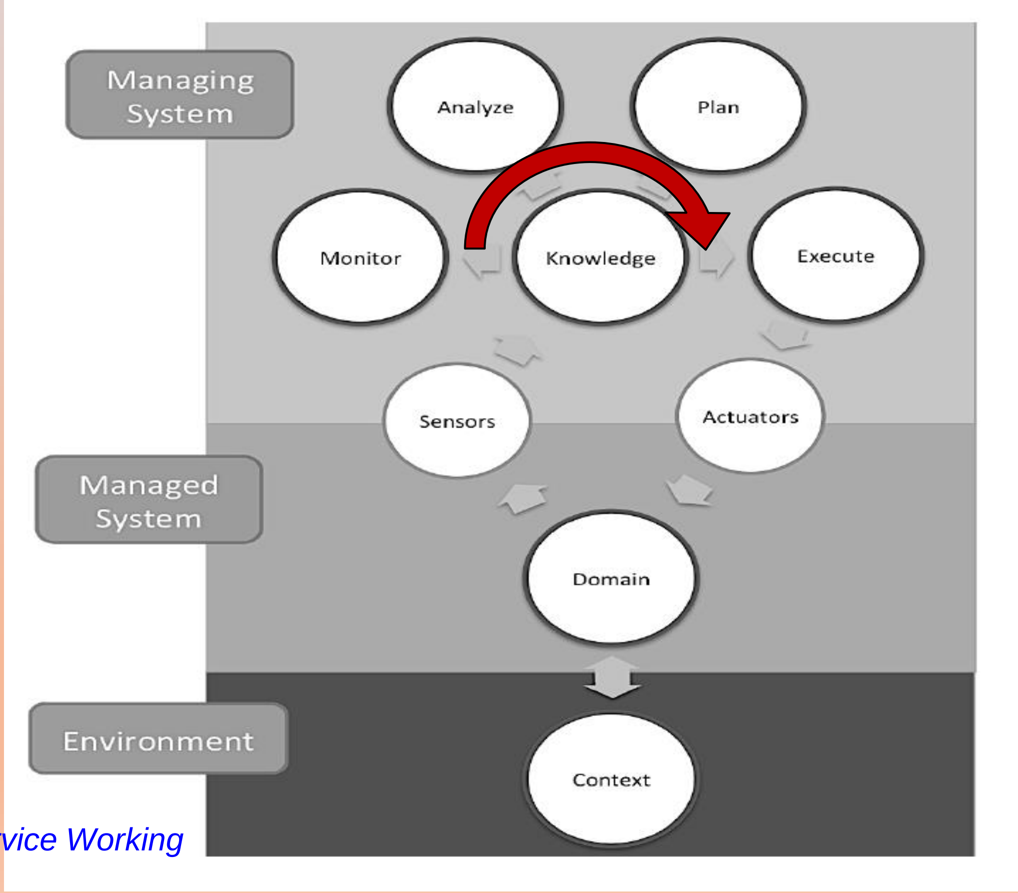
- Cognitive management– extension of **Autonomic Management (AM)** (coined by IBM ~ 2001)- later extended in networking domain → ANM
  - **AM + Machine learning = Cognitive Management (CogM)**

- **Challenge:** to deploy the CogM and its orchestration across multiple heterogeneous networks:
  - Radio & Other Access Networks
  - Edge/ Aggregation/ Core Networks,
  - Edge and centralized Computing Clouds
  - Satellite Networks

2. Network and services management issues and technologies

- **2.4 Cognitive Management concepts** (cont'd)
- **Autonomous Network Management (ANM) :** introduces self-governed networks for pursuing business and network goals while maintaining performance

  - **Loop:** The **Monitor-Analyse-Plan-Execute** over a shared Knowledge
  - (**MAPE-K**) is a control theory-based feedback model for self-adaptive systems
  - Full-duplex communication between ***managing systems, managed system*** and the ***environment***
  - **ANM –** hierarchical and recursive approach
  - IETF ANIMA working group



Source: 5GPPP Network Management & Quality of Service Working Group, "Cognitive Network Management for 5G", 2017

2. Network and services management issues and technologies

2.4 Cognitive Management concepts (cont'd)

- **Autonomic Network Management functions**
  - **Monitoring**: active/passive, centralized/distributed, granularity-based, timing-based and programmable
  - **Analysis:** many approaches exist –relying, e.g., on probability and Bayesian models for anticipation on knowledge, timing, mechanisms, network-level, user applications
    - **Challenge: to define a concentrated data set** that comprehensively captures information across all anticipation points
    - Recent solutions – **use learning and reasoning** to achieve specific goals
  - **Planning and Execution**
    - The network **adaptation plan** – several aspects: knowledge, strategy, purposefulness, degree of adaptation autonomy, stimuli, adaptation rate, temporal/spatial scope, open/closed adaptation and security
    - **Current status**: the adaptation solutions differ broadly and there is no unanimity in defining proper planning and execution guideline

2.4 Cognitive Management concepts (cont'd)

- **Autonomic Network Management functions** (cont'd)
  - **Knowledge base**
  - The network information is shared across the MAPE-K architecture
  - Many approaches exist - to build knowledge on network/topology, including models from learning and reasoning, ontology and DEN-ng models.

  - Integrated solution- able to capture knowledge on: ***structure***, ***control*** and ***behavior***

  - **Typically:**
    - In order to drive the decisions of **Self Organizing Network (SON)-type** (e.g., self-planning, self-optimization and self-healing), the knowledge-based framework should :
      - process the input data from multiple sources
      - extract relevant knowledge, **through learning-based classification, prediction and clustering models**

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3. Intent Based Networking (IBN)- concepts and architecture
4. IBN approach in 5G slicing life-cycle management and orchestration- examples
5. Conclusions

3. Intent Based Networking (IBN)- concepts and architecture

- **3.1 General characteristics**
- **IBN**
  - Novel intelligent technology for **orchestration and automation** of networks
  - IBN **let operators focus** on their **desired outcomes,** while **leaving details about how those outcomes would be achieved**

  - **Intent Based Networking is about "what" not "how"!**

  - IBN is adopted by IETF, ITU, … and also industriy (e.g., Cisco, Huawei, etc.)
  - IBN can
    - **automatically** convert, deploy, and configure the network resources according to operator intentions
    - **overcome** and **control** abnormal events or failures
    - **continuously monitor** the network resources to get statistics, in order to help the **life-cycle management (LCM)** actions upon virtualized subsystems and adjust network functioning and performance towards desired business **outcomes**

See: A.Clemm et al., Intent-Based Networking - Concepts and Definitions , draft-irtf-nmrg-ibn-concepts-definitions-07, March 2022

3. Intent Based Networking (IBN)- concepts and architecture

- **3.1 General characteristics** (cont'd)
- IBN transforms a hardware-centric, manually configured network into a controller-led network, that **captures business intent and translates it into policies** that can be **automated** and applied consistently across the network
- IBN uses a centralised controller (e.g., SDN)

- The closed-loop system of IBN operates with functional building blocks:
- ***Translation***: capture , **translation of intent into policies** the network can act on;
- ***Activation*****:** **policies installation** across the Physical/Virtual (P/V) network infrastructure, using networkwide automation;
- ***Assurance:*** use of analytics and ML to **continuously monitor** the network, to **verify if the desired intent has been applied** and the business **outcomes** are achieved
- Current trends (IETF, etc.) : to address *E2E management* and not individual devices in isolation : e.g. YANG models for network topology [RFC8345]: service models used by service orchestration systems and controllers [RFC8309])

3. Intent Based Networking (IBN)- concepts and architecture

- **3.1 General characteristics**
- The IBN concepts are related to **Autonomic Network Management (ANM)**
  - ANM lowers operational expenses and creates adaptive management framework
  - ANM introduced "self-management" properties(CHOP)
  - However, **ANM still require input from an operator** or outside system to provide operational guidance and information about **goals, purposes**, and **service instances**
- *Note: in this section the word "user" can also refer to operators and administrators who are responsible for the OMC.*

- In IBN the input and operational guidance are commonly referred to as "intent“

- The system implementing the IBN is the **Intent-Based Systems (IBS)**
  - IBS can be implemented in several ways, e.g., a controller or management system are implemented
    - as an application that runs on a server or set of servers
    - or as a set of functions distributed across a network and that collectively perform their intent-based functionality

3. Intent Based Networking (IBN)- concepts and architecture

- **3.2 IBN- related – definitions**
  - **Intent:** a set of operational goals and outcomes, defined in a declarative manner without specifying how to achieve or implement them
  - **Intent-Based Analytics (IBA):** defined and derived from users' intent; it is used to validate the intended state
  - **Intent-Based System (IBS):** s system that supports management functions, guided using intent
  - **Service Model:** a model that represents a service that is provided by a network to an end user
  - **Single Source of Truth (SSoT):** a functional block in an IBS that normalizes users' intent and serves as the single source of data for the lower layers
  - **Single Version of Truth (SVoT)**
  - **User:** In the context of this section, it is an operator and/or administrator responsible for the management and operation of communication services and networking infrastructure (as opposed to an **end user** of a service).

Source: A.Clemm et al., Intent-Based Networking - Concepts and Definitions , draft-irtf-nmrg-ibn-concepts-definitions-07, March 2022

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- Networks, even if autonomic, **have no way of automatically knowing**:
  - particular operational goals
  - which instances of networking services to support

- So, networks do not know the **network provider (NP) intent** (that gives the network the purpose to live). This still needs to be communicated to the network by what informally constitutes **intent**

- **Intent** defines goals and outcomes in a *declarative manner,* specifying **what to accomplish, not how to achieve it**.
- Intent applies several important concepts simultaneously:
  - **data abstraction**: users do not need to be concerned with low-level device configuration
  - **functional abstraction** from particular OMC logic: users (here they are operators) are not concerned with how to achieve a given intent
- The **desired outcome, is specified by intent** and the IBS automatically figures out a course of action (e.g., using an algorithm or applying a set of rules derived from the intent) to achieve the outcome

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Examples of intent** (expressed in natural language) :
- Note: the **intent specifies "what" and not "how"**
  - *"Avoid routing traffic originating from a given set of endpoints through a particular vendor's equipment, even if this occurs at the expense of reduced service levels."*
  - *"Maximize network utilization, unless service levels have deteriorated 20% or more from their historical mean*
  - *"VPN service must have path protection at all times for all paths."*
- **Examples of what would not constitute intent** :
  - *"Configure a given interface with an IP address."* This is device configuration, not an intent
  - *"If an interface utilization exceeds a specific threshold, then emit an alert"* This is a rule that can support network automation, not an intent.

Source: A.Clemm et al., Intent-Based Networking - Concepts and Definitions , draft-irtf-nmrg-ibn-concepts-definitions-07, March 2022

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Specific aspects of Intent, Policy, and Service Models**
- All three models involve a higher-layer of abstraction of a network (not involving device-specifics) However differences exist

- **Service model:** data model describing instances of services
  - It has **dependencies on lower-level models** (device and network) to describe the service mapping onto the underlying network and IT infrastructure.
  - A **service model instantiation requires orchestration**
    - The logic to orchestrate/manage/provide the service model and its mapping onto underlying resources is not included in the model **itself.**

- **Policy:** set of rules, typically modeled around a variation of **events/ conditions/ actions**, used to express control loops that can be rendered by devices without intervention by the outside system
  - They let operators to define **what to do** under what circumstances, but **they do not specify the desired outcome**

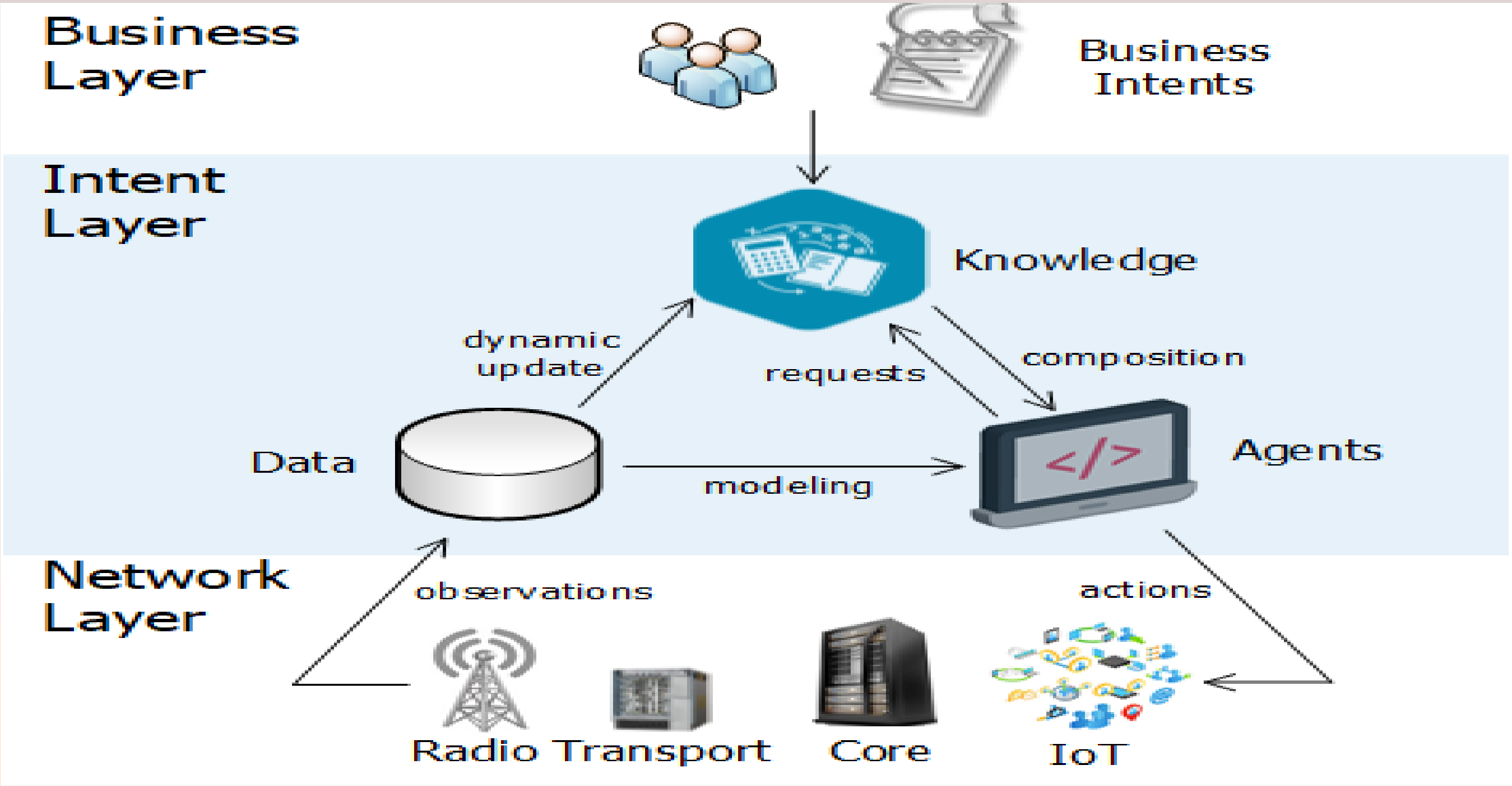
3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Specific aspects of Intent, Policy, and Service Models**
- **Intent** : high-level, declarative goal, operating at the level of a network and services it provides, not individual devices
  - It **defines outcomes** and high-level operational goals, but **does not specify how the outcomes should be achieved,** neither how goals should specifically be satisfied
  - **It does not enumerate specific events, conditions, and actions.**
  - The algorithm or rules to apply can be automatically "learned/derived from intent" by the IBS.

- **Subcategories of intent :**
  - **Operational Intent**: defines intent related to operational goals of an operator; corresponds to the original "intent" term and the concepts defined in this document
  - **Rule Intent:** a synonym for policy rules regarding what to do when certain events occur
  - **Service intent:** a synonym for customer service model [see RFC8309]
  - **Flow Intent:** a synonym for a *Service Level Objective* for a given flow

3. Intent-based networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Intent based networking architecture**



Source: E.Zeydan and Y.Turk "Recent Advances in Intent-Based Networking: A Survey", https://ieeexplore.ieee.org/document/9128422, 2020, Spanish MINECO grant TEC2017-88373-R (5G-REFINE) and Generalitat de Catalunya grant 2017 SGR 1195.

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Intent based networking architecture** (cont'd)
  - **Business Layer:** higher-level declarative policy that operates at the level of a network and services; provide semantic to consume network resources; allowing high-level guidance by a central entity; detect and resolve conflicts between multiple intents.
  - **Intent Layer**
    - **Knowledge:** access to knowledge and execute judgement; performs inference from relations between objects
    - **Agent:** capture the business intent and translate into policies; utilize ontology-based approach to communicate with users; communication interface directly to the network objects
    - **Data:** keep the state of each intent and the relation between network objects; provides models for the observed data; provides algorithms for data modeling
  - **Network Layer** : presents the abstraction of domain-specific data and control plane technologies; specifies context-aware architecture for enhancing the network intelligence

3. Intent Based Networking (IBN)- concepts and architecture

- **3.4 Intent based management (IBMg)**
- **IBN Operational principles**
- **Single Source of Truth (SSoT)** - the set of validated intent expressions
  - SSoT and the records of the operational states enable comparing the intended/ desired state and actual/operational states of the system and determining drift between them
  - SSoT + drift information - provide the basis for corrective actions
  - IBS
    - can predict states
    - develop strategies to anticipate, plan, and pro-actively act on any diverging trends
- **Single Version (or View) of Truth** derives from the SSoT
  - It can be used to perform other operations, such as *querying, polling, or filtering measured and correlated information* in order to create so-called "views."
  - These views can serve the IBS users to create intents as single sources of truth; the IBS must follow well-specified and well- documented processes and models.

See: A.Clemm et al., Intent-Based Networking - Concepts and Definitions , draft-irtf-nmrg-ibn-concepts-definitions-07, March 2022

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **IBN Operational principles**
- **One-touch but not one-shot**
  - The user expresses intent (in different forms) and then the system takes over all subsequent operations (one-touch)
    - The I/F user-IBS could be designed as an interactive and iterative process.
    - The intent expressions may initially contain more or less implicit parts and unprecise or unknown parameters and constraints
    - **The IBS parses, understands and refines the intent expression** to reach a well- formed and valid intent expression, further used by the system for operations
    - An intent refinement process could use a combination of iterative steps

- **Autonomy and Supervision**
  - The **IBS – autonomous- to conduct its tasks and operations** (no user intervention)
  - It tqakes its own decisions as to meet the user expectations in terms of (performance, quality) and providing the proper level of supervision

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **IBN Operational principles** (cont'd)
- **Learning**
  - IBS can learn, reasoning, get knowledge representation and management
  - Different from an imperative-type of system, (e.g., PBM):
    - the user only declares outcome and not how to achieve these goals
  - The AI/ML naturally provide support for IBS ability for learning
- **Capability exposure**
  - It consists in the need for expressive network capabilities, requirements, and constraints to be able to compose/decompose intents and map the user's expectations to the system capabilities
- **Abstract and outcome-driven (IBN – focused on "what" and not "how"**
  - Users are not concerned with outcomes
  - They can refer to concepts at a higher level of abstractions, independent, e.g., of vendor-specific renderings

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Intent-Based Networking - Functionalities**
- **Intent Fulfillment :** functions and I/Fs that
  - allow **users to communicate intent to the network**
  - **perform actions** (e.g., algorithms and functions to learn and optimize
  - It can include also **traditional functions**
    - orchestration of coordinated configuration operations
    - rendering of higher-level abstractions into lower- level parameters

- **Intent Assurance :** functions and I/Fs that
  - allow users to **validate and monitor** that the network is adhering with intent
  - this **assesses the actionseffectiveness**
  - **feedback -**allow training trained or tunning
  - addresses the **"intent drift."** Intent is not meant to be transactional, i.e., "set and forget", but expected to remain in effect over time (unless explicitly stated otherwise)
    - **Intent drift** : the system originally meets the intent, but over time gradually change its behavior

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Intent-Based Networking – Functionalities** (cont'd)
- **Intent Fulfilment details**
  - **Intent Ingestion and Interaction with Users**
    - **"Ingesting" intent = obtaining intent through interactions with users.**
    - The specific functions:
      - **recognize intent from interaction with the user**
      - allow users to refine their intent so that it becomes actionable by an IBS
      - go beyond those provided by a traditional API
      - may support unconventional human-machine interactions
  - One may have a set of intuitive workflows to guide users through the intent ingestion phase, (assuring that all inputs are gathered and translation have been done)

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Intent-Based Networking – Functionalities** (cont'd)
- **Intent Fulfilment details** (cont'd)
  - ***Intent Translation***
    - The IBS core functions **translate user intent into courses of action and requests** to take against the network, which will be meaningful to network configuration and provisioning systems
    - They are bridging the gap between interaction with users and the traditional management and operations side that orchestrate provisioning and configuration across the network
  - ***Intent Orchestration-*** deals with the **actual configuration and provisioning** steps to be orchestrated across the network and that were determined by the previous intent translation step

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Intent-Based Networking – Functionalities** (cont'd)
- **Intent Assurance- details**
  - Functions to ensure that the **network complies with the desired intent** once it has been fulfilled.
  - **Monitoring**
    - It include the usual network monitoring (events, performance measurements) to assess service levels to be delivered
    - Monitored data are inputs for the next set of functions that assess whether the observed behavior is compliant to the intent
  - **Intent Compliance Assessment**
    - Functions to compare the observed network behavior with the intended one
    - This includes assessing the effectiveness of intent fulfillment actions
    - The assessment results can *be fed back to facilitate learning* functions that optimize outcomes
    - Assessing whether intent drift occurs over time

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Intent-Based Networking – Functionalities** (cont'd)
- **Intent Assurance- details** (cont'd)

  - **Intent Compliance Actions**
    - When intent drift occurs or network behavior is inconsistent with desired intent, these functions are triggering corrective actions to resolve intent drift.
    - Or, if necessary, reporting functions need will alert operators (provide information and tools to react appropriately).
    - Maybe modifications of the original intent is necessary

  - **Abstraction, Aggregation, Reporting**

    - The Intent Assurance outcome is reported back to allow the user to relate the outcomes to their intent
    - Functions are needed to analyze, aggregate, and abstract the results of the observations accordingly

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Intent Life Cycle**

```
             User Space   :      Translation / IBS          :  Network Ops
                          :            Space                :     Space
                          :                                 :
           +----------+   :  +----------+   +-----------+   : +-----------+
  Fulfill  |recognize/|---> |translate/|-->|  learn/    |-->| configure/|
           |generate  |      |          |   |  plan/     |   | provision |
           |intent    |<---  |  refine  |   |  render    | : |           |
           +----^-----+   :  +----------+   +-----^-----+   : +-----------+
                |         :                       |         :       |
  ..............|.................................|.................|.....
                |         :                  +----+---+     :       v
                |         :                  |validate|     : +----------+
                |         :                  +----^---+ <---| monitor/ |
  Assure     +---+---+    :  +---------+    +-----+---+     : | observe/ |
             |report | <---- |abstract |<---| analyze | <---|          |
             +-------+    :  +---------+    |aggregate|     : +----------+
```

Source: A.Clemm et al., Intent-Based Networking - Concepts and Definitions , draft-irtf-nmrg-ibn-concepts-definitions-07, March 2022

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Intent Life Cycle (**tied to interconnection functions)
  - Intent **comes into being**, may **change** over time, and **retracted**
  - **Two** functional planes, (**fulfillment and assurance**); **three** (vertical) spaces
  - **User Space -**its functions interface the network and IBS with the human user
    - Users can articulate intent and IBS recognize that intent
    - Functions reporting back the network status and which allow users to assess outcomes and whether their intent was achieved
  - **IBS functions**
    - Translation
      - bridge the gap between intent users and the network operations infrastructure
      - translate an intent into a course of actions
    - Algorithms to plan and optimize actions based on network feedback
    - Analyze and aggregate network observations in order to validate compliance with the intent and to take corrective actions
    - Abstract network observations
  - **Network Operations Space:** traditional orchestration, configuration, monitoring, and measurement functions

3. Intent Based Networking (IBN)- concepts and architecture

- **3.3 Intent based management (IBMg)**
- **Intent Life Cycle** (cont'd)
- There is an ***"inner" intent control loop,*** fully autonomic between IBS and Network Operations
  - The closed-loop involves **automatic analysis and validation of intent** based on observations from the network operations space
  - In order to make adjustments in the network configuration, the observations are input into the functions that plans the rendering of networking intent
  - The loop
    - addresses and counteracts any intent deviation/drift that may occur
    - allows to assess the effectiveness of actions taken in order to continuously learn and improvement

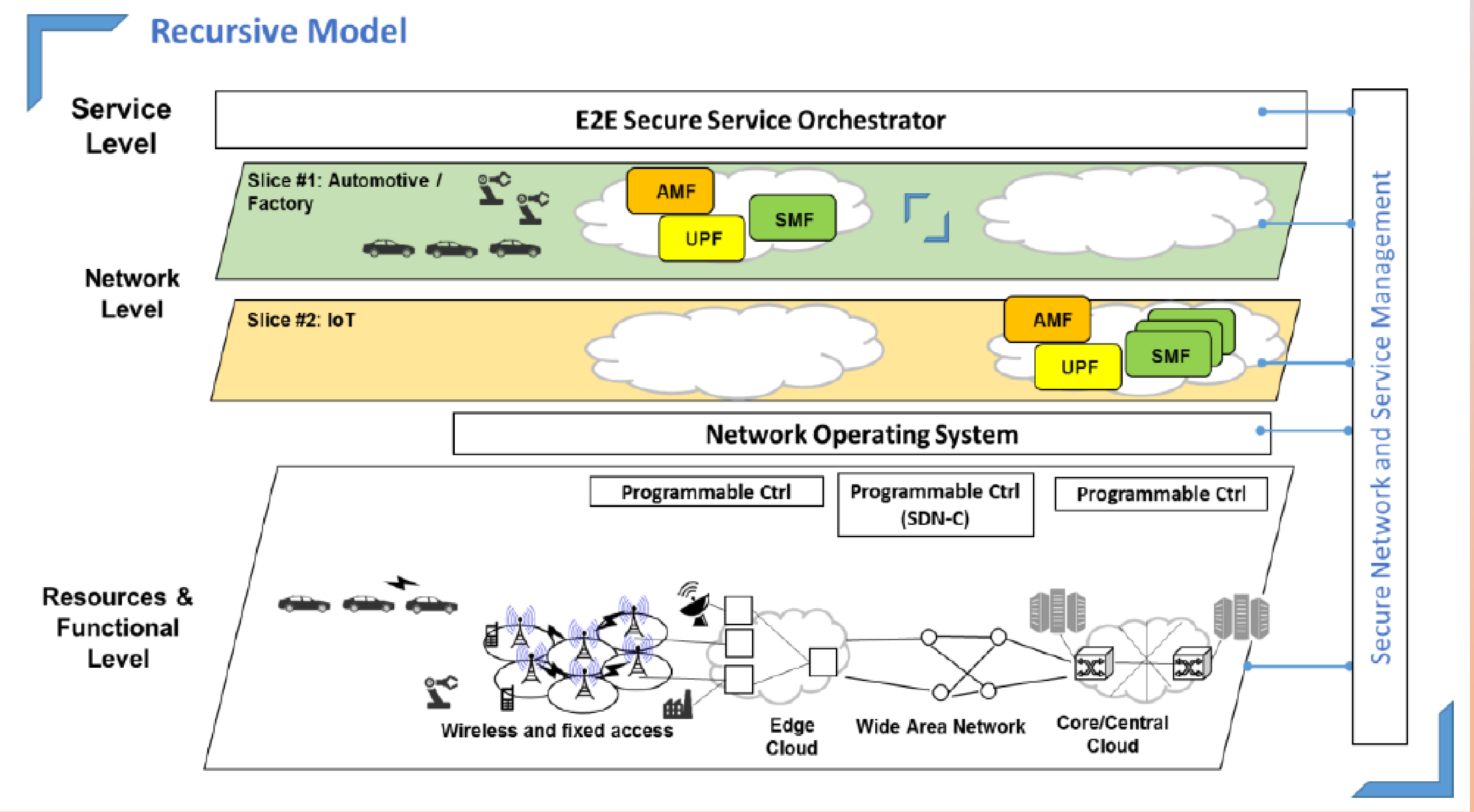
- The ***"outer" intent control loop* is** extended to the user space
  - It includes the user taking actions and (possibly) adjusting their intent based on observations and feedback from the IBS
  - **Intent is thus subjected to a lifecycle**: It comes into being, may undergo refinements, modifications, and changes in time, and retracted later

CONTENTS

1. Introduction
2. Network and services management issues and technologies
3. Intent Based Networking (IBN)- concepts and architecture
4. IBN approach in 5G slicing life-cycle management and orchestration- examples
5. Conclusions

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.1 5G Slicing –overall architecture



Source: 5GPPP Architecture Working Group , View on 5G Architecture, Version 2.0, December 2017

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

- **4.2 5G slicing orchestration, management and control (OMC) aspects**
  Work phases
  - **Service/data model & mapping on slices**
  - Customized slice **design ,preparation, instantiation stitching / composition in a single domain and cross-domain**
  - Network slice **life cycle management- LCM (** monitoring ,updating, ..)

- **OMC system:**
  - may
    - provision initial slice instances
    - or create them at tenants' requests
  - must react during slice life cycle, by taking decision to adapt resources to dynamic conditions of the network and user needs
  - **Cognitive network management technologies can be a strong help to traditional OMC**
    - Using AI/ML one can achieve: **self-x** characteristics – of the network, where [x= awareness, configuration, optimization, healing, protecting]

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.2 Example: 5G slicing management and control (M&C) aspects

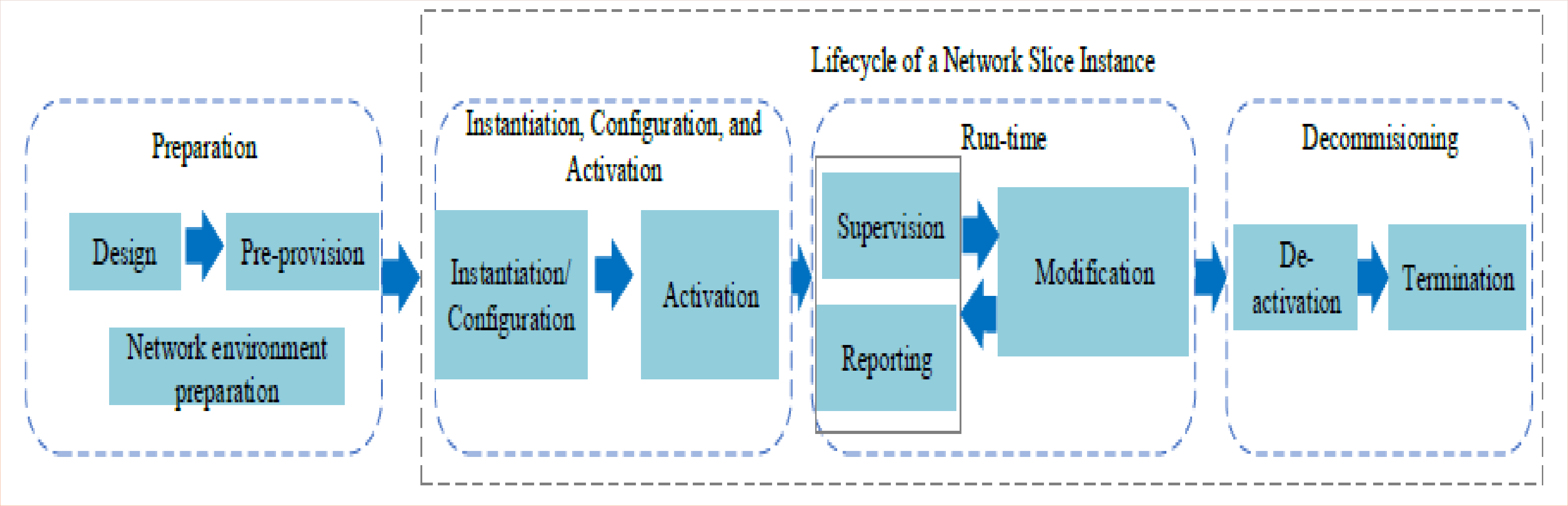
- **Network functions requiring automation**
  - **Planning and design**: Requirements and environment analysis, topology determination
  - **Construction and deployment**: Static resource allocation, VNF placement, orchestration actions
  - **Operation, control and management**: Dynamic resource (re)allocation, adjustment; policy adaptation; it interact bi-directionally with
    - **Fault detection**: Syslog analysis, behavior analysis, fault localization
    - **Monitoring**: Workload, performance, resource utilization
    - **Security:** Traffic analysis, DPI, threat identification, infection isolation

Adapted from source: V. P. Kafle, et. al., "Consideration on Automation of 5G Network slicing with Machine Learning" , ITU Caleidoscope Santafe 2018

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.2 5G slicing orchestration, management and control (M&C) aspects

- **Network Slice Instance Life**
  - **Generic view**



Source: A.Galis, T. Francesc, C.E,.Rothenberg, S.Clayman, "Slicing 5G Networks: An Architectural Survey",2020, DOI: 10.1002/9781119471509.w5GRef095, https://www.researchgate.net/publication/341437156

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.2 5G slicing orchestration, management and control (M&C) aspects

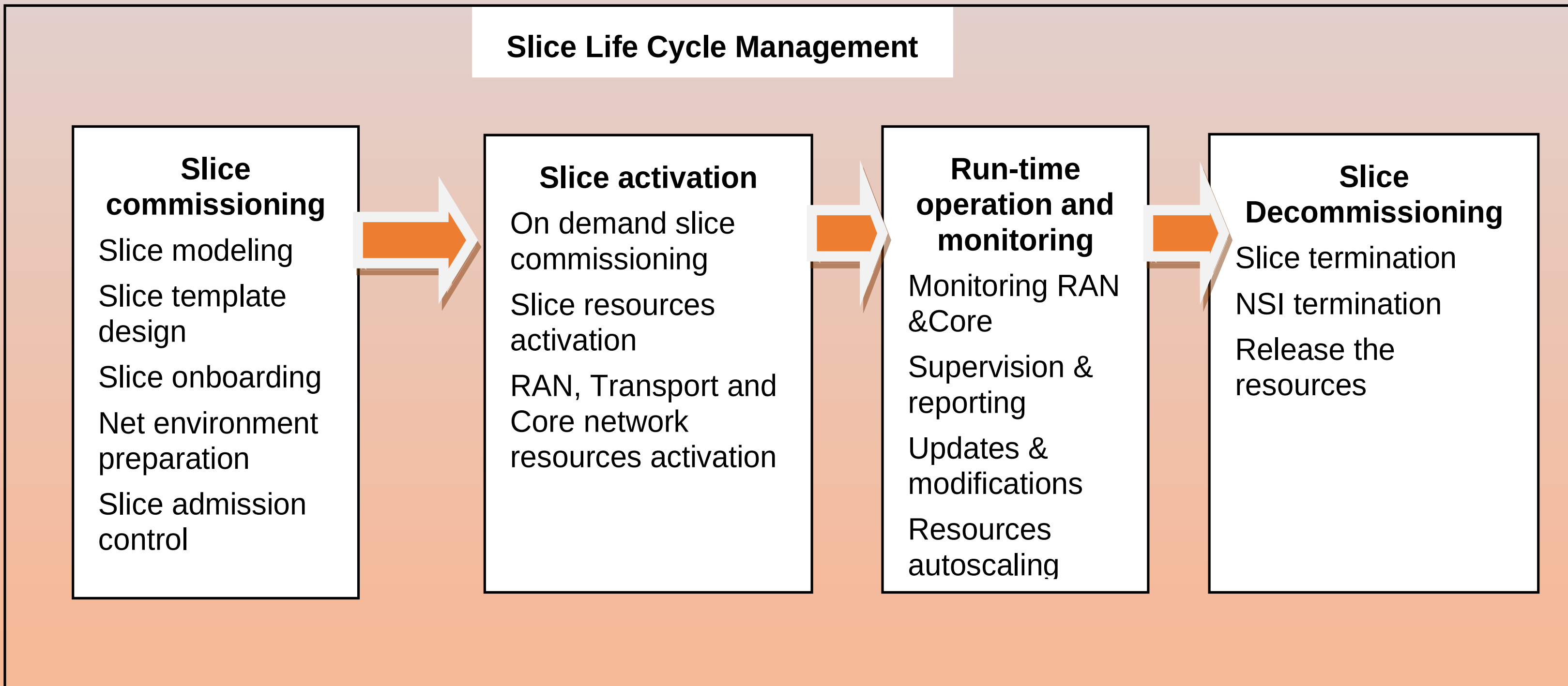
- **Network Slice Instance (NSLI) Life**
  - **Preparation phase:** creation and verification the feasibility of NSL template(s); preparation of the network environment to support the NSLIs lifecycle (e.g., provisioning databases)
  - **Instantiation / configuration**:
    - Instantiation, configuration and activation of shared / non-shared NFs
    - All resources shared/ dedicated to the NSLI are created and configured, i.e. to a state where the NSLI is ready for operation
    - Activation makes the NSLI active, e.g., diverting traffic to it.
  - **Run-time phase:** NSLI handles traffic to support services of certain type(s)
    - Supervision/reporting (e.g., for KPI monitoring)
    - Modification could be : upgrade, reconfiguration, NSLI scaling, changes of NSLI capacity or topology, association and disassociation of NFs with NSLI
  - **Decommissioning phase**
    - Deactivation (taking the NSLI out of active duty); free the dedicated resources (e.g. termination or re-use of NFs) and re-configuration/updating of shared/dependent resources.
    - Finally, the NSLI does not exist anymore.

Source: A.Galis, T. Francesc, C.E,.Rothenberg, S.Clayman, "Slicing 5G Networks: An Architectural Survey",2020, DOI: 10.1002/9781119471509.w5GRef095, https://www.researchgate.net/publication/341437156

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.2 5G slicing orchestration, management and control (M&C) aspects

- **3GPP Vision on LCM of a network slice**



Adapted from: 3GPP- TS 28.530 v 16.5.0 5G; Management and Orchestration; Concepts,Use Cases and Requirements, 2021, https://www.etsi.org/deliver/etsi_ts/128500_128599/128530/15.00.00_60/t%s_128530v150000p.pdf

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.2 5G slicing orchestration, management and control (M&C) aspects

- **3GPP Vision on LCM phases of a network slice instance** (cont'd)
- **LCM : commissioning, activation, runtime monitoring , decommissioning**

  - **Commissioning** : the preparation and design for a slice is handled, e.g., a slice template is created (it contains information about the user requirements and resources to be deployed)
    - After that, the designed slice template is deployed on the underlying infrastructure with NFVO and network controllers
  - **Activation:** the specified resource should be assigned to a slice and activated.
  - **Run-time operations and monitoring** : the activated slice resources are monitored continuously
    - any failure → the NFVO orchestrator is notified in order to resolve the error
  - **Decommissioning:** the created slice instance is deleted automatically at the specified time

Source: 3GPP- TS 28.530 v 16.5.0 5G; Management and Orchestration; Concepts,Use Cases and Requirements, 2021, https://www.etsi.org/deliver/etsi_ts/128500_128599/128530/15.00.00_60/t%s_128530v150000p.pdf

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing LCM

- The main phases are those defined by 3GPP LCM i.e.:
  - ***commissioning, activation, runtime monitoring,* and *decommissioning***
- The IBS includes a
  - **Web-based Graphical User Interface (GUI)**
  - **IBN manager** (mediator for all IBN components)
  - **Knowledge base/ policy store, policy**
  - **Configurators/slice template generators**
    - Performs Intent translation for
      - RAN policy generator – for RAN network
      - Open Source MANO (OSM) policy generator- for Core network
  - **AI-based intelligent update engine**
    - e.g., engine belonging to Deep Learning (DL) - family

Adapted from source: K. Abbas, T.A.Khan, M.Afaq, and W.C.Song, "Network Slice Lifecycle Management for 5G Mobile Networks: An Intent-Based Networking Approach", IEEE Access,2021

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

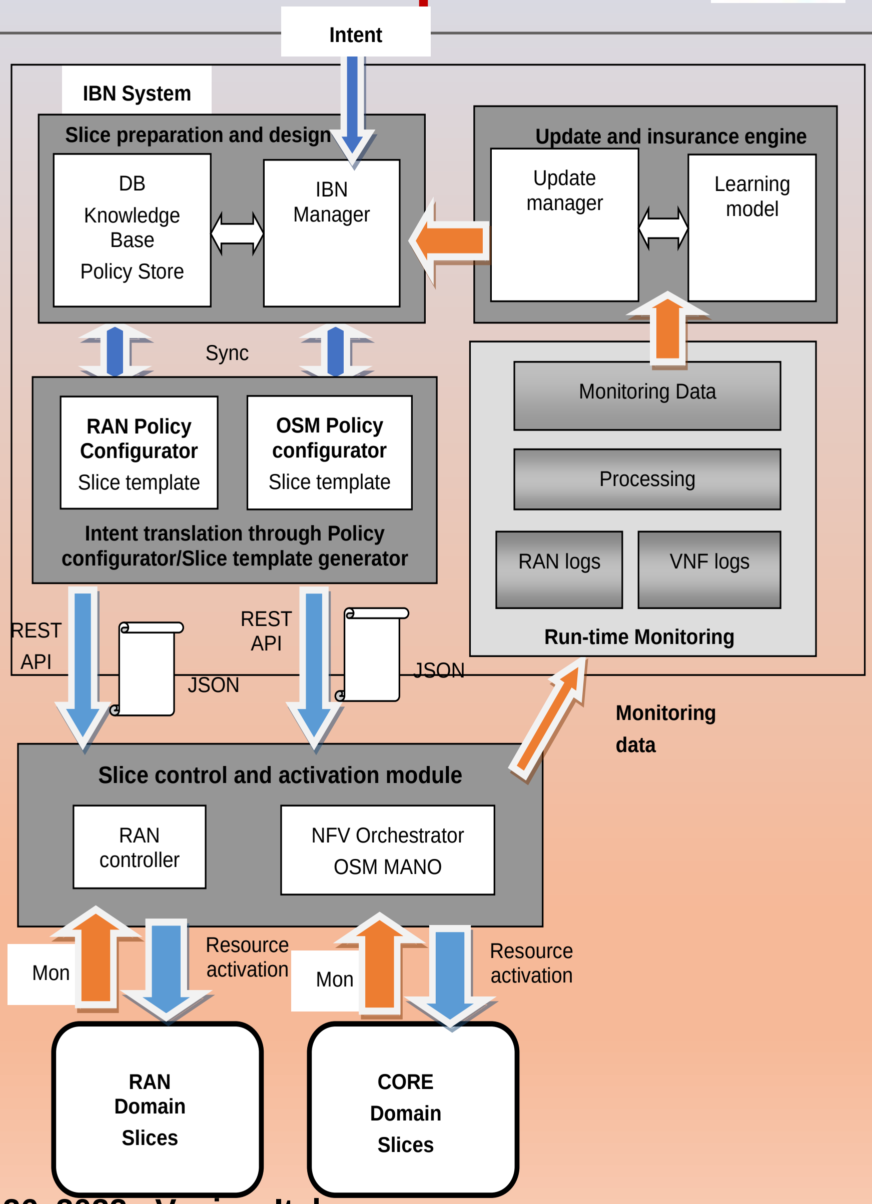
4.3 Example of Intent Based Management applied in 5G slicing LCM (cont'd)

- The users input their slice requirements (**user intents**) through IBN GUI
- The policy DB contains : information on VNFs, instance images, versions, IP addresses, and infrastructure and information related to the deployed intents
- The **IBN manager**
  - prepares a VNF forwarding graph (VNFFG) by **mapping the intent requirements into the required resources and**
  - sends it to the **slice template generator** which has policy configurators for translating higher-level QoS requirements into policy configurations
- The policy configurators forwards the slice templates to
  - the *Open Source MANO (OSM)* – for core part control
  - the RAN controller
- The IBNS intelligent update and assurance engine automatically updates the resources at runtime in failure or overload cases

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**
- **Main functional components**
  - **IBN System**
    - Slice preparation and design
      - Data Base, Policy store
      - IBN Manager
    - Intent translation/Policy configurator (RAN, OSM)
    - Update and insurance engine
    - Run-time monitoring
  - **Slice control and activation module**
    - RAN Controller
    - NFV Orchestrator
  - **RAN Domanin, Core Domain**
    - **(slice instances)**



Adapted from source

K. Abbas, T.A.Khan, M.Afaq, and W.C.Song, "Network Slice Lifecycle Management for 5G Mobile Networks: An Intent-Based Networking Approach", IEEE Access,2021

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management** (cont'd):
- ***Slice Commissioning***
- The **users** (customers, MNOs, resource vendors) input (via GUI) slice QoS requirements in **the form of user intents**
  - **Intents : higher-level abstract requirements (SLAs) for a slice**
    - e.g., slice information (slice ID/S-NSSAI), QoS requirements (up-rate, down-rate), service type (eMBB, URLLC, IoT), slice instantiation time, and deletion time-period
  - The IBN manager *interacts with the network orchestrators the REST API I/F*
  - When a user intent comes, the IBN manager fetches the resource and architecture information from the knowledge DB, maps them with the available resources, and creates a VNF graph (VNFG)
    - The **knowledge base** or catalog repository stores all the **information regarding the underlying resources,** (VNFs, PNFs, IP addresses scheme, instance images, and deployed intents)
    - The generated VNFG is sent to **slice template generators/policy configurators**
    - The slice template generators receive and **translates the user intent forward into the underlying NFVO acceptable format**

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management: Slice Commissioning** (cont'd):
- **Implementation examples**

- The **OSM** slice template generator generates the slice template into JSON string format (OSM NFVO accepts this form) and similar actions are performed by slice template generator for RAN
- Multiple slice template generators can exist, for multi orchestrators (e.g., NFVO OSM, SDN RAN controller FlexRAN and ONOS controller)
- The ***CORD*** *(Central Office Re-architected as a Datacenter*) (https://opennetworking.org/cord/) is a platform that leverages SDN, NFV and Cloud technologies to build agile datacenters for the network edge. Integrating multiple open source projects, CORD delivers a cloud-native, open, programmable, agile platform for network operators to create innovative services.

- *NX.Foukas, N.Nikaein, M.M. Kassem, M.K.Marina,K Kontovasilis ,"FlexRAN: A Flexible and Programmable Platform for Software-Defined RAN", European FP7 FLEX project (612050), https://dl.acm.org/doi/10.1145/2999572.2999599*

https://opennetworking.org/cord/, https://opennetworking.org/m-cord/

"Open Source Mano" https://osm-download.etsi.org/ftp/Documentation/201902-osm-scopewhite-%paper/#!02-osm-scope-and-functionality.md

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management: Slice Commissioning**
- **Implementation examples** (cont'd)

- *The* ***M-CORD*** is an open source reference solution (https://opennetworking.org/m-cord/), built on CORD for 5G mobile networks. It is a cloud-native solution built on SDN/NFV/Cloud technologies. It includes virtualized RAN functions and a *virtualized mobile core (vEPC)*. M-CORD enables the creation of use case-specific services that can be dynamically scaled.
- The ***(TOSCA)*** *Topology and Orchestration Specification for Cloud Applications* *(*https://www.techtarget.com/searchcloudcomputing/definition/TOSCA-Topology-and-Orchestration-Specification-for-Cloud-Applications)
  - *open-source language* used to describe the relationships and dependencies between services and applications that reside on a cloud computing platform.
- In the system example, the M-CORD policy configurators convert the user requirements in TOSCA format. The slice template is designed and prepared In the slice instantiation module, according to the underlying NFVOs.

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management** (cont'd):
- ***Slice Activation***
  - **Slicing the Core network resources**
  - Network Orchestrator (OSM) (ETSI)- enables MNOs to automatically deploy E2E network services, based on NFV.
  - **Components: NFVO (NFV orchestrator); VNFM (Virtual Network Function Manager) ; VIM (Virtual Infrastructure Manager);** see ETSI NFV
  - A GUI portal allows for automatically managing, monitoring, and deploying the network resources
  - The NFVO OSM
    - deploys Core network VNFs such as Evolved Packet Core (EPC) VNFs (vMME, vHSS, vSPGW)
    - facilitates slice LCM in E2E context
  - The **OSM slice template generator/ OSM policy configurator** generates the slice configurations for OSM NFVO (e.g., in the JSON string format)
  - The slice template is forwarded to OSM (vie REST API)
  - The OSM deploys the core network VNFs with the help of VIM (OpenStack) over the infrastructure

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- ***Slice Activation*** (cont'd)
  - **Slicing the RAN resources**
  - Inside IBN, the **RAN slicing policy configurator** converts the high-level slice configuration provided at the IBN tool to JSON slice template format and send it to the underlying RAN controller
  - A **SDN controller** could be used, (e.g. FlexRAN), to manage multiple BSs and to slice RAN resources; it contains a **Control plane (CPL)** and an **agent API**
  - The agent acts as a local controller, interacting with the other agents and the master controller
    - It can control one eNodeB at a time
    - The agent API : SB I/F decoupling the CPL from the eNodeB DPL
  - On top of the RAN controller: control and monitoring applications exist and communicate with the master controller through the NB interface
    - for automatic management, modifications, and control of the RAN resources
  - RAN controller deploys these configurations at eNodeB for slice creation

Source: NX.Foukas, et al.,,"FlexRAN: A Flexible and Programmable Platform for Software-Defined RAN", European FP7 FLEX project (612050), https://dl.acm.org/doi/10.1145/2999572.2999599

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management** (cont'd):
- **Run-time monitoring and dynamic scaling**
  - **RAN domain (eNodeBs) monitoring**
    - RAN controller and a special *elasticMon* tool
      - monitor the high real-time data traffic to control and manage it
      - store the statistics of the eNodeBs
  - Visualizing tools (e.g., Kibana, Grafana) can be used on the top of the RAN controller and *elasticMon* to visualize the data traffic on runtime
  - **Core network monitoring**
    - *Openstack telemetry service* or ceilometer can monitor the VNFs
    - On top of that, MON OSM monitoring service collects the VNFs data logs and further forward them to a DB (e.g., Prometheus -an open-source tool for monitoring the real-time data traffic and store them into a time-series database).
    - The DB keeps the VNFs data logs into the real-time database repository
  - Visualizing tools are integrated with the DB to visualize theVNFs resource status (CPU, RAM usage, etc.)
  - Failures → reconfiguration and dynamic updating the slice resources

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):

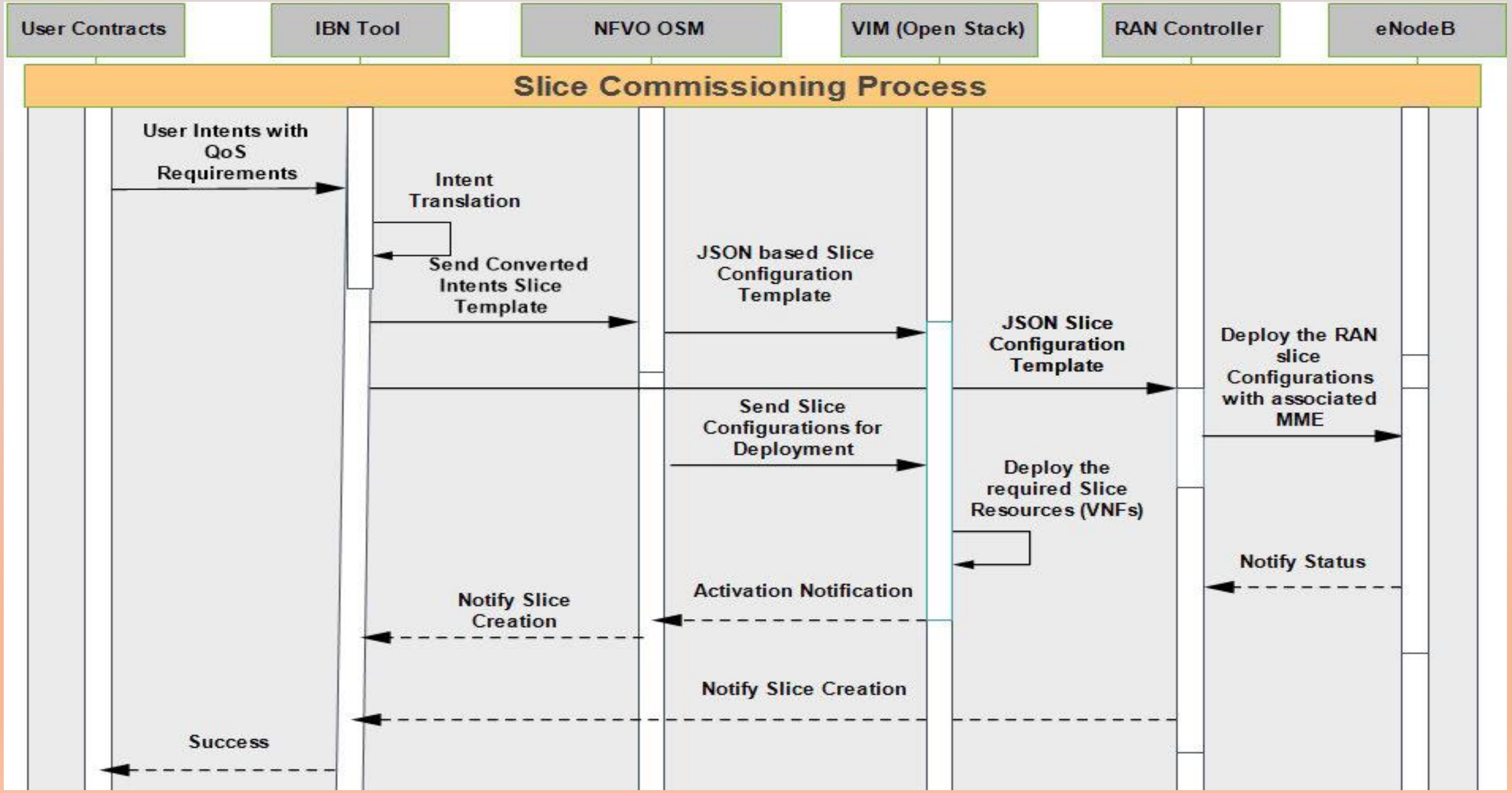
- **Slice decommissioning**
- **Two ways for decommissioning**
  - **The slice termination request is generated through the IBN system** web portal, which contains the slice SNSSAI (single network slice selection assistance information), SliceID.
    - The slice deletion configurations are rendered the same as the slice creation process
    - The slice deletion template is forwarded to the NFVOs; the OSM and RAN controller can delete the resources

  - **The slice instance life time is inserted during the slice creation phase**
    - When the life time is finished the IBS automatically generates the slice deletion request and performs the same process
    - A deletion confirmation notification is sent back to the operator through the IBN platform.

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Slice Life Cycle Management -summary**

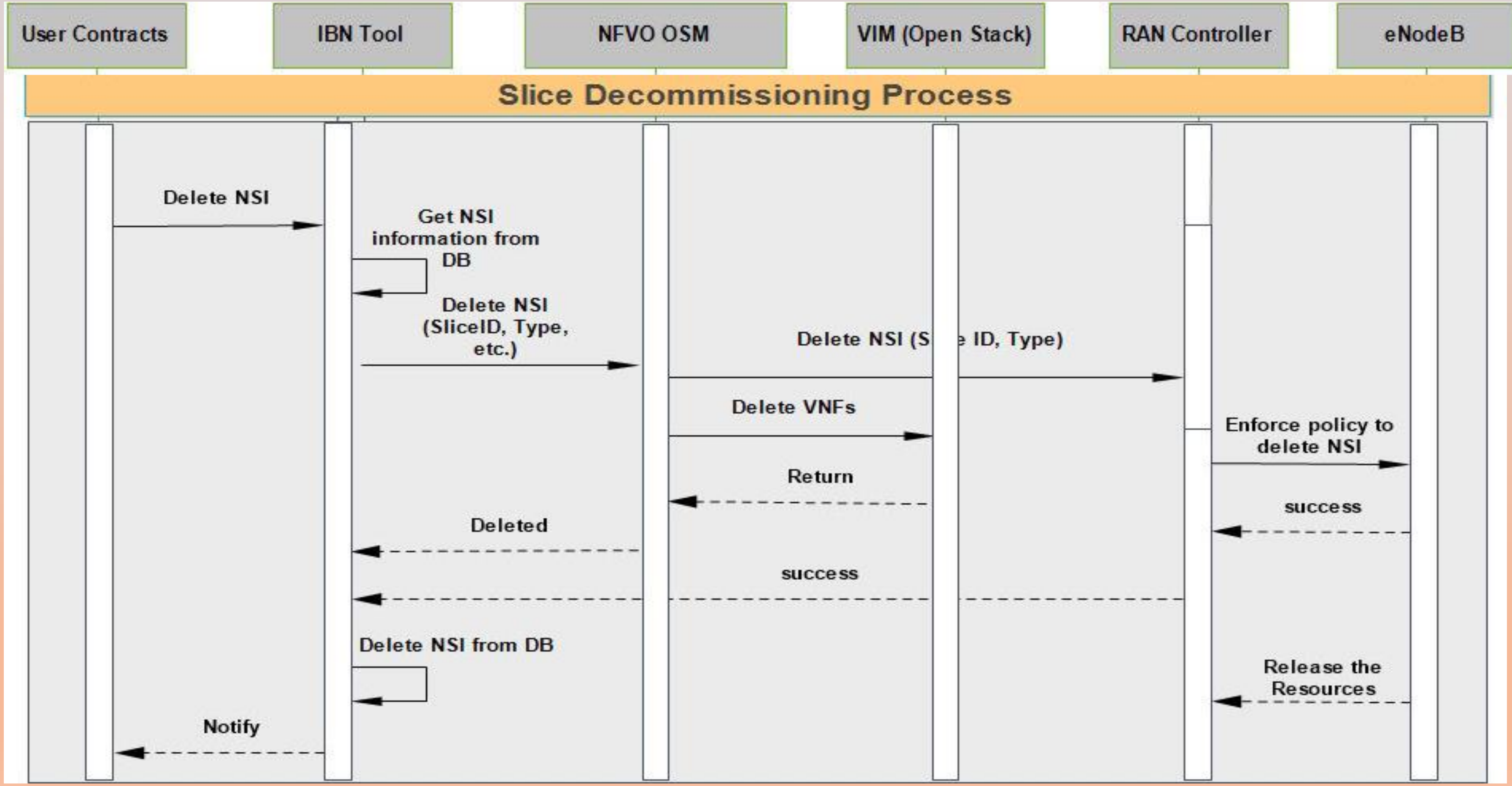


See for details- Source: K. Abbas, T.A.Khan, M.Afaq, and W.C.Song, "Network Slice Lifecycle Management for 5G Mobile Networks: An Intent-Based Networking Approach", IEEE Access,2021

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Slice Life Cycle Management –summary** (cont'd)



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4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- **Slice Life Cycle Management –summary** (cont'd) (see the previous slides
- **Slice commissioning**
  - The users define slice requirements (in intent form) of through the GUI of the IBN system
  - The IBN policy configurators translates the requirements into policy configurations for each domain and forwards them to OSM and RAN controller to deploy resources
  - The OSM prepares the core network EPC VNFs resources for the requested slice using Open-Stack
  - The RAN controller deploys the slice configurations at the RAN domain
  - The slice configurations include information about dedicated vMME, slice SNSSAI, and QoS requirements used to stitch RAN slice with core VNFs
  - The IBN notifies the user of successful slice activation

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- **Slice Life Cycle Management –summary** (cont'd) (see the previous slides

- **Slice decommissioning**
  - The user inputs the network *sliceID* information
  - TheIBN manager checks the slice information from the catalog repository of the IBS
  - The IBN again translates the slice information into policy configurations and forwards them to OSM and RAN controller to delete resources associated with that slice instance
  - The OSM with OpenStack deletes the core EPC VNFs, and the RAN controller deletes the slice at *eNodeB.* The OSM and RAN controller notify the IBN platform about slice deletion

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management** (cont'd):
- **User Intents and contract design**
  - The contract design in IBS define the underlying **platform resources requirement** in an understandable way by the network operators.
  - The contract design is the user intent for creating a slice (resource requirements)
  - User contract main fields: **S-NSSAI (single network slice assistance information), architecture ID, up-rate, down-rate**
    - S-NSSAI identifies the service domain for each slice (URLLC, eMBB, mMTC, etc.)
    - The network architecture type can be LTE, LTE advanced, 5G, etc.
    - The QoS parameters contains slice up-rate and down-rate data requirements (bandwidth, latency)
- The IBN framework has an interactive web-based front-end for NOs
  - The Nos can input the information of the user contracts
- The IBN framework generates the **service graph** for network resources allocation (RAN, core) and suitable network functions for a requested slice.

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management** (cont'd):
- **User Intents and contract design**

User Intents/Contracts

Slice Information

S-NSSAI

Architecture (LTE, LTE-A, 5G, etc.)

QoS parameters

Up-link

Down-link

IBN Tool

Intent Manager

Update Manager

Policy Store

OSM Policy Configurator

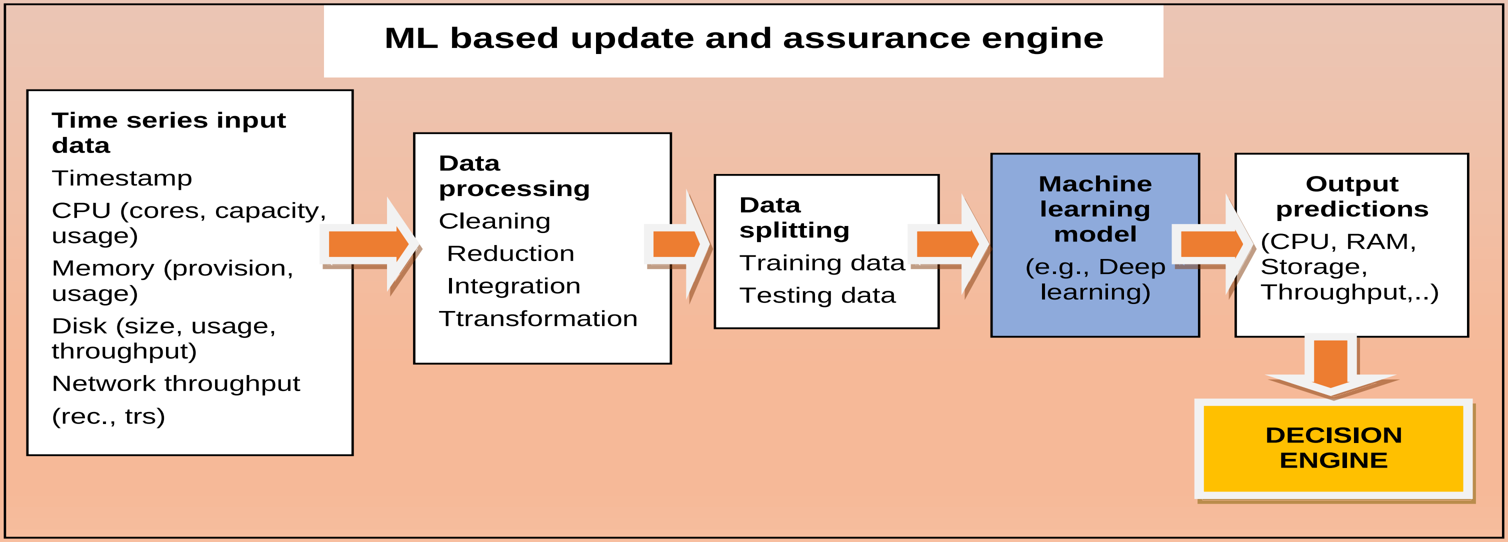
RAN Policy Congfigurator

Adapted from source: K.Abbas, M.Afaq, T.A.Khan, A.Rafiq and W-C Song, "Slicing the Core Network and Radio Access Network Domains through Intent-Based Networking for 5G Networks", Electronics 2020, 9, 1710; doi:10.3390/electronics9101710, www.mdpi.com/journal/electronics

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.3 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management** (cont'd):
- **Intelligent self- assurance and updating methods in IBN (ML –based)**
  - **Machine learning-based update and assurance engine – example**
    - **Working phases:** real-time cloud resource time-series dataset, data processing, data splitting, ML model processing, decision engine
    - The ML provides predicted resource utilization (CPU, RAM, storage, throughput); the decision engine decides on the updating



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4. IBN approach in 5G slicing life-cycle management and orchestration- examples

- **4.4 Network applications examples and relevant ML techniques**
- **ML summary**
- **Learning methods in basic ML**
  - **Supervised learning (SML)**-predicting one or more dependent variables
    - based on (initially) labeled data
    - *use cases examples*: **classification** and **regression**
    - **semi-supervised learning (SSML)**: not all data is labeled
  - **Unsupervised learning (UML)**- look for structure in (unlabelled) data sets
    - *use cases examples*: clustering or pattern mining
- **Specific classes of ML**
  - **Reinforcement learning (RL)** -using **feedback** to an **agent actions** in a dynamic environment; figures out predictions through trial and error
    - *use cases examples*: network and services management, self driving cars,
  - **Deep learning (DL) -** use a cascade of *multiple layers* of nonlinear processing units for *feature extraction* and *transformation*
    - *use cases examples*: network and services management, ….
  - **Deep Reinforcement Learning**: **DRL = RL + DL (**general intelligence)
    - RL defines the objective; DL gives the mechanism
- **Note: a complete ML taxonomy is very rich; it is out of scope for this presentation**

- **4.4 Network applications examples and relevant ML techniques**
- **ML summary**
- **Deep Learning (DL) versus Reinforcement Learning (RL)**
- **Deep learning (DL)**
  - subset of ML based on artificial neural networks (ANN/NN)
  - it is considered as one of the many ML methods
  - types: Convolutional NN, Recurrent NN, ..

  - use the current information in teaching algorithms to look for pertinent patterns which are essential in forecasting data
  - applies learned patterns to a new set of data (while RL gains from feedback)

  - is also known as *hierarchical learning* or *deep structured learning*
  - the applications are more often in recognition and area reduction tasks

  - can be supervised, unsupervised, semi-supervised, self-supervised, or even RL-mode (depending mostly on how the neural network is used)

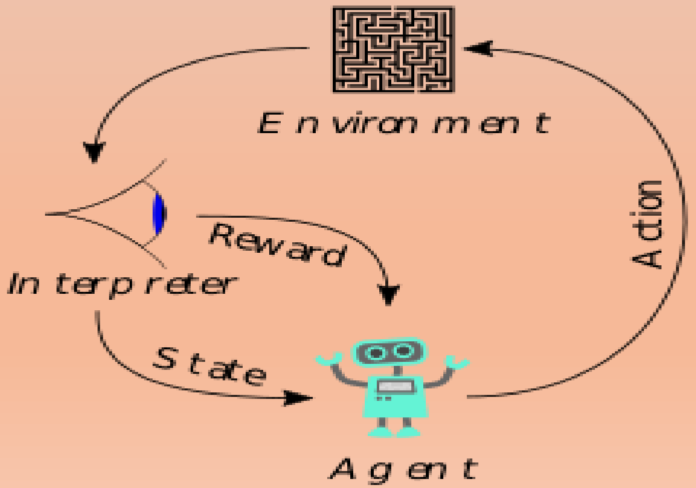
4. IBN approach in 5G slicing life-cycle management and orchestration- examples

- **4.4 Network applications examples and relevant ML techniques**
- **ML summary** (cont'd)
- **Deep Learning versus Reinforcement Learning**
- **Reinforcement Learning (RL)**
  - is one of the main basic ML paradigms
  - in supervised and unsupervised learning, there is no 'consequence' to the ML engine if it fails to properly understand or categorize data
  - however, RL, generally figures out predictions through trial and error
  - applications are usually oriented on systems with environment interaction and optimal control objectives
  - does not need a current data set to learn (it can be unsupervised -type)

Working phases

Training phase: is to tell the agent which action shall be taken, under a given environment, from a series of trials

Inference phase: the agent takes appropriate actions according to the experience learned during the training



4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.4 Network applications examples and relevant ML techniques

Networking application		Steps of ML workflow					
General objective	Specific works	Problem formulation	Data collection		Data analysis	Offline model construction	Deployment and online inference
			Offline collection	Online measurement			
Traffic prediction	traffic volume prediction	SL: prediction with Hidden-Markov Model (HMM)	Synthetic and real traffic traces with flow statistics	Observe the flow statistics	The flow count and the traffic volume are correlated	Training HMM model with Kernel Bayes Rule and **Recurrent Neural Network with Long Short Term Memory unit**	Take flow statistics as input and obtain the output of the traffic volume
Resource management	job scheduling	**RL: decision making with deep RL**	Synthetic workload with different patterns is used for training	The real time resource demand of the arrival job	Action space is too large and may have conflicts between actions	Offline training to update the policy network	Directly schedule the arrival jobs with the trained model

Adapted from source (see details there): M.Wang, et al., "Machine Learning for Networking: Workflow, Advances and Opportunities", IEEE Network Vol.32, Issue 2 , March-April 2018

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

- **4.4 Network applications examples and relevant ML techniques** (cont'd)

Networking application a		Steps of ML workflow					
General objective	Specific works	Problem formulation	Data collection		Data analysis	Offline model construction	Deployment and online inference
			Offline collection	Online mon			
Network adaptation nd perf prediction	routing strategy	SL: decision making with *Deep Belief Architectures (DBA)*	Traffic patterns labeling with routing paths computed by OSPF protocol	Online traffic patterns in each router	Pb.: difficult to characterize the I/O patterns to reflect the dynamic nature of large-scale het. networks	Take the Layer-Wise training to initialize and the backpropagation process to fine-tune the DBA structure	Record and collect the traffic patterns in each router periodically and obtain the next routing nodes from the DBAs
	general QoE optimization	**RL: decision making with a variant of UCB Upper confidence bound) algorithm**	Session quality information with features in large time scale	Session quality information in small time scale	Application sessions sharing the same features can be grouped	Backend cluster determines the session groups using CFA with a long time scale	Front-end performs the group-based exploration-exploitation strategy in real time
	throughput prediction	SL: prediction with HMM	Datasets of HTTP throughput measurement from iQIYI	users' s session features as input	Sessions with similar features tend to behave in related pattern	Find set of critical feature and learn a HMM for each cluster of similar sessions	new session is mapped to the most similar session cluster and corresponding HMM are used to predict throughput

Adapted from source (see details there): M.Wang, et al., "Machine Learning for Networking: Workflow, Advances and Opportunities", IEEE Network Vol.32, Issue 2 , March-April 2018

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**
- **Intelligent self- assurance and updating methods in IBN II** (cont'd)

  - IBN-based closed-loop system is capable of self-assurance and updating
  - The IBS performs **monitoring** and can use **machine learning (ML)** to autonomously update the system to dynamic conditions
  - Several features are possible*: service assurance, update, failure detection, auto-recovery,* etc.
  - Network resource continuous monitoring will support adaptation of service provisioning, according to the system state
  - **ML proactive models** can be used to **observe the resource status** and decide to **update the system** according to predicted future needs
  - The intelligent engine's work may consist in a chain of phases: *real-time cloud resource time-series dataset, data processing, data splitting, DL model, and decision engine*

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**
- **Intelligent self- assurance and updating methods in IBN**
  - **Example of ML model appropriate for an IBN engine**
  - **Deep learning (DL)** can solve problems, e.g., prediction, classifications, detection, etc.; **Deep Neural Networks (DNN)** implement DL
  - DL DNN- process the data in a *feed-forward way* from the input layer to several hidden layers and the final output layer
    - Each node (neuron) is directly connected with other nodes of the next layer
    - The first input layer has multiple input neurons that are further connected with multiple weight factors according to the design of the model and dataset features.
  - **Recurrent Neural Network (RNN)-** special class DNN :
    - The connections between nodes form a *directed* or *undirected* graph along a **temporal sequence**
    - This allows it to exhibit temporal dynamic behavior
    - RNNs are derived from feedforward neural networks, they can use their internal state (memory) to **process variable length sequences of inputs**
    - RNN can run arbitrary programs to process arbitrary sequences of inputs

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- **Intelligent self- assurance and updating methods in IBN**
  - **Example of ML model appropriate for an IBN engine** (cont'd)

  - **Recurrent Neural Network (RNN)**
    - Ordinary *Feedforward Neural Networks* FNNs are only meant for data points, which are independent of each other; FNN pass information through the network without cycles
    - However, for data in a sequence with dependence between points, a modification in NN is needed to model the dependencies

    - **RNNs have 'memory'** that helps them store the states or information of previous inputs to generate the next output of the sequence.
    - RRN take the previous output or hidden states as inputs
    - In RNNs, their intermediate values (state) can store information about past inputs for a time that is not fixed a priori
    - RNN has cycles in its graph, and transmits information back into itself

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management** (cont'd):
- **Intelligent self- assurance and updating methods in IBN**
  - **Example of ML model appropriate for an IBN engine** (cont'd)
  - **Recurrent Neural Network (RNN)**
  - **Advantages: capabilities to**
    - **handle sequence data; handle inputs of varying lengths; store historical information**
  - **Disadvantages :**
    - The computation can be very slow
    - The basic network does not consider future inputs to make decisions
    - Vanishing or exploding gradient problem
      - The gradients used to compute the weight update may go to zero, preventing the network from learning new weights
        - the deeper the network, the more pronounced is this problem
      - One can avoid this by initializing the weights very carefully
        - If the weights are too small, the gradients shrink exponentially; too big then the gradients grow exponentially
      - Typical FNN can cope with these effects (low number of hidden layers)
    - In an RNN trained on long sequences the gradients can easily explode or vanish
    - RNNs have difficulty dealing with long-range dependencies

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

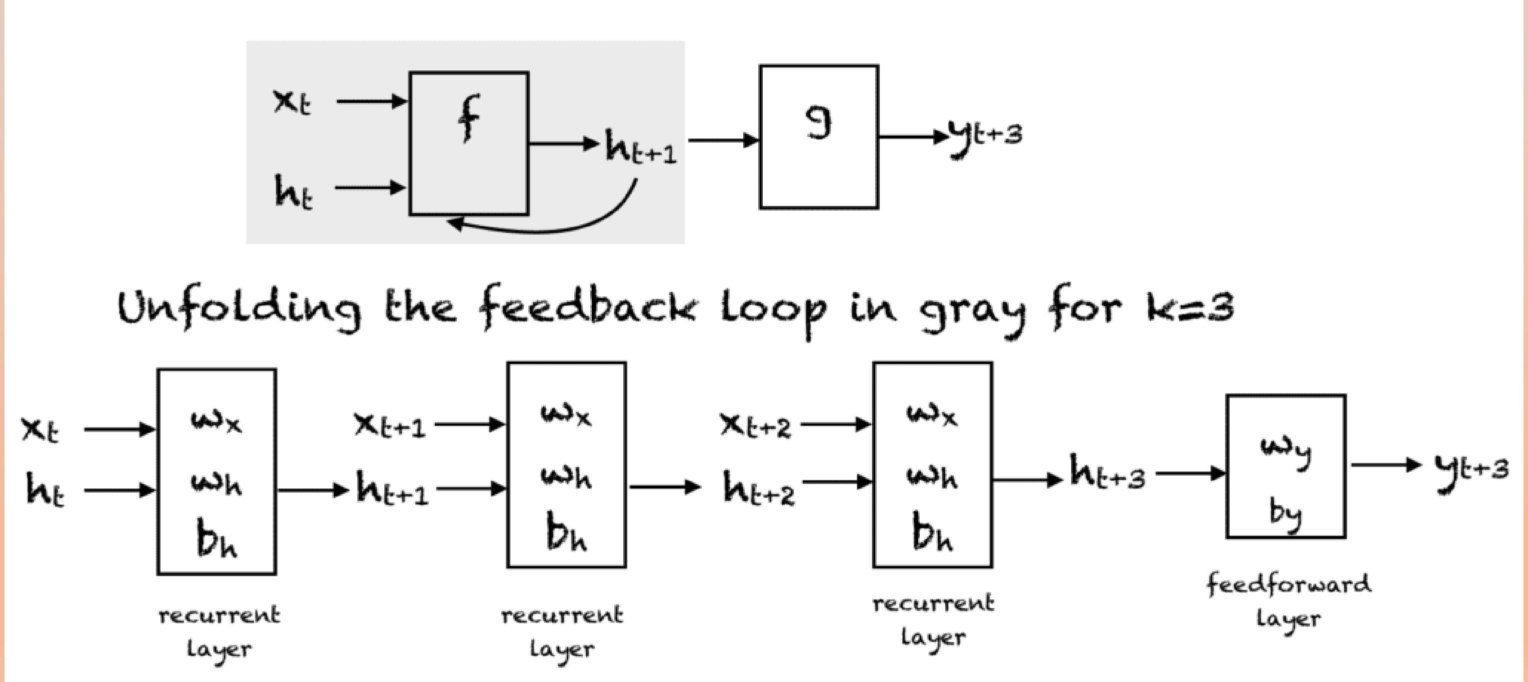
4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- **Intelligent self- assurance and updating methods in IBN**
  - **Recurrent Neural Network (RNN)**
  - **RNN Architectures**
    - **Bidirectional recurrent neural networks (BRNN)**
      - The inputs from future time steps are used to improve the accuracy of the network
      - (It is like having knowledge of the first and last words of a sentence to predict the middle words).
    - **Gated Recurrent Units (GRU)**
        - Networks designed to handle the vanishing gradient problem
        - They have a reset and update gate
        - These gates determine which information is to be retained for future predictions
      - **Long Short-Term Memory (LSTM)**
        - Designed to address the RNNs vanishing gradient problem
        - LSTM use three gates called input, output and forget gate
        - Similar to GRU, these gates determine which information to retain

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- **Intelligent self- assurance and updating methods in IBN**
  - **Recurrent Neural Network (RNN)- details**
  - Simple RNN example: feedback loop shown in the gray rectangle can be unrolled in 3 time steps to produce the second network of the above figure



Source: J. Brownlee, https://machinelearningmastery.com/an-introduction-to-recurrent-neural-networks-and-the-math-that-powers-them/

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- **Intelligent self- assurance and updating methods in IBN**
  - **Recurrent Neural Network (RNN)-details**
  - **Notations in the above figure**

x_t Є R - the input at time step t; in a simple case it is a scalar, but one can extend it to a d-dimensional feature vector

y_t Є R - the output of the network at time step t; in this example there is one output, but one can produce multiple outputs

h_t Є R^m - vector stores the values of the hidden units/states at time t (this is called the current context; m is the number of hidden units; h_0 vector is initialized to zero

w_x Є R^m - weights associated with inputs in recurrent layer

w_h Є R^{mxm} - weights associated with hidden units in recurrent layer

w_y Є R^m - weights associated with hidden to output units

b_h Є R^m - the bias associated with the recurrent layer

b_y Є R - the bias associated with the feedforward layer

Source: J. Brownlee, https://machinelearningmastery.com/an-introduction-to-recurrent-neural-networks-and-the-math-that-powers-them/

4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- **Intelligent self- assurance and updating methods in IBN**
  - **Recurrent Neural Network (RNN)-details**

At every time step one can unfold the network for k time steps to get the output at time step k+1

The unfolded network is very similar to the FFN

The rectangle in the unfolded network shows an operation taking place.

Example, with an **activation function f**:

$$h_{t+1} = f(x_t, h_t, w_x, w_h, b_h) = f(w_x x_t + w_h h + b_h)$$

The output y at time t is

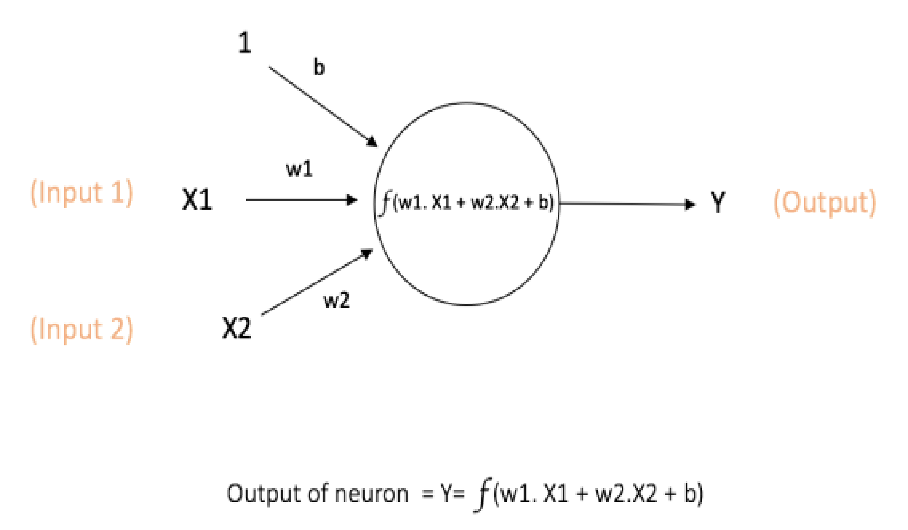
$$y_t = f(h_t, w_y) = f(w_y . h_t + b_y);$$ the . is the dot product

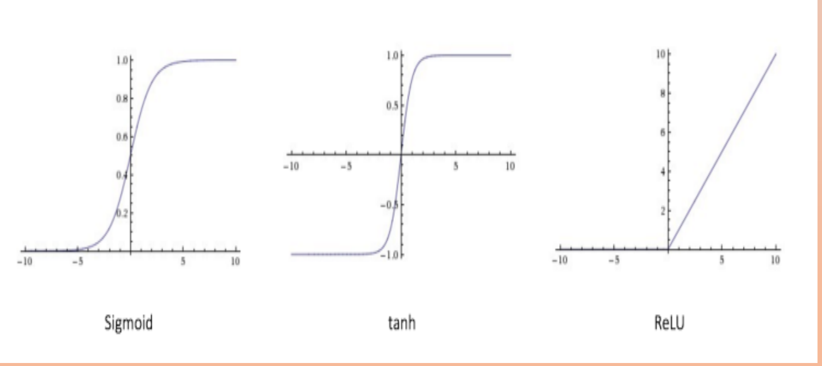
- In the feedforward pass of a RNN, the network computes the values of the hidden units and the output after k time steps
- The weights associated with the network are shared temporally
- Each recurrent layer has two sets of weights; one for the input and the second one for the hidden unit.
- The last feedforward layer, computes the final output for the kth time step; it is just like an ordinary layer of a FNN

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- **Intelligent self- assurance and updating methods in IBN**
  - **Recurrent Neural Network (RNN)- details**
  - **Activation functions examples** (similar to FNN)
    - **Sigmoid:** σ(x) = 1 / (1 + exp(−x))
    - **tanh**: tanh(x) = 2σ(2x) − 1
    - **ReLU**: Rectified Linear Unit. f(x) = max(0, x)

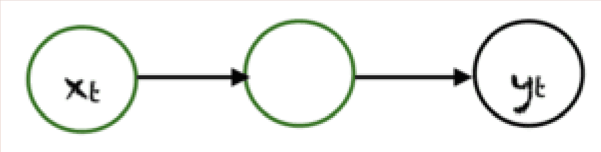




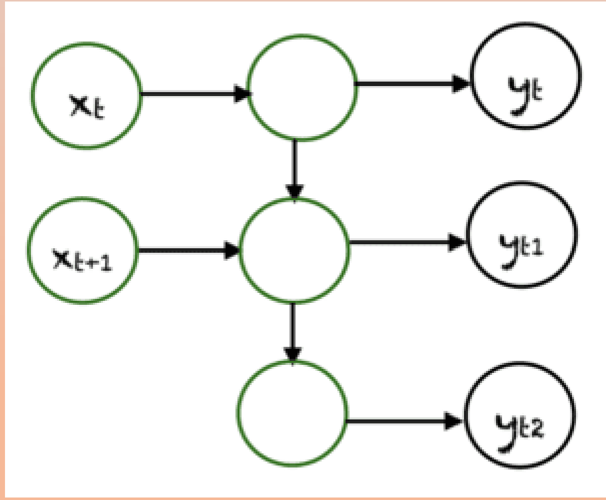
4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- **Intelligent self- assurance and updating methods in IBN**
  - **Recurrent Neural Network (RNN)- details**
  - **Types of RRNs**
    - One to One
    - One to Many
    - Many to one
    - Many to Many



Example: One to One



Example: Many to Many

Source: J. Brownlee, https://machinelearningmastery.com/an-introduction-to-recurrent-neural-networks-and-the-math-that-powers-them/

4. IBN approach in 5G slicing life-cycle management and orchestration- examples

4.5 Example of Intent Based Management applied in 5G slicing

- **Life Cycle Management**(cont'd):
- **Intelligent self- assurance and updating methods in IBN**
  - **Recurrent Neural Network (RNN)**
  - **Training the RNN**
    - The backpropagation algorithm of an ANN is modified (to include the unfolding in time to train the weights of the network).
    - This algorithm: computing the gradient vector and is called back propagation in time (BPTT)
    - **The pseudo-code for training**
    - The value of k can be selected by the user for training. The p_t is the target value at time step t:

1. Repeat till stopping criterion is met:
   1. Set all h to zero.
   2. Repeat for t = 0 to n-k
      1. Forward propagate the network over the unfolded network for k time steps to compute all h and and y
      2. Compute the error as: e= $y_{t+k} - p_{t+k}$
      3. Backpropagate the error across the unfolded network and update the weights.

CONTENTS

5. Conclusions

- The **Intent Based Networking (IBN)** approach and platforms offer automation of management of the network slice lifecycle for single or multi-domain environment
- The user has to define its higher-level service requirements through GUI without dealing with the realisation of them
- IBN system translates the user requirements for a slice into policy configurations/ slice templates through domain policy configurators and forwards them to underlying orchestrators to automatically activate resources over the infrastructure.
- Core controllers (e.g., OSM) and RAN controllers can be used to responsible for handling the core network and RAN slices
- An IBN system can perform the 5G network slicing in single or multi-domain environment and E2E in a flexible way

5. Conclusions

- The IBN System eliminates the requirement of professional-level expertise for provisioning of the network service.
- Machine learning (ML) algorithms offer support for intent update engines, making IBN an intelligent platform that can update the run-time resources on demand
- The ML updating machine forecasts and predicts the network resources state on runtime, which helps the intent manger in deciding slice admission
- **Challenges**
  - Refining the IBN architecture and systems in the context of multi-tenant, multi-domain, multi-operator, E2E
  - Backward compatibility issues
  - Initial admission control of new slice requests, to preserve the resources already allocated to other tenants
  - Optimization issues related to ML algorithms, real-time monitoring and decisions

- Thank you !
- Questions?

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- **List of Acronyms**

5G CN	Core Network
5G-AN	5G Access Network
5GS	5G System
AF	Application Function
AI	Artificial Intelligence
CC	Cloud Computing
CP	Control Plane
CRAN	Cloud based Radio Access Network
D2D	Device to Device communication
DL	Deep Learning
DN	Data Network
DNN	Deep Neural Network
DP	Data Plane (User Plane UP)
DT	Decision Tree
IoT	Internet of Things
IBN	Intent Based Networking
IBS	IBN System
k-NN	k-Nearest Neighbours
M&C	Management and Control
ML	Machine Learning
NaaS	Network as a Service
NAI	Network Access Identifier

- **List of Acronyms**

NF	Network Function
NFV	Network Function Virtualization
NN	Neural Networks
NSL	Network Slice
NSLI	Network Slice Instance
NS	Network Service
NSLID	Network Slice Instance Identifier
NSSAI	Network Slice Selection Assistance Information
NSSF	Network Slice Selection Function
ONF	Open Networking Foundation
PaaS	Platform as a Service
PCF	Policy Control Function
QoE	Quality of Experience
RAN	Radio Access Network
RL	Reinforcement Learning
SaaS	Software as a Service
SD	Slice Differentiator
SDN	Software Defined Networking
SLA	Service Level Agreement
SM	Service Management
SMF	Session Management Function
SML	Supervised Machine Learning
S-NSSAI	Single Network Slice Selection Assistance Information
SST	Slice/Service Type
SVM	Support Vector Machine
UML	Unsupervised Machine Learning
UPF	User Plane Function
VLAN	Virtual Local Area Network
VM	Virtual Machine