Νέες και Παλιές Προκλήσεις στα Δίκτυα Κινητών Επικοινωνιών (M301)

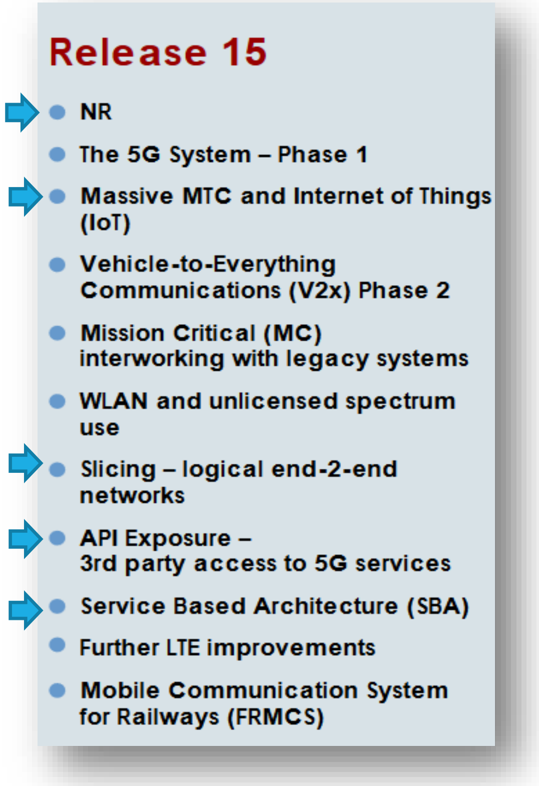
ΤΜΉΜΑ ΠΛΗΡΟΦΟΡΙΚΉΣ ΚΑΙ ΤΗΛΕΠΙΚΟΙΝΩΝΊΩΝ, ΕΚΠΑ

ΔΡ. ΔΗΜΗΤΡΗΣ ΤΣΟΛΚΑΣ & ΚΑΘ. ΛΑΖΑΡΟΣ ΜΕΡΑΚΟΣ

Take-aways (from 5G intro) and specific topics to dig into

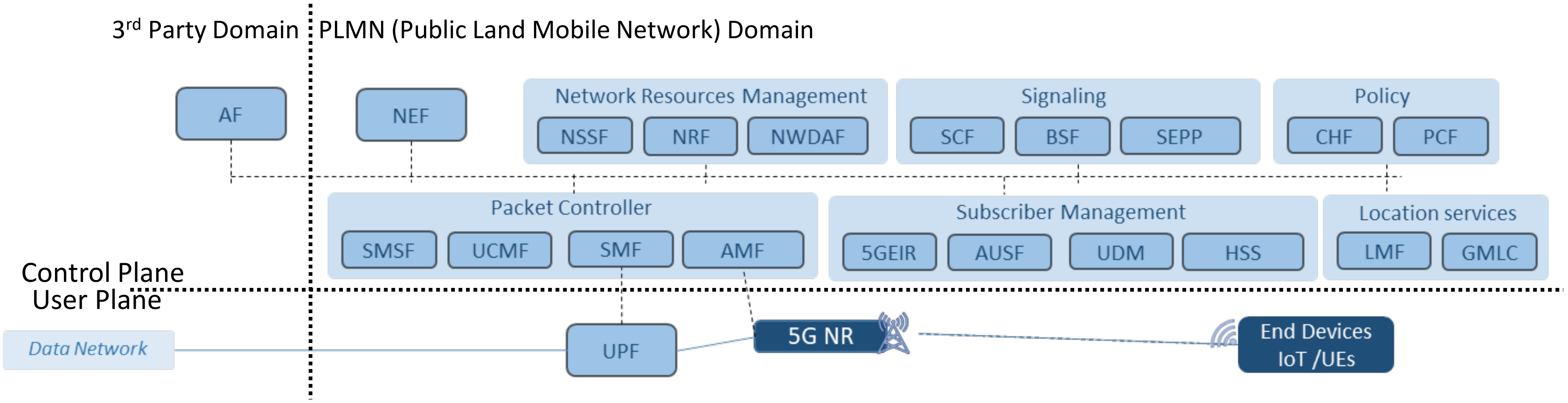
- 5G mobile system is not only about better performance for the end user.. is also a flexible management platform that creates business opportunities for verticals
- From the standardization point of view 3GPP Rel15/Rel16/Rel17 define the 5G architecture and the related technologies
- There are key advancements from IT sector that are consider in the Telco sector for the realization of 5G features (e.g., ETSI MANO for network slicing)
- The 5G research in EU has recognized the need for 5G (and B5G) experimentation platforms (dedicated spectrum for experimentation, development of 5G testbeds around EU)

Target topics



5G-SBA

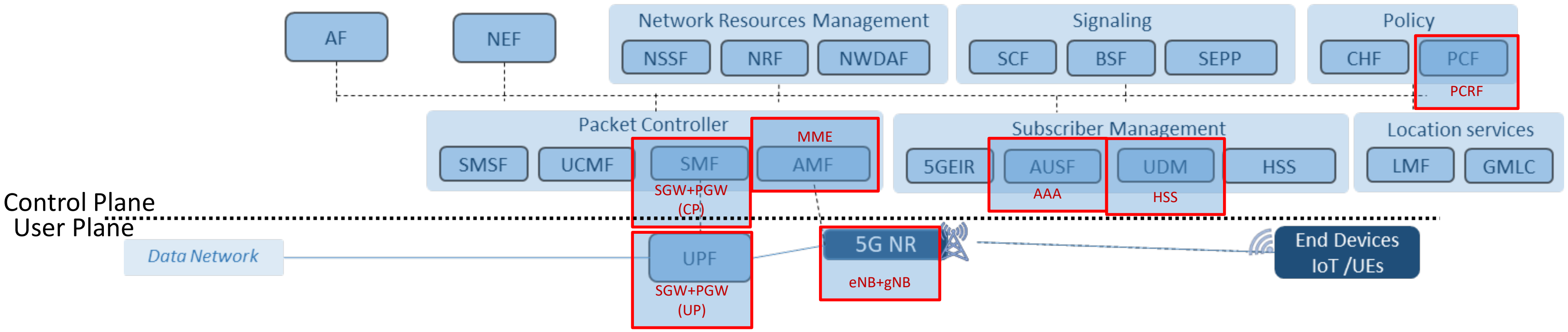
Main entities and capabilities



5G Architecture (comparison with 4G)

3GPP 23.501

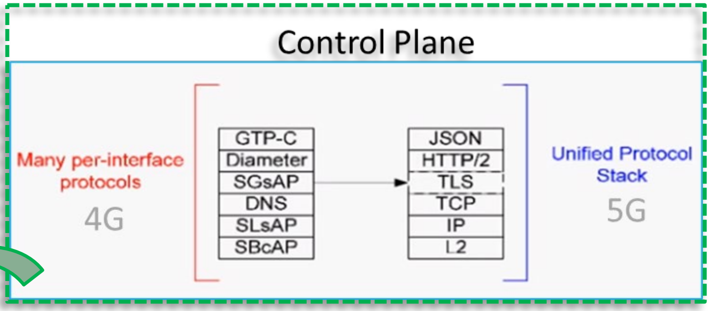
- ‘Rearrangement’ of 4G functions
- full decoupling of data (user) and control plane

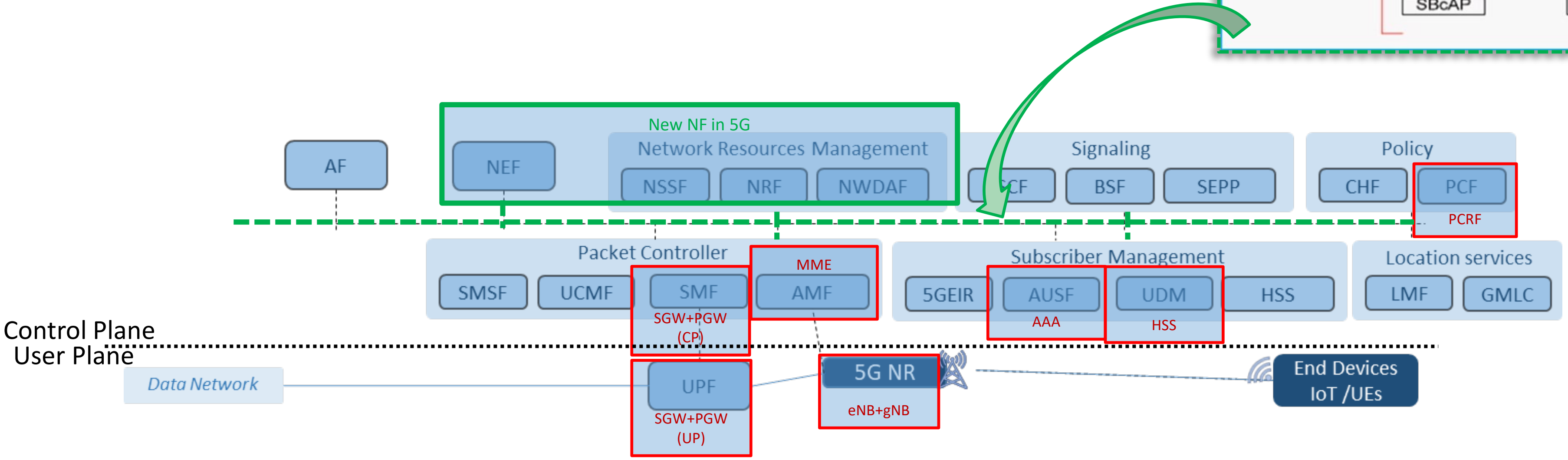


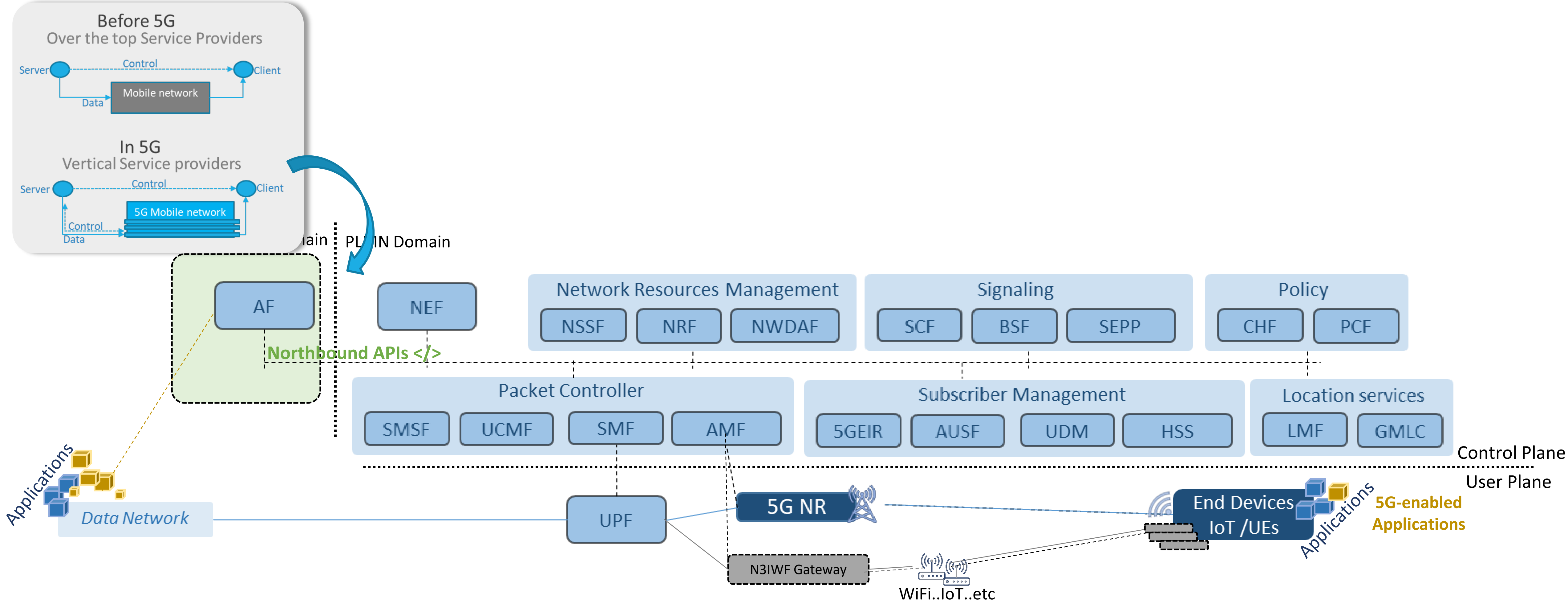
5G Architecture (comparison with 4G)

3GPP 23.501

- SBI (Service based Interfaces) -> SBA (Service based architecture)
- New functions for Slicing support

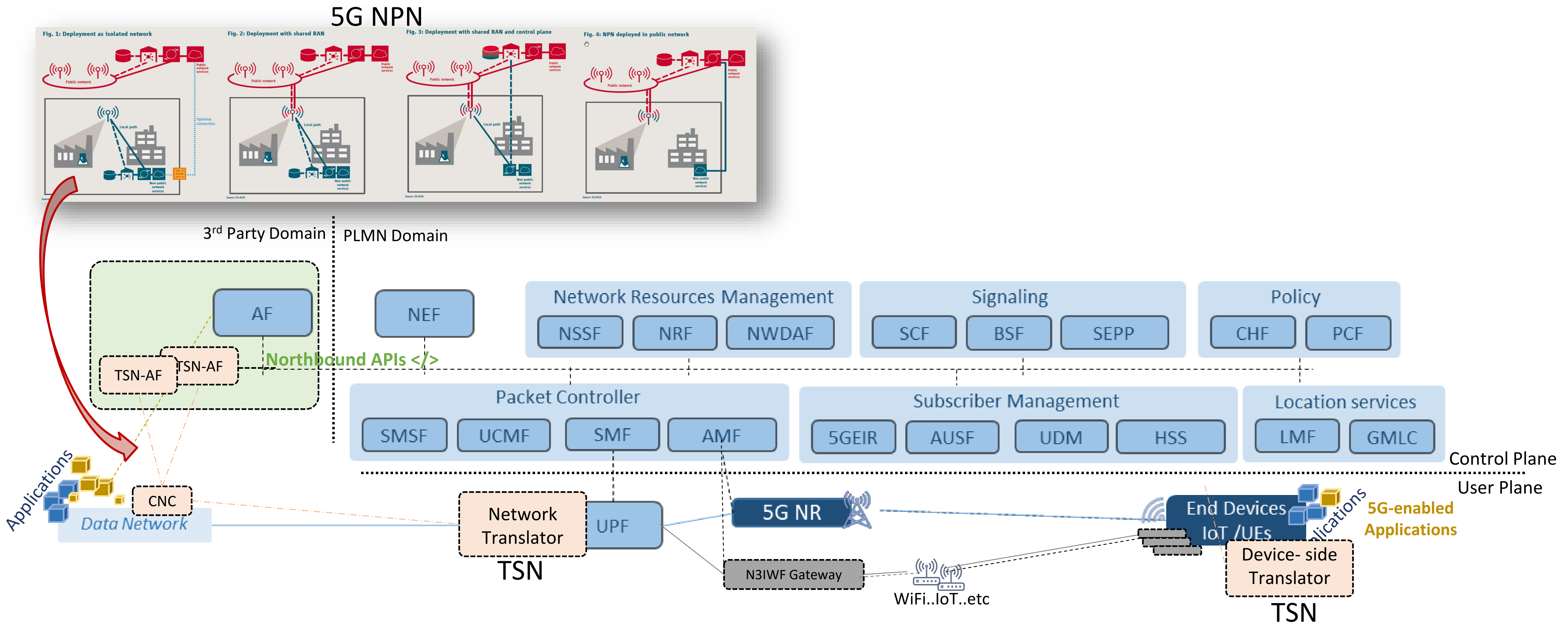






5G Architecture

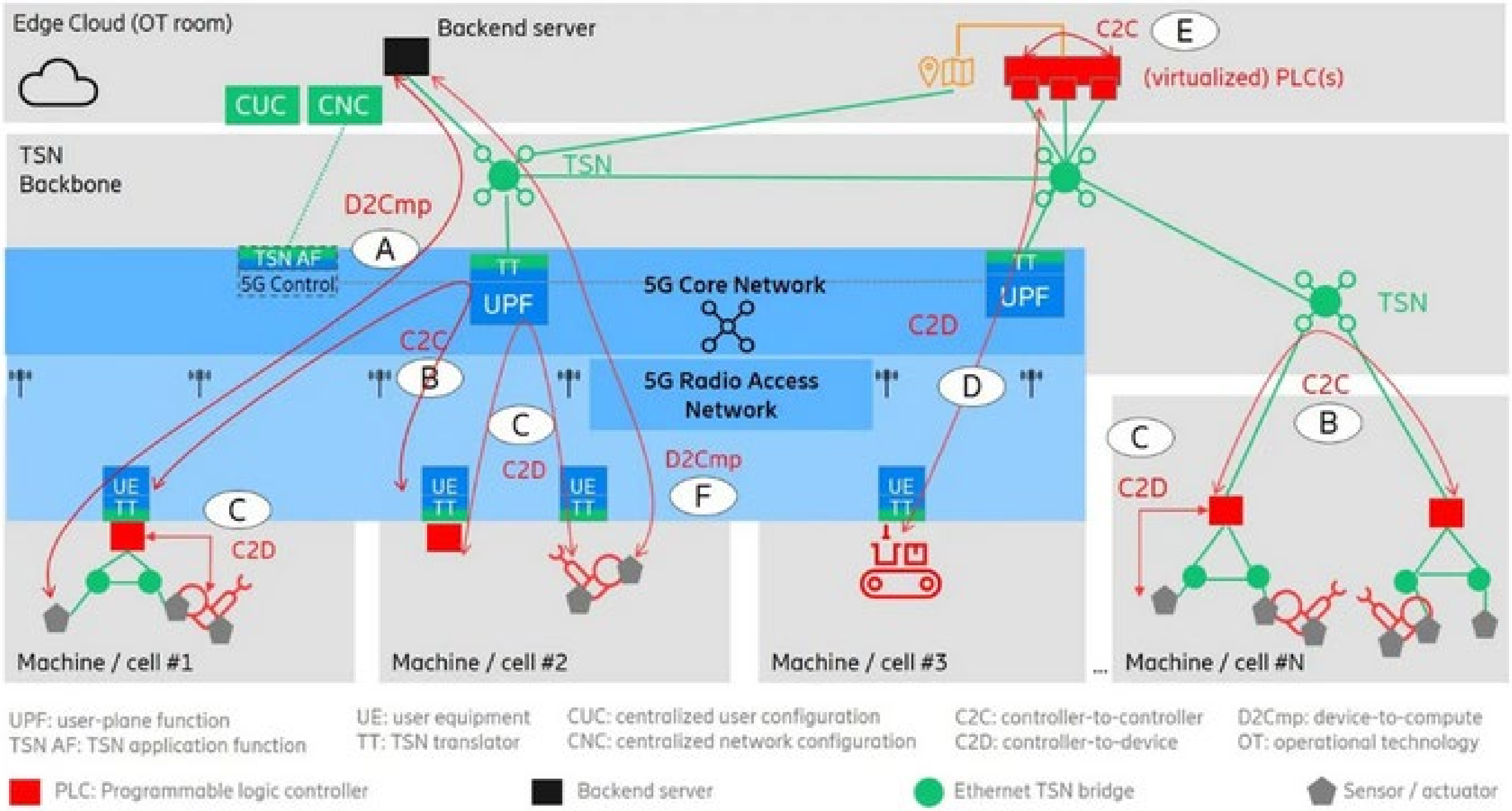
3GPP 23.501



5G Architecture

3GPP 23.501

5G SBA and TSN (the factory example)



5GACIA 5G Alliance for Connected Industries and Automation https://5g-acia.org/wp-content/uploads/2021/05/5G-ACIA_Integration_of_5G_with_Time-Sensitive_Networking_for_Industrial_Communicatins_single-pages.pdf

5G Architecture (key entities beyond 4G)

- The **NEF** entity realises a dedicated exposure function, to guarantee that functionality from other entities of the core network is securely exposed to verticals (mobile network externals). It incorporates the interfacing of 5GC with services coming from different vendors. From the verticals' perspective, *NEF enables the creation of new services by consolidating, though APIs, features of the 5G Core.*
- The **AF** is a function that *may or may not reside at the PLMN domain and interacts with the 5GC via the NEF*. Its main functionality includes the provision of Packet-Flow Description - PFD(s) to NEF, and the consumption of RESTful APIs to utilize services and capabilities that are securely exposed by NEF.

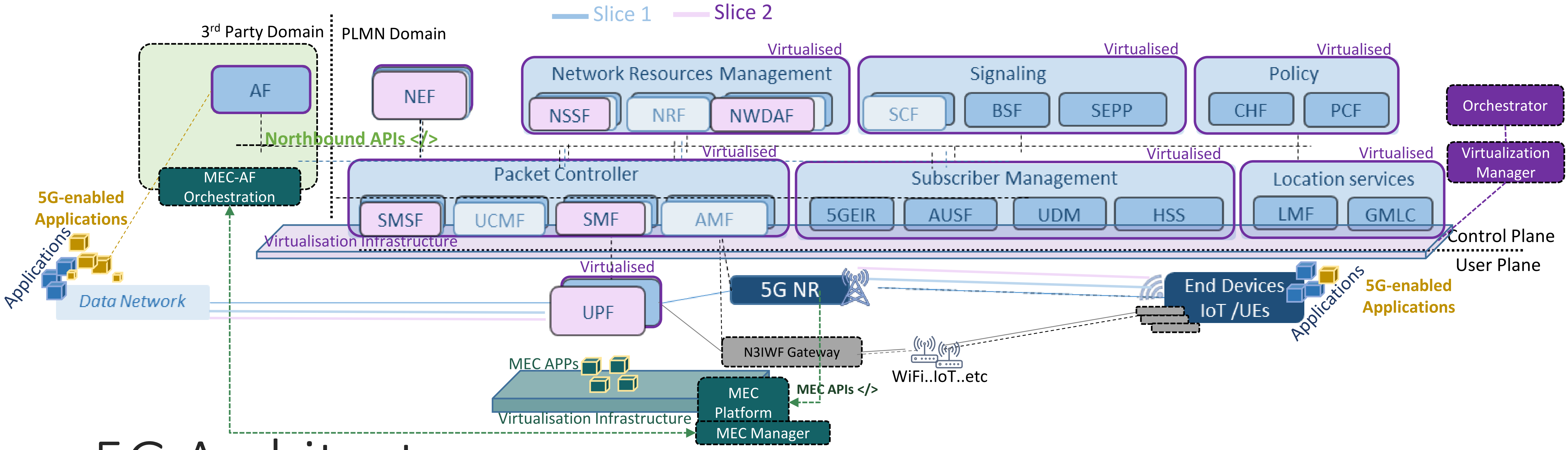
API exposure / 5G openness

- The **NWDAF** incorporates standard interfaces from the service-based architecture to collect data by subscription or request model from other network functions and similar procedures. This is to deliver *analytics functions in the network for automation or reporting*, solving major custom interface or format challenges. *NWDAF is expected to have a distributed architecture* providing analytics at the edge in real-time and, a central function for analytics which need central aggregation (e.g., service experience).

Data analytics and AI for 5G

- The **NSSF** conducts the selection of the *Network Slice instances* that will serve a particular device. As such, the NSSF determines the Allowed NSSAI (Network Slice Selection Assistance Information) that is supplied to the device. The NSSAI is a collection of up to 8 S-NSSAI (Single – Network Slice Selection Assistance Information) and is sent to the network by the UE to assist the network in selecting a particular Network Slice

Network Slicing

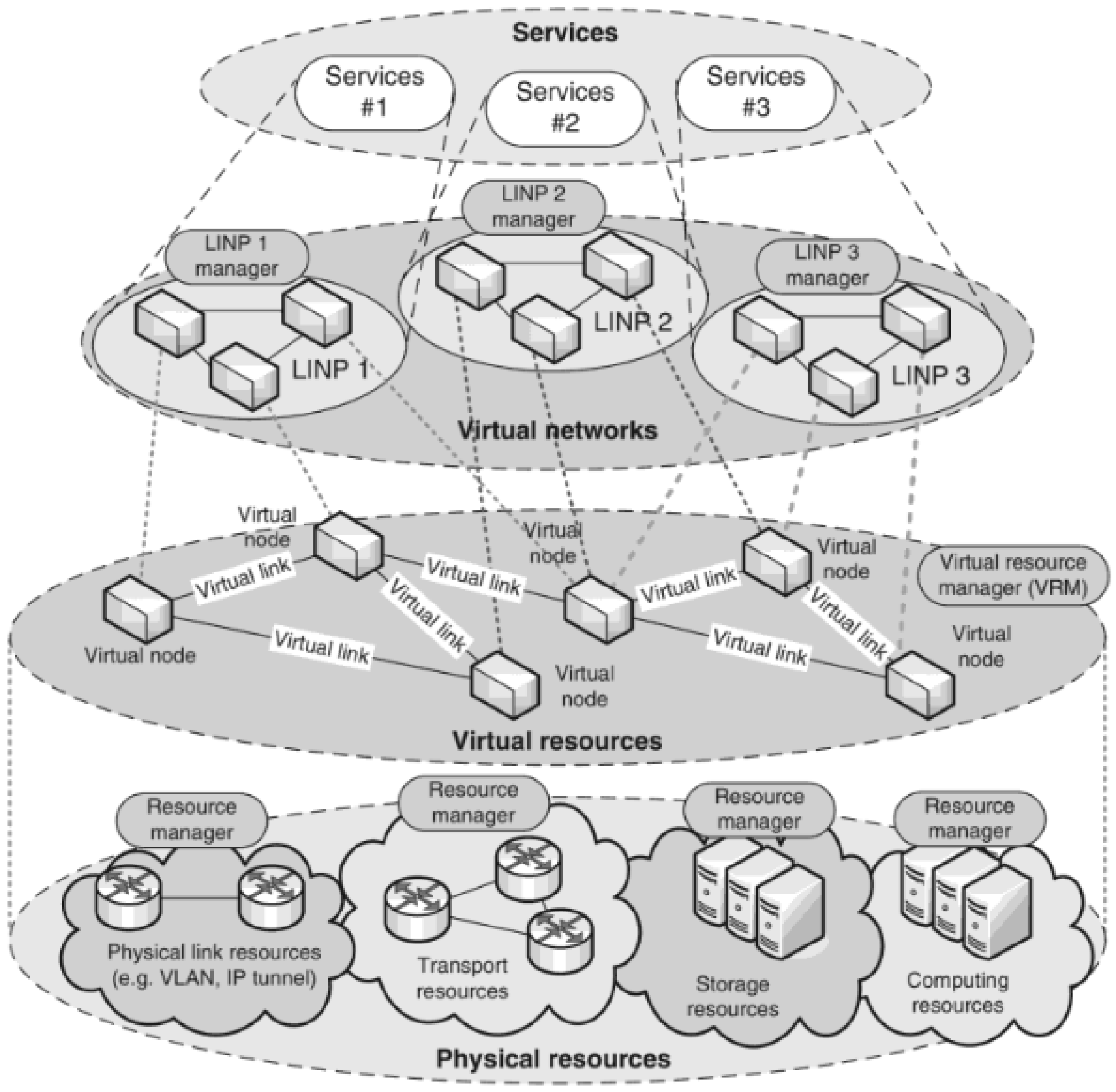


5G Architecture

3GPP 23.501

Network Slicing

"the capability to "slice" network resources and functions and to offer isolated end-to-end network services over shared physical infrastructures"



LINP – Logically isolated network partitions
VLAN – Virtual local area network

Network slicing realisation

From the Functional point of view

- NSSF has been added to the 5G SBA + the required features at the UE (5G enabled UEs)

From the Implementation point of view

- The Virtualisation/Containarisation of the 5G core functionalities is required

Main step prior understudying the Network Slicing realization is the explanation of ETSI MANO and the NFV architecture

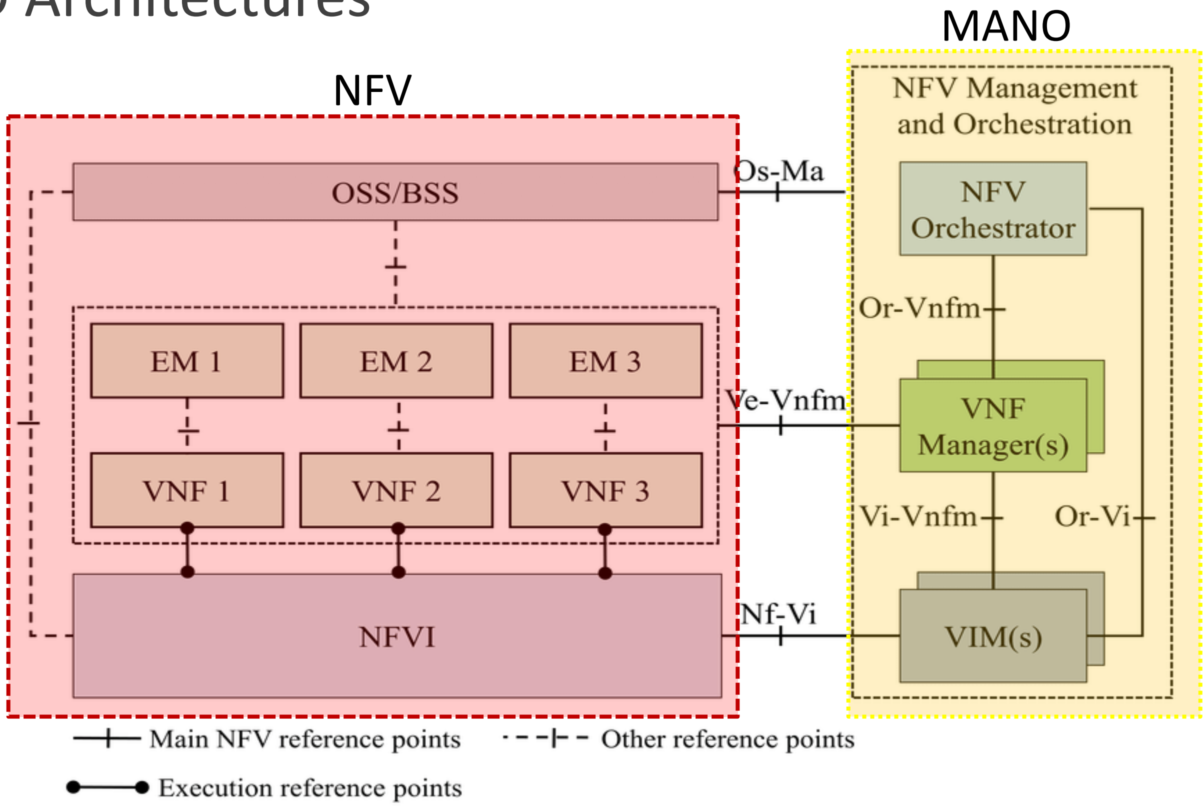
New NFV Release 3 features that closely relate to 5G include: “Support for network slicing in NFV”, “Management over multi-administrative domains”, and “Multi-site network connectivity”. These features are essential to address the variety of applications expected to run on top of a 5G system, whether using distributed resources over multiple sites, centralized or a combination of both.

3GPP TR 28.801 is about the relationship of services and slices and how to manage them

Network slicing realisation

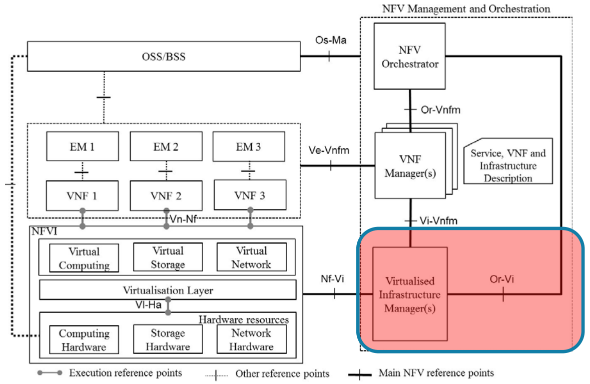
NFV and MANO Architectures

Four main components
- Operation Support System /Business Support System (OSS/BSS)
- Element Manager (EM)
- Virtual Network Functions (VNF)
- Network Function Virtualisation Infrastructure (NFVI)



Three main components
- Virtualized Infrastructure Manager (VIM)
- VNF Manager (VNFM)
- NFV Orchestrator (VNFO)

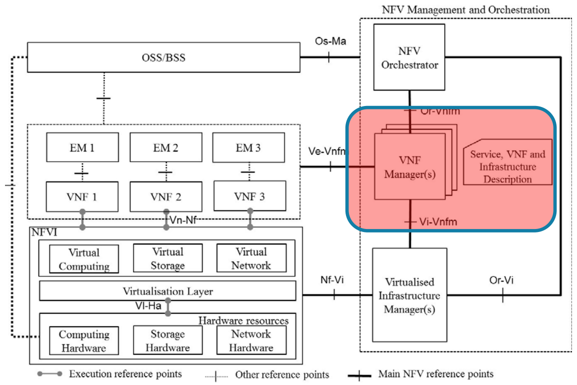
5G Architecture
Taking advantage of MANO



Virtualized Infrastructure Manager (VIM)

- Manages life cycle of virtual resources in an NFVI domain. That is, it creates, maintains and tears down virtual machines (VMs) from physical resources in an NFVI domain.
- Keeps inventory of virtual machines (VMs) associated with physical resources.
- Performance and fault management of hardware, software and virtual resources.
- Keeps north bound APIs and thus exposes physical and virtual resources to other management systems.

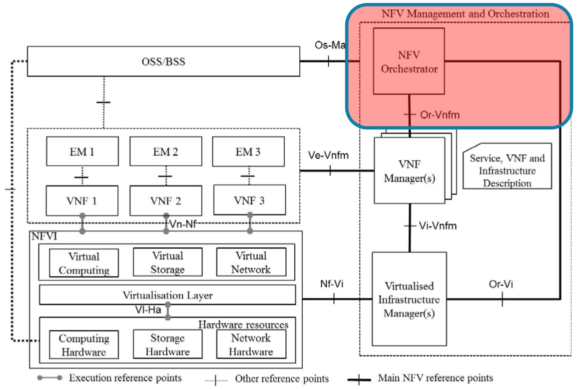
5G Architecture
Taking advantage of MANO



VNF Manager (VNFM)

- VNFM manages life cycle of VNFs. That is it creates, maintains and terminates VNF instances. (Which are installed on the Virtual Machines (VMs) which the VIM creates and manages)
- It is responsible for the FCAPs of VNFs (i.e. Fault, Configuration, Accounting, Performance and Security Management of VNFs).
- It scales up/scales down VNFs which results in scaling up and scaling down of CPU usage.

5G Architecture
Taking advantage of MANO



VNF Orchestrator (VNFO)

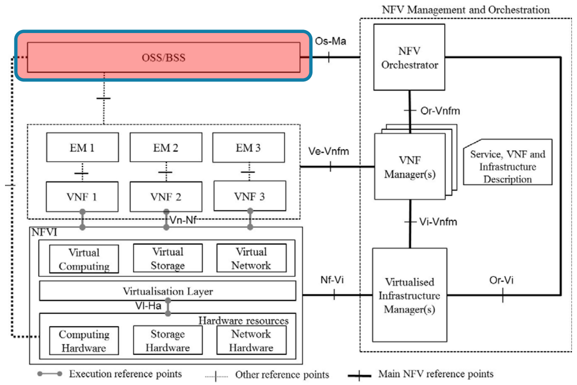
Resource Orchestration

- NFVO coordinates, authorizes, releases and engages NFVI resources among different PoPs or within one PoP. This does so by engaging with the VIMs directly through their north bound APIs instead of engaging with the NFVI resources, directly.

Service Orchestration

- Service Orchestration creates end to end service between different VNFs. It achieves this by coordinating with the respective VNFMs so it does not need to talk to VNFs directly. Example would be creating a service between the base station VNF's of one vendor and core node VNF's of another vendor.
- Service Orchestration can instantiate VNFMs, where applicable.
- It does the topology management of the network services instances (also called VNF Forwarding Graphs).

5G Architecture
Taking advantage of NFV Architecture



OSS (Operations Support Systems)

- Operator / service provide judge and assess the health of the overall telecommunications network **– PNFs also considered**
- FCAPS (Fault Management, Configuration Management, Accounting Management, Performance Management and Security Management)
- The focus of the OSS is towards maintenance of the network.

BSS (Business Support Systems)

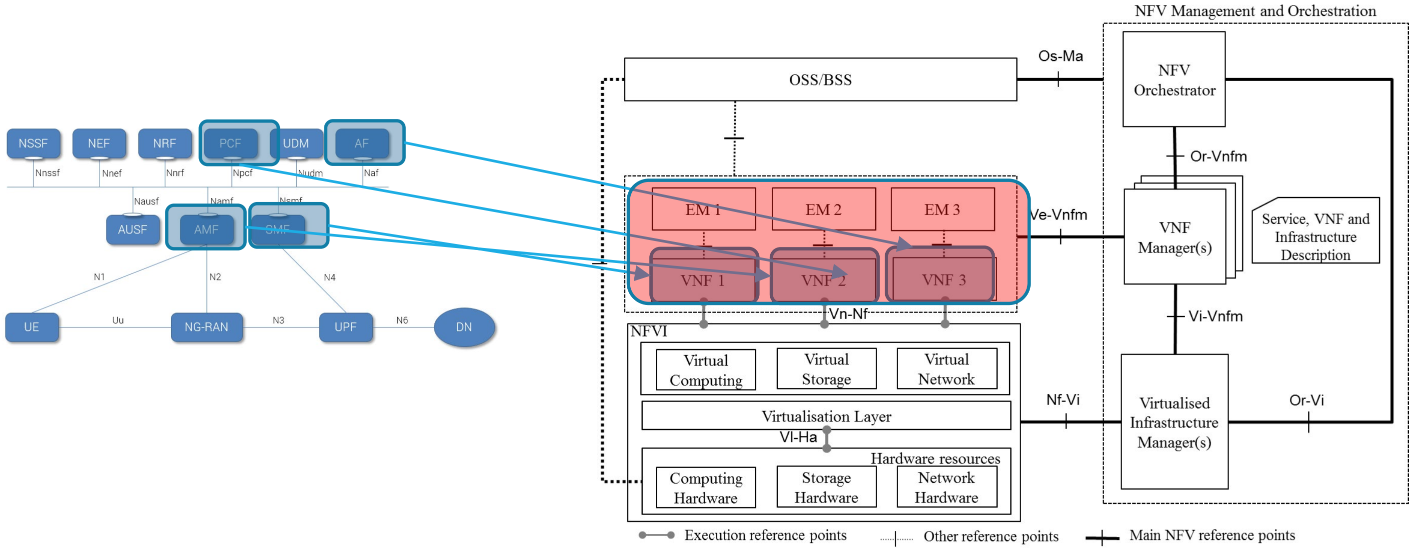
- Enable the operator to define the billing parameters, rate plans & associated logic, customer schemes, etc.
- The focus of the BSS is towards managing the business aspects associated with the telecommunications network.

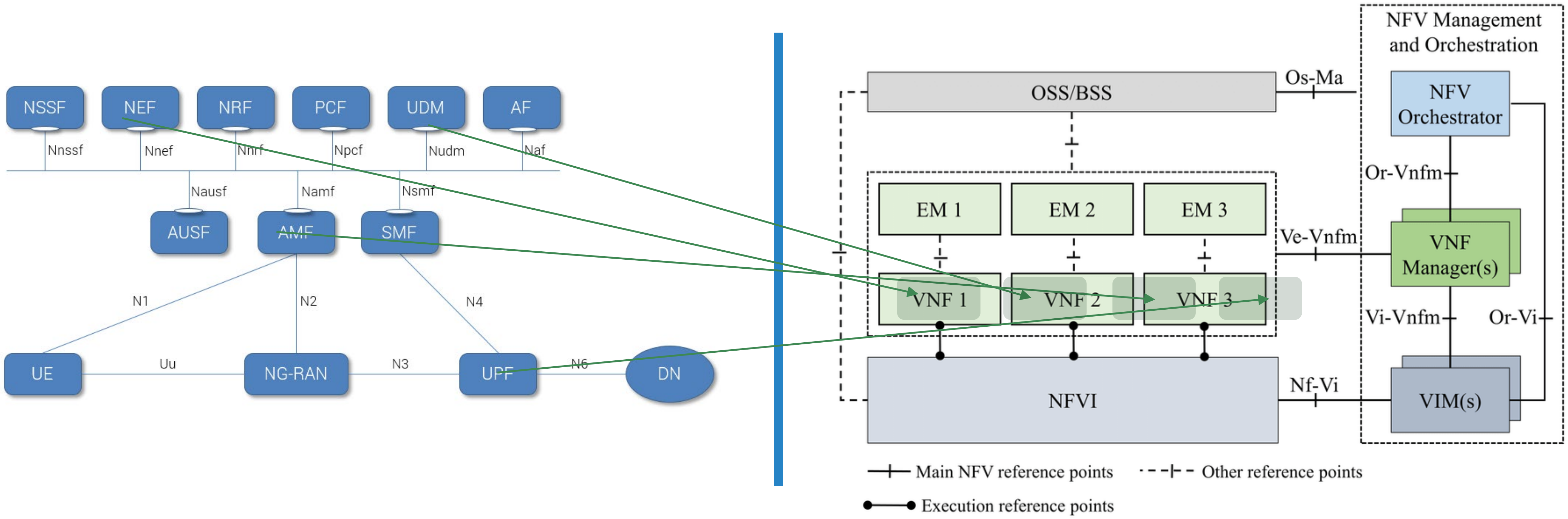
5G Architecture

Taking advantage of NFV Architecture

The 5G architecture allows for the full usage of the MANO architecture

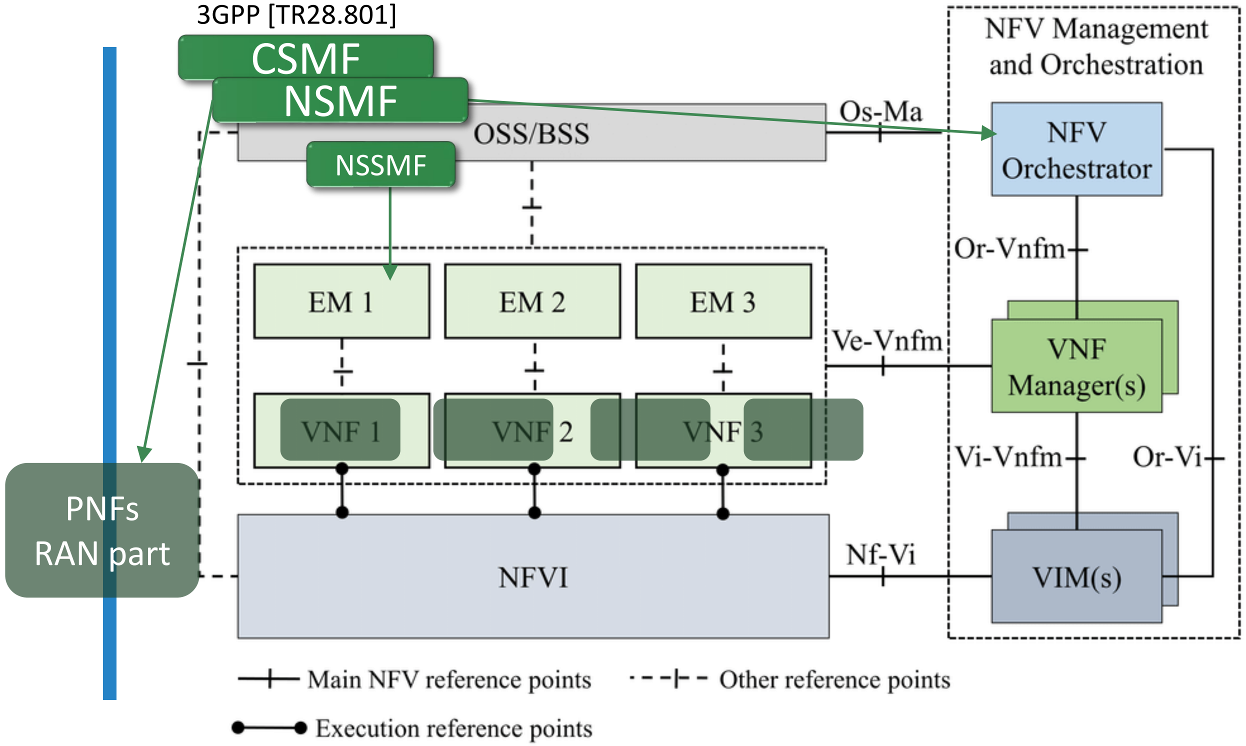
- 5G Functions can be realized in VNFs (all?)
- The MANO toolset can be used to manage the VNFs
  - Set a virtual 5G network
  - Control the reuses of the network





Network slicing realisation

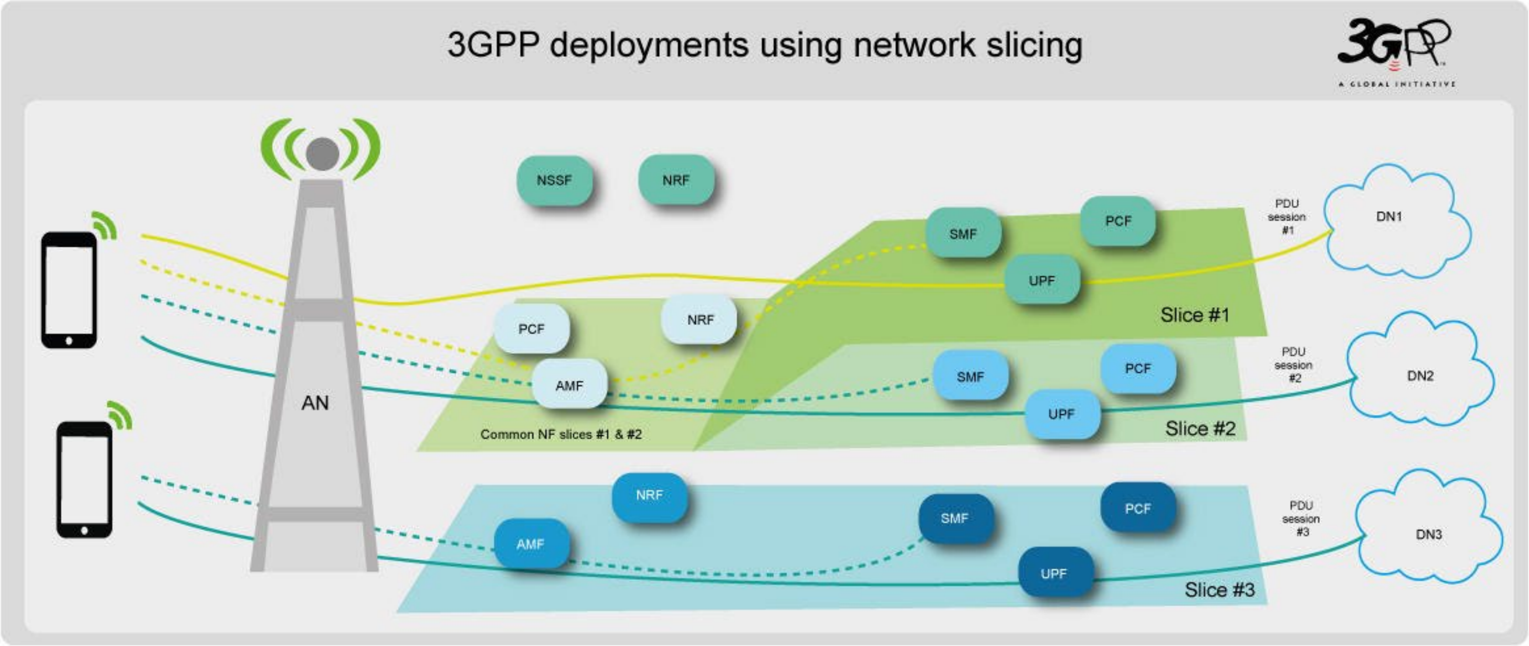
- Communication Service Management Function (CSMF):Acts as a translator from the CS related requirements to network slice related requirements.
- Network Slice Management Function (NSMF): Performs management and orchestration of the network slice in-stance and derives network slice subnet requirements from network slice requirements.
- Network Slice Subnet Management Function (NSSMF):Responsible for management and orchestration of network slice subnet instance.



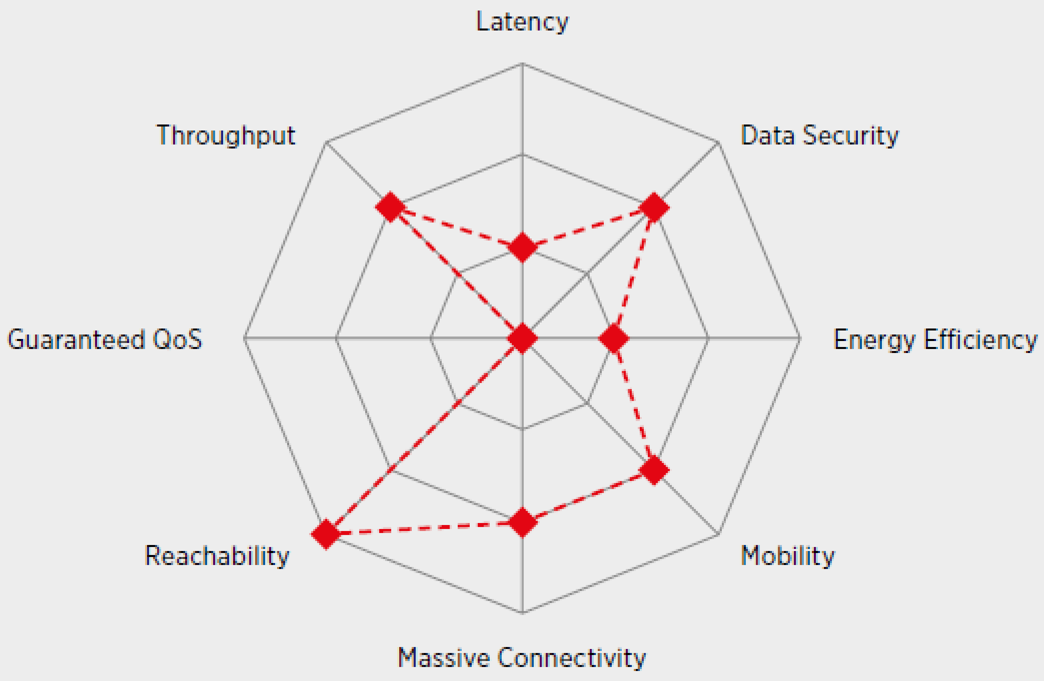
Network slicing realisation

Network slicing realisation

Given the fact that the 5GC entities are virtualized (provided as VNFs) the MANO toolset can be used together with the Slice management functionality standardized by 3GPP for instantiating Network slices (multiple copies of the network functionality)



Network Slicing Customization



Network Capability

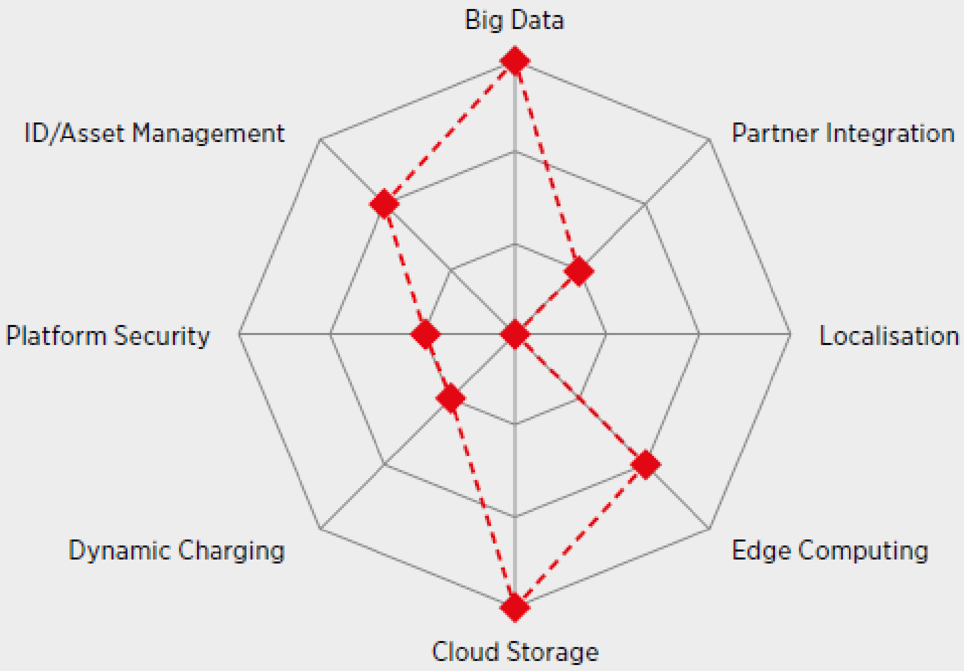
- Latency
- Data Security
- Energy Efficiency
- Mobility
- Massive Connectivity
- Reachability
- Guaranteed QoS
- Throughput

*GSMA Introduction to Network Slicing

Network Slicing Customization

Network Services

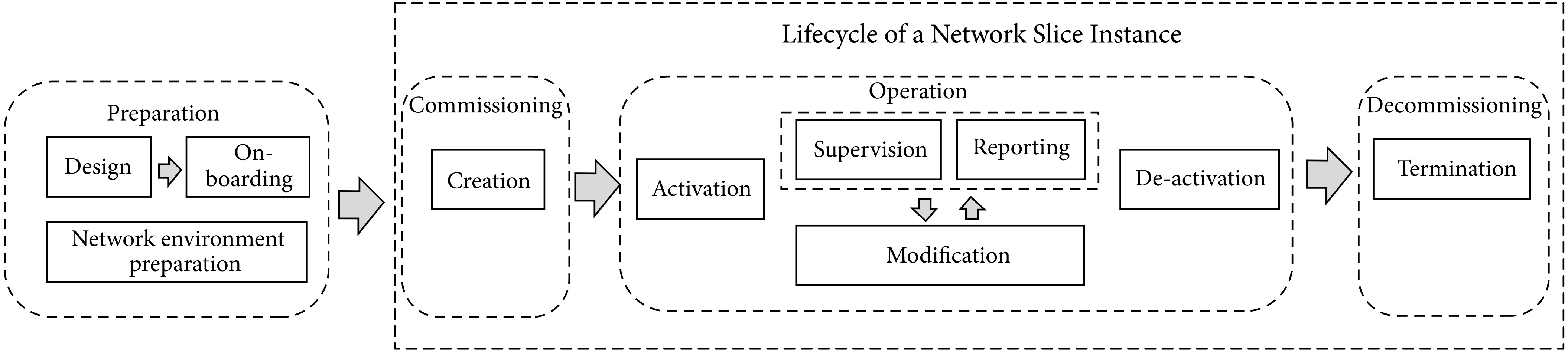
- Big Data
- Partner Integration
- Localisation
- Edge Computing
- Cloud Storage
- Dynamic Charging
- Platform Security
- ID Management



*GSMA Introduction to Network Slicing

The lifecycle of a Network Slice

- The main phases



General aspects of Network Slicing can be found in 3GPP TS 23.501 and TS 23.502

The lifecycle of a Network Slice

- Time budget decomposition

Phase	Actions performed
Platform Provision	Platform configuration, Platform deployment
Onboarding	Onboard Network Slice Template, Network Slice Descriptor etc.
Instantiate, Configure & Activate	Instantiate Network Slice, Instantiate & Activate Network Service, Instantiate & Configure VNFs in service chain etc.
Modify	Modify Slice, Service or VNF configuration
Terminate	Terminate Slice, Service, VNF

The Network Slice set up time, as major part of the service creation time, can have great impact on the performance of a system
Thus, it gets a lot of attention among other research challenges in the Network Slicing field

Network Slicing

Research challenges

- Resource management/sharing among Network Slices
- Isolation among Network Slices
- life-cycle management of the Network Slices (Network slicing as a service – NSaaS)
- Security Aspects
- Slicing in wireless part (virtualization of RAN functions)
- …

Network Slicing

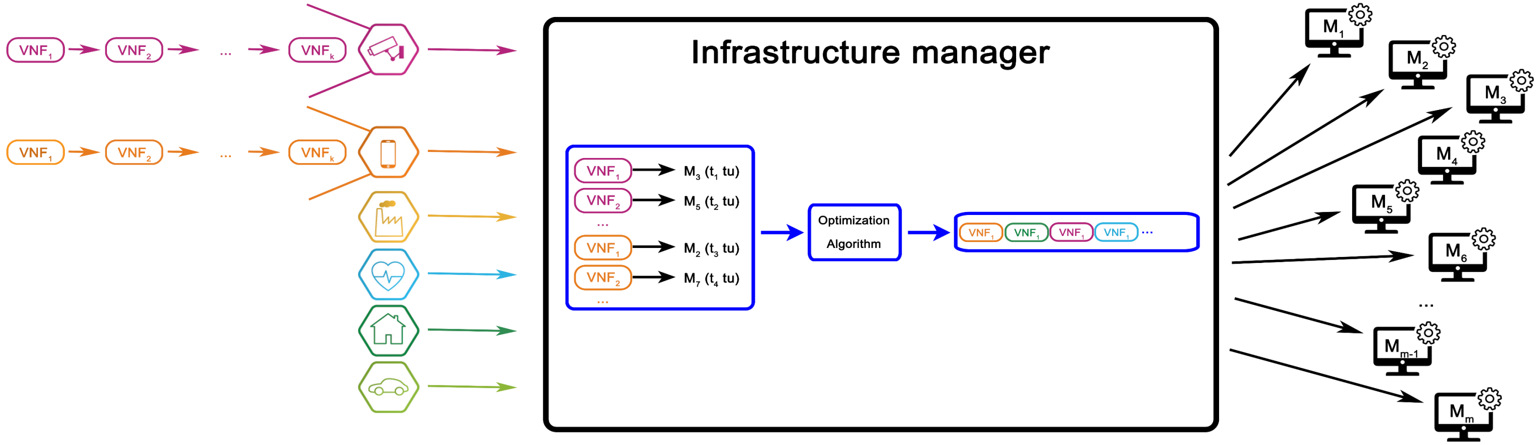
Research challenges

- Resource management/sharing among Network Slices
- Isolation among Network Slices
- life-cycle management of the Network Slices (Network slicing as a service – NSaaS)
- Security Aspects
- Slicing in wireless part (virtualization of RAN functions)
- …

.. scheduling methods that minimizes the time needed for instantiation and configuration of all the VNFs of a set of slices

System Model

- Chunks of requests for network service deployment are periodically received at an infrastructure manager
- Each request includes the required installation plan of the VNFs of each service
- The infrastructure manager, based on monitoring of past set ups and knowledge of the capabilities of the available processing machines, estimates the time needed for setting-up a VNF to one of the available machines
- An optimisation algorithm is applied to schedule each chunk of requests, taking all constrains into account, and to export the total VNF execution plan



Mapping to the JSSP

- JSSP (Job Shop Scheduling Problem): A combinatorial problem that addresses resource allocation and scheduling tasks
- Basic characteristics
  - A set of jobs, denoted as J_1, J_2, … J_n of varying processing times
  - A set of machines, denoted as M_1, M_2, … M_m , where the jobs are deployed
  - A set of operations O_1, O_2, ..., O_i, within each job
  - Each operation must be executed is a specific machine according to initial plan
  - Each machine can process one operation at a time and when an operation is assigned to a machine, the machine can not interrupt its execution
- Objective
  - Find the optimal execution plan of the jobs, applying system constraints, to minimize the time in which all operations will be executed (makespan)

Mapping to the JSSP

Map the work of the Infrastructure Manager to the JSSP

- JSSP machines = Network provider's machines that host VNFs
- Jobs = Network Slice requests
- Operations of a job = VNFs, comprising a network slice

.. We need an Algorithm that solves the translated JSSP

Solution approach

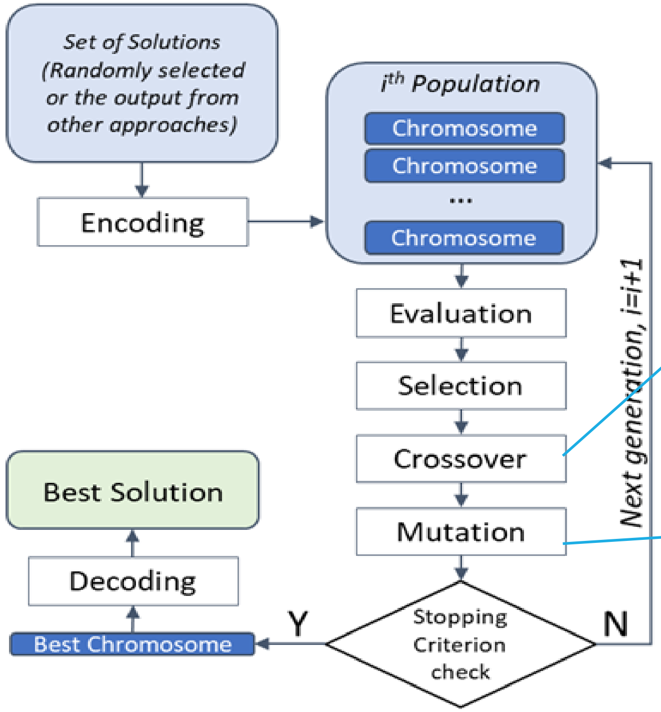
- Two important observations
  - JSSP is an NP-hard problem, exact methods are ineffective
  - Response time of the optimization algorithm must be negligible
- Heuristic methods
  - Advantages
    - Work well for dynamic problem sizes
    - Reasonable execution time
    - Can be combined with other methods
  - Disadvantages
    - Problem dependent
    - Greediness may lead to suboptimal results (especially for large input)
- Meta-heuristics
  - Simple and easy implementation,
  - Avoid stucking on local optima
  - Tunning of the execution time through execution parameters that can change based on the input size

Solution approach

- Meta-heuristics
  - Various categories and approaches
  - Nature-based Meta-heuristics can be classified into four groups:
    - Evolution-based
    - Physics-based
    - Swarm-based
    - Human-based

Proposed Algorithm

- Resolve the problem by using an evolution-based metaheuristic approach; a Genetic Algorithm
- Best solution= minimum makespan=minimum slice set up time

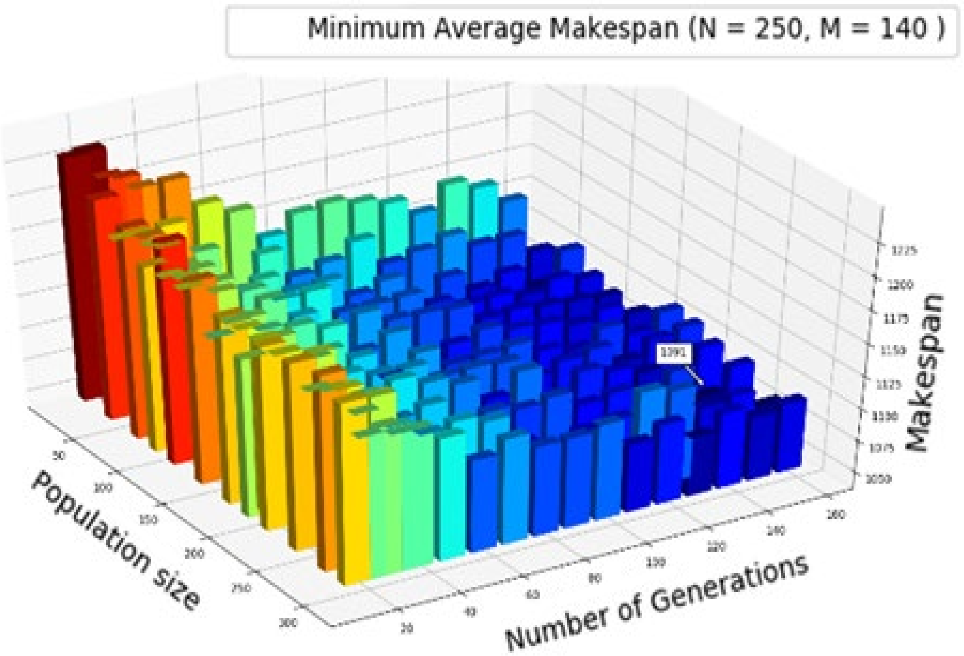


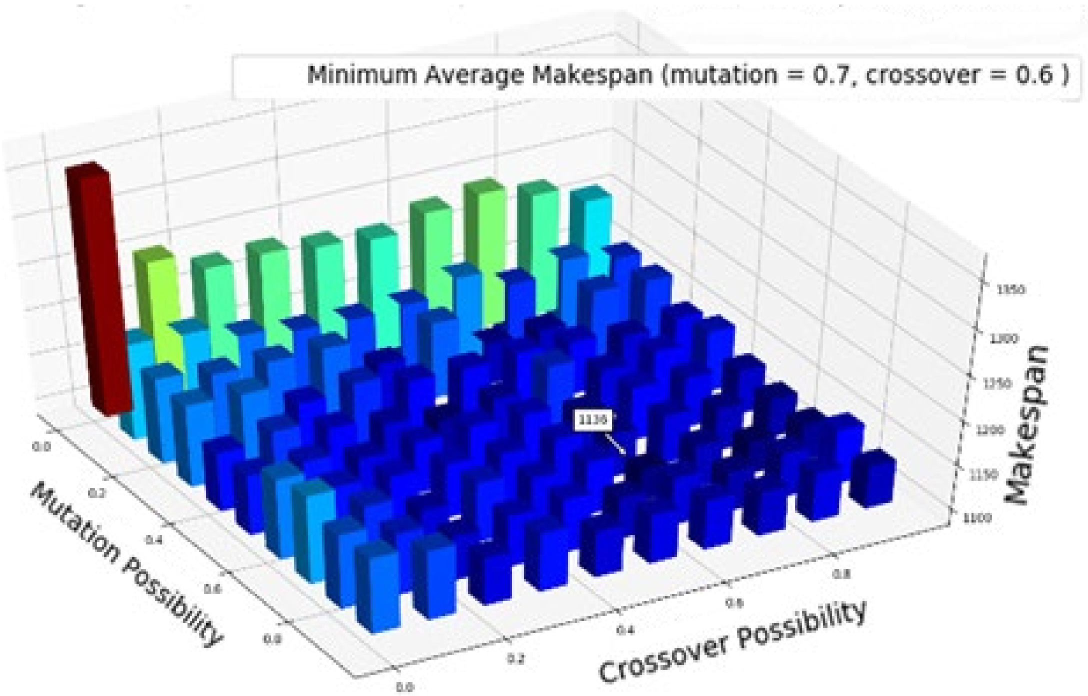
Partitioned Chromosome of Parent 1		
f_{31}, f_{21}, f_{32}	$f_{41}, f_{22}, f_{11}, f_{33}, f_{42}, f_{23}, f_{34}, f_{12}, f_{43}$	$f_{13}, f_{44}, f_{14}, f_{24}$
Partitioned Chromosome of Parent 2		
f_{21}, f_{31}, f_{32}	$f_{11}, f_{41}, f_{33}, f_{42}, f_{22}, f_{23}, f_{34}, f_{12}, f_{43}$	$f_{44}, f_{13}, f_{24}, f_{14}$
Crossover result for Child 1		
f_{31}, f_{21}, f_{32}	$f_{11}, f_{41}, f_{33}, f_{42}, f_{22}, f_{23}, f_{34}, f_{12}, f_{43}$	$f_{13}, f_{44}, f_{14}, f_{24}$
Crossover result for Child 2		
f_{21}, f_{31}, f_{32}	$f_{41}, f_{22}, f_{11}, f_{33}, f_{42}, f_{23}, f_{34}, f_{12}, f_{43}$	$f_{44}, f_{13}, f_{24}, f_{14}$

Chromosome of Child 1 with selected genes for mutation
$f_{31}, f_{21}, \boldsymbol{f_{32}}, f_{11}, f_{41}, f_{33}, \boldsymbol{f_{42}}, f_{22}, f_{23}, f_{34}, f_{12}, f_{43}, f_{13}, f_{44}, f_{14}, f_{24}$
Chromosome of Mutated Child 1 [Non-Acceptable]
$f_{31}, f_{21}, \boldsymbol{f_{42}}, f_{11}, f_{41}, f_{33}, \boldsymbol{f_{32}}, f_{22}, f_{23}, f_{34}, f_{12}, f_{43}, f_{13}, f_{44}, f_{14}, f_{24}$
Chromosome of Mutated Child 1 [Acceptable]
$f_{31}, f_{21}, \boldsymbol{f_{22}}, f_{11}, f_{41}, f_{33}, f_{42}, \boldsymbol{f_{32}}, f_{23}, f_{34}, f_{12}, f_{43}, f_{13}, f_{44}, f_{14}, f_{24}$

Evaluation Results

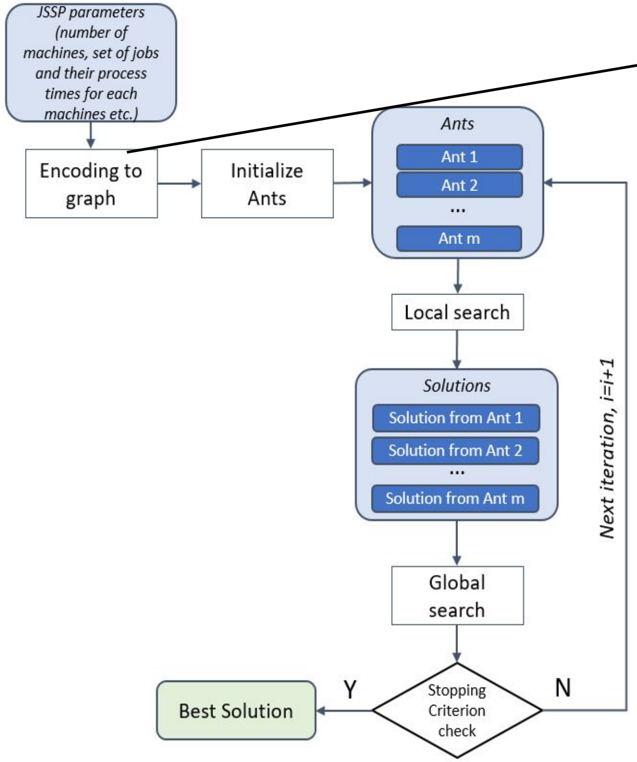
- Time units needed for slice set up for different configurations of the proposed algorithm



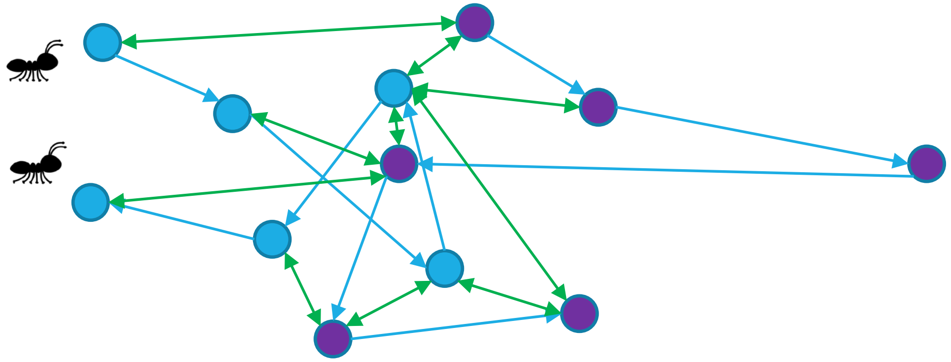


Proposed Algorithm

- Resolve the problem by using a swarm-based metaheuristic approach; an ACO Algorithm
- Best solution= minimum makespan=minimum slice set up time



- Each VNF is represented by a node
- VNFs belonging to the same network slice request are connected with unidirectional edges, respecting the order of processing. The rest of the VNFs are connected with bidirectional edges
- The cost of its edge is a two-dimensional value consisting of i) deployment time of VNF (called distance), ii) an ant-inspired parameter analyzed below, called pheromone concentration



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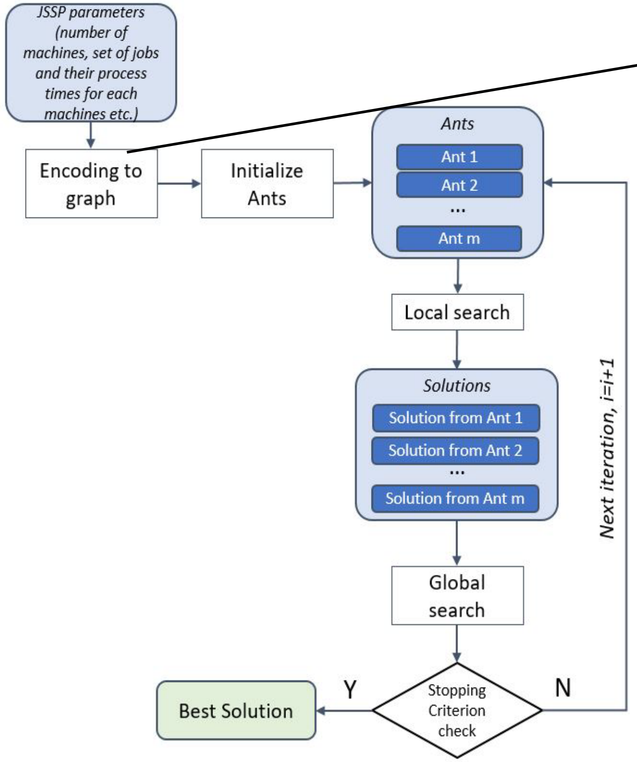

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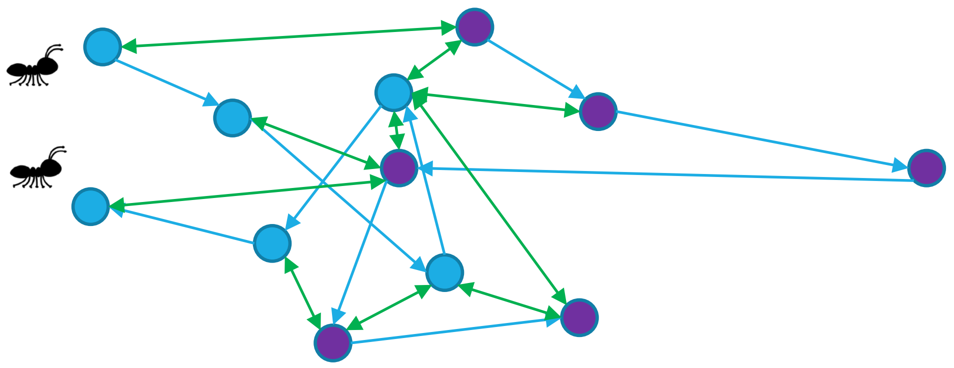

Evaluation Results

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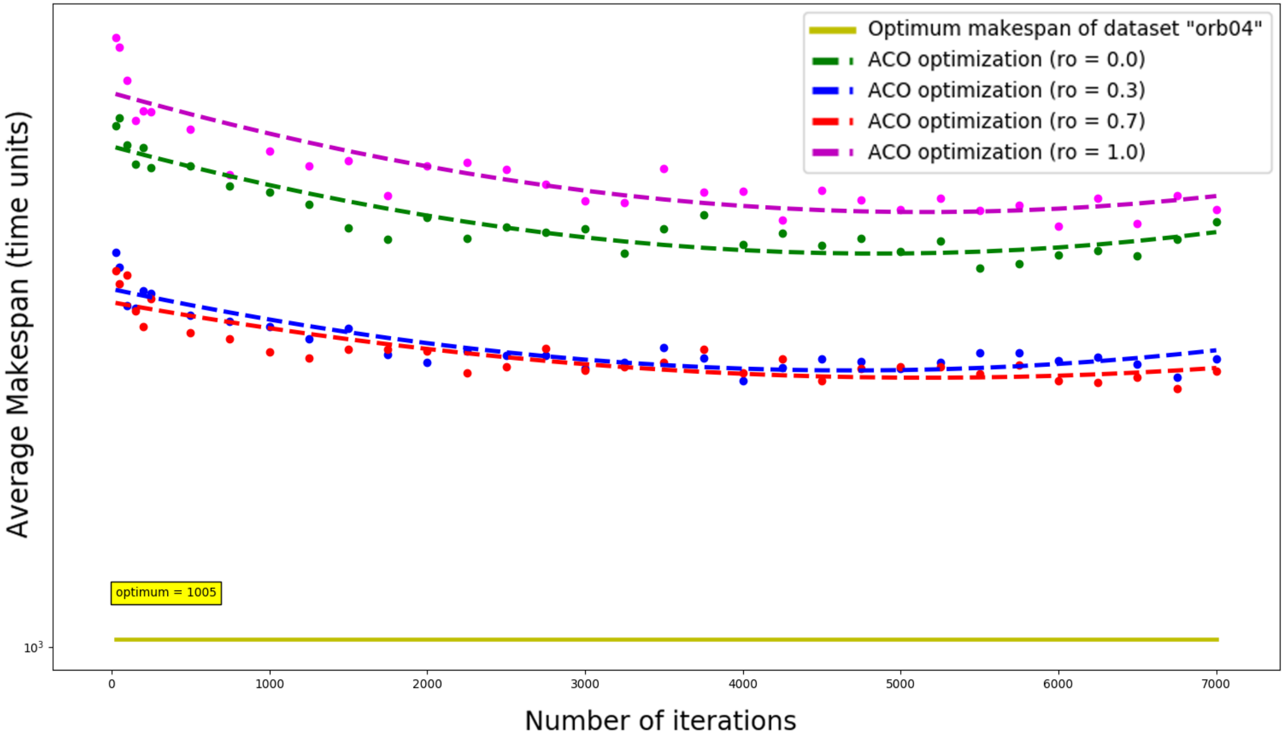

r parameter:

- full-memory (rate equal to 0)
- no-memory (rate equal to 1)

Evaluation Results

- Evolution based Vs Swarm based approach

Problem size (number of concurrent slices x number of VNF hosts)	Optimal Makespan	ACO performance		GA Performance	
		Makespan	Configuration	Makespan	Configuration
10x10	1005	1126	iter=4500 r=0.7 time=2min	1042	N=200 M=140 crossover=0.7 mutation=0.7 time=8min
20x5	1165	1388	iter=3000 r=0 time=3min	1277	N=280 M=220 crossover=0.7 mutation=0.7 time=36min
20x20	826	1162	iter=6750 r=0.7 time=37min	1070	N=80 M=120 crossover=0.7 mutation=0.7 time=76min

Evaluation Results

- Slice set-up time has high impact on the performance of a system
- Metaheuristic approach can be used to optimize the slice set up time
- Some insights
  - GA provides a close-to-optimal result in adequately low processing time
  - Both can be fine-tuned easily to fit our problem
  - ACO could be functional in more realistic scenarios - dynamic arrival of network slice requests

Take-aways

- 5G Architecture – 4 aspects to remember compared to 4G architecture
  - Functions rearrangement | User and control plane decoupling | service-based concept | slicing support
- 5G Core and edge exposure through APIs
- Key functionality in SBA beyond 4G: NEF+AF-> Openess, NSSF-> slicing, NWDAF-> AI
- Slice Concept realization through MANO+NFV Architectures
- Research challenges in Network slicing
  - Slice set up time minimization by using meta-heuristic algorithms