WP6 Task 1: Neutral Host Architectures

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References

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[2]	ATIS: Neutral Host Solutions for 5G Multi-Operator Deployments in Managed Spaces (available online)
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[4]	5g Rural First Project: https://www.5gruralfirst.org/
[5]	5G; System architecture for the 5G System (5GS), 3GPP TS 23.501 (Release 15)
[6]	3GPP TS 23.122: "Non-Access-Stratum (NAS) functions related to Mobile Station in idle mode".
[7]	3GPP TS 38.331: "NR; Radio Resource Control (RRC); Protocol Specification".
[8]	3GPP TS 38.304: "NR; User Equipment (UE) procedures in idle mode".
[9]	5G NR and 4G LTE Coexistence, A Comprehensive Deployment Guide to Dynamic Spectrum Sharing White Paper https://newsletter.mediatek.com/hubfs/mediatek5gprogress/Dynamic-Spectrum-Sharing-WhitePaper-PDFDSSWP-031320.pdf

Table of Contents

Table of Figures

Abbreviations

NH	Neutral Host
LTE	Long-Term Evolution
CN	Core Network
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
5GC	5G Core
AMF	Access Mobility Function
UPF	User Plane Function
SMF	Session Management Function
UDM	Unified Data Management
AUSF	Authentication Server Function
PCF	Policy Control Function
NSSF	Network Slice Selection Function
AF	Application Function
NRF	Network Repository Function
DN	Data Network
PLMN	Public Land Mobile Network
HPLMN	Home PLMN
vPLMN	Visiting PLMN
N3IWF	Non 3GPP Interworking Function
eNB	E-UTRAN Node B
gNB	gNodeB
MORAN	Multi-operator radio access network
MOCN	Multi-operator Core Network
DSS	Dynamic Spectrum Sharing
RAN	Radio Access Networks
QoS	Quality of Service
VPN	Virtual Private Network
NOC	Network Operator Centre

Introduction

The mobile Neutral Host Network (NHN) is 3rd-party cellular network providing wholesale, commercial mobile coverage solutions - typically on a localised basis - to national Mobile Network Operators (MNOs) or other Communications Service Providers (CSPs). The idea is that an NHN builds a network (with or without its own local spectrum), and the other telcos either 'roam onto it' or use its shared facilities for their own radios [1]
More specifically, the resources that could/should be provided by a neutral host service provider are the following:

- Permanent Physical Equipment infrastructure: This refers to permanent (or quasi-permanent in the case of special events) structures and utility infrastructure needed to support the installation and operation of equipment.
- Spectrum: This refers to mobile coverage as licensed (e.g., owned or leased/borrowed from hosted clients) or unlicensed.
- Radio Access Network (RAN) edge nodes: This refers to the typical "base station" node such as 5G enabled Node B (gNB) base station, a 4G Long-Term Evolution (LTE) eNB (eNodeB), Wi-Fi access point or other radio technologies as appropriate.
- Backhauling solutions to the hosting MNO Core, in the case that only the radio equipment is provided by the neutral host.
- Optionally, all or parts of a mobile packet core providing common core support functions for the neutral host network [2]

A typical high level Neutral Host (NH) architecture based on shared spectrum, is illustrated in Figure 1

The neutral host entity provides access services to one or more client network operators. More specifically, a subscriber of a client network operator, upon entry into an area served by the neutral host, can receive access services from the neutral host as if the subscriber were directly connected to the client network. Service characteristics will be very similar to roaming with the primary difference being that the "visited network" could be also served by a business entity (the neutral host provider) that may not be a network operator. Neutral host business entities could include enterprises, venue owners or managers or other business entities/operators which may provide access infrastructure as a service.

The following use cases can be exploited using neutral host deployments:

- Rural / remote areas such as the areas investigates by 5G Rural Dorset [4]
- Urban centres needing 4G/5G RAN densification [3]
- In-building / on-premises coverage for large sites such as shared office-space, entertainment venues and resorts [2]
- Road and rail-side coverage
- Industrial sites and transport hubs [2]

- Temporary sites and events, such as cultural events and major civil-engineering projects [2]

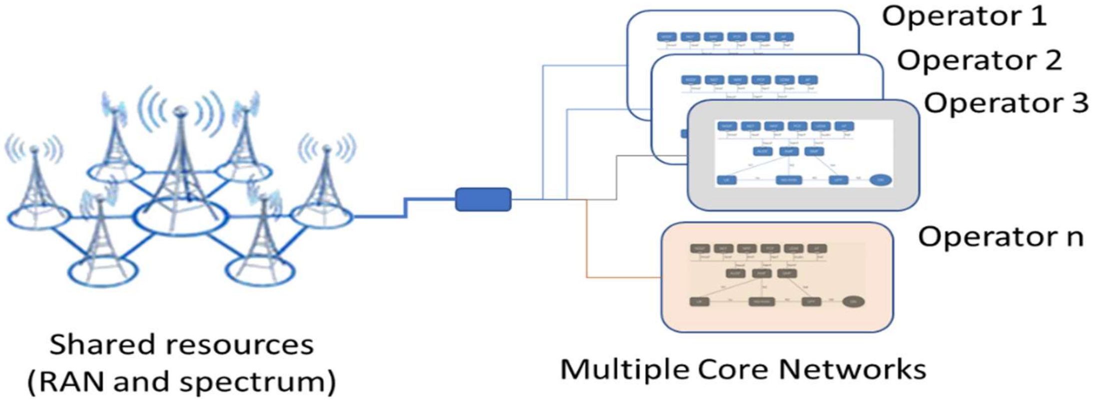

Figure 1. Neutral Host MOCN Model - shared radio resources with multiple core networks

Roaming Architectures

This study is mostly associated with 5G network architectures. Therefore, it is useful to summarize the 5G Core Network (CN) architecture before diving into the respective architectures for Neutral Hosting. In Figure 2, the 5G system architecture is depicted based on the reference point representation. A detailed explanation on the network functions and the reference points of the 5G system can be found in [5]. However, we do provide a brief description of the basic components, necessary to illustrate the NH roaming architecture.

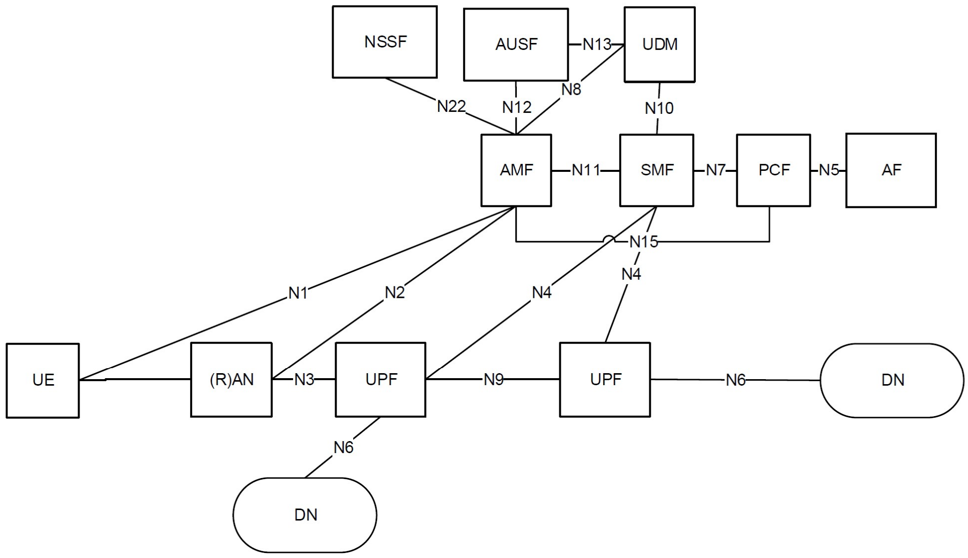

Figure 2. 5G System architecture for concurrent access to two (e.g. local and central) data networks (single PDU Session option) in reference point representation

- UE RAN and DN correspond to User equipment Radio Access Network and Data Network respectively
- Access and Mobility Management function (AMF) is responsible amongst all, for connection management, mobility management, access authentication and authorization.
- Session Management Function (SMF) is responsible amongst all, for Session Management (e.g., session Establishment, modify and release, including tunnel maintain between UPF and RAN node) UE IP address allocation and management, charging and relative data collection and
- User Plane Function (UPF) provides user packet routing and forwarding as well as packet inspection, traffic steering, legal intercept and Quality of Service (QoS) marking.
- The Unified Data Management (UDM) supports amongst all, subscription data storage and management, access authorization based on subscription data (e.g. roaming restrictions) and generation of 3GPP AKA Authentication Credentials
- The Authentication Server Function (AUSF) supports authentication for 3GPP access and untrusted non-3GPP access
- The Policy Control Function (PCF) supports unified policy framework to govern network behaviour, provides policy rules to Control Plane function(s) to enforce them and

support access to subscription information relevant for policy decisions in a Unified Data Repository (UDR)
- The Application Function (AF) interacts with the 3GPP Core Network to provide services, for example to support application influence on traffic routing (clause 5.6.7 [5]), accessing Network Exposure Function (clause 5.20 [5]) and Interacting with the Policy framework for policy control (clause 5.14 [5])
- The Network Slice Selection Function (NSSF) supports the selection of the network slice instances serving the UE, determines the allowed NSSAI (Network Slice Selection Assistance Information) and, if needed, the mapping to the Subscribed S-NSSAIs. Further, it determines the AMF set to be used to serve the UE, or based on configuration, a list of candidate AMF(s), possibly by querying the Network Repository Function (NRF).

As discussed, NH network presents similarities to roaming, however there is the possibility that only the radio part will be shared among the clients which in this case are the Mobile Network Operators supported. Furthermore, NH providers may not be network operators, and therefore they may utilize part of the network functionality required for an autonomous 5G core, for example NH could manage the infrastructure required for user plane functionality, leaving the control plane to the home network. Therefore, low latency applications can be achieved through edge node deployments at the NH side.

Finally, in contrast to roaming, there is the possibility that authentication and subscriber management functions (AUSF, UDM) could located at the NH network. This sharing of resources and network functions and a trade-off analysis is the scope of Task 2 on security and privacy, where inputs from MNO (i.e. Vodafone) are quite crucial in order to assess the practicalities of such architectures.
For the roaming NH architectures there are four main configurations:

- Home routed roaming for 3GPP access (Figure 3)
- Local breakout roaming for 3GPP access (Figure 4)
- Home routed roaming for non-3GPP access through the non-3GPP Interworking function (N3IWF) (Figure 5)
- Local breakout roaming for non-3GPP access through N3IWF.

Please note that the visited PLMN (VPLMN) refers to the neutral host and the HPLMN refers to the hosted MNO core network.

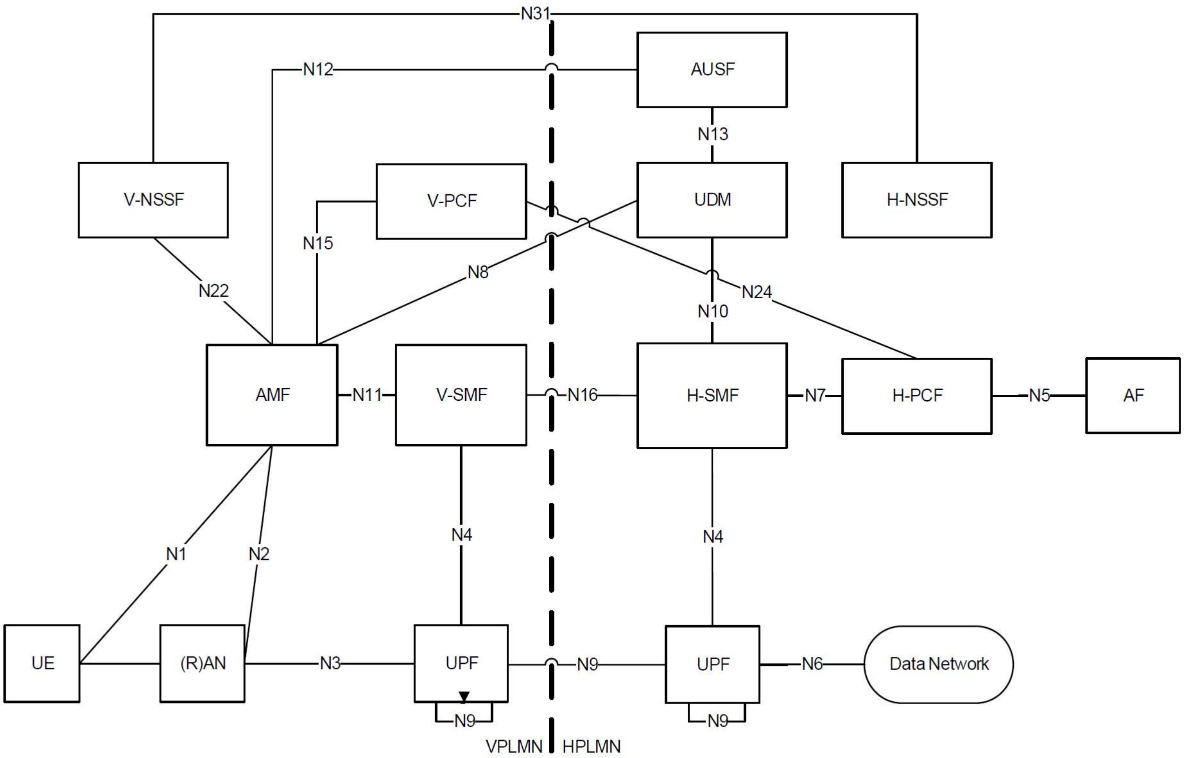

Figure 3. NH 3GPP access Roaming architecture – home-routed scenario.

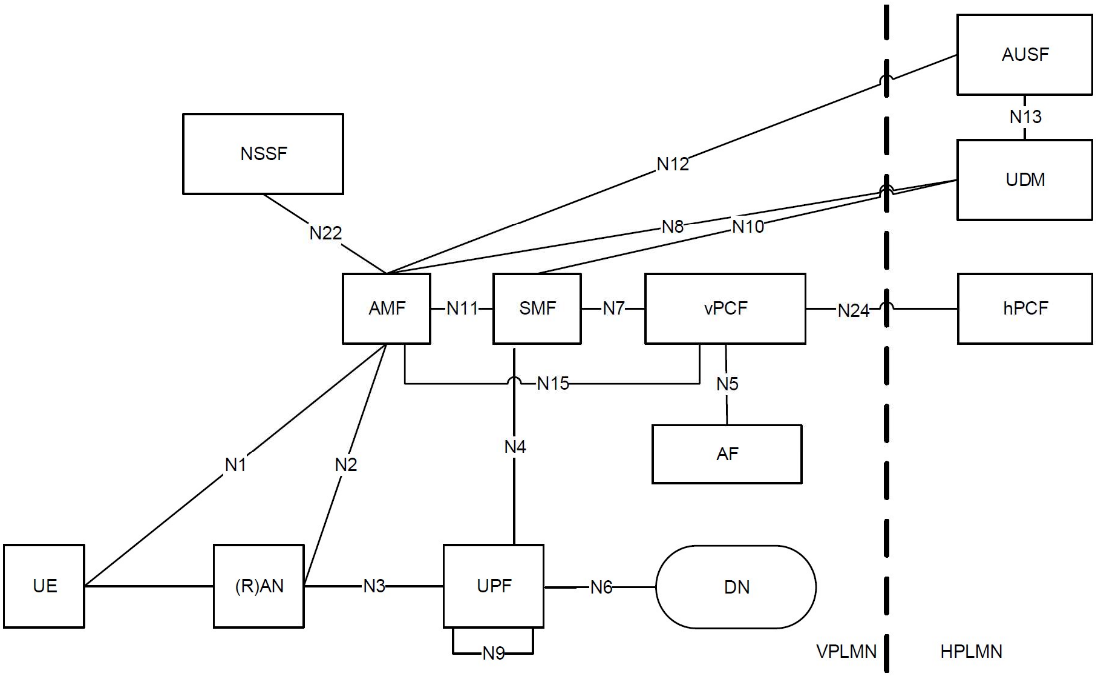

Figure 4. NH 3GPP access Roaming architecture - local breakout scenario.

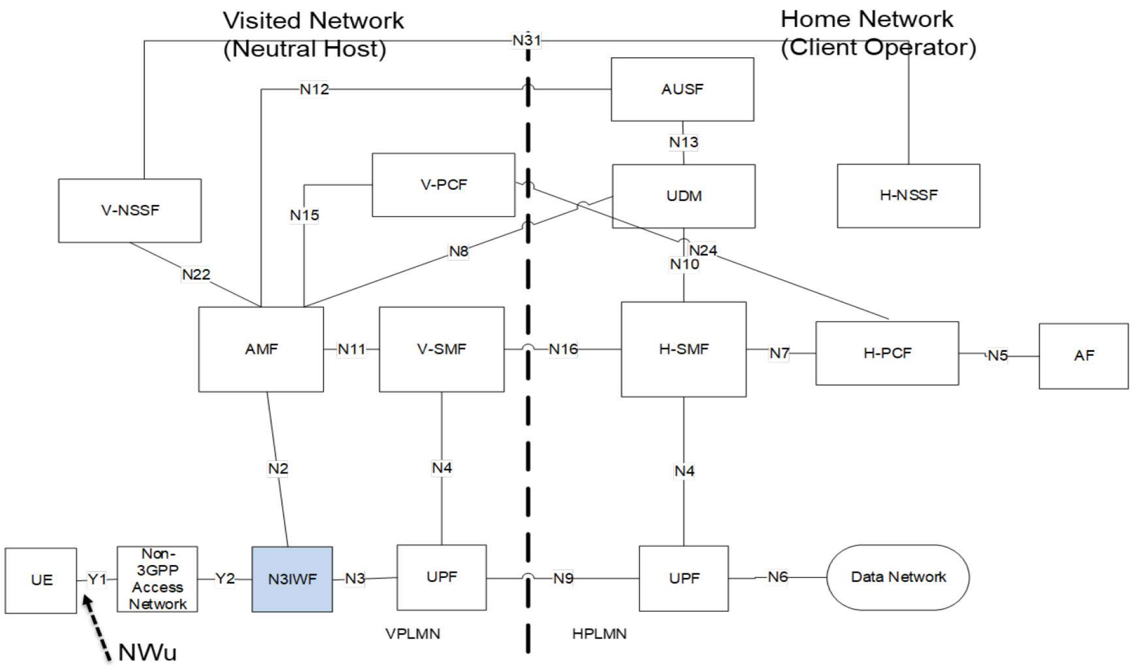

Figure 5. NH 3GPP access Roaming architecture – home-routed scenario

A similar architecture is to be deployed for non-3GPP access with local breakout. For the non-3GPP access the access network can be a Wi-Fi access point establishing connectivity with the 5G Core through procedures like Wi-Fi calling. The CN can be part of NH, or the connection can be directed to the client operator core network.

The functionality of N3IWF in the case of untrusted non-3GPP access includes the following:

- Support of IPsec tunnel establishment with the UE: The N3IWF terminates the IKEv2/IPsec protocols with the UE over NWu and relays over N2 the information needed to authenticate the UE and authorize its access to the 5G Core Network.
- Termination of N2 and N3 interfaces to 5G Core Network for control - plane and user-plane respectively.
- Relaying uplink and downlink control-plane NAS (N1) signalling between the UE and AMF.
- Handling of N2 signalling from SMF (relayed by AMF) related to PDU Sessions and QoS.
- Establishment of IPsec Security Association (IPsec SA) to support PDU Session traffic.
- Relaying uplink and downlink user-plane packets between the UE and UPF. This involves:
- De-capsulation/ encapsulation of packets for IPSec and N3 tunnelling
- Enforcing QoS corresponding to N3 packet marking
- N3 user-plane packet marking in the uplink.
- Supporting AMF selection.

RAN Sharing Architectures

In the previous section we have assumed that the NH provider is serving hosted clients through application of roaming procedures on an existing NH core network. However, the use case of NH can be limited to that occasion that only the RAN resources are shared with the client MNOs. This is the most primitive and common type of neutral hosting and prompts to the sharing of either physical resources such as radio equipment or sharing both radio equipment and spectrum. In the first case, the relevant architecture is referred as Multi Operator RAN (MORAN) and in the second case Multi Operator Core Network (MOCN). Both systems are described in the following paragraphs.

MORAN Architecture

The MORAN model shares backhaul interfaces and base station hardware, including feeder cables, antenna and power supply, but excludes spectrum sharing. This means that licensed radio resources, their schedulers and configuration are not shared, resulting in each operator being responsible for configuring their own cell to broadcast their respective public and mobile network (PLMN) identities.

In contrast to MOCN, this model is not standardized by 3GPP, and implies that baseband units (BBUs) are deployed separately for each of the hosted MNOs. In the case of 5G deployments, traffic is backhauled through N2 and N3 interfaces to each operator's core network for the control and user plane respectively. This configuration is illustrated in Figure 6, where two exemplary MNOs are served by the NH RAN.

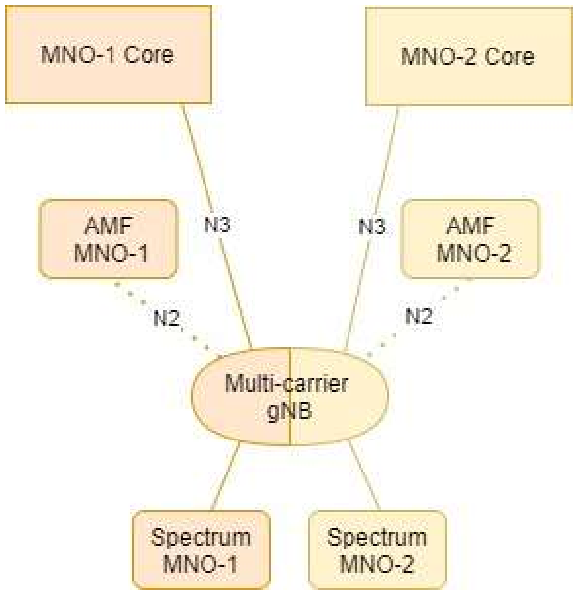

Figure 6. MORAN model for Neutral Hosting

MOCN Architecture

MOCN allows multiple participating operators to share resources of a single shared network according to agreed allocation schemes. The shared network includes a radio access network, and the shared resources include radio resources. MOCN is has been standardized by 3GPP with the relevant procedures mentioned in clause 5.18 [5]. A high-level diagram of the MOCN model is shown in Figure 7.

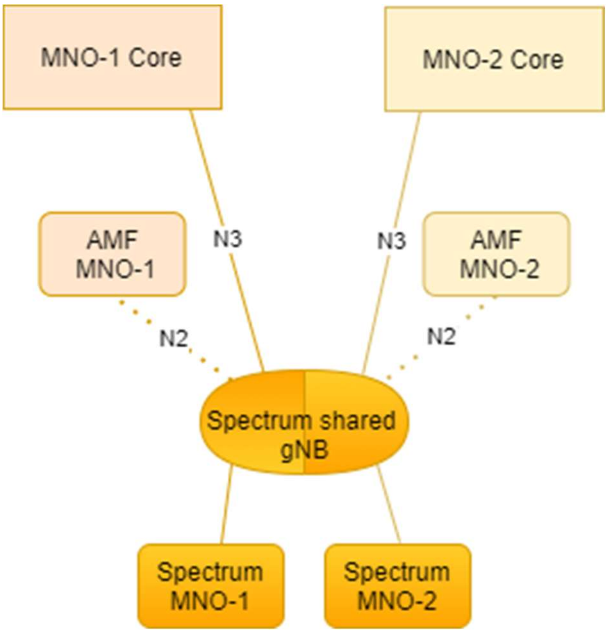

Figure 7. MOCN model for Neutral Hosting.

If a shared NG-RAN is configured to indicate available PLMNs for selection by UEs, each cell in the shared radio access network shall in the broadcast system information include PLMNs concerning available core network operators in the shared network. The Broadcast System Information broadcasts a set of PLMN IDs and one or more additional set of parameters per PLMN e.g. cell-ID, Tracking Areas. All 5G system capable UEs that connect to NG-RAN can support reception of multiple PLMN IDs and per PLMN specific parameters.

When a UE performs an initial registration to a network, one of available PLMNs shall be selected to serve the UE. UE uses all the received broadcast PLMN-IDs in its PLMN selection processes which is specified in TS 23.122 [6] and selects the corresponding PLMN. This information is communicated to the selected NG-RAN so that it can route correctly by informing the core network of the selected PLMN.
Broadcast system information is specified in TS 38.331 [7] and related UE access stratum idle mode procedures in TS 38.304 [50].

Network sharing and interworking between EPS and 5GS is described in TS 23.502 [3]. This is a very interesting use case as both 4G and 5G systems can share common RAN resources and is a significant addition towards 4G-5G migration.

Catapult MOCN Testbed at Westcott

Within the scope of this WP, the MOCN model shown in Figure 8 will be implemented. In this implementation, multiple core networks are to be connected to the same NG-RAN (in this case a gNB). Specifically, the shared NG-RAN will be configured to advertise multiple PLMNs for selection by UEs, each PLMN to be used by a single operator. When a PLMN is selected by a user, RAN will route the UE to the respective core network of this specific operator, will be registered and eventually have access to MNO's core network's resources and services. In our case the gNB will be configured to advertise two (2) PLMNs – PLMN 1 and PLMN 2, connected to Fraunhofer 5G Core and Amarisoft 5G Core, respectively.

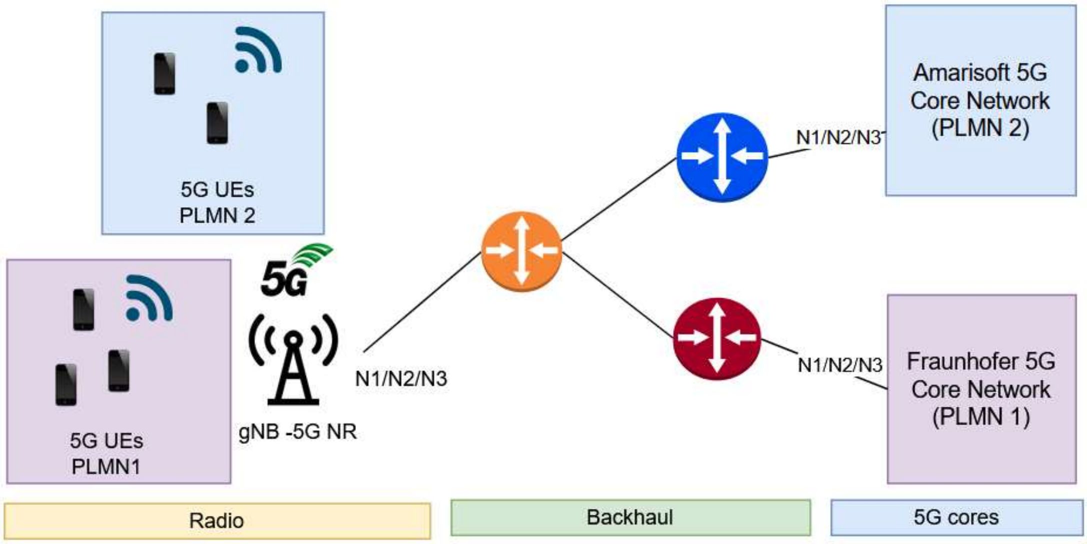

Figure 8. Catapult MOCN Testbed Plan at Westcott

Neutral Hosting over both EPS and 5GS

Another radio technology investigated in this WP is the Dynamic Sharing Spectrum (DSS). This technology for the first time investigates the capabilities of Neutral Hosting over both LTE and 5G while at the same time enables the parallel use the two technologies in the same frequency band. Until now, at least two antennas were required to operate different cellular network standards. Dynamic Spectrum Sharing promises to increase the efficiency of spectrum usage as it makes it possible to share spectrum dynamically.

The DSS concept is based on the flexible design of NR physical layer. It uses the idea that NR signals are transmitted over unused LTE resources. With LTE, all the channels are statically assigned in the time-frequency domain, whereas the NR physical layer is extremely flexible for reference signals, data and control channels, thus allowing dynamic configurations that will minimize a chance of collision between the two technologies. One of the main concepts of DSS is that only 5G users are made aware of it, while the functionalities of the existing LTE devices remain unaffected. Therefore, fitting the flexible physical layer design of NR around that of LTE is needed in order to deploy DSS on a shared spectrum. [9]

From the end user perspective, if a 5G capable device is within the coverage of an 5G-NR antenna, then they are able to access the 5G services and take advantage of the improved

efficiency and performance in throughput, slicing capabilities and the ultra-reliable low latency communications (URLLC) that 5G offers. On the other hand, if end users have 4G only capable devices within the signal range of the same antenna, then they will be using the 4G technology instead. This means that one antenna can serve at the same time two different generation networks and achieve more efficient spectrum usage.
A further investigation of the technology and architecture will be conducted within the context of Task 7.

Catapult DSS Testbed at Westcott

Within the scope of this WP, the Dynamic Spectrum Sharing (DSS) model shown in Figure 9 will be implemented. In this implementation two Core Networks are to be deployed, a 4G Network (Amarisoft) and a 5G Network (Fraunhofer) both connected to a single RAN. Both 4G LTE and 5G NR are deployed in the same frequency band, which allows a dynamic allocation of spectrum resources between LTE and 5G based on user demand. The Core Networks can be configured to advertise multiple PLMNs for selection by UEs or a single one. Thanks to this implementation, the same spectrum is to be shared by 4G LTE and 5G NR technologies which makes full use of the scarce spectrum resources.

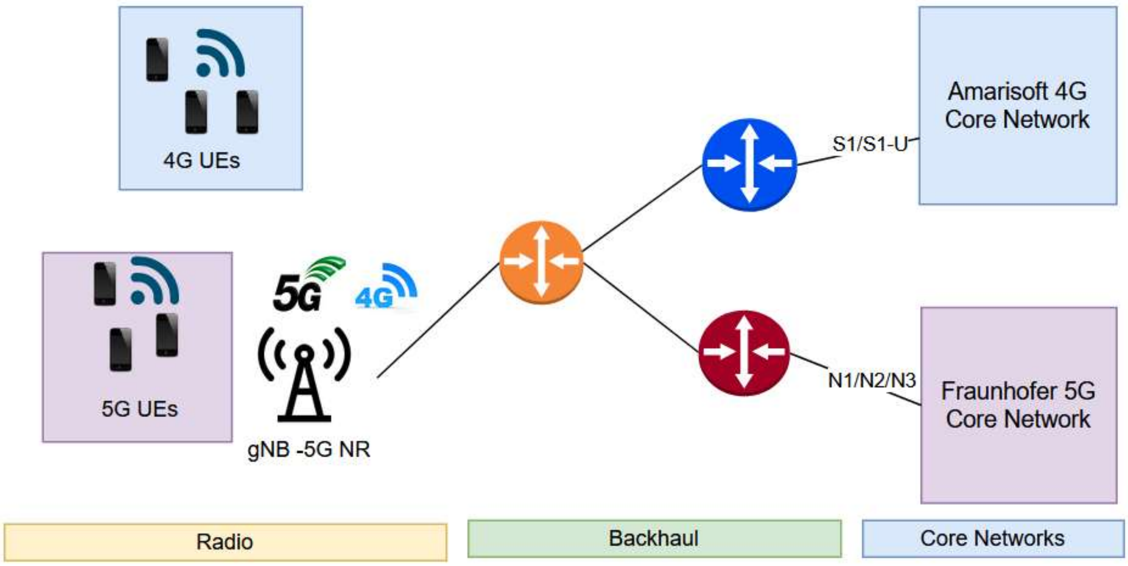

Figure 9. Catapult DSS Testbed at Westcott

Slicing Architecture

Although the initial conception of network slicing was based on partitioning traffic based on services (e.g., enhanced Mobile Broadband, IoT, Ultra-reliable Low Latency), the concept has since broadened. A network slice can be established to support a logical network dedicated to a customer (e.g., an enterprise, or for the case of neutral a hosted MNO) to a Mobile Virtual Network Operator (MVNO), to partitions based on individual applications (or groups of applications). A 5G UE may support up to eight simultaneous distinct active slices.

A 5G network slice is minimally defined as an SMF/UPF pair, though it will likely contain other network functions as well. All the active slices from a particular UE share the same AMF but will likely be mapped to a different SMF and UPF instance. The access and mobility characteristics for a particular UE will be the same for all application, but each application may have its own unique session management, policies, user plane characteristics, etc.

Figure 10 shows an example of a network slicing architecture applied to the Neutral Host use case [2]. It shows two UEs, each belonging to a different client operator and each connected via the NH network to its respective home network. For illustrative purposes, the diagram also shows a car that is generating traffic for a manufacturer's IoT network, and simultaneously generating browser traffic. In this example, the car is a customer of the neutral host.

In the figure, there is a network wide UDM, and a global NSSF and NRF, all of which serve the entire NH network. Slices 1 and 2 are assigned to two different NH client operators. In addition to the dedicated SMF and UPF that define the slice, each contains its own NRF, AMF, and PCF. The slice dedicated NRF in each of these slices is used to enable discovery of the NFs assigned to that slice, and that discovery is only available within that slice. Please, note that instead of individual AMFs, a centralized AMF could also serve all slices and communicate with the global NFs such as NRF.

This slicing paradigm is essentially a more flexible roaming architecture, where now partial network functions are handled by the NH core. Communication to the operator (hosted client MNO) is essential in the case of home routing scenario, as well as for some additional control plane messaging services with PCF and /or AF.

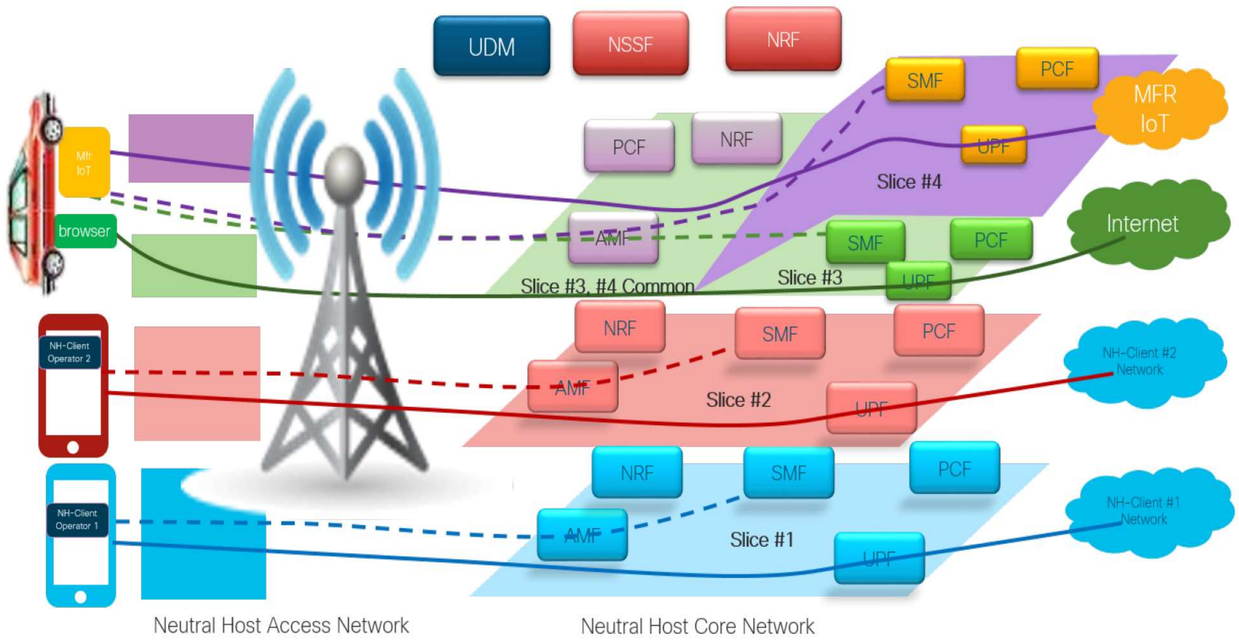

Figure 10. Network Slicing Architecture for NH.

Satellite Multi Core Backhauling

An exemplary architecture for satellite backhauling to multiple cores, is illustrated in Figure 11. The architecture implements multiple VPN connections from the backhaul link / router to the different core sites. IPSEC AES 256 Encryption will be implemented from Multi WAN routers at designated sites back to the multiple core VPN / Firewalls. In connecting to more than one 5G core, multiple IPSEC AES 256 Encryption VPN Tunnels would be created from a router located at the site of the satellite uplink to routers / infrastructure based at each of the 5G cores. For instance, pepwave routers would be installed at the site of the satellite uplink, these would then connect to similar / cisco devices within the multiple 5G Cores over multiple IPSEC VPN links. Backhauling can operate into multiple bands: Ku, and Ka band. A comparison between the two is provided below.

KU Backhaul:

The band network operates with UK based teleports and are National Critical Infrastructure approved. We have the ability to 'group' a number of antennas on a single VLAN meaning that multiple sites can operate on one network. This is particularly important for efficiency and the ability to offer a single interconnect to a server. Our Critical Cloud infrastructure is hosted in a resilient manor at the teleports meaning we can offer a premium hosting service as an alternative to AWS or Azure as examples, keeping the service contained if required and just a single hop from the satellite remotes. Excelerate's private Cellular APNs can also be terminated with the same infrastructure allowing for a hybrid private network connecting multiple sites via both satellite and/or cellular connections.

Excelerate's KU satellite network is fully managed and monitored allowing visibility of network loads, SNR and many other important information streams to ensure uptime and availability and the ability to swiftly rectify any issues without relying on third party providers.

The KU satellite provides a stable, reliable connection with less contention that can also be managed from the NOC. The frequencies used on a KU network provide a more stable connection from an RF perspective being less likely to be impacted from atmospheric interferences such as rain fade meaning higher availability of network uptime.

A key advantage of the KU satellite network is that Excelerate own the NOC (Network Operation Centre). This means that a far greater quality of service can be provided over a KA network.

A disadvantage of a KU network is the cost is slightly greater than KA and data throughput speed is less however this is more than justified by the reliability and level of QOS (Quality of Service) provided over a KU connection.

KA Backhaul:

An alternative to a KU connection is a KA Satellite connection. This would provide a higher data throughput at a lower cost. However, the disadvantages of a KA network are that the contention rates can be high and are unable to be managed via the NOC (Network Operation Centre). This means that network control is very limited from a Quality-of-Service perspective. The frequency used over a KA network is also more likely to be susceptible to atmospheric interference such as rain fade meaning the reliability and uptime of the connection is likely to be less than the KU solution.

Satellite technology can often be heavily impacted using VPNs and encryption. This is due to TCP windowing which is affected by the latency of satellite communications. Typical satellite latency is around 600-800 seconds and each TCP message during a TCP connection has this latency delay to contend with during the handshake process. We would recommend encrypting the link after this point-to-point VSAT hop to avoid any performance problems, then encrypting from our data centres to the data's destination, which would continue to protect data that would be transiting out to the internet. As the VSAT/VPN is for control plane data, TCP windowing should have a minimal effect vs standard user traffic such as HTTPS. In relation to the WP3 installation work IPSEC AES 256 Encryption will be implemented from Multi WAN routers at designated sites back to the core VPN / Firewall.

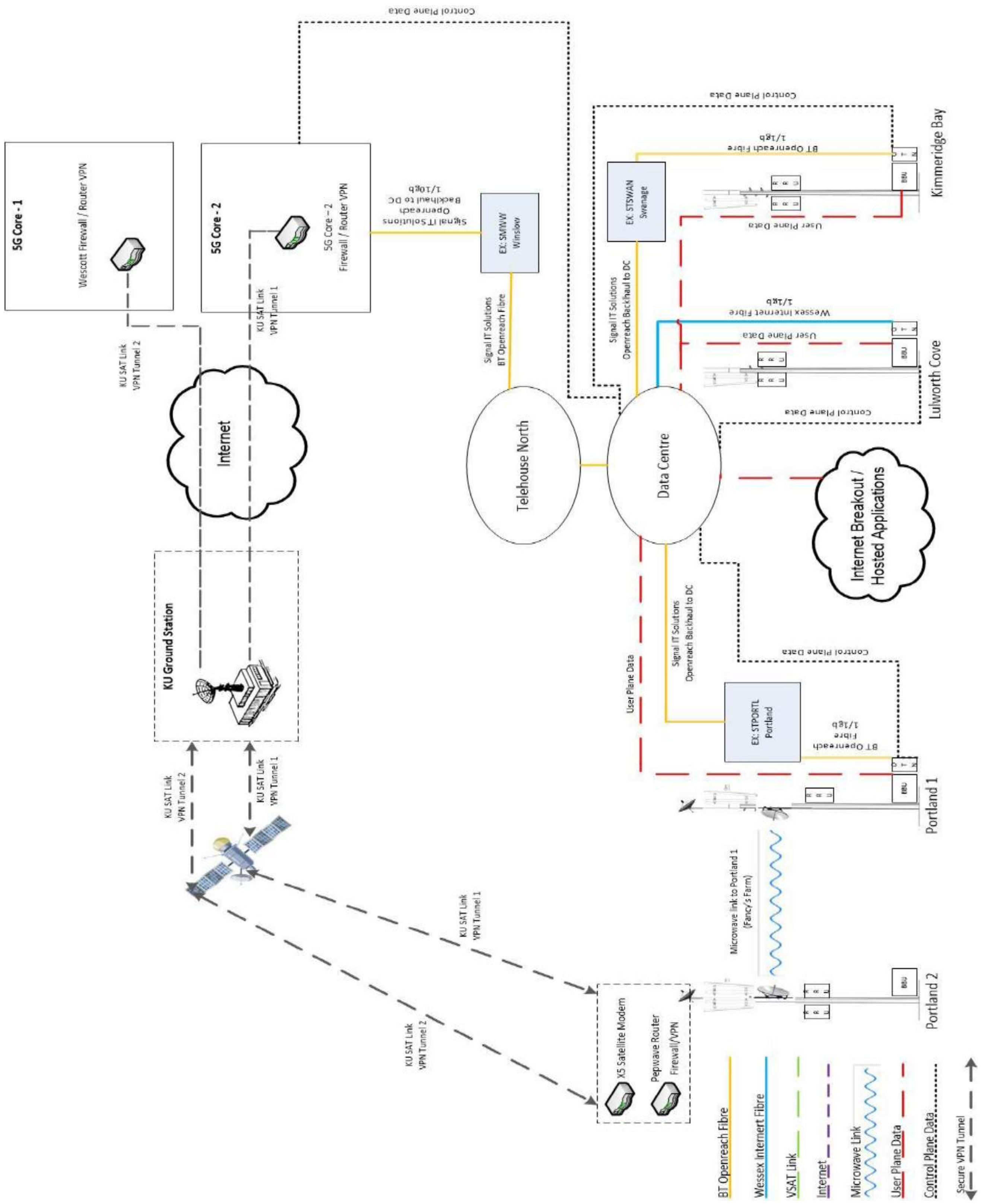

Figure 11. Satellite Backhauling to multiple cores.

Conclusions

This report presents a range of implementation architectures for the successful deployment of NH platforms. The idea is that an NH operator builds a network (with or without its own local spectrum), and the other Telcos either 'roam onto it' or use its shared facilities for their own radios, to increased coverage and high QoS in underserved rural areas.

Initially, the 5G CN architecture and its respective network functions and interfaces are described. Thereafter, the different NH roaming architectures are presented ranging from home routed roaming for 3GPP access, to local breakout roaming for non-3GPP access. Next, different RAN sharing architectures are discussed, focusing on MORAN and MOCN architectures. Furthermore, different NH deployment aspects are discussed, through the concept of network slicing. In addition, a reference architecture for backhauling to multiple cores using satellite networks at Ka and Ku band is presented.

Finally, this report sets the goals and presents the various deployment scenarios towards the implementation work undertaken as part of Task 7 -NH and Multi-Core deployment, by discussing MOCN, 4G/5G DSS testbed activities, at Catapult's Westcott 5G Step-Out centre.

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