Network Slicing

Understanding Wi-Fi Capabilities

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Executive Summary

Slicing is seen as foundational to 5G networks and is perceived by some as being unique to 3GPP. However, many of the concepts behind slicing have already been implemented by the Wi-Fi community, delivering solutions that enable multiple use cases to be simultaneously supported on a common Wi-Fi infrastructure. This document describes how a combination of standardized capabilities, coupled with widespread support of vendor-specific capabilities, are being used to implement all of 3GPP's slicing functionality and enable Wi-Fi networks to be "sliced". After analyzing the various slicing requirements, it is concluded that Wi-Fi systems can support the majority of slicing use cases.

1 Introduction to Slicing

Network slicing is seen as a foundational capability of 5G networks to simultaneously support the various different 5G use cases on a common 5G architecture. These use cases may have vastly different service needs, with 3GPP's TS 22.261 [1] describing the variety of functionalities that can be tailored per slice, (e.g., priority, charging, policy control, security, and mobility), differences in performance requirements (e.g., latency, mobility, availability, reliability and data rates), or the ability to serve only specific users (e.g., Public Safety users, corporate customers, roamers, or hosting an MVNO).

Being able to support a variety of different use cases on a common Wi-Fi infrastructure is widespread. For example, many enterprises simultaneously support enterprise users and guest on a converged architecture. Additionally, Wi-Fi service providers have delivered residential offerings, where logical separation of services within the hardware is augmented by network and service intelligence. This enables public carrier Wi-Fi and private home services, that exhibit vastly different security, mobility, charging and policy behaviors, to be supported on the same Wi-Fi infrastructure

However, it is evident that 3GPP's definition of network slicing doesn't merely impact the radio, rather as described in TS 22.261, it represents the functionality of a complete network, including radio access network functions and core network functions. Moreover, with 3GPP's 5G Core Network being positioned as access agnostic and able to support both 5G New Radio based radio access as well as 802.11 based "non 3GPP" access, it will become increasingly important to understand the ability of 802.11-based networks to support slicing concepts.

This short document looks into those requirements defined by 3GPP in its definition of network slicing and compares those with capabilities that are able to be supported using Wi-Fi architectures.

2 3GPP Slicing

Network Slicing is fundamentally an end-to-end partitioning of the network resources and network functions so that selected applications/services/connections may run in isolation from each other for a specific business purpose.

2.1 3GPP Slicing Definition

3GPP defines slicing procedures for the core network, directives for the access network and suggestions for the transport network [2].

> *A network slice instance (NSI) is complete in the sense that it includes all functionalities and resources necessary to support certain set of communication services thus serving certain business purpose. The NSI contains Network Functions (NFs)* (e.g. belonging to AN and CN).
>
> *For the part of the Transport Network (TN) supporting connectivity between the NFs, the 3GPP management system provides link requirements (e.g. topology, QoS attributes) to the management system that handles the part of the TN supporting connectivity between the NFs.*

2.2 Access Network Related 3GPP Slicing Requirements

3GPP TS 22.261 lists the top-level slicing requirements. The requirements pertinent to access network definition are:

1. The ability to configure the information which associates a UE to a network slice
2. The ability of an operator to assign a UE to a network slice, to move a UE from one network slice to another, and to remove a UE from a network slice, e.g., based on subscription.
3. The ability to isolate traffic between different network slices in the same network. Traffic and services in one network slice shall have no impact on traffic and services in other network slices in the same network
4. The system shall enable the network operator to define a minimum and maximum available capacity for a network slice.
5. The ability of an operator to define prioritization between slices, in case network resources become over-subscribed
6. The ability to enable a UE to be simultaneously assigned to and access services from more than one network slice of one operator

2.3 Management related Slicing Requirements

3GPP TS 22.261 additionally lists slicing requirements related to slice management:

1. The 5G system shall allow the operator to create, modify, and delete a network slice.
2. The 5G system shall allow the operator to define and update the set of services and capabilities supported in a network slice.
3. The 5G system shall allow the operator to configure the information which associates a service to a network slice.
4. Creation, modification, and deletion of a network slice shall have no or minimal impact on traffic and services in other network slices in the same network.

In order to meet these requirements, 3GPP defines a framework and requirements for management and operation of network slicing as illustrated in Figure 2-1.

3GPP TR 28.801 defines the Communication Service Management Function (CSMF) that is responsible for translating the service requirements into the slice requirements through the Network Slice Management Function (NSMF) to define the Network Slice Template (NST) and orchestration of the Network Slice Instance (NSI).

- The Network Slice Template describes the NSI with required instance specific policies and configurations
- The Network Slice Instance contains Network Functions (NF) constituting Access Network (AN), Core Network (CN) and Transport Network (TN).

3GPP defines the Network Slice Instance lifecycle as an independent process which includes preparation, instantiation, run-time and decommissioning:

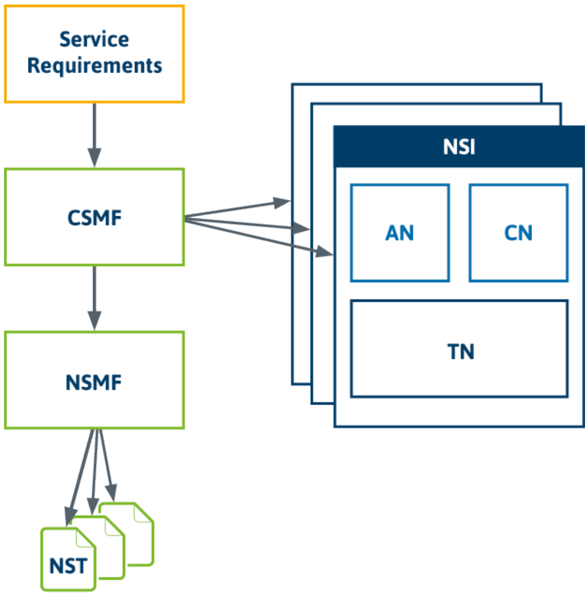

Figure 2-1: 3GPP Network Slicing Management

3 Wi-Fi Architectures and Slicing Requirements

This section compares the above key slicing requirements with capabilities currently available in Wi-Fi based networks. Where functionality leverages vendor proprietary functionality, examples of such are provided to illustrate how such functions are broadly available across the Wi-Fi ecosystem.

3.1 Ability to associate a Wi-Fi device to a network slice

In Wi-Fi networks, the isolation associated with slicing requirements can be realized using different techniques. In controller-based deployments, VLANs can be dynamically allocated by the network to packet flows associated with different groups of users, as illustrated in Figure 3-1. RFC 3580 [3] specifies how the tunnel attributes defined in RFC 2868 can be used to allocate the authenticated Wi-Fi user into a particular VLAN. The use of dynamic VLAN assignment enables the slice selection to be based on network policy, rather than handset configuration.

Such capabilities are widely used within the Wi-Fi industry and are used within enterprise deployments, e.g., enabling to associate guest Wi-Fi users with a particular VLAN that is distinct and isolated from the corporate VLAN used to support enterprise employees. Carrier Wi-Fi deployments leverage the same capabilities, supporting partitioning of resources and hence enabling simultaneous support of private and public devices.

3GPP also defines Network Slice Selection Assistance Information that is provided by a UE to help determine which slice to associate a UE with. In Wi-Fi networks, this slice selection assistance functionality can be realized using multiple BSSID functionality. With such a configuration, a Wi-Fi device will use its selected SSID to "indicate slice selection assistance information" to the Wi-Fi network. Importantly, the selected SSID used

by the device together with the AP's MAC address can be signaled to other network functions in the RFC 3580 specified RADIUS signaling messages. This enables the network to take into account the assistance/SSID information when determining which slice/VLAN to allocate to a particular user.

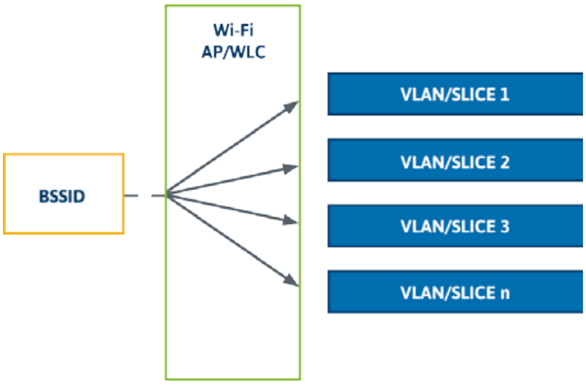

Figure 3-1: Slice support using single BSSID

In those use cases where slicing selection is entirely controlled by the user, the multiple BSSID functionality can also be used to realize slicing. For example, in residential deployments, home gateways typically enable independent configuration of parameters on a per BSSID basis, including security type, bridge mode, network address translation, together with WAN tunneling capabilities. This enables BSSID selection to be used to support a "home network slice" and a "carrier Wi-Fi slice" on a single home gateway. Packets associated with the "carrier Wi-Fi slice" will be switched directly between the Wi-Fi interface and the WAN tunnel. This ensures isolation between the carrier Wi-Fi traffic and the home traffic that is being bridged onto the home network.

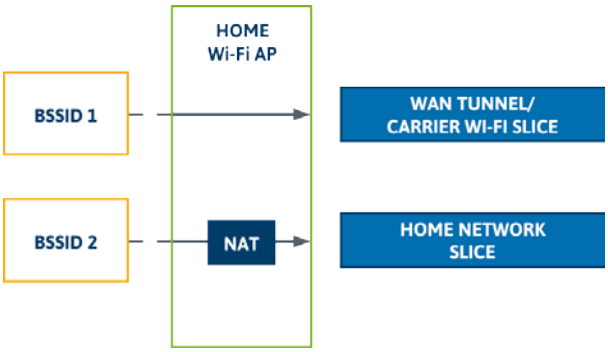

Figure 3-2: Slice support using multiple BSSIDs

3.2 Ability to move a Wi-Fi device from one network slice to another, and to remove a UE from a network slice

Being able to move a Wi-Fi device from one network slice to another is a scenario which is already used within carrier Wi-Fi deployments. Significantly, the definition of Hotspot2.0 leverages such capabilities, allowing the user to first receive service from a "provisioning slice" where they are able to access on-line signup services and then be moved to a "production slice" where users leverage their newly provisioned credentials to access Carrier Wi-Fi services.

Enterprise Wi-Fi deployments leverage the same capabilities for delivering enhanced security services that deal with endpoint posture. Enterprises may define endpoint requirements, e.g., in terms of anti-virus/anti-spyware enablement. Endpoints which are determined to be non-compliant will be associated with a "remediation service slice" that enables them to access posture remediation services. Once the device has complied with the appropriate policy, the network can then move the Wi-Fi device to the "compliant service slice".

Being able to move a particular Wi-Fi client from one "network slice" to another and to remove a Wi-Fi client from the network is achieved using RFC 5176 [4] specified dynamic authorization mechanisms. Importantly, if this is to avoid client-side impacts, it will require that the BSSID is common between the two slices, further motivating the use of dynamic VLAN assignment for slice allocation. In an enterprise environment, such techniques can be used to move a Wi-Fi device from one VLAN to another, or can be used in a carrier Wi-Fi environment to move a Wi-Fi device from a default APN on one Trusted WLAN Access Gateway (TWAG) to another.

Note, 802.11v (since incorporated in 802.11-2012) introduced the ability for the Wi-Fi network to trigger a BSS transition. Although this functionality could conceivably be used to assist in moving devices between slices, the device response to the network triggering a transition event between BSSIDs is often vendor dependent.

3.3 Ability to isolate traffic between different network slices in the same network

As described in section 3.1, the combination of multiple BSSIDs over the 802.11 interface, coupled with network based VLAN allocation, can be used to provide the traffic isolation between different network slices over a common Wi-Fi architecture, or even isolation between traffic from different Wi-Fi devices in the same slice.

3.4 Ability to define resources for a network slice

This capability is typically realized in the access network using vendor proprietary capabilities. For example, in 3GPP the exact details of the RAN scheduling algorithms are not defined, enabling RAN vendors to differentiate their offerings. The same approach is used by the Wi-Fi community, with resource allocation being implemented using vendor proprietary capabilities. Examples of such are described below, highlighting the widespread availability of such functionality across the Wi-Fi ecosystem.

- Arris-Ruckus: The WLAN Prioritization feature enables a priority (high/low) to be configured per SSID, to enable traffic corresponding to "one slice" to be prioritized over traffic of "another slice". In addition, rate limiting controls fair access to the network. When enabled, the network traffic throughput of each network device (i.e., client) is limited to the rate specified in the traffic policy, and that policy can be applied on either the uplink or downlink.

- Cisco: Air Time Fairness (ATF) functionality enables operators to allocate resources between different groups of users, including being able to allocate different resources on a per-SSID basis. Note, ATF only operates in the downlink direction. If up-link resource allocation is required, this is supported by defining upstream and downstream bandwidth limits for different SSIDs, or even for different groups of users using a single SSID.
- HPE-Aruba: Airtime allocation can be configured on a per SSID basis that controls the aggregate amount of airtime that all clients on the SSID can use to send/receive data.
- Huawei: Virtual Access Points (VAPs) use a combination of WMM, security and traffic profiles together with a VLAN ID to define a virtual service. This functionality can be used to segment users and traffic with the ability to configure traffic policing on a per-VAP basis. The traffic profile can be used to limit the rate of upstream and downstream traffic for a single user or all users of the VAP.

Whereas current generation of Wi-Fi equipment enables strict controls to be applied to down-link traffic, it is currently difficult to control the resources applied to up-link traffic, as devices will be autonomously contending for up-link access, competing for resources until they succeed. In particular, strict control cannot be enforced

at the station (device) level, but can be enforced at the AP level, where traffic in excess of the allocated upstream BW is removed. Importantly, 802.11ax the next generation of Wi-Fi, enables the network to schedule (multi-user) up-link transmissions, and will therefore enable enhanced 802.11 resource partitioning between different users and/or slices.

Note, unlike when operating in exclusively licensed spectrum, allocating minimum resources to a Wi-Fi slice will need to accommodate the limitations associated with operating in un-licensed spectrum and the requirement to contend for access with potentially overlapping third party Wi-Fi systems, or other users of the unlicensed spectrum.

Moving forward, Fast Session Transfer (FST), originally defined in IEEE 802.11ad and since incorporated in IEEE 802.11-2016 standard, will deliver additional capabilities to define more granular resource for a network slice, specifically in a multi-band environment. FST enables steering of entire mobile devices to different bands near instantaneously and also separation of traffic streams such as video, and data (and hence network slices) to multiple bands/channels within the same AP, enabling the optimization of frequency resources allocated to particular slices.

3.5 Ability to define prioritization between slices, in case network resources become over-subscribed

This capability is related to the vendor proprietary Wi-Fi capabilities described in section 3.4.

- Arris-Ruckus: Rate limiting currently defined on a per client basis.
- Cisco: Air Time Fairness (ATF) functionality is defined to operate on a percentage of overall resources and therefore scales with available 802.11 bandwidth. Using a percentage definition then avoids the requirement to deal with the over-subscription described by 3GPP.
- HPE-Aruba: WLAN Airtime SSID configuration is configured by specifying a percentage of airtime able to be used to serve the aggregate clients allocated to a particular SSID. Using a percentage definition then avoids the requirement to deal with the over-subscription described by 3GPP.
- Huawei: The cumulative rate limit values corresponding to the traffic profiles associated with the different VAPs will typically be configured to avoid over-subscription.

3.6 Ability to enable a Wi-Fi device to be simultaneously connected to more than one network slice

Unlike 3GPP that has traditionally defined the capability of a UE to have different contexts/Access Point Names, conventional Wi-Fi has no such concepts. These separate contexts can be viewed as a precursor to functionality defined to support simultaneous connectivity to multiple slices.

Already in Release 12, 3GPP has defined an approach to enable trusted WLANs to access EPC based services that are based on PDN connectivity concepts that include APNs. The WLCP protocol specified in 3GPP TS 24.244 [5] enables the signaling of such information, together with distinct destination MAC addresses that are used by a Wi-Fi device to identify multiple flows over an 802.11 based access network.

However, the above description of current Wi-Fi capabilities highlights the challenges associated with re-using multiple BSSIDs and VLAN allocation to support all network slicing use cases. In particular, the inability of the native 802.11 layer to enable a Wi-Fi device to simultaneous associate to multiple BSSIDs looks to be a deficiency compared with 3GPP network slicing requirements.

Note, one example of a use case which is described as requiring such capability is a connected car scenario that needs to deliver high throughput for in-car infotainment, whilst simultaneously supporting ultra reliable and low latency (URLLC) for assisted/autonomous driving [6]. However, whilst there is a subset of use cases that

may benefit from a device being able to simultaneously connect to multiple network slices, it is equally evident that perhaps the majority of slicing use cases do not require such functionality. Indeed, some enterprise security administrators may perceive the simultaneous slice support as being a security risk, in much the same way as split-tunneling VPNs are seen as a security risk.

Note, Wi-Fi allows for two phases when joining a network: an authentication phase, where the device requests the network to validate the device ability to connect, and an association phase, where the device actively enables data forwarding through the target network. A client can authenticate to more than one network, thus being ready to communicate with more than one BSSID, but can associate to only one BSSID.

Note, some device implementations do support simultaneous association to multiple networks, and in these cases the client device will comprise of multiple logical stations. For example, Broadcom's Virtual Simultaneous Dual Band (VSDB) functionality enables a single client device to simultaneously provide connectivity to peer-to-peer services as well as access point provided services.

3.7 Slicing of Wi-Fi Core Networks and Transport Networks

3GPP defines slicing procedures for the core network, directives for the access network and suggestions for the transport network. The previous sub-sections have described important capability that enables the Wi-Fi access network to be sliced.

Importantly, the typical use of VLANs to isolate different network slices can also be used with switch configurations to define bandwidth policers that operate on the aggregated per-slice traffic. This enables transport resources to be allocated to particular Wi-Fi slices.

Furthermore, if the Carrier Wi-Fi architecture is deployed using 3GPP's Trusted WLAN architecture, the same capabilities used to partition the 3GPP Core Network can be applied to deliver sliced services for Wi-Fi users.

3.8 Management and Orchestration of Sliced Wi-Fi Networks

While Wi-Fi equipment typically supports management reporting on a per SSID basis, including the ability to report the resource usage on a per-WLAN basis, the additional use of AAA based VLAN assignment to dynamically associate devices to network slices creates new requirements for management reporting from a slicing perspective. Being able to report key performance indicators on the basis of a combination of selected WLAN and allocated VLAN should enable Wi-Fi management systems to support reporting on a per slice basis.

As with cellular networks, the current generation of carrier Wi-Fi networks are often managed on a per domain basis, with separate management systems being used to address Wi-Fi, transport and, where EPC components are re-used, 3GPP core network components. However, support for network slicing in the cellular network is driving a need to deliver cross domain orchestration across access, core and transport domains and it should be expected that a similar need for cross domain orchestration will become apparent in Carrier Wi-Fi networks.

The transition to Software Defined Networks (SDN) that enable increased network programmability, is expected to lead to an associated evolution of the management plane, with the introduction of domain controllers. These domain controllers will typically expose an abstracted service model northbound, enabling a cross-domain service orchestrator to program the end-to-end network.

With Wi-Fi and networking vendors increasingly adopting SDN concepts, it should be apparent that support for model based northbound APIs will enable the management and orchestration of end-to-end sliced Wi-Fi networks.

4 Summary

Network slicing is seen as a foundational 5G capability. With WBA's 2018 projects including analysis of "unlicensed integration with 5G networks", it is obvious for WBA to examine the ability of Wi-Fi systems to support slicing concepts.

This whitepaper has shown how 5 out of the 6 key network slicing requirements associated with the access network can be addressed using commercial Wi-Fi capabilities. Baselining network slicing on SSID selection coupled with dynamic VLAN assignment enables Wi-Fi network to dynamically associate devices to network slices, isolate traffic between slices and partition 802.11 resources allocated separate slices.

From a management plane perspective, it is highlighted that the above approach drives new requirements from a KPI reporting perspective, necessitating information be aggregated based on a combination of selected WLAN and allocated VLAN.

Importantly, it is anticipated that the introduction of 802.11ax, the next generation of Wi-Fi, will see further enhancements in the ability to partition resources between users and/or slices within Wi-Fi networks.

It is noted that the baselining network slicing on multiple BSSID and dynamic VLAN allocation functionality supported in current Wi-Fi networks does restrict the ability to support the requirement that a device can be simultaneously attached to multiple slices.

However, with the majority of use cases requiring devices to be associated with a single slice, or with sequential slices, it is evident that Carrier Wi-Fi operators can embrace the slicing concepts being defined by 3GPP and leverage already existing capabilities to deliver sliced Wi-Fi networks.

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ACRONYMS AND ABBREVIATIONS

ACRONYM / ABBREVIATION	DEFINITION
AN	Access Network
APN	Access Point Name
ATF	Air Time Fairness
BSSID	Basic Service Set Identifier
CN	Core Network
CSMF	Communication Service Management Function
EPC	Evolved Packet Core
FST	Fast Session Transfer
MVNO	Mobile Virtual Network Operator
NF	Network Function
NSI	Network Slice Instance
NSMF	Network Slice Management Function
PDN	Packet Date Network
QoS	Quality of Service
SDN	Software Defined Network
TN	Transport Network
TWAG	Trusted WLAN Access Gateway
UE	User Equipment
URLLC	Ultra-Reliable Low Latency
VAP	Virtual Access Point
VSDB	Virtual Simultaneous Dual Band
WBA	Wireless Broadband Alliance
WLCP	Wireless LAN Control Plane Protocol