5G and Wi-Fi 7 Network Convergence with End-to-End Network Slicing

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1. Introduction

The commercial rollout of both 5th generation (5G) mobile communication and Wi-Fi 6 began around 2020, jointly ushering in an era of comprehensive wireless connectivity with high-bandwidth, low-latency technology features spanning both outdoor and indoor environments. These advancements have sparked industry discussions comparing these two technologies. The central question revolves around whether the rapid deployment of mobile communication will eventually supplant indoor Wi-Fi. The prevailing consensus is that both 5G and Wi-Fi possess distinct application scenarios, making them suitable for different purposes. The progression of communication technology doesn't necessitate an either-or choice; rather, it underscores the importance of these technologies coexisting and complementing each other in various scenarios.

As a typical use case, people use 5G signals on their phones when they're outdoor, but when they return to indoor environment, they expect to leverage Wi-Fi for internet access. In such case, this leads to a technology that converges both the mobile 5G network and Wi-Fi access, allowing 5G devices to seamlessly connect with the communication network without disrupting the 5G services. The core challenge lies in linking Wi-Fi devices to the mobile core network using wired connections.

The integration of mobile networks and wireless LANs originated with 3GPP R6 version and was further refined in the 4G specification. However, due to limited business benefits and the complexity of the technical solutions, such convergence has not been widely commercialized by operators.

In the era of mobile 5G, the convergence of mobile and Wi-Fi networks presents a fresh opportunity. The gradual construction of 5G base stations and enhancements to indoor coverage are ongoing, representing medium to long-term engineering advancements. Additionally, the progression of 5G technology into millimeter wave technology necessitates robust indoor data transmission solutions.

Furthermore, leveraging service modular architecture and network functions virtualization technology, the 5G core network distinguishes control and data planes, making it easier to integrate and adapt to Wi-Fi access networks compared to the mobile 4G framework. Additionally, mobile 5G introduces support for network slicing. Enabling slicing in mobile networks requires support from the 5G Radio Access Network (RAN), core networks, and terminal equipment. To ensure comprehensive end-to-end coverage for 5G network slicing, a seamless solution involves connecting Wi-Fi and including slicing support within 5G network management. This naturally becomes part of the convergence of mobile and Wi-Fi networks, enabling Wi-Fi access networks to seamlessly integrate with 5G's management, configuration, and service operations, thereby supporting network slicing.

From the Wi-Fi technology perspective, Wi-Fi 7 [1] and Wi-Fi 6 [2] standards have made significant advancements in carrier-grade data transmission, allowing for high-speed data handling with minimal delays. The convergence of Wi-Fi access networks with the dynamic capabilities of mobile 5G results in a win-win situation for both technologies, boosting their performance together. As we look ahead to Wi-Fi 7's mass deployment, Wi-Fi 7 is anticipated to further improve the Quality of Service (QoS) for managing 5G traffic. This exciting journey showcases how Wi-Fi and mobile 5G are collaborating to transform the wireless technology landscape.

The convergence of Wi-Fi access network and mobile 5G mainly includes two parts. First, it is about setting up the mechanism of 5G traffic roaming through indoor wireless LAN and wired networks to reach the mobile core network. Second, it is about making sure 5G end-to-end services managed with required performance within this setup.

The references [3], [4], and [5] provided a basic introduction of the convergence evolution between 5G and Wi-Fi networks, along with brief insights into the slicing requirements supported by Wi-Fi 7 technology and mesh network. Based on original preliminary study, this paper aims to offer a more comprehensive illustration of the convergence architecture with key Wi-Fi technologies to support architecture evolution, including an up-to-date analysis of the new Wi-Fi 7 technology and EasyMesh™, which offers the capabilities of supporting advanced slicing requirements. This will be followed by an enhanced application scenario, illustrated based on a foundational instance drawn from reference [3].

The subsequent sections begin with a comparison of the technology characteristics of mobile 5G, Wi-Fi 6, and Wi-Fi 7. Based on an overview of convergence standard evolution, the discussion then explores the essential technologies driving the convergence of mobile 5G and Wi-Fi networks. Next, the paper describes the implementation of end-to-end network slicing within a converged 5G and Wi-Fi access network, including a feasibility analysis of incorporating Wi-Fi 7 technologies and Wi-Fi Mesh into the slicing strategy. Furthermore, it illustrates application scenarios of network slicing in the converged 5G and Wi-Fi 7 access network, such as enterprise deployment or campus environment. Finally, the paper discusses the future evolution of the convergence of 5G and Wi-Fi networks, considering several key aspects.

2. Comparison Between Wi-Fi 7 and 5G Technology

In 2018, the mobile 5G R15 standard was finalized, with Enhanced Mobile Broadband (eMBB) serving as a pivotal feature for high-bandwidth mobile transmission, coinciding with the release of the Wi-Fi 6 standard.

The subsequent R16 version, ratified on July 16, 2020, represents the first comprehensive standard for 5G, extending its application into various industries through the integration of massive Machine Type of Communication (mMTC) and Ultra Reliable Low Latency Communications (uRLLC). The upgraded Release 17 (R17), standardized in June 2022, further enhanced the network's core capabilities and explored new applications such as medium and low-speed Internet of Things (IoT), extended reality, and etc. The anticipated 5G Release 18 (R18), expected in 2024, will mark the beginning of the second phase of 5G technical standards, spanning R18 to R20.

Coincidentally, in 2024, Wi-Fi 7 starts to take the market share from Wi-Fi 6.

Wi-Fi 7, also known as IEEE 802.11be or Extremely High Throughput (EHT), builds upon the capabilities of Wi-Fi 6, representing a significant leap forward in wireless networking technology. It triples the maximum throughput of its predecessor, facilitating rapid data transmission and seamless streaming of ultra-high-definition content, among other capabilities. With enhancements such as multi-link operation, 4K-QAM modulation, and channel bandwidth extending up to 320 MHz, Wi-Fi 7 dramatically enhances network capacity, making it adept at handling a high density of devices in homes, offices, and public areas.

The IEEE Wi-Fi 7 study group was formed in June 2018, with the final version of Wi-Fi 7 planned to be ratified by IEEE in 2024. In parallel, Wi-Fi Alliance took a step forward in 2021 by establishing a dedicated task group for Wi-Fi 7, which had certification ready by the end of 2023.

It is clear that mobile 5G, Wi-Fi 6, and Wi-Fi 7 will evolve and synergize across various industries and application scenarios in coming years.

A comparison of the key technologies in 5G, Wi-Fi 6, and Wi-Fi 7 can be found in Table 1[1],[2],[3].

Table 1 - Technical Comparison between Mobile 5G, Wi-Fi 6 and Wi-Fi 7

Technical characteristics	Mobile 5G	Wi-Fi 6	Wi-Fi 7
Physical Rate	20 Gbps	9.6 Gbps	36 Gbps with MLO
Average user experience Rate	1 Gbps	1 Gbps	1 Gbps-10 Gbps
Modulation techniques	Maximum 256-QAM	Maximum 1024-QAM	Maximum 4096-QAM
Channel bandwidth	100MHz	Maximum 160MHz	Maximum 320MHz
Channel access	OFDMA	OFDMA and CSMA/CA	OFDMA and CSMA/CA
Multiple Input Multiple Output (MIMO).	Outdoor: 64 spatial streams Indoors: 4 spatial streams	8 spatial streams	8 spatial streams
Delay	eMBB:4ms uRLLC:0.5ms	10ms to 20ms (depending on indoor environment)	Less than 10ms (depending on indoor environment)
Connection Density	$10^6/km^2$	Usually 64-128 (per 100 square meters; Dependent on access devices).	Usually 128-256 (per 100 square meters; Dependent on access devices).
QoS support	QCI (QoS Class Identifier) management	Basic Access Categories with four priority queues	QoS Characteristic

In the following section, we will further discuss the technical characteristics, the advantage of Wi-Fi technology evolution in indoor scenarios, as well as the strengths of mobile 5G in outdoor situations.

A. The evolution of Wi-Fi technology maintaining its dominance in indoor deployment scenarios

Over the past decades, Wi-Fi technology has proven to be highly suitable for indoor deployments due to several key characteristics: its applicability to a **vast number of stationary household devices**, its support for peer-to-peer data transmission within **local wireless networks**, and its simplicity coupled with **low investment costs**.

Wi-Fi is particularly effective in providing broadband access to the last meters within homes, making it the preferred choice for extending connectivity. Non-3GPP household devices that do not require mobility often incorporate Wi-Fi functionality, enabling seamless data transmission. The widespread embedding of Wi-Fi capabilities in a multitude of electronic products and networking equipment underscores its enduring presence. Given that Wi-Fi operates in unlicensed spectrum, manufacturers of diverse devices are likely to continue embracing this technology, regardless of future advancements in mobile technology.

Furthermore, the latest Wi-Fi technologies will continue to be integrated into new household devices as they enter the market, remaining unhindered by the progress of mobile technology.

Secondly, devices equipped with Wi-Fi can seamlessly interact within this local wireless network over short distances. For example, files can be transferred between a PC and a laptop, or images and videos can be shared between a smartphone and a television. Wi-Fi acts as the glue that connects household devices into a cohesive network.

Moreover, the use of unlicensed spectrum is a primary factor contributing to Wi-Fi's rapid global proliferation. It is cost effective to set up a wireless LAN for short-range data transmissions compared to mobile network technologies.

Beyond these advantages, Wi-Fi 7 has further enhanced the indoor user experience significantly. For example, Wi-Fi 7 boosts data transmission rates exceeding 10 Gbps, marking a significant physical layer enhancement crucial for supporting high-bandwidth services such as ultra-high-definition video streaming, online gaming, and virtual reality within short indoor distances; The Wi-Fi 7 standard also enables QoS characteristics recognition from the traffic flows, facilitating the scheduling of low-latency traffic for applications with stringent timing requirements. Additionally, Wi-Fi 7 supports the aggregation of non-contiguous channels in both downlink and uplink directions, thereby not only expanding channel bandwidth, but also enhancing resilience against interference.

Although Wi-Fi APs are stationary devices, the ongoing support for Wi-Fi EasyMesh™ networking enhances indoor coverage, thereby increasing the flexibility of indoor Wi-Fi deployment.

B. 5G Holding an Undisputed Position in Terms of Technology and its Deployment Scenarios

Regardless of the generation of mobile communications are considered, mobility has always remained a unique technological characteristic that sets it apart from Wi-Fi.

The advent of Mobile 5G has opened broader opportunities for various applications across industries. For example, mobile 5G enhances the capability to connect over 100,000 devices simultaneously, making it a foundational communication technology for IoT deployments in large public spaces. Its low power consumption also makes it a suitable solution for basic communication needs in IoT applications. Mobile 5G's millisecond-level low latency is particularly valuable in domains such as the Internet of Vehicles and the Industrial Internet. Both individual and industrial applications leverage 5G's high-bandwidth mobility, making it a standout technology for wireless communication, especially in outdoor environments.

In summary, Wi-Fi 6 and Wi-Fi 7 continue to excel in indoor settings, while mobile 5G particularly shines in outdoor environments. Each technology plays to its strengths, ensuring a comprehensive approach to wireless communication across various scenarios.

Conversely, exploring collaborations between mobile 5G and Wi-Fi technologies in specific application scenarios is equally intriguing. Questions arise, such as whether Wi-Fi terminals can be regarded as trusted 5G devices, capable of effectively communicating with other 5G User Equipment (UE) within the 5G network via wired connections, or if the 5G network can extend its reach to encompass Wi-Fi access points with end-to-end service quality. These topics delve into the technical aspects of integrating Wi-Fi access networks with mobile 5G, which we will explore further in the following discussion.

3. The Convergence of Mobile 5G and Wi-Fi Access Networks

A fundamental application of convergence between Wi-Fi access networks and mobile networks revolves around how mobile devices can fulfill their intended functionalities using Wi-Fi networks. Figure 1 illustrates this concept [3]: mobile phones, initially connected to mobile networks for calls and internet access. However, they may switch to Wi-Fi connections in situations where the mobile network experiences issues such as service failures, congestion, limited signal coverage, or high tariffs. By connecting to the mobile network through a wired connection, the desired functions required by 5G network are still completed. As depicted in Figure 1, merging Wi-Fi access networks and mobile networks necessitates alterations to the 3GPP mobile network framework. A key challenge is to identify and support mobile devices connecting to the network via Wi-Fi.

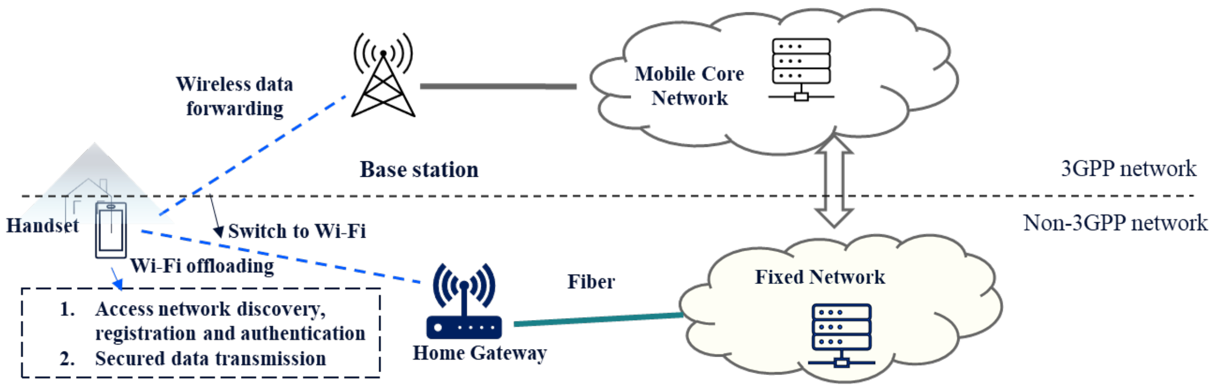

Figure 1- Convergence of Mobile and Wi-Fi Access Networks

During the 4G era, the integration of mobile network and Wi-Fi networks did not find significant favor with operators. Firstly, the integration of Wi-Fi access into the 4G system required changes within the 4G core network and radio access network nodes (eNBs). Traditional 4G network architecture featured intricate interfaces and gateways, complex connections between core network and radio access network nodes, and various solutions for integrating core and radio access networks to accommodate non-3GPP Wi-Fi networks. Based on the anchoring point of the Wi-Fi access, one can consider two classes of solutions: those involving Core Network integration and those involving RAN level integration [12]. Each of these classes can be further broken down into different modes or scenarios. Apparently, such a variety of solutions led to increased technical complexities.

Secondly, 4G network itself provided strong indoor coverage and did not rely on Wi-Fi to extend its reach. Moreover, as operators actively promoted high bandwidth services on their rapidly expanding 4G networks, the integration of 4G networks and Wi-Fi access did not add substantial value.

3.1. 5G R15's convergence framework for mobile network and Wi-Fi access

Entering 5G era, the core network is based on a service-based modular architecture and network function virtualization technology, which enables the separation of the control and user planes, as well as the core network from the access network. Compared to mobile 4G, the 5G system framework is more adaptable for integrating with Wi-Fi access networks.

Figure 2 illustrates the convergence depicted in the 3GPP R15 standard [4], centered on untrusted non-3GPP networks. The existing Wi-Fi access network, referred to as untrusted non-3GPP networks, becomes the avenue through which Wi-Fi terminals connects to the 3GPP-defined mobile core network.

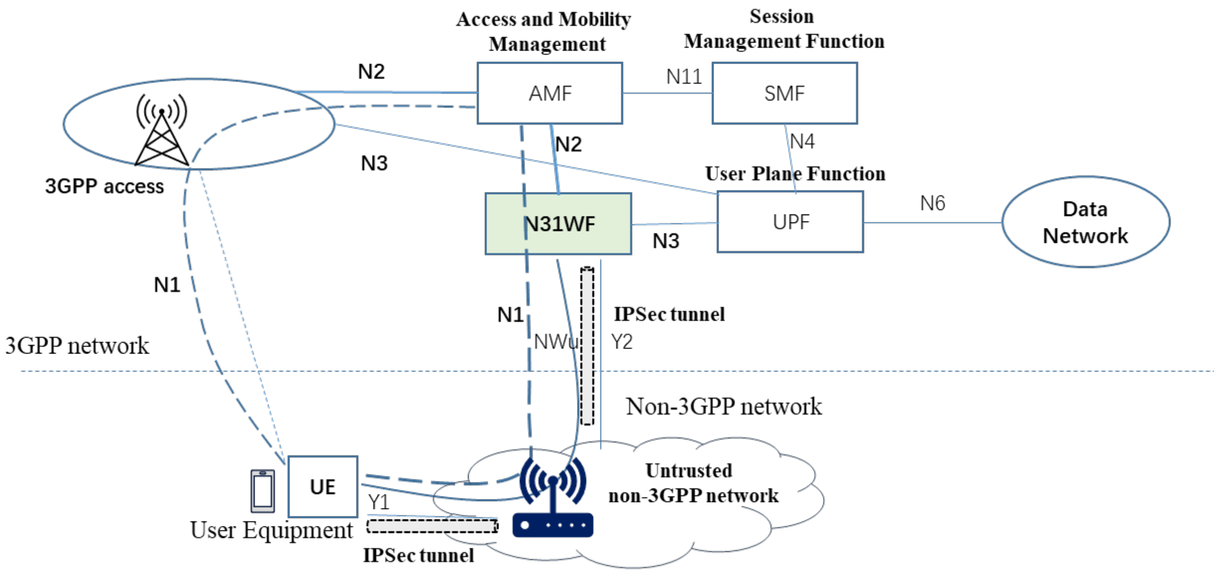

Figure 2 - Untrusted Non-3GPP Network Convergence Architecture in 5G R15 Version

From this converged architecture of 3GPP R15 [3],[4],[12], a new non-3GPP InterWorking Function unit (N3IWF) is introduced to the original 5G core network, which plays a crucial role in bridging untrusted non-3GPP access networks to the 5G core network by securing the connection and handling the necessary control plane and user plane functionalities.

The only element where the integration of Untrusted Wi-Fi access to the 5G core network differs from the basic principle of having the Wi-Fi as a regular access is the N3IWF selection [12]. N3IWF is responsible for establishing an N2 interface connection with the AMF (Access and Mobility Management Function) and routing data traffic via the N3 interface to the UPF (User Plane Function). It supports the establishment of Internet Protocol Security (IPSec) tunnels to ensure the security of data transmission and handles NAS (Non-Access Stratum) signaling over the N1 interface. The N3IWF also manages packet forwarding, encapsulation, and decapsulation between the UPF and UE, along with session management.

UE hardware need not be altered; only a software upgrade is required to support N3IWF network discovery and IPsec secure channel capabilities. Upon successful authentication and registration with the 5G core network via the Wi-Fi network, an IPsec tunnel is established between the UE and N3IWF.

The access to 5G core network from the untrusted networks involves the following procedures:

- UE uses the Access Network Discovery and Selection Policy (ANDSP) to discover and prioritize non-3GPP access networks
- UE initiates the procedure with N3IWF to finish registration, authentication, and authorization
- Then both UE and the network can start the Packet Data unit (PDU) session establishment

3.2. 5G R16's Convergence Framework for Mobile Networks and Wi-Fi access

The 3GPP R16 standard, ratified in July 2020, further advances the integration of 5G core networks with Wi-Fi access, building upon the foundation laid by R15. The network architecture specified in the R16 is illustrated in Figure 3[4],[10]. R16's key alteration involves extending the network architecture to accommodate two Wi-Fi access deployment models [3], which are detailed below:

Trusted Non-3GPP Wi-Fi Access: In this scenario, the Trusted Non-3GPP Gateway Function (TNGF) is introduced to supplant the N3IWF function from R15.

Wi-Fi Access in Residential Gateway (RG) or Cable Modem (CM): Another novel addition is the Fixed Access Gateway Function (FAGF), facilitating Wi-Fi access in situations involving Residential Gateway or Cable Modem configurations. Based on 5G capability, wireline access falls into two categories: the 5G Residential Gateway (5G-RG) and the Fixed Network Residential Gateway (FN-RG). The 5G-RG functions as a UE device, engaging in NAS signaling with the 5G core network. Conversely, the FN-RG refers to legacy gateways found in pre-existing wireline access networks, such as Digital Subscriber Line (DSL) routers, which do not possess native 5G capabilities. Both gateway types predominantly communicate with the core network via the Wireline Access Gateway Function (W-AGF) [14].

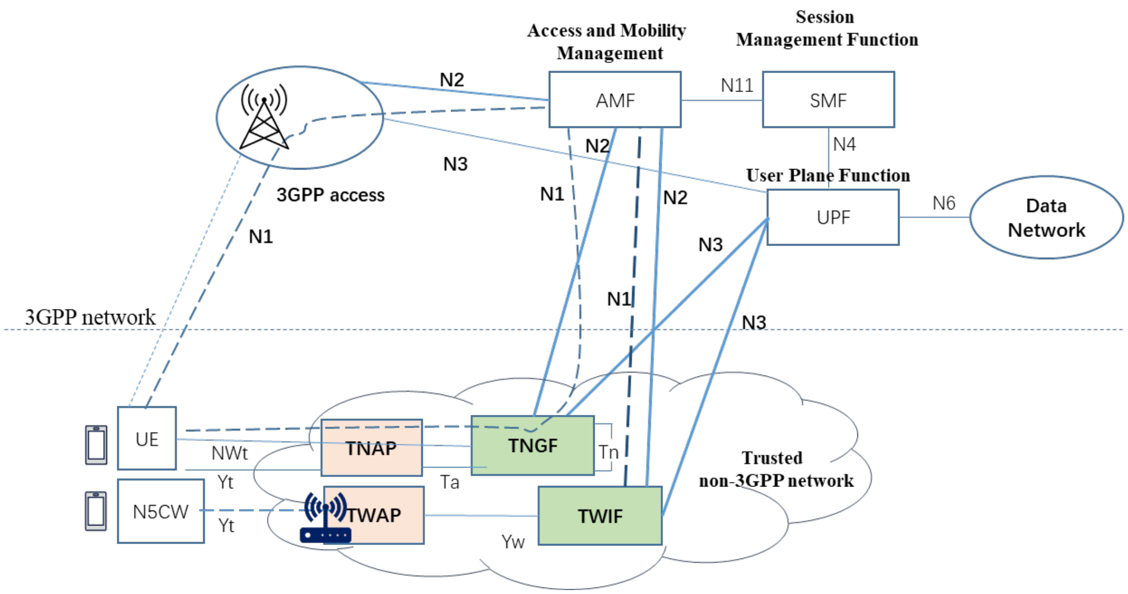

Figure 3 - Trusted Non-3GPP Network Convergence Architecture in 5G R16 Version

In Figure 3, the mobile phone establishes a connection with the trusted non-3GPP network through Wi-Fi, and it is the responsibility of TNGF to manage authentication requests, establish data channels, and meet the service needs of mobile devices accessing the network via Wi-Fi. This evolution in the R16 standard amplifies the seamless interaction between mobile networks and Wi-Fi access.

The R16 standard does not explicitly define trust levels for such trusted non-3GPP networks [14]. In a trusted network, operators have full control over Trusted Non-3GPP Access Points (TNAP) and radio link access. Therefore, the encryption is controlled by the operator or there is trust in the security offered by the non-3GPP access network. TNAP allows user equipment to access the trusted access network through non-3GPP wireless or wired access technologies.

Pure Wi-Fi end devices don't utilize mobile network defined signaling for registration. Such devices are referred to as "Non-5G-Capable over WLAN" (N5CW) devices. A N5CW devices can access 5G network via a trusted WLAN access network, which is a particular type of a Trusted Non-3GPP Access Network (TNAN) that supports WLAN access technology such as Wi-Fi. From Figure 3, a N5CW device connects to Trusted WLAN Access Point (TWAP) that interacts with Trusted WLAN Interworking Function (TWIF) that enables N5CW devices to access network.

From untrusted non-3GPP network in R15 to trusted non-3GPP in R16, and the support for Wi-Fi access via residential gateways or cable modems in R16, 3GPP has accomplished key network architecture definitions, functional division of modular units, and specifications of standard interfaces for Wi-Fi network integration within the 5G standards. The transition from Wi-Fi network access in 4G to Wi-Fi network convergence solutions in 5G is fundamentally an evolution from a structure designed based on 4G system nodes to a new design based on modular functions for both the core network and access network, enabling terminals to seamlessly connect to the 5G core network from any access point.

3.3. Wi-Fi Paving the Path for 5G Network Convergence

Wi-Fi technology plays a pivotal role in underpinning the convergence framework that propels mobile 5G forward. This fusion, whether stemming from R15's untrusted non-3GPP network or R16's trusted non-3GPP network, necessitates robust Wi-Fi terminal and AP support. Figure 4 showcases a spectrum of key technologies requirements [3],[4],[7], spanning from Wi-Fi terminal discovery, registration authentication within mobile networks to data security, quality-of-service assurance, seamless roaming between mobile networks and Wi-Fi access, end-to-end service support, and unified network management.

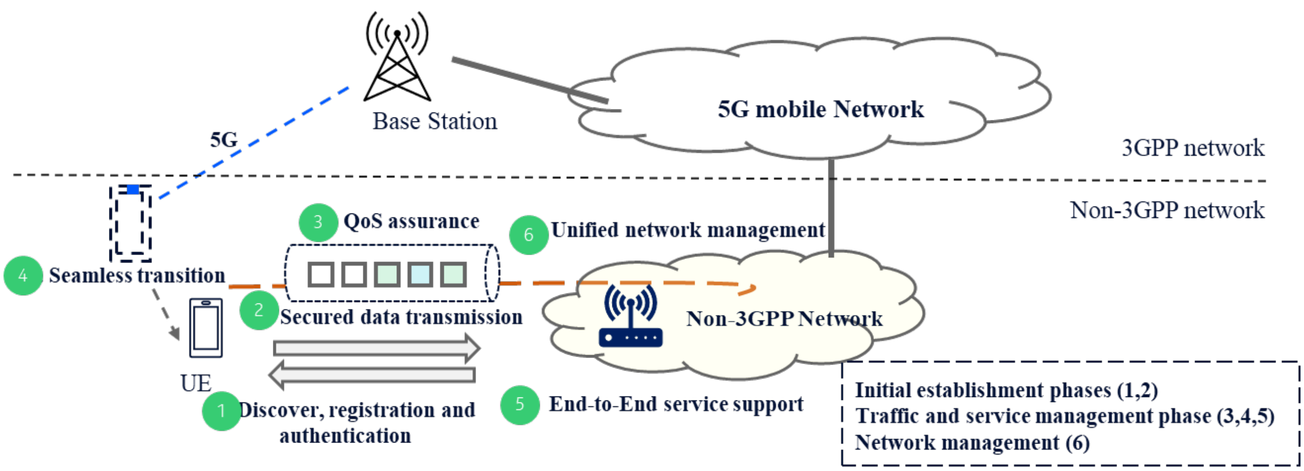

Figure 4 - Technologies enabling Wi-Fi's Role in mobile network convergence

Initial establishment phases for Wi-Fi devices

Besides the network architecture depicted in Figure 3 and 4, the primary distinction between untrusted non-3GPP network and trusted non-3GPP network is found in the initial procedures, specifically registration/ authorization and PDU session establishment.

As Table 2 illustrated, both untrusted and trusted networks utilize an Extended Extensible Authentication Protocol (EAP) based authentication for UE devices. However, the security between UE and untrusted access point in R15 non-3GPP network can be established with any key, including no security at all. In this context, untrusted networks do not perform link-layer authentication between UE and AP [14].

Conversely, for R16's trusted non-3GPP network access, a secure Layer 2 link is established between the UE and the Wi-Fi access point. Subsequently, an IPSec tunnel is set up over this link to ensure data forwarding security. Notably, the data forwarding protocol remains consistent with the untrusted non-3GPP network.

In untrusted network, N3IWF key is utilized between UE and N3IWF, while TNGF key is employed between UE and TNGF under trusted network. Since there is a trust relationship in trusted networks, it allows IPSec encryption to negotiate null security options avoiding double encryption. It is worth noting that EAP is supported in Wi-Fi standards, facilitating the access for UE or N5CW to 5G network.

Table 2 - Comparison of Establishment Procedure between Untrusted and Trusted Networks

Key Technology	Untrusted non-3GPP Network	Trusted non-3GPP Network
Discover, registration and authentication	EAP based authentication; Security between UE and untrusted network can be any security key	EAP based authentication; Security between UE and trusted network will be TNAP or WLAN key derived by EAP based authentication
Secured data transmission	Require IPSec Encryption	Allow IPSec encryption to negotiate null security options if applicable

Traffic and service management phase

5G and Wi-Fi network manage the radio resource independently. With the convergence of both networks, it is crucial that QoS and user experience remain consistent when a UE switches between the two networks.

The 5G air interface specification dictates a user access rate of 10 Gbps and ultra-low latency in milliseconds. Comparatively, traditional Wi-Fi 6, prevalent indoors, provides connection rates in the hundreds of megabits and latency in tens of milliseconds. However, refer to previous Table 1, Wi-Fi 7 technology significantly bolsters the technical foundation for a seamless 5G service transition, offering ultra-high throughput and ultra-low latency capabilities that fully meet 5G service requirements.

During the operation of services on a UE, the capability for a seamless transition between 5G and Wi-Fi networks is a critical feature in the evolution of 5G networks that support Wi-Fi access.

Such a roaming transition can be autonomously initiated by UE devices, which detect Wi-Fi signal quality, monitor wireless interference, assess Wi-Fi bandwidth, and evaluate service quality. 5G networks can also provide network policies to devices, aiding network selection based on user preferences and policies.

The 3GPP specification outlines the roaming process between 5G and Wi-Fi networks. Core network units share authentication status and user data channel information, enabling smooth roaming and uninterrupted services. This technology ensures uninterrupted connectivity as users move between networks.

In addition, in the new convergence network, expectations will rise for supporting end-to-end service, including consistent priority handling, policy management, security, seamless mobility, and transmission performance. Exploring slice management in the following sections will provide valuable insights into how the evolution of Wi-Fi 7 technology can further facilitate convergence developments, thereby enhancing user experience with end-to-end service.

Network Management between 5G network and non-3GPP network

Operators traditionally prefer to maintain control over every aspect of telecommunications network to ensure optimal performance and service quality. When 5G network converges with Wi-Fi access network, operators will seek technical solutions that increase their oversight into this heterogeneous network integration. Enhanced visibility allows for proactive management and troubleshooting, leading to improvements in Wi-Fi network stability and performance, which ultimately benefits end-users by reducing complaints about weak or inconsistent connections.

BBF has been pivotal in advancing home network management through its evolving specification. For instance, User Services Platform (USP) has been designed to assist broadband operators with one of major objectives in enhancing the management of home Wi-Fi networks. Mobile Network Operators (MNOs) may similarly desire a standard for managing Wi-Fi network within a convergence infrastructure. This presents a technology opportunity for Wi-Fi AP to collect and report the measurements from UE, encompassing both Wi-Fi radio strength and cellular signal connectivity. By aggregating this data, operators can gain a comprehensive view of the network's health and performance, enabling them to make informed decisions about resource allocation and network optimization.

3.4. 5G-RG configuration scenario defined in 5G R18 specification

Unlike non-3GPP Wi-Fi access network described in previous sections, which works to facilitate fixed network convergence with mobile network, 5G Residential Gateway (5G-RG) can serve as a direct bridge between the 3GPP network and the home network. In 3GPP R18, specifically in TS23.316, the architecture specifications are ratified, outlining how a 5G-RG can be configured to enable the connectivity between non-3GPP devices and the 3GPP access network.

A pivotal component of this setup is the Connectivity Group ID, defined on the 5G-RG and corresponding to a distinct physical or virtual port on the gateway. These ports may include separate physical ethernet interfaces, distinct Wi-Fi SSIDs or dedicated VLANs.

The Non-Authenticable Non-3GPP(NAUN3) devices connecting to a particular logical port are considered part of the same Connectivity Group ID, identified by its unique Each Connectivity Group ID is then associated with a separate PDU session, established by the 5G-RG. The overall architecture is depicted below in Figure 5.

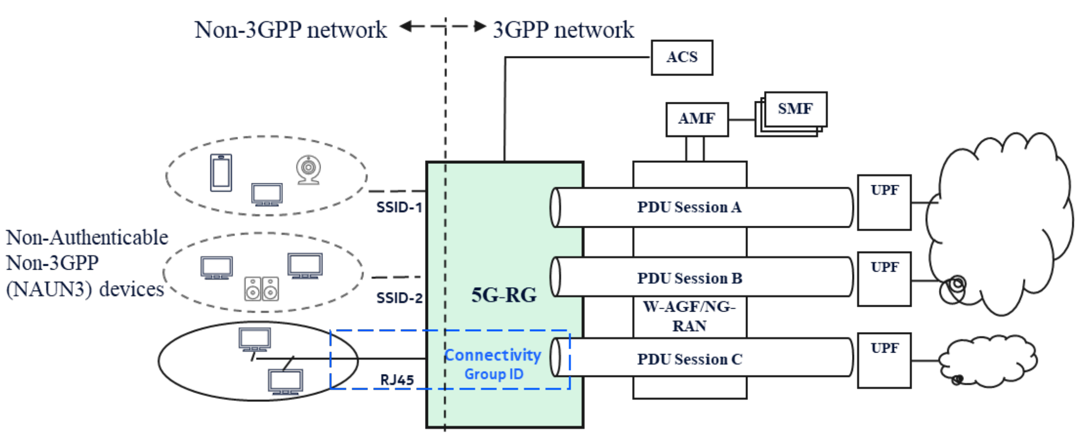

Figure 5 - Connectivity Group ID mapping with PDU session with 5G-RG case

The 5G-RG can be configured by BBF TR069, TR369 and TR181, including the setup of (virtual) port configurations such as VLANs and SSIDs. To facilitate traffic routing, User Equipment Route Selection Policy (URSP) rules can be provisioned to the 5G-RG. These rules dictate how the Connectivity Group ID should be mapped to the parameters of the PDU session, ensuring efficient carriage of traffic from corresponding devices. Table 3 lists the varied non-3GPP access information in R15 and R16 [14].

Table 3 – Non-3GPP Access in R15 and R16

Access Network	Terminal	Residential gateway	Traffic channel	Network function
Untrusted	Non-3GPP UE	Access Point	Unsecure	N3IWF
Trusted	Non-3GPP UE	TNAP	Secure	TNGF
Trusted	N5CW	TWAP	Secure	TWIF
Wireline	Non-3GPP UE	5G-RG	Secure	W-AGF
Wireline	Non-3GPP UE	FN-RG	Secure	W-AGF

4. 5G Network Slicing With Network Convergence

Within the realm of integrating 5G networks with Wi-Fi access, the capabilities and service standards of 5G can be extended to Wi-Fi networks. The following sections describes the standard specifications for 5G network slicing and the technical requirements for related Wi-Fi access.

The essence of 5G network slicing lies in its ability to virtually divide a physical network into several software-defined virtual networks, tailored to various applications or services. Each network slice has its own distinct topology, resource allocation, traffic management, and configurations. This enables 5G networks to cater to diverse user needs and application scenarios effectively.

Customized requirements arise across different industries and scenarios, such as priority, security, mobility, and transmission performance. 5G network slicing accommodates these differences by establishing multiple independent logical networks within the same physical network framework.

Figure 6 presents an illustration of two slices within the convergence of 5G and Wi-Fi networks. One is focused on internet data transmission, while the other emphasizes low-latency connections, suitable for tasks like video conferencing.

As can be seen in the figure, the 5G network slicing structure encompasses radio access networks, core networks, transmission networks, and non-3GPP networks. Local Wi-Fi network is one of typical non-3GPP networks. The radio access network slice utilizes wireless spectrum resources and hardware for diverse access functionalities. Through software-defined control functions in radio access network slicing, different slices share wireless spectrum resources efficiently.

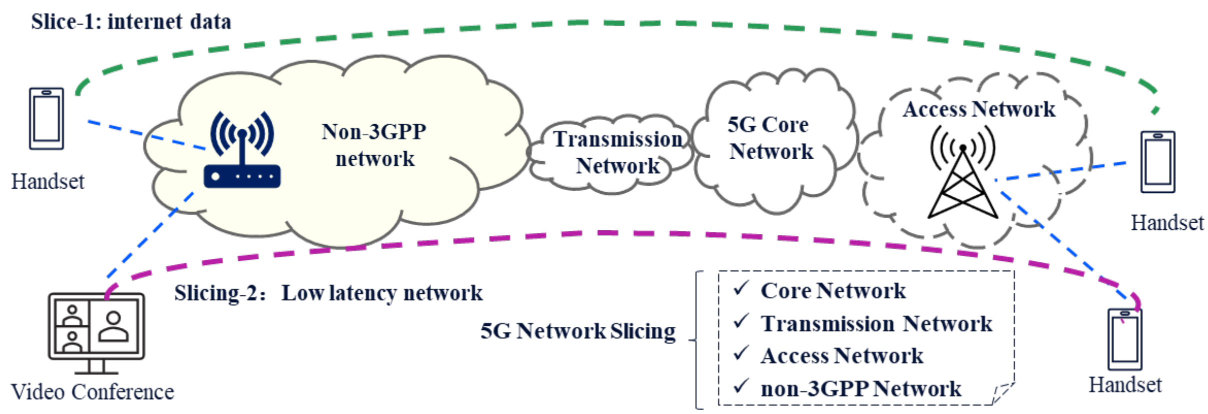

Figure 6 - Example of end-to-end 5G Network Slicing

In the context of 5G-WiFi network convergence, realizing the potential of 5G network slicing involves Wi-Fi networks supporting slicing in management and service operation. Current Wi-Fi technologies can align with certain 5G slicing specifications, while new Wi-Fi solutions might be necessary to meet other specifications.

4.1. Development of 5G network slicing specifications

The formulation of 5G network slicing standards has undergone extensive deliberations within 3GPP. Within 3GPP TR23.799[9], three distinct network slicing scenarios are introduced. These scenarios encompass various aspects, such as fully slicing all core network functions including user and control planes, slicing core network control planes while keeping user planes unsliced, and scenarios where only user plane slicing is relevant.

These scenarios emphasize the need for user plane slicing, especially in the context of Wi-Fi access network and mobile network integration. As Wi-Fi access network integration progresses, the focus on slicing requirements for Wi-Fi access networks becomes paramount.

TS22.261[8] defines the framework for slice requirements. This framework encompasses aspects like device association and management within network slices, service-to-slice associations, and device-to-multiple-slice associations. These aspects address diverse requisites such as priority, billing, policy management, security, mobility, and transmission performance.

3GPP TR28.801[11] defines the network slice management and operation framework. This framework encompasses key components such as Communication Service Management Function (CSMF), Network Slice Management Function (NSMF), Network Slice Instances (NSI), Network Slice Subnet Management Function (NSSMF), and Network Slicing Subnet Instances (NSSI). However, it's worth noting that the current framework doesn't yet encompass non-3GPP network slice management.

Figure 7 illustrates the service requirements for slice management, presenting a holistic view of TR28.801 network slice management integrated with Wi-Fi access [3]. This amalgamation results in a unified framework for managing 5G networks, including non-3GPP access. Wi-Fi terminals interface with segmented virtual networks via non-3GPP networks, facilitating the realization of specific service scenarios.

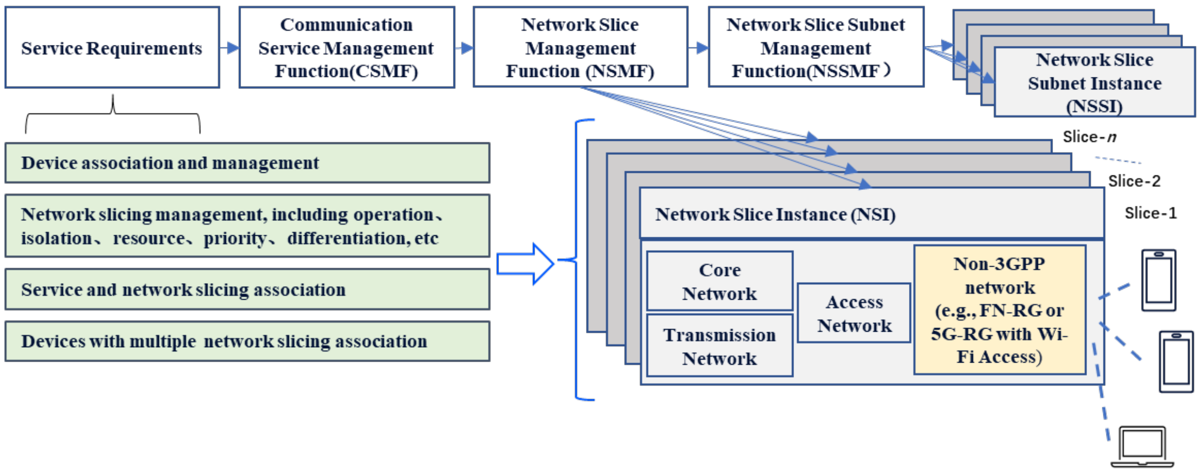

Figure 7 - Management Architecture for 3GPP Network Slices

In Figure 5 of section 3.4, when NAUN3 devices connects to 5G-RG via Wi-Fi access, the architecture, augmented with Connectivity Group ID concept, facilitates an extension of slicing services from the 5G access network all the way to the final Wi-Fi connection.

Generally, the Wi-Fi specification outlined by IEEE has progressed independently of 3GPP standard. Nonetheless, it is noteworthy that recent advancements in Wi-Fi technology, including more efficient and flexible spectrum utilization as well as enhanced connectivity capabilities, align to support a broader range of slicing requirements outlined in TS 22.261.

4.2. Wi-Fi Technology's Role in 5G Network Slicing

Before diving into slicing technology for 5G networks, let's explore a scenario that's quite familiar – supporting various user needs on a Wi-Fi access network. Think about it: on a single Wi-Fi network, we have regular users and heavy data users coexisting, and in enterprise Wi-Fi handles both employees and visitors. As it turns out, the Wi-Fi access network has already paved the way for some of the slicing concepts that 5G networks demand. This interplay is depicted in Table [3],[5].

Table 4 - Wi-Fi Technology Supports 5G Network Slices

Index	Category	The requirement entry for the slice	Current Wi-Fi technology
1	Device affinity and management in network slices	**Device association:** Network operators achieve the association between devices and network slices through configuration.	Wi-Fi APs use VLAN port bonding, and SSID to associate devices with slices.
2		**Device management:** This involves allocating devices to network slices, migrating devices from one network slice to another, or removing devices from network slices.	Hotspot 2.0 and enterprise Wi-Fi support device mobility across slices.
3	Management of network slices	**Slice management:** Operators can create, modify, and delete network slices; they can also define and update the services and capabilities of network slices.	VLANs and SSIDs create and maintain slices.

4		**Slice isolation:** In the same physical network, network slices are isolated from each other, ensuring that traffic or services do not impact one another. The creation, modification, and deletion of network slices do not affect other slices.	Logical isolation of slices' traffic via multiple VLANs and SSIDs.
5		**Slice resources:** Network operators can define minimum or maximum resource capacities for network slices and adjust these capacities as needed.	Manufacturer to develop resource allocation mechanisms, like utilizing SSIDs or air resources.
6		**Slice priority:** In cases of network resource conflicts, priorities between network slices can be defined to manage allocation.	Manufacturer to develop solution, such as using the proportion of air interface resources and traffic rate limiting to achieve priority differentiation.
7		**Slice differentiation:** Operators can configure different policy controls, functions, and performance levels for various network slices, enabling tailored service offerings	Manufacturer to develop varied policy controls and functions.
8	Service association	**Service association:** Through configuration, it is possible to establish a link between services and network slices.	Manufacturer to develop mechanisms to link services with slices.
9	Multi-slice support	**Multi-slice support:** Devices have the capability to simultaneously support multiple network slices under a single operator.	There is no traditional scheme

Looking at Wi-Fi from a technical lens, device association, management, slice control, and isolation is doable with existing Wi-Fi technology. However, resource allocation, priorities, differentiation, and business linkage demand custom solutions from manufacturers. Notably, standardization bodies like the Wi-Fi Alliance haven't addressed these aspects yet. The arrival of Wi-Fi 7 or Wi-Fi mesh starts to spark conversations about these topics which are illustrated in the following sections.

Device association and slice management [3]**:** Referring to Figure 8, in a Wi-Fi access network, VLAN 1 is associated with a specific SSID, and the terminals are associated with that slice. Similarly, another set of terminals is connected over same SSID and associated with VLAN 2. This configuration isolates the traffic between VLAN1 and VLAN 2, enabling creation of network slicing in the Wi-Fi access network [13].

In addition, Wi-Fi APs can work their magic using multiple SSIDs. Look at Figure 8 again, SSID 1 and SSID 3 each accompany the distinct Wi-Fi endpoints. SSID 1 serves regular Internet access, while SSID 3 rolls out high-speed, low-latency services. This setup answers network slicing's call for diverse devices and distinct business needs.

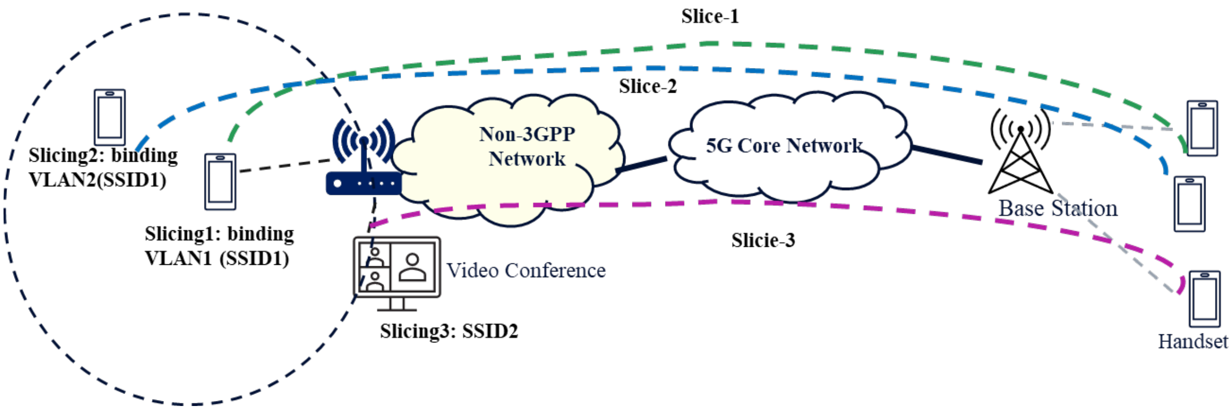

Figure 8 - Wi-Fi network slicing scheme for device management and service differentiation

4.3. Enabling Network Slicing with Wi-Fi 7 Technology

Wi-Fi access networks are stepping up to support the realm of 5G network slicing. The crux lies in how we utilize the physical Wi-Fi resource efficiently and logically carve them up to build distinct virtual networks. In Wi-Fi 6, the physical layer employed Orthogonal Frequency Division Multiple Access (OFDMA) technology [2] to split subcarriers into separate clusters, each functioning as an independent Resource Unit (RU). These RUs were assigned to various devices for data transmission, birthing a fresh spectrum-driven resource setup that catered to the needs of slices.

Wi-Fi 7 advances this capability further with its multi-link operation, introducing another way to segment network resources – this time based on physical links. The flexibility of managing multiple resource units further refines the management of spectrum resources, making it an even better fit for various application scenarios. Plus, Wi-Fi 7 steps up in the low-latency game, brings in a capability to identify specific service features. This introduces the technical avenue for aligning "service and network slicing."

In Figure 9, we delve into three pivotal technologies [1],[3] of Wi-Fi 7 that rally behind network slicing.

Multi-Link Operation (MLO) Technology: it mandates that that Wi-Fi 7 enables AP and device to establish multiple links over the 2.4 GHz, 5 GHz and 6 GHz bands. Consequently, an AP and a device can simultaneously send and receive data over separate frequency bands. MLO technology paves the way for flexible data transmission, which harnesses the capability to map diverse services from a single device to different links. As a result, network slicing can also be applied to individual links to cater to specific service requirements.

In Figure 9, a Wi-Fi 7 AP establishes both Link 1 and Link 2 with a Wi-Fi station. Each link is respectively associated with Slice 1 and Slice 2, thereby exemplifying the fulfillment of the "device association with multiple network slices" criterion, which was not supported by traditional Wi-Fi technology. In this scenario, low-latency services are allocated to Slice 1 via Link 1, whereas normal data traffic is allocated to Slice 2 through Link 2.

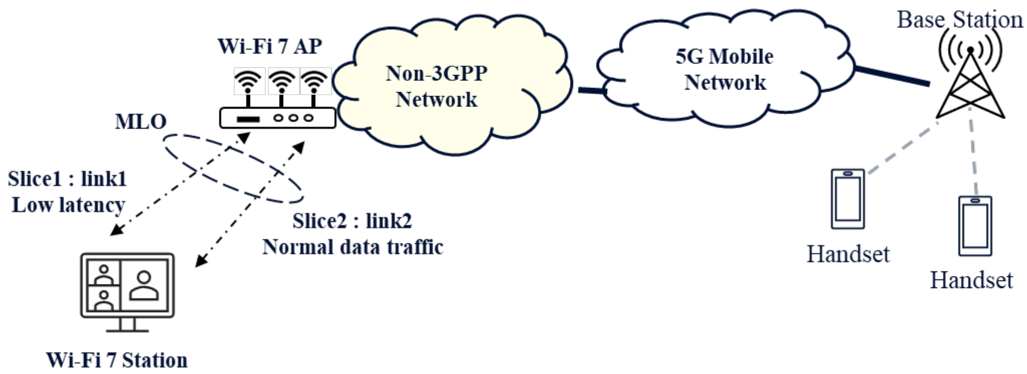

Figure 9 - Slicing supported by Wi-Fi 7 MLO technology

Multi-Resource Unit (MRU) Technology: Wi-Fi 7 enables the aggregation of non-contiguous Resource Units (RUs) into a single, unified Multi-RU (MRU). This enhancement grants greater flexibility in spectrum resource allocation by AP to individual devices using OFDMA. Consequently, various devices connected to the same AP can transmit data simultaneously, each utilizing a distinct MRU. This capability implies that different network slices can be assigned according to dedicated MRUs, tailored to the needs of each device.

In Figure 10, each slice is assigned an MRU. Slice 1 is assigned MRU 1(106+26 tone), while Slice 2 and Slice 3 are assigned RU 3 (52- tone) and RU 4 (52- tone) respectively. The size of the MRU is determined by the particular slice requirement. This feature is quite remarkable for enabling slicing, and its adaptable to different business needs.

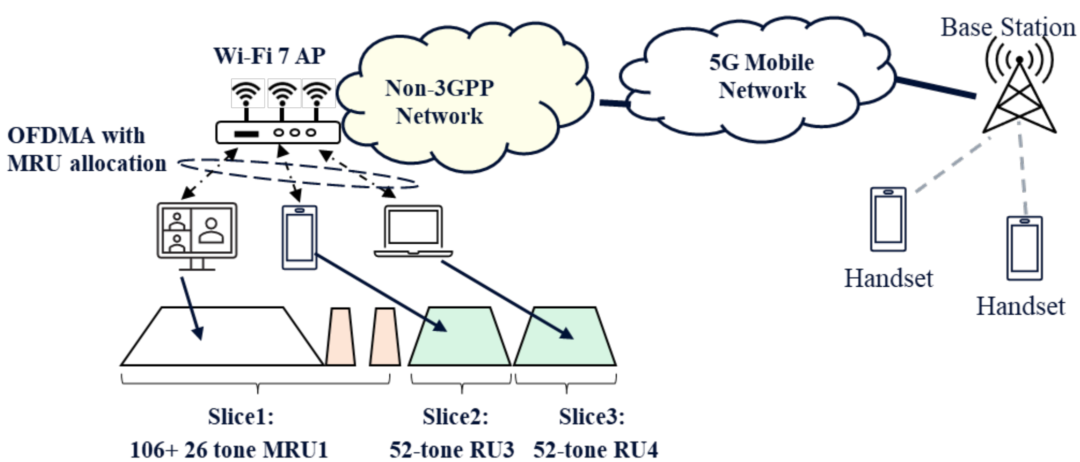

Figure 10 - Slicing supported by Wi-Fi 7 MRU technology

Low-Latency Service Feature Recognition: Wi-Fi 7 introduces more advanced **QoS characteristics** that allow for more precise traffic scheduling according to service characteristics. From the traffic flow, a Wi-Fi 7 AP can identify parameters such as maximum delay, service start and end time, service interval, and maximum packet error rate based for different services. Using this information, an AP can then schedule the traffic based on the specific latency requirements of each service. The capability of service characteristic recognition offers the technology feasibility to support "service and network slicing."

In Figure 11, the spotlight is on recognizing services in the Wi-Fi network that need quick responses, for example, services that can't tolerate delays, such as virtual reality and network video services. Once these are identified by an AP, they will be easily connected to their respective slices for smooth operation, while the slices can be configured via distinct links, SSID or VLAN in a Wi-Fi network.

Based on service characteristic, the traffic flow can be mapped to Wi-Fi access categories (AC) to prioritize data streams: Voice, Video, Best Effort, and Background. Each access category contends for the wireless medium using distinct channel access parameters. From slice perspective, this approach based on service priority will meet the “slice priority”.

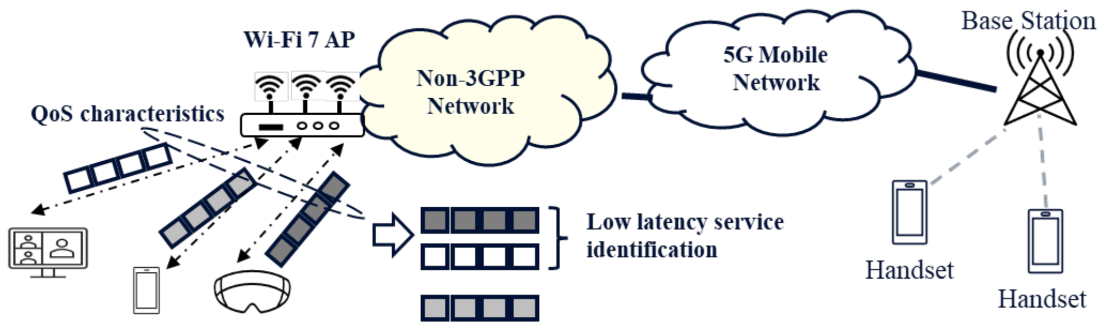

Figure 11 - Slicing supported by Wi-Fi 7 Low-latency Service Recognition

To effectively realize low latency services within a dedicated slice, Wi-Fi 7 introduces another new feature as one option for real implementation: Restricted Target Wake Time (R-TWT). Refer to Figure 12, with R-TWT, the AP segments the total service time into multiple service periods, reserving some exclusively for latency-sensitive services. These priority services are then scheduled more frequently for data transmission, which significantly reduces transmission delays. As depicted in Figure 12, the service parameters of Slice 1 can be aligned with the R-TWT settings, including the scheduling interval and service period, thereby effectively realizing the slicing requirements.

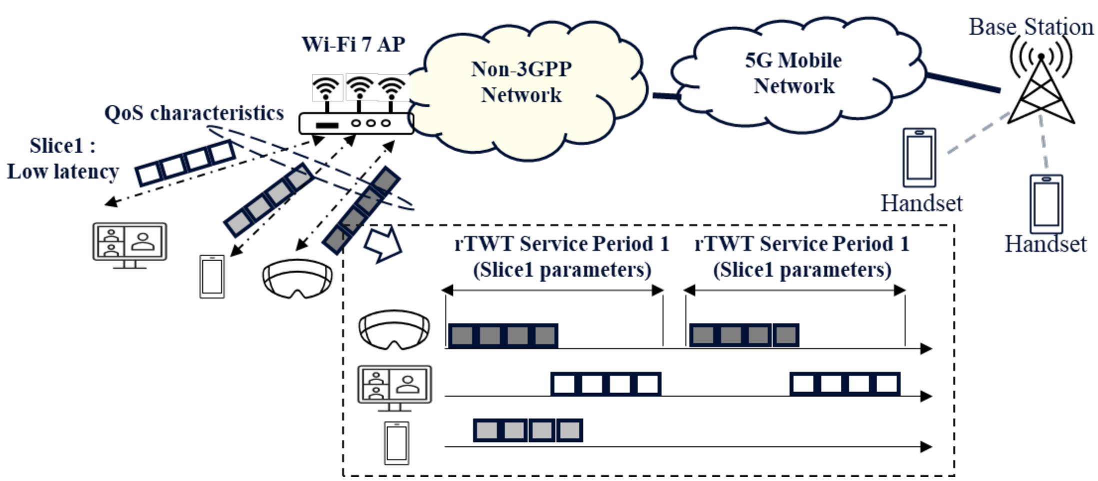

Figure 12 - Slicing Supported by Wi-Fi 7 R-TWT Technology

It's evident that Wi-Fi 7 advanced technology in segmenting and managing network resources positions the Wi-Fi 7 standard as a more suitable candidate for achieving comprehensive network slicing alongside 5G networks slicing. For details about slice management techniques specific to Wi-Fi 7, refer to Table 5 below.

Table 5 - Connection between Wi-Fi 7 Technology and Slicing Requirements

Index	Slice Requirement	Wi-Fi 6, or legacy Wi-Fi technology prior to Wi-Fi 6	Wi-Fi 7 technology
1	**Device association**	Same as Table 4: Wi-Fi APs use VLAN port bonding, and SSID to associate devices with slices	Wi-Fi 7 adds Multi-link or MRU management. This allocates sliced resources to different devices for seamless data transmission.
2	**Device management**	Same as Table 4: Hotspot 2.0 and enterprise Wi-Fi support device mobility across slices.	Wi-Fi 7 facilitates switching Wi-Fi devices between slices through link or MRU reassignment.
3	**Slice management**	Same as Table 4: VLANs and SSIDs create and maintain slices.	Wi-Fi 7 empowers the creation and maintenance of sliced links or MRU.
4	**Slice isolation**	Same as Table 4: Logical isolation of slices' traffic via multiple VLANs and SSIDs.	Wi-Fi 7 based distinct slices ensure effective isolation of traffic and services.
5	**Slice resources**	Not supported by legacy Wi-Fi technology; but Wi-Fi 6 can leverage RU as slice resources allocated to devices	Wi-Fi 7 supports Multi-links or MRU allocation to devices
6	**Slice priority**	Same as Table 4: Not supported; Manufacturer needs to develop solution, such as using the proportion of air interface resources and traffic rate limiting to achieve priority differentiation.	Supported: Based on Wi-Fi 7 QoS characteristics, low latency service can be recognized by AP so that they can be put into priority queue for transmission. This offers one option of slice priority achievements.
7	**Slice differentiation**	Not supported by legacy Wi-Fi technology; But Wi-Fi 6 can leverage RU as slice resource to adapt policy controls, functions, and performance to their product needs.	Partially supported: Wi-Fi 7 can utilize QoS characteristics with R-TWT technology, particularly low latency service, to realize part of policy controls, functions, and performance to their product needs.
8	**Service association**	Same as Table 4: Not supported; Manufacturer to develop mechanisms to link services with slices.	Partially supported; Wi-Fi 7 can utilize QoS characteristics to support low-latency service identification, and manufacturers can at least associate low-latency related services to slices.
9	**Multi-Slice support**	Same as Table 4: Not supported; There is no traditional scheme	Partially supported; Wi-Fi 7 MLO permits associating distinct services of the same devices with various links. This empowers devices to support multiple network slices concurrently.

4.4. Wi-Fi EasyMesh™ Technology plus Wi-Fi 7 for Network Slicing in the 5G Framework

Wi-Fi-based EasyMesh™ have gained prominence in the home network market. To achieve end-to-end network slicing within the 5G framework, the network slicing of Wi-Fi mesh plays a pivotal role. The crux of mesh network slicing lies in establishing data connections between Wi-Fi AP, specifically through the backhaul channel, to enable slicing[3],[5].

For multiple network slices to coexist on a shared backhaul channel, Wi-Fi technology can classify data streams smartly using VLANs or SSIDs. From Table 5, legacy Wi-Fi technology lacks a standardized approach for managing resources and adjusting priorities of diverse data streams. However, Wi-Fi 7 MLO technology can assign distinct links within the backhaul channel to different slices. Additionally, Wi-Fi 7's capability to identify QoS characteristics aligns well with associating low-latency slices and their corresponding service data streams.

In Figure 13, the backhaul linking Wi-Fi APs is ingeniously divided into two slices using the multi-link approach. Slice 1 caters to operator network management, handling control and management messages with high reliability albeit limited bandwidth. On the other hand, Slice 2 caters to high-bandwidth, low-latency needs, accommodating home video streaming or network gaming. Both slices can be created based on VLAN, SSID, or Wi-Fi 7 multi-links operations in the backhaul. Leveraging the recognition of service QoS characteristics from different links, this physical segment of distinct links under Wi-Fi 7 accommodates the slice resource management efficiently for services traffic flow in the backhaul.

This illustration in Figure 13 demonstrates how network slicing within the Wi-Fi mesh, guided by technologies like Wi-Fi 7 multi-link associations and low-latency recognition, can effectively meet the slicing requirement for 5G-WiFi convergence.

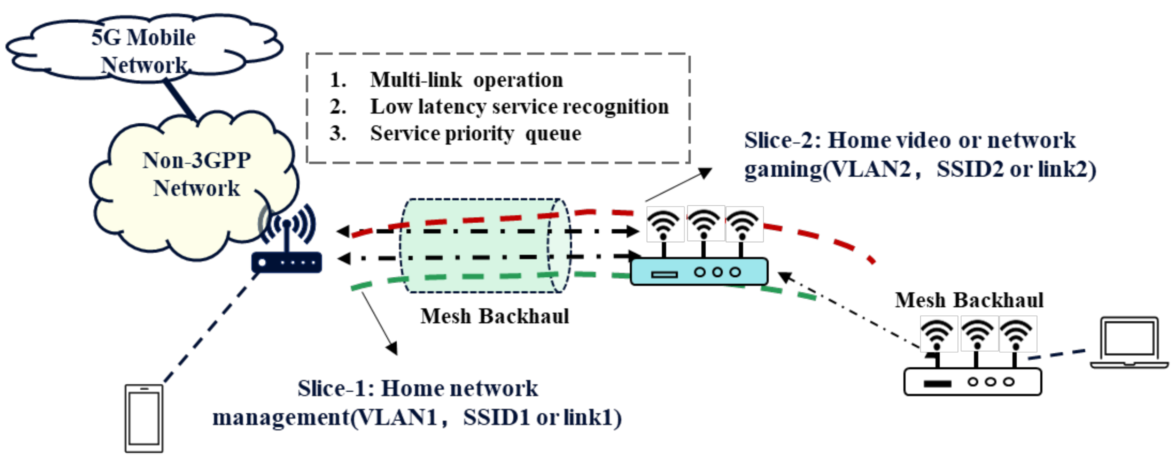

Figure 13 - Slice scheme for a Wi-Fi Mesh network

In Wi-Fi Alliance EasyMesh™ R6 (i.e., Multi-AP R6), Wi-Fi 7 technology has been fully integrated. This allows most of Wi-Fi 7 critical features to be centrally controlled and coordinated by Multi-AP controller, which is supported by all Multi-AP agents. With the latest EasyMesh™ technology, network slicing within a 5G framework can now not only reach the entrance of home network, such as Residential Gateway, PON ONTs, or cable modem, but also extend deep into to the internal home network.

The Multi-AP Controller can instruct the Multi-AP Agents to operate across channel bandwidths ranging from 20 MHz to 320 MHz depending on their capabilities. It may also employ static puncturing to exclude 20 MHz blocks, thereby minimizing interference and optimizing spectrum usage.

The Multi-AP Controller configures the EasyMesh™ network to perform either legacy association to a backhaul BSS or Wi-Fi 7 MLO association to a backhaul supporting multiple links. Additionally, it can configure the fronthauls to enable MLO operation, thereby serving Wi-Fi 7 terminals.

Furthermore, the Multi-AP Controller has the ability to steer Wi-Fi 7 terminals associated with MLO to any Access Point Multi-Link Device (AP MLD) for improved service delivery.

With the aid of EasyMesh™ technology, traffic between different slices is effectively separated in layer 2 on each of mesh node belonging to a specific slice. Slice resources, such as MLO links or Traffic Identifier (TID) mapped to links, can be allocated cross the entire mesh network. Traffic for each slice can be prioritized on every mesh node based on unified configuration of QoS management spanning the mesh network.

Referring to Table 6, aside from the first four items of slice requirements that are already accommodated by conventional Wi-Fi technology, Table 6 illustrates how the mesh network incorporated with Wi-Fi 7 can support the remaining critical slice requirements.

Table 6 – Slice Requirements Supported by Mesh Network Incorporated with Wi-Fi 7

Items in Table 4	Slice requirements	Technology in mesh network with Wi-Fi 7
Item-5	Slice resources	A shared backhaul, acting as a sliced resource, can be allocated among distinct VLANs, SSIDs, or across different links facilitated by MLO
Item-6	Slice priority	Wi-Fi 7 AP at the ends of the backhaul can leverage QoS characteristic technology to identify low-latency traffic and transmit it using a priority queue that is linked to the relevant slice
Item-7	Slice differentiation	By leveraging sliced resource allocation and prioritized data flow by Wi-Fi 7 technology within the mesh network, a home network can effectively implement portions of policy controls, functionalities, and performance requirement
Item-8	Service association	Low latency traffic flow, identified by Wi-Fi 7 AP, can be linked to slices throughout the entire mesh network by manufactory development
Item-9	Multi-Slice support	Wi-Fi 7 MLO technology enables the association of distinct services with different links in the backhaul, empowering devices at either end of the backhaul to simultaneously support multiple network slices

5. Application Scenarios for Wi-Fi and 5G Mobile Convergence

Bringing together the benefits of 5G mobile networks and Wi-Fi access networks finds relevance in various contexts such as smart cities, industrial Internet, hospitality, enterprise spaces, and smart homes. While certain key technologies remain to be thoroughly addressed for their seamless fusion, and standardization organizations continue to refine specifications, the inevitable union of these two technologies is bound to provide support across multiple scenarios.

5.1. Types of Scenarios for 5G and Wi-Fi Access Network Convergence

Drawing insights from earlier discussions on the pivotal technologies of 5G networks and Wi-Fi, as well as the essence of network slices, let's delve into the distinctive demands of 5G networks in Wi-Fi access convergence. Refer to Table 7 for a comprehensive view of these scenarios [3],[4], including performance indices and the corresponding focus on key technology design.

Table 7 - Scenarios of 5G and Wi-Fi Network Convergence

Scene Type	Scene Example	Convergence Network Requirements	Key Technologies in Convergence Network	Network Slicing Requirements
High traffic and high connection in public areas	Public Wi-Fi Hotspots (e.g. airports, stadium)	**Access density:** 128 terminals/wireless access points **User rate:** 10Mbps **Low latency:** Supports 10ms-50ms latency	Terminal registration and authentication, data forwarding security, roaming between mobile networks and Wi-Fi, etc.	Slicing differentiating the traffic and service requirements
Specialized fields with real-time requirements	Industrial areas, telemedicine, IoT, etc	**Access density:** 32~64 terminals/wireless access points **User rate:** 200Mbps-600Mbps **Low latency:** Supports 1-10ms latency	Terminal registration and authentication, data forwarding security, QoS assurance, unified network management, etc.	Slicing differentiating low-latency services and common services
Ordinary living or office environments	Homes, communities, hotel apartments, office environments, etc.	**Access density**: 32~64 terminals/wireless access points **User rate:** 200Mbps-1Gbps **Medium and high latency:** Supports 10-50ms latency	Terminal registration and authentication, QoS assurance, roaming between mobile networks and Wi-Fi, etc	Slicing differentiating high-bandwidth, low-latency services, and common services

5.2. Examples of 5G and Wi-Fi access network convergence

Figure 14 showcases a 5G private network and a converged Wi-Fi network in an enterprise campus or community setting [3],[12]. The 5G private network, aligned with the 3GPP 5G standard, can be established in collaboration with the public 5G network or independently. Either way, the convergence of 5G networks and Wi-Fi access networks is similar. It is worth noting that mobile operators typically do not control or manage enterprise Wi-Fi networks. This means that their convergence solutions often do not have comprehensive support for wireless measurements, performance metrics, policy configurations, and system manageability across both 5G and Wi-Fi networks. This presents a business opportunity for operators to collaborate with enterprises to enhance network management and improve user experience.

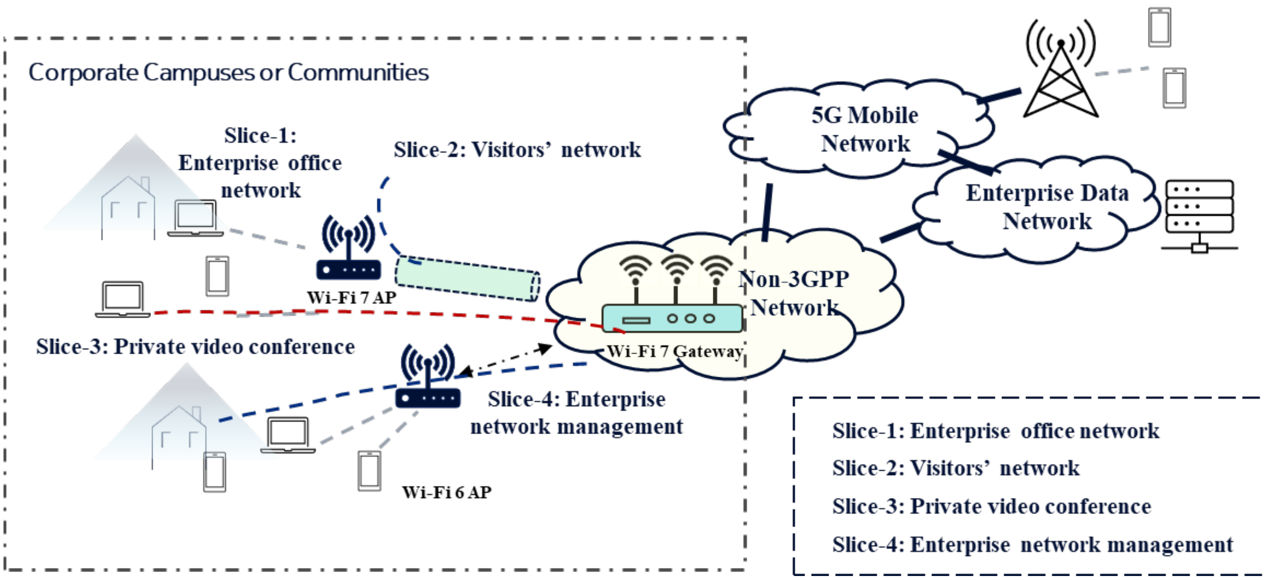

Figure 14 - 5G and Wi-Fi convergence in corporate campuses or communities

In the example of Figure 14, a Wi-Fi 7 gateway collaborates with diverse standard Wi-Fi APs to create a wireless LAN. This LAN integrates with the 5G mobile core network through trusted or untrusted non-3GPP networks, thereby establishing a comprehensive enterprise private network in tandem with the enterprise data network.

This converged network, beyond meeting the stipulated requirements of access density, user rates, and latency, also showcases four end-to-end network slicing instances, encompassing Wi-Fi 7 and Wi-Fi Mesh. These slices cater to various needs, including employee office network access, temporary external visitor internet access, high-bandwidth, low-latency enterprise-specific video conferencing, and enterprise network management.

Table 8 lists examples of service requirements in an enterprise network [3]. These include various performance levels and priorities for data transmission to accommodate the needs of office routines, visitors' requests, and network management.

Table 8 – Service Requirements in an Enterprise Network

Service Requirements	Email handling	Document Sharing	Information Browsing	Conference Meetings	Instant Messaging	Network Management
Wi-Fi latency	50ms	100ms	100ms	10ms	10ms	50ms

Bandwidth requirements per person	2 Mbps	2 Mbps	1 Mbps	3 Mbps	0.256 Mbps	1 Mbps
Bandwidth requirement for 500 people	1000 Mbps	1000 Mbps	500 Mbps	1500 Mbps	128 Mbps	500 Mbps
Data Priority	Medium	Low	Low	High	High	High

The convergence is required to support dual-radio devices and Wi-Fi-only devices, regardless of whether they have 3GPP identity or SIM credentials. This enables seamless access to enterprise services or 5G services via either Wi-Fi or 5G access networks ([12]). Devices equipped with both radios can roam effortlessly between the Wi-Fi network and a 5G RAN, maintaining continuous access to the enterprise network services.

To address the varied scenarios and capitalize on business opportunities within the same physical enterprise network, integrating both mobile and Wi-Fi access, the allocation of resources through network slicing with appropriate configurations and QoS parameters is a crucial strategy. This ensures efficient and effective management of service requirements.

Each network slice occupies distinct resources, configurations, and connections within the enterprise private network. These diverse slicing requirements and types are outlined in detail in Table 9 [5].

Table 9 - Wi-Fi Network Slicing Examples in Application Scenarios

quantity	The slice type	Requirements for slicing
Slice-1	Office network access for enterprise employees	**Functions**: Support terminal registration and authentication, QoS guarantee of data services, end-to-end data encryption, reserved enterprise bandwidth. **Performance**: High slicing priority, low transmission delay, and high access reliability.
Slice-2	Temporary access by external visitors	**Function**: Support terminal registration and authentication, basic internet access, no billing, adequate bandwidth. **Performance**: Low slicing priority, average transmission delay, and average reliability.
Slice-3	High-bandwidth, low-latency enterprise-specific video conferencing	**Functions**: Support terminal registration and authentication, QoS guarantee for data services, end-to-end data encryption, reserved enterprise bandwidth. **Performance**: High slicing priority, low transmission delay, and high access reliability.
Slice-4	Enterprise network management	**Functions**: Support terminal registration and authentication , QoS guarantee of data services, end-to-end data encryption, reserved enterprise bandwidth.

		Performance: High slicing priority, low transmission delay, and high access reliability.

In the converged 5G and Wi-Fi access network, the hardware specifications and functions [3] of Wi-Fi 7 Gateway and AP are mentioned in Table 10. Remember, not all Wi-Fi 7 devices have every standard feature, and they might not achieve the best possible performance defined in the Wi-Fi 7 standard. So, when talking about product specs, focus on the unique technologies that match the specific scenario.

Table 10 - Hardware Specifications and F1unction Requirements for Wi-Fi 7 Gateways and APs

AP Selection	Wi-Fi 7 Gateway and AP Specifications
Hardware Requirements	Wi-Fi 7 gateway as BE19000, Wi-Fi 7 AP as BE19000 or BE7200
	Wi-Fi 7 tri-band or dual-band
	Multi-antenna 4x4 2.4GHz, 4x4 5GHz, 4x4 6GHz, or 4x4 2.4GHz, 4x4 5GHz
	1x10G or 2.5G Ethernet interface, 1 or more 1G interface interfaces
Functional Requirements	4K-QAM modulation and 320 MHz bandwidth
	EasyMesh™ networking based on Wi-Fi 7
	Wi-Fi 7 multi-link operation technology and load balancing technology
	Wi-Fi 7s Multi-resource unit technology
	802.1x authentication methods, WPA3 security level
	QoS characteristics including low-latency service recognition
	QoS prioritizing of traffic flow including video or voice
	128 users' services simultaneously

6. Conclusion

The evolution of network convergence for Wi-Fi access since 3GPP R15 has been more comprehensive compared to the 4G era. However, in the coming years, practical deployment experience will be crucial for these solutions to achieve widespread commercialization. Wi-Fi's new technology, which supports network slicing, still requires refinement by operators and equipment manufacturers. The technical challenges and opportunities regarding end-to-end service quality, data security, and network management in converged networks will remain critical topics for ongoing discussion and consideration in the years ahead [3],[4].

Support for Network Slicing by Wi-Fi 7 Technology and EasyMesh™

Though Wi-Fi 7 supports most slicing requirements and can recognize low-latency services through traffic characteristics, its primary focus is not on service identification and management. As a result, the differentiation of slices and service association requires further enhancement. In practical applications, multi-link support for managing multiple slices is influenced by environmental factors that affect link states, necessitating ongoing technical refinement to improve multi-slice management effectiveness.

EasyMesh™ networking is a critical component for implementing slice management in home networks. However, EasyMesh™ standard is still evolving and must be integrated with the latest Wi-Fi technologies, such as Wi-Fi 7's R-TWT feature, which aims to enable low-latency services within whole-home mesh networks. These capabilities will require either enhancements to the standard by the Wi-Fi Alliance or proprietary technical solutions from manufacturers.

End-to-End Service Quality of Converged Networks

In 5G, network slicing necessitates end-to-end service quality management. However, integrating Wi-Fi access network operations into slice management lacks detailed specifications, as 3GPP and IEEE standards have evolved independently with different focuses. Air interface resource priority and delay control in Wi-Fi remain separate from 5G's deployment. Achieving unified management of service quality parameters across 5G and Wi-Fi poses a significant technical challenge for effective network convergence, requiring further evolution of standards by both 3GPP and IEEE. On a positive note, Wi-Fi 7's multi-link operations, multi-resource management, and low-latency service features present opportunities to support and advance network slicing technology.

Data Security for 5G Terminals Switching to Wi-Fi

Wi-Fi networks operate within unlicensed frequency bands, allowing diverse terminals to connect to the same gateway. When 5G terminals switch to standard Wi-Fi nodes for data forwarding, end-to-end network security must be reassessed. Currently, there is little research or discussion on ensuring end-to-end security in such scenarios, making this a critical topic for standard bodies in the ongoing development of converged networks.

Converged Network Operations and Maintenance

The operation and management of Wi-Fi based broadband access gateways generally focus on network interface parameters and lack sufficient management methods for the Wi-Fi access performance and service quality parameters. As 5G and Wi-Fi access networks converge, unified network operation and enhanced maintenance and supervision of 5G terminal access to Wi-Fi networks will become essential. This convergence presents new technological opportunities for operators and equipment vendors as they plan for future network deployments.

Abbreviations

5G-RG	5G Residential Gateway
AP	access point
AP MLD	Access Point Multi-Link Device
BSS	Basic Service Set
CSMF	Communication Service Management Function
EAP-TLS	Extensible Authentication Protocol-Transport Layer Security
EAP-TTLS	Extensible Authentication Protocol-Tunneled Transport Layer Security
eMBB	Enhanced Mobile Broadband
FAGF	Fixed Access Gateway Function
IoT	Internet of Things
IPsec	Internet Protocol Security
MLO	Multi-Link Operation
mMTC	massive Machine Type of Communication
MRU	Multi-Resource Unit
N3IWF	non-3GPP InterWorking Function unit
N5CW	Non-5G-Capable over WLAN" devices
NAUN3	Non-Authenticable Non-3GPP
NSI	Network Slice Instances
NSMF	Network Slice Management Function
NSSI	Network Slicing Subnet Instances
NSSMF	Network Slice Subnet Management Function
OFDMA	Orthogonal Frequency Division Multiple Access
PDU	Packet Data Unit
QoS	Quality of Service
RAN	Radio Access Network
RG	Residential Gateway
R-TWT	Restricted Target Wake Time
RU	Resource Unit
SCTE	Society of Cable Telecommunications Engineers
SSID	Service Set Identifier
TNAN	Trusted Non-3GPP Access Network
TNGF	Trusted Non-3GPP Gateway Function
TWAP	Trusted WLAN Access Point
TWIF	Trusted WLAN Interworking Function
UE	User Equipment
uRLLC	Ultra Reliable Low Latency Communications
URSP	User Equipment Route Selection Policy
W-AGF	Wireline Access Gateway Function

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