RAN Convergence Paper
by WBA and NGMN Alliance

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1 EXECUTIVE SUMMARY

As both Wi-Fi and 5G evolve, we will have new business opportunities and face challenges to enable key use cases through the convergence of these two technologies. This paper follows the short NGMN/WBA RAN Convergence publication in 2018, further expanding on the topic. It analyzes the key RAN Convergence use cases covering Enterprises, Factories of the Future (Industry 4.0/IIoT), Public Hotspots, Connected Cities, Residential, and derives some of the convergence related requirements that are needed to make these use cases achievable.

In order to examine the best future solutions for convergence of Wi-Fi and 5G, this paper examines the current Wi-Fi interworking solutions available for 4G systems using either trusted or untrusted Wi-Fi access, through either Core Network based or RAN level integration. It also reviews the 3GPP 5G system approach to Wi-Fi access, which includes integration of untrusted Wi-Fi access in Release 15 and the new opportunities in Release 16 for trusted Wi-Fi access as well as wireline and cable modem access such as from a residential gateway. Release 16 specified Access Traffic Steering, Switching and Splitting (ATSSS) functionality is analyzed which enables data session over one or more concurrent accesses.

Some of the key challenges for Wi-Fi and 5G convergence have been examined covering tight integration between 5G New Radio (NR) and Wi-Fi, cross network visibility, manageability and policy control, enablement of Wi-Fi only devices, traffic routing across NR and Wi-Fi, network slicing synergies and ease of adoption on the device. A tight integration between NR and Wi-Fi could provide improved session continuity and better resource utilization between the two access networks. New business opportunities between 5G and Wi-Fi networks can be supported by defining interfaces enabling network visibility, manageability and policy control between 5G core and Wi-Fi networks. For example, such an interface could enable the business model for cellular operators to provide Wi-Fi network management solutions for Small and Medium Businesses. It could also enable enterprise Wi-Fi networks to request access to operator-provided 5G services or 5G network slices, for certain enterprise users and/or applications as a means to provide differentiated services. Wi-Fi operators could also provide better user experience through a standardized solution providing improved visibility and transition management in the operation of overlapping cellular and Wi-Fi networks.

Finally, taking into account the convergence use case requirements and the current set of 5G and Wi-Fi convergence solutions available, being developed and planned, this paper concludes that further action is needed to address key gaps identified. In particular some recommendations are made in areas requiring further study by the industry and standards bodies (3GPP, IEEE and/or WFA). An interesting challenge is to enable Wi-Fi only devices, with or without 3GPP identity and SIM credentials on the device, to access 5G services on PLMN networks, to expand 5G experiences to existing as well as future Wi-Fi only devices.

It is only with enhanced RAN Convergence between 5G and Wi-Fi that the users of 5G networks will truly enjoy the real life benefits that the vision of 5G networks promise to deliver.

2 INTRODUCTION

Wi-Fi and cellular ecosystems have traditionally followed their own development paths. The latest versions of each technology have greatly enhanced capability compared with early offerings, with the Wi-Fi 6 and 3GPP's 5G technology, encompassing New Radio (NR) and LTE as well as the 5G Core from Release 15 onwards. As society increasingly depends on fast reliable data connectivity, an important capability for the industry would be the convergence between 3GPP's 5G and Wi-Fi, so that

the unique and complementary capabilities of both access networks can be leveraged to provide seamless network services.

It has been over 16 years since GSMA first published their WLAN Roaming Guidelines (1)   describing how Wi-Fi could be integrated into conventional cellular architectures. In the intervening period, the industry has seen a plethora of architectures defined for converging carrier Wi-Fi and cellular networks. However, with the majority of Wi-Fi usage being in so called "non-carrier environments" typified by enterprise, residential and public use cases, there is a need to revisit the subject of integrating Wi-Fi in these environments with the 5G network.

As we move into the 5G era with new emerging 5G usages including eMBB such as AR/VR, massive machine type communication (mMTC) and URLLC use cases such as autonomous driving and industrial automation, connectivity becomes even more important, together with delivery of a harmonised set of 5G services (i.e. services from the 5G core), whether the access includes Wi-Fi, cellular or both. New set of 5G use cases and verticals may require combined resources from both 3GPP and Wi-Fi networks in providing cost effective solutions that meet diverse sets of requirements on throughput, latency, connection density, coverage, availability and reliability. Bearing in mind that a significant amount of data traffic from smartphones uses a Wi-Fi access, convergence between 5G and Wi-Fi will lead to a better user experience and create new business opportunities for both Wi-Fi and cellular providers.

While Wi-Fi and Cellular are two technologies with very different origins, their individual evolution is leading to adoption of certain common features bringing the two technologies closer than before. Wi-Fi 6 adoption of Orthogonal Frequency Division Multiple Access (OFDMA) enables the unlicensed technology to benefit from scheduled up-link transmissions that can be used to address one of the significant limitations of earlier Wi-Fi generations of poor performance in heavily congested environments. The 5G Core Network definition of access neutral functionality together with a common EAP authentication framework similar to Wi-Fi, enables seamless integration of Wi-Fi and cellular into a common system that can deliver a converged set of services over Wi-Fi and Cellular-based access networks.

This joint paper from NGMN and WBA describes some of the key opportunities, use cases, requirements and key challenges associated with being able to offer 5G experiences and services over both 5G NR and Wi-Fi based access networks, and highlights gap items which need to be addressed by the industry to fully realize the opportunities presented by the convergence between 5G and Wi-Fi.

3   WI-FI AND 5G CONVERGENCE USE CASES

There are some specific convergence related use cases that have been identified, where Wi-Fi can be used to extend and enhance the 5G experience by offering a complement to cellular access, and 5G can be used to extend Wi-Fi experience as well

3.1   Enterprise Wi-Fi Convergence with 5G

3.1.1   Description

Enterprise deployments today predominantly use Wi-Fi technology to provide wireless connectivity to end users, including permanent employees, contractors and visitors. The enterprise may place some restrictions on the use of their Wi-Fi network, for example as captured in the Table 3-1.

Requirement Area	Description	Example
Policy Control	The enterprise requires specific policies to be enforced when access is made using their Wi-Fi infrastructure	Permanent employees are limited to accessing only business relevant content/services
		The individual and/or total aggregate throughput associated with visitor access is capped to ensure normal enterprise business services are not degraded
		Enterprise InfoSec prohibits employees from using services perceived as threatening enterprise security
Terms of Service	Prior to using the service, visitors are required to accept the enterprises' terms of service	A browser redirect/captive portal is used to ensure that visitors can view and accept enterprise terms of service/acceptable use policies
		The enterprise requires guest access to be associated with a permanent employee so that any failure to adhere to terms of service can be followed up.
Regulatory	The enterprise IT organization is responsible for ensuring regulatory compliance	The enterprise IT organization requires a permanent identity associated with guest usage.
		The enterprise IT organization keeps logs of usage against permanent identity.

Table 3-1 Enterprise Wi-Fi Requirements

While the Table 3-1 describes requirements for an enterprise deployed Wi-Fi service, a mobile service provider will typically have already ensured that their subscribers have accepted the service provider's terms of service and/or acceptable use policies. Furthermore, the mobile service provider is already able to ensure regulatory compliance. As a consequence, there is benefit to the enterprise in having these aspects managed by a mobile service provider, e.g., after agreeing that the existing service provider' terms of service address enterprise requirements and how any transgressions are handled.

This leaves the policy control capability as being a key capability required by any 5G converged Wi-Fi system targeted at the enterprise use case. Given the breadth of policies that may be defined by the enterprise for its employees, this may motivate the mobile service provider to deploy an "enterprise slice", enabling the enterprise InfoSec fine grain control over the policy control and integration with other IT services.

Also, some of the indoor enterprise venues may experience gaps in cellular coverage, which adversely impacts user satisfaction and also results in cellular operators losing contact with their subscribers in

these venues. Services of the 5G core should be accessible from both 5G and Wi-Fi access networks to enable access-neutral service availability. Moreover, the latest Wi-Fi standard, Wi-Fi 6, includes substantial improvements, such as higher efficiency and capacity in high density deployments, better spectral usage, scheduling and other mechanisms, enabling better user experience and positioning Wi-Fi as a strong access technology for delivering 5G experiences. In addition, the enterprise workforce is becoming more mobile, creating the need for seamless location-independent connectivity and secure IT management for mobile enterprise devices over cellular networks.

Today, the cellular operations do not generally have control over and/or access to enterprise Wi-Fi, despite the market interest in balancing traffic load across cellular and Wi-Fi and ubiquitous service availability. In particular, current solutions may not include full support for policy settings, wireless access measurements/metrics and network manageability between Wi-Fi and 5G networks. There is potential to use a common management system to manage 5G networks and enterprise Wi-Fi deployments across one or more sites, creating a multi-site enterprise environment. There is also potential to share access measurements to enable improved 5G experiences through co-ordination of Wi-Fi and cellular accesses. The convergence of 5G and enterprise Wi-Fi can bring great benefits to cellular operators and enterprise Wi-Fi providers, giving access to 5G and enterprise services from both Wi-Fi and 5G access networks.

To enable a diverse set of deployment scenarios and business opportunities for enterprise Wi-Fi providers and cellular operators, convergence of Wi-Fi and 5G is needed. The convergence solution should provide support for dual radio devices and Wi-Fi only devices, with and without 3GPP identity or SIM credentials on the device, enabling access to the enterprise services and/or 5G services from either Wi-Fi or 5G access networks.

3.1.2 Scenarios

Some possible deployment scenarios for enterprise Wi-Fi and 5G convergence are captured here to highlight convergence requirements resulting from this use case.

Scenario 1:
Figure 3-1 shows an example deployment for convergence of enterprise Wi-Fi network with the 5G core network. Enterprise Wi-Fi network has a number of devices such as laptops, workstations, tablets, security camera and mobile phones connected over Wi-Fi access to a Wi-Fi AP. The enterprise Wi-Fi access network (including Wi-Fi AP and Wireless LAN Controller (WLC)) is integrated with a 5G Core network deployed by a mobile network operator. Devices connected over enterprise Wi-Fi access can access services provided by 5G core network. Some of these devices accessing 5G core network services over enterprise Wi-Fi may only support Wi-Fi radio and may not include 3GPP identity or SIM credentials on the device. Some other devices support both Wi-Fi and 5G radios and can have dual connectivity over both Wi-Fi and NR access links within the enterprise environment.

In this scenario an enterprise device supporting both radios may roam seamlessly between the enterprise Wi-Fi network and a 5G RAN managed by the mobile operator while it continues to access the enterprise network services. The mobile network operator could have certain level of visibility of and input to policy settings and network manageability of enterprise Wi-Fi access network. The enterprise IT organization could have the ability to request 5G core network resources for enterprise users.
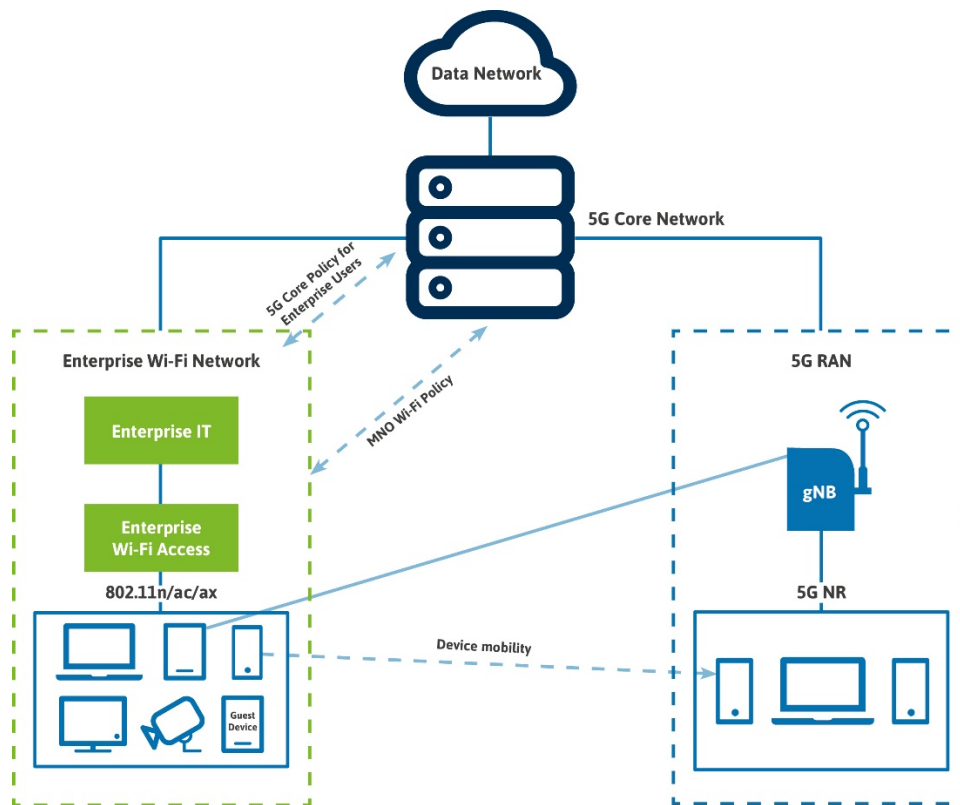
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Figure 3-1 Example Deployment for Convergence of Enterprise Wi-Fi with 5G

Scenario 2:

In this scenario the mobile network operator deploys and owns both the enterprise Wi-Fi access as well as the cellular 5G RAN and 5G Core. The 5G Core network sets network management related policies on the enterprise Wi-Fi network, as in Scenario 1. Devices operating in the enterprise Wi-Fi deployment can be Wi-Fi only devices (with or without 3GPP identity or SIM credentials on the device) or devices with both Wi-Fi and cellular radios. Devices supporting both radios can seamlessly roam between enterprise Wi-Fi and 5G radio access networks operated by the mobile network operator, and access relevant enterprise/5G network services using either one of the access networks.

Scenario 3:

The enterprise owning the enterprise Wi-Fi network also deploys and owns a private 5G Core network to provide 5G core functionality to devices in the enterprise network. The enterprise sets network management related policies for the operation of enterprise Wi-Fi and 5G network. These policies may be defined in the 5G Core, as in other scenarios. Devices operating in the enterprise Wi-Fi deployment can be Wi-Fi only devices (with or without 3GPP identity or SIM credentials on the device) or can support both Wi-Fi and cellular radios. Devices supporting both radios can seamlessly roam to a PLMN (Public Lane Mobile Network) operator deployed 5G access network, per business agreements. Such dual radio devices can access enterprise network services while connected over PLMN operator 5G RAN.

3.1.3   Requirements

The following requirements are derived to address convergence aspects between 5G and Wi-Fi for the Enterprise Wi-Fi use case:

- Enable devices to access 5G Core services over Wi-Fi access.
- Enable devices to access Enterprise network services over 5G NR access.
- Enable simultaneous connectivity over 5G NR and Wi-Fi access for dual radio devices.
- Enable policy rules to be defined that control the traffic allocation to a particular access network, including being able to steer, switch and split traffic across NR and Wi-Fi accesses.
- Enable device mobility between Wi-Fi access and NR access networks.
- Enable mobile network operator to have visibility of and input to policy settings and network manageability of the Enterprise Wi-Fi network.
- Enable Enterprise Wi-Fi to have the ability to request 5G core network resources for enterprise users.
- Enable Wi-Fi only devices, with and without 3GPP identity or SIM credentials on the device, to connect to the 5G Core.

3.2 Factories of the Future

3.2.1 Description

The manufacturing industry is on the verge of a major technological transformation, being referred to as the "Fourth Industrial Revolution". This revolution is touted to enable faster, more flexible, more versatile and efficient production processes in the manufacturing industry leading to new business models, increased productivity and fostering industrial growth.

McKinsey defines Industry 4.0 as the next phase in the digitization of the manufacturing sector, driven by four disruptions (2):
- The astonishing rise in data volumes, computational power, and connectivity, especially new low-power wide-area networks;
- The emergence of analytics and business-intelligence capabilities;
- New forms of human-machine interaction such as touch interfaces and augmented-reality systems; and
- Improvements in transferring digital instructions to the physical world, such as advanced robotics and 3-D printing.

Factory automation, which underpins the Factories of the Future, is at the heart of this manufacturing revolution enabling automated control, monitoring, data collection, analysis and optimization of processes and workflows within the factory. Communications is highlighted as one of the key inhibitors from taking Industry 4.0 pilots to roll-out (3).

As reported in (4), industrial factory automation with communications for closed-loop control applications such as motion control of robots, machine tools, packaging and printing machines, has stringent end-to-end latency constraints of 1ms as well as high service availability (99.9999%) requirement. Also, the discrete automation, encompassing all types of factory production that result in discrete products, have use cases which require support of a large number of sensor devices per plant, high communication service availability (99.99%), efficient power consumption for battery powered sensor devices with targeted battery lifetime of several years and end-to-end latency which can vary between 10ms and 1s. The typical connection densities for discrete automation use cases is noted as 10^5 devices per km^2.

The mission-critical operations in factories imposes strict requirements on the underlying wireless communication network in terms of ultra low latency, high reliability, high service availability and deterministic nature of the system. With recent analysis indicating that unplanned production downtime

can cost an average of $250,000/hour (5), the reliability and associated service level guarantees of any wireless system used to support production critical functions in the Factory of the Future will be a key.

Given the varied requirements around latency, reliability and power efficiency for devices in the factory, including sensors, actuators, controllers, machines, robots, HMIs (Human Machine Interfaces), IT systems and user devices, the underlying wireless connectivity across these devices can be better realized by using multiple heterogeneous communication technologies including 5G and Wi-Fi. In the Factories of the Future, devices connected over 5G and/or Wi-Fi access technologies should be able to seamlessly interact with each other and access the 5G core network independent of the access being used (5G NR or Wi-Fi).

Wireless connectivity for devices in the factory can be guided by cost efficiency, spectrum considerations (licensed/interference protected vs unlicensed/limited interference protection), coverage requirements and ease of deployment, among other factors. For example some devices performing mission-critical closed-loop control operations may include 5G Ultra Reliable Low Latency Communication (URLLC) functionality while other devices performing non mission-critical operations may not have URLLC capability or even NR radio and use only Wi-Fi to support their services. The latest Wi-Fi standard Wi-Fi 6 can meet many IMT-2020 requirements targeted for various 5G verticals. We believe that the Factories of the Future will make use of both licensed 5G connectivity and unlicensed Wi-Fi connectivity to enable cost effective solutions that leverage resources from both 5G NR and Wi-Fi access to meet diverse sets of requirements for Industrial IoT.

In the Factories of the Future, convergence between 5G NR and Wi-Fi can provide improved reliability and latency for CP and UP data with capabilities such as simultaneous connectivity, traffic routing and mutual anchoring across 5G NR and Wi-Fi access. The convergence solution should include support for Wi-Fi only devices with and without 3GPP identity or SIM credentials on the device.

3.2.2 Scenario

Figure 3-2 shows an example deployment scenario where a factory floor has adopted wireless connectivity for factory devices performing automation, control, HMI, monitoring, maintenance, warehousing and other functions. Certain set of devices performing non mission-critical functions could be Wi-Fi only devices (with or without 3GPP identity or SIM credentials on the device) connected over Wi-Fi access network to a Wi-Fi AP. Such devices could include sensors proving environmental updates, HMI devices, security cameras and end user devices used by the factory workers. Other devices performing mission-critical functions are connected over 5G NR access network to a gNB (5G base-station). Such devices could include sensors, actuators, controllers, robots and other machines. Some devices could have dual connection on both Wi-Fi and 5G NR access networks. Some devices supporting dual radios could be connected to only one of the access networks (either 5G NR or Wi-Fi) based on services being consumed. The Wi-Fi access network (including Wi-Fi AP and Wireless LAN Controller (WLC)) is integrated with a common 5G Core Network, which can be accessed by factory devices connected over either 5G NR or Wi-Fi access. Factory devices can seamlessly communicate with each other and with the industrial network functions implemented in the cloud per network policy settings, independent of which access network is being used for the wireless connectivity.
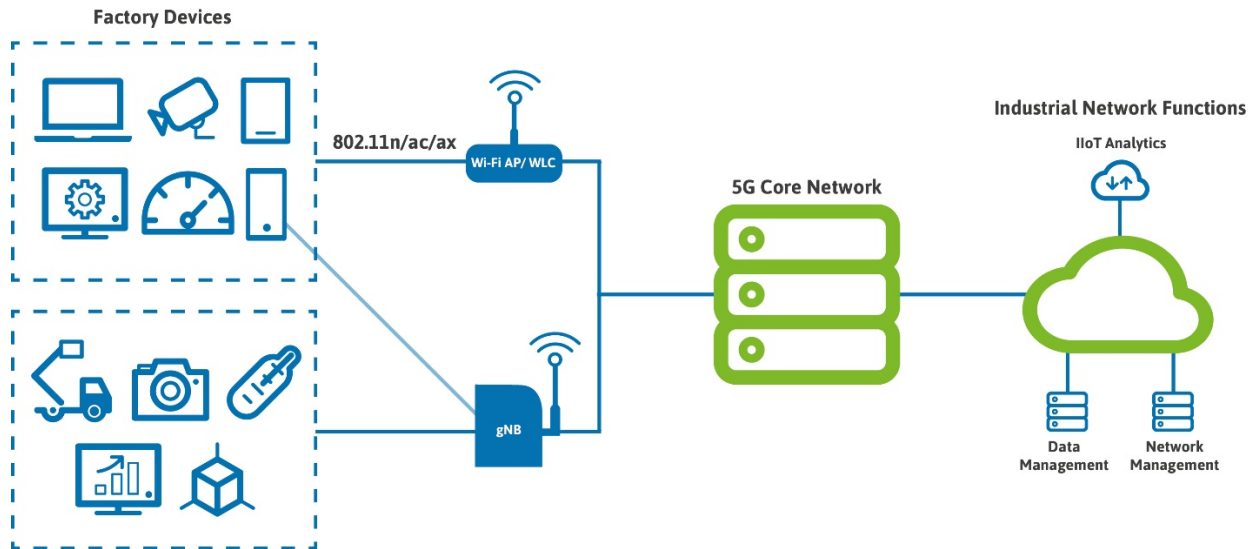
Figure 3-2. Example deployment of the Factory of the Future using 5G and Wi-Fi

3.2.3   Requirements

Following additional requirements are derived to address convergence aspects between 5G and Wi-Fi for the Factories of the Future use case:

Enable factory devices to seamlessly interact with each other irrespective of access connectivity (5G NR or Wi-Fi).
Enable highly reliable production-critical communications with associated service level guarantees between factory devices.
Provide improved reliability and latency for CP and UP data by leveraging resources from both 5G NR and Wi-Fi access networks.

3.3   Public Hotspot and Connected City

3.3.1   Description

It is well understood that data consumption is spatially non-uniform. As reported in (6), measures in population density can provide an initial indication of such spatial non-uniformities. Figure 3-3 illustrates the variation in UK's population density, with the maximum density over 160 times higher than the national mean and even 12 times higher than the most densely populated 80% area. Also, as per (6), the spatial non-uniformity in data consumption increases dramatically when mobility is taken into account.
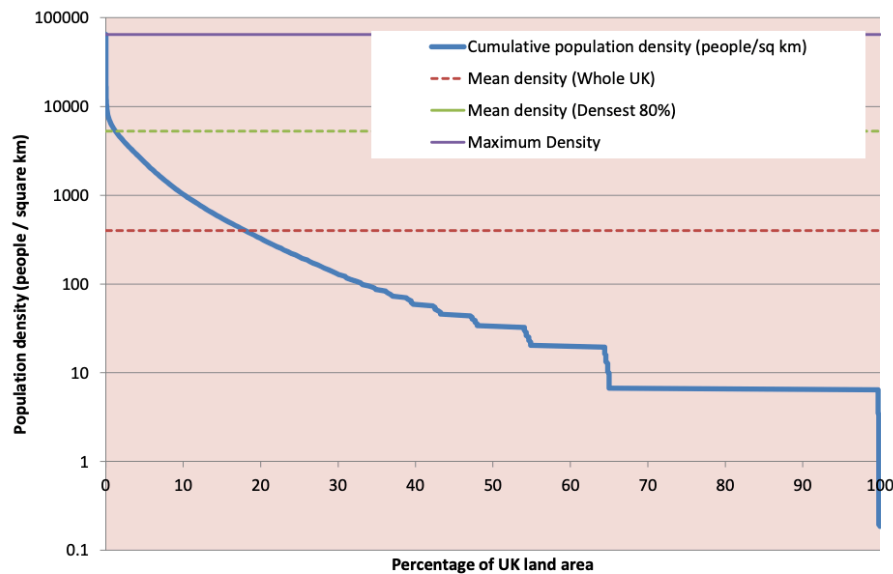
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Figure 3-3: UK population density (6),

This concentration of data consumption into so called "hotspots" motivates cellular operators to deploy localized Wi-Fi hotspot capacity to serve the non-uniform peaks in traffic demand, with the ITU-R Report M.2320 (7) highlighting Ultra-Dense Network (UDN) as one of the technology trends to meet the high throughput requirements of 5G. More and more businesses are deploying Wi-Fi hotspots to provide internet connectivity to their consumers at their venues. Public Wi-Fi deployments are becoming more common as cities look to provide their own connectivity capability. Operators and cities are deploying Passpoint enabled Wi-Fi hotspots, to provide seamless authentication with cellular credentials. Key considerations in such deployments include:

- Enabling simple, secure and seamless connectivity experience for the users
- Enabling device mobility and seamless service continuity between public Wi-Fi hotspots and 5G networks.
- Enabling policy settings between 5G networks and public Wi-Fi hotspots to realize different business scenarios and opportunities e.g. reserving bandwidth on public Wi-Fi for cellular customers/services.
- Catering for different business models where public Wi-Fi may or may not be deployed by cellular operators.
- Enabling devices to authenticate and connect to 5G services over public Wi-Fi, without 3GPP identity or SIM credentials on the device.

Also with the peaks in data consumption being likely linked to increased population densities, there is an additional motivation for other entities responsible for providing community services to deploy localized capabilities to meet the Connected City objectives, e.g., bridging the digital divide and increasing the operational efficiencies of community service delivery, while providing amenities to both residents and visitors.

As reported in (8), no single wireless access technology can be used to meet all the requirements of a connected city, driving the deployment of multiple radio technologies, that include 5G, as well as Wi-Fi and other Low Power WAN and LAN technologies. Convergence and interworking between 5G and public Wi-Fi can provide the backbone of a secure scalable wide area communication platform, an important element to realize the key Connected City objectives mentioned above.

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3.3.2 Scenarios

Some possible deployment scenarios for Public Wi-Fi Hotspot and Connected City delivering converged Wi-Fi and 5G capabilities are captured here to highlight convergence requirements resulting from this use case.

Scenario 1:

Barcelona City Council's "Barcelona Wi-Fi" free Internet service is available in over 600 locations across the city, including various municipal amenities and various public places (9). In 2017, the service was expanded to cover over 1,000 vehicles in the regular bus fleet and 16 major metro stations (10). Initially, the service required all first time users to register manually with their email address and place of residence. The City, in collaboration with the Barcelona-El Prat Airport and the City's Barcelona Sants train station, later enabled automatic Passpoint authentication with cellular credentials across their public Wi-Fi networks, to facilitate easy adoption of their service. The City also wanted to address enterprise specific requirements as part of this seamless Passpoint based authentication for their public Wi-Fi. The City of Barcelona worked with other vendors to enable enterprise users to use their enterprise credentials to deliver the same easy, seamless and secure access to the Connected City's Wi-Fi deployments (11).

Such public hotspot deployments can be evolved to provide convergence with 5G network as shown by a possible example deployment for convergence of Barcelona Public Wi-Fi network with the 5G system in Figure 3-4. The Public Wi-Fi Core is integrated with a 5G Core Network operated by a mobile network operator. Devices can connect to 5G services/applications while connected over public Wi-Fi access, dual radio devices can be simultaneously connected over both Public Wi-Fi and 5G access and users can experience seamless authentication and service continuity while moving between the public Wi-Fi and 5G access networks.
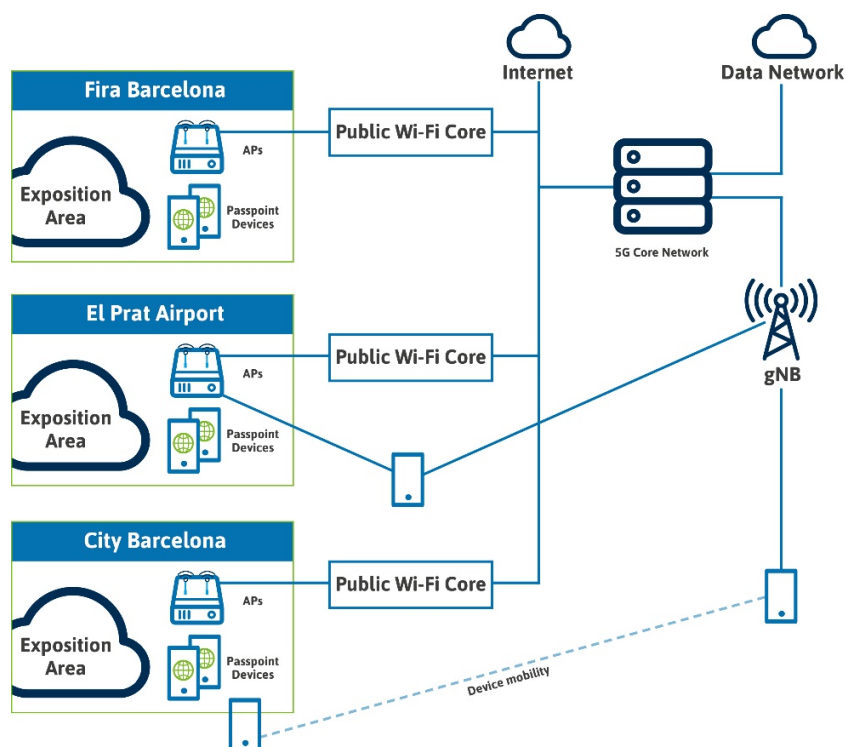

Figure 3-4 Example Deployment for Convergence of Public Wi-Fi with 5G

Scenario 2:
This Connected City scenario is based on WBA Connected City paper (8). Figure 3-5 shows an example Connected City profile from (12).

Wi-Fi hotspot is used to provide public internet access and simultaneously transport video surveillance camera footage over a short distance of several hundred meters outdoors without requiring a cabled backhaul.

5G deployment in millimeter wave with frequencies in the tens of GHz is employed by the city where very high throughput backhaul is required over short hops, e.g., for aggregating feeds of data and providing a high speed wireless backbone where multi-gigabit fiber is unavailable.

Low Power WAN Technologies, offering much better coverage, better building penetration and requiring considerably less power, are used to support sensor networks that collect, aggregate and forward periodic data or send notification when triggered by certain events.

5G technologies operated in licensed spectrum are used to support mission critical applications, such as traffic control and power grid communications, where interference cannot be tolerated and quality of service requirements are more stringent.

In such Connected City deployment, dual radio devices can be simultaneously connected over 5G NR access and public Wi-Fi access and devices can move between public Wi-Fi hotspot and 5G access networks with seamless service continuity. Through policy definitions/settings the operational efficiencies for delivering community services can be improved by leveraging resources from both 5G access and public Wi-Fi.

Figure 3-5: Connected City Profile (12)

3.3.3 Requirements

Following additional requirements are derived to address convergence aspects between 5G and Wi-Fi for the Public Hotspot and Connected City use case:

- Enable device mobility and service continuity between public Wi-Fi access and 5G NR access networks.
- Enable policy settings between 5G networks and public Wi-Fi hotspots to realize different business scenarios.
- Enable devices to authenticate and connect to 5G services over public Wi-Fi without 3GPP identity or SIM credentials on the device.
- Improve the operational efficiencies for delivering community services by using a combination of public Wi-Fi and 5G NR accesses.

3.4 In Home Wi-Fi Convergence with 5G

3.4.1 Description

Today, the vast majority of homes use Wi-Fi to deliver LAN connectivity to both mobile and fixed devices. This is typically accompanied by a range of wired LAN technologies such as Ethernet, powerline (HomePlug Powerline Alliance) and/or structured Coax (Multi-media over Coax Alliance). The home LAN is increasingly being complemented with a community Wi-Fi service which is delivered by the same equipment and provides an internet access service to other customers of the broadband service provider. In parallel with this, home owners in areas of poor cellular coverage can install femto-cells from a cellular network provider to deliver cellular coverage within the home. So, a home can easily have multiple wireless networks with different services available on each:
- Private Wi-Fi providing access to LAN devices, broadband ISP services and internet access
- Community Wi-Fi providing internet access
- Femto-cell and/or macro-cell providing cellular network services and internet access

This selection of networks leaves open the possibility of devices being connected to the wrong network and either receiving a worse connectivity experience than is achievable or being unable to access the desired services. 5G and Wi-Fi convergence offers the opportunity to ensure that customers are always best connected and that the radio resources are managed appropriately. Key considerations include:
- Management of Wi-Fi and backhaul resources used by the community Wi-Fi service, to ensure that the private home network is not unduly affected by the community Wi-Fi traffic.
- Ensuring that applications on end user devices can connect to the required services and devices, either by selection of the correct radio access(es) or by appropriate policy routing through any given radio access.
- Prioritization of latency critical traffic (voice, real-time video, gaming), including who sets the policy.
- Catering for different business models where the public Wi-Fi, broadband and 5G operators may or may not be the same entity.

3.4.2 Scenario

Figure 3-6 shows a possible mix of traffic within the home with Wi-Fi, femto-cell and macro-cell 5G deployments:
1. Smartphone accessing the internet via private Wi-Fi (including optional Wi-Fi extender), the fixed access network and the fixed core.
2. TV accessing home media server via private Wi-Fi.

3. (a) Smartphone accessing 5G services over a bonded connection of macro cellular and private Wi-Fi.
   (b) Smartphone accessing 5G services over a bonded connection of macro cellular and community Wi-Fi (not shown).
4. Tablet accessing 5G services via private Wi-Fi, the fixed access network and the fixed core and 5G core.
5. Smartphone accessing the internet via community Wi-Fi, the fixed access network, the fixed broadband core and the public (community) Wi-Fi core.
6. (a) Smartphone accessing 5G services via home 5G femto-cell, residential gateway, fixed core and 5G core.
   (b) Smartphone accessing home media server via home 5G femto-cell, residential gateway and private Wi-Fi.
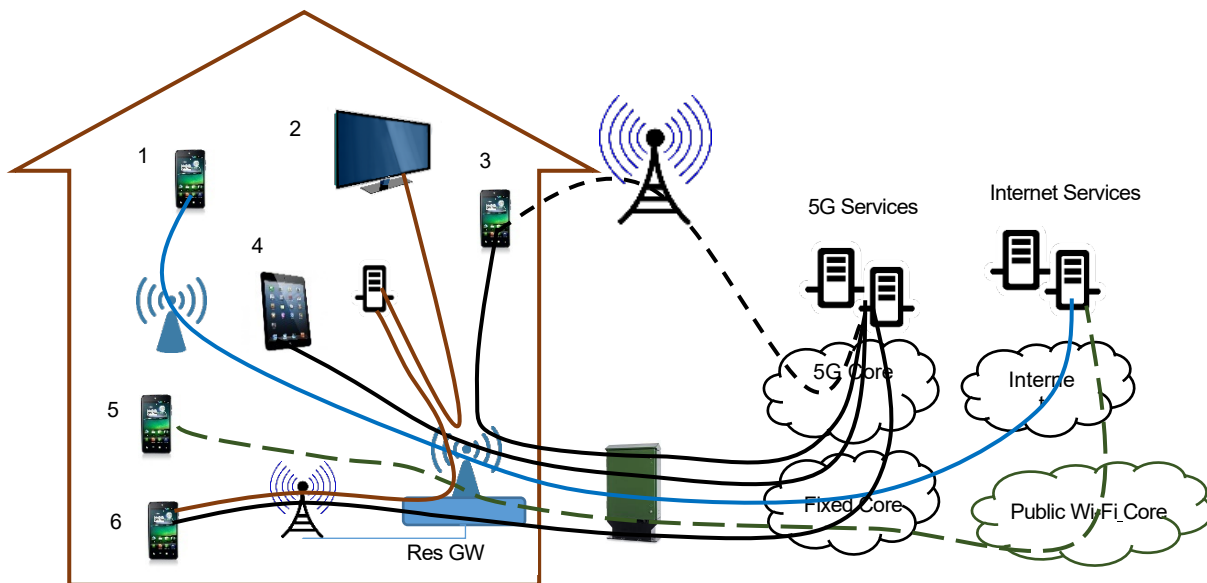

Figure 3-6 Example mix of traffic in the home

3.4.3 Requirements

Following additional requirements are derived to address convergence aspects between 5G and Wi-Fi for the In Home Wi-Fi Convergence use case:

- Enable home devices to seamlessly interact with each other irrespective of access connectivity (Wi-Fi or 5G NR home femto-cell). Access to some edge-based services/resources will only be available locally.
- Enable visiting devices to connect to 5G Core over community Wi-Fi, 5G macro or 5G home femto-cell.
- Enable selective local breakout of traffic within the home to local services and the internet (not via 5G Core).
- Maintain separation between traffic from home and visiting devices.
- Enable management of airtime and scheduling resources for visitors versus home users, and prioritization of latency critical traffic by the appropriate party/parties.

4 CELLULAR AND WI-FI INTERWORKING APPROACHES

3GPP releases have defined solutions for integration and interworking of Wi-Fi access for the 4G and 5G systems. Here we examine 3GPP's Wi-Fi access solutions defined for 4G and being developed for 5G to enable integration of Wi-Fi access into the cellular systems.

4.1 Wi-Fi Access in 4G System

Wi-Fi has been a complementary access technology for access to 4G services from the very first releases. In a 4G system, UEs (user equipment) under the cover of a licensed spectrum-based access also have the opportunity to use Wi-Fi access as a secondary access. However, in a 4G system, a UE can only access 4G services over Wi-Fi access if it has been registered over the cellular access and it keeps access connectivity over the cellular access.

There are two main criteria which differentiates solutions for integrating Wi-Fi access in the 4G system: 1) Anchoring Point, and 2) Mechanisms for Access Selection and Traffic Steering.

4.1.1 Cellular – Wi-Fi Interworking Anchoring Point

In a 4G system there is a multitude of solutions for integrating Wi-Fi access. Based on the anchoring point of the Wi-Fi access one can consider two classes of solutions: 1) Core Network integration (13), and 2) RAN level integration (14).

In **Core Network Integration,** the Wi-Fi access is connected directly to a PDN Gateway (P-GW) node in the EPC through a gateway node as shown inFigure 4-1 from (13). There are two modes for a UE to access the 4G services in this scenario:

- **Untrusted Wi-Fi Access:** The UE connects to a core network node called Evolved Packet Data Gateway (ePDG) using IPsec tunneling. The ePDG is connected to PDN Gateway via S2b interface (13).
- **Trusted Wi-Fi Access:** The UE connects to a Trusted WLAN Access Gateway (TWAG) node within the Trusted WLAN Access Network (TWAN). The TWAG is connected to PDN Gateway via S2a interface (13). UE is informed by the core network regarding the relation of trust with the Wi-Fi access that is used by the terminal. If the access is trusted the UE is authenticated in the WLAN access and one or more data sessions may be established over this access.
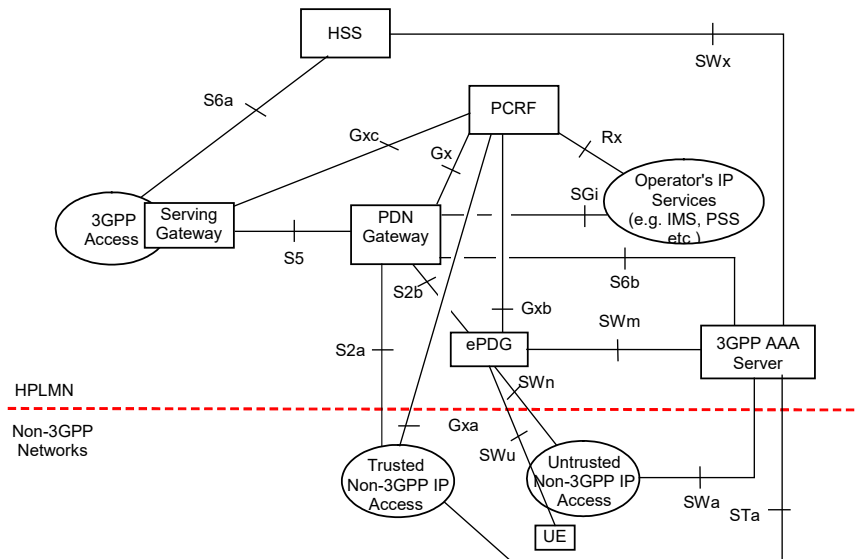
Figure 4-1 Core Network Integration Architecture for Wi-Fi Access in 4G

In *RAN level integration:* the Wi-Fi access is connected to a RAN node (eNB) through a dedicated interface (Xw). This scenario is similar with the regular LTE dual connectivity scenario; the anchor eNB operates as a macro providing overall coverage, while the Wi-Fi access provides an improved throughput. In order to accommodate different Wi-Fi deployments, two solutions have been defined as shown in Figure 4-2:

- *LTE WLAN Aggregation (LWA)* (clause 22A.1 in (14)): a solution which addresses integrating new and existing Wi-Fi deployments within the RAN anchored to an eNB. A new authentication procedure (EAP-LWA) has been designed for accommodating the Wi-Fi access. Both collocated and non-collocated network deployment options are possible. In the collocated option, the WLAN AC/AP functionality is integrated with the eNB, more suited for small cell deployments. For non-collocated deployment, the eNB and WLAN access is connected via an Xw interface through a new logical node called WLAN Termination (WT) which can be integrated with the Wi-Fi Access Controller. Transport of the data over the Wi-Fi access requires a Layer 2 Ethernet connectivity to be established between the Wi-Fi Access Point and the WT node. Security of the data is done end to end between the eNB and the UE using PDCP layer encryption.

- *LTE WLAN Integration with IPsec Tunnel (LWIP)* (clause 22A.3 in (14)): a solution which addresses generic Wi-Fi deployments anchored in RAN. This solution mimics the non-trusted Wi-Fi access through the ePDG. In this solution an LWIP-SeGW node is anchored to an eNB operating as a macro node. Same as in LWA, data radio bearers (DRBs) can be sent either over the cellular access (eNB) or over the Wi-Fi access via the LWIP-SeGW or over both accesses. The traffic over the Wi-Fi access is using IPsec tunneling between the LWIP-SeGW and the UE.
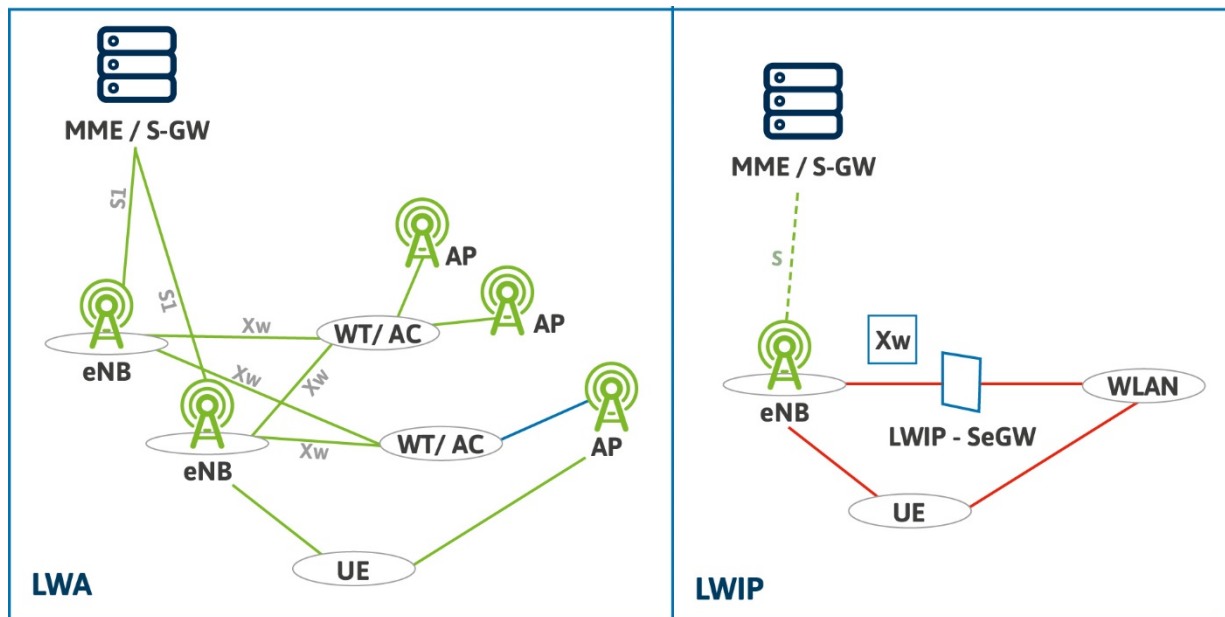
Figure 4-2 Non-collocated LWA and LWIP Architecture

4.1.2 Mechanisms for Access Selection and Traffic Steering

Access selection in the 4G System is described in clause 4.8 of (13). Access network selection and traffic steering between 3GPP access and WLAN is supported using ANDSF (Access Network Discovery and Selection Function) and is also supported using RAN assisted procedures without ANDSF as described in clause 4.3.23 of (15). The mechanism provides operators with means to provide Access Selection and Traffic Steering policies to a UE. The access selection and traffic steering procedures are done by the UE based on the operator policies, UE policies and/or user preferences. Traffic Steering can also be done under the network control through NAS signaling, when the Wi-Fi access is anchored in the core network.

The WLANSP management object (clause 4.1.7 in (16)) defines operator rules for selection of WLAN access by the UE for ANDSF procedures. Starting with Release 12, the WLANSP Management object for access selection has been expanded to include HotSpot2.0 metrics as well as other access specific metrics (clause 22A.2 in (14)).

When the Wi-Fi access is anchored in RAN (e.g. LWA or LWIP), the Wi-Fi access selection and traffic steering procedures can be done under the control of the eNB node, following the procedure described in clause 4.8 of (13).

The granularity of the traffic steering varies based on the anchoring point of the Wi-Fi access. When the Wi-Fi access is anchored in the core network the granularity is at a PDU level or IP flow level. Finer granularity can also be obtained using Layer 4 protocols e.g. MPTCP. When the Wi-Fi access is anchored at an eNB, the traffic steering granularity is either at a data radio bearer or at a packet level for both LWA as well as LWIP solutions. For LWIP, the traffic can also be steered at the IP flow level over cellular and Wi-Fi access, without requiring complex reordering mechanisms on the receiver side.

4.2 Wi-Fi Access in 5G System

The 5G system brings few fundamental architectural changes compared with the 4G system:

1. A transition from a structural design (node based) to a functional design for both the access network and the core network.
2. Access neutral architecture, a UE shall be able to connect and access 5G Services seamlessly across any access.

Integration of the Wi-Fi access in the 5G system has taken into account the previous experience of using Wi-Fi access in the 4G system. In the 4G system, despite various solutions been developed for Wi-Fi access integration, VoWLAN using untrusted Wi-Fi access via ePDG is the only widely deployed feature so far besides non-seamless Wi-Fi offload. Major reasons for the lack of deployment of these Wi-Fi integration solutions in 4G have been: 1) each of the proposed solution required different Wi-Fi architecture design, 2) each solution introduced different requirements on the UE implementation, and 3) each solution has different core network impacts. The Wi-Fi access solutions being developed in 5G attempt to address some of these challenges, to enable wide spread adoption of Wi-Fi access integration in 5G.

4.2.1 Wi-Fi Access in 5G System Release 15

Release 15 defines solution for the integration of Untrusted Wi-Fi access with the 5GC. The integration of Wi-Fi access to 5GC is done through a new function N3IWF (Non-3GPP Interworking Function) which relays both signaling and data between the 5GC and the WLAN access through defined interfaces (N2 for control plane and N3 for user plane) as shown in the diagram in Figure 4-3 (clause 4.2.8.2 in (17)).

Figure 4-3 Untrusted Wi-Fi Integration in 5GS

The transport of both signaling (NAS messages) and user plane data is done by using IPsec tunneling. Once a UE authenticates and register for 5G services over Wi-Fi access, an IPsec tunnel (signaling IPsec SA) is created for the transport of all the future NAS signaling. One or more IPsec child security associations (IPsec child SA) are created for each PDU Session. The creation of IPsec SAs and the association of the QoS flows to IPsec SAs is done using IKEv2 commands.

In a 5G system, a UE can associate and register for 5G services using Wi-Fi access only, without the need of having a primary access over cellular access (NR or LTE). The authentication procedure in the

5GS is an EAP based procedure and it mandates the use of SIM based credentials for the authentication with the 5GC. A certificate based scheme using EAP-TLS or EAP-TTLS has also been designed, however it is limited in scope to IoT only devices and private networks.

The access selection in Release 15 is provided by the Access Network Discovery and Selection Policy (ANDSP). This uses the ANDSF WLANSP Management Object policy mechanism and it is now delivered over NAS signaling. It is optional for a network to support ANDSP. However, if a UE supports non-3GPP access, it must support ANDSP (clause 6.6.1 in (18)).The traffic selection and steering across accesses is network controlled using UE Route Selection Policy (URSP) delivered over NAS signaling (clause 6.6.2 in (18)). As in the case of the 4GS the granularity of traffic steering in Release 15 is done at the PDU session level. Improved granularity levels are addressed in the Release 16.

The only element where the integration of Untrusted Wi-Fi access to the 5GC differs from the basic principle of having the Wi-Fi as a regular access is the N3IWF selection. In order to keep compatibility with previous ePDG deployments, the N3IWF selection procedure follows the same steps as in the case of ePDG selection.

4.2.2 Wi-Fi Access in 5G System Release 16

The Release 16 work for the 5G system is defining solutions to enable Wi-Fi access in a multitude of deployments:

1. ***Trusted non-3GPP Access:*** in this scenario a UE accesses the 5G services through a Wi-Fi access network trusted by the operator. The connection to the 5GC is provided through a Trusted Non-3GPP Gateway Function (TNGF) as shown in Figure 4-4 (clause 7.1.2 in (19)), which in the context of a Wi-Fi deployment can be collocated with a WLAN Controller.

2. ***Wireline and Cable Modem based access:*** in this scenario a Residential Gateway (RG) or a Cable Modem (CM) plays the role of a 5G UE that gets connected to the 5GC through a Fixed Access Gateway Function (FAGF) (similar to TNGF) as shown in Figure 4-5 (clause 6.1 in (19)). The connectivity between the RG/CM and FAGF can be done using DOCSIS or other fixed wireline technologies. Both RG and CM may or may not terminate NAS signaling. Also both these devices may not support SIM based credentials and instead use access specific identifiers (e.g. Line ID, etc.). Wi-Fi based devices can get connected to 5G services through the RG/CM. Such devices, when operating as Wi-Fi only devices may or may not support NAS as well as SIM based credentials.
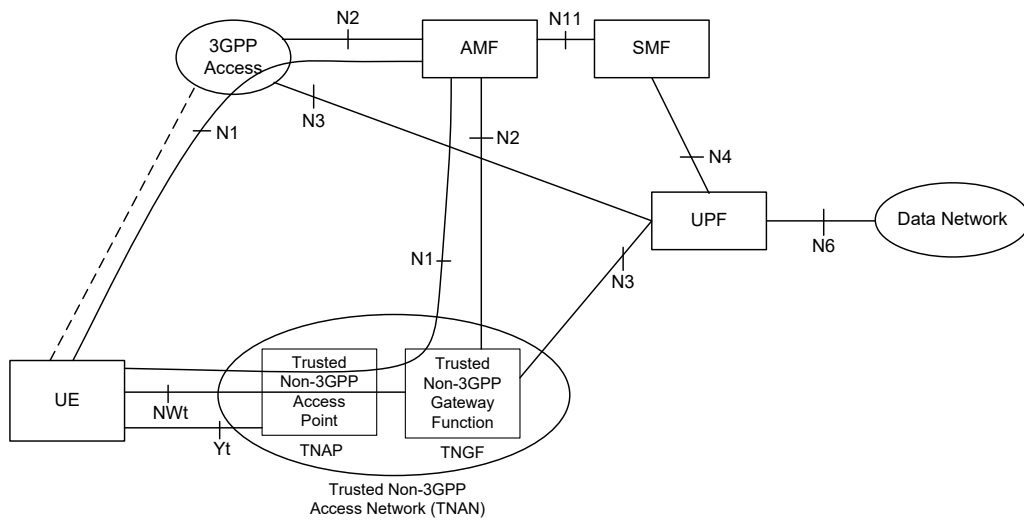
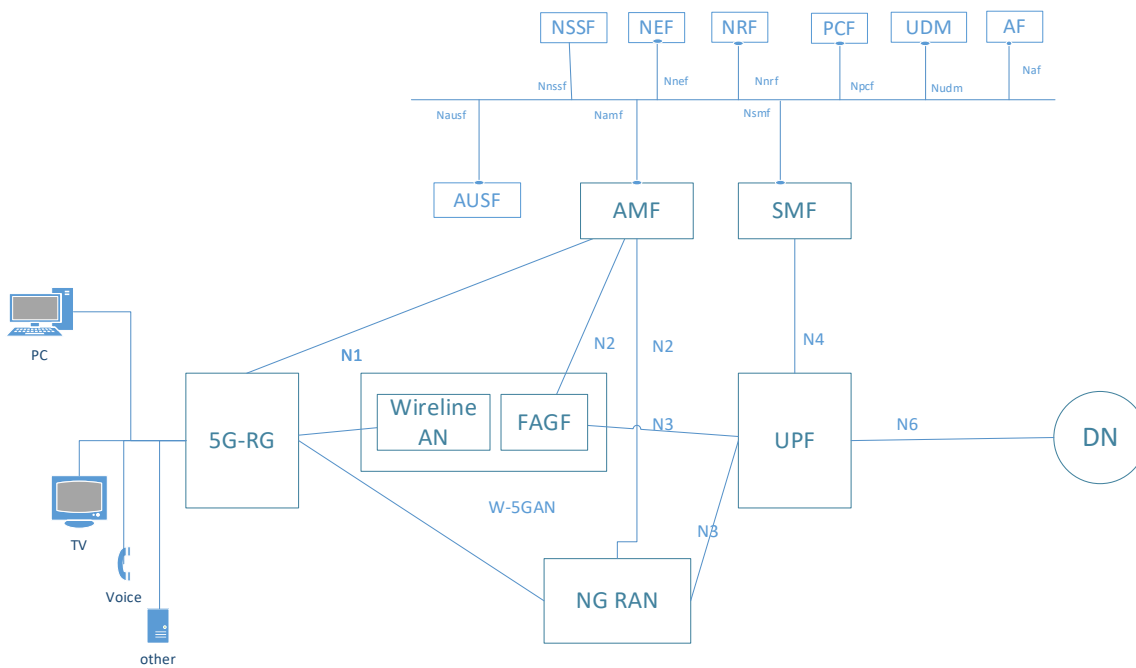**Figure 4-4 Trusted Wi-Fi Integration in 5GS**

Figure 4-5 Wireline Access integration in 5GS

Release 16 work for the Wi-Fi access in 5G system continues to take into consideration the ease of adoption within the device ecosystem across multiple device platforms. Both the control path and user plane path for the trusted non-3GPP access are similar with the ones in Release 15 untrusted non-3GPP access. The role of N3IWF in Release 15 is taken by the TNGF in Release 16. The major difference is that once a UE is informed by the core network regarding the relation of trust with the Wi-Fi access, the NULL encryption is used for NAS signaling and user plane IPsec SAs established between UE and TNGF.

The control path takes into account the possibility for the Wi-Fi Access to provide QoS for its users. For each QoS flow, the TNGF is the decision function and it can establish the QoS treatment over the Wi-Fi Access. The QoS flow parameters received by TNGF via the N2 interface are converted by the TNGF into Wi-Fi access QoS parameters, and are also signaled to the UE via extensions of IKEv2 commands (clause 4.12a.5 in (20)). For a QoS flow an existing IPsec SA may be used or a new IPsec SA may be created.

Device mobility over the Wi-Fi access can be provided inside the TNGF coverage (intra TNGF mobility) using EAP Re-authentication Protocol (ERP). Inter TNGF mobility can be provided in Release 16 via the core network. Inter-TNGF mobility using a new Tn interface between the source and target TNGF has been studied during the Release 16 Study Phase. Definition of the Tn interface is still an open item of the Release 16 and there is a strong likelihood that this work is going to be deferred to the next Release.

Wi-Fi only devices (with no NAS and no SIM credentials) accessing the 5G services can be accommodated over the Trusted Wi-Fi access. In this scenario a Trusted WLAN Interworking function (TWIF) collocated with the TNGF terminates the N1 signaling for the UE. A solution for the authentication and registration of such devices with the 5G core has been designed using EAP-TLS and EAP-TTLS in Release 15. At the time of this writing the support for UEs without NAS is still an open item between 3GPP SA2, SA3 and SA1.

4.2.2.1 Access Traffic Steering, Switching and Splitting in Release 16

New Access Traffic Steering, Switching and Splitting (ATSSS) functionality has been designed in Release 16, which allows traffic steering across multiple accesses at a finer granularities than a PDU session. The ATSSS feature is an optional feature in Release 16 both on the UE and the 5GC network.

ATSSS introduces the notion of Multi Access PDU session, a PDU session for which the data traffic can be served over one or more concurrent accesses (3GPP access, trusted non-3GPP access and untrusted non-3GPP access). Release 16 normative work establishes the framework for MA-PDU management, policy mechanism for traffic steering across accesses as well as a generic UP framework capable of accommodating different protocols for multi access ((20) (18)). The UL traffic distribution by the UE and the DL traffic distribution by the UPF takes into account ATSSS rules provided by the network.

The user plane traffic gets transported between the UE and the ATSSS Function collocated on an anchor UPF. There are two multi-access steering functionality that are supported for user plane: 1) the MP-TCP functionality which uses the MP-TCP protocol and in which the ATSSS function operates as an MP-TCP proxy for the TCP traffic between the UE and the 5GC; and 2) the ATSSS-LL (ATSSS-Low Layer) functionality which provides a data switching function and implements traffic steering, switching and splitting at a fully specified IP flow level.

If the UE supports both the MPTCP functionality and the ATSSS-LL functionality, it uses the provisioned ATSSS rules to decide which functionality to apply for taking ATSSS decisions for a specific packet flow. Within the same MA PDU session in the UE, it is possible to steer the MPTCP flows by using the MPTCP functionality and, simultaneously, to steer all other flows by using the ATSSS-LL functionality. For a given packet flow, only one steering functionality is used.

5 KEY CHALLENGES FOR WI-FI AND 5G CONVERGENCE

5.1 Tight Integration between 5G and Wi-Fi

The benefit of defining a RAN level tight convergence approach for supporting carrier-centric use cases is the high degree of homogeneity across mobile service provider architectures. However, even within such a controlled environment, there is growing adoption of "loose integration" approaches for Wi-Fi access in 4G using multi-path-based technologies, e.g., when compared with 3GPP defined tight interworking using LWA and/or LWIP (21). Within the heterogeneous enterprise, residential and public Wi-Fi environments, the challenges of enabling tight integration of Wi-Fi and 5G are much more complex.

3GPP Releases 15 and 16 provide interworking between the 5G and Wi-Fi networks by enabling access to the 5G Core via untrusted and trusted non-3GPP access networks such as Wi-Fi. These efforts are focussed on defining architectures and messaging to provide secure transport for the 5G control plane and data plane over non-3GPP access via gateway functions, N3IWF for Untrusted non-3GPP access and TGNF for Trusted non-3GPP access. Further study is needed to ensure a tight integration between 5G and Wi-Fi networks, to better utilize resources from both access networks to meet requirements for a wide array of current and future 5G use cases including low latency AR/VR and factory automation.

A tight integration between 5G and Wi-Fi may provide improved session mobility control, reduce signalling complexity by providing better anchoring points, improve resource utilization with faster response to changing channel conditions, and improve reliability and data path support through the use of both 5G NR and Wi-Fi accesses when available. This can result in improved session continuity performance for low latency applications (such as AR/VR, Gaming) in cellular dead spots with Wi-Fi coverage, in turn providing better user experience.

5.2 Access Visibility, Network Manageability and Policy Control

The current Wi-Fi and cellular access systems manage the radio resources independently of each other. Whereas 3GPP have defined the ability to share a limited set of Wi-Fi related instrumentation over 3GPP, with LWA defined enhancements including being able to signal WLAN ids, RSSI, STA count, backhaul rate, and channel utilization using LTE RRC signaling (22), these measurements have not been defined to be carried over 5G NR's RRC signalling. Conversely, the Wi-Fi defined 802.11k and 802.11v functionality provides capabilities for managing Wi-Fi resources. However, these assume a homogeneous radio environment, precluding, for example, the triggering of a transition to a specific non-Wi-Fi access point, e.g., due to network load balancing or BSS termination.

There are business opportunities which could be enabled for cellular operators with a standardized solution for cellular operations to have improved visibility and control in the configuration and management of Wi-Fi access networks. Such manageability and control could also enable the business model for cellular operators to provide Wi-Fi network management solutions for SMBs (Small and Medium Businesses). In addition, some Enterprise Wi-Fi Providers would like to have ability to request 5G core network resources for users/applications accessing via their Wi-Fi infrastructure.

To realize new sets of business opportunities between cellular and Wi-Fi networks, an interface is needed to enable certain level of network manageability and policy control between 5G core and Wi-Fi networks. For example, such an interface can be used to set Wi-Fi bandwidth dedicated for 5G service traffic, configurations and QoS settings for the Wi-Fi slice dedicated for 5G services and devices allowed to access the dedicated Wi-Fi slice. Such an interface can also enable enterprise Wi-Fi networks to request access to operator-provided 5G services, or access to operator-provided network slices, for certain enterprise users and/or applications.

Conversely, there are business opportunities which could be enabled by a standardized solution for Wi-Fi operators to have improved visibility in the operation of overlapping cellular networks. Such manageability and control could also benefit users as the Wi-Fi network can be configured to avoid poorly performing connections to users at the very edge of the Wi-Fi coverage, instead indicating that improved service may be accessible via the cellular network. This may be achieved by enhancing the 802.11 defined Wireless Network Management radio measurements, e.g., to enable non-AP STAs to report measurements made on cellular broadcast channels, and enhancing transition management procedures, e.g., to enable transition candidates to include overlapping cellular cells. WFA' Agile Multiband certification (23) provides some foundation work to address these aspects e.g. UE reports whether it has cellular data connectivity to Wi-Fi AP and AP can use that information to steer the UE to cellular if needed, but further enhancements e.g. reporting of cellular signal strengths and other measurements may be needed.

A standardized management/control interface between 5G and Enterprise/Public Wi-Fi can also enable management of Wi-Fi access networks from 5G, resulting in operational benefits.

5.3   Enablement of Wi-Fi Only Devices

Many enterprise deployments today support a large number of Wi-Fi only devices being managed by the enterprise Wi-Fi provider. It is important that such Wi-Fi only devices be able to connect to the 5G core and receive 5G services providing 5G experiences to their users. This also in return creates new market opportunities to 5G service providers.

Enabling Wi-Fi only devices requires support for alternative device identity types, based on Wi-Fi centric subscription and authentication types, and support for corresponding alternative authentication credentials in the 5G Core network. The 3GPP standard currently supports core identities and authentication based on 5G-AKA or EAP-AKA' authentication schemes, which require presence of SIM credentials. The current 3GPP standard also supports EAP-TLS and EAP-TTLS non-3GPP identification/authentication, although it limits the usage to private 5G networks only. Further work may be needed to enable Wi-Fi only devices connect to 5G core, including devices with or without 3GPP identity or SIM credentials on the device and devices that support or do not support the 5G NAS protocol.

5.4   Traffic Routing across Multiple Accesses

At the heart of cellular and Wi-Fi convergence is the ability of a client to route traffic over one or more accesses, making optimal use of the available connectivity. This might involve using more than one access network at the same time, or seamlessly switching traffic flows between the access networks as the network conditions vary. A traffic routing solution over multiple accesses should ideally have all of the following characteristics:
- Fast reaction (sub-second) to changes in connection quality
- Support session continuity
- Support all IP protocols (not just TCP)
- Traffic routing should be under policy control

- Should not rely on radio access networks being physically co-located
- Should be efficient, in terms of network traffic, computation and battery power
- Should be standardised

As mentioned above, 3GPP Release 16 ATSSS work is defining traffic steering, switching and splitting over 3GPP and non-3GPP access and addressing many of the above requirements for traffic routing over 3GPP and Wi-Fi access. Further study might be needed to achieve fast-reaction time to changes in connection quality for traffic routing.

5.5 Network Slicing

Synergies between the slicing capabilities from 802.11 technologies and 5G network slicing have been previously published by the WBA (24). With segmentation being widely deployed in enterprise environments, there is the opportunity to define the interworking between an enterprise segment and a 5G slice to then enable enterprise users to receive seamless access to their services, irrespective of which access network is used. The interworking can also enable 5G network users to receive seamless access to 5G services over Wi-Fi segment(s) allocated for 5G services/applications

5.6 Device Support

As per (25), one of the dependencies on delivering effective integration of Wi-Fi and cellular systems is device support. For example, the original (e)PDG based core-centric proposition for interworking between Wi-Fi and LTE was defined in 2005 and subsequently enhanced in 2008, however, it took the release of Apple's iOS8 in 2014 to see native support of ePDG based access introduced into the device ecosystem. Also integration of WLAN as a trusted non-3GPP access network with the LTE core has currently seen little adoption across the device ecosystem, which could be because of lack of trusted non-3GPP network side deployments.

For 5G releases, 3GPP is defining an access neutral architecture that includes both trusted and untrusted Wi-Fi access. For both of these accesses, an IPsec/IKEv2 mechanism is being defined for signaling and data transport. This approach is intended to lower barriers for adoption of Wi-Fi access in the device ecosystem.

Any 5G and Wi-Fi interworking and convergence solution should take into consideration the ease of adoption within the device ecosystem across multiple device platforms, for various deployment scenarios and business models.

6 RECOMMENDATIONS & CONCLUSION

The evolutions in 5G and Wi-Fi are offering new business opportunities for the industry to enable new use cases through the convergence of Wi-Fi and 5G at the network and RAN layers. These new opportunities bring new set of challenges that the industry needs to address to provide deployable solutions in different verticals such as enterprise, manufacturing (Industry 4.0/IIoT), connected city, public spaces and residential connectivity. In this paper, we have analysed some key use cases and requirements supporting them, and identified the gap items that would require further study by the industry and standards body (3GPP, IEEE and/or WFA) to fully realize the opportunities presented by the convergence between 5G and Wi-Fi.

One of the key challenges highlighted is to enable tight integration between 5G-NR and Wi-Fi for improved session continuity and better resource utilization between NR and Wi-Fi for heterogeneous enterprise/verticals, residential and public Wi-Fi environments. A tight integration can also enable fast reaction time for traffic switching/splitting/steering over NR and Wi-Fi access based on changes to

connection quality. To address this gap, further study is needed on top of the 3GPP Release 15 & Release 16 defined solutions for Core Network based interworking between 5G and Wi-Fi. Another important challenge is to enable Wi-Fi only devices, with or without 3GPP identity and SIM credentials on the device, to access 5G services on PLMN networks, to expand 5G experiences to existing as well as future Wi-Fi only devices. Addressing this gap might require support for EAP-TLS/EAP-TTLS by the PLMN networks.

Yet another challenge emphasized relates to network visibility between 5G and Wi-Fi. To realize new business opportunities there is demand from cellular operators for a standardized interface providing improved visibility and control in the configuration and management of Wi-Fi access networks. Wi-Fi providers would also like to request 5G core network resources via a standardized interface for enterprise users/applications, to provide service differentiation to their users. In addition, the Wi-Fi operators could provide better user experience through a standardized solution providing improved visibility and transition management in the operation of overlapping cellular and Wi-Fi networks. These gaps might need to get addressed across different standards body including 3GPP, IEEE and/or Wi-Fi Alliance.

There are some work items already in the pipeline to be addressed in 3GPP future releases for further enhancing Wi-Fi access in 5G, e.g. update to RAN based signaling to include Wi-Fi assistance information, enhancements to ATSSS functionality and a new interface definition to enable inter-TNGF mobility and the mobility between TNGF and NR nodes without access through the core functions. However, the key gaps identified above are not currently being addressed by already planned study items in 3GPP. Further actions are needed by the industry and standards bodies to address key gaps highlighted in this paper for realizing new business opportunities presented by the RAN convergence between 5G and Wi-Fi.

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