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Founded in 2003, the mission of the Wireless Broadband Alliance (WBA) is to accelerate global leadership for enabling wireless services that are seamless, secure and interoperable. Building on our heritage of Next Generation Hotspot (NGH) and carrier Wi-Fi, the WBA will continue to drive and support the adoption of Next Generation Wireless services across the entire public Wi-Fi ecosystem, including IoT, Converged Services, Smart Cities, 5G, etc. Today, membership includes major fixed operators such as BT, Comcast and Charter Communications; seven of the top 10 mobile operator groups (by revenue) and leading technology companies such as Cisco, Microsoft, Huawei Technologies, Google and Intel.

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Executive Summary

This WBA white paper follows on from “Roadmap for Coexistence and Convergence in 5G – Market Research” paper published in November 2016. It forms part of the WBA strategy to actively embrace 5G and ensure that WBA connected cities and Wi-Fi network operators are positioned to exploit 5G and provide the services and experiences essential to our customers and users.

At the time of writing, 5G’s market requirements and use cases have been defined by various industry bodies. However, 5G is still being specified and will continue to be the subject to standardization work in various industry bodies for many years to come.

WBA has examined the many aspects of the 5G landscape being created by the major leading industry bodies, including amongst others, ITU, IEEE, IETF, 3GPP, NGMN and 5GPPP. This is focused on the aspects of 5G that are relevant to Wi-Fi and are of interest to WBA members.

The paper examines the high-level standardization landscape - in particular, the work of 3GPP and how the staged work in Release 15 and onwards will define 5G. Some aspects of work being carried out stretch across a broad expanse of technologies, such as the issue of identity which is being considered in several industry bodies as the use of UICC and EAP is explored. There is also the impact of concepts such as network slicing and network function virtualization and their implementation as well as the impact of spectrum issues on 5G from sub-6GHz frequencies to mm-wave bands.

This is followed by examining some of the potential use cases currently envisaged as being able to exploit the capabilities of 5G. On top of supporting the evolution of the current coverage and capacity focused consumer business models, 5G will expand to new ones to support different types of customers, partnerships, and ecosystems. Importantly, these new 5G environments such as factories, cities, automotive, energy, and eHealth are typically served by private networks, frequently based on Wi-Fi technology.

The known future evolution of Wi-Fi is discussed in new unlicensed bands and how developments in 802.11 being worked on in the 802.11ax High Efficiency Wireless project will deliver improved Wi-Fi performance within the timeframe of 5G. This performance is matched against the requirements laid out for IMT-2020 and demonstrates how Wi-Fi can meet most of the demands of IMT-2020.

A section looks at how Wi-Fi networks are potentially impacted by 5G, what might be missing from Wi-Fi technology and what might need to be done to enable Wi-Fi to meet the challenges presented by 5G. It is observed that in many aspects, 5G is following Wi-Fi in its adoption of several key capabilities. From a Wi-Fi perspective, however, the integration of Wi-Fi into the Multi-Access Edge Computing environment, the use of Wi-Fi in transportation environments as well as the support of slicing over Wi-Fi networks are called out for attention.

The final part looks at the potential next steps that WBA may need to do to prepare for 5G. For example, existing work on Quality of Service and associated metrics will be required as well as enhancements to the WRIX framework to meet the needs of 5G roaming. As well as new potential projects such as the use of Wi-Fi in high speed transport environments such as vehicles and railways.

WBA will continue to develop its 5G strategy to work towards ensuring WBA and Wi-Fi networks are ready and enabled to meet the needs of a 5G based world. The organization will continue to satisfy the use cases and needs of the millions of customers and users of the world’s Wi-Fi networks and the WBA operators and WBA connected cities dedicated to delivering that strategy and vision.
1 Introduction

5G intends to enable a seamlessly connected society in the 2020 timeframe while bringing together people along with things, data, applications, transport systems and cities in a smart networked communications environment.

Several industry bodies are currently defining and working on 5G related topics, including ITU, 3GPP, NGMN, 5GPPP, Small Cells Forum, IEEE, IETF and Broadband Forum. This paper reviews the outline of these bodies’ 5G output, summarises their opinions and evaluates their possible impact on WBA stakeholders in key dimensions such as identity, slicing and value creation enables.

The vision of the WBA is not to focus on the definition of 5G but rather on the business model evolution and respective use cases being discussed, in addition to how Wi-Fi and other unlicensed technologies can play a key role in enabling those in a 5G framework.

On the high-level technical plane, the objective is to explore how unlicensed technologies, in combination with licensed technologies, can meet the broad range of IMT-2020 requirements.

In fact, the role of Wi-Fi as an integral part of 5G is outlined based on the key capabilities set by the industry, with very encouraging results and directions towards a bright symbiosis on the 5G umbrella. New Wi-Fi developments such as 802.11ax and the spectrum bands combination derived efficiencies of technologies such 802.11ad, sub-6Ghz and mmWave set the scene for 5G to leverage.

Moreover, further analysis indicates that Wi-Fi is having a significant impact on the definition of 5G, with 5G following Wi-Fi in its adoption of several significant characteristics, including from a technical perspective the use of an EAP authentication framework and associated broadening of identity concepts, and from a business perspective the focus on new non-consumer, vertical value propositions.

Whilst the improvements and integration points should be discussed towards a cooperative ecosystem, the work on 5G is an open field and the next steps may range on the following dimensions:

- Wi-Fi related evolution - Address Wi-Fi provisioning gaps, Wi-Fi Performance Instrumentation to enable enhanced aggregation solutions
- Roaming framework - WRIX enhancements for 5G Roaming of new non-SIM based identifiers
- New use cases and projects - 802.11 in Vehicular Environments and Rail Environments and Integrated Keying Hierarchy
- 5G Testing & Interoperability - Testing the 5G unlicensed wireless building blocks aided by a convergent approach with the cellular world and interworking

1.1 Roadmap for Coexistence and Convergence in 5G

The main objective of this project within WBA has been to provide an initial industry assessment on how unlicensed technologies will contribute to the 5G framework definition.

The industry was invited to participate in a global survey, and in total, more than 65 companies across six different continents have provided their extensive inputs.

Leveraging the valuable contributions provided, the following conclusions were reached:
5G Technologies perspective

- The industry is certain on 5G being a combination of licensed and unlicensed technologies
- Wi-Fi is the leading unlicensed technology under the 5G umbrella

Convergence & coexistence is key on the 5G Roadmap

- Convergence of services and technologies is currently the most important topic to the industry
- The coexistence of technologies in 5G aims to leverage efficiency levels achieved nowadays in Wi-Fi networks

Business case & services development

- High priority industry verticals start to unfold, top ranked three were smart cities, IoT sensor networks and safety/surveillance
- Infrastructure investment rationale is key for operators
- 5G spectrum getting worldwide attention
- Spectrum allocation, usage, cost, regulation is on the radar of the industry and regulators across the globe
- Shared spectrum topics are raised as priority issues for operators, including new 3.5 GHz technologies such as Citizens Broadband Radio Service (CBRS) and Authorised Shared Access (ASA)

Standardisation as the key milestone towards 5G becoming a reality

- Standardisation is clearly underway and highly likely to happen before 2020; however, bridging further licensed and unlicensed needs to be a fast-tracked
- Coexistence of technologies, convergence of services, certification and operator guidelines were indicated as major gaps towards 5G

The research is available at the following link: WBA resource center

2 5G definition / Standardisation high-level landscape

2.1 NGMN

Scope/Use cases: NGMN 5G white paper’s main objective is to provide industry-wide 5G guidance based on the requirements defined by its members around 5G radio access, architecture, vertical services, security, and spectrum [1]. It is anticipated that the need for new radio interface(s) will be driven by use of higher frequencies, specific use cases such as Internet of Things (IoT) or specific capabilities (e.g., lower latency), which go beyond what 4G and its enhancements can support. Specifically, NGMN has defined the concept of eight use case families, ranging from broadband access everywhere to ultra-reliable communications.
Technical impacts: NGMN envisions 5G as an end-to-end system that includes all aspects of the network, with a design that achieves a high level of convergence and leverages today’s access mechanisms (and their evolution), including fixed, and any new ones in the future. In this context, 5G may operate in a highly heterogeneous environment characterised by the existence of multiple types of access technologies, multi-layer networks, multiple types of devices, multiple types of user interactions, etc., driving a fundamental need to achieve seamless and consistent user experience across time and space.

Unlicensed/Wi-Fi reference: On a key section of their white paper, Requirements, Wi-Fi is first referenced on the “Connectivity Transparency” bucket, for delivering consistent experience in a highly heterogeneous environment. Stating it is expected that a terminal may be connected to several radio access technologies (RATs), including both new RATs and LTE, and this may involve non-3GPP RATs, e.g., IEEE 802.11ax (High Efficiency Wi-Fi). After, on the Technology and Architecture section, within an improving dimension identified as an enabler for operational sustainability, Wi-Fi is referenced as an offloading trend. Therewith the subsection outlining 5G Interfacing Options, depict a potential interface to a fixed network function hooked onto Wi-Fi. Finally, on the technology building blocks annex, Wi-Fi is referenced on:

- Integrated license-exempt spectrum (reference some experience with Wi-Fi integration available)
- Enhanced multi-RAT coordination (study item in 3GPP Rel-13)
- Device-to-Device communications (Wi-Fi Direct)

Overall, recommendations derived from NGMN promote Wi-Fi along with LTE/LTE-Advanced, as well as their evolution, are to be supported by the new 5G Network Functions (5GF) design. Thus, the access-agnostic network functions should accommodate any new RATs, as well as LTE/LTE-Advanced, Wi-Fi, and their evolution.

Timelines: The white paper has been published and liaised to other SDOs. The follow-on work areas on the radar of NGMN are a 5G trial & testing, end-to-end architecture and Vehicle-to-X evaluation; these will span along the timeframe of 2020 with scheduled deliverables.

2.2 3GPP

The 3GPP is specifying 5G as part of its Release 15 specifications according to the following timeline:
Back in September 2016 the 5G New Radio (NR) requirements were approved as well as Technical Report TR 23.799 (part of 3GPP Release 14), the architectural specification for the Next Generation System (NGS) comprising the 5G (Radio) Access Network ((R)AN) and the Next Generation Core Network (NG CN). The term “NG CN” was replaced by “5GC” in January 2017 (5G Core Network). From a Wi-Fi perspective, Key Issue 20 in 23.799 addresses architectural issues related to Access Traffic Steering, Splitting and Switching (ATSSS). Functionality related to ATSSS is applicable to trusted WLANs and untrusted WLANs, and for both, seamless and non-seamless WLAN offload.

In December 2016, the TSG SA WG2 (SA2) working group was tasked to produce the TS 23.501 (architectural) and TS 23.502 (procedural) specifications for the 5GC based on the agreements in TR 23.799 section 7.

In the 3GPP Release 15 5GC, the UE can set up PDU (Protocol Data Unit) sessions of the type IP, Non-IP and Ethernet. The latter is new compared to the PDN (Packet Data Network) types in the EPS, which were only IPv4, IPv6, IPv4v6 and Non-IP.

In Release 14 EPC the gateways (SGW, PGW and TDF) are split in a Control Plane part and User Plane part, a principle known as Control and User Plane Separation (CUPS). This principle is maintained in the 5GC, where the SMF (Session Management Function) is controlling the User Plane Function (UPF); the novelty being that a SMF can anchor a single PDU session in multiple UPF instances. Since Session & Service Continuity (SSC) is considered a Key Issue (Key Issue number 8 in TR 23.799) it will be possible to re-anchor an established PDU session to a new Terminating UPF (TUPF).

The 3GPP Release 14 EPC supports access by 2G GERAN, 3G UTRAN, 4G E-UTRAN, Untrusted and Trusted non-3GPP Access Networks. In particular, these last two access approaches have been leveraged by the Wi-Fi industry for enabling integration of Wi-Fi based access networks into a
converged 3GPP core network. However, in Release 15 only 5G (R)AN (supporting eLTE and/or NR) and Untrusted Non-3GPP Networks can be connected to the 5GC, as illustrated on the following diagram:

![Diagram](image)

**Figure 2-2: Contrasting EPC and Release 15 5GC support of trusted non-3GPP access. (Reference source: Nokia)**

Besides the SMF and UPF the main functions in the 5GC are the AMF (Access and Mobility Management Function) which replace the MME and N3IWF (Non-3GPP Interworking Function). The latter is comparable to the ePDG (evolved Packet Data Gateway) in previous releases (TS 23.402 Release 13/14) since it provides Untrusted Non-3GPP access. IPSec Security Associations will be set up between the UE and the N3IWF, that may result in performance impacts for broadband data applications on the UE supporting WLAN, e.g., compared with R13/R14 based Trusted WLAN integration that did not require an overlay of IPSec security.

*Note, it is expected that Release 16 will see the N3IWF functionality enhanced to enable trusted WLAN to be integrated into the 5GC.*

In February 2017 a joint BBF-3GPP task force was set up to examine the requirement for Fixed-Mobile Convergence (FMC), upon request of leading Operators who expressed their desire to connect the broadband RG/CPE to the 5GC via both fixed and mobile access networks, concurrently and using a consistent authentication scheme such as AKA’ (3GPP Authentication & Key Agreement relying on the USIM).

### 2.3 ITU-R

The objective from ITU-R is to provide a vision for IMT to address the anticipated needs of users of mobile services for 2020 and beyond, by describing potential user and application trends, growth in traffic, technological trends and spectrum implications, and by providing guidelines on the framework and the capabilities of IMT for 2020 and beyond [2].
The observation of trends shows greater density of users, all wanting high quality and high mobility with enhanced multimedia services as well as the increasing use of IoT and massive machine type communications. There is a need for the technology to enhance the radio interface with flexible network nodes with enhanced broadband services, improved efficiency with higher data rates, including at frequencies between 6 and 100 GHz. Impacts on spectrum are described, including harmonisation as well as the need for contiguous and wider bandwidth.

The paper covers the evolution of IMT with wireless infrastructure connecting the world, new ICT markets, new ways of communication, promoting energy efficiency, all impacting social change and new art and culture.

The usage scenarios include expected use case such as enhanced mobile broadband, ultra-reliable and low latency communications and massive machine type communications. As additional use cases are expected to emerge, which are currently not foreseen, flexibility will be necessary to adapt to new use cases that come with a wide range of requirements.

The capabilities of IMT-2020 are based around spectrum utilisation, achievable data rates and many other characteristics of radio communications being improved for the user over the capabilities of previous technology generations.

The research forums and other external organisations wishing to contribute to the future development of IMT-2020 are encouraged to focus especially in the following key areas:

a) radio interface(s) and their interoperability;
b) access network related issues;
c) spectrum related issues;
d) traffic characteristics.

In February 2017, ITU-R issued a document outlining minimum technical performance requirements with the purpose of achieving a consistent definition, specification, and evaluation of the candidate IMT-2020 radio interface technologies (RITs)/Set of radio interface technologies (SRIT) [3], with ITU-R M.2083 defining eight key “Capabilities for IMT-2020”, which form a basis for the technical performance requirements:

- **Peak data rate** - The minimum requirements for peak data rate (maximum achievable data rate under ideal conditions per user/device) are as follows:
  o Downlink peak data rate is 20 Gbit/s
  o Uplink peak data rate is 10 Gbit/s
- **Peak spectral efficiency** - The minimum requirements for peak spectral efficiencies are as follows:
  o Downlink peak spectral efficiency is 30 bit/s/Hz
  o Uplink peak spectral efficiency is 15 bit/s/Hz
- **User experienced data rate** - The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment:
  o Downlink user experienced data rate is 100 Mbit/s
  o Uplink user experienced data rate is 50 Mbit/s
- **Average spectral efficiency** - The minimum requirements for average spectral efficiency for various test environments per Transmission Reception Point (TRxP) are summarised on the following table:

<table>
<thead>
<tr>
<th>TEST ENVIRONMENT</th>
<th>DOWNLINK (BIT/S/Hz/TRxP)</th>
<th>UPLINK (BIT/S/Hz/TRxP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor Hotspot – eMBB</td>
<td>9</td>
<td>6.75</td>
</tr>
<tr>
<td>Dense Urban – eMBB</td>
<td>7.8</td>
<td>5.4</td>
</tr>
<tr>
<td>Rural – eMBB</td>
<td>3.3</td>
<td>1.6</td>
</tr>
</tbody>
</table>

*Table 2-1: IMT-2020 Spectral Efficiency Targets*

- **Area traffic capacity** - The target value for Area traffic capacity in downlink is 10 Mbit/s/m² in the Indoor Hotspot – eMBB test environment

- **User plane latency** - The minimum requirements for user plane latency are 4 ms for eMBB and 1 ms for URLLC

- **Control plane latency** - The minimum requirement for control plane latency is 20 ms. Proponents are encouraged to consider lower control plane latency, e.g. 10 ms

- **Connection density** - The minimum requirement for connection density is 1,000,000 devices per km²

- **Reliability** - The minimum requirement for the reliability is \(1 \times 10^{-5}\) success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms in channel quality of coverage edge for the Urban Macro-URLLC test environment, assuming small application data (e.g. 20 bytes application data + protocol overhead)

- **Mobility** - Mobility is the maximum mobile station speed at which a defined QoS can be achieved (in km/h). The following classes of mobility are defined: Stationary: 0 km/h; Pedestrian: 0 km/h to 10 km/h; Vehicular: 10 km/h to 120 km/h; High speed vehicular: 120 km/h to 500 km/h

- **Bandwidth** - The requirement for bandwidth is at least 100 MHz. The RIT/SRIT shall support bandwidths up to 1 GHz for operation in higher frequency bands (i.e., above 6 GHz)
2.4 5GPPP

The 5G Public-Private Partnership (5GPP) is a joint initiative between the European Commission and the European ICT industry (https://5g-ppp.eu/).

In their Architecture paper [4], 5GPP discusses the challenges, requirements and key differentiating characteristics giving an overview of the 5G eco-system and its design objectives. It discusses some of the architectural, technical and security aspects along with the challenges.

The paper covers the overall 5G architecture and its impact on mobile networks and physical networking as well as service and deployment aspects. This includes discussion of the NFV and SDN aspects covering multi service, domain and security considerations, as well as the logical and functional architecture and the considerations of virtual network functions in 5G. The radio and core network aspects being tailored to the service requirements is covered with NFV and SDN being described in detail.

The physical 5G architecture needs to be adapted to allow the NFV/SDN solutions to be deployed and supported with flexibility and support for multiple services being mapped to the available physical resources. This allows software network technologies and how this software will carry out many of the functions of the radio and core network currently being done in a fixed hardware method. This includes resource and service orchestration and security aspects.

The paper highlights the impact on standardisation and how organisations that are active in the field of 5G architecture and security, such as 3GPP, ETSI, IETF, ONF, BBF and oneM2M, typically have subgroups that have a specific role on architecture and security.

2.5 Small Cell Forum

The Small Cell Forum (www.smallcellforum.org) has a mission to drive the wide-scale adoption of small cells and accelerate the delivery of integrated HetNets. The SCF defines HetNet as a ‘multi-x environment – multi-technology, multi-domain, multi-spectrum, multi-operator and multi-vendor. It must be able to automate the reconfiguration of its operation to deliver assured service quality across the entire network, and flexible enough to accommodate changing user needs, business goals and subscriber behaviors.’

From a 5G perspective, the SCF has published a number of deliverables that examine aspects of 5G business models, architecture and market adoption.

SCF055 [5] looks to define the role of small cells in 5G’s evolution and describes its role as:

- Defining more specifically how small cell architectures can contribute to achieving objectives like network density and energy efficiency.
- Providing leadership for the ecosystem in how to apply principles, such as the open ecosystem and consistent user experience, specifically to small cells.

Further, issues associated with small cells - such as new levels of cost and power efficiency, self-organisation, dynamic capacity allocation and automation - are already visible in 3G and 4G small cells, so the Forum will be able to draw on existing real-world work and experiences in order to inform 5G initiatives.

SCF056 [6] goes further describing three key technologies that can be built into 5G to accelerate adoption and enable value creation using HetNets. Those three elements are:
- Interface for virtualised small cell
- Multi operator/neutral host
- API/services framework

SCF056 further details SCF’s vision for the key enablers for the ultra-dense HetNet that comprises of multiple radio technologies in licensed and unlicensed spectrum, including cellular technologies and Wi-Fi, and emerging standards such as WiGig.

Finally, while service creation and management are important in today’s small cell networks, they will become essential in tomorrow’s 5G network. SCF166 [7] highlights how 5G systems will differentiate themselves from fourth generation (4G) systems, not only through further evolution in radio performance and capacity, but also through greatly increased end-to-end flexibility, in all segments of the 5G networks. This end-to-end flexibility will come in large part from the incorporation of softwarisation into every component of the network. Well known techniques such as software defined networking, network function virtualisation, and cloud computing will allow unprecedented flexibility in the 5G system.

2.6 IEEE 802.11

In late 2015, the IEEE 802.11 Working Group began discussing the possibility of submitting IEEE 802.11 to ITU-R as an IMT-2020 technology [8, 9]. Some of the claimed benefits of taking such an action included:

- Access to additional spectrum allocated for 5G use, particularly in countries that focus on ITU-R allocations
- Better insight into what is required for 5G, which may impact work on IEEE 802.11ax, IEEE 802.11ah and other existing or future standardisation efforts
- Stronger influence to ensure the Wi-Fi industry and its market experiences of a diversity of use cases are reflected in 5G requirements

In early 2016, the discussions in the IEEE 802.11 Working Group were expanded into an IEEE 802 wide activity to examine:

- The costs and benefits of developing an IEEE 5G specification
- The costs and benefits of making a proposal to IMT-2020, with a single technology, a set of technologies or as one or more technologies within a proposal from external bodies (e.g., 3GPP)

Ultimately, IEEE 802 decided to proceed with two parallel activities: [10]

- Ensure relevant IEEE 802 technologies are part of the incumbent mobile operator 5G universe. This work is primarily being driven by the IEEE 802.11 AANI (Advanced Access Network Interface) Standing Committee, which is planning to lead collaboration activities with 3GPP to achieve this goal in the context of IEEE 802.11.
- Ensure IEEE 802 technologies interface with networks of new wireless operators as well as incumbent mobile operators. The main effort to achieve this goal is being driven by the IEEE 802.1 OmniRAN Task Group [11], which is defining a reference model and functional description of an IEEE 802 Access Network (see example in Figure 2-3), suitable for enabling
the use of IEEE 802 technologies by mobile and other operators. This effort is also likely to be supported by an industry outreach (using an IEEE-SA mechanism called Industry Connections Activity) to assess emerging requirements for IEEE 802-based wireless and higher-layer communication infrastructures outside of the IMT domain, identify commonalities, gaps, and trends not currently addressed by IEEE 802 standards and projects, and facilitate building industry consensus towards proposals to initiate new standards development efforts.

Figure 2-3: Considered option for leveraging P802.1CF Interface option to define 5G integration [12]

2.7 IETF

There are several activities being pursued at IETF that have an impact on the 5G vision, especially as it relates to aspects of heterogeneous multi-access connectivity that have been defined, e.g., multi-RAT operation as identified by NGMN, and the establishment of simultaneous multiple connections as identified by 5GPPP.

2.7.1 The QUIC Working Group

QUIC is a multiplexed and secure transport protocol that runs on top of UDP. As its name infers, QUIC is concerned with minimising latency, effectively minimising connection establishment and overall transport latency for applications [13].

In addition, another key focus areas of the QUIC WG is to extend the QUIC protocol to enable multi-path capabilities for connection migration between paths and load sharing across multiple paths. Hence QUIC can be used to help address 5G’s capacity, increased reliability requirements, and lower latency requirements.
2.7.2 Multi-Path TCP

The Multi-path TCP working group has developed mechanisms that add the capability of simultaneously using multiple paths to a regular TCP session [14]. One of the particular use cases described in [15] addresses cellular/Wi-Fi offload. Different configurations of MP-TCP are possible that may be relevant to 5G deployments, including:

- The ability to enable simultaneous use of two wireless networks, whereby Multipath TCP effectively pools the available resources on all wireless interfaces so as to meet 5G’s capacity requirements.
- The ability to provide a backup mode where Multipath TCP opens a TCP subflow over each interface but where data flows only one of those. If one interface fails, 5G’s requirements for enhanced reliability can be met by leveraging Multi-Path TCP’s ability to quickly switch to using the already established subflow over alternative wireless interface.
- The ability to support inter-RAT handover using the break-before-make capability of MPTCP.

As described in [16], the biggest deployment of Multipath TCP is on smartphones, with Siri, Apple’s digital assistant, already using MP-TCP. The paper describes how Siri establishes MP-TCP subflows over both Wi-Fi and cellular interfaces. iOS then uses round-trip time measurements across both interfaces to determine which subflow to use to send the Siri communication.

Another example of MP-TCP deployment is Korea Telecom’s “giga LTE” service. As described in [17] the commercial giga LTE service is based on an MP-TCP proxy service, whereby the UE maintains 2 subflows per session. The LTE access network is used to establish the TCP connection and indicate the UE as being MP CAPABLE and the Wi-Fi access network is then used for the MP JOIN procedure. The network based MP-TCP proxy is used to relay traffic between MP-TCP and TCP, aggregating subflows to provide increased throughput by leveraging both LTE and Wi-Fi simultaneously, as well as performing path monitoring to detect when the Wi-Fi path is unavailable.

2.7.3 BANdwidth Aggregation for interNet Access (BANANA)

BANANA is an early stage group looking into how to take advantage of multiple access links, provided by one or more access providers, in cases where the end nodes and applications may not be multi-access aware. Use cases include [18]:

- Using of multiple access links to provide bandwidth aggregation when multiple links are available (i.e. improved performance)
- Session continuation when a link becomes unavailable (i.e. increased reliability).

2.8 Broadband Forum

The BBF’s TR-348 [19] defines a framework that enables operators to offer coordinated and simultaneous use of fixed broadband and 3GPP access networks. In one deployment scenario, a Hybrid CPE is deployed that can make simultaneous use of two heterogeneous access connections. In addition, a new logical function is introduced in the operator network, the Hybrid Access Gateway (HAG). The HAG implements the network side mechanisms for simultaneous use of both fixed broadband and 3GPP access networks.
3  Evaluate the possible impact of 5G based on output from other bodies.

3.1  Identity

3.1.1  Identity Support

Previous generations of cellular architecture have focused on a monolithic approach to authentication and key agreement based on the EPS AKA algorithm [20] and where the high entropy secret and authentication and keying algorithms are stored and implemented on a tamper resistant UICC card. This can be contrasted with the approach taken by 802.11 defined Robust Security Networks (RSN) that have adopted a generic authentication framework that leverages the Extensible Authentication Protocol [21] that enables support of multiple authentication methods. This EAP framework has been leveraged by WBA in its Next Generation Hotspot activities, enabling a range of use cases that use EAP-SIM, EAP-AKA, EAP-TLS and EAP-TTLS based authentication. Furthermore, this same functionality has been adopted more broadly by enterprises, verticals and their device ecosystems. For example, iOS currently natively supports 7 EAP methods [22], with Android devices currently supporting 8 different methods [23]. In advance of 5G, the Multefire Alliance has enhanced 3GPP defined LTE to support EAP based authentication. Annex A describes in greater detail the evolution of cellular identities, in advance of 5G.

3.1.2  5G Identity and Authentication Architecture

At the time of writing, 3GPP SA3 is still defining specifics around the 5G’s security architecture. However, Figure 3-1 illustrates the 5G core network high level architecture focusing on authentication aspects. The figure shows the use of the newly defined Authentication Server (AUS) to support EAP based authentication. In particular, two of the key security issues that were identified by SA3 in 33.899 [24] are:

- the support of non-AKA based authentication
- the support of a flexible authentication framework for network and service access

Recent agreement in SA3 [25] means that these approaches will see the AUSF be used to support EAP authentication for the (untrusted) non-3GPP access network as well as the trusted 5G gNB New Radio based access. Furthermore, an additional EAP method will be described as an example of how the 5G authentication framework for primary authentication can be applied to EAP methods other than EAP AKA.

As noted by 3GPP, the additional EAP methods are assumed to be used in special use cases, such as in private networks or with IoT devices. Using such capabilities should enable 5G to better target the vertical markets that require identity management and network access security to be managed by the traditional enterprise, a capability that today Wi-Fi is able to uniquely address. However, the 3GPP study into next generation security aspects is clear that 3GPP roaming is only applicable to SIM based identities/authentication.
Figure 3.1: 5G Authentication/Security Architecture

<table>
<thead>
<tr>
<th>5GC Identity Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMF</td>
<td>Responsible for managing UE registration, reachability, connection and mobility. Performs access authentication and authorisation</td>
</tr>
<tr>
<td>AUSF</td>
<td>Responsible for providing EAP server functionality</td>
</tr>
<tr>
<td>gNB</td>
<td>The next generation of NodeB that supports 5G’s New Radio air interface</td>
</tr>
<tr>
<td>N3IWF</td>
<td>Non-3GPP Interworking Function which enables UEs to attach to the 5GC either via trusted non-3GPP access or via untrusted non-3GPP access. (Only untrusted non-3GPP access is defined in 3GPP Release 15)</td>
</tr>
<tr>
<td>SMF</td>
<td>Supports Allocation of UE IP address, User plane function selection and control</td>
</tr>
<tr>
<td>UDM</td>
<td>Provides the repository for user service authorisation information and access to security credentials</td>
</tr>
<tr>
<td>UPF</td>
<td>Responsible for data plane handling functionality, including providing an anchor point for mobility</td>
</tr>
</tbody>
</table>

Table 3-1: 5GC Functionalities associated with authentication and security

In addition, the 5GC will also support enhancements to support secondary authentication between a UE and an external data network [26]. Whereas previous capabilities have been based on PAP/CHAP based authentication between a UE and an external AAA server, 5G will specify the use of general EAP
methods for secondary authentication between a UE and an external data network, and where the EAP method is completely transparent to the 3GPP network.

3.2 Use Cases for IMT in bands above 6GHz

High data rate and service capacity of the network in dense urban environments has become an important application requirement of 5G. The bands with large frequency ranges above 6 GHz offer the potential for increased network capacity as well as network densification. ITU-R M.2243 [27] demonstrates that deployment of small cells is an efficient solution to cope with the ever-increasing demand of high data rate applications.

- Indoor

  Indoor small cells are deployed to improve indoor public spaces with steady daily nomadic (non-mobile) traffic and occasional peaks within the enclosed structures such as hotels and office spaces, often isolated from the macro cell outdoor coverage. In-home small cells will benefit from the favourable radio environment characteristics that avoid interference between neighbouring apartments to offer an enhanced wireless service.

- Outdoor

  In big cities streets with tall sky-scrappers, there are more signal transmission barriers and sudden mobile traffic peaks. Networks and street canyons are truly 3-dimensional, which need to provide communication services at different altitudes. One approach to increase capacity and coverage of existing networks is to combine different networks in different bands while extending indoor systems to outdoor hotspot extensions utilising bands above 6 GHz.

  The mobility and high capacity of public transport in urban environments is also one of the challenges for mobile operators in the future. IMT in bands above 6 GHz could be used to provide access and back-haul/front-haul dedicated to public transportation capable of providing ubiquitous high data rates to users as they enter and leave public transportation facilities.

  In addition, IMT with higher frequencies can also extend wide area coverage to mobile users at macro cells edge, improved quality of service (QoS) and enhanced data throughput can be delivered by exploiting tracking capabilities and adaptive beam forming. The use of bands above 6GHz for small cells is expected to provide the scalability, capacity and density required for a seamless integration of these cells into the cellular network infrastructure.

3.2.1 5G Operation in mmWave

The deployment of new 5G use cases and applications is expected to trigger rapid traffic growth and hence a drive for wider channel bandwidths, ideally delivered in contiguous allocations. These characteristics motivate the need for 5G to be deployed in higher frequency ranges.

ITU-R Report M.2376 [28] examines the feasibility of deploying IMT in bands between 6 GHz and 100 GHz, looking at propagation characteristics, path loss issues, antenna technology and deployment scenarios. As expected, the results of the analysis highlight that the lower bands have better propagation characteristics and coverage, whereas the higher bands are more suitable for outdoor hot-spot and indoor deployments. The report advocates that 5G be defined to allow flexibility in
spectrum usage between 6 and 100 GHz, additionally commenting that there could be advantages with using the same spectrum for access and fronthaul/backhaul.

In July 2016, the FCC published their Report and Order 14-177 [29] covering new rules for wireless broadband operations in frequencies above 24 GHz. This report opens up nearly 11 GHz of high-frequency spectrum for wireless broadband, 3.85 GHz of licensed spectrum and 7 GHz of unlicensed spectrum. In the US, focus is on licensed service use in 27.5-28.35 GHz, 37-38.6 GHz and 38.6-40 GHz bands and unlicensed service in the band at 64-71 GHz.

Within the EU, the Radio Spectrum Policy Group has recommended the 24.25-27.5 GHz band be designated as a pioneer band for 5G above 24 GHz and that Europe should accelerate the development of a harmonisation plan for this band in advance of 5G’s deployment [30].

3.2.2 5G Combining sub-6GHz and mmWave spectrum bands

In their paper examining the potential of mmWave for 5G mobile access [31], Qualcomm highlight that mmWave is a critical access technology to enable 5G to meet its challenging performance targets. The first 3GPP 5G NR specification defined as Release 15 will make use of both sub-6 GHz and mmWave spectrum bands, enabling 5G devices to connect to sub-6GHz and mmWave based accesses simultaneously.

![Figure 3-2: The Role of mmWave in Multi-Connectivity Network. (Reference source: Qualcomm)](image)

3.3 Slicing

The section on 5G business model evolution highlights that the 5G system needs to support different usage scenarios that diverge significantly in their characteristics, from cost-efficient video-centric enhanced mobile broadband, to the diversity of devices used in massive machine type communications, through to the lowest latency and highest reliability systems. Normally an engineering compromise would have to be made in order to realise a system, meaning that not all use cases can be supported. Instead, 5G conceived of the concept of a “slice” which enables the system characteristics to be tailored to a particular use case, as illustrated in Figure 3-3 [32]. Although primarily focusing on partitioning the core network, slicing concepts can include the RAN, enabling partitioning of radio resources between different slices.
3GPP 22.891 examines slicing as a new technology enabler, describing new operational requirements:

- Different network slices shall be able to be operated in parallel with isolation that e.g. prevent data communication in one slice from negatively impact services in other slices.
- Individual slices may be used to deliver service-specific security assurance requirements.
- Slices provide isolation, confining a potential cyber-attack to a single network slice.
- Third parties may be able to create and manage a network slice configuration via suitable APIs.
- Scaling slice capacity shall include the ability to elastically adapt capacity.
- The 3GPP System shall be able to support E2E (e.g. RAN, CN) resource management for a network slice.

### 3.4 Value Creation Enablers

Multi-Access Edge Computing provides an IT service environment and cloud-computing capabilities at the edge of the mobile network, within the Radio Access Network (RAN) and in close proximity to mobile subscribers. The aim is to reduce latency, ensure highly efficient network operation and service delivery, and offer an improved user experience [33].

**Note:** Multi-Access Edge Compute was previously known as Mobile Edge Compute (MEC). In March 2017, the ISG was renamed to better reflect non-cellular operators’ requirements.

The multi-access edge computing environment is characterised by low latency, proximity, high bandwidth, and real-time insight into radio network information and location awareness. Features enabled by the multi-access edge environment include: [34]

- The ability to instantiate a multi-access edge application on a multi-access edge host.
- The ability to relocate a multi-access edge application instance from one edge host to another.
• The ability to expose up-to-date radio network information regarding the current radio conditions.
• The ability to provide information about the location of specific UEs.
• The ability to allocate bandwidth and/or assign priority to any session or to any flows corresponding to an application.
• The ability to register a UE identity and to authorise routing of user-plane traffic associated with the UE to a local network connected to the multi-access edge host.

The MEC architectural framework is illustrated in Figure 3-3, and is split into 3 domains:
• The multi-access edge system level management provides overall visibility of the complete mobile edge system,
• The multi-access edge host level comprises the multi-access edge hosts enabling the multi-access edge applications to be supported on Network Function Virtualisation Infrastructure.
• The network level consists of the network connectivity layer, which may be 3GPP defined, or with the recent re-focusing of MEC, non-cellular.

3.5 Integrated Keying Hierarchy

The 5G Core Network is defining a common keying hierarchy that is intended to encompass all 3GPP and non-3GPP access networks. This can be contrasted to traditional approaches to Wi-Fi integration.
that have defined independent approaches to keying, e.g., with the base-key $K_{ASME}$ being generated as a result of EPS-AKA authentication and the 802.11r key, $R_0$-$KH$, being derived from the Master Session Key generated as a result of an EAP-AKA authentication (e.g., for an 802.11r deployment). Figure 3-5 below shows the 5G integrated keying hierarchy, where now the Master Session Key generated from the EAP exchange will be used to generate $K_{ng}$ which in turn is used to generate the $K_{non-3GPP,RAT}$ for the integrated Wi-Fi access.

3.6 Virtualised Access

Unlike virtualisation of other network functions, virtualisation of wireless access requires that some physical network function is still present to provide the radio frequency capability necessary to support the base station operation. Hence, the first task prior to virtualising the wireless access is to first decompose the access layer into two components. 5G New Radio gNB is characterised by the definition of a new internal RAN split for supporting a decomposition between the gNB Central Unit and gNB Distributed Unit. In particular, the definition of such a split facilitates the realisation of the gNB Central Unit as a Virtual Network Function (VNF), in contrast to the gNB Distributed Unit that can be realised as a Physical Network Function (PNF). After analysing various different split options, 3GPP RAN3 WG concluded that the interface between gNB-CU and gNB-DU will be based on a “non-real time” split, corresponding to the interface between PDCP and RLC sub-layers that can be supported over transport links with latency ranging from 1.5 to 10ms. 3GPP is defining the F1 interface, as illustrated in Figure 3-6, for supporting the decomposition between CU and DU.
More recently, 3GPP RAN3 has started discussing the further decomposition of the gNB-CU into Control Plane and User Plane functions [35]. As described in the contribution, such an approach provides the possibility of optimising the location of different RAN functions based on the scenario and desired performance. For example, the CU-CP could be placed in a location close to the DU, thus providing short latency for the critical CP procedures. On the other hand, the CU-UP could be centralised in a regional or national data center, thus favoring cloud implementation, and providing a central termination point for UP traffic in dual-connectivity and tight-interworking scenarios. An additional CU-UP could be also placed closer (or co-located) with the DU to provide a local termination point for the UP traffic for applications that require very low latency.

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**Figure 3-6: 3GPP defined split for supporting New Radio**

**Figure 3-7: 3GPP proposal to enable flexibility in gNB-CU CP and gNB-CU UP functionality**
4 5G Business Model Evolution

As reported by NGMN, on top of supporting the evolution of the current coverage and capacity focused consumer business models, 5G will expand to new ones to support different types of customers and partnerships. 5G is targeted at supporting vertical industries, and contribute to the mobilisation of industries and industry processes.

With the return on investment skewed towards the vertical enterprise, these segments are typically served by private networks and frequently based on Wi-Fi technology. These can be independently deployed and can be configured to serve all users, irrespective of carrier affiliation. This section looks at 5G business model evolution and its impact on Wi-Fi and WBA Stakeholders.

4.1 3GPP

3GPP TR 22.891 [32] lists potential use cases for 5G networks into 4 main categories:

- enhanced Mobile BroadBand (eMBB)
- Massive Internet Of Things (MIOT)
- Critical Communications (CriC)
- enhanced Vehicle-to-X communications (eV2X)

However, to give 3GPP Release 13 IoT technologies a chance to succeed, the IoT use cases have been removed from the scope of 3GPP Release 15. Similarly, there is no urgency in Release 15 to enhance the V2X communication already being defined in Release 14.

The specific new business models enabled by 3GPP Release 15 RAN and 5GC will include:

- Higher-throughput mobile broadband in the 1 Gbps – 10 Gbps range
- Short-latency communications, such as for VR/AR applications
- Mobile broadband communication re-anchoring the user at new IP anchors, thereby minimising latency or maximising bandwidth
- RAN/5GC operators authenticating non-SIM based UE based on new identities which are more independent from the access technology
- eMBB Layer 2 wholesale, using the new PDU definition of “Session Type = Ethernet”.

4.2 NGMN

In their 5G whitepaper [1], NGMN predict that the business context beyond 2020 will be notably different from today, with the emergence of new use cases and business models. In addition to supporting the evolution of the current consumer-centric business models, 5G will expand to enable operators to support vertical industries with new vertical revenue streams, and contribute to the mobilisation of industries and industry processes.

These requirements can be contrasted with NGMN’s view of 4G system design, that has been focused primarily on supporting mobile broadband services, leaving it ill equipped to address new services that do not cleanly fit in this monolithic service category. NGMN highlights the lack of well-defined
interfaces to the service layer as being a specific deficiency, resulting in expensive proprietary solutions being frequently required to launch new services.

Specifically, these new vertical opportunities are often interested in supporting value chains outside of the classical MNO-centric coverage and capacity propositions and hence the 5G system needs to be defined to facilitate these new markets. No area highlights this evolution as much as the focus on IoT, which is disrupting the classical cellular value chains, where the IoT stack necessitates moving beyond basic connectivity towards enablement platforms and customised vertical specific IoT applications [36].

The 5G mobile technology needs to be able to support new value chains on a converged infrastructure, via standardised APIs that expose information associated with a set of value creation opportunities. In their whitepaper, NGMN describe 9 areas of value creation that complement baseline network connectivity, as shown in Figure 4-1.

![Figure 4-1: NGMN Identified Value Creation Opportunities](image)

These new value creation opportunities, enabled by standardised APIs, will allow 5G to facilitate the realisation of different business models. Hence, compared with legacy mobile networks which have been largely monolithic in their supported value chains of ubiquitous access to mobile network capacity, 5G networks and their associated resources need to be able to be logically partitioned into different slices, providing the necessary functionality to support a particular use case and associated value chain while avoiding all other unnecessary functionality. These logical slices allow the different use cases to be supported on a common, shared infrastructure. Naturally, the associated network sharing support has been highlighted as a foundational capability of the 5G systems. This capability will ensure that new as-a-Service consumption models can be supported, by asset providers that support multiple connectivity providers with enriched services which can be provided by partner organisations, as illustrated by NGMN in Figure 4-2.
The 5G value chain evolution is following a path that, to date, has been focused on Wi-Fi based technologies. For example, context based value creation is already a popular use case being championed by vertical solutions based on Wi-Fi. Access network exposure of device hyper location is already being used by Wi-Fi systems to enable new vertical value chains to be supported. Various verticals using location derived from the access network to support innovative vertical value chains include:

- Airports that are using Wi-Fi derived location analytics to predict security queuing times
- Shopping malls that are using Wi-Fi location to provide personalised mobile shopping experiences as well as providing shop window conversion rates to retailers
- Hotel operators that are using Wi-Fi derived location analytics to match front of desk staffing with visitor demand

4.3 ITU-R

IMT for 2020 and beyond is envisaged to expand and support diverse usage scenarios and applications that will continue beyond the current IMT. The following three usage scenarios are described in the ir whitepaper [2]:

- **Enhanced Mobile Broadband**: In addition to existing mobile broadband applications, IMT for 2020 will improve network capability and enhance user's seamless experience to provide new applications and meet the requirement of enhanced multimedia services such as medical care, security, entertainment and other high-definition multimedia services. From a business model perspective, this can be seen as an evolution of traditional coverage and capacity based value propositions, including supporting wide-area coverage, and seamless coverage and higher data rate with high mobility, as well as targeted hotspot deployments, requiring large traffic capacity and higher data rates for high user density.
• **Ultra-reliable and low latency communications**: This use case has strict requirements for capabilities such as throughput, latency and availability, enabling instantaneous connectivity without waiting times, the new services enabled around virtual reality and augmented reality applications. These capabilities will enable service providers to build new value propositions, delivering slices that are dedicated to new applications with real-time constraints, e.g. autonomous transportation, telemedicine surgery, and so on.

• **Massive machine type communications**: This use case is characterised by a large number of connected devices typically transmitting relatively smaller data with non-delay sensitivity. The number of devices connected to network through wired or wireless links is growing rapidly and is expected to exceed the number of human user devices in the future. As described in [37], this evolution will see value migrating to so called “IoT middleware” that delivers M2M application enablement, device management and analytics platforms. Moreover, massive machine type communications brings with it a diverse set of value chains, likely delivered in a phased approach that includes:

  - Phase 1 - Operational efficiency: Looking to optimise asset utilisation, deliver operational cost reduction and/or worker productivity.
  - Phase 2 - New Product and services: including taking traditional products (e.g., a car) and delivering value added services (e.g., connected car, infotainment, remote engine diagnostics, etc.), that are software based and consumable on a pay-per-use basis.
  - Phase 3 - Outcome based offerings: Applying advanced analytics to a broad range of data derived from IoT systems as well as external systems, companies will be able to gain a better understanding of interactions and causality among a set of observed data variables, and to determine what it takes to manipulate the variables in order to achieve a desired outcome.
  - Phase 4 - Autonomous Pull Economy: Defining closed loop systems that are continually self-optimising for optimised resource utilisation.
4.4 Vertical Requirements For Multi-Operator/Neutral-Host (MO-NH)

5G needs to be designed to thrive in an environment where, even today, over 80% of mobile data is being consumed indoors. It’s becoming increasingly evident that a significant proportion of these indoor environments where the vast majority of data is being consumed, comprising retail properties, transportation hubs, healthcare environments and education establishments, want to be able to offer wireless connectivity to all their visitors, irrespective of carrier affiliation. These are the observations from a new paper on multi-operator challenges produced by 5G Americas and the Small Cell Forum [37].

Furthermore, in their whitepaper, NGMN calls out requirements for 5G to enable new flexible business models based on network sharing agreements, providing functionality to accommodate the capacity needs of dynamically hosted operators, on a real-time basis (e.g., for capacity brokering architecture, where network resources are provided dynamically depending upon bids offered).

More recently, GSMA in their recent report on 5G [38] describe how 5G will see network sharing intensify in the 5G era. Specifically, GSMA highlights that neutral host approaches could be required for small cell deployment.
Once again, 5G looks to be following the experience of Wi-Fi and the use of unlicensed spectrum which enables Wi-Fi to simply address a broad range of multi-operator use cases, including enabling the vertical to operate as the Neutral Host provider, using a shared Wi-Fi infrastructure to support its own vertical specific requirements as well as multiple Carrier Wi-Fi operators.

Separate WLAN SSIDs are used to partition, or “slice”, traffic with tunnels and VLANs being used in the network to ensure isolation between the different providers operating on the shared infrastructure. Furthermore, enhanced configuration can be used to ensure radio resources are allocated on a per SSID basis, offering the neutral host provider better control of how resources are shared. With such capabilities, it is evident why today’s Wi-Fi is considered by both Small Cell Forum and 5G America’s as the default choice for addressing the multi-operator needs of the verticals.

### 4.5 Sliced/Shared Network Supporting XaaS Business Models

With the focus on vertical markets, new value creation via API definition and the logical partitioning of resources in different network slices, 5G is set to enable a transition in the established mobile business models. NGMN predicts a partitioning of roles between asset provider, connectivity provider and enriched service providers that are focused on agile service realisation using different XaaS business models.

Specifically, the virtualisation of 5G network will enable new service offerings, including software license based solutions as functions evolve from dedicated hardware towards generic Virtual Network Functions running on standardised Network Function Virtualisation Infrastructure (NFVI). This evolution enables rapid deployment of service instances as well as on demand service replication with isolation between individual service instances to support the network slicing capabilities.

This business model transformation anticipated with 5G is already being experienced by using Wi-Fi technology. From a radio perspective, back in 2005 the Wi-Fi industry decomposed the autonomous Access Point into a lightweight Access Point and a Wireless LAN Controller (WLC) and now the industry is leveraging the virtualisation of the Wireless LAN Controller to revolutionise carrier Wi-Fi deployments. Compared with legacy deployment models, the as-a-Service approach is enabling...
Service Providers to already offer reduced TCO and rapid expansion of carrier Wi-Fi deployments that can be customised and targeted towards verticals such as hospitality, education and government.

As is evident, virtualising the Wi-Fi access layer has enabled new business models to be created, including asset providers supporting Infrastructure-as-a-Service, cloud based connectivity providers that deploy the virtualised RAN components, including control plane, data plane and management functions, and the enriched service providers that are able to leverage the APIs exposed by the connectivity provider to allow agile realisation of vertical offerings.

### 4.6 5GPPP Business Models input

5GPPP has produced papers on topics covering vertical sectors including:

- Automotive
- Energy
- eHealth
- Factories of the Future
- Media Entertainment

5GPPP suggests possible new business models for each sector and how 5G can be a catalyst for the definition of new sector specific propositions.

#### 4.6.1 Automotive

New business models suggested include Pay as you Drive, Mobility as a Service (a solution to find the most appropriate means of transport, with the best conditions, according to the actual needs and mobility conditions in real time) and Predictive Maintenance. There are various automotive use cases considered including: automated driving, road safety and traffic efficiency services, digitalisation of transport and logistics, intelligent navigation and information society on the road as well as pay as you drive, mobility as a service and predictive maintenance. 5G is seen as a catalyst as it has improved performance over existing technologies such as those based on IEEE 802.11-2016. This includes, amongst others, latency, data rate, reliability, range and security.

#### 4.6.2 Energy

New business models suggested include Smart Grid (an enhanced electricity supply network that uses digital communications technology to detect and react to local changes in usage) with Smart assets with secure safe reliable and sustainable operations enabled by 5G. The smart grid becomes more flexible and efficient but critically depends on the availability of high-quality data collection, transmission and analysis for operations and marketing. All this results in a customer-centred industry, possibly a shared economy for electric power. However the paper is focused on electricity distribution and does not consider other utilities such as gas and water.

#### 4.6.3 eHealth

The eHealth vertical considers delivering treatment and care outside hospitals in homes, rural areas and with the attention shifted to root causes such as lifestyle and wellness. One of the main focuses is on lifestyle and the early prevention of health issues. 5G could help in areas such as asset
management, robotics, smarter medication and remote monitoring of health and wellness data. There are some specific performance requirements of 5G needed to meet some of the use cases including reliability, latency, mobility and positioning accuracy. Business models and value chains should be flexible and adaptable to allow each stakeholder group to focus on its core competencies, such as delivery of care, sector application development, platform, infrastructure or network service provisioning.

4.6.4 Factories of the Future

5G is expected to help areas such as facilitating automation, addressing ubiquitous communication, contributing to wide-area resource monitoring networks, and minimising energy consumption. This includes three concepts:

- **Smart Factories** with the automated operation of the shop-floor, integrated embedded computers, real-time monitoring, adaptive control, autonomous actuation and cooperative machine to machine interaction.
- **Digital Factories**: with human-team agile exploitation and analysis of vast amounts of digital information, knowledge management, informed planning and complex simulation and collaborative product-service engineering support.
- **Virtual Factories**: that are connected and collaborative enterprises of highly flexible global supply chains of connected eco-systems.

4.6.5 Media Entertainment

Some typical use cases include Ultra High Fidelity Media, On-site Live Event Experience, Immersive and Integrated Media, Cooperative Media Production and Collaborative Gaming. In the 5G services market, new business models will emerge, with collaboration between network service providers, and between network service providers and their suppliers. It has been seen that users are already changing their consumption of media moving to on-demand rather than linear delivery, but still a need to cope with peaks of demand for live events such as Olympics.

5G is a catalyst for Media and Entertainment, growing demand for video presents challenges to cellular networks and it will not be efficient or economic to distribute live video and audio across thousands of network cells. One solution will be Content Delivery Networks with 5G will be needed to deliver the service with parameters to meet new business cases as they arise.

5 Foreseen Wi-Fi evolution to cope with 5G predicted requirements

5.1 802.11 and Combining sub-6GHz and mmWave spectrum bands

Compared with the relatively recent investigation into operations in mmWave spectrum by the licensed cellular community, back in 2012, the 802.11 community published IEEE 802.11ad [39] which covers enhancements to deliver very high throughput by operating 802.11 in the 60 GHz band. In addition to defining operation in the 60GHz band, the 802.11ad amendment also defines multi-band operation where a multi-band capable device can manage operation over more than one frequency band/channel and where such operation can be simultaneous or non-simultaneous.
Because of the different propagation characteristics of sub-6GHz and mmWave spectrum, the 802.11ad amendment specified the use of Fast Session Transfer (FST) which is the ability to seamlessly transfer a session from a channel to another channel, in the same or different frequency bands. The aim of this capability is to be able to compensate for the quick spatial transitions that may see 60 GHz operation be blocked, requiring a very rapid switching to operate at sub-6 GHz.

Depending on the device’s capabilities, during the FST session establishment, the FST session can be set up to be operational in one band/channel, or may be operational in multiple bands and/or channels simultaneously. FST can be non-transparent where the MAC addresses used on the different bands are different, or transparent, where the same MAC address is used on all bands/channels.

Figure 5-1 illustrates the operation of Fast Session transfer where a new FST virtual MAC sub-layer is defined to link all concurrent interfaces. The one FST virtual MAC is the only one seen by the network, meaning operation of FST is transparent to such. Finally, the figure shows the use of a forwarding decision based on a table to link the interfaces to each flow of a virtual MAC address.

Figure 5-1: FST Operation in STA and AP [40]

5.2 IEEE 802.11ax

When 5G starts getting deployed in 2020, IEEE 802.11ax, the next version of Wi-Fi, should already have been published and equipment readily available. However, at the time of writing, IEEE 802.11ax standardisation activities are still in progress and so this section describes those features and capabilities likely to be in the final specification, based on Draft 1.0 of the enhancements for High Efficiency WLAN [41].
In many regards, the enhancements being defined in the 802.11ax amendment can be seen as a revolution compared with earlier iterative enhancements that have taken us from 802.11b through to 802.11ac. 802.11ax adopts OFDMA where subcarriers are divided into several groups and where each group is represented as a Resource Unit (RU). This is illustrated in Figure 5-2 below, showing the shift from OFDM and 802.11ac where only a single user can access up-link resources at any moment in time and the OFDMA in 802.11ax whereby multiple users are able to be allocated distinct Resource Units to enable multiple users to transmit over the up-link at any moment in time.

![Figure 5-2: Predicted IEEE 802.11ax timeline [42]](image1)

![Figure 5-3: Comparison of OFDM in 802.11AC and OFDMA in 802.11AX](image2)
The shift to a multi-user PHY in 802.11ax triggers a significant change in the design on the MAC layer. In previous versions of 802.11, the medium can be sensed as busy by a contending station. With a multi-user PHY, the contending stations need further information pertaining to the availability of resource units and hence the radio resources need to be managed on a finer granularity. IEEE 802.11ax solves this problem by switching to a centralised allocation of radio resources. A new Trigger Frame is used to signal the Resource Allocation to the different Stations, as illustrated in Figure 5-4. The figure illustrates the trigger frame that carries the scheduling information for the multi-user uplink, which is followed after a SIFS by the requested immediate responses from the identified stations.

![Figure 5-4: Example of a triggered UL multi-User transmission with an immediate Multi-STA Block Ack frame acknowledging the UL transmissions](image)

A new Random Access procedure is also defined to enable 802.11ax Stations to send their requirements, either a Bandwidth Query Report (used to report channel availability information) or a Buffer Status Report (where the BSR details the up-link queue depth for each access category). The 802.11ax Access Point can use this information when determining how to allocate RUls between the different Stations. For example, when serving periodic traffic, the AP can allocate RUls periodically to serve the traffic. In other scenarios, if the Station indicates that more data is ready, then the AP can continuously allocate Resource Units to this endpoint. In other scenarios, the AP can avoid allocating Resource Units until a new BSR is received from the Station.

Simulations have demonstrated that the ability of 802.11ax to avoid the heavy collisions associated with dense Wi-Fi deployment leads to significant improvements over baseline 802.11ac performance. Figure 5-5 shows recent simulation results, comparing 802.11ax and 802.11ac up-link performance for different density of Stations [43]. The results show that the benefits of the 802.11ax scheduled up-link compared with the legacy unmanaged approach, delivering better resource utilisation and an impressive increase in efficiency.
As it relates to 5G, the lack of up-link scheduling in previous versions of 802.11 has been highlighted as one of the claimed benefits by the 3GPP ecosystem of LTE operation in un-licensed bands. Evidently, the divergences between 3GPP and IEEE 802.11 MAC designs are set to diminish with the introduction of 802.11ax.

5.3 WBA’s Analysis of IoT Vertical Value Chains and Interoperability

One of the key characteristics identified by the WBA’s earlier work on IoT [36] is the increasingly diversified and complex value chains that need to be supported, e.g., when compared to the conventional network connectivity focused value chains that apply in today’s mobile broadband type service. Analysis indicates that as 5G aspires to address new use cases, there will be a migration of value from coverage and capacity, towards “higher layer” value, e.g., associated with increase asset utilisation, decreasing resource wastages, increasing energy efficiency, etc.

![Figure 5-5: Throughput improvement of 802.11ax compared with 802.11ac vs Density for UL MU MIMO](image)
The WBA’s IoT analysis has also highlighted the need for some IoT use cases to be supported over connectivity networks with enhanced service assurance and reliability. It has been concluded that there is an opportunity for WBA to describe best practice aspects of Wi-Fi system configurations necessary to address the support of time critical communications, service reliability and service outage avoidance.

These capabilities are crucial in demonstrating that Wi-Fi based systems can be used to support the Ultra-reliable and low latency use cases described in ITU’s 5G Vision [2], which describes a set of 5G use cases that have stringent requirements for capabilities such as throughput, latency and availability.

5.4 Decomposition of Wi-Fi Access

The decomposition that is driving the 5G ecosystem to enable the 5G gNB to be decomposed into VNF and PNF components can be likened to the established decomposition of a Wi-Fi access point into Access Controller and Wireless Termination Point functions. Figure 5-7 illustrates this decomposition of the Wireless Access, contrasting the conventional decomposition of the Wi-Fi access point into Access Controller and Wireless Termination Point functions and the 5G NR decomposition into gNB-CU and gNB-DU components.
Moreover, the recent proposals to further modularise the gNB-CU into Control Plane and User Plane modules then facilitates the same deployment options that are available with today’s Wi-Fi, whereby the Layer 2 can be handled locally, e.g., with the 5G NR gNB CU User Plane module being co-located with the gNB-DU, or where the Layer 2 can be handled remotely, e.g., with a composed 5G NR gNB-CU being deployed centrally and 3GPP New Radio’s layer 2 functions split between DU and CU locations, as illustrated in Figure 5-8.

![Figure 5-7: Decomposing access into PNF and VNF components](image)

5.5 Evolution of Wi-Fi capabilities

Earlier in section 2.3, the 8 broad capabilities that IMT 2020 based systems are expected to support were introduced. These capabilities are linked to the various usage scenarios and applications for IMT-2020, but with an assumption that the system has the flexibility and diversity to be configured to be able to support different use cases and scenarios.
ITU M.2083 defines key targets for these capabilities, and has represented these on a spider diagram which is used to compare the values associated with IMT-Advanced with those targets for IMT-2020, as illustrated in Figure 5-9.

**Figure 5-9: Comparison of key capabilities between IMT-Advanced and IMT-2020**

This same representation can be used to compare the anticipated capabilities of 802.11 based systems using published data, enabling the foreseen evolution of Wi-Fi to be described, together with its ability to accommodate the predicted 5G use cases:

- **Peak data rate** – 802.11ax peak data rates [44]
- **User experienced data rate** – 802.11ac specifies that a receiver at -67 dBm (e.g., edge of cell for VoWi-Fi deployment) will be able to receive 16-QAM \(\frac{1}{2}\) for a 80 MHz transmission, equivalent to 117 Mbps for 1 SS (800 ns GI) [45]
- **Latency** – 802.11ax latency [46]
- **Mobility** – 802.11p mobility [47]
- **Connection density** – 802.11ax connection densities [48]
- **Energy efficiency** – 802.11ax [49]
- **Spectrum efficiency** – 802.11ax [50]

*Note: In ITU M.2083, both the energy and spectrum efficiency values are ratios comparing IMT-2020 to previous IMT-Advanced capabilities. In order for completeness, the equivalent ratios defined for 802.11ax enhancements compared to previous 802.11 versions are used in the analysis.*

- **Area traffic capacity** – 802.11ad [51]

*Note: Figures associated with 802.11ad are used as they are representative of an 802.11 mmWave deployment, e.g., compared with ITU M.2083 that discusses frequencies up to 100 GHz and channel bandwidths up to 1 GHz.*
This data has been overlaid on the same spider diagram used to represent the enhanced capabilities in M.2083, as illustrated in Figure 5-10. This figure clearly illustrates that 802.11 based systems can outperform the IMT-2020 requirements related to area traffic capacity and latency, whereas network efficiency values are above those associated with IMT-Advanced, and they do not meet the target requirements for IMT-2020. Finally, the figure shows that when it comes to mobility support, the enhanced requirements to support vehicular use cases defined in the original IEEE 802.11p amendment (since incorporated into the 802.11-2012 standard) are lower than the 350 km/h speeds that can be supported with the baseline IMT-advanced systems.

**Figure 5-10: Enhanced 802.11 capabilities compared with IMT-Advanced and IMT-2020**

### 6 Impact of 5G on Wi-Fi Networks & What is missing from Wi-Fi Technology

At a high level, it is clear that Wi-Fi is having a significant impact on the definition of 5G. As reported previously, we see 5G following Wi-Fi in its adoption of several key characteristics, including:

- The adoption of an EAP authentication framework that decouples authentication techniques from the underlying infrastructure.
- The broadening of identity concepts in 5G, with the likely specification of asymmetric keying and EAP-TLS.
- The definition of combined operation in <6 GHz and mmWave bands.
- Supporting new vertical value chains with API based value creation enablers.
- Private 3GPP-based deployments with shared spectrum and WFA defined on-line signup integration.
• Shared infrastructure propositions for supporting wireless service to all indoor users, in a multi-operator deployment.
• 5G business model transformation with XaaS following cloud Wi-Fi solutions that are already available in the market.

However, there are also key areas where 5G technology and market segmentation are anticipated to impact Wi-Fi and so the remainder of this section analyses those key areas.

6.1 Next Generation Hotspot and Seamless Authentication

The issue of seamless authentication for Wi-Fi as a trusted access in a 5G architecture is one area that needs to be considered. As described earlier, 3GPP Release 15 provides integration of Wi-Fi only as an untrusted non-3GPP access, meaning that any solution that requires integration of Wi-Fi as a trusted access network, e.g., leveraging Next Generation Hotspot capabilities, will need to wait until the N3IWF is enhanced with such capabilities (targeted for Release 16) or rely on earlier Release 12 SaMOG functionality.

More broadly, seamless access to Wi-Fi connectivity already works well for supporting specific use cases, including:

• Residential users automatically authenticated to residential Wi-Fi networks using WPA2-PSK
• Enterprise users automatically authenticated to enterprise Wi-Fi networks using EAP/802.1X
• Carrier Wi-Fi customers automatically authenticated to carrier-Wi-Fi networks using Next Generation Hotspot/802.1X.

There are still gaps in providing seamless access to Wi-Fi due to the poor provisioning experience outside of the above groups. For example, the provisioning of devices from partners, contractors and guests onto enterprise Wi-Fi networks is still poor, and the provisioning of the massive numbers of IoT devices, that may lack the display and input capabilities used to sign-up smartphone and that may be supported using a diverse set of Identity Providers is yet to be addressed by the industry.

These issues are currently being addressed by the WBA in its IoT and Dynamic Roaming Project.

6.2 Instrumentation for Optimised Aggregated Access using Wi-Fi and 5G

There is now consensus that there are three broad approaches of how to integrate Wi-Fi and 5G:

• Access Centric Integration: these approaches were first introduced in Release 13 for LTE based access, with LWA for integrating trusted Wi-Fi and LWIP for integrating untrusted Wi-Fi. These approaches have been described in greater detail in [52].
• Core-Centric Integration: these approaches were standardised in Release 8 for the integration of un-trusted Wi-Fi via an ePDG and in Release 11 for integrating trusted Wi-Fi into LTE’s Evolved Packet Core, as described in [53].
• Above-the-core integration: using techniques such as Multi-Path TCP, Quick UDP Internet Connection (QUIC).

Furthermore, there is increasing interest in being able to move from a “handover-centric” switched use case where only a single access is used at any time towards an “aggregation-centric” simultaneous use case where a device has access to multiple accesses at any time.
What is evident is that the performance of various aggregation approaches can be enhanced by having instrumentation related to the performance of the different access mechanisms. To date, this has been used to the advantage of access-centric approaches to integration that benefit from real-time instrumentation of the operation of the LTE access network, together with inferred instrumentation representing the performance of the Wi-Fi network, e.g., using Xw user-plane flow control [54], as well as the relaying of Hotspot 2.0 broadcast channel load information via the UE back to the LTE eNB.

Instead of using Wi-Fi instrumentation to promote any specific approach to Wi-Fi integration into 5G, WBA has the opportunity to define enhanced instrumentation capabilities that can then be consumed by access-centric, core-centric, or above-the-core architectures to improve the overall aggregated performance of such combined propositions.

6.3 Wi-Fi and MEC

The exposure of information related to access network performance discussed in the previous section is one of the MEC application platform services. The MEC defined Radio Network Information Service (RNIS) provides authorised applications with low-level radio and network information, including cell load and throughput guidance. The RNIS service can also provide measurements and statistics related to the user plane.

With the broadening of MEC to look at non-cellular use cases, there is the opportunity for the WBA to take the lead in defining a set of RNIS services for Wi-Fi, addressing the instrumentation requirements for optimised Wi-Fi and 5G aggregation.

6.4 Extreme Real-Time Communications

In their 5G whitepaper, NGMN describe automated traffic control and driving as two leading use cases that drive requirements around low latency communications. 5GPPP go on to describe how 5G’s 1ms latency for direct mode is compatible with the stringent requirements of automated driving [55].

As it relates to Wi-Fi based technology, although 5G proponents naturally advocate the use of 3GPP based technologies for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, currently the Dedicated Short Range Communications (DSRC) is implemented using the original 802.11p amendment (since incorporated into the 802.11-2012 standard).

In December 2016, the US Department of Transport’s National Highway Safety Administration issued a notice of proposed rulemaking [56] which proposes to mandate to vehicle-to-vehicle (V2V) communications for new light vehicles and to standardise the message and format of V2V transmissions. It is proposed that manufacturers will be required to implement Basic Safety Messages transmitted over DSRC within the 5.850 to 5.925 MHz band, whereby the lower layers of DSRC are defined primarily by the original IEEE 802.11p amendment with enhancements defined in IEEE P1609.4 [57].

6.5 Wi-Fi and Slicing

The concept of network slicing is considered a key mechanism for 5G networks to serve vertical industries with widely different service needs, in terms of latency, reliability, capacity, and domain specific extra functionalities. It does so by exposing isolated partitions of network resources and services.
Wi-Fi networks have offered “slicing-like” capabilities using support for multiple SSID and/or the ability to use RADIUS based signaling to allocate a user to a particular VLAN. Whilst this provides isolation between slices, the resources can be partitioned using a variety of approaches, including:

- Rate limiting applied per SSID
- Rate limiting applied per client
- Rate limiting per radio
- Partitioning 802.11 airtime resources between SSID, between user-groups or between device categories

Compared with the excellent isolation and resource partitioning available over Wi-Fi, network slicing concepts cover a broader set of capabilities, including efficiently sharing different resources, including radio spectrum, infrastructure and transport [4]. Consequently, a sliced architecture in a Wi-Fi environment will need to address the end-to-end orchestration of resources across different domains.

6.6 Supporting High Speed Transport Use Cases

ITU M.2083 describes the use cases that drive requirements to enable high mobility (up to 500 km/h) are associated with high speed train environments. As reported in [58], Wi-Fi has already been used to provide train to trackside connectivity. [59] provides results of trials with 802.11b technology, concluding that this technology is able to provide communications with a train travelling at speeds of up to 144 km/h (90 mph), but with significant variation in throughput due to handover issues. More recently [60] has demonstrated that 802.11n can be used to provide train to trackside connectivity with coverage ranges between 5 and 9km of railway line.

In order to address the handover and latency issues, several companies have modified 802.11 technology to adapt it to the high-speed rail environment. For example, Fluidmesh (www.fluidmesh.com) use unlicensed spectrum together with a modified 2x2 MIMO 802.11 system to provide trackside wireless systems operating in the 5GHz band that is claimed to provide connectivity of up to 100 Mbps on trains travelling at up to 350 km/h with handover interruptions below 3ms.

6.7 Roaming for Non-3GPP Subscription Identifiers

Section 3 has highlighted that 5G will see the broadening of identity concepts to include non-SIM/IMSI use cases. These are called “Non-3GPP subscription identifiers” in [24].

However, the 3GPP study into next generation security aspects is clear that 3GPP roaming is only based on 3GPP subscription identifiers. Even though an identifier of the type "sensor12345@factory.example.com" can be used within a 5G industrial automation environment, because 3GPP roaming is not based on NAI, the non-3GPP subscription identifier cannot be used in roaming scenarios.

However, there may be scenarios where such a capability is desirable. Such a scenario then motivates the support for a “roaming” use supporting 5G access by the non-3GPP subscription identifier outside of the factory environment.
As WRIX based roaming is based on supporting NAI-based roaming, there is the opportunity to broaden the definition of WRIX to support roaming of 5G non-3GPP subscription identifiers.

6.8 Wi-Fi within 5G’s Integrated Keying Hierarchy

Earlier in section 3, 5G’s integrated keying hierarchy was described, where now the Master Session Key generated from the EAP exchange will be used to generate $K_{mg}$ which in turn is used to generate the $K_{\text{non-3GPP,RAT}}$ for the integrated Wi-Fi access.

Note however, as also discussed, the integration of trusted non-3GPP RATs is not included in the scope of Release 15.

In the current Wi-Fi systems, the EAP Master Session Key is used to generate Wi-Fi keying material. For example, when using 802.11r, the MSK is used to derive the Pairwise Master Key R0 (PMK–R0), which is the first-level key of the Fast Transition key hierarchy.

In future, the standards for 802.11 key generation will need to enable the PMK–R0 to be derived from $K_{mg}$.

7 Next steps for the WBA

7.1 Address Wi-Fi provisioning gaps

Next Generation Hotspot (NGH) is a set of capabilities, including enhanced network discovery and automatic authentication defined by the Wi-Fi Alliance Hotspot 2.0 Technical Specification [61] to deliver a set of features that enhance the carrier Wi-Fi user experience. NGH deployments may look to re-use already provisioned credentials, e.g., using EAP-AKA based SIM card authentication, or provision new credentials using an on-line sign-up procedure.

In the enterprise environment, processes are commonly used to provision, or on-board, corporately owned and liable devices using employee credentials to trigger the downloading of a profile to the specific device.

In the residential environment, users are increasingly accustomed to using Wi-Fi Protected Setup (WPS) to provision new devices onto their home Wi-Fi network, or sharing their WPA2-PSK passwords with friends and family to enable them to benefit from the in-home Wi-Fi network.
However, outside of these carrier Wi-Fi, enterprise, residential environments, Wi-Fi still suffers from a poor provisioning experience which is set to be challenged by the large increases in IoT devices. These devices typically lack the display and user input capabilities used in conventional On-line Sign-Up (OSU) provisioning.

The WBA’s IoT Dynamic Roaming project is looking at how the WBA and broader industry can address these gaps.

### 7.2 Wi-Fi Performance Instrumentation

MEC’s Radio Network API [62] Radio Network Information Service (RNIS) provides radio network related information to multi-access edge applications and to multi-access edge platforms. The analysis around aggregation indicates that the performance of such systems is improved by having real time instrumentation as to the performance of the various wireless access technologies being combined/aggregated.

Previously, work by the WBA has analyzed the issue of Quality of Service, including mechanisms to monitor various QoS metrics in a deployed Wi-Fi network [63]. While the use cases discussed in that project focused on the communications of QoS metrics to connecting devices, in order to allow the device to learn about the Wi-Fi network, the aggregation use cases described in this document, highlight the need for a common framework that can expose similar information to devices or other network elements, e.g., those involved with aggregating Wi-Fi and cellular communications links.

![Figure 7-1: Wi-Fi Network Metrics](image)

WBA should, in co-operation with ETSI MEC, define an API to enable the exposure of radio network related information from Wi-Fi access networks, with one of the requirements being to improve the various approaches to aggregation (splitting), as well as steering and switching (irrespective to whether those be access-centric, core-centric or above-the-core). Issues where decisions need to be made based on instrumentation with different delays and/or averaging algorithms will likely need cross industry analysis.
7.3 WRIX enhancements for 5G Roaming

Even though from a 3GPP perspective an identifier of the type "sensor12345@factory.example.com" can be used within a 5G industrial environment, because 3GPP roaming is defined to be SIM based and not based on NAI, the 3GPP Study on 5G security is clear that the non-3GPP subscription identifier cannot be used in 5G/GSMA roaming scenarios.

However, back in 2011, a joint taskforce was set-up between GSM Association (GSMA) and the WBA to address Wi-Fi roaming, with the intention of bringing together the Wi-Fi and cellular ecosystems. Compared with 3GPP defined SIM based NAIs, GSMA procedures had originally been enhanced to support web based logon, such that GSMA procedures can be used to support NAI based roaming for legacy web-based authentication of Wi-Fi users.

As part of on-going GSMA engagements, WBA should consider raising the issue of NAI-based roaming involving non-3GPP subscription identifiers.

7.4 802.11 in High Speed Vehicular and Rail Environments

WBA should consider forming a new project on the use of Wi-Fi in vehicular and rail environments.

7.5 Integrated Keying Hierarchy

WBA should monitor the development of the system architecture for trusted non-3GPP RAT integration and should engage with its stakeholders to understand the impact on Wi-Fi equipment and standards.

WBA members are kicking-off new 5G streams to address the mentioned areas and have created a 5G Testing & Interoperability group that will drive the definition of comprehensive test plans on the different unlicensed wireless 5G blocks in straight alignment with convergent cellular streams and therefore interworking.

For more information and to learn how to engage please contact WBA PMO (pmo@wballiance.com).
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Cellular Identity Evolution in Advance of 5G - Appendix A

There is increasing recognition that cellular’s use of a monolithic authentication and identity framework is restricting its ability to address new vertical opportunities. In its report on New Services and Markets Technology Enablers for Critical Communications [64], 3GPP have highlighted requirements to enable identity management, authentication, confidentiality and integrity to be provided by third parties, e.g., the factory owner in an industrial automation scenario who will then be responsible for network access security.

These same requirements for supporting a broader identity ecosystem have resulted in the MuLTEfire Alliance (http://www.multefire.org/) to augment the LTE architecture with the ability to support EAP based authentication [65], as illustrated in Figure A-1.

As shown, EAP messages are transported over NAS to enable a wider range of authentication methods to be supported by the enhanced LTE architecture, including the conventional EAP-AKA, but also EAP-TLS and on-line signup.

MFA TS MF.202 [66] describes how the EAP Master Session Key (MSK) is used derive the LTE key $K_{ASME}$ which is then used to derive the remainder of the keying hierarchy, as shown in Figure A-2. This means that both SIM based EAP-AKA’ and non-SIM based EAP-TLS and EAP-TTLS authentication methods.
In addition to the EAP methods and their identities described above, MF.202 additionally defines the support of Online Signup capability over the LTE based system. When using online signup, the device initially uses EAP-TLS together with its device certificate for gaining access to the provisioning service. Once a PDN connection is established to allow connectivity to the Online Signup server, the Provisioning function in the UE is used to interact with the OSU. More specifically, the UE initiates the Subscription selection and Subscription certificate provisioning with the OSU server over HTTPS, using OMA DM or SOAP-XML, as defined in Hotspot 2.0 (Release 2) Technical Specification. The adaptation of Hotspot 2.0 Online Signup procedure for the Multefire Alliance use cases is illustrated in Figure A-3.
Figure A-3: Adaptation by Multefire Alliance of Hotspot 2.0 On-line signup for LTE credential provisioning.
# ACRONYMS AND ABBREVIATIONS

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<tr>
<th>ACRONYM</th>
<th>DEFINITION</th>
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<td>3GPP</td>
<td>Third Generation Partnership Project</td>
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<td>5GNF</td>
<td>5G Network Function</td>
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<td>5GPPP</td>
<td>5G (infrastructure) Public Private Partnership</td>
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<td>AKA</td>
<td>Authentication and Key Agreement</td>
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<td>AMF</td>
<td>Access and Mobility Management Function</td>
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<td>AR</td>
<td>Augmented Reality</td>
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<td>Buffer Status Report</td>
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<td>CBRS</td>
<td>Citizens Broadband Radio Service</td>
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<td>DN</td>
<td>Digital Network</td>
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<td>DSCR</td>
<td>Dedicated Short Range Communications</td>
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<td>EAP</td>
<td>Extensible Authentication Protocol</td>
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<tr>
<td>eMBB</td>
<td>Enhanced Mobile Broadband</td>
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<tr>
<td>EPS</td>
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<td>eV2X</td>
<td>Enhanced Vehicle-to-Everything</td>
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<tr>
<td>FST</td>
<td>Fast Session Transition</td>
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<td>GSMA</td>
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<tr>
<td>HAG</td>
<td>Hybrid Access Gateway</td>
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<tr>
<td>IMT</td>
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<td>IoT</td>
<td>Internet of Things</td>
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<tr>
<td>LTE</td>
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<tr>
<td>MEC</td>
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<td>MFA</td>
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<tr>
<td>MIoT</td>
<td>Massive Internet of Things</td>
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<td>MME</td>
<td>Mobility Management Entity</td>
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<tr>
<td>MNO</td>
<td>Mobile Network Operator</td>
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<td>MP-TCP</td>
<td>Multi-Path TCP</td>
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<td>Abbreviation</td>
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<td>N3IWF</td>
<td>(untrusted) Non-3GPP Interworking Function</td>
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<tr>
<td>NFV</td>
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<td>NFVI</td>
<td>Network Function Virtualisation Infrastructure</td>
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<tr>
<td>NGN</td>
<td>Neutral Host Network</td>
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<tr>
<td>NGMN</td>
<td>Next Generation Mobile Networks</td>
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<tr>
<td>NR</td>
<td>New Radio</td>
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<tr>
<td>OSU</td>
<td>Online Sign Up</td>
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<td>PDN</td>
<td>Packet Data Network</td>
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<td>PDU</td>
<td>Protocol Data Unit</td>
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<tr>
<td>PSP</td>
<td>Participating Service Provider</td>
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<td>QUIC</td>
<td>Quick UDP Internet Connection</td>
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<td>RAT</td>
<td>Radio Access Technology</td>
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<td>RSN</td>
<td>Robust Security Network</td>
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<td>SCF</td>
<td>Small Cell Forum</td>
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<td>SDN</td>
<td>Software Defined Network</td>
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<td>SMF</td>
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<td>SSC</td>
<td>Service and Session Continuity</td>
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<td>SSID</td>
<td>Service Set Identifier</td>
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<td>TSG</td>
<td>Technical Specification Group</td>
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<td>TWAG</td>
<td>Trusted WLAN Access gateway</td>
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<td>TRxP</td>
<td>Transmission Reception Point</td>
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<td>UPF</td>
<td>User Plane Function</td>
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<td>VR</td>
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<td>WAVE</td>
<td>Wireless Access in Vehicular Environments</td>
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<td>Wi-Fi Protected Setup</td>
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<td>WRIX</td>
<td>Wireless Roaming Intermediary eXchange</td>
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<tr>
<td>WWD</td>
<td>World Wi-Fi Day™</td>
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# PARTICIPANT LIST & EDITORIAL TEAM

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<tr>
<th>COMPANY</th>
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<td>Thierry Van de Velde</td>
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