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5G SMALL CELLS AT HOME

5G Small Cells at Home

by NGMN Alliance

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Project:	**RAN Convergence / 5G Home Gateway**
Editor / Submitter:	**Christian GALLARD (Orange)**
Approved by / Date:	**NGMN Board / 12th July 2019**

Address:
ngmn e. V.
Großer Hasenpfad 30 • 60598 Frankfurt • Germany
Phone +49 69/9 07 49 98-04 • Fax +49 69/9 07 49 98-41

Abstract: Short introduction and purpose of document

It is observed that traffic offload - from cellular networks to indoor local Wi-Fi connectivity - takes place when users are at home, but tends to decrease, due to increasing cellular data volumes and due to sometimes better user experience (coverage, throughputs) offered by 4G compared to Wi-Fi 5 (mainly available today at home).

In order to reverse the current trend, this white paper proposes to consider 5G New Radio- Unlicensed (NR-U) technology (that will be part of the future 3GPP Release 16 – Dec. 2019) as a potential (additional) candidate for future small cells deployed at home.

It is expected that small cells at home using NR-U technology will provide – at least – radio performance as good as what Wi-Fi 6 could do, will enable the optimization of the management of radio resources as NR-U could be connected to operators' core network. Furthermore, the deployment of small cells at home can ensure that the traffic generated at home will be transported via the fixed network, regardless if the Wi-Fi interface of the device is switched on or off.

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1 INTRODUCTION AND CONTEXT

This is widely assumed today that roughly 80% of mobile traffic is currently consumed indoors, while the global IP traffic is still increasing significantly from year to year.

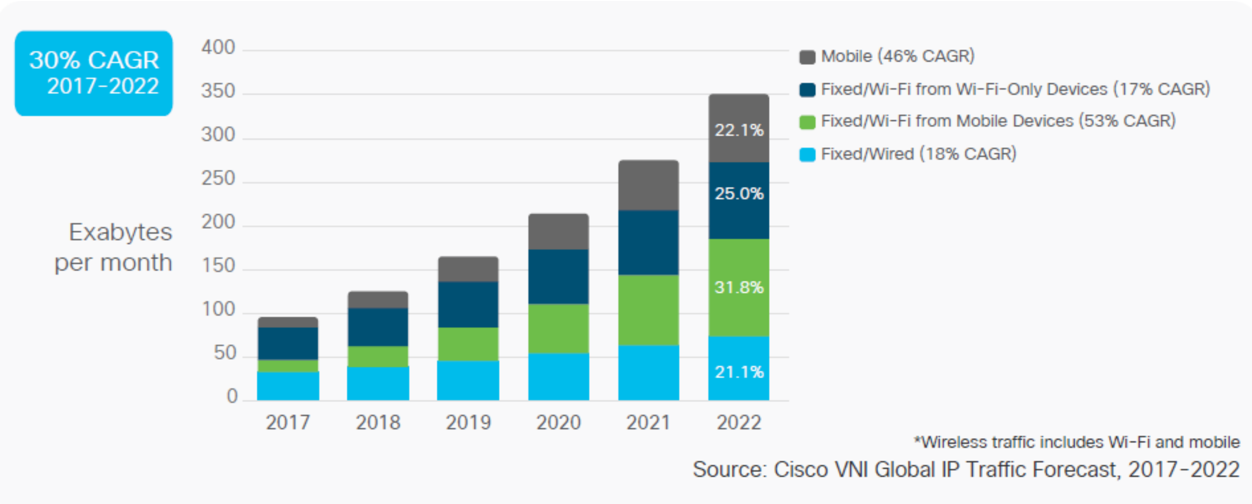

Figure 1 – Global internet traffic (wired and wireless)

As far as “Home scenario” is concerned, a specific case of “indoor environment”, the following trend is observed: customers, once at home, do not connect to their local access network (mainly based on Wi-Fi technology), but stay connected to the cellular macro network (e.g. 4G), feeling that the overall quality of 4G is better than the quality of Wi-Fi. Different explanations can be given to this:

- The Wi-Fi coverage may be seen as limited, e.g. in large accommodations, for which repeaters / extenders may be required in order to guarantee Wi-Fi coverage more or less everywhere at home;
- In dense environments (where multiple Wi-Fi access points are visible), interference becomes an issue; the current generation of Wi-Fi, namely IEEE 802.11ac (a.k.a. Wi-Fi 5), was not designed to be deployed in such scenarios and may lead to “impossible to connect to Wi-Fi” situations;
- The total capacity of Wi-Fi 5 is somehow limited as soon as multiple devices try to access to the same access point simultaneously (what happens quite frequently when a whole family is back at home);
- Another critical point is the limited bandwidth available when ADSL is used as access network, and fiber cannot be deployed for some reason (e.g. cost / no profitability for the operator);
- On the other side, the high monthly available data volume on 4G subscriptions (e.g. 20 - 50 GB) does not encourage customers to look for “free of charge” Wi-Fi connectivity.

The following figure gives an overview of the quality of Wi-Fi versus cellular technologies (mainly 3G and 4G), betting on a similar evolution in a 5G perspective.

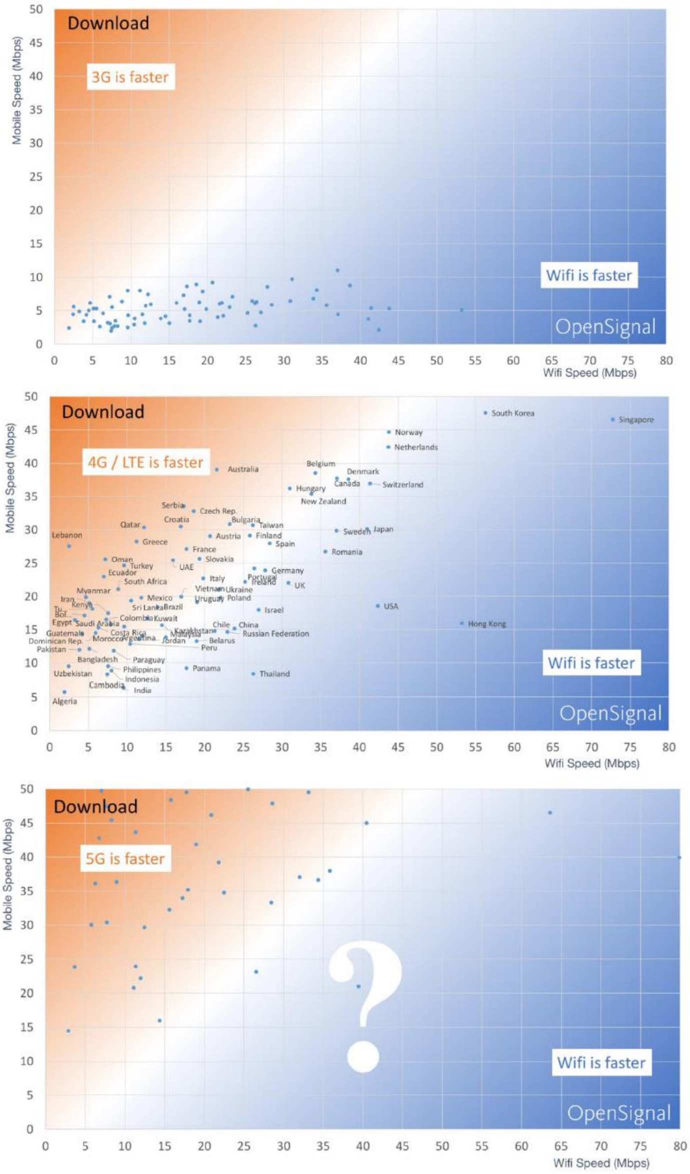

Figure 2 – "The State of Wi-Fi vs Mobile Network Experience as 5G Arrives", Nov. 2018 – OpenSignal

This "reverse offload" effect (i.e. customers are using cellular access also at home, even when fixed access and Wi-Fi are available) may have non negligible impact on the investments operators would have to do on their mobile network in order to absorb this indoor traffic, what is not the primary objective for mobile network deployments and should not become a long term situation.

The first objective of this white paper is then to explore the potential technologies that could help improve the performance of local connectivity at home.

In addition to this, the second objective is to look for solutions of radio resources management at home that would be controlled by the network. The current situation is that the local connectivity is selected by a connectivity manager embedded in the operating system of smartphones that may not have a complete view of what happens, for instance in terms of traffic on cellular networks.

The global objective for operators is then to keep home users connected wirelessly to their local – fixed access network based - connectivity (delivered e.g. by Wi-Fi, a “small cell at home”) with a “premium” quality of service instead of adding pressure on the Radio Access part of the mobile macro network. Challenges for mobile macro networks are for example a lack of (licensed) spectrum that can cover efficiently indoors from outdoor macro network (e.g. low bands spectrum), cost of the radio sites, incl. equipment….

2 CURRENT AND SHORT-TERM TECHNOLOGIES TO COVER INDOORS

2.1 Mobile network indoor coverage

Mobile coverage at home does not always require a dedicated infrastructure at home such as a small cell. Mobile network connectivity provided from outdoor base stations may be sufficient if coverage and capacity requirements can be matched, either from traditional macro cells or from dedicated outdoor small cells close to customer premises. In order to enable (deep) indoor penetration, lower frequency bands must be used: in that case, radio waves can penetrate more easily through windows or walls. The drawback is that available bandwidths are smaller when using lower bands, leading to lower capacity and throughputs per user. The effect of indoor penetration can be mitigated as well by the use of more robust modulation and coding schemes. However, this again has a negative impact on capacity.

2.2 Wi-Fi evolutions

The IEEE 802.11ax standard, also known as Wi-Fi 6, is the latest generation of Wi-Fi that should be available end of 2019 for commercial use.

The initial goals of this standard were:

- to enhance operation in 2.4GHz and 5GHz bands
- to cover “dense residential apartments/buildings”, “corporate office”, “outdoor hotspot” and “stadiums” scenarios (then including both indoor and outdoor environments)
- to increase throughputs by at least x4 in a dense deployment scenario, compared to previous 11ac specifications
- to deliver a maximum capacity near 10Gbps.

The main new features, part of Wi-Fi 6, enabling the support of high density and high throughput use cases are:

- spatial reuse / BSS coloring
    - To increase capacity in dense environment, frequency reuse increase between Basic Service Sets (BSS) is required. BSS coloring is a mechanism introduced in 802.11ah to assign a different color per BSS and this is extended to 11ax. The BSS Color is an identifier of the BSS and is used to assist a receiving station (STA) in identifying the BSS from which a data payload originates. This mechanism allows access points or clients to transmit on a channel even if they detect an existing signal on it, provided the color code from this “interfering” signal is different and its power low enough.

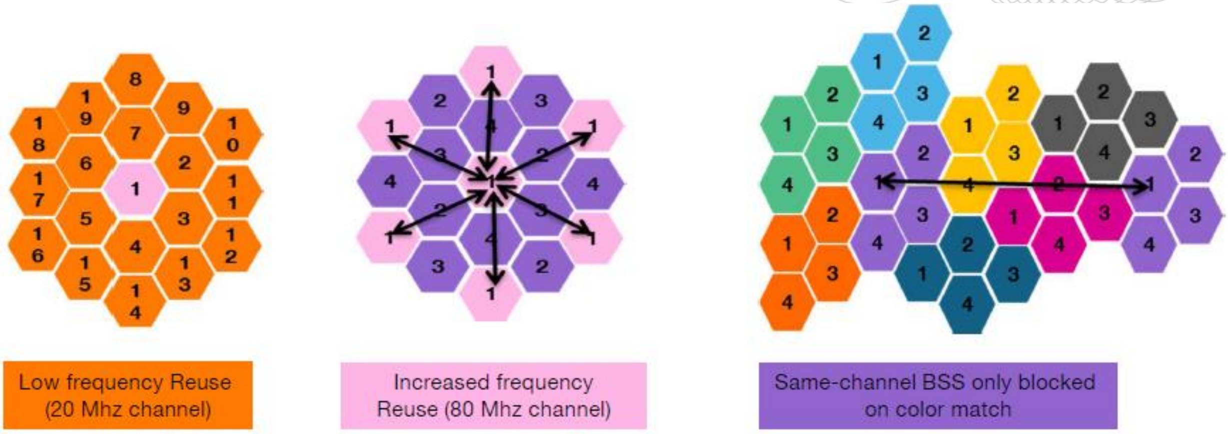

Figure 3 – Wi-Fi 6 BSS coloring concept

- Orthogonal Frequency Division Multiple Access (OFDMA)
  - OFDMA introduces the concept of Resource Units and allows for a reduction of overhead in a Wi-Fi context
- Multi User-MIMO schemes
  - Improvement of downlink MU-MIMO and introduction of uplink MU-MIMO
- 1024 QAM
  - Can lead to up to +25% higher capacity versus 256QAM (highest constellation used in former Wi-Fi 5)

Wi-Fi 6 should then outperform Wi-Fi 5 (see Table 1 below), especially in dense environments, what can be considered as a relevant solution to cope with “reverse offload” effect (this being said, whatever the generation considered, if Wi-Fi remains switched off by customers at home on their gateways or on their devices it will not be helpful to offload indoor traffic).

		Wi-Fi 5	Wi-Fi 6
Frequency bands (GHz)		5	2,4, 5, 6*
Modulation technology		OFDM	OFDM/OFDMA
MU-MIMO feature		DL only	DL + UL
Channel bandwidths (MHz)		20, 40, 80, 80+80, 160	
Sub-carrier spacing (kHz)		312,5	78,125
FFT sizes		64, 128, 256, 512	256, 512, 1024, 2048
OFDM symbol duration + Cyclic Prefix (us)		3,2 (0,8/0,4)	12,8 (0,8/1,6/3,2)
Highest constellation		256QAM	1024QAM
Number of Spatial Streams (SS)		Up to 8	
Data rates (Mbps)	80MHz + 1SS	433	600
Data rates (Mbps)	160MHz + 8SS	6933	9607

Table 1 – Comparison between Wi-Fi 5 and Wi-Fi 6 features and capabilities

(*) wave 2 devices only.

In order to have a clearer idea of the improvements brought by Wi-Fi 6, it is recommended to wait for real products. Indeed, to the best of our knowledge, Wi-Fi 5 products do not implement 8 spatial streams yet; so the implementation choices made by the Wi-Fi industry will decide the real performance of Wi-Fi 6 products.

2.3 Small Cells at Home

3G small cells at home, also named as “femto-cells” or “femtos” have been deployed in high numbers across the world (notably in the US and Western Europe). 3G femtos provide coverage extension for home users in poor radio conditions from mobile network, as the only means to ensure voice & SMS/text services prior to availability of Voice over Wi-Fi and SMS/text over Wi-Fi services. When it comes to 4G, we have the following options for residential coverage:

- 4G femto-cells on licensed bands
    - provide superior bit rates than 3G femto-cells
    - If VoLTE is not supported by the customer UE, a 3G femto is still required to provide voice services or alternatively 4G femto cells should support the *CS fallback* mode.
- LTE-LAA (Licensed Assisted Access) femto-cells
    - LTE-LAA is the aggregation of LTE on a licensed band (as the primary carrier) with LTE on an unlicensed band (as the secondary carrier)
    - This is a 3GPP Rel13/14 feature which embeds :
        - Unlicensed carrier at 5 GHz (although technology is frequency agnostic) used opportunistically to boost the data rates
        - Energy Detection and Listen Before Talk mechanisms for co-existence with Wi-Fi
        - The unlicensed (secondary) carrier, DL-(Rel13) and UL/DL CA – Carrier Aggregation – (Rel.14).
- MuLTEfire
    - MuLTEfire is a variant of LTE-LAA that does not require the use of a licensed carrier, i.e. LTE only on the unlicensed carrier without the assistance of the licensed carrier. This mode of operation is known as *standalone* LTE on unlicensed bands. Note that MuLTEfire is not a 3GPP technology; it is standardized by MuLTEfire Alliance [1].
    - Commercial availability of MuLTEfire products is not clear.

[2] gives a comparative analysis of these technologies with technical details and an overview of the related regulations in different parts of the world.

2.4 Aggregation of Wi-Fi and 3GPP technologies

Figure 2 illustrates where in the mobile network protocol stack the different licensed and unlicensed spectrum aggregation solutions operate.

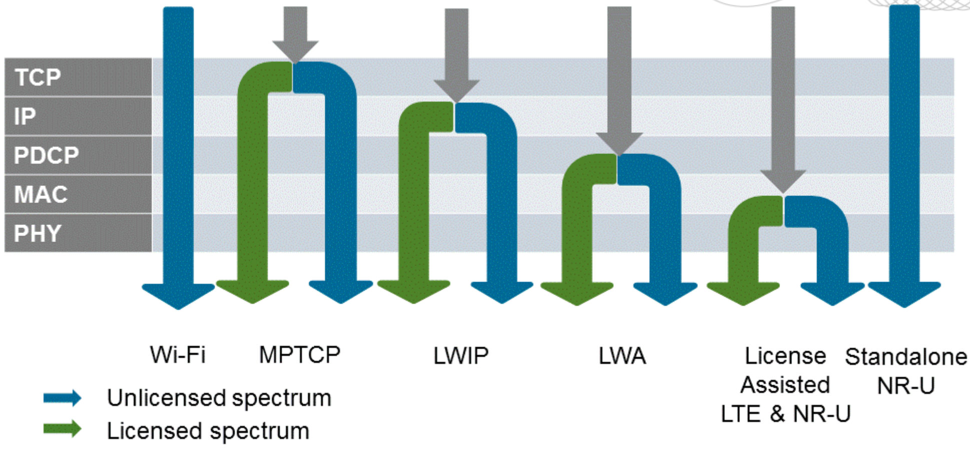

Figure 4 – Aggregation of Wi-Fi and 3GPP technologies

- LWA (at RAN level)
    - LWA stands for LTE-WLAN Aggregation
    - LWA corresponds to Licensed + Unlicensed CA with 802.11 PHY/MAC
    - User plane Aggregation is performed at the PDCP layer based on Rel-12 LTE Dual-Connectivity Wi-Fi traffic steered by the LTE network as an LTE network extension
    - Additional unlicensed "carrier" using 802.11 PHY/MAC
    - A single S1 interface for both LTE & Wi-Fi radio
    - 2 architecture options :
        - 1. co-located eNB + Wi-Fi: no need for WLC (Wireless LAN Controller)
        - 2. non co-located eNB & Wi-Fi: requires connection through WLC
    - Requires an upgrade of the existing WLAN nodes
- LWIP
    - LWIP stands for LTE/WLAN Radio Level Integration Using IPsec Tunnel
    - The LTE-WLAN RAN level integration at the UE and RAN side is based on IPsec tunneling above PDCP protocol layer between eNB and UE over WLAN.
    - This solution supports legacy WLAN deployments without any need for upgrade of the deployed WLAN nodes.

- LTE-Wi-Fi aggregation options at core network level
    - MP-TCP for Multi-Path Transmission Control Protocol with TCP Aggregation based on Multi-Path TCP
    - PGW Aggregation of LTE and Wi-Fi traffic (from untrusted or trusted access access)
    - TWAG – Trusted Wireless Access Gateway
    - IFOM – IP Flow Mobility
    - MAPCON – Multi Access PDN Connectivity
    - NBIFOM – Network Based IP Flow Mobility

In the license assisted LTE-LAA / NR-U and NR-U scenarios, the eNB / gNB-DU scheduler controls the distribution of the traffic over the licensed and unlicensed spectrum links towards the subscriber.

3 LONGER TERM APPROACH: 5G

3.1 Current Standardization Activities

Several standards for integration of Wi-Fi access and Cellular access are already available. The main scope of existing 3GPP standards has been the integration of Cellular access and public Wi-Fi access. However, business potentials and / or cost saving potentials by using public Wi-Fi access so far have been limited. This is one of the reasons why none of these standards has been widely implemented so far. Among them is "LTE Wi-Fi Aggregation (LWA)" as described in Chapter 2.4, which is a RAN-based integration approach.

In the ongoing 5G Rel. 16 standardization, an integration of Cellular access and Fixed/Wi-Fi access using new functionalities in the 5G Core (5GC) network is envisaged. The mid- to long-term goal is to establish the 5GC as a "converged" core supporting any kind of access network ("access agnostic" core). In contrast to previous standards, the current standardization is focusing on the integration of Cellular access and residential Wi-Fi access. Two complementary approaches are currently in the normative phase at 3GPP and BBF (Broadband Forum):

- **Access Traffic Steering, Switching, and Splitting (ATSSS)**
- **5G Wireless Wireline Convergence (5WWC)**

ATSSS will extend the (Rel. 15) 5G System in order to support flexible, network-based traffic steering, switching and splitting between 3GPP and "non-3GPP" access networks (e.g. Wi-Fi). The basic concept of the ATSSS architecture framework is to support "Multi-Access Packet Data Unit (MA PDU)" sessions, as illustrated in Figure 5. A MA PDU is a type of PDU session that allows application to send/receive traffic either over 3GPP access, or over non-3GPP access, or over both accesses simultaneously. A MA PDU session comprises of a PDU session over 3GPP access and a "linked" PDU session over non-3GPP access, or vice versa. Both PDU sessions share a common "PDU Session Anchor (PSA)". For MA PDU session, applications in User Equipment (UE) and the Server Host (connected via the "N6" interface to the PSA) are not aware of traffic split across multiple accesses.

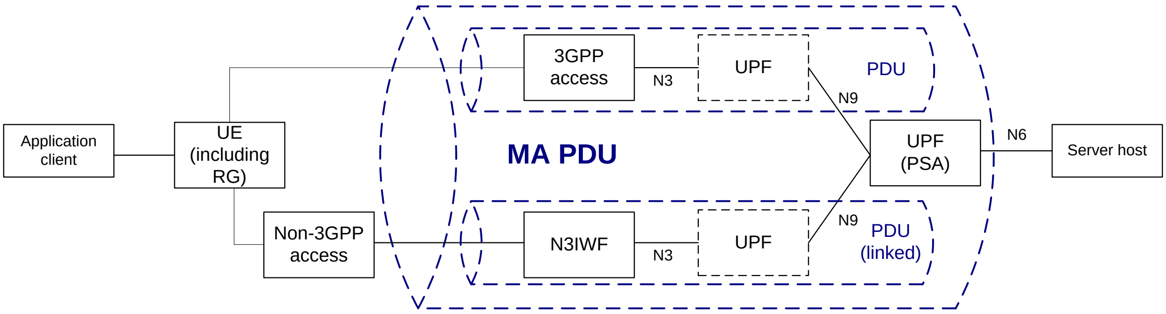

Figure 5 – Basic approach for Multi-Access Packet Data Unit (MA PDU) session.

As first protocol for the splitting of traffic, MP-TCP (Multipath-TCP) has been selected. During the MA PDU session establishment the UE includes an "MA PDU capability" to indicate it is ATSSS capable and indicates whether it is capable of supporting the MP-TCP functionality or the so-called "ATSSS-LL ("lower layer") functionality (i.e. steering or switching).

5WWC aims to provide solutions for an integration of a Fixed Access network into the 5GC. The standardization is carried out jointly by BBF and 3GPP. A high level architecture from BBF related to 5WWC is sketched in Figure 6.

Based on a "5G Converged Core Network" with separated Control Plane and User Plane (C-Plane / U-Plane Split – CUPS), two basic models are considered for connecting wireline access networks to the 5GC:

- **The Integration Model** – in this model, the converged 5GC is used to deliver functions traditionally offered by the "wireline core network" (e.g. the BNG). This model assumes a new function to mediate between the wireline access network and the converged core network, called the "Access Gateway Function (AGF)".

- **The Interworking Model** – in this model, the wireline core network continues to provide subscriber management and IP functions, but an interworking function (Fixed Mobile Interworking Function – FMIF) enables some form of service convergence by linking the wireline core network to the converged core network.

Note: In the high level BBF architecture one Control Plane and one User Plane is shown. However, it will be possible to use one Control Plane and several User Planes, which can be optimized according to different requirements, such as service requirements, traffic demands, operation and implementation costs, etc.

As "Residential Gateways (RGs)", legacy Home Gateways ("FN RG – Fixed Network RG") as well as new "5G RGs" are taken into account. For mobile devices, also two categories are considered: a) "UE with N1 interface" (e.g. SIM-based UE); b) "UE without N1 interface" (e.g. Wi-Fi only device), including solutions how devices (3GPP UEs and Wi-Fi only devices) behind the Residential Gateways (RGs) can be identified and supported.

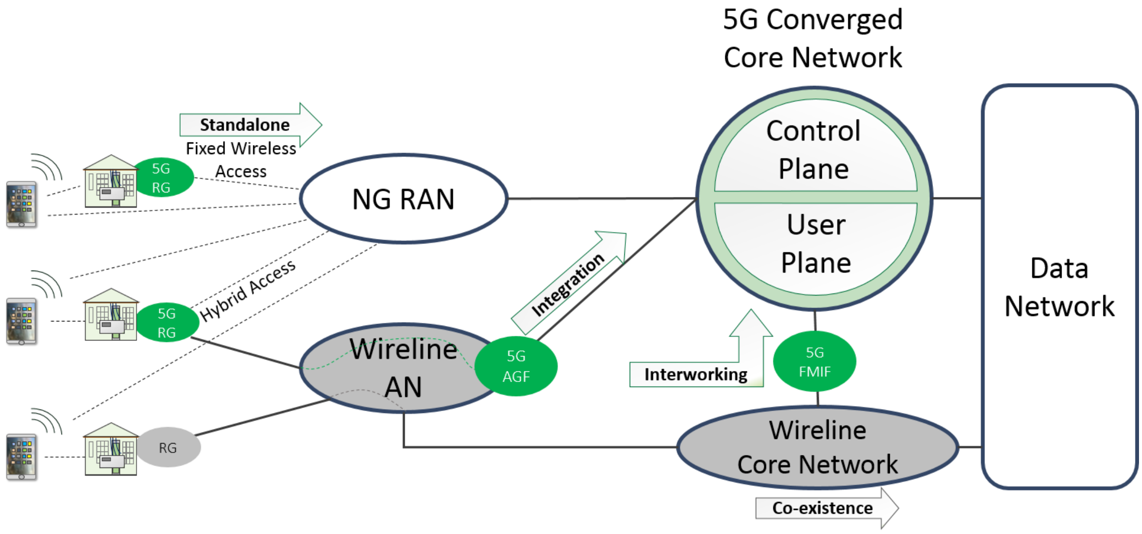

Figure 6 – BBF high-level architecture with cellular and wireline access networks, using 5G Converged Core Network.

3.2 5G Small Cells at Home (licensed / unlicensed)

Beyond the short-term solutions presented in section 2, deployment of 5G small cells at home can be considered in future as well in order to transport the residential indoor traffic. The specificity of 5G in this context is that it can be deployed indifferently in both licensed and unlicensed spectrum bands:

- in licensed bands:
    - first, relevant spectrum must be identified:
        - spectrum between 3.4 – 3.6 GHz and 3.6 – 3.8 GHz bands should be the initial spectrum used for macro deployment; applicability to deployment in houses should be assessed.
        - mm-waves spectrum (so-called 26GHz and 28GHz bands) could be considered as well, assuming a per room access point deployment (cost should be assessed here).
    - In this case a frequency planning between outdoor macro deployment and indoor deployment should be required, what could lead to additional complexity.
- In unlicensed bands
    - 3GPP will specify New Radio technology in unlicensed bands (known as NR-U), either operating in a non-standalone [1] mode (i.e. with an anchor carrier in licensed spectrum) or operating in a standalone mode (i.e. utilizing unlicensed spectrum only, in a similar fashion to Wi-Fi).

[1] In this context, "non-standalone" means "combined with a 4G licensed spectrum band" while …

- The deployment of 5G in unlicensed bands (standalone mode [2]) will enable simple deployment of small cells with no need of frequency planning.

3.3 Expectations on NR-U

3GPP have started work to develop a single global solution for NR-based access to unlicensed spectrum, to be compatible with the NR concepts and global regulations for unlicensed spectrum. The NR-U work is not limited to a particular unlicensed band; rather the target NR-U design is applicable to a set of frequency ranges. However, the initial focus for product development is to support 5 GHz and 6 GHz unlicensed bands. The 3GPP work is planned to be completed as part of 3GPP Release 16 specifications.

Coverage and throughput of NR-U devices will, like other unlicensed technologies, be limited by regulatory factors and product implementation (supported bandwidths, output power, number of antennas, receiver and filter quality).

When NR-U is operating in unlicensed spectrum only (i.e. without the use of licensed spectrum, frequently referred to as 'standalone NR-U'), it is expected that coverage and performance will be superior to Wi-Fi due to a number of NR-U characteristics:

- NR-U uplink traffic is scheduled. This reduces the number of contending nodes at any given time. In addition, the UL transmissions can make use of the shared Channel Occupancy Time (COT) Listen Before Talk (LBT) procedure of the 5G base station (gNodeB = gNB). By contrast, all Wi-Fi nodes with non-empty UL buffer contend to access the channel leading to a higher collision rate.
- Per transmission burst bandwidth adaptation.
- UE uplink resources can be scheduled in both time and frequency domains.
- NR-U PHY design is robust to interference leading to fewer re-transmissions which both reduces latency and frees up the channel for other users.
- NR-U MAC design includes fast dynamic HARQ and Code Block Group level HARQ ACK/NACK, again reducing the number and volume of re-transmissions.

When NR-U is used in conjunction with a licensed carrier through 3GPP carrier aggregation or dual connectivity (frequently referred to as 'non-standalone NR-U'), the licensed carrier can be used to transmit critical control information, e.g. HARQ responses, as well as higher QoS traffic flows, further reducing the need for contention to the unlicensed channel which improves the latency and throughput of the NR-U system while at the same time reducing the load on the unlicensed channels.

When compared to 3GPP LAA, the NR-U MAC and PHY protocol is based on 3GPP Rel-16 NR with adaptations for operating in unlicensed spectrum in order to provide a more flexible frame structure allowing faster processing:

- Dynamic downlink/uplink structure by scheduling – more responsive to load variations
- Shorter TTIs with higher numerologies
- Front-loaded DMRS for faster demodulation
- Shorter scheduling / HARQ latencies
- Flexible scheduling allowing more responsive access to the medium (e.g. mini-slots)

3.3.1 Coexistence Methods of NR-U

The NR-U coexistence functions are built on the extensive work done for 3GPP LAA:

[2] … "standalone" means "operating exclusively in unlicensed spectrum" (like Wi-Fi does). A different definition applies for section 3.4.

- Channel access based on listen-before-talk (LBT) with energy detection threshold ED = -72 dBm
- NR-U LBT behaves very much like IEEE 802.11
- Proven good coexistence with deployed Wi-Fi and LAA networks

Many companies provided simulation results for NR-U and Wi-Fi coexistence in both indoor and outdoor scenarios during the study phase of the 3GPP NR-U specifications. The simulated Wi-Fi networks were operating according to IEEE 802.11ac specifications. In addition, no licensed carrier is considered in the simulation, i.e. NR-U uses self-scheduling for UL transmissions and grants are sent on the same unlicensed carrier as the data transmission. Full details of the simulation methodology can be found in 3GPP TR 38.889. Some of the findings from indoor coexistence simulations are given below.

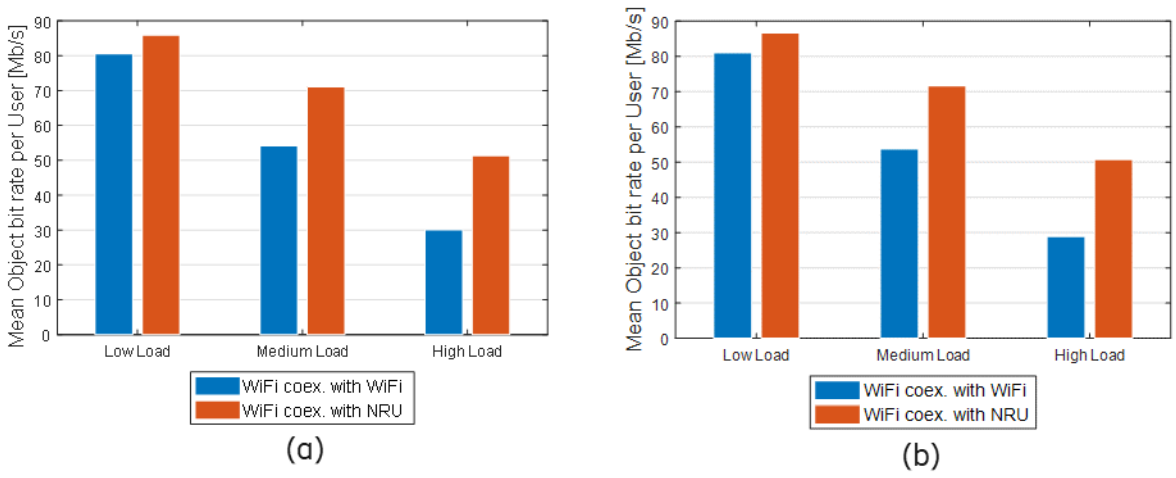

Figure 7 – (a) DL and (b) UL mean object bit rate in indoor scenario of Wi-Fi coexisting with Wi-Fi/NR-U [3][4]

In Figure 7above, the blue columns show the throughput of a Wi-Fi network when coexisting with another Wi-Fi network. The red columns show the throughput of the Wi-Fi network when the other Wi-Fi network is replaced with a NR-U network.

As can be clearly seen, the throughput of the Wi-Fi network improves significantly when coexisting with a NR-U network compared to another Wi-Fi network. Simulation details and results can be found in 3GPP TR 38.889 and 3GPP contribution R1-1813454.

The Energy Detection (ED) threshold is used by technologies that utilize a Carrier Sense, Multiple Access with Collision Avoidance (CSMA/CA) mechanism when accessing shared medium such as unlicensed spectrum. Examples include the Listen-Before-Talk (LBT) procedures incorporated into IEEE 802.11 Wi-Fi and 3GPP LTE-LAA. It is a value (expressed in dBm) at which sensed energy on the carrier will cause the sensing node to defer transmitting. Since the ED sensing is based purely on energy levels, LBT operation using ED is considered technology neutral.

IEEE 802.11 Wi-Fi also supports the concept of a Preamble Detection (PD) threshold. This sensing threshold requires the sensing and decoding of IEEE 802.11 preambles that are transmitted at the start of a 802.11 transmission. If a sensing node can successfully decode the preambles and the energy of the preamble transmissions is above the PD threshold (expressed in dBm), the sensing node defer its own transmissions. The PD threshold is at a lower energy level than the ED threshold and is intended to avoid collisions of 802.11 transmitters. Since PD is based on decoding 802.11 preambles, it is not technology neutral. Furthermore, if a node starts LBT sensing in the middle of another 802.11 transmission, it will have missed the preambles and will revert to the ED threshold even for 802.11 transmissions. Some Wi-Fi devices selectively defer at the PD threshold while others employ a variable PD threshold value.

Simulations performed by many companies and published in 3GPP TR 38.889 have shown that using a PD threshold (i.e. transmitting and decoding Wi-Fi preambles) in NR-U reduces both NR-U and Wi-Fi performance. This is due to a number of factors including loss of spatial multiplexing gains when operating at a lower PD threshold (ref: 3GPP RAN1 contribution R1-1813458), and missed preambles by 802.11 nodes (thus reverting to the higher ED threshold of -62dBm even for many Wi-Fi transmissions).

For the greenfield 6 GHz band where there are no incumbent RLAN technologies, a harmonized ED threshold across technologies is preferred, as this has been demonstrated to have superior performance for both IEEE 802.11 and NR-U when compared to existing IEEE 802.11 ED and PD based LBT.

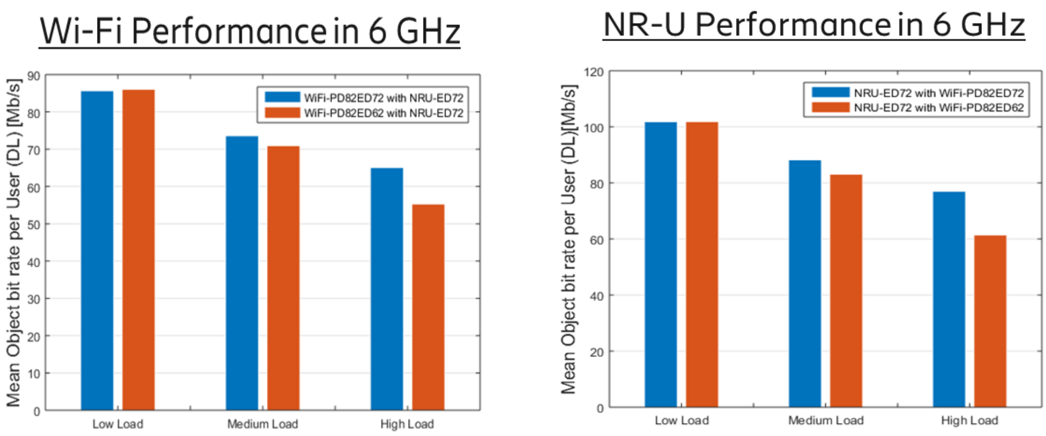

Figure 8 – (a) DL mean object bit rate in indoor scenario of (left) Wi-Fi coexisting with Wi-Fi/NR-U and (right) NR-U coexisting with NR-U/Wi-Fi [3] [4]

As can be seen from the left-hand figure above, Wi-Fi network performance is higher when using a ED threshold of -72dBm (blue columns) compared to a ED threshold of -62dBm (red columns) in the presence of a NR-U network. Similarly in the right-hand figure, NR-U network performance is higher when Wi-Fi using a ED threshold of -72dBm (blue column). I.e. Performance is enhanced for both technologies if a harmonized ED threshold is used.

In addition to the co-channel LBT coexistence mechanism for NR-U described above, products are anticipated to include proprietary dynamic channel selection functions that aim to avoid or at least minimize co-channel operation where possible.

3.4 Deployment Scenarios, use case and indoor services

The objective of the concept presented is to introduce a new radio technology, in small cells at home, in order to enable a better coverage and provide higher data rates on the Local Access Network (LAN) compared to Wi-Fi 5 in a dense environment – and at least similar to Wi-Fi 6 – as well as an automatic operator-driven access point selection between the operators' Public Land Mobile Network (PLMN) and this local radio on the home gateway. The assumption is to rely on the future NR-U technology (section 3.3).

Beyond mobility between cellular network and local connectivity, it is also important to grant access to the LAN resources to users belonging to the home network. In other words, a user shall be able to access any device of its home network when connected to the 5G NR-U radio of its own small cell at home; this feature is referred to as local breakout. Furthermore, any other user connected to the NR-U shall only get access to Internet when connected to the PLMN.

Whatever the radio technology deployed, the following (family of) services have to be delivered at home (preferably offloaded on the local connectivity, if relevant) and some of them are critical for offload of macro network:

- Voice : this is a "basic" but required service that is not critical for offload of the macro network
- Text / SMS :
    - High need for home users, notably due to payment codes (e.g. VISA) sent by text / SMS
- Internet access
- Delivery of TV services
    - Can be live, on-demand
- Smart home services
    - Connected lights, connected shutters, smart speaker…)
- Security
    - CCTV cameras, presence / motion sensors…

5 scenarios are being considered within the NR-U Work Item in 3GPP release 16:

- Scenario A: Carrier aggregation between licensed band NR (PCell – Primary Cell) and NR-U (SCell – Secondary Cell).
    - NR-U SCell may have both Downlink (DL) and Uplink (UL), or DL-only.
    - In this scenario, NR PCell and NR-U SCell are connected to 5GC. The PCell and Scell are provided by a common gNB Distributed Unit (DU) baseband or separate gNB DU basebands that are connected by a low latency Xx interface as scheduling is performed at the MAC layer.
    - This scenario provides a capacity boost and throughput boost (more bandwidth).
    - Mobility is handled by the NR gNB Pcell. NR-U SCells are deactivated / deconfigured and then configured / activated on target gNB.
    - A use case for this scenario is where the outdoor NR cellular macro network antennas also provide indoor coverage and handles mobility (PCell), for example using low band spectrum, and indoor capacity is further enhanced with NR-U, for example from a street level small cell or indoor enterprise small cell.
    - A second example is where the indoor small cell provides both NR PCell and NR-U Scell coverage.
- Scenario B: Dual connectivity between licensed band LTE (PCell) and NR-U (PSCell – Primary Secondary Cell)
    - In this scenario, LTE PCell connected to EPC as higher priority than PCell connected to 5GC. E-UTRA-NR Dual Connectivity. The NR-U PSCell gNB DU baseband is connected to the LTE eNB by Xx and S1-U interfaces.
    - This scenario provides throughput, Opportunistic Offload benefits.
    - A use case for this scenario is where the outdoor cellular macro network antennas also provide indoor coverage and handles mobility (PCell), for example using low band spectrum, and indoor capacity is further enhanced with an NR-U indoor small cell.
    - A second example is where the indoor small cell provides both LTE PCell and NR-U Scell coverage.
- Scenario C: Stand-alone NR-U
    - In this scenario, NR-U is connected to 5GC.
    - Also includes NR-U + NR-U carrier aggregation.
    - Mobility is performed between the outdoor cellular network and indoor NR-U small cell via the 5GC.

- It is to be defined if the indoor small cell will be connected via Xx interface to the macro outdoor cellular network.

- Scenario D: A stand-alone NR cell in unlicensed band and UL in licensed band (single cell architecture).
  - In this scenario, NR-U is connected to 5GC.
- Scenario E: Dual connectivity between licensed band NR and NR-U. (as a second priority)
  - In this scenario, PCell is connected to 5GC.
  - Similar use case as B but with 5GC.

3.5 Mobility mechanisms between 5G NR-U and macro network

Mobility mechanisms between 5G NR-U and the 5G macro network (including continuity of Service Level Agreement) can be achieved in both Non-StandAlone (NSA[3]) and StandAlone (SA[4]) contexts . In NSA, mobility is controlled by the anchor cell and NR-U secondary cells are deactivated and reactivated on the target gNB. In SA, mobility can be done using existing NR mechanisms (measurement reports, handover). However, note that mobility to a technology in unlicensed band is not trivial because there is no guarantee that the cell will be available at the handover execution and a Listen Before Talk (LBT) must be done to be sure that the coexistence is ensured with other technologies in the unlicensed band. 3GPP is working such mobility mechanisms and the solutions are mostly based on Licensed Assisted Access (LAA) mechanisms.

Mobility between 5G cellular access and Wi-Fi in the LAN is part of Rel. 16 core specifications (see section 3.1).

The activation and use of NR-U by subscriber devices should be under the control of the cellular network service provider in the same way that the use of licensed bands is done today.

3.6 Cost Issues

One of the objectives of this NGMN white paper is to identify and promote solutions helping the offload of traffic carried by cellular networks on local connectivity when customers are at home, while guaranteeing a good quality of service and experience.

Beyond technological considerations, what is key in the approach proposed is to evaluate the cost impact of the deployment of such solutions at home; in other words:

- If nothing is done, cellular networks will have to be densified or upgraded in order to absorb this indoor traffic, and this will have a cost for mobile operators;
- If additional small cells at home have to be deployed to carry this indoor traffic, this will lead to an increased cost for these small cells.
- It has to be assessed which solution is the most efficient one if a “reverse offload effect” of x% is assumed on a per year basis.

For the specific case where NR-U standalone connectivity could be embedded in current residential gateways delivering typically Wi-Fi LAN connectivity today, the following key question can be raised:

- How NR-U chipset will be provided by chipset companies?
  - It should be delivered in a combined way with Wi-Fi as NR-U and Wi-Fi may share the same spectrum bands; in this case we can expect a chipset with a reasonable cost as some NR features not useful for NR-U standalone may be removed. This being said the economy of scale effect would be reduced as this would require a specific development compared to NR chipsets for smartphones.
  - It should be delivered together with NR; in this case the economy of scale would be a positive factor but the price of a single chipset, embedding all NR features, would likely be too high for residential gateways products.

[3] In this context Non-StandAlone (NSA) means the gNB is connected to 4G EPC and can only work together with an LTE carrier, while

[4] StandAlone (SA) means gNB is connected to 5GC.

4 CONCLUSION

With increasing data volumes provided by mobile tariffs, a growing number of customers tend to use cellular access also in their home environment (e.g. by manually switching off the Wi-Fi interface of their device). This leads to a "reverse offloading" effect i.e. to an unexpected increase of traffic load on macro cells.

The deployment of small cells at home (with existing fixed access as "backhaul") as complement to Wi-Fi provides a solution to transport the residential traffic via the (more cost efficient) fixed access network, independent from the decision of the device OS or the customer to use Wi-Fi access or cellular access in the device.

3GPP is currently (i.e. in 2019) specifying, in Rel. 16, NR-Unlicensed technology (in both standalone – operating in unlicensed bands exclusively – and non-standalone – operating with an anchor band in licensed spectrum – flavors), that is foreseen as a potential radio candidate for providing connectivity in 5G small cells at home:

- based on NR building blocks, this technology will provide up-to-date performance in terms of coverage and capacity
    - Standalone NR-U should have at least similar performance compared to Wi-Fi 6 (inc. in dense areas)
- the inherent ability of NR-U to connect to 5G core network should enable operators to optimize the use of radio resources.

Beyond a radio performance comparison between technologies candidate for a deployment at home (e.g. Wi-Fi 6, NR-U standalone/non-standalone), a cost comparison should be done in order to assess which solution is the most cost efficient: either a densification of the macro network in order to absorb the indoor traffic at home, or a deployment of e.g. NR-U standalone-based small cells at home.

5 REFERENCES

[1] https://www.multefire.org/

[2] https://arxiv.org/pdf/1709.04458.pdf

[3] 3GPP TR 38.889 "Study on NR-based access to unlicensed spectrum"

[4] 3GPP RAN1 contribution R1-1813454 "Evaluation Results for NR-U operations", Ericsson