NOKIA CONTRIBUTION

To the Consultation Paper Issued by the Info-Communications Media Development Authority of Singapore on

5G Mobile Services and Networks

FOR THE ATTENTION OF:

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1 About Nokia

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Nokia has established a broad range of innovation partnerships to find a common direction through collaboration in requirement setting, technology research and finally in standardization. Therefore, we are driving collaborative research with customers (AT&T, CMCC, Deutsche Telekom, MTS, NTT DOCOMO, SKT, KT, Verizon, Vodafone…), governmental bodies, regulatory and industry bodies (e.g. NGMN, 5G Americas, 5G IA, 5G AA...), industry & scientific community, 5G labs (e.g. 5G Lab at TU Dresden, 5G Test Network Finland…) and universities (e.g. New York University for channel measurements and characterization or University of Kaiserslautern for 5G architecture).

Nokia is the consortia leader of the METIS- II, 5G NORMA and FANTASTIC 5G research projects inside the 5G PPP, which will deliver input, for example, for the 5G air interface and network architecture work in 3GPP.

For more information: https://networks.nokia.com/innovation/5g

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Disclaimer: This response is based on Nokia's current understanding of the market dynamics and various standards bodies; these dynamics are changing and hence our views may update with these changes

2 Introduction – 5G paving the way to the Fourth industrial revolution

2.1 5G General Principles

5G is the new generation of radio systems and network architecture that will deliver extreme broadband, ultra-robust low latency connectivity, and massive networking for human beings, objects and sensors. Enabled by 5G, the programmable world will transform our individual lives, economy and society. It sounds like a bold claim but the reality is starting to take shape as 5G research pushes ahead to make rapid developments.

5G will be far more than just a new radio technology. It will combine existing Radio Access Technologies (RATs) in both licensed and unlicensed bands while adding novel RATs optimized for specific bands and deployments, scenarios, and use cases. 5G will also implement a radically new network architecture based on Network Function Virtualization (NFV) and Software Defined Networking (SDN) technologies. Programmability will be central to achieving the hyper-flexibility that operators will need to support the new communications demands coming from a wide array of users, machines, companies from different industries and other organizations such as administrations and municipalities. 5G networks will have to be programmable, software-driven, and managed holistically to enable a diverse and profitable range of services.

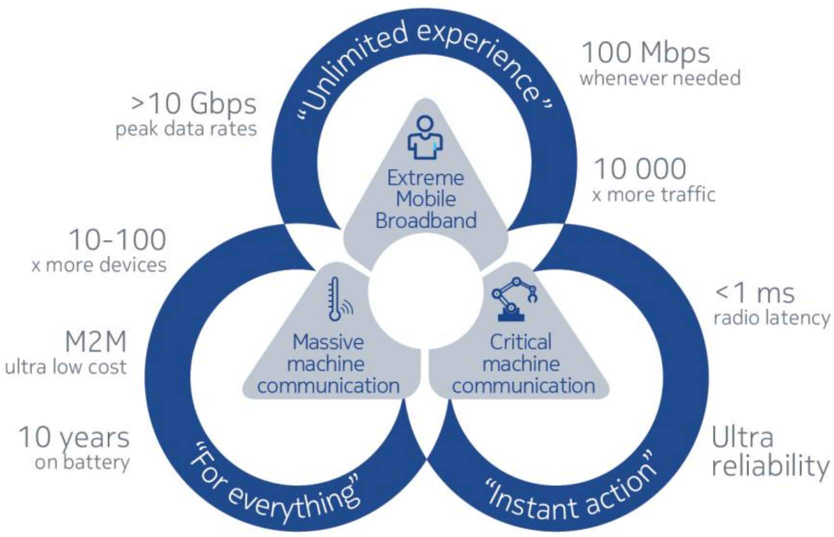
5G mobile communications will cover a wider range of use cases and related applications including video streaming, augmented reality, different ways of data sharing, and various forms of machine type applications, including vehicular safety, different sensors, and real-time control. 5G also needs the flexibility to support future applications that are not yet fully understood or even known. Starting with trials in 2016 and the deployment of first use cases in 2017, the full 5G system will be introduced in 2019/20 and will be in use well beyond 2030.

Nokia envisions 5G as a system providing scalable and flexible services with a virtually zero latency gigabit experience when and where it matters. In addition, 5G will provide at least a ten-fold improvement in the user experience over 4G, with higher peak data rates, improved "everywhere" data rates and a ten-fold reduction in latency.

The biggest difference between 5G and legacy design requirements is the diversity of use-cases that 5G networks must support compared to today's networks that were designed primarily to deliver high speed mobile broadband. However, 5G will be about people and things that can be broadly split into three use-case categories:

- Massive broadband that delivers gigabytes of bandwidth on demand
- Critical machine-type communication (uRLLC) that demands immediate, synchronized eye-to-hand feedback to remotely control robots and deliver the tactile Internet
- Massive MTC (mMTC) that connects billions of sensors and machines,

as graphically represented in the picture below:



2.2 5G and the Internet of Things

uRLLC and mMTC use cases are seen as enablers for IoT. There are also expectations for IoT to drive the development of 5G. The relationship between 5G and IoT can be summarised succinctly as: IoT is a driver for 5G; 5G is an enabler of IoT.

The IoT is already seeing a rapid growth — well in advance of commercial 5G deployments — using networks that employ both short-range wireless technologies and proprietary low power wide area network (LPWAN) technologies in unlicensed spectrum such as Sigfox and LoRaWAN, as well as in licensed spectrum on existing 2G-4G networks employing technology standards such as LTE Cat-1, LTE Cat-M1 and NB-IoT. As such, IoT will be engulfed by 5G networks but some analysts trust that 5G mMTC will go well beyond the capabilities of NB-IoT, which is largely focused on enhanced coverage, low cost, and enhanced battery life, while 5G will be required to connect massive numbers of devices — in the order of 100,000 devices per cell. That said, mMTC might utilise a future evolution of NB-IoT in the radio access layer, making it more evolutionary than revolutionary.

Depending on the type of application, the IoT can be supported either by mMTC or uRLLC:

- 5G uRLLC use cases may target eHealth remote treatment/surgery, connected cars, including critical V2V communications and even autonomous vehicles, as well as the automation of industrial processes and mission-critical applications like drones deployed in emergency situations. While the strict latency and availability requirements are the key features of this use case, it is still expected that it will also need to support moderately high bandwidth requirements.
- 5G mMTC is likely to be support IoT applications such as monitoring in smart cities, smart homes, remote health and industrial and agricultural processes.

Nokia and the wider telecommunications industry are already well along the road to 5G. Nokia has run several proofs of concept for most of the key elements that will form the future 5G standard and is already preparing 5G for commercial reality.

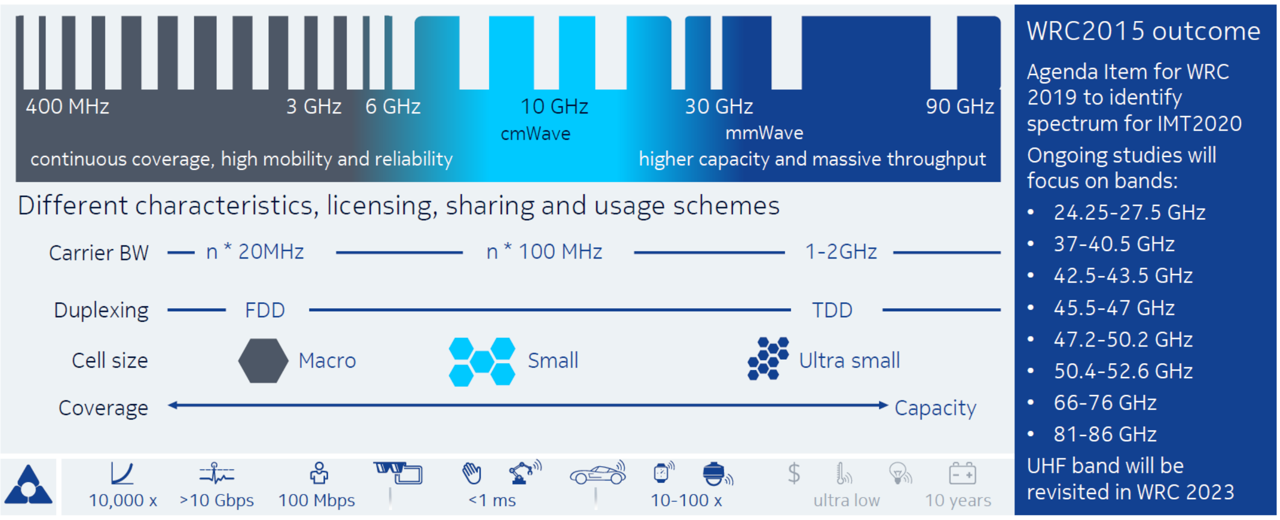
3 Spectrum Identification and Requirements

Nokia expects that wireless data traffic will grow 10,000-fold within the next 20 years due to ultra-high resolution video streaming, cloud-based work, entertainment and increased use of a variety of wireless devices.

These will comprise smartphones, tablets and other new devices, including machine type communications for the programmable world.

IMDA's spectrum modelling suggests that the spectrum supply does not meet the potential demand forecasted in Singapore. Nokia suggests that all the potential spectrum bands to meet this demand should be explored, such as the bands currently under discussion for the upcoming World Radiocommunication Conference WRC-19, but also other promising bands in trials (such as the 28GHz). IMDA's spectrum modelling suggests that high bands (above 6Ghz) should be provided by 2022. Nevertheless, based on the modelling and the current situation around the world (detailed below), Nokia suggests to release these bands earlier to meet the demands and to ensure Singaporean citizen are reaping the benefit of 5G. The value might be conservative for year 2022 and onwards. It's expected that 5G deployment will gain considerable scale in developed markets at around 2022. The mobile data traffic by year 2025 is expected to increase a lot from previous years, also because the availability of 5G network will trigger further usages – both for human and for machines, and will also enable new applications that will consume additional traffic. Therefore, the proposed projection could be under-estimated.

5G radio is likely to use a combination of frequency bands between 400 MHz and 86 GHz to respond to different requirements based on the bands' characteristics, as visually described in the figure below:



A "core" band below 6 GHz needs to be found: one that provides sufficiently large channels to enable future 5G operators to provide innovative services and a higher quality of service than with 4G.

In November 2015, the World Radiocommunication Conference (WRC) agreed an agenda item for WRC 2019 to study new spectrum ranges for IMT-2020 (see table in the figure above).

The lower frequency bands being made available for 5G have good penetration characteristics that provide coverage to support applications with high mobility and reliability. Efficiently using sub-6 GHz spectrum will require different carrier bandwidths and flexible spectrum aggregation techniques. Within this range, for sub-3 GHz FDD deployments, carrier bandwidths of 40-100 MHz and efficient spectrum aggregation techniques will be needed. For the 3-6 GHz range, bandwidths of minimum 100 contiguous MHz per operator will be especially relevant. In the higher frequencies ranges above 6 GHz several bands are available to provide huge capacity and throughput.

Nokia has proven that it is possible to take advantage of x*100 MHz bandwidths in the band up to 40 GHz and 1–2 GHz bandwidths in the band 40 GHz up to 86GHz. Substantial Nokia research, including channel measurements, Proof of Concept (PoC) verifications, and live trials with key operators, shows that these bands can be used for access and backhaul to help support large volumes of small cell traffic.

Current spectrum allocations and the work for the WRC-19 indicate that by about 2020 the focus will be on frequencies below 6 GHz and some non-harmonized national / regional spectrum bands above 6 GHz.

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3.1 Low Bands - Spectrum below 1GHz

IMDA has released almost every spectrum band available below 1GHz during the last auction. The 700 MHz band becomes globally harmonized for mobile communications, as now it includes Africa, Europe and the Middle East; this band is of significant importance for remote areas because of its coverage attributes and for indoor penetration in urban areas due to its building penetration characteristics. 700 MHz band will potentially have an important role for 5G deployment but 3GPP will need first to address the use of this spectrum.

In addition to the bands already allocated, Nokia would like to draw IMDA attention on the potential of the sub-700MHz band. The 600 MHz band is rising in importance in countries in the Americas and in some countries in Asia-Pacific for IoT use in remote areas and for indoor penetration in urban areas. In the United States, following the Voluntary Incentive Auction of the 600 MHz band, T-Mobile and Nokia are planning to collaborate to enable the 5G network capabilities where 600MHz spectrum is the preferred coverage layer[1].

As an alternative, in situations where the lower UHF band (470 – 694 MHz) is still used for TV broadcasting, the Supplemental Downlink (SDL) can help to add substantial downlink capacity to mobile networks for flexible distribution of audio visual content, while ensuring co-existence with digital terrestrial television (DTT) where required. LTE SDL has the potential to allow broadcasters to offer interactive broadcast services over tablets and smartphones without causing interference to existing digital terrestrial television services. The technology allows media publishers and network operators to optimize the usage of available UHF frequencies. Besides LTE support, the technology is also expected to be supported in the early stages of 5G. In Europe, the European Commission has proposed to introduce more flexibility over the use of the lower UHF spectrum and Nokia has demonstrated the first trial of LTE SDL in 2016[2].

3.2 Mid Bands 1-6 GHz

3.2.1 The L-Band (1452-1492 MHz)

Nokia welcomes the position of IMDA regarding the L-Band, that, as indicated in IMDA’s document, benefits of some starting discussion at APT AWG level. As such, we are pleased to see that IMDA will provide some inputs.

The L-band can be potentially used as SDL. This approach has a lot of traction as it is already specified in 3GPP; a possible extension is considered in Europe.

The Supplementary Downlink option allows operators to optimize investments by avoiding the costs of additional base station and backhaul infrastructure; once mobile broadband demand exceeds network capacity, networks can be easily expanded by deploying a 1.4 GHz Supplementary Downlink on existing base station sites.

Supplementary Downlink and carrier aggregation have been enabled in standards from HSPA+ Release 9 and LTE Release 10. Nokia has for some time offered Supplementary Downlink radios for the two most common bands: The North American B29, and the 3GPP B32.

The 1.4 GHz Supplementary Downlink L-band, when paired with low frequency spectrum such as the 700 MHz in APAC (B28), offers similar propagation characteristics as sub-1 GHz spectrum, because the uplink, which is the limiting factor for coverage, is only carried on the low frequency, while the 1400 MHz frequency is only used for the downlink. The Supplementary Downlink radios offer additional downlink link capacity

[1] https://www.nokia.com/en_int/news/releases/2017/05/02/nokia-to-play-key-role-in-t-mobiles-5g-nationwide-network-plans
[2] https://yle.fi/aihe/artikkeli/2016/09/02/yle-qualcomm-and-nokia-announce-worlds-first-demonstration-lte-supplemental

and receivers, resulting in 4RX diversity for the primary band to deliver better service quality, in particular better indoor coverage.

FDD solution is also getting traction around the world and it will be implemented in Japan. Therefore, there is an option for IMDA to wait for the work in 3GPP and AWG to be finalized and ensure that a harmonized approach is taken among neighbouring countries, in ASEAN, or in the whole APT region that will indeed also create a healthy ecosystem regardless if it is an SDL or FDD solution.

3.2.2 The (Extended) C-Band (3300-4200 MHz)

The 3300-4200 MHz band offers the unique opportunity for largest amount of spectrum below 6 GHz. The amount of contiguous spectrum that can be made available in the 3300-4200 MHz range offers an interesting opportunity for the exploitation of the innovative capabilities of the latest IMT technologies, with particular reference to the 5G New Radio air interface which will deliver increased capacity and connectivity.

The 3300-4200 MHz IMT ecosystem is developing fast; while the 3400-3600/3800 MHz is now nearly-globally available, a large number of countries globally are taking actions in order to make available between 200 and 400 MHz of contiguous bandwidth for 5G, and designating as such the C-band as the largest continuous band for IMT below 5GHz.

In Europe, the 3400-3800 MHz has been decided by the EC RSPG as one of the 5G pioneer band and trials are being prepared for 2018, in line with the “5G Action Plan” roadmap proposed by the EC, European Commission.

Parts of the extended C-band are being considered for early trials and introduction of 5G services in a number of countries/regions in the world including China (3400-3600 MHz) and Japan (3600-4200 MHz). The 3400-3800 MHz band might also be a good candidate in the U.S. and Korea for 5G deployments: in the U.S. “The Mobile Now Act” proposes further studies for a number of bands, including 3100-3550 MHz and 3700-4200 MHz in addition to the already allocated 3.55-3.7GHz band. Operators and regulators in Africa, Middle East, Latin America and Asia are supporting the harmonization of the newly identified 3300-3400 MHz and the sharing opportunities in the 3400-3600/3800 MHz range

Nokia supports the availability of largest contiguous frequency range within the 3300-4200 MHz. At national level, many countries will need to plan and carry out actions in order to address current fragmentation of existing assignments.

The availability of largest unpaired assignments to operators will provide optimal support for 5G which will operate in TDD duplex method in this band. 5G-NR (New Radio) is being designed to inherently incorporate advanced wireless techniques across a wide range of requirements that take full benefit of wideband channels to deliver improved spectral efficiency, better capacities and user experiences.

In countries where the FSS service is not heavily using the C-band and where other communication networks can be used to replace FSS systems, Nokia believes that regulators should carefully consider the option of clearing the band from the FSS incumbent use in the short term.

In countries where the FSS service is still using the band intensively (e.g. with ubiquitous rollouts of VSAT to support satellite TV reception, Nokia believes that regulators should define migration plans. Impact assessments can be performed when necessary to compare the social and economic benefits that would derive from using the band for IMT. The industry trends in the relation to the future use of the C-band should also be carefully taken in to account.

3.2.3 Unlicensed range 5GHz

Many countries apply various spectrum within the unlicensed bands, such as DECT or WiFi systems. They are still governed by regulations limited by bandwidth and power emissions.

A popular application of LTE within the unlicensed spectrum is emerging in the 5GHz range, see section 4 for more details.

3.3 High Bands - Above 6GHz

The use of millimetre wave frequencies constitutes one of the disruptive 5G technologies, as frequencies above 6 GHz have never been considered before for mobile fronthaul network rollouts, for reasons of technological maturity and propagation quality. However, the very wide channels of the frequencies in this range (> 6 GHz) can provide the spectrum resources required to achieve the increased data rates and traffic volumes of 5G. In exchange, due to the high frequencies poor propagation quality, each individual cell will have limited coverage and will require the use of beamforming to better focus the power transmitted by the antenna.

Following the WRC-15, a number of bands situated between 24 GHz and 86 GHz (33.25 GHz in total) were retained to focus future 5G studies (AI 1.13 of WRC-19): 24.25 - 27.5 GHz, 31.8 - 33.4 GHz, 37 – 43.5 GHz, 45.5 - 50.2 GHz, 50.4 - 52.6 GHz, 66 - 76 GHz, 81 - 86 GHz.

Nokia supports the view that the industry needs an initial focus and prioritization on selected bands from the bands under study in WRC-19 under AI 1.13. Such focus provides early visibility and plannability and thus allows concentrated efforts to allow an early 5G launch.

Nokia shares the view that global harmonisation is key for affordable device ecosystems and reducing co-existence issues.

The bands 24.5-27.5 GHz (26 GHz) and 31.8-33.4 GHz (32 GHz) (under study for WRC-19) are considered to be required for large contiguous RF carriers providing carrier bandwidths of several hundreds of MHz to enable up to double digit Gbps data rates with higher order MIMO and similar new technologies. The 32 GHz band has specific challenges regarding the protection of the passive services right below and of military radiolocation service right above that band that significantly limit available RF bandwidth to 5G and also limit and restrict the usability of 32 GHz for 5G. Additionally, 32 GHz band is relatively small (1.6 GHz) compared to 26 GHz (3.25 GHz) and the band might be further reduced by the need to protect the services operating in the adjacent bands.

Moreover, Nokia expects an ecosystem for the 28 GHz range to emerge around 2018 for US, Korea and eventually Japan but also due to strong support from Finland, Sweden, Columbia, Singapore, Canada and Slovenia. A potential tuning range between 26GHz (24.25-27.5) and 28 GHz band (26.5/27.5-29.5 GHz) is under study. The 26 GHz band is adjacent, right below 28GHz (and the 28 GHz band considered in Korea is overlapping by 1GHz), therefore the tuning range of 24.25 – 29.5 GHz could allow Singapore to benefit from early developments in the 28GHz (in Korea, the United States and Japan), while being in line with Europe's plan that considers 24.25-27.5GHz band under AI 1.13 suitable for initial deployments of 5G at high frequencies. We, therefore, encourage Singapore to study 24.25-29.5 GHz as a potential band for 5G/IMT-2020.

Furthermore, the 37-43.5 GHz band presents an excellent opportunity for global harmonisation and implementation (also by use of a tuning range). The 37-40 GHz band (39GHz) has already been decided in the United States and Nokia considers that this band will be used for early deployment. In Europe, the 40.5-43.5 GHz frequencies are not extensively used by incumbents and therefore, could provide large additional 5G capacity in subsequent upgrade steps to 5G networks as more and more services will be put onto 5G networks.

We also welcome IMDA proposal to open for trial the E-band (70/80 GHz), 71-76GHz paired with 81-86 GHz, for commercial applications. The system concept at E-Band is supposed to complement small cell deployment. Similar antenna and transceiver technologies as in the 60 GHz band can be used, and the 5G at E-Band could provide simultaneous access and backhaul for 4G and 5G (a.k.a self-backhauling).

Role of mmwave[3]:

[3] The 5G mmWave revolution Nokia Whitepaper (https://resources.ext.nokia.com/asset/200779)

The mobile communications industry is exploring the utilization of higher mmWave frequency spectrum for future 5G networks, coupled with the densification of networks. By their nature, those high frequencies provide much more bandwidth than the spectrum below 6 GHz that is currently being used for mobile communication, and mmWave spectrum is more amenable to small cell deployments.

The higher frequencies have several bands available to provide huge capacity and throughput. Nokia has proven that it is possible to take advantage of 1–2 GHz bandwidth in the mmWave bands. Substantial Nokia research, including channel measurements, Proof of Concept verifications and live trials with key operators shows that these bands can be used for access and backhaul to help support large volumes of small cell traffic.

Time division duplex (TDD) is the preferred duplexing method in mmWave cells because it eliminates the need for paired spectrum and is more flexible for handling the elastic demand of uplink and downlink traffic. Nokia Bell Labs is at the forefront of the research. For more details please check our white paper on 5G mmWave revolution[4].

[4] https://blog.networks.nokia.com/5g/2016/12/01/5g-mmwave-small-antennas-giant-leap-mankind/

However, to take full advantage of the small cells technology and the network densification, regulatory steps should be considered to allow for a cost-efficient and timely deployment of small size equipment.

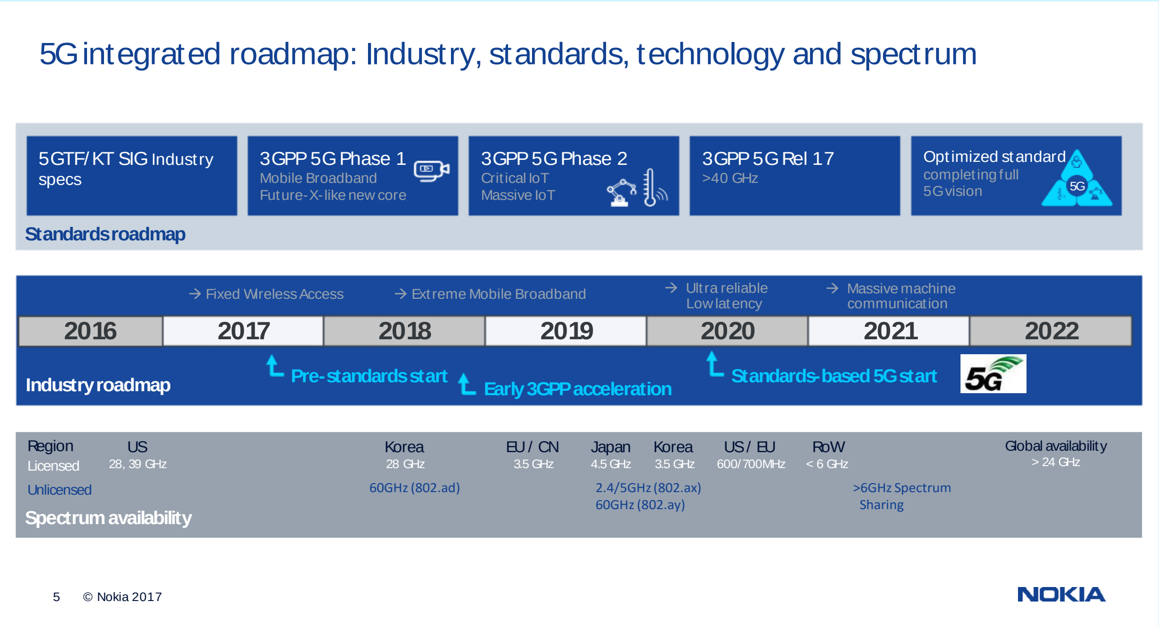
Key points

5G is emerging as a technology that will use both low frequencies (< 1 GHz), high frequencies (between 1-6 GHz) and, for the first time ever in consumer networks, very high frequencies referred to as "millimetre wave" frequencies (> 6 GHz).

This spectrum diversity is directly linked with the promises of 5G: extended coverage (low frequencies), ultra-high speeds (very large channels in very high frequency bands), and low power consumption.

Following the decisions taken at WRC-15 on WRC-19 5G agenda item for 5G spectrum, and considering the bands agreed for future study, the de facto spectrum being used in some countries, and the possibilities for the use of tuning ranges, Nokia believes that the following frequencies are the most suitable as a basis for harmonization on a global or regional basis:

- Short-term bands: 600 MHz, 700 MHz, 3.3–3.4 GHz, 3.4–3.8 GHz, 24.25-29.5 GHz using a tuning range approach (parts of the 24.25-29.5 frequency range for 5G allows APT to benefit from early developments in 28 GHz band in US, Korea and Japan and, in line with Europe, considering the 24.25-27.5 GHz band under AI 1.13 as suitable for initial deployments of 5G at high frequencies) and 37–43.5 GHz using a tuning range approach as different parts of this band are also considered in different regions (37 – 40 GHz already decided in the USA and 40.5 – 43.5 GHz in Europe
- Longer-term bands: 3.8-4.2 GHz, 71–76 GHz and 81–86 GHz.
- Other bands relevant in the context of 5G: 31.8–33.4 GHz (mindful that all emissions are prohibited in 31.3–31.8 GHz) and 66–71 GHz.



Public

4 Use of licence-exempt spectrum for IMT service

Nokia has been a long-time supporter, contributor and innovator of technologies operating in licensed but also in licence-exempt (unlicensed) spectrum such as LTE-U/LAA, LWA and MulteFire. As a provider of technology in licensed and unlicensed spectrum, Nokia believes that the principles of the unlicensed spectrum should be preserved by maintaining ease of use and keeping entry barriers low. Those are critical elements to the progress of technology and the benefit of the economy.

4.1 LTE-U/LAA/LWA[5]

The technology co-existence issue associated with LTE-U has been openly discussed in the technical community amongst equipment vendors, service providers and technology alliances. Contained in this issue is the position forwarded by some advocates of incumbent technologies in unlicensed spectrum that LTE-U does not provide sufficient co-existence and that regulators should require the use of a Listen-Before-Talk (LBT) function that has never been required in unlicensed spectrum in the United States. It is Nokia's position that any technology introduced into the unlicensed spectrum should co-exist with incumbent technologies in an equitable manner. We also believe that rigid governance of the unlicensed spectrum will significantly restrict future progress. To that end, IMDA should remain technology agnostic, focusing on facilitating the stated purpose of the unlicensed spectrum: innovation. We contend that the needs for compatible spectrum sharing in the unlicensed bands are sufficiently fulfilled and no LBT requirement for LTE-U should be mandated as it is the case in the United States, and Korea and should follow the Wi-Fi Alliance co-existence plan. Co-existence concerns are neither unique to nor new with the introduction of LTE-U and IMDA should promote the deployment of LTE-U to ensure that operators are meeting the demand for speed and connectivity.

LAA provides the same powerful benefits as LTE-U from aggregating LTE in both licensed and unlicensed spectrum with the additional benefit that LAA meets global regulations. LTE-U was introduced to address time-to-market needs in specific regions such as USA, India and Korea. LAA includes "Listen Before Talk" (LBT) suitable for global deployment, including EU and Japan. Both LAA and LTE-U ensures fair co-existence with Wi-Fi. Operators should freely decide if/when they want to upgrade to LAA subject to hardware/software availabilities.

Both Licensed-Assisted Access (LAA) and LTE-WLAN Radio Aggregation (LWA) have been standardized as part of the Release 13 of the E-UTRA specifications (a.k.a. LTE-A Pro). One of the main differences between LAA and LWA is that LAA uses LTE radio access technology in unlicensed spectrum, while LWA access in the unlicensed spectrum is still based on IEEE 802.11 standards. LWA is based on LTE dual connectivity and supports scenarios where licensed spectrum is not co-located with Wi-Fi Access Points. Moreover, LWA can be used by existing Wi-Fi deployments in both 2.4 and 5.0 GHz bands. LAA based on LTE carrier aggregation only supports co-located deployments. On the other hand, LAA can benefit from the higher spectral efficiency and interference robustness of LTE, resulting in increased coverage and higher capacity than Wi-Fi. LAA can provide a major capacity boost from the unlicensed band.

It is also important to note that LTE-A Pro evolution will continue to put a focus on unlicensed spectrum, particularly the 5 GHz band. Support for LAA uplink is planned for Release 14 of the 3GPP E-UTRA specifications (eLAA), and support for uplink via Wi-Fi with LWA is also a candidate feature for future 3GPP releases. LAA is also likely to evolve towards support for dual connectivity, which will finally allow use of LAA in non-co-located deployments with licensed spectrum, and with relaxed requirements from the backhaul connections.

[5] Unlicensed band opportunities for mobile Broadband (https://resources.ext.nokia.com/asset/200296)

4.2 MulteFire

As one of the founding members of the MulteFire Alliance, Nokia is driving the development of a global technical specification. We are collaborating with stakeholders to develop new ways of utilizing spectrum to meet the network demands. Multefire could potentially be a new opportunity for private and business networks.

The MulteFire Alliance recently made public its first specification, Release 1.0. As stated before, we suggest that limited regulation is applied to unleash the innovative potential of this technology

5 Evolution of the regulatory framework

Considering that the 4G networks are the foundation of the 5G infrastructure and that 5G will encompass services for both consumers and business, including vertical sectors, the spectrum policy and regulatory framework needs to be upgraded to the 5G era by aligning the regulation applicable to most applications running on terrestrial networks, but also to the wireless component of transport, audio-visual, health, energy, and Internet of Things/M2M services. Consistency in spectrum management between the different spectrum users should be achieved.

While licensed spectrum will continue to be essential for the development of the networks of the future, a balanced spectrum management should be kept between the licensed and licensed-exempt schemes.

In regards to the licensed spectrum use, the regulatory framework provides certainty of the legal framework and the investments in the networks of the future. However, considering the future use of high frequency bands and the ultra-dense network architecture of 5G, regulation should evolve to adapt to the technological and architectural evolutions.

A balanced pricing policy for licensed spectrum should be favoured to avoid hampering the investments required in the networks. As such, long licenses durations, accompanied by transparent renewal conditions, would give operators the necessary timeframe and incentives to continuously invest and upgrade their networks to be 5G-ready. Transparent renewal conditions would justify continuing investments at near license end-dates, avoiding investments gaps until the license renewal.

Also, a simplified secondary market for spectrum trading would benefit of a more efficient use of non-utilised / underutilised spectrum. All forms of spectrum secondary trading among spectrum licensees – spectrum leasing, trading, and swapping should be allowed – assuming that the market competition is not distorted. This may lead to more consolidation of spectrum owning in wider contiguous bands that can be used more efficiently for further network evolutions.

While exclusive licensed spectrum will be at the foundation of the 5G ecosystem, high frequency bands will be subject to access methods that are partially covered by the regulation and little or not used in the present.

In view of 5G developments and deployments, the bands above 24 GHz are considered to be required for large contiguous RF carriers providing carrier bandwidths of several hundreds of MHz to enable up to double digit Gbps data rates with higher order MIMO and similar new technologies. Given their characteristics, the exclusive licensing schemes may not alone be applicable in the case of high frequency bands. 5G applications of vertical industries are expected to typically be served by networks slices in 5G MNO networks. Consequently, regulators should aim at assigning very wide RF bandwidths to MNOs to allow efficient networks slicing models rather than assigning (narrow) slices of spectrum per vertical industry. Among the several spectrum access schemes we consider the sub-licensing, co-primary sharing and the light licensing:

- Sub-licensing can allow MNOs to pass on locally usage rights to users e.g. in an enterprise use context to parties interested to build and operate services not economically viable for MNOs.
- Co-primary sharing is a concept designed to enable sharing between primary users of the spectrum, for instance between several mobile operators. However, pricing of spectrum and sharing conditions will be preconditions in identifying scenarios.

- Light licensing is of a similar category but without the need for exclusive licenses per operator. The band can be shared between a group of users in an agreed way, e.g. in time, in space, and/or in frequency, with pooling rules a priori known.

Licensing schemes adapted to the new frequency bands are under investigation by the industry and regulators around the world in order to identify the best management scenarios that would provide benefits in efficient usage of these bands for 5G.

Nokia is of view that exclusive licensed spectrum will continue to play a major role in assuring the investments in the networks and the quality of the services provided, but the evolution of use of technologies in various spectrum bands will be reflected in the consequent evolution of the licensing regime.

Last but not least, network configurations are evolving constantly to better meet users' needs in terms of indoor and outdoor coverage and to improve quality of service: new radio base stations are installed on a regular basis to increase the networks' capacity and their size deems to better match the ultra-dense architectures. As such a high number of smaller cells is estimated to make part of the new 5G networks and regulatory and administrative frameworks should evolve to take into consideration rules that adapt to the processing of volumes of requests by the administrations. Nonetheless, apart of the need to streamline the administrative processes, as the French regulatory authorities ARCEP identified in its 5G report6, two major aspects should be equally considered: the simplification of the declaratory regime based on the equipment's power and the taxation of the small cells. Altogether, lighter administrative processes and low taxes of volumes of small cells can improve the operators' business cases and incentivize the fast deployment of ultra-dense 5G infrastructures for the benefit of citizens that will have access to state-of-art networks and applications using them.

[6] https://www.arcep.fr/uploads/tx_gspublication/Report-5G-issues-challenges-march2017.pdf (pages 30/31)