INVITED PAPER *Special Section on 5G Radio Access Networks — Part I: Radio Access Technologies and System Design*

5G Wireless Access

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SUMMARY 5G is the next step in the evolution of mobile communication and a key component of the future networked society. It will include the evolution of LTE as well as new non-backwards-compatible technology. With capabilities such as massive system capacity, higher data rates, very low latency and ultra-high reliability, 5G will provide significantly enhanced mobile-broadband experience but also support a wide range of new wireless applications and use cases. Key technology components include operation at higher frequency bands and flexible spectrum usage, advanced multi-antenna/multi-site transmission, lean transmission, access/backhaul integration, and possibility for direct device-to-device communication.

key words: *5G, 5G mobile communication, 5G wireless access, future wireless access*

1. What is 5G?

The world has witnessed four generations of mobile-communication technology

- The first generation, based on analog transmission, was the first time mobile telephony became available to ordinary people.
- The second generation introduced digital transmission and, eventually, made mobile telephony available essentially anywhere and for anyone.
- The third generation (3G) and its evolution [1] introduced mobile broadband and paved the way for the ubiquitous mobile internet access of today.
- The fourth generation (4G), also known as LTE [2], is currently being introduced all around the world. It further enhances the mobile-broadband experience by providing peak data rates of several 100 Mbps with higher efficiency and lower latency compared to 3G.

The *fifth generation* (5G) is the next step in the evolution of mobile communication, expected to be introduced around 2020. 5G will be a key component of the future networked society aiming at providing essentially unlimited access to information and sharing of data anywhere and anytime for anyone and anything. Thus, 5G will not only be about mobile connectivity for people. Rather, the aim of 5G is to provide ubiquitous connectivity for any kind of device and any kind of application that may benefit from being connected.

Mobile broadband will continue to be important and will drive the need for higher system capacity and higher data rates. But 5G will also provide wireless connectivity for a wide range of new applications and use cases, including wearables, smart homes, traffic safety/control, and critical infra-structure and industry applications, as well as for very-high-speed media delivery. 5G must also be able to adapt to future applications with yet unknown characteristics and requirements.

2. Requirements and Capabilities

In order to enable connectivity for a very wide range of different applications with vastly different characteristics and requirements, the capabilities of 5G wireless access must extend far beyond those of previous generations of mobile communication.

2.1 Massive System Capacity

Although estimates of the traffic demands for future mobile-communication systems vary they all predict a massive increase in traffic demand [3], [4]. To support this traffic in an affordable way, 5G networks must be able to deliver data with much lower cost per bit compared to the networks of today. Furthermore, to be able to operate with the same or preferably even lower overall energy consumption compared to today, 5G must enable radically lower energy consumption per delivered bit.

The main tool for increased traffic capacity will be a further densification of the radio-access network, that is, additional network nodes, in combination with additional spectrum. However, improved spectral efficiency, for example by means of advanced multi-antenna transmission and inter-site coordination, will also be an important component to satisfy future traffic demands.

Another aspect of 5G system capacity is the need to support a much larger number of devices compared to today. The new use cases envisioned for 5G include, for example, the deployment of billions of wirelessly connected sensors, actuators and similar devices. Each such device will typically be associated with very little traffic, implying that, even jointly, they will have a limited impact on the overall traffic volume. However, the sheer number of devices to be connected provides a challenge, for example, in terms of efficient signaling protocols.

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2.2 Very High Data Rates Everywhere

Every generation of mobile communication has been associated with higher end-user data rates compared to the previous generation.

In the past, much focus has been on the peak data rate that can be supported by a wireless-access technology under ideal conditions. However, a much more relevant capability is the maximum data rate that can actually be provided under real-life conditions in different scenarios.

- 5G should be able to provide data rates exceeding 10 Gbps in specific scenarios such as indoor and dense outdoor environments.
- Data rates of several 100 Mbps should be generally achievable in urban and suburban environments.
- Data rates of several 10 Mbps should be achievable essentially everywhere, including sparsely-populated rural areas in both developed and developing countries.

Extending the maximum transmission bandwidths up to at least several 100 MHz and, for very high frequencies, even beyond that will be key to achieve very high data rates in, for example, indoor and very dense outdoor environments. However, in many deployment scenarios, especially in suburban and rural areas, the achievable data rates will not be limited by the available transmission bandwidth but rather by the received signal power. In such cases, a wider transmission bandwidth will not enable higher data rates. Rather, means must be taken to increase the signal power available at the receiver. Although, in some cases, this can be achieved by a further densification of the radio-access network, this is not always economically feasible. Another means, not requiring the deployment of additional network nodes, is to apply extensive beam-forming based on multi-antenna systems at the transmitter and/or receiver.

2.3 Very Low-Latency

Lower latency has been a key target for both 4G and the evolution of 3G, driven mainly by the continuous quest for higher achievable data rates. Due to properties of the internet protocols, lower latency over the wireless interface is critical to realize the higher data rates.

As already mentioned, 5G wireless access targets even higher data rates and this, in itself, will drive a need for even lower latency. However, lower latency will also be driven by the support for new applications. Some of the envisioned 5G applications, such as traffic safety/control and control of critical infra-structure and industry processes, may require much lower latency compared to what is possible with the mobile-communication technologies of today. To support such latency-critical applications, 5G should allow for an application end-to-end latency as low as 1 ms or even lower.

Key tools to achieve lower latency on the radio interface include shorter transmission-time intervals and means for faster detection/decoding of received data. The later may, for example, be enabled by specific structures for channel coding and reference-signal transmissions. On a higher level, means for faster access to the channel for example through faster channel assignment or contention-based access will also be relevant from a latency point-of-view.

2.4 Ultra-High Reliability and Availability

In addition to very low latency, 5G should also enable connectivity with ultra-high reliability and ultra-high availability. For critical services, such as traffic safety or control of critical infra-structure, connectivity with a certain characteristics, such as a certain maximum latency, should not only be "typically available". Rather, connectivity with the required characteristics should *always be available* with essentially *no deviation*.

Multi-level diversity, allowing for multiple alternative transmission paths on different levels, is one important component to achieve such very high reliability and availability. This may also include the possibility for direct device-to-device communication, especially for applications where the connectivity requirements are mainly local.

2.5 Very Low Device Cost and Energy Consumption

The possibility for low cost and low energy consumption for mobile devices has been a key requirement since the early days of mobile communication. However, in order to enable the vision of billions of wirelessly connected sensors, actuators and similar devices, a further step has to be taken in terms of device cost and energy consumption. It should be possible for such 5G devices to be available for very low cost and with a battery life of several years without recharging.

It should be understood that not all 5G devices will have such low cost and energy consumption. The key thing is that 5G wireless access should *allow* for devices with extremely low cost and extremely long battery life for specific application. Furthermore, such devices should be able to co-exist on the same carrier with, for example, high-end mobile-broadband devices.

2.6 High Network Energy Performance

While device energy efficiency has always been important, high energy performance on the network side has more recently emerged as a key performance indicator.

- Network energy consumption contributes a substantial part of the overall operational cost of many networks. High network energy performance is therefore an important component to reduce cost and enable affordable services.
- High network energy performance may allow for off-grid network deployments relying on decently-sized solar panels for power, thereby enabling wireless connectivity to even the most remote areas.
- High network energy performance can be seen as part of

a general operator aim of providing wireless access in a sustainable and more resource-efficient way.

Lean radio-access design, see also Sect. 6.3, is one key component to enhance the network energy performance.

3. Machine-Type Communication

Applications such as mobile telephony, mobile broadband, and media delivery are, fundamentally, about information for humans. In contrast, many of the new applications and use cases that drive the requirements and capabilities of 5G are about end-to-end communication between devices. In order to distinguish them from the more human-centric wireless communication use cases, these applications are often labeled *Machine-Type Communication* (MTC).

Although spanning a wide range of different applications, many of which are yet unknown, MTC applications can be divided into two main categories, *Massive MTC* and *Critical MTC*, as outlined in Fig. 1.

Massive-MTC corresponds to applications that typically span a very large number of devices, such as different types of sensors, actuators, and similar devices. These devices typically have to be of very low cost and have very low energy consumption enabling very long battery life. At the same time, the amount of data generated by each device is normally very small and very low latency is not a critical requirement.

Instead of providing direct mobile-network connectivity for all MTC devices, connectivity may alternatively be provided by means of so-called *capillary networks*. In a capillary network, local connectivity is provided by means of some short-range radio-access technology, for example Bluetooth [5] or 802.15.4/6LowPAN [6]. Connectivity outside the local area is then provided by the mobile network via some concentration node/device.

Critical-MTC corresponds to applications such as traffic safety/control, control of critical infra-structure and wireless connectivity for industrial processes. Critical-MTC applications require very high reliability and availability on the wireless connectivity. Furthermore, they may often be associated with requirements on very low latency. On the other hand, low device cost and energy consumption is not as critical as for Massive-MTC applications

There are suggestions of providing different MTC services using specific radio-access technologies operating in separate spectrum. However, there is a lot to gain from being able to provide as many different application as possible, including mobile broadband, media delivery, and a wide range of different MTC applications by means of the same basic wireless-access technology and within the same spectrum. This would avoid spectrum fragmentation and allow for operators to offer support for new MTC services, for which the business potentials are inherently uncertain, without having to deploy a separate network and reassign spectrum specifically for these applications.

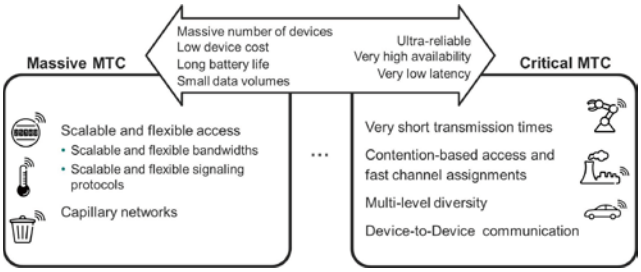

Fig. 1 Massive MTC and critical MTC.

4. Spectrum

4.1 New Spectrum

Every generation of mobile communication has extended the range of frequencies within which communication may take place, from being confined to frequencies below 1 GHz for the first generation analog technologies to stretching beyond 3 GHz for fourth-generation LTE.

In order to further extend traffic capacity and to enable the transmission bandwidths needed to support very high data rates, 5G will further extend the range of frequencies used for mobile communication. This includes new spectrum below 6 GHz, expected to be allocated for mobile communication at the World Radio Conference (WRC) 2015, as well as spectrum above 10 GHz, expected to be on the agenda for WRC 2019.

It has historically been assumed that high frequencies are unsuitable for mobile communication due to, for example, higher basic path loss, less diffraction leading to higher shadowing losses, and inferior wall penetration. However, recent investigations, see for example [7], have indicated that, with proper antenna configurations, frequencies at least up to 30 GHz can be used for outdoor non-line-of-sight communication up to a few 100 m distance.

As a consequence, spectrum above 10 GHz has emerged as highly interesting for 5G wireless access. It is important to understand though, that such frequencies can only serve as a complement, providing additional system capacity and very wide transmission bandwidths for extreme data rates in dense deployments. Lower frequencies will remain the backbone for mobile-communication networks also in the 5G era, providing ubiquitous wide-area connectivity.

It is still unclear exactly what spectrum above 10 GHz will be available for mobile communication and the entire frequency range from 10 GHz up to 100 GHz, i.e. well into the milli-meter-wave (mmw) range, should be considered as this stage. The lower part of this frequency range, below 30 GHz, is clearly preferred from the point-of-view of propagation properties. At the same time, very large amount of spectrum and possibility for very wide transmission bandwidths, in the order of a GHz or even more, will only be available in frequency bands above 30 GHz.

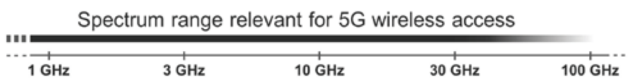

Fig. 2 Spectrum relevant for 5G wireless access.

4.2 New Means for Spectrum Assignment

Since its inception, mobile communication has relied on spectrum licensed on a per-operator basis within a geographical area. This will remain the foundation for mobile communication also in the 5G era, allowing operators to provide high-quality connectivity in a controlled-interference environment. However, per-operator licensing of spectrum may be complemented with the possibility to operate under more flexible spectrum regimes. This may include sharing of spectrum between a limited set of operators, as well as operation in unlicensed spectrum. Note that the later, that is the possibility to operate also in unlicensed spectrum, is currently under progress of being introduced as part of the LTE evolution [8].

Deviating from conventional per-operator spectrum licensing should mainly be considered for higher frequency bands above 10 GHz.

In high frequency bands, focus will be on very wide transmission bandwidths. It may sometimes be difficult to find sufficiently large spectrum blocks to allow for per-operator-dedicated spectrum supporting such bandwidths for multiple operators.

Furthermore, high frequency bands will typically be used for very dense deployments for which one can expect much more dynamic traffic variations. Statically dividing the spectrum between different operators may, in such situations, not necessarily lead to the most efficient spectrum usage. Rather, making it possible for operators to jointly access at least part of the spectrum in a dynamic way could, potentially, lead to more efficient overall spectrum utilization.

5. Evolution of LTE and New Technology

In contrast to earlier generations, 5G wireless access should not be seen as a specific radio-access technology. Rather, it should be seen as the overall wireless-access solution addressing the demands and requirements of future, beyond-2020, mobile communication.

LTE will continue to evolve in a backwards-compatible way and will be an important part of this overall 5G wireless-access solution for frequency bands below 6 GHz. Around 2020, there will be massive deployments of LTE providing service to an enormous number of devices in these bands. For operators with limited spectrum resources, the possibility to introduce 5G capabilities in a backwards-compatible way, thereby allowing for legacy devices to continue to be served on the same carrier, is highly beneficial and, in some case, even vital.

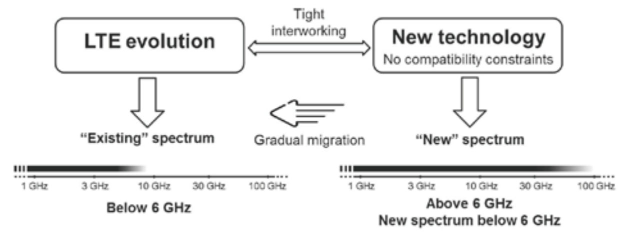

Fig. 3 Overall 5G wireless-access solution.

In parallel, new radio-access technology with no backwards-compatibility constraints will emerge, at least initially targeting new spectrum for which backwards compatibility is not relevant. Relaxing the constraints on backwards compatibility may allow for further optimization, for example allowing for even lower latency over the radio interface.

New spectrum will primarily be available at higher frequencies above 10 GHz. However, new spectrum for which new non-backwards-compatible technology may apply may also become available at lower frequencies. If new technology is needed to achieve, for example, a very low latency required by some specific applications it may not be sufficient to enable such applications only on high frequencies in dense deployments. Rather, the applications may have to be available also in suburban and rural deployments for which lower-frequency bands need to be used.

Note that, in a longer-term perspective, new non-backwards-compatible technology may also migrate into existing spectrum as legacy devices disappear from the market.

Although the overall 5G wireless-access solution will consist of different components, including the evolution of LTE as well as new technology, it is important to ensure that the different components are highly integrated with the possibility for tight interworking between them. This may, for example, include *dual-connectivity* between LTE operating on lower frequencies and new technology on higher frequencies, see further Sect. 6.2. It may also include the possibility for joint delivery of data via both LTE and a new radio-access technology. Possibility for such *user-plane aggregation* would reduce the threshold of migrating LTE spectrum to new technology as this could then be done without reducing the aggregated transmission bandwidth, and, consequently the maximum data rate, that can be offered to a device.

6. Technology Components

Beyond extending operation to higher frequencies, there are several other key technology components relevant for the evolution to 5G wireless access.

6.1 Multi-Antenna Transmission

Multi-antenna transmission plays an important role already for current generations of mobile communication as a means for

- *beam-forming* to enhance coverage and provide higher data rates in power-limited scenarios,
- *spatial multiplexing* to provide higher data rates in bandwidth-limited scenarios, and
- *multi-user-MIMO* to enhance system capacity by simultaneously serving multiple users/devices

Multi-antenna transmission will most likely play an even more important role in the context of 5G wireless access.

Especially for operation at higher frequencies, the use of multiple antennas for beam-forming at the transmitter and/or receiver is a critical component. In essence, the use of multiple antenna elements can counter the inherently smaller antenna aperture of each antenna element at higher frequencies, thereby allowing for more energy to be captured. In principle, by applying beam-forming at both the transmitter and receiver side the basic path loss at higher frequencies could even be turned into an overall gain, something which is utilized, for example, in case of point-to-point radio links. In a mobile-communication scenario, the overall propagation would still be degraded by effects such less diffraction and worse wall penetration though.

While being a necessary component for higher frequencies, beam-forming will be an important component also for lower frequencies, for example to further extend coverage and to provide higher data rates in sparse deployments.

In contrast to beam-forming, spatial multiplexing will be more relevant for lower frequencies where bandwidth, rather than power, may more often limit the achievable data rates.

6.2 Inter-Site Coordination and Dual-Connectivity

Any mobile-communication network consists of a large number of geographically separated network-access nodes, potentially in multiple layers. System performance, in terms of, for example, capacity, achievable data rates, and connection reliability, can be enhanced by means of coordination between the different nodes. In 3GPP/LTE terminology this is often referred to as *Coordinated Multi-Point* (CoMP) transmission.

Coordination between network nodes of the same layer may range from relatively slow scheduling coordination for interference control to joint transmission to a single device from multiple nodes. The amount of coordination that is possible depends on, for example, the capacity and latency of the connectivity between the different network nodes. The capability of the inter-node connectivity will clearly differ between different deployments. In some cases, very capable connectivity, with high capacity and very low latency, will be available, allowing for very tight coordination. In other cases, only much less capable connectivity is available, limiting the coordination. 5G wireless access should allow for different types of inter-site coordination matching different capabilities of the available inter-node connectivity.

Another form of inter-site coordination is coordination between different network layers, for example coordination between a macro layer and an under-laid high-density layer of low-power ("pico") nodes. One important type of such *inter-layer* coordination is *dual-connectivity* where a device has connectivity to multiple layers simultaneously. This is especially of interest in case of high-density layers operating at higher frequencies leading to more fragmented coverage. The underlaid high-density layer would then provide high-rate/high-capacity user-plane connectivity while the overlaid macro layer would ensure continuous coverage connectivity for the devices. An example of such dual-connectivity is the "phantom-cell" concept outlined in [9].

Note that the different layers in a dual-connectivity scenario may very well be based on different radio-access technologies. An important scenario could, for example, be a high-density layer using new technology operating on higher frequencies with a macro layer based on LTE.

6.3 Lean Design

For current wireless-access technologies, such as LTE, there are often several types of mandatory downlink transmissions not directly related to user-data transmission. In LTE this includes, for example, the transmission of synchronization signals, common reference signals, and different types of broadcast system information.

In a high-load situation, these transmissions contribute only a small fraction of the overall downlink transmission and thus have minor impact on the system performance. However, access nodes often operate under relatively low-load conditions with user-data transmission only taking place in a small fraction of the available time slots. In such case, the mandatory non-user-data transmissions impact

- *network energy efficiency* by reducing the time during which transmitter power amplifiers can enter truly low-energy modes
- *achievable data rates* by causing interference to transmissions from neighbor access points

Mandatory downlink transmissions will also constrain the possibilities to evolve a radio-interface technology as such transmissions cannot be modified/removed without breaking backwards compatibility for legacy devices.

Lean design should be seen as a design principle rather than a specific technology component. More specifically, the radio-access design should minimize transmissions not directly related to the transmission of user data. For example:

- It should be possible to provide the main part of system information on a per-need basis, minimizing the system information that needs to be broadcast
- It should be possible to provide broadcast system information in a separate *system-control plane*, see further below.

- User-data transmissions should rely on dedicated reference signals rather than cell-common always-transmitted reference signals. This does not only lead to a lean design but also provides additional higher flexibility in terms of beam-forming solutions.

6.4 Separate System Control Plane

For current wireless-access technologies, including LTE, delivery of system information including, for example, information about initial access, is provided very much integrated with the user-data delivery mechanisms. Also, the full set of system information is provided explicitly by each cell despite the fact that the system information is typically identical between cells.

A separate independent system-control plane provides more freedom in the delivery of system information.

System information relevant for the nodes of a high-density low-power layer could, for example, be provided by an overlaid macro node allowing for the low-power nodes to only be activated on a per-need basis. Note that this can be generalized to a situation where system information relevant for a set of macro nodes is delivered by an overlaid "super-macro" node.

One could also have system information being shared between different radio-access technologies. For example, system information relevant for a new radio-access technology operating on high frequencies could be provided by an overlaid evolved LTE layer operating at lower frequencies.

Separate system control plane aligns to the principle of lean design as described above. It also creates additional flexibility for future evolution of the radio-access technology as the user-plane can be evolved without impacting system control.

6.5 New Waveforms

Earlier generations of mobile communication has been associated with new waveforms, from single-carrier TDMA for 2G/GSM, via direct-spread CDMA for 3G/HSPA, to OFDM for 4G/LTE. As of today, OFDM is the main candidate also for the 5G era, although there are alternatives being considered. Two such alternative paths are *filtered multi-carrier transmission* and different forms of *single-carrier transmission*.

Filtered-multi-carrier transmission includes, for example, *Filter-Bank Multi-Carrier* (FBMC), *Generalized Frequency Division Multiplexing* (GFDM), *Universal Filtered Multi Carrier* (UFMC), see [10] for more details and further references. These transmission schemes can all be seen as generalizations of conventional OFDM with additional spectrum shaping applied either on a per-sub-carrier basis or on a group of sub-carrier.

The benefit of the spectrum shaping is a more confined spectrum, which could, potentially, simplify co-existence of different waveforms in the same spectrum. A more confined spectrum also means that orthogonality between different frequency-separated transmissions could be retained also in the absence of tight time synchronization between the transmissions. This could potentially enable faster uplink access by avoiding the need for initial synchronization of uplink transmissions.

The main drawback of filtered multi-carrier transmission has been related to complexity and channel estimation, especially in relation to spatial multiplexing. Although recent studies have resolved some of these issues there is still a question mark about filtered multi-carrier transmission in relation to spatial multiplexing

The other alternative waveform being considered is different forms of single-carrier transmission. An example of this is DFT-spread OFDM as currently used in the LTE uplink [2]. The main benefit of single-carrier transmission is higher power-amplifier efficiency, which allows for lower-complexity transmitters with less energy consumption. In the 5G era, this may not only be relevant for the device side. Possibility for low-cost transmitters with high energy efficiency may also be relevant for very-low-cost access points, especially for very high frequency bands where energy-efficient implementation of OFDM may be more challenging.

It should be noted that the detailed waveform may very well vary between different frequency bands. As an example, OFDM may be used up to a few 10 GHz while, for even higher frequencies, single-carrier transmission may be a better choice.

6.6 Flexible Duplex

Since the inception of mobile communication, Frequency Division Duplex (FDD) has been the dominating duplex arrangement.

For lower frequency bands, FDD will remain the main duplex scheme also in the 5G era. However, for higher frequency bands, especially above 10 GHz, Time-Division Duplex (TDD) will play a more important role.

- In higher frequency bands, focus will be on wider transmission bandwidths. Finding paired (FDD) spectrum supporting very wide bandwidths is more challenging, compared to unpaired (TDD) spectrum.
- Higher frequencies will typically be used for dense deployments for which one can expect more dynamic variations in the instantaneous downlink/uplink traffic demands. TDD with the possibility for dynamic assignment of downlink and uplink transmission resources could better adapt to such variations.
- A main reason for the preference for FDD in current mobile-communication networks is the additional *base-station-to-base-station* and *device-to-device* interference that may occur in TDD. However, higher frequencies will typically be used in dense deployments with low-power base-stations deployed indoor and outdoor on street-level. Thus, radio-wise and in terms of created interference, there will not be a major difference between base sta-

tion and device transmissions. Thus base-station-to-base-station and device-to-device interference should not be fundamentally different and more severe, compared to the base-station-to-device and device-to-base-station interference present also for FDD.

In order for TDD to reach its full potential, the air-interface design should allow for fully flexible and dynamic assignment of the transmission resources (time slots) to the downlink and uplink transmission directions respectively. This is in contrast to current TDD-based mobile technologies, including LTE/TDD, for which there are restrictions on the downlink/uplink configurations and for which there are typically an assumption about the same configuration for neighbor cells and also between neighbor operators.

Recently there have been several reports on investigation of *full-duplex*, that is *simultaneous* transmission and reception *on the same carrier frequency*, see e.g. [11]. Full-duplex operation relies on advanced interference suppression to handle the self-interference from the transmitter to the receiver. Current implementation technology has not reached a state where full duplex is commercially feasible on the access (network-to-device) link. However, this situation may change in the future and future 5G wireless-access technology should be designed and specified in such a way that full-duplex can be introduced if/when technology so allows.

6.7 Direct Device-to-Device Communication

The possibility for limited direct device-to-device (D2D) communication has recently been introduced as an extension to the LTE specifications [12].

In the 5G era the possibility for D2D as part of the wireless-access solution should be considered from the start. This includes device-to-device communication for peer-to-peer user-data communication between devices as well as the use of devices as relays to extend the network coverage.

Device-to-device communication in the context of 5G should be an *integral part of the overall wireless-access solution* rather than a stand-alone solution. The possibility for direct device-to-device communication should extend the capabilities and enhancing the overall efficiency of the wireless-access network. Furthermore, in order to avoid uncontrolled interference to other links, direct device-to-device communication should be under network control. This is especially important for the case of device-to-device communication in licensed spectrum.

6.8 Access/Backhaul Integration

Already today, wireless technology is frequently used as part of the backhaul solution in many regions of the world. Such *wireless-backhaul* solutions then typically operate under line-of-sight conditions using proprietary radio technology in higher frequency bands, for example the mmw band.

As described above, in the future higher frequency bands, including the mmw bands, is being considered also for the access link, i.e. for communication with mobile devices. At the same time, there will be a need for wireless-backhaul solutions that can operate also under non-line-of-sight conditions, for example for backhaul to small network nodes deployed on street level.

Based on these observations, it is obvious that the requirements and characteristics of the access and backhaul links are converging. In the 5G era, one should not see the wireless-access link and wireless backhaul as two separate things with separate solutions. Rather, backhaul and access should be able to use the same basic technology and operate using a common spectrum pool. This will lead to more efficient overall spectrum utilization and reduced operation and management effort.

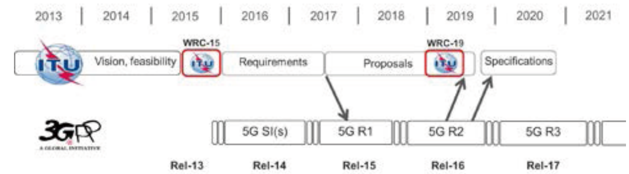

Fig. 4 5G time plan in ITU and possible 3GPP time plan.

7. Time Schedule

ITU has agreed to a timeline and process for radio-interface specifications for 5G. The agreed process is similar to the process used for IMT-2000 and IMT-Advanced, starting with the definition of technical performance requirements and definition of the evaluation criteria and methods in 2016. After completing this, ITU will solicit submissions for proposals and will compile the evaluation reports of external evaluation groups. The ITU timeline concludes with publication of the final specifications in 2020.

In order to secure timely availability of 3GPP specifications for ITU submission, the technical work needs to be completed in 3GPP by the end of 2019. In addition to ITU submission, 3GPP specifications may be needed in time for initial commercial deployments, currently envisioned around 2020. To achieve all this, the initial 3GPP technical work should be started during 2016 and first release of specifications might be needed around mid-2018.

8. Ericsson 5G Trials

Ericsson has demonstrated some of the key 5G technology components using commercial hardware to achieve data rates exceeding 5 Gbps over the air. The Ericsson 5G network development activities include new antenna technologies for wider bandwidths, higher frequencies and shorter transmission time intervals. Base stations built with baseband and radio units are being developed specifically for 5G trials. Small cells in heterogeneous-network environments, new frequency bands (including 15 GHz) and high-speed, high-capacity backhaul transmission are also key 5G focus areas for Ericsson.

9. Conclusions

5G will be the next step in the evolution of mobile communication. It will be a key component of the future Networked Society. 5G wireless access will consist of the evolution of LTE for frequency bands below 6 GHz, in combination with new non-backwards-compatible technology targeting new spectrum, mainly at higher frequencies. By providing massive traffic capacity, very high data rates, very low latency and ultra-high reliability, 5G will enhance the mobile-broadband experience and will also extend mobile communication to many new applications and use cases. Key technology components for 5G include operation at higher frequency bands and flexible spectrum usage, advanced multi-antenna/multi-site transmission, lean transmission, and access/backhaul integration.

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