12

Future Trends and Recommendations

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12.1 Introduction

Wireless technologies are constantly evolving and have done so for more than two decades, when only considering mobile communications, going from 1G to 4G and soon 5G. This strong evolution has been driven by meeting between the technology push that is the DNA of academia, research centres and industry, and the market pull resulting from the increasing greediness of consumers. The momentum is maintained not only by the younger ones, but also by the elder, who now see the digital technologies as an extension to their own body functionalities and are always depending more on these technologies in their everyday life. The Edholm law of bandwidth [Che04] predicts an exponential increase of the data rate, which has been verified and generates the same expectations in consumers as those prevailed in the decades between 1990 and 2010 for the computer's power in relation with Moore's law. However, in both cases, the laws are not magic theorems that are obeyed without doing anything; they require treasures of imagination and dedicated efforts of crowds of engineers and researchers to achieve their predictions.

We are not at the end of wireless technology development, far from that, as the penetration of wireless objects closer and closer to humans and more and more embedded environments is anticipated in the next decade and beyond. Then the question of how to do it arises. A major step should be crossed within the next 5 years through the elaboration of "5G" networks, but the increasing complexity and wide versatility expected from these networks generates much questioning about what 5G will be and how far it should be standardised? Beyond 5G there might be (or will certainly be?) further developments to better translate fundamental discoveries into practical solutions and improve

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system capabilities in parameter domains such as the energy consumption, the latency, the throughput, the reliability, the security, and others.

In this chapter, we modestly attempt to elaborate on the work presented in the previous chapters, based on the results obtained by the European COST IC1004 network of scientific experts, in order to risk a vision on the future challenges and developments in mobile and wireless communications, on a time scale of about 5 years. This is done below in the three main "pillars" of the success story of follow-up mobile communications COST Actions (COST 207, 231, 259, 273, 2100, and IC1004), which are antennas and channels, signal processing, and device networking.

12.2 Antennas and Channels

Channel modelling will likely continue to be of fundamental importance. A rich spectrum of radio channel measurements, characterisation, and modelling results is available in the 0.7- to 6-GHz band. For higher frequency bands (cm- and mm-waves), now being considered for some 5G implementations, there were studies made in previous projects [Ver12], but specific measurement campaigns and a global regulation of such spectrum for mobile services is still missing. The models available so far cover cellular access between base and mobile stations, vehicular communications, and device-on-body scenarios. A number of reference channel models are available, such as IEEE [Mal$^+$09], WINNER [Kyo07], and COST2100 [LPQ$^+$12].

Likewise, the impact of antennas "in free-space" on the radio channel characteristics has been thoroughly investigated between 0.7 and 6 GHz, leading to a number of design criteria for a "good antenna array" on a small device and antenna evaluation methods [Lau11]. However, this simplistic free space approach is no longer adequate in long-term evolution (LTE) and beyond systems that more critically depend on good antenna performance to deliver the specified system performance. This has led to recent requirements by major mobile operators for handset vendors to provide performance figures relating to realistic usage conditions. Moreover, new wireless devices are required to cover many more frequency bands (over 40 for LTE alone), as well as implementing beyond 2 × 2 MIMO, which are highly challenging due to compact design space.

More accurate radio channel models are, therefore, required, including: (i) "new" deployment scenarios, such as very high mobility (vehicular, drone), different human body postures and tissues, harsh physical environments, ultra-dense device deployment, very-short links, highly directional front/backhaul links, among others; (ii) Multiband and wideband channel modelling with carrier frequencies above UHF up to Terahertz; and (iii) 3D modelling with site-specificity.

New deployment scenarios in complex propagation median raise a problem of scale. In many heterogeneous environments, the size of the area to be modelled can indeed be very large and also contain a number of very complex objects (e.g., planes in an airport and human bodies in a room). This multi-scale aspect results in a methodological issue, each scale being usually modelled by a different method: on the one hand, stochastic and asymptotic physical models such as ray-tracing (used in earlier works by the authors) enable to model large-scale structures; the computational cost depends on the required level of accuracy and the determinism of the model (i.e., it is larger for ray-based tools than for stochastic models) but remains manageable thanks to simplified descriptions; on the other hand, full-wave electromagnetic models such as the method of moments (MoMs) and its fast extensions are able to calculate spatial fields in complex scenarios (in terms of shape, etc.) but the required meshing associated with these methods limits the size of the environment to be modelled. Although both approaches presented above are appealing and could in theory be combined, this combination cannot be achieved by a mere superposition for two reasons: not only both approaches use different tools and assumptions, but also small- and large-scale interactions are mutually coupled. As a result, heterogeneous deployments often call for the development of hybrid models which correctly account for mutual coupling.

Multiband channels should extend the current model range well above 6 GHz, in particular towards the centimetre and millimetre wavelengths. Whereas, quite a few models exist for indoor environments, directional outdoor models are still largely missing, in particular those based on measurements (recent results are only based on ray-tracing simulations). Such measurements are challenging and would likely require new methods to be devised. Furthermore, many other aspects are also lacking, e.g., indoor-to-outdoor propagation, polarisation modelling, and channel dynamics caused by moving scatterers.

Classical directional channel modelling in the literature, including the 3rd generation partnership project (3GPP)-SCM models, represents the angular characteristics in the azimuthal domain [Tuf14]. This is related to the fact that capacity improvements by multiple-antenna systems are greatest when the angular spread is large, which usually occurs in the azimuth domain. In the elevation plane, the angular spread observed at the base station is usually restricted to a fairly narrow range. However, the emergence of massive MIMO systems has renewed the interest in using the elevation domain for beamforming purposes, in particular in multi-user settings. Within COST IC1004, an extension of the COST 2100 model for massive MIMO systems has been proposed. The biggest gaps in existing data sets and 3D models are related to outdoor-to-indoor links [Tuf14]. As examples, the impact of the indoor floor plan or the horizontal location of the mobile terminal within a building is still yet to be modelled accurately.

Finally, the needed radio channels also require new measurement methods, such as multiband channel sounding for a wide frequency range including micro-/millimeter-wave bands, distributed massive MIMO channel sounding, and portable channel sounding for drones, sensors, body environments and near-field links. Similarly, new channel emulation techniques should cope with carrier aggregation, isolating the different environments of multiple users, and testing objects up to the size of cars. To this end, innovative metrics for emulation accuracy are required, which could be user-oriented (subjective), or application specific.

On the antenna system side, the time is ripe for a more comprehensive strategy in optimising the interactions of the antennas, not only between the antenna elements, but also between the antennas and their surroundings (Figure 12.1). In this context, there has been some recent progress in co-optimising the antennas and the device platform using the theory of characteristic modes (TCM), as was described in Section 10.2. However, significant opportunities exist to extend the design framework to take into account nearby objects as well as the propagation channel. Moreover,

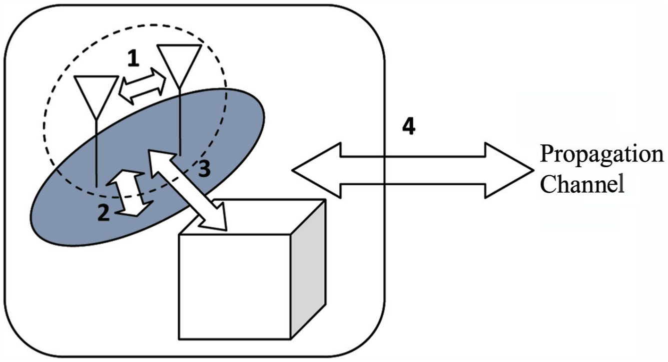

Figure 12.1 Multiple interactions of antenna elements with (*1*) each other and its surroundings, including (*2*) wireless device platform, (*3*) objects in proximity, and (*4*) propagation channel.

the non-stationary nature of the surroundings can be addressed using novel circuit technologies (e.g., low-loss MEMS circuits) to provide flexible and power efficient pattern-reconfigurable antennas to optimise near/far-field interactions with channels in any given deployment scenarios, under the constraints of size and disturbances in the vicinity (Figure 12.1). Existing work on pattern reconfigurable antennas are largely confined to canonical structures in free space operation, neglecting the device platform, nearby objects or even channel properties.

Apart from designing optimised antenna solutions, the properties of the antennas and objects in proximity that critically influence the physical channel must be derived in order to provide realistic channels for link and system evaluations. Prior work in joint antenna–channel modelling focused on traditional antenna solutions and statistical characterisation using large sample populations of possible antenna configurations, orientations, etc. The impact of flexible and ambient-optimised antenna systems must be accurately represented in order to facilitate overall system design.

12.3 New Challenges for the Fifth-Generation Physical Layer

COST IC1004 has focused on many of the issues that arise in communication networks for “green, smart environments”. One of the most significant of these is interference, where there has been significant research in working group 2 (WG2) on both interference modelling and interference management approaches, including interference alignment. Another is advanced MIMO techniques, which have the potential to reduce the effect of interference, as well as to increase link capacity. Advanced iteratively decodable error correction codes have been investigated: again, these have potential to improve robustness to interference and to increase capacity. And in the context of “green” communications, important work on energy efficiency has been carried out. However, much more remains to be done. In particular, we are now well into the development of the fifth generation (5G) of wireless communication, and it is clear that many new challenges will arise from this. In this context, COST IC1004 with its emphasis on wireless communication in a range of different environments and applications was very well positioned to provide the basis of this development, since 5G is expected to fulfil precisely this function of an “inclusive” wireless communication system, covering a much wider range of environments and applications than previous generations. This also leads to a much broader set of key performance indicators (KPIs), for which very challenging targets have been set.

These KPIs and their target values include the "traditional" ones we have been used to in the fourth generation (4G), and especially both greatly increased peak data rates (increased to 20 Gbps) and increased capacity density (10 Tbps/km^2), plus increased spectral efficiency and user mobility (up to 500 km/h), but also new ones such as connection density increased to 1 million/km^2 and latency reduced to 1 ms. A challenging target for increased energy efficiency (100 times compared with 4G) has also been set. The new targets represent new applications, especially internet of things (IoT) applications, including critical system control applications, and provide particular challenges in the design of 5G systems.

These new applications, and also requirements such as increased capacity density also have implications for the architecture of 5G networks, which in turn have implications for the physical layer. This will require further extension of a theme that has already been well-established in WG2 (and especially in SWG2.1) of COST IC1004, as well as appearing in the title of the Action—that of *cooperation*. This turns out to be fundamental to achieving the required performance, and calls for a completely new paradigm for the role of the physical layer in wireless networks, which we call the *network-aware physical layer*. Rather than regarding the physical layer only as providing the link between two network nodes, with signals from other transmitting nodes treated as interference, a node is aware of its position in the network, which enables it to process all signals it receives appropriately, as well as to generate appropriate signals. We address some of the KPIs and their implications, and some possible research directions arising from them in what follows:

- **Peak data rate up to 20 Gbps**

This could in principle be achieved in a number of ways: (i) by increasing modulation order; (ii) by increasing the number of antennas, at both base station and at the terminal; or (iii) by increasing the bandwidth. Point (i) has limitations in practice, and cannot provide the extent of the increase required; point (ii) is also limited by the number of antennas that can reasonably be accommodated on a terminal, which leaves point (iii). The extent of the data rate required is such that several GHz of bandwidth may be called for – which would be very difficult to find at frequencies below 6 GHz, and hence had led to calls for the development of millimeter-wave (mm-wave) transmission. The problem with this is the inherent path loss increase at these frequencies. To balance this, the gain available from an antenna of given size also increases proportionately. Note, however, that this gain cannot be realised on non-line-of-sight channels, at least not simply by reducing beam width, because of the multipath spread which occurs on such channels. To realise the gain requires antennas at both transmitter and receiver that can adapt to the multipath environment, which may in turn require complex channel estimation and adaptation algorithms. A promising approach which may simplify this might be the use of passive beam-forming technologies, for example based on the Butler matrix.

Also, increased diffraction loss may make mm-wave links less reliable. It is likely, therefore, that "backup" links at lower frequencies may be needed. Because of the fragmentation of spectrum below 6 GHz, carrier aggregation may be required in these bands, and since relatively small spectrum slots may be dominated by the guard bands required for OFDM side lobes, technologies such as filter bank multi-carrier (FBMC) have been proposed to improve frequency localisation by filtering side lobes, albeit at the cost of reducing orthogonality between sub-carriers, and (inevitably) of degrading time localisation.

- **Capacity density 10 Tbps/km^2**

While increasing peak data rate might be expected also to increase capacity density, we should note that the targeted peak data rate increase over 4G is 20 times, while the capacity density increase is 100 times. Moreover, it may be desirable to provide capacity density increase even for users who do not need the full data rate, and may operate in the bands below 6 GHz. This will help to fulfil another KPI: user-experienced data rate of 1 Gbps.

Two main technologies have been proposed to fulfil this target: *small cells* and *massive MIMO*. The small cell approach continues the previous trend of increasing the density of cell sites—but also takes it further, such that the number of access points may exceed the number of terminals served. Massive MIMO, on the other hand, increases the number of antennas at a cell site (possibly to 100 or more), again so that there may be several times more antennas than terminals served. It then uses multi-user MIMO techniques on a massive scale to serve an increased number of users in the cell. This relies to a large extent on the richness of multipath in the channel, and the evaluation of its performance at the physical layer poses new challenges for channel modelling as well as many aspects of physical layer design. Of course both technologies have the effect of increasing the density of infrastructure antennas—the difference is the distribution of the antennas. There are also proposals for *distributed massive MIMO*, in which the antennas are distributed to a number of cell sites across the cell. Cloud radio access network (C-RAN) takes this to the extreme, by cocentrating the baseband processing functions of a large number of cells in one central baseband unit (BBU) and replacing access points with remote radio heads (RRHs) which forward sampled versions of the received signals to the BBU over what is now known as the *fronthaul* network. This has the benefit over the conventional small cell approach of enabling base station cooperation (as in cooperative multipoint (CoMP)) over a wide area. To all intents and purposes the concept of the cell is abolished, and with it those disadvantaged cell-edge users, and the entire service area can use the same resources via a number of antenna sites which together act like a single MIMO base station.

The main problem with C-RAN, as is rapidly being realised by operators and manufacturers when they seek to implement it, is the load on the fronthaul, which can easily exceed 50 Gbps even for a relatively modest antenna site (because of the signal bandwidth operating over multiple antennas with dual polarisation), and may be tens or even hundreds of times the user data rate. Even if optical fibre is available, there are substantial costs in providing this bandwidth, and in many cases wireless may be the only medium available for fronthaul. There is thus a huge challenge for the 5G physical layer both in implementing the required fronthaul bandwidth, and also in evaluating the effect on access segment performance—since an imperfect fronthaul network will distort the signals forwarded and degrade access network performance. One approach, which has already been developed in COST IC1004, is the application of wireless physical layer network coding (WPNC) which provides benefits similar to CoMP with a front/backhaul load (in this case it is difficult to define which term applies) that is no greater than the total user data rate.

- **Latency 1 ms**

A dramatic reduction in the latency/delay limit has been proposed in order to enable a number of new applications, from the *tactile Internet* to safety–critical applications like vehicular and process control. This will, however, be an especially challenging target to meet, because it enforces changes in the way error correction coding has been implemented ever since Shannon. A latency limit implies a limit on code length, especially for machine-type communications (MTCs) where the data rate is low, and conventionally code designers have tried to approach the Shannon limit by increasing code length. This is one area in which the new targets may require a fundamental re-examination of the principles of communication theory. Perhaps new types of code will be required, not so much related to the random-like codes inspired by Shannon. This is also an additional challenge for C-RAN, as the fronthaul network inevitably adds further latency, which must be minimised.

- **Connection density 1 million/km^2**

MTCs in general are likely to involve very large numbers of devices which typically may be small and low power, requiring a similar density of access nodes to serve them. Because of the cost of individual backhauling, these in turn are likely to require in-band backhaul, in the form of a mesh network. Note also that this type of communication is likely to consist of very large numbers of very short data packets; moreover, with very low latency limits. Conventional mesh network paradigms will find it quite difficult to meet these requirements: this is another case where the new network-aware physical layer paradigm (mentioned above) is called for. For example for this application, the DIWINE project has proposed the *wireless cloud network*, in which the network becomes a multitude of small devices cooperating to relay data using the principles of WPNC. This minimises contention for resources, which is one of the major causes of latency in conventional wireless networks. WPNC is one example of how the conventional paradigm requiring orthogonal transmission of separate data streams can be circumvented. We have also seen that strict orthogonality in both time and frequency domain within the air interface may no longer be achievable. Part of the new paradigm is therefore coping with the loss of orthogonality, in such a way that the interaction between data streams provides diversity that enhances, rather than interference that degrades. This type of approach may inform the development of new air interfaces (or perhaps a single, but highly adaptive air interface) for the 5G physical layer.

12.4 Next Generation of Wireless Networks

Future 5G mobile ecosystem is oriented to ubiquitous ultra-broadband wireless connectivity, improving many metrics with respect current standards. What characterises a 5G Network is that it has to satisfy simultaneously extremely different requirements: it should be capable to deliver connections at “faster than thought” speeds (known also as “zero distance” connection) to offer ultra-high definition visual communications and immersive multimedia interactions, and simultaneously, massive IoT low-energy devices and applications with a large volume of data but at low data rates and being not sensitive to latency.

To accomplish this, 5G networks should, in addition to requirements mentioned in the previous section, provide:

- Massive connectivity
- Quality of experience (QoE) for the end user, independently of user’s location.

- Flexibility: an enormous, diverse and wide range of services and applications with different performance requirements.

5G radio access will be built upon both new radio access technologies (RATs) and evolved existing wireless technologies (LTE, high-speed packet access (HSPA), global system for mobile communications (GSM), and WiFi). A joint optimisation to efficiently use these radio resources providing on-demand resource and capacity wherever needed will lay on a combination of Cloud Architecture, software-defined networking (SDN), and network functions virtualisation (NFV) technologies. Additionally, Cognitive Network Management will be used, a smart network technology being the evolution of self-organising network idea (SON), which automatically learns from data demands and problems experienced on the network.

In particular, many breakthrough developments are required on different aspects of RATs involved in the network operating principles:

- New air interface and novel transmission techniques: multiple access and advanced waveform, coding, and modulation algorithms, as non-orthogonal multiple access (NOMA), FBMC, white space techniques, space-division multiple access (SDMA) with multi antenna pre-coding to serve multiple users in parallel while performing an adaptive control of interference, single frequency full duplex radio technologies, etc.
- New Traffic patterns to model machine-to-machine (M2M), human-to-human, and human-to-machine services.
- Algorithms to balance the centralised versus distributed control and execution of functions.
- Network slicing and user oriented radio resource management (RRM) algorithms.
- Energy Efficiency improvements through coordinated transmission, beam-forming, massive MIMO, new radio waveforms with less control overhead, shorter transmission ranges with ultra-small cells or device-to-device (D2D) communications, load adaptive, and context aware activation of additional resources, opportunistic transmission, etc.
- Dynamic spectrum access: efficient techniques to opportunistically use any portion of non-used available spectrum.
- Optimisation of wireless and optical backhauling.
- Definition of virtualised and cloud-based radio access infrastructure.
- Specific requirements for vehicular networks, advanced robotics, body centric communications, M2M, IoT, etc.

- Heterogeneous networking in terms of transmitted powers, frequency bands, bandwidths, antenna configuration, multi-hop architectures, duplex technologies, etc.
- heterogeneous networks (HetNets) in terms of seamless integration of all available technologies with an ultra-dense deployment of small cells, macro and micro cells, with different degrees of centralised/distributed networking. Research on seamless vertical handover, multi-technology load balancing, multi-operator roaming should be done.

12.5 From Ideas to Standards

12.5.1 Introduction

The road from a scientific concept to its implementation into a commercial system is often very long and obstructed by many pitfalls. Among them is the necessity to standardise, which implies the support of a sufficient number of actors, mainly from industry, agreeing to produce interoperable systems obeying common standards. In the area of wireless communications, the role of regulation is also extremely important, given that the spectrum is a natural public resource that can't be used freely. This is obviously related to interference between different users wanting to access the same resource defined by a frequency, a time instant, a geographical location and other parameters.

In Europe, the roles in regulation and standardisation are shared among several actors. The European Commission gives mandates to the European conference of postal and telecommunications administrations (CEPT) and especially to its electronic communications committee (ECC) in order to harmonise the use of radio spectrum in Europe and coordinate the views of European regulators in preparing the triennial world radio communication conference (WRC). This very important event, held every 3 or 4 years, can among others revise the Radio Regulations and any associated Frequency assignment and allotment Plans. Once the conditions of spectrum use are well established, the European telecommunications standards institute (ETSI) is able to be active in preparing standards for future technologies and systems employing the wireless resource. Actually ETSI signs memorandum of understanding with major bodies such as the international telecommunications union (ITU), CEPT and other such international organisations, so that the standardisation and regulation processes were jointly developed and converged efficiently. Major activities under ETSI are 3GPP, which proposes specifications for mobile communications systems (originally 3G and now encompassing all standards from 2G to 5G under European initiative), and M2M for M2M communications as part of the IoT.

12.5.2 Academia versus Industry Participation to Standardisation in the Context of a Network of Experts

Standardisation bodies commonly involve the main participation of large companies and SME/Mid-size companies, sometimes also prominent research centres (private/public), for which it is strategic to have their own technology included as far as possible in the standard. The motivation is much less for academia and the difficulty much higher, given that improvement of a standard comes after a large number of regular international meetings, the participation to which being costly and uneasy to valorise in an academic institution.

Still, gathering experts from academia and industry together toward a common goal, such as in IC1004 or other COST Actions, may be seen as a very powerful tool for achieving a consensual and technically/scientifically grounded proposal to standardisation bodies. In case sufficient symbiosis can be achieved by such a network, the benefits are mutual as the industry representative, participating in standardisation body meetings can but reference their proposal to the underlying joint work (giving it also more credibility), providing recognition to involved academic participants at a reduced overhead for them.

Given these preliminaries, the participation of academia and in particular of a COST Action can take place through a pre-standardisation approach, as follows:

- by producing a set of jointly achieved research results that pave the way to definition of a standard;
- by initiating new methods/new approaches that can be directed toward validating new kinds of standards yet non–existing;
- by encouraging relevant actors (mainly industry members or major research centers) to act in coordination in order to propose/influence standards in a way mostly issued from COST work;
- by making available (publicly or through an open and free membership) databases/software tools/reference scenarios, platforms... that can be exploited by standardisation bodies (and any contributor to these bodies) toward standardisation.

Among relevant contributions to standardisation, models have a recognised role in order to provide all actors who want to demonstrate the performance of some scheme a unified way to test this performance. In the past, much referenced work was carried out within the set of mobile communications COST Actions regarding the development of radio channel models, which are of paramount importance in the performance evaluation of physical layer schemes or network architecture principles. Radio channel models are indeed now, and have been for several decades (the GSM being a good example, based on COST 207/231 channel models), part of many published standards such as UMTS, IEEE 802.11n, IEEE 802.16, LTE to name just a few. COST IC1004 has pushed novel methods/approaches in terms of modelling of terminals antenna performance [Sib13], which may trigger future contributions to standards. Indeed such modelling, of statistical nature, may have numerous advantages in terms of realistic performance evaluation of physical layer schemes or of wireless networks, taking into account the high variability of terminals performance in use conditions [Sib14].

In the following, a vision on potential future contributions to standards is provided, focusing on 5G networks.

12.5.3 5G Timeline for Channel Models

5G is currently a “hot” topic and widely discussed among researchers and industry. However, 5G is not yet standardised, and there are different opinions about the 5G requirements and technologies. This section defines the timeline for 5G channel model standardisation as accurately as possible based on the currently available information.

Channel model is an essential tool for system evaluations—without channel model many 5G technologies cannot be evaluated. Understanding the timing of 5G channel model standardisation is important. Many good contributions are not taken into account because of wrong timing. The channel model should reflect reality, but shouldn’t be too complex. There are several points for a 5G channel model:

- Frequency range: The channel model should cover frequency range from sub-1 GHz up to 100 GHz. Propagation is very different in the two extremes of that range. Therefore, frequency dependence of the channel model parameters should be investigated and a unified channel modelling methodology could be exploited to facilitate the implementation of system evaluation.
- Link type and deployment scenario: The variety of foreseen 5G link types and deployment scenarios (e.g., vehicle-to-vehicle (V2V), M2M, D2D, sensor networks, mobile base stations, ultra-dense networks, stadium, and festival cases) set additional requirements to channel models.
- More advanced MIMO features: Massive antenna arrays have much more accurate angular resolution than conventional diversity and MIMO antennas in 3G and 4G. It means the spatial characteristics of the channel need to be modelled very accurately.

It should be noted that some of the above points need to be considered jointly to fulfil the requirement of 5G system evaluation.

Recently, several research projects/organisations have shown their view on 5G development, and mentioned the requirement of channel models. The METIS project reports the "foundation" for the *beyond 2020* 5G mobile and wireless communication systems by providing the technical enablers needed to address the requirements foreseen for this time frame [METIS, FT15]. METIS vision of a future access is that information and sharing of data is available anywhere and anytime to anyone and anything. Next generation mobile networks (NGMN) 5G white paper says that propagation is not well understood for higher frequencies [NGMN15].

International mobile telecommunications (IMT)-2020 (5G) promotion group identified all-spectrum access as a key enabler for 5G system, and mentioned that more channel measurements on higher frequency are needed before well designing an all-spectrum access system working on both high- and low-frequency band [IMT15].

ITU and 3GPP described 5G schedule recently [ITU15, Flo15].

12.5.4 5G Schedules

Besides the channel modelling study, the industry is approaching 5G standardisation. The ITU and 3GPP schedule of 5G activities are summarised in this section, and a consideration on 5G channel modelling time plan is presented, based on the observed state-of-art of 5G channel model, and the ITU and 3GPP schedule.

12.5.4.1 ITU schedule

Recently, ITU radiocommunication sector (ITU-R) WP5D agreed the work plan for "IMT-2020" (i.e., the formal name of "5G" in ITU-R context) [ITU15, Flo15].

- Initial technology submission, deadline June 2019
- Detailed specification submission, deadline October 2020

ITU work plan for "IMT-2020" is shown in Figure 12.2. Channel models will be described in the evaluation criteria & method document during Feb 2016–June 2017 (highlighted in Figure 12.2).

12.5.4.2 3GPP schedule

To meet ITU's 5G schedule, 3GPP discussed the 5G schedule in its RAN#67 meeting.

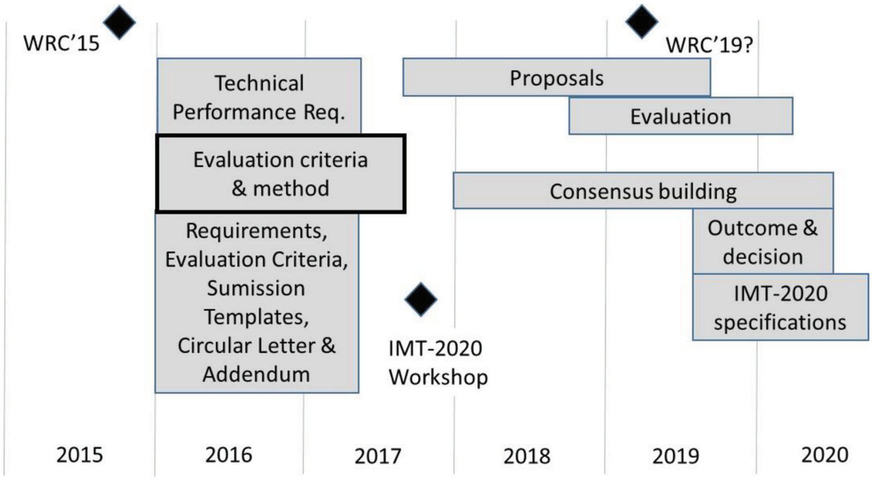

Figure 12.2 ITU-R 5G timeline.

It is assumed that 3GPP will submit a candidate technology for "IMT-2020". 3GPP RAN will lead the 3GPP submission process to ITU-R. 3GPP will import the relevant IMT-2020 requirements from ITU, and subsequently may add its own requirements on top of that. 3GPP assumes that a new radio technology and new system architecture are needed [Flo15]. However, the technical requirements and solutions are not yet exactly known.

The tentative timeline in 3GPP RAN is shown in Figure 12.3 [Flo15]. A "RAN workshop" on 5G requirements and scopes was held in the 3GPP RAN#69 meeting in September 2015. Then a study item (SI) dedicated to 5G channel modelling is likely to be approved (highlighted by black in Figure 12.3, 3GPP assumes that 5G work will also cover frequencies above 6 GHz). It is also mentioned that the first stage of this SI would be to identify the potential frequency band, which is vital information for channel modelling.

It is clear that the 5G channel modelling work would start in late 2015/early 2016 in 3GPP and ITU-R WP5D. WP5D will accomplish the work in June 2017, and requires the initial 5G proposal before June 2019. It is likely that 3GPP will submit its 5G proposal to ITU in early 2019, to meet the deadline of 5G proposal submission.

When considering the 5G channel model time schedule, it needs to take into account the state-of-the-art of channel modelling, and also the time plan of ITU and 3GPP. By the above observations, it seems appropriate to

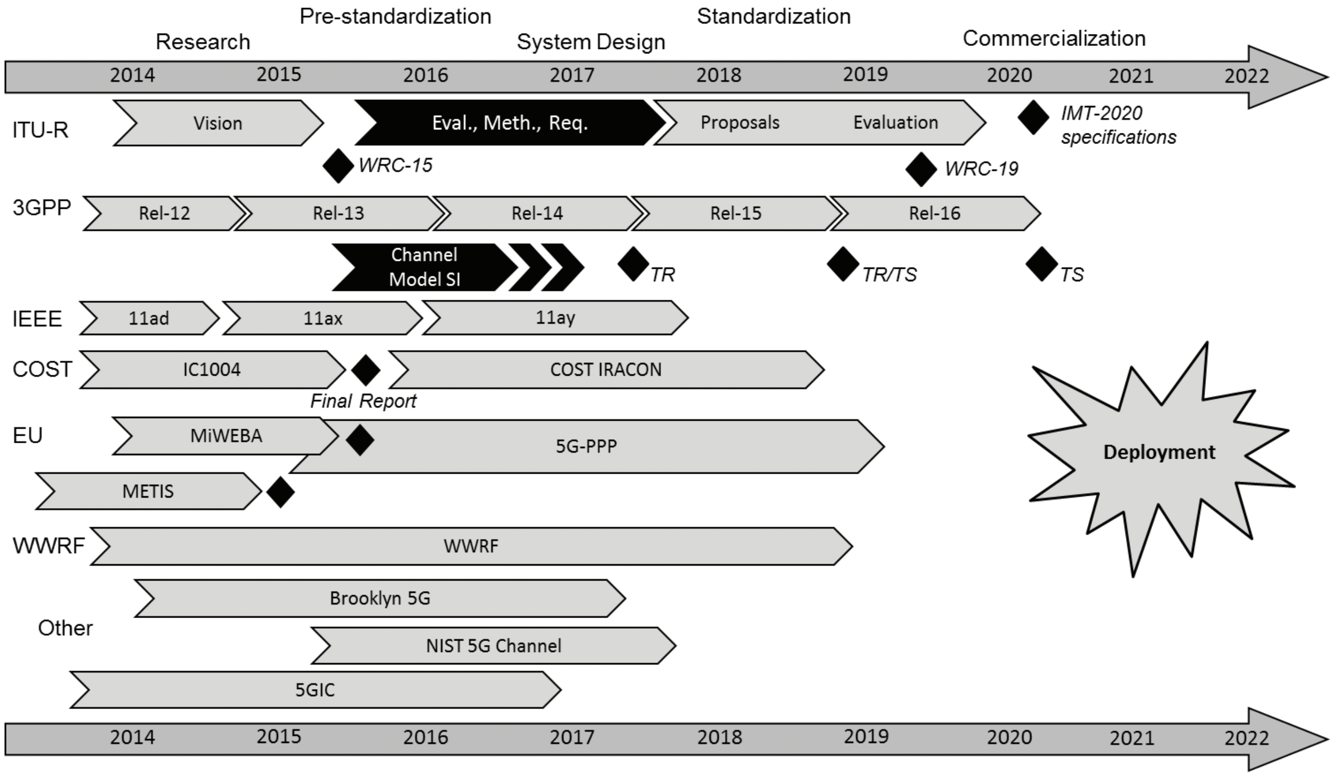

Figure 12.3 Standardisation timeline.
Note: This is a sketch only and is not accurate.

assume the accomplishment of the 5G channel modelling work in the end of 2016/beginning of 2017. On one hand, such a plan would fully meet the 5G standardisation timeline proposed both by ITU and 3GPP. On the other hand, it could guarantee a thorough and mature input to ITU and 3GPP. An earlier or aggressive schedule would be too rush, and may lead to misleading system design and deployment which raise the risk of 5G's grand success. A late or conservative schedule (e.g., accomplish in H2 2017) would be unacceptable for ITU, and would delay the 3GPP submission.

Figure 12.3 sketches the overall schedule of 5G channel model standardisation. METIS and COST IC1004 final reports could be useful inputs for next stage study that will appear in both 3GPP and ITU-R WP5D. It is proposed that experts of COST IC1004 continue the study of channel modelling by taking into account all the points mentioned in Section 12.1 (and to see if there is any others not mentioned), and contribute to 3GPP and ITU-R WP5D in their timeframe, as well as to collaborate with other organisations, e.g., NGMN, wireless world research forum (WWRF), 5G infrastructure public private partnership (5G PPP), etc. to polish this work.

12.5.5 Other Important Aspects

In addition to the mainstream 3GPP–ITU standardisation on IMT-2020, we should not forget other channel model standardisation activities such as IEEE Wi-Fi evolution, V2V, M2M, BAN, and sensor networks. They shall define their channel models and COST IC1004 members may consider contributing to them. Related topic is future test methodologies, e.g., OTA testing of adaptive antenna arrays, massive-MIMO, and vehicles.

12.5.6 Conclusions on Channel Model Standardisation

This section presented the state-of-the-art of 5G channel model studies, and the timeline for 5G channel model. It is shown that 3GPP and ITU-R WP5D will start the work in late 2015/early 2016, and ITU-R will finish the work in June 2017. Sufficient time for the 5G channel model study should be ensured, but it is also important to meet the standardisation time plan, e.g., it needs to be finished before H1 2017. Therefore it is proposed that experts of COST IC1004 continue the study of 5G channel model, and contribute to 3GPP and ITU-R WP5D in their timeframe. The following COST action (IRACON) should continue the channel modelling work, and could provide help for the members contributing to standardisation.