



**Report ITU-R M.2516-0**  
(11/2022)

**Future technology trends of terrestrial  
International Mobile Telecommunications  
systems towards 2030 and beyond**

**M Series**  
**Mobile, radiodetermination, amateur  
and related satellite services**



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## Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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| <b>BT</b> | Broadcasting service (television)                                                    |
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| <b>SF</b> | Frequency sharing and coordination between fixed-satellite and fixed service systems |
| <b>SM</b> | Spectrum management                                                                  |

**Note:** This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.

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## REPORT ITU-R M.2516-0

# Future technology trends of terrestrial International Mobile Telecommunications systems towards 2030 and beyond

(2022)

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## 1 Introduction

International Mobile Telecommunications (IMT) systems are mobile broadband systems encompassing IMT-2000, IMT-Advanced and IMT-2020.

IMT-2000 provides access through one or more radio links to a wide range of telecommunications services supported by fixed telecommunications networks (e.g. public switched telecommunication network (PSTN)/Internet) and other services specific to mobile users. Since the year 2000, IMT-2000 has continuously improved. Recommendation ITU-R M.1457, which provides the detailed radio interface specifications for IMT-2000, has also been updated accordingly. New features and technologies have been introduced to improve the capabilities of IMT-2000.

IMT-Advanced is a mobile system that can support high-quality multimedia applications across a wide range of services and platforms. The system provides a significant improvement in performance and quality relative to IMT-2000. IMT-Advanced systems can operate in low to high mobility conditions over a wide range of data rates in multiple user environments according to user and service demands. Such systems provide access to a wide range of telecommunication services, including advanced mobile services, which are supported by packet-based mobile and fixed networks. Recommendation ITU-R M.2012 provides the detailed radio interface specifications of IMT-Advanced, and it also has been updated accordingly.

IMT-2020 includes new capabilities of IMT that go beyond those of IMT-2000 and IMT-Advanced. These new capabilities make IMT systems more efficient, fast, flexible and reliable when providing a variety of services. Diverse usage scenarios were introduced in IMT-2020 such as enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC) and massive machine-type communications (mMTC). Besides significantly enhancing the data rate and mobility provided in IMT-Advanced, IMT-2020 introduced advantages such as spectrum efficiency, latency, reliability, connection density, energy efficiency and area traffic capacity to efficiently support emerging usage scenarios and applications. Recommendation ITU-R M.2150 provides the detailed radio interface specifications of IMT-2020.

ITU-R studied technology trends that led to the development of IMT-Advanced and IMT-2020, and the results were documented in Reports ITU-R M.2038 and ITU-R M.2320, respectively. Since the publication of Report ITU-R M.2320 in 2014, there have been significant advances in IMT technologies and the deployment of IMT systems. The capabilities of IMT systems are being continuously updated in line with user trends and technological developments. Accordingly, this Report provides information on the technology trends of terrestrial IMT systems considering the time frame up to 2030 and beyond such as emerging technology trends and enablers, technologies to enhance the radio interface, and technology enablers to enhance the radio network.

## 2 Scope

This Report provides a broad view of future technical aspects of terrestrial IMT systems considering the time frame up to 2030 and beyond, characterized with respect to key emerging services, applications trends and relevant driving factors. Technologies described in this Report are collections of potential technology enablers which may be applied in the future. It comprises a toolbox of technological enablers for terrestrial IMT systems, including the evolution of IMT through advances in technology and their deployment. This Report does not preclude the adoption of any other existing technologies and emerging technologies expected in the future.

### 3 Related ITU-R documents

#### 3.1 ITU-R Recommendations

Recommendation ITU-R M.1457

Recommendation ITU-R M.2012

Recommendation ITU-R M.2150

#### 3.2 ITU-R Reports/Questions

Report ITU-R M.2320

Report ITU-R M.2330

Report ITU-R M.2038

Report ITU-R SM.2352

Report ITU-R M.2376

Report ITU-R F.2416

Report ITU-R M.2417

Question ITU-R 229/5

Question ITU-R 262/5

#### 3.3 ITU-R Resolutions

Resolution ITU-R 56

Resolution ITU-R 57

Resolution ITU-R 59

Resolution ITU-R 65

### 4 Overview of emerging services and applications

The development of IMT systems for 2030 and beyond calls for a thorough reconsideration of several types of interactions. The roles of modularity and complementarity of new technological solutions become increasingly important in the development of increasingly complex systems. The use of data and algorithms such as artificial intelligence (AI) will play an important role, and technological complementarities are required to ensure that the technology innovations complement each other. This is particularly important as the role of IMT-2030 and beyond can be seen as a pervasive general-purpose system, instead of simply an enabling technology, resulting in complex technical dependencies.

In this section, a summary information of emerging services and applications is presented to explain the need and motivation of corresponding technology developments.

#### 4.1 New services and application trends

The role of the users of new services and applications is important in the technology development for IMT towards 2030 and beyond, and users will need to have access to the services, required devices, as well as the knowledge to use them. Users' opportunities to actively participate as experientials and developers will increase through a deeper understanding of technologies and skills allowing to shape the technologies for personalized needs. In particular, the role of IMT towards 2030 and beyond can be considered a pervasive general-purpose system instead of a simple enabling technology, resulting in complex technical dependencies.

New services and application trends for IMT towards 2030 and beyond can be summarized as follows:

- Networks will support enabling services that help to steer communities and countries towards reaching the United Nations' Sustainable Development Goals (UN-SDGs)
- Customization of user experience will increase with the help of user-centric resource orchestration models
- Localized demand–supply–consumption models will become prominent at a global level
- Community-driven networks and public–private partnerships will bring about new models for future service provisioning
- Networks will have a strong role in various vertical and industrial contexts
- Market entry barriers will be lowered by the decoupling of technology platforms, enabling for multiple entities to contribute to innovations
- Empowering citizens as knowledge producers, users and developers will contribute to a process of human-centred innovation, contributing to pluralism and increased diversity
- Privacy will be strongly influenced by increased platform data economy or sharing the economy, emergence of intelligent assistants, connected living in smart cities, transhumanism, and digital twins
- Monitoring and steering of circular economy will be possible, helping to create a better understanding of sustainable data economy
- Sharing and circular economy-based co-creation will enable the promotion of sustainable interaction with existing resources and processes
- Development of products and technologies that innovate to zero will be promoted; for example, zero-waste and zero-emission technologies
- Immersive digital realities will facilitate novel ways of learning, understanding and memorizing in several fields of science.

The role of IMT towards 2030 and beyond will be to connect many devices, processes and humans to a global information grid cognitively, thereby offering new opportunities for various verticals. Considering their different development cycles, a full complement of potential advances and vertical transformations will continue in the post-2030 era. The trend towards higher data rates will continue leading up to 2030, where peak data rates may approach Tera bits per second (Tbit/s) indoors, requiring large available bandwidths giving rise to (sub-) Tera hertz (THz) communications. At the same time, a large portion of the vertical data traffic will be measurement-based or actuation-related small data. In most cases, this will require extremely low latency in tight control loops, which may necessitate short over-the-air latencies to allow time for computation and decision making. Simultaneously, the reliability and the QoS requirements in many vertical applications will increase so that required services are available in the areas where it is needed. Industrial devices, processes and future haptic applications, including multi-stream holographic applications will require strict timing synchronization with tight requirements for jitter.

#### **4.1.1 Potential new services, trends and opportunities**

The three usage scenarios described in IMT-2020, eMBB, mMTC and URLLC will still remain relevant. New use cases and applications should be considered for continuing evolution, especially for those driving the technologies development and reflecting the future requirements. Consequently, the following new services are envisioned as trends and opportunities:

- Holographic communication  
Holographic displays are the next evolution in multimedia experience delivering 3D images from one or multiple sources to one or multiple destinations, providing an immersive 3D

experience for the end user. Interactive holographic capability in the network will require a combination of very high data rates and ultra-low latency.

– Tactile and haptic Internet applications

Human operators can monitor the remote machines by virtual reality (VR) or holographic-communications, and are aided by tactile sensors which may also involve actuation and control via kinaesthetic feedback.

Tele-diagnosis, remote surgery and telerehabilitation are just some of the many potential applications in healthcare. Tele-diagnostic tools, medical expertise/consultation could be available anywhere and anytime regardless of the location of the patient and the medical practitioner. Remote and robotic surgery is an application where a surgeon gets real-time audio-visual feeds of the patient that is being operated upon in a remote location. The technical requirements for haptic internet capability cannot be fully provided by current systems.

– Network and computing convergence

Mobile edge computing (MEC) will continue being deployed towards future IMT networks. When clients request a low latency service, the network may direct this to the nearest edge computing site. Augmented reality/virtual reality (AR/VR) rendering, autonomous driving and holographic type communications are all candidates for edge cloud coordination.

– Extremely high-rate access

Access points (APs) in transport nodes, shopping malls, and other public places may form information access points. These access points will provide fibre-like speeds. They could also act as the backhaul needs of millimetre-wave (mmWave) small cells. Co-existence with cellular services as well as security appears to be the major issue requiring further attention in this direction.

– Connectivity for Everything

Scenarios include real-time monitoring of buildings, cities, environment, cars and transportation, roads, critical infrastructure, water and power amongst others. The Internet of bio-things through smart wearable devices, intra-body communications achieved via implanted sensors will drive the need of connectivity much beyond mMTC.

It is anticipated that Private networks, applications, or vertical-specific networks, Internet of Things (IoT) sensor networks will increase in numbers in the coming years. Interoperability is one of the most significant challenges in such a ubiquitous connectivity/compute environment (smart environments), where different products, processes, applications, use cases and organizations are connected. Interactions among telecommunications networks, computers and other peripheral devices have been of interest since the earliest distributed computing systems.

Vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication and coordination, autonomous transport can result in a reduction of road accidents and traffic jams. Latency in the order of a few milliseconds will likely be needed for collision avoidance and remote driving.

– Extended Reality (XR) – Interactive immersive experience

This interactive immersive experience use case will have the ability to seamlessly blend virtual and real-world environments and offer new multi-sensory experiences to users. Extended Reality (XR), such as virtual reality (VR), augmented reality (AR) and mixed reality (MR) is expected to provide higher resolution, larger field of view, higher frames per second and lower motion-to-photon, which all translate into higher demand on the transmission data rate and end-to-end latency.

A key challenge to address when supporting interactive experiences in network include synchronized transport of multi-modality of flows (e.g. visual media, audio, haptics) to and from different devices in a collaborative group serving the same XR application. Another important consideration is supporting real-time adaptations in the network relative to user movements and actions to ensure the interactions with other users and objects appear highly realistic in terms of placement and responsiveness. Enabling spatial interactions will also require fast accessibility and ease of integration of content containing up-to-date and accurate representations of real/virtual environments from different content sources.

- **Multidimensional sensing**

Sensing based on measuring and analysing wireless signals will open opportunities for high-precision positioning, ultra-high-resolution imaging, mapping and environment reconstruction, gesture and motion recognition, which will demand high sensing resolution, accuracy, and detection rate.

- **Digital Twin**

Digital twin is a digital replica of entities in physical world, which demands real time and high accuracy sensing to ensure the accuracy, and low latency and high data transmission rate to guarantee the real time interaction between virtual and physical worlds. It could be capable of generating perceptive and cognitive intelligence based on collection of historical and on-line network data. It may also be capable of continuously seeking the optimal state of the physical network in advance and enforcing management operations accordingly.

- **Machine Type Communication**

Enabling efficient Machine Type Communication (MTC) continues to be an important driver for IMT towards 2030 and beyond. It allows machines and devices to communicate with each other without direct human involvement. MTC is a major driver behind the Internet of Things (IoT) and the future digitalization of economies and society. MTC encompasses critical MTC (cMTC) and massive MTC (mMTC). cMTC targets mission-critical connectivity with stringent requirements on key performance indicators (KPI) such as reliability, latency, dependability, and synchronization accuracy. On the other hand, mMTC addresses connectivity needs for massive number of potentially low-rate, low-energy simple devices, where the connection density and the energy efficiency are the most important KPIs.

- **Proliferation of intelligence**

Real-time distributed learning, joint inferring and collaboration between intelligent robots demand a re-thinking of the communication system and networks design.

- **Global Seamless Coverage**

To connect the unconnected and provide continuously high quality mobile broadband service in various areas, it is expected that a number of technology solutions and their combinations are needed. Additionally, the interconnection of terrestrial and non-terrestrial networks may facilitate the provision of such services.

#### **4.1.2 Diversification of terminals**

Until now, humans have been the main consumers of data. However, the appearance of intelligent smart machines, which also consume a significant volume of data is now witnessed. Moreover, it is also expected that various types of terminals in the form of wearables, skin-patches, bio-implants and exoskeletons can be combined with state-of-the-art man-machine interfaces, such as gestures, haptics, and brain sensors, to expand and become new industries. While smartphones remain, non-portable terminals such as cars, Unmanned Aircraft Systems (UASs), vessels and robots equipped with multisensory integration and intelligent capabilities, are expected to play an increasingly significant role

in every field of the future society. The diversification of terminals will lead new verticals to emerge and thrive.

#### 4.2 Drivers for future technology trends towards 2030 and beyond

The continuing evolution of the IMT systems and the underlying technologies must be guided by the imperative to satisfy fundamental requirements and contextualized in terms of how they can help society, the end users, and value creation/delivery. These necessities and key driving factors are as follows:

- Societal goals – Future technologies should contribute further to the success of several UN-SDG goals including environmental sustainability, efficient delivery of health care, reduction in poverty and inequality, improvements in public safety and privacy, support for aging populations and managing expanding urbanization.
- Market expectations – new technologies should enable significant and novel capabilities, support radically new and differentiated services, and create greater market opportunities.
- Operational necessities – The need to manage complexity, drive efficiency and reduce costs with end-to-end automation and visibility is also an imperative motivation and driving factor.

Key drivers for IMT Systems for 2030 and beyond include:

- Energy efficiency  
Energy efficiency has long been one important design target for both network and terminal. While improving the energy efficiency, the total energy consumption should also be kept as low as possible for sustainable development. Power efficient technology solutions are needed both in backhaul and local access to make use of small-scale renewable energy sources.
- Data Rate, Latency and Jitter  
The data rate for future systems should be increased as much as practical in order to support extremely high bandwidth services such as extremely immersive XR and holographic communications.  
Services with real-time and precise control usually have high demands on the latency of communications, such as the air interface delay, end-to-end latency, and roundtrip latency.  
Jitter refers to the degree of latency variation. Some of the future services such as time sensitive industry automation applications may request the jitter close to zero.  
Future system should guarantee users' experience regardless of users' location and network traffic conditions.
- Sensing resolution and accuracy  
Sensing based services, including traditional positioning and new functions such as imaging and mapping, will be widely integrated with future smart services, including indoor and outdoor scenarios. Very high accuracy and resolution will be needed to support a better service experience.
- Connection density  
Refers to the number of connected or accessible devices per unit space. It is an important indicator to measure the ability of mobile networks to support large-scale terminal devices. With the popularity of the IoT and the diversification of terminal accesses in the specific applications such as industrial automation and personal health care, mobile systems need to have the ability to support ultra-large connections.

- Coverage and full connectivity

The future network should be able to provide global coverage and full connectivity with heterogeneous multi-layer architecture. The full connectivity network should support intelligent scheduling of connectivity according to application requirements and network status to improve the resource efficiency and service experience. It will extend the provision of quality guaranteed services, such as MBB, massive IoT, high precision navigation services, from outdoor to outdoor from urban to rural areas and from terrestrial to non-terrestrial spaces.

- Mobility

Refers to the maximum speed supported under a specific Quality of Service (QoS) requirement. Future systems will not only support terminals on land (e.g. high-speed train), but also provide services to terminals in airplanes, drones and so on.

- Spectrum utilization

With new services and applications towards 2030 and beyond, more spectrum may be required to accommodate the explosive mobile data traffic growth. Further study may be introduced on novel usage of low and mid band, and the extension to much higher frequency bands with broader channel bandwidth. The smart utilization of multiple bands and improvement of spectrum efficiency through advanced technologies are essential to achieve high throughput in limited bandwidth.

- Simplified user-centric network

With huge amounts of new services and scenarios towards 2030 and beyond, the network is required to satisfy diversified demand and personalized performance. The concept of soft network was proposed as a fully service-based and native cloud-based radio access network (RAN), which can guarantee the QoS and provide consistent user experience. The simplified user-centric network is a globally unified access network with the simple architecture and the powerful capabilities of robust signalling control, accurate network services and efficient transmission through the converged communication protocols and access technologies with plug-and-play, on-demand deployment. A user-centric network enabling a fully distributed/decentralized network mitigates a single point of failure as well as to enable the user-controlled data ownership which is critical to the next generation network.

- Native Artificial Intelligence (AI)

The future mobile system should have stronger capabilities and support more diversified services, which will increase the complexity of the network. AI reasoning will be native wherever it is required in the future network including physical (PHY) layer design, radio resource management (RRM), network security and application enhancement, as well as network architecture, which results in a multi-layer deep integrated intelligent network design. The future network is also expected to support distributed AI as a service for larger scale intelligence.

- Security/Trustworthiness

A future network may support more advanced system resilience for reliable operation and service provision, security to provide confidentiality, integrity and availability, privacy with self-sovereign data and safety regarding the impact to the environment.

The roles of trust, security and privacy are somewhat interconnected in various facets of future networks. Inherited and novel security threats in future networks should be addressed. Diversity and volume of novel IoT and other networked devices and their control systems will continue to pose significant security, privacy risks and additional threat vectors when moving to IMT towards 2030 and beyond. IMT towards 2030 and beyond should strive to support embedded end-to-end trust such that the level of information security in networks is

significantly better than today's network. Trust modelling, trust policies and trust mechanisms need to be defined.

Security algorithms may use machine learning (ML) to identify attacks and respond to them. Continuous deep learning on a packet/byte level and machine learning can enforce policies, detect, contain, mitigate, and prevent threats or active attacks.

- Dynamically controllable radio environment

A dynamically controllable radio environment may be able to change the characteristics of the radio propagation environment, therefore creating favourable channel conditions to support higher data rate communication and improve coverage.

## 5 Emerging technology trends and enablers

### 5.1 Technologies for AI-native communications

The success of AI in image, video and audio signal processing, data mining and knowledge discovery amongst others has made it possible to shift wireless communication to an intelligent paradigm. More specifically, architectures, protocols and algorithms for the IMT towards 2030 and beyond will be designed by learning from wireless big data which has yet to be comprehensively exploited. In turn, with the wide deployment of base stations (BSs), edge servers and intelligent devices, mobile networks will provide a novel and powerful platform for ubiquitous data collection, storage, exchange, and computing which are potential enablers for future mobile distributed/collaborative ML. For the future communication system, an innovative and transformative shift will provide the access of AI to everyone, every business, every service anywhere anytime. AI is the design tablet of the future communication system, and it will be the cornerstone to create intelligence everywhere. One of the main differences between the future communication systems relative to IMT-2020 is that it will use mobile technologies to enable the proliferation of AI and utilize the radio networks to augment ubiquitous, distributed ML.

#### 5.1.1 AI-native air interface

Applying tools from AI and ML, and its sub-set deep learning, in wireless communications have gained a lot of traction in recent years. This trend in large part has been motivated by the significant increase in the system complexity in the IMT-2020 RAN and its evolution over previous wireless technology generations. Deep neural networks allow the characterization of specific or even unknown channel environment and network environment, i.e. the traffic, the interferences and user behaviours, and then adapt the radio signalling to the channel and network environment. With learning it can optimize user signalling, power consumption as well as its end-to-end connectivity, and smartly coordinate the multi-user access of radio resources, thus optimizing the data and control plane signalling and improving the overall system performances.

Sensing communication environment is the most challenging issue in air interface design, i.e. the estimation and prediction of propagation channels. To this end, traditional air interface pays much effort to pilot design and channel estimation. Now with ML and especially the capability of black-box modelling and hyper-parameterization of a deep neural network, the unknowns of the underlying channel could be properly learned provided that sufficient data is available. The learned model can be transferred to adjacent nodes via transfer learning. It provides new way to air interface design. Several components in the transceiver chain are expected to be implemented through AI/ML based algorithms. It includes the transmitter (TX) side – beamforming and management and the receiver (RX) side – channel estimation, symbol detection and/or decoding. Therefore, there will be an emphasis on redesigning the PHY layer of the communication protocol stack using AI. However, the

implementation issues related to the periodic updating of deep learning models used in various blocks of the PHY layer must be addressed.

Examples of the proposed areas to be investigated are presented next.

**AI in symbol detection/decoding:** ML techniques can be used for symbol detection and/or decoding. While de-modulation/decoding in the presence of Gaussian noise or interference has been studied for many decades, and optimal solutions are available in many cases, ML could be useful in scenarios where either the interference/noise does not conform to the assumptions of the optimal theory, or optimal solutions are too complex. Meanwhile, IMT towards 2030 and beyond is likely to utilize even shorter codewords than IMT-2020 with low-resolution hardware, which inherently introduce non-linearity that is difficult to handle using classical methods. Accordingly, ML could play an important role in symbol detection, precoding, beam selection, and antenna selection.

**AI in channel estimation:** Another promising area for ML is the estimation and prediction of propagation channels. IMT systems of prior generations have mostly exploited channel state information (CSI) at the receiver, while CSI at the transmitter was mostly based on roughly quantized feedback of received signal quality and/or beam directions. In systems with even larger number of antenna elements, wider bandwidths and higher degree of time variations, the performance loss of these CSI feedback scheme is non-negligible. ML may be a promising approach to overcome such limitations.

**AI in MAC layer design:** Medium access control (MAC) layer is a major application area of AI where many problems with legacy solutions can be replaced with AI-based methods using supervised learning, data collection and ML model deployment. To jointly update the deployed ML models, collect data for supervised learning tasks and enable reinforcement learning on different blocks of the network, next generation MAC algorithms need to consider the coordination with AI functions used in various layers of the network, especially in PHY layer.

**AI in radio resource management:** Radio resource management or resource allocation can also be implemented via AI/ML based methods. In a multi-user environment, with reinforcement learning, BSs and UE can automatically coordinate the channel access and resource allocation based on the signals they respectively received. Each node calculates its reward for its transmission, and adjusts its power, beam direction and other signalling to accomplish the distributed interference coordination and improve the system capacity.

**Semantic communications:** With the progresses of ML and information theory, the ultimate air interface can perform the automatic semantic communications. There are many open fundamental problems in this issue. For example, learning algorithms usually relies highly on the wireless data which may be hard to obtain or be preserved under privacy constraints. To solve it, it is possible to learn with both the practical wireless data and the statistical models.

Questions related to the optimal ML algorithms given certain conditions, required amount of training data, transferability of parameters to different environments, and improvement of explainability will be the major topics of research in the foreseeable future. There will be various phases towards development of AI for radio interface technologies, and it is imperative to ensure the increased integration of the technology comes with minimum disruption to the rollout and operation of radio interface technologies. In the short and medium terms, AI models can target for optimization of specific features within radio interface technologies for IMT-2020 and its evolution. In the longer term, AI can be used to enable new features over legacy wireless systems.

### 5.1.2 AI-native radio network

Future IMT-systems must support extremely reliable and performance-guaranteed services. They will introduce a multi-dimensional network topology, which will make network management and operation more difficult and introduce more challenging problems. To address these problems, AI

technologies can be adopted for automated and intelligent networking services. Consequently, radio access network for IMT towards 2030 and beyond will evolve into an AI-native network architecture to assist computationally intensive tasks.

The highest level of AI-native radio network is expected to be designed and implemented by AI to act as an intelligent radio network, which can automatically optimize and adjust the network based on the specific requirements/objectives/commands, or environmental changes. The research includes high-layer protocols, network architecture and networking technologies enabling intelligent radio network.

Numerous use cases of AI-empowered network automation have been proposed, including fault recovery/root cause analysis, AI-based energy optimization, optimal scheduling, and network planning. Key challenges of training issues have been identified: lack of bounding performance, lack of explainability, uncertainty in generalization and lack of interoperability to realize full network automation. Four types of analytics can be classified for future AI-native networks: descriptive, diagnostic, predictive and prescriptive analytics.

The future RAN will be able to perceive and adapt to complex and dynamic environments by monitoring and tracking conditions in the radio network while diagnosing and restoring any RAN issues in an automated fashion. To achieve autonomy for its full life cycle management, at least the following novel networking technologies could be considered: 1) efficient and intelligent network telemetry technologies that leverage AI to apply management operations based on a collection of historical and live network data; 2) automated network management and orchestration technologies that continuously seek the optimal state of the RAN and enforce management operations accordingly; 3) automatically perform life cycle management operations, adjust configurations on radio network elements, and optimize new services and features during and after deployment; and 4) provide AI based assistance, in particular for aspects such as forecasting, root cause analysis, anomaly detection and intent translation.

Examples of the proposed areas to be investigated are presented next.

**Intelligent data perception:** Large quantity of data transportation will bring burdens to each network interface. Besides, data sensed from the radio environment sometimes do not have the corresponding labels. Intelligent data perception, e.g. utilizing Generative Adversarial Networks (GAN) to generate the required data so as to simulate real data, will avoid transferring large amount of data over interfaces, and protect the data privacy to a certain degree. To further this vision of zero-touch network management, an open network data set and open eco-system could be established.

**Introducing user feedback:** It is also possible that user feedback is introduced into the decision-making process of the network to improve the decision-making of AI algorithms and help the machine to better understand user preferences and make more user-preferred decisions.

**Pervasive computation nodes:** In future IMT-systems, more computation nodes will be required to support highly computationally intensive services. Thus, computation nodes will be pervasive from core to edge and from network to device. To cope with this trend, the control and user planes of the network for future IMT-systems could be redesigned, and emerging technologies such as programmable switches and distributed/federated learning could be adopted.

**Supply of on-demand capability:** To support services in multiple application scenarios, an intelligent network is needed. In the AI-native Radio Network, AI is no longer just optimizing the wireless resources of the wireless network, but an intelligent system integrating with radio network, which can realize the supply of on-demand capability.

**Collaboration of sensing and AI:** In order to realize the intelligence of Radio Network, the new functions of sensing and AI need to be supported. The end-to-end collection, processing and storage of network data can be realized through the data sensing function. AI function can use these data on

demand to support different application scenarios. In this way, the utilization and support of AI capabilities can be realized more efficiently and globally.

**Distributed and unified AI control:** AI system in AI-native radio network is expected to be distributed over various network functions. For example, AI algorithms running on different functions or AI models trained on different functions are integral components of this distributed AI system. There should be a unified AI control centre for the distributed AI system, and under the control or coordination of this AI control centre, each component of the distributed AI system independently completes the assigned tasks, interacts with other components and reports measurements to the control centre. By doing this, distributed AI system is expected to be an end-to-end solution.

**Adaptive solutions for different usage:** AI techniques can be used to target one or more wireless domains, including non-real-time network orchestration and management, such as configuration of antenna parameters and near-real-time network operation, e.g. load balancing and mobility robustness optimization. Each wireless domain involves different sets of physical and virtual components, family of parameters including KPIs, underlying complexities, and time constraints for updates. Hence, there is a need to consider tailored AI solutions for different classes of the RAN, and their associated problems. There already exists a rich body of research and practical demonstrations of the potential benefits of AI for wireless, including significant network energy savings.

### 5.1.3 Radio network to support AI services

The radio network will be migrated from over the top towards the AI era. Wireless networks should consider AI applications and paradigms that require the exchange of large volumes of data, ML models, and inference data between different entities in the networks. Long-term platform technologies are needed to better support AI services, which will have a significant impact on the design of future radio networks, i.e. radio network for AI. Distributed and collaborative ML is required to comprehensively exploit the computing/communication load and the efficiency and comply with the local governance of data requirements and data privacy. Hence, the data-split and model-split approaches will be emphasized in future research. The impacts of this on the future network design are threefold:

**Shift from downlink (DL) -centric radio to uplink (UL) -centric radio:** Unlike the current DL-centric radio which usually supports heavier traffic and better QoS for DLs, AI requires more frequent model and data exchanges between a BS and the users it serves. The ULs should be reconsidered in network design to attain a balanced, efficient, and robust distributed ML.

**Shift from the core network to the deep edge:** The locality of data and the computing/communication needed for deep ML bring big challenges to the end-to-end delay. To mitigate it, new network as well as the corresponding protocols should be redesigned. One of such research directions is to place the major learning processes and threads close to the edge and thus forms a deep edge which can greatly mitigate the system delay.

**Shift from cloudification to ML:** Due to the distributive nature of data and computing power, the communication and computing procedures of an ML algorithm often take place across the whole network from the cloud to the edge and the devices. Therefore, traditional cloudification should also be reconsidered to be application-centric, i.e. to meet the specific needs of the more general distributed ML applications with proper deployment of computing and communication resources.

In addition, future data-intensive, real-time applications require distributed AI/ML solutions. These solutions support augmenting human-decision processes, developing autonomous systems from small devices to complete factories, and optimising the network performance and marshalling the billions of IoT devices expected to be interacting in the future. Since heterogeneous IoT devices are not as reliable as high-performance centralized servers, distributed and self-organising schemes are essential to provide strong robustness in device and link failures. Currently there are still many open questions