GSR-16 Discussion paper

EMERGING TECHNOLOGIES AND THE GLOBAL REGULATORY AGENDA

Work in progress, for discussion purposes
Comments are welcome!

Please send your comments on this paper at: gsr@itu.int by 30 May 2016

This paper was prepared by *Kathryn Martin, Kelly O'Keefe and Logan Finucan from Access Partnership.*

Contents

1 Executive Summary

This report surveys recent developments in technology and explores their implications for telecommunications and spectrum regulators. The ICT community is striving to bring robust connectivity to all corners of the globe, which is helping drive both innovation and ways in which technologies can be used to improve economic and social development. New means of connectivity plus enhanced architectures promise improved coverage, greater capacity, more efficient use of spectrum, and more flexibility for effective delivery of the ICT services. In turn, technological innovations are unlocking new applications, such as those composing the Internet of Things (IoT) and the emerging Smart Society.

The prospect of constant connectivity and complex interconnection of devices is also shaping private-sector business models. Providers of telecommunications services are moving fast, investing in future systems, and exploring new commercial opportunities with other industry sectors as they try to find their place in a new ecosystem that demands flexibility to meet changing demands. Increasingly, new classes of companies (not just those previously thought of as "technology" companies) are developing new capabilities and developing innovative products and services that rely on new connectivity and data services.

These changes are placing increasing demands on spectrum resources, with implications for spectrum management practices. New platforms – principally 5G (IMT-2020) as well as others, such as high altitude platforms (HAPS), or NGSO satellite constellations – will need new spectrum resources in order to reach their full potential. Regulators must be familiar with these evolving technologies, understand their spectrum needs, and ensure that their own spectrum management practices are sufficiently nimble to adapt while protecting existing services.

Regulators will need to ensure that legal and regulatory frameworks are sufficiently flexible. This paper makes a number of recommendations on how they can meet these challenges and best position themselves to unlock the benefits of new technologies for their citizens. These suggestions will help them:

1. harness these technologies to pursue policy goals;
2. develop more effective regulatory approaches;
3. create an environment for growth and innovation;
4. manage limited spectrum resources more productively;
5. build trust and confidence in new technologies;
6. contribute to the development of effective standards.

2 Introduction

Information and communication technologies (ICTs) are the foundation of growth and development in the modern global economy. Many of these technologies rely on spectrum, raising questions of how existing spectrum resources can be efficiently used. How regulators manage spectrum resources and provide an enabling environment to support the development of innovative wireless technologies will be a critical component of the 5th Generation Regulators' toolkit.

Information and communication technologies are advancing in three key areas:

1. New *platforms* for the delivery of broadband and connectivity services are enabling new services and the possibility of being always connected.
2. New network *architectures* and complementary technologies are increasing the capabilities of platforms and Internet-based services.
3. New *applications* of these advances are transforming consumer demand, available services, and private-sector business models.

Systems	*Architectures*	*Applications*
• IMT-2020 (5G) • HTS • Nanosatellites • HAPS	• Cloud-RAN • HetNets • Network slicing • Beamforming	• IoT • Smart Cities • Connected Cars • UASs

Due to the crucial importance and regulatory implications of these technological advances and their applications, particularly the roll-out of IMT-2020 (5G), regulators must look ahead to understand these new frontiers, emerging business models, and the regulatory practices that allow innovation to thrive. This paper will help regulators understand these challenges. It proceeds as follows:

Chapter 3 examines evolving platforms, including International Mobile Telecommunication (IMT-2020), the ITU name for future 5G systems, and mobile-based networks, new satellite systems, high-altitude platforms, and other wireless network technologies that will enable new forms of connectivity.

Chapter 4 examines trends toward new network architectures, software advances, and other complementary technologies that increase the flexibility and efficiency of services, such as Cloud-RAN, heterogeneous networks, network function virtualization (NFV), and network slicing.

Chapter 5 examines new applications of these technologies that regulators may expect to grapple with, including the Internet of Things (IoT), unmanned aircraft systems (UAS), intelligent transport systems (ITS), and other applications to infrastructure, manufacturing, and health.

Chapter 6 investigates the implications of these technological changes for private-sector practices, business models, and traces how telecommunications operators are evolving.

Chapter 7 discusses how these new technologies and applications impact spectrum management decisions, and outlines tools regulators have to grapple with them.

Chapter 8 discusses the challenges these advances present to regulators in a number of areas and makes recommendations on how to address them while maximizing the benefits new technology can bring.

3 Evolving Delivery Platforms

Choices in the communications market have been fairly clear and consistent to date. Though technology has changed and capabilities have improved, clear types of platforms have used wireless technologies to offer predictable types of services; terrestrial mobile networks have provided voice communications and high-quality data services, while satellite operators have provided mobile and fixed communications, as well as data services and direct-to-home video. Recent advances in technology are transforming these platforms, the way that they use spectrum and the services they can provide. Traditional players and some new classes of operators are moving quickly to develop new types of services, especially internet based services. Importantly, the development of these platforms is often driven by the need to use spectrum more efficiently while also delivering more capabilities for users who need to always be connected, and also to link those who remain un-connected to the digital economy.

To understand the evolving marketplace, regulators need to understand these changing platforms and their capabilities. The following section will provide an overview of these technologies, including evolving expectations of IMT-2020, which is the ITU's global standard for International Mobile Telecommunication systems (also known as 5G), new geostationary and non-geostationary satellite systems, nanosatellites, and high-altitude platform stations.

3.1 Fifth-generation Mobile Networks (IMT-2020 or 5G)

User demand for data is rapidly rising and will soon surpass the capabilities of current mobile networks. To give an indication of the growth in mobile services, US mobile network operator AT&T reports that they witnessed a 100,000% increase in data traffic in its wireless network from January 2007 through December 2014.[1] This unprecedented growth is expected to continue as demand changes not just in developed markets but as more of the global population becomes connected. Ericsson estimates that over 90% of the world's populations above the age of six will have a mobile phone by 2020.[2] Beyond 2020, ITU-R (the Radiocommunication Sector of ITU) has estimated that between 2020 and 2030 global International Mobile Telecommunications (IMT) traffic will further increase by a factor of between 10 and 100. [3]

How will mobile operators keep up with this demand? Many are working hard to develop fifth-generation mobile networks of IMT-2020 systems and expect introduction to begin in 2020. IMT-2020 refers to the next stage of the evolution of mobile communications, following IMT-Advanced (i.e. 4G/LTE). It is more accurately an "ecosystem" than a platform, offering greater data rates and mobility, lower latency, and supporting billions of users/connected devices and multiple applications.

Discussions on IMT-2020 future mobile systems are well underway in ITU as well as in several research bodies and standards organizations around the world. Despite, or perhaps because of, diverse potential approaches to IMT-2020, private-sector companies have already begun to make substantial investments in

[1] "AT&T Adds High-Quality Spectrum to Support Customers' Growing Demand for Mobile Video and High-Speed Internet," *AT&T*, 30 January 2015, http://about.att.com/story/att_adds_high_quality_spectrum_to_support_growing_demand_for_mobile_video_and_high_speed_internet.html

[2] Ericsson, *Ericsson Mobility Report*, November 2014, http://hugin.info/1061/R/1872291/659558.pdf

[3] Report ITU-R M.2370-0 (07/2015): *IMT traffic estimates for the years 2020 to 2030* , http://www.itu.int/pub/R-REP-M.2370-2015

order to try to become industry leaders in IMT-2020. SNS Research recently estimated that USD 6 billion will be spent on IMT-2020 research, development, and trial deployments by 2020.[4]

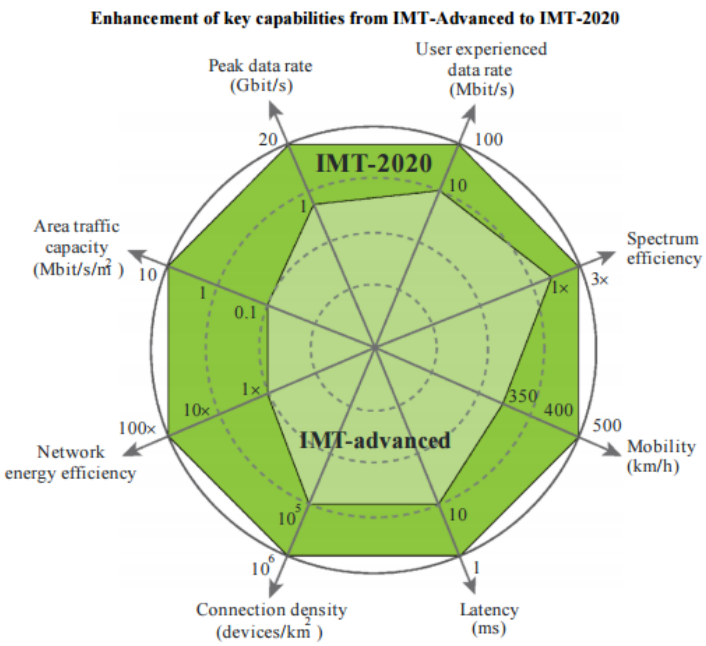
3.1.1 What will IMT-2020 offer?

IMT-2020 is being designed to meet the growing and changing demands of the marketplace for bandwidth and data rates, as well as to support a multitude of application. Some of the expected criteria are:

1. increase in peak data rate and data capacity;
2. massive increase in the number of connections;
3. significant increase in the number of applications supported (for example, the IoT, M2M, gaming, and specialized vertical market support services)
4. decrease in latency;
5. decrease in energy consumption (improvement in energy efficiency);
6. increase in spectrum efficiency;
7. increase in mobility (in terms of speed); and
8. increase in user density.

In September 2015, the Recommendation ITU-R M.2370-0"*IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond*" provided some specific targets for these criteria, measuring IMT-2020 relative to IMT-Advanced.[5] These include:

- 100 Mb/s user experienced data rates;
- 20 Gb/s peak data rates;
- up to 500 km/h with acceptable QoS;
- 1 ms air interface latency;
- 10^6/km^2 connection density;
- 100x better network energy efficiency than IMT-Advanced;
- 3x better spectrum efficiency than IMT-Advanced; and
- 10Mb/s/m^2 area traffic capacity.



Several standards development organizations have already begun to develop parameters for IMT-2020 systems that go towards these IMT goals, such as the 5G Infrastructure PPP in Europe (5G PPP), who published a vision document in 2015. In this report, 5G PPP included the following as some of the targets,

[4] SNS Telecom, *5G Wireless Ecosystem: Technologies, Applications, Verticals, Strategies & Forecasts*, February 2016, http://www.snstelecom.com/5g.

[5] Recommendation ITU-R, M.2083-0 (09/2015):, *IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond*, https://www.itu.int/rec/R-REC-M.2083-0-201509-I/en

noting that they were under discussion within the ITU, 3GPP and Next Generation Mobile Networks Alliance:[6]

- 1 000× in mobile data volume per area reaching a target of 0.75 Tb/s for a stadium;
- 1 000× in number of connected devices, reaching a density ≥ 1M terminals/km^2;
- 100× in data rate reaching a peak rate ≥1 Gb/s for cloud applications inside offices;
- 1/10× in energy consumption over 2010, with traffic increasing dramatically;
- 1/5× end-to-end latency, reaching delays ≤ 5 ms;
- 1/5× network management operational expenditure;
- 1/1 000× service deployment time reaching a complete deployment in ≤ 90 minutes;
- guaranteed user data rate ≥ 50 Mb/s;
- capable of supporting IoT terminals ≥ 1 trillion;
- service reliability ≥ 99.999% for specific mission-critical services;
- mobility support at speed ≥ 500 km/h for ground transportation; and
- accuracy of outdoor terminal location ≤ 1 m.

Regulatory Challenges: Finding the spectrum for /IMT-2020

Given IMT-2020's potential importance in bringing ubiquitous connectivity, and the long timelines needed for development and deployment, discussions are already well underway regarding its regulatory needs. One of the most challenging questions remains what spectrum resources it may rely upon.

Because of the diverse technical performance criteria required to meet targets, studies of IMT-2020 technical requirements, including Report ITU-R M.2290-0, "Future spectrum requirements estimate for terrestrial IMT," published in 2013, have concluded that a diverse number of spectrum bands may be required.[7] In Resolution 238[8], WRC-15 resolved to undertake the appropriate studies to determine the spectrum needs for the terrestrial component of IMT in the frequency bands above 24.25 GHz to support /IMT-2020 in advance of WRC-19. These studies are currently ongoing.

These and other discussions encompass a large number of disparate criteria, all of which may or may not be satisfied by eventual systems. What is likely at this point is that to meet high expectations, IMT-2020 systems will require a combination of different approaches, different technologies, and various frequencies for different purposes. Some of these are existing technologies, such as greater deployment of small cell or employment of satellite links, and others are newer technologies that are seen as revolutionary, such as the use of millimeter-wave frequencies for wireless backhaul and/or access.
IMT-2020 systems will take advantage of many of the advances in network architectures and software, such as software-defined networking (SDN), network function virtualization (NFV), network slicing, advanced

[6] 5G PPP, *5G Vision: The 5G Infrastructure Public Private Partnership: the next generation of communication networks and services*, February 2015, https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf

[7] Report ITU-R M.2290-0 (12/20130: *Future spectrum requirements estimate for terrestrial IMT (* http://www.itu.int/pub/R-REP-M.2290-2014)

[8] RESOLUTION 238 (WRC-15): Studies on frequency-related matters for International Mobile Telecommunications identification including possible additional allocations to the mobile services on a primary basis in portion(s) of the frequency range between 24.25 and 86 GHz for the future development of International Mobile Telecommunications for 2020 and beyond; Final Acts WRC-15, page 296 (http://www.itu.int/pub/R-ACT-WRC.12-2015/en)

modulation access schemes, and cloud computing systems. These tools allow for greater virtualization and centralization of operations, which can reduce cost and increase flexibility in meeting customer and network requirements. It is expected that IMT-2020 will also use multiple frequency bands. Some of bands below 6 GHz are already available and globally harmonized for IMT. A number of other bands between 24.25 GHz and 86 GHz are under active study at the ITU-R. What spectrum resources IMT-2020 systems will use in the 5G future will depend on the direction of these discussions.

3.1.2 Small Cells

To meet the demand for wireless broadband, future generations of wireless technology and services must continue to increase their yield of bits per hertz per second. Future wireless traffic demands may also require new wireless network architectures as well as new approaches to spectrum management. For example, small cells using IMT technologies have the ability to enhance capacity and per-user throughput, as well as reducing costs and uniquely offering tight cooperation with the macro coverage layer.

Small cells using low power nodes are considered promising to cope with the expected mobile traffic demands, especially for hotspot deployments in indoor and outdoor scenarios. They are often employed by mobile network operators to extend the reach and quality of their networks. Small cells, which can include femtocells, picocells and microcells, provide a small radio footprint ranging from 10 meters within urban areas to 2 km in rural locations. Mobile operators often use small cells to extend their service coverage or to increase network capacity in areas of high demand. They may have an important role to play in enabling IMT-2020, which many expect to rely on heterogeneous networks (discussed below) of different cell sizes to provide more ubiquitous connectivity. Providing backhaul to these small cells can be challenging since they are often in hard to reach places and require carrier grade connectivity.

3.1.3 Millimeter Waves

One of the design elements under consideration to enable IMT-2020 to meet high demand is to use millimeter-wave frequencies (between 30 and 300 GHz) to deliver faster, higher-quality services. Since at these frequencies, allocations to the mobile service have a larger bandwidth and the transmission range of millimeter waves is relatively shorter than in lower frequency bands – in the hundreds rather than thousands of meters – mobile network operators may find millimeter waves useful to support the use of small cells in their networks.

The recent World Radiocommunication Conference 2015 (WRC-15)[9] debated bands to study for IMT for 2020 and beyond. It decided to consider the following bands, many of which are millimeter-wave bands: 24.25-27.5 GHz, 31.8-33.4 GHz, 37-40.5 GHz, 40.5-42.5 GHz, 42.5-43.5 GHz, 45.5-47 GHz, 47-47.2 GHz, 47.2-50.2 GHz, 50.4-52.6 GHz, 66-76 GHz and 81-86 GHz. Since several other services use portions of these bands (e.g. fixed, radiolocation, radionavigation and different satellite services) and considering that parts of those bands do not have a global mobile allocation, the ITU-R will undertake compatibility studies to determine the feasibility of using these bands for /IMT,IMT-2020 (5G), for consideration and adoption by WRC-19.

ITU and IMT standards towards 5G

Both ITU-R and ITU-T have begun to specify standards and target performance criteria for IMT-2020. ITU-R Study Group 5, in particular Working Party 5D which is the leading group of IMT-2020. systems comprising the IMT-2000, IMT-Advanced and IMT-2020, is continuously driving the studies and the standardization process in full collaboration with national and regional standards development organizations, equipment manufacturers, network operators, as well as academia and industry forums.

9 http://www.itu.int/en/ITU-R/conferences/wrc/2015/Pages/default.aspx

ITU-R Working Party 5D has already produced a number of Recommendations and Reports dealing with IMT-2020 and is working following a detailed time schedule to produce a IMT standard for 5G in 2020.

ITU-T Study Group 13 established a Focus Group in May 2015[10] to encourage the participation of members of other standards organizations, including experts who may not be members of ITU. The Focus Group will conclude its work at the end of 2016 and report to Study Group 13 at the beginning of the next study period. One of the primary activities of the Focus Group was to undertake a gap analysis of the standardization activities underway, based on the studies on several key technical topics and related non-radio parts of IMT-2020. The Focus Group provided a final report that addresses five study areas: high-level network architecture, an end-to-end quality of service (QoS) framework, emerging network technologies, mobile front haul and back haul, and network softwarization.[11]

3.2 Satellite Communications Technologies

In addition to its important role in television broadcasting and video distribution worldwide, fixed and mobile satellite communications also are widely used in remote and rural areas, during times of disaster when terrestrial networks are damaged, and in support of maritime, aviation, and other vertical markets. Satellite communications form part of the Internet connectivity ecosystem, and are used to support commercial and consumer data services, such as through VSATs, residential and commercial broadband services, and M2M/IoT connections. Satellite communications are used particularly in remote and rural areas and to complement terrestrial networks by increasing resiliency, ubiquity, and capacity.

Much like others in the ICT sector, satellite network operators and manufacturers are facing a world that is hungry for more data, more speed, lower latency, and competitive pricing – all while feeling pressures on limited spectrum resources. The satellite sector is also seeing new operator and manufacturing entrants, and competitive pressures from other access technologies such as high-altitude drones or balloons aiming to provide Internet services to remote and rural areas. Can satellites remain relevant in the 5G environment?

New “breeds” of satellite technologies already are responding to these challenges. Well-established manufacturers are seeking ways to innovate traditional satellite designs, and entrepreneurs and new entrants are completely rethinking the manufacture, launch, and deployment of satellites to connect the unconnected. Advances have affected the cost, capacity, and capabilities of larger geostationary satellites and innovations in smaller satellites allow for deployment more quickly and cheaply. This section will describe three particular innovations in the satellite sector, with consideration of whether or how regulators may need to address them: high-throughput satellites (HTS), non-geostationary fixed-satellite service (NGSO FSS) satellites, and nanosatellites.

3.2.1 Geostationary High-throughput Satellites

The introduction of a new class of geostationary high-throughput satellites (GSO HTS) – high-powered, spectrally efficient satellites with spot beams offering considerably higher bandwidth than earlier versions – promises to significantly reduce the basic cost of bandwidth. Geostationary satellites operate at an altitude of approximately 35 800 kilometers (22 300 miles) directly over the equator, thus appearing to be fixed relative to the Earth.

[10] ITU-T, *Focus Group on IMT-2020*, http://www.itu.int/en/ITU-T/focusgroups/imt-2020/Pages/default.aspx

[11] ITU-T, *FG IMT-2020: Report on Standards Gap Analysis*, December 2015, http://www.itu.int/en/ITU-T/focusgroups/imt-2020/Documents/T13-SG13-151130-TD-PLEN-0208!!MSW-E.docx

There are several distinguishing features of HTS satellites compared to earlier GSO networks – primarily higher speed, greater capacity, lower cost, and increased flexibility. Older generations of GEO satellites have been limited by power, capacity, and transmission delays. HTS satellites address these challenges through the application of enhanced solar power systems, on-board processing to maximize the efficient use of every available hertz and hybrid terrestrial/satellite innovations to divert latency-sensitive traffic over shorter terrestrial routes. By 2020-2025, there will be over 100 HTS systems in orbit delivering terabytes of connectivity across the world using Ku and Ka bands, reducing unit bandwidth costs by an estimated factor of 10.[12]

Some of the new features include adjustable spot beams, which enable greater flexibility for the operator to direct capacity to suit changing demands of customers. Considering that the average lifespan of a satellite is 15 to 20 years – a period of time during which market requirements can change significantly – having the ability to make changes in footprint or offerings enables operators to remain responsive to a changing environment. These satellites are already starting to be introduced into the marketplace, with more than fifteen HTS systems in orbit now, many of which are operated by the incumbent global and regional satellite operators.[12]

For regulators, it is important to take account of the ongoing and planned investments in satellite innovations – it may cost more than $200 millions[13] and seven years to plan, design, and launch a new geostationary satellite. Relative to previous iterations of satellite technologies, HTS promise a more competitive market and a key enabler to meet universal broadband targets than previous iterations of satellite technologies. Careful consideration should be given to satellite spectrum resources, whether existing resources should be protected or whether or how certain spectrum resources may be shared with other services. Regulators may also take account of satellite licensing regimes, particularly for the Ka band, to allow for deployment of services when these satellites are launched in increased numbers.

3.2.2 NGSO Systems

Non-geostationary satellites (NGSOs) operate at lower orbital altitudes than GSOs – typically low-Earth orbits (LEO, around 500 to 2.000 km above the Earth) and medium-Earth orbits (MEO, between LE and GEO: some 2.000 to 36000 km above the Earth) or and require multiple satellites to allow for continuous commercial coverage. NGSOs have been a feature of the space science and Earth exploration domains for decades; however, new classes of commercial NGSO systems are under development, with plans to launch hundreds or possibly thousands of satellites. Promising to bring broadband anywhere in the world and to obviate the need for expensive fiber infrastructure in difficult-to-reach places, new NGSO systems have received a new wave of investment from key players, both from within and outside the traditional satellite industry. They are being designed with the intention of connecting users in under-served areas.

---

[12] European Satellite Operators Association (ESOA);

[13] The Economist, "Nanosats are go!," 7 June 2014, http://www.economist.com/news/technology-quarterly/21603240-small-satellites-taking-advantage-smartphones-and-other-consumer-technologies

Regulatory Challenges: Mega NGSO Constellations

The ITU Radio Regulations provide the regulatory framework for filing, notification, and coordination of satellite networks, including for NGSO networks. Effective coordination between different users is critical to ensure that spectrum is used efficiently and to prevent harmful interference. Operators of planned NGSO networks have submitted to the ITU the required satellite filings, through notifying administrations and, in some cases, are already in the process of coordinating their networks with other affected administrations and operators using the regulatory framework established by the ITU in the 1992-2003 timeframe to enable the first generations of NGSO constellations to coexist with GSO and terrestrial networks. Is this framework fully adequate for these planned "mega-constellations"?

WRC Resolution 86 (Rev. WRC-12) provides a framework for ongoing studies of the satellite regulatory framework including satellite filing, notification, and coordination procedures. While WRC-15 did not make any changes to address NGSOs, the ITU-R is able to study this topic in the lead up to WRC-19, reviewing the current rules and evaluating whether any changes are needed to ensure the most efficient use of the orbital resource.[14]

These constellations aim to provide direct broadband capacity to users all around the globe, extending terrestrial broadband connectivity and providing direct-to-consumer Internet connectivity in remote areas. Given their relatively low altitude (compared to GSO satellites), these networks will have low latency (often competitive with terrestrial fiber), high capacity, and wide coverage of the globe. The links they can provide could support mobile backhaul, traditional fixed services, or offer broadband capacity directly to end-users.

3.2.3 Nanosatellites

Some of the most exciting advances in satellite technology have occurred in the "small satellite" realm. Known as nanosatellites or picosatellites, these small and lightweight satellites are lowering the costs of entry and expanding the range of applications possible. In the next five years or so some 1 000 small satellites are expected to be launched into lower Earth orbits, fueled by the rapid development of low-cost commercial launch vehicles.

Nanosatellites have proved popular with research institutions, government agencies, and industry alike. Because of their low cost, they are enabling the field of satellite players to expand very quickly and bring to market a wide variety of innovative applications – from Earth exploration, to data imaging, tracking, and weather sensing. Communications networks are being developed using large number of such satellites to provide useful capacity.

Compared to their larger cousins, nanosatellites bring a number of benefits, including:

- **Innovative designs** – Nanosatellites take advantage of recent advances in consumer electronics. Small-satellite engineers are able to incorporate the latest technologies into the design, particularly many of the sophisticated functions from smartphones.
- **Standardized designs** – Some, known as cubesats, follow a standard design. Cubesats are 10 cm (4 inch) long each side, weighing 1.3 kg (2.9 lb) or less. This makes them easier to mass-manufacture, simpler to launch into space, including as a secondary payload, and able to be easily combined into larger versions two, three, or more units in length for specific purposes.

[14] See Agenda and presentations from: ITU Workshop on the Non-GSO Satellite Issues; Geneva, 21st April 2016; http://www.itu.int/en/ITU-R/space/workshops/2016-NGSO/Pages/programme2.aspx

- **Lightweight** – These satellites are a fraction of the size and weight of the larger satellites, making them easier to manufacture and launch. They often "piggy-back" on other launches, or in some cases have been deployed from the International Space Station.
- **Low cost** – According to an estimate in the *Economist*, the cost of a nanosat of CubeSat dimensions might cost $150 000 - $1 million (including the launch), compared to a full-sized satellite system cost exceeding $ 200 million.[15]
- **Shorter life** – Missions are typically just one to two years in LEO, before re-entering the atmosphere and burning up. Some operators intend on replacing their fleet often, such as Planet Labs, which plans on replacing some of its satellites with newer versions every year.

WRC-15 considered whether existing satellite regulatory frameworks were sufficient to accommodate nanosatellites and it was determined that no changes were required. Additionally, the Radiocommunication Assembly 2015 adopted ITU-R Resolution 68 entitled "*Improving the dissemination of knowledge concerning the applicable regulatory procedures for small satellites, including nanosatellites and picosatellites*"[16], which aims to ensure regulators and small satellite operators are informed about the proper ITU regulations and filing procedures, including through training and capacity building. Regulators should consider providing clarification and information for national small satellite developers to guide them on how they may apply for licenses through domestic rules, including any applicable ITU Radio Regulations filing requirements Having clear information on any regulatory requirements will help stimulate growth in this sector, and ensure an interference free environment. Additional experiences of nanosatellite operators will also help inform any future studies of the ITU-R.

WRC-15 also invited WRC-19 to study the spectrum requirements for telemetry, tracking, and command in the space operation service for the growing number of non-GSO satellites with short duration missions.

[15] The Economist, "Nanosats are go!," 7 June 2014, http://www.economist.com/news/technology-quarterly/21603240-small-satellites-taking-advantage-smartphones-and-other-consumer-technologies

[16]Resolution ITU-R 659 (WRC-15) '*Studies to accommodate requirements in the space operation service for non-geostationary satellites with short duration missions*"; Book of ITU-R Resolutions, Edition 2015, issued from last Radiocommunication Assembly, RA-15 (10/ 2015): http://www.itu.int/pub/R-VADM-RES/en

Regulatory Challenges: Nanosatellites and space law

By lowering barriers to entering space, nanosatellites have brought many new actors who may not be familiar with national and international regulatory frameworks. Consequently, many small satellite operators do not register their satellites according to the agreed national and international procedures for registration and de-orbiting. Lack of compliance makes it more difficult to get a true sense of the number of satellites launched as well as to then track those small space objects in orbit. Such missions do not always fully comply with international obligations, regulations, and relevant voluntary guidelines, including those related to orbital debris. This can increase the risk to other fully compliant space missions and may threaten the long-term sustainability of low earth orbit space activities.

In 2015, the ITU Symposium on Small Satellite Regulation and Communication Systems met to discuss some of these issues, especially interference and registration issues. The outcome was the Prague Declaration, in which regulators acknowledged the challenges small satellites can pose, urged conformity to existing international instruments, and resolved to increase awareness of existing regulatory and licensing requirements for small satellites[17]. The ITU Radiocommunication Assembly (RA-15) also recognized this (See Resolution ITU-R 68).

3.3 High-altitude Platform Stations (HAPS)

While previously providers of communications services have fallen clearly into one of two categories – satellite or terrestrial – new efforts are underway to give a second wind to a delivery platform, which is physically located between the two: high-altitude platform stations (HAPS), placed on air above 20 km height.[18]

Regulatory Challenges: Finding a place for HAPS in telecommunications regulations

As part of its agenda, WRC-19 will consider additional spectrum requirements for gateway and fixed terminal links for HAPS. Spectrum identifications and international regulations already exist for HAPS, but these may not be sufficient for the delivery of broadband services. Studies are underway in ITU-R Study Group 5 in preparation for WRC-19[19] . It is expected that national regulatory frameworks would need to be adopted for this type of technology. These needs may include a licensing framework to authorize operators to operate unmanned airplanes or balloons as well as provide communications capacity.

While the ITU-R has studied the delivery of radiocommunication services over HAPS for years, operational HAPS systems communications services have yet to been realized. Recent improvements in lightweight aircraft technology offers potential for realizable HAPS systems. The growing urgency to expand the availability of broadband has renewed the interest in these platforms.

Improvements in composite materials, low-power computing, battery technology, and solar panels paved the way for this concept. These planes will be kept approximately 20 km above the Earth's surface, enabling them to provide broadband services to a wide area below,

[17] See "*Prague Declaration on Small Satellite Regulation and Communication Systems*", issued from: ITU Symposium and Workshop on small satellite regulation and communication systems, Prague, Czech Republic, March 2015; http://www.itu.int/en/ITU-R/space/workshops/2015-prague-small-sat/Pages/default.aspx

[18] According to national and international spectrum regulations, both HAPS and Stations placed on land masses are part of terrestrial stations, in opposition to space stations, i.e., satellites

[19] Resolution 160 (WRC-15): *Facilitating access to broadband applications delivered by high-altitude platform stations*; Final Acts WRC-15, page 261 (http://www.itu.int/pub/R-ACT-WRC.12-2015/en)

allegedly with latency similar to terrestrial technologies. These planes will use free-space laser communications or radio frequencies to connect to other planes and the ground. Powered by solar panels, they are planned to remain in the air for months at a time. Flexibility and ease of deployment are its biggest advantages, noting their ability to move easily to new locations. This flexibility enables them to be relocated in order to meet demand and the changing requirement of the operator or service provider's business plan

With respect to spectrum resources for these applications, the ITU Radio Regulations currently contain several frequency bands designated for HAPS in 2 GHz, 6.5 GHz, 27/31 GHz and 47/48 GHz ranges. However, these bands have geographical limitations and may not be large enough to provide high-rate broadband. The ITU-R is currently studying potential additional bands for HAPS in the bands 21.4 – 22 GHz, 24.25-27.5 GHz and 38-39.5 GHz allocated to the fixed service. WRC-19 will consider the results of these studies and could take decision on designation of some additional bands for HAPS.

Engineers are also studying the upper parts of spectrum, including optical bands. Recent test deployments of stations delivering broadband from approximately 20 km above ground have demonstrated the potential of providing connectivity to underserved communities with minimal ground-level infrastructure and maintenance. Although results of recent tests still need some verification, HAPS can probably be an effective tool to help close the digital divide in remote communities, particularly those with challenging terrain or climate. These stations are also highly resilient in the face of natural disasters and therefore can be an effective tool for disaster recovery. Some other potential applications of broadband delivered from HAPS include public protection and disaster relief, distance learning, tele-medicine and healthcare.

3.4 Evolving platform stations

Leveraging on new and emerging technologies, platform stations are evolving. Facebook is currently developing a system known as project Aquila. It has designed a plane approximately the weight of an automobile, which is able to stay at an altitude of 60 000 feet for months at a time. [20] This space plane will use lasers to transmit data between planes and to terrestrial stations within 50 kilometers, which can then provide Wi-Fi or 4G coverage locally.[21]

Separately, Google is developing the capability to use drones to provide wireless internet access using millimeter wave transmissions, which could offer up to 40 times more than today's 4G LTE systems. Google plans for thousands of high altitude drones to deliver Internet access around the world.[22]

Google is also developing a more traditional HAPS project, known as Project Loon, which will rely on balloons to deliver connectivity to those on the ground. This project, which has officially been in development since 2013, aims to provide 4G LTE internet via balloons traveling through Earth's stratosphere. The system has been tested in New Zealand, California, and Brazil. Google hopes Loon can eventually provide high-speed Internet to those in rural and underserved areas.[23]

---

[20] Danny Yadron and Jemima Kiss, "Facebook F8: Zuckerberg shows off chat bots, VR... and a dig at Donald Trump," *The Guardian,* 13 April 2016, https://www.theguardian.com/technology/2016/apr/12/mark-zuckerberg-facebook-donald-trump-f8

[21] Ania Nussbaum and Robert Wall, "Aquila, Facebook's First Drone for Internet.org," *Wall Street Journal*, 31 July 2015, http://blogs.wsj.com/digits/2015/07/31/the-aquila-facebooks-first-drone-for-internet-org/

[22] Mark Harris, "Project Skybender: Google's secretive 5G Internet drone tests released," *The Guardian,* 29 January 2016, https://www.theguardian.com/technology/2016/jan/29/project-skybender-google-drone-tests-internet-spaceport-virgin-galactic

[23] Ben Thompson, "What is Google's Project Skybender?" *Christian Science Monitor,* 31 January 2016, http://www.csmonitor.com/Technology/2016/0131/What-is-Google-s-Project-SkyBender

4 Changing Architectures and Complementary Technologies

The ICT industry is actively developing new ways of building networks to accommodate increased demands for data – some that centralize resources in order to attain economies of scale, others that distribute resources to the edges of networks so as to respond more flexibly to changing needs. These innovations are also emerging in part because of the increasing role that software is assuming relative to hardware in network technologies. This includes software defined networking (SDN), the practice – rapidly growing over the past five years – of transforming control of high-level network functions into software abstractions. SDN, which allows for greater agility, flexibility, and control in large networks, forms the foundation of many emerging network technologies. Some of these technologies, such as cloud computing, are already widespread and well understood, while others may be less known.

Regulators need to be aware of these developments and evaluate how existing regulatory frameworks may already be able to accommodate them. They may also need to consider where regulatory reforms are necessary to address new challenges, for example security, and allow these innovations to take shape. Importantly, the following section demonstrates the rapid pace of research and development being undertaken to meet current and anticipated challenges in the ICT sector. Governments can also play a role in supporting and stimulating research and development, and in providing an economic and legal environment supportive of innovation and entrepreneurship.

4.1 Advances in Network Architectures

4.1.1 Cloud Computing

Already a well-recognized technology, cloud computing is a major disruption to the ICT industry and is still evolving as more and more consumers and businesses move into the cloud. It is enabling new cellular network architectures such as cloud-RAN, discussed below, and will become increasingly important to the delivery of big data services and the IoT.

Cloud computing is an on-demand computing method that enables users to access shared computing resources and data over the Internet. Working on a principle of centralization, this model enables pooling of configurable computing resources (for example network servers or storage) as well as applications and services. This centralization provides economies of scale, which cloud service providers can leverage to deliver cheaper computing solutions to multiple users. Some of the major advantages cloud computing provides to users and enterprises are:

1. **Affordability** – Users and enterprises, especially small and medium sized entities, are able to access computing resources without upfront infrastructure costs.
2. **Scalability** – Enterprises can sign up to different packages depending on their business need, with the possibility to upgrade and downgrade as needed.
3. **Efficiency** – Enterprises can focus on their core business instead of spending resources on IT problems.
4. **Availability** – Users are able to access services over the Internet regardless of their location and the type of devices used, encouraging better collaboration through “anywhere, anytime” access to IT for users located around the world.
5. **Cost Savings** – Greater automation of processes can lead to reduced labor costs and a reduction in human errors.

Regulatory Challenges: Weighing the benefits and challenges of cloud computing

Cloud-based technologies are central to many of the technologies and architectures discussed in this report. ITU-D Study Group 1 is currently examining cloud computing in Question 3/1, "Access to cloud computing: challenges and opportunities for developing countries."[24] The question notes that cloud computing can be "a possible solution to the lack of adequate computing resources" in developing countries, and provides benefits both in the form of economies of scale and flexibility of use. The responsible Rapporteur Group is expected to produce a final report in 2017 containing analysis of factors influencing effective access, capacity building guidelines, and draft guidelines or recommendations.

Despite the potential benefits cloud solutions can bring, they can raise regulatory questions regarding privacy, security, and international transfers of data. Centralized systems, such as cloud networks, may offer greater protection from threats by simplifying and centralizing control, and cloud providers likely are able to provide more up to date and state-of-the-art security protections than a small business could afford; however, such systems also raise the stakes that security failures may impact a wider population. Regulators should examine existing national cybersecurity frameworks to ensure consistency with international best practice. Cloud systems are also generally sensitive to international restrictions on the transfer of data. By centralization resources to attain economies of scale, data sometimes needs to flow across borders to where it can be most efficiently processed. Regulations that provide for international transfers of data are therefore important to gaining access to many cloud services.

4.1.2 Cloud-RAN Using Fronthaul

A cloud radio access network (Cloud-RAN or C-RAN) was first promoted by China Mobile Research Institute in April 2010, nowadays several other operators are considering this technology very promising for the development of future mobile networks. C-RAN is a centralized cloud-based architecture for radio access networks that supports a wide variety of networks including 2G, 3G, 4G and future wireless standards. It is based on two major ideas to improve base station baseband processing: centralization and virtualization.

Centralization is key to improving performance and reducing operational costs (such as support and maintenance costs). This is enabled by a practice known as "fronthaul", where the baseband unit (BBU, which processes user and control data) and the radio unit (RU, which generates radio signals transmitted over antennas) are located further away from each other than in the traditional backhaul model. In this model, the BBU is separated from the RU and relocated to a centralized and protected location – up to several kilometers away – where it can serve several remote radio heads (RRHs) also known as remote radio units (RRUs). The optical links that connect the centralized BBU to the multiple RRHs are referred to as fronthaul.

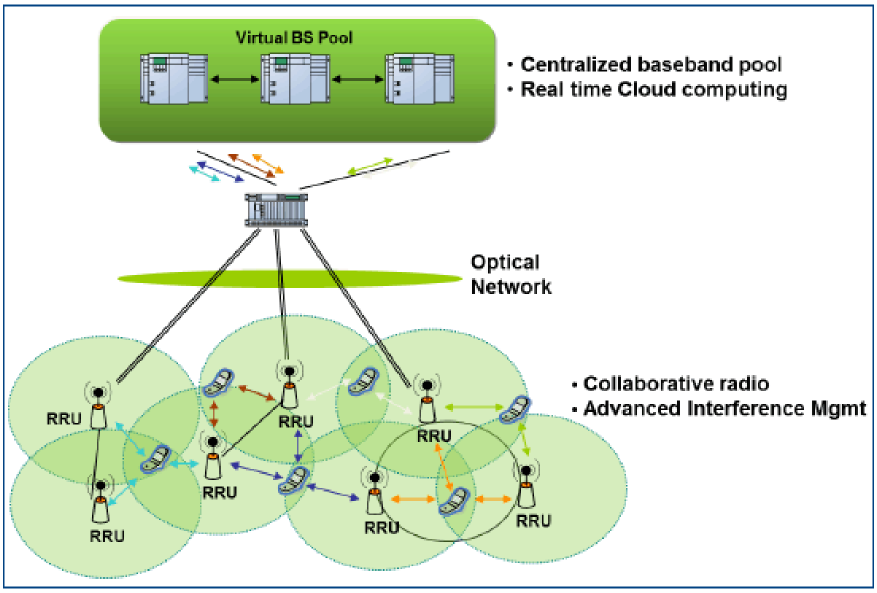
This stands in contrast to the conventional backhaul model, in which the BBU resides close to the RU within a typical macro cell, connected to the larger network infrastructure through long distance optical links. This allows for tighter coordination between cells than is available in traditional networks dependent on backhaul. This is a critical feature especially in HetNets and when small cells are deployed in the same frequency bands as the macro cells (especially in LTE), as a way to more effectively manage interference between cells and increase user data throughput.

Virtualization rooted in cloud computing aims to reduce capital expenditures by applying network function virtualization (NFV) to RANs. This allows operators to use commercial servers for base station hardware instead of custom-built products. This has a number of advantages: it allows operators to leverage economies of scale; by decreasing the complexity of hardware needs, it decreases the time to develop and

[24] ITU-D, *Question 3/1 Access to cloud computing: challenges and opportunities for developing countries*, http://www.itu.int/net4/ITU-D/CDS/sg/rgqlist.asp?lg=1&sp=2014&rgq=D14-SG01-RGQ03.1&stg=1

deploy new services; and it enables dynamic shared resource allocation and supports multi-vendor, multi-technology environments.

There are reports that deployments of C-RAN systems have already begun. This technology has attracted various equipment vendors working in collaboration in the recent few years. Research and development on C-RAN is also on-going, and it is expected to gain popularity in the near future.



Cloud-RAN is a cellular architecture that separates the "remote" radio head (RRH) from centralized baseband unit pool through long distance fronthaul optical links.[25]

4.1.3 Mobile Edge Networking (MEN)

Mobile edge networking (MEN) or mobile edge computing (MEC) applies the principle of decentralization of resources to better meet the needs of mobile network operators and users. MEN is a network architecture that enables application developers and content providers to deploy cloud computing capabilities (for example a cloud server) and IT services nearer to the edge of the mobile network – performing a task that could not be achieved with traditional network infrastructure.

The idea of running applications and the related processing task closer to the cellular customer enables an improved quality of experience to users, lower latency, higher bandwidth, as well as real-time access to radio network information. Mobile core networks are also relieved from further congestion and can efficiently control resources for a more optimized network. This helps operators cope with increasing demand for ubiquitous, high speed, and high performance Internet access.

ETSI and MEC standards

New MEC industry standards and deployment of MEC platforms will help generate new revenue for operators, vendors, and third-party service providers. Currently, the European Telecommunications Standards Institute (ETSI) Industry Specification Group (ISG) is conducting work on MEC. The work of ETSI MEC aims to define elements needed in a specification, and to address the necessary legal and regulatory requirements for wider deployment.

MEN infrastructure consists of standardized hardware resources and a software-implemented virtualization layer. High-volume, off-the-shelf IT hardware is used to achieve economies of scale and enables rapid and cost-effective upgrades. This creates a new ecosystem and value chain, allowing operators to open their RAN's edge to authorized third parties, encouraging rapid deployment of innovative applications and

[25] Global Information Inc., "C-RAN and LTE-Advanced: The Road to "'True 4G", 4G' & Beyond," 28 October 2013, https://www.gii.co.jp/report/heav288660-c-ran-lte-advanced-road-true-4g-beyond.html

services to the mobile subscribers. It allows software applications to tap into local content and real-time information about local access network conditions.

4.1.4 Heterogeneous Networks (HetNets)

In addition to changing the way that they carry out computing and route network functions, network operators are finding that they can improve performance by refining the architecture of the wireless portion of their networks. Accordingly, heterogeneous networks (HetNets) are gaining popularity as a mechanism of expanding network coverage through the deployment of different sized cells and types of technology.

A typical HetNet comprises multiple radio access technologies, architectures, transmission solutions, and base stations of varying transmission power. This technique represents an evolution of existing network technologies, rather than a new type of network technology itself.

Combining a variety of technologies together allows the most appropriate option to be chosen for a given area and helps provide ubiquitous service. Operation of the network in different cell sizes can also be used to satisfy different coverage needs and augment overall network capacity. For example, small cells such as femtocells and Wi-Fi hotspots can be deployed within buildings, whereas traditional macro cells are needed to provide general coverage for mobile users. Cell selection techniques can optimize these choices. Figure 1 illustrates the potential configuration of a HetNet, using both indoor and outdoor small cells.[26]

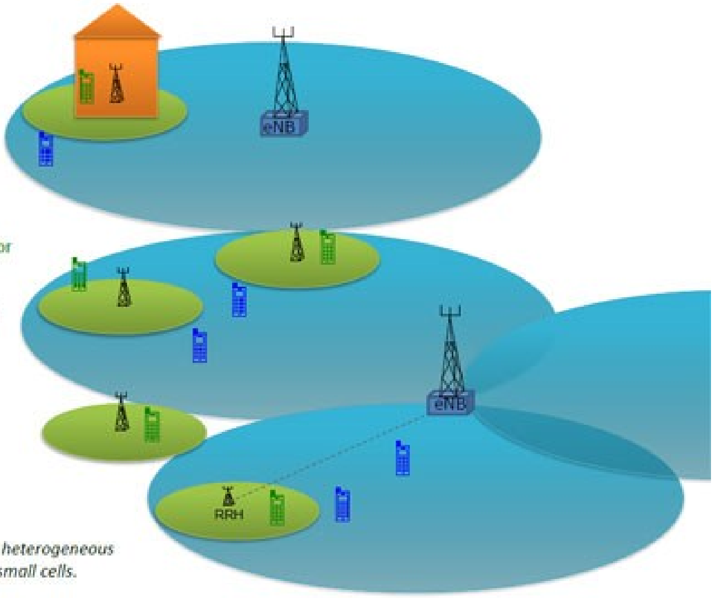


***Figure 1**: Illustration of a heterogeneous network, with large and small cells.*

If all these parts can provide a high level of performance, they can appear to the user as a single seamless network. This is also useful for mobile operators who are looking to adopt cellular HetNets to meet coverage and capacity goals when demands on the mobile networks rise - for example at stadiums or events with large numbers of people. The operators can offload data away from the central backhaul network through other technologies in the HetNet, allowing better use of the radio spectrum and an improved user quality of service.

4.1.5 Network Slicing

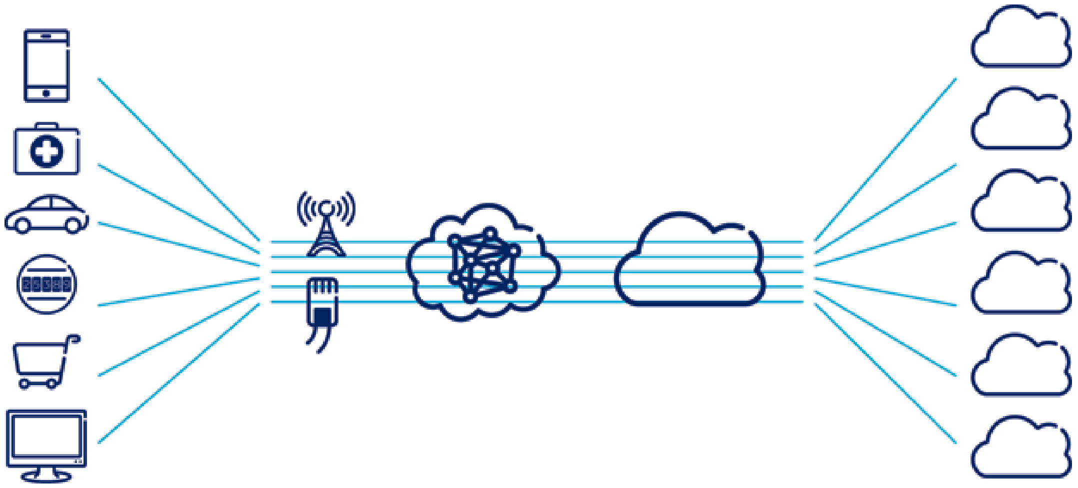
Network function virtualization techniques discussed above enable mobile operators to deploy a number of new features. One of the most discussed is network slicing, a mechanism proposed for 5G/IMT-2020

[26] Jeanette Wannstrom and Keith Mallinson, *HetNet/Small Cells*, http://www.3gpp.org/hetnet

systems that operators can use to support multiple virtual networks behind a single air interface. The technique "slices" the network into multiple virtual networks to support different RANs of different service types across the fixed part of the network, both in the backhaul and the core networks.

Traditionally, operators build network systems with certain predictable network traffic and expected growth. This type of vertical architecture is difficult to scale or to adapt to changing demands, making it harder to quickly meet the requirements of emerging use-cases. Network Function Virtualization (NFV) and software-defined networking (SDN) provide the tools to create networks with a greater degree of abstraction by enabling vertical systems to be broken apart into building blocks, resulting in a horizontal network architecture which can be chained together to focus on providing certain kinds of service.

Network slicing allows an operator to deliver diverse services over one RAN infrastructure, rather than constructing different RAN infrastructures for discrete services. [27]



This enables creation and expansion of separate logical nodes and functions for a specified group. In IMT-2020 systems, the transformation of a network into slices allows connectivity to be defined by a number of software functions that provide a certain coverage area, duration, capacity, speed, latency, robustness, and security parameters as needed. Network slicing enables IMT-2020 to be defined according to the requirements of users and operators, and to provide networks-on-demand supporting a wide range of use cases ranging from low-cost, low power, and low speed Internet of Things (IoT) connections to more bandwidth hungry video streaming connection.

Network slicing enables networks to be defined with greater flexibility and therefore provides a wide range of connectivity services. Rather than build multiple networks to support many different types of services, operators using network slicing can build a single, virtually segmented network to support many different types of users and applications with different needs. Since each slice is customized to match the complexity required for that service, network slicing can also enable more accurate billing according to usage by improving insights on network utilization.

[27] Ericsson, *White Paper: 5G systems – enabling industry and society transformation*, 26 January 2015, http://www.ericsson.com/news/150126-5g-systems-enabling-industry-and-society-transformation_244069647_c

Network slicing is rapidly gaining acceptance and is widely expected to be integral to IMT-2020 future mobile system designs to support the highly differentiated characteristics of various connections envisioned in a IMT-2020 system. The Republic of Korea's SK Telecom recently announced a partnership with Ericsson, an early leader in developing network slicing, to develop network slicing for use in a IMT-2020 network.[28] This continues their existing partnership in building a 5G testbed.

4.2 Advances in Software

Many have observed that advances in hardware processing power have begun to slow.[29] As processors have become smaller and smaller, designers have begun to reach the limits of miniaturization. This does not necessarily mean that advances in computing will stop, but that future advances may come in the form of software innovations, rather than hardware. Correspondingly, "softwarization" has become a broad trend, referring to the ever more important role that software has come to play today in the drive to develop more efficient, cost-effective, and agile delivery of ICT services. More advanced software is coming to replace more advanced or specialized hardware, and is increasingly used to provide improved performance and greater efficiencies in the ICT and telecom industries.

Regulators should take account of these advancements and ensure that any applicable regulatory frameworks allow sufficient flexibility to allow for software based changes or upgrades without requiring a modification to the licensing or regulatory requirements, particularly if regulations are tied to specific equipment. Support should be given to research, development, and standardization efforts in developing these software-based techniques to enhance networks.

4.2.1 Network Function Virtualization (NFV)

Network operators are looking for ways to handle new types of demand and develop services more quickly. NFV seeks to meet this challenge by using IT virtualization techniques to transform conventional network node functions into software building blocks that can be mixed and matched to provide network functionalities rapidly.

Rather than use customized hardware for each network function as in conventional network nodes, NFV allows operators to substitute software to simulate specialized hardware, which can run on generic, standardized equipment such as high volume servers, switches, and storage. Network service providers are increasingly finding that this capability improves the flexibility of service provisioning and reduces the time to market of new services.

[28] Ericsson, *Ericsson and SK Telecom to collaborate on 5G network slicing*, 27 July 2015, http://www.ericsson.com/news/1942903

[29] Technology Quarterly, "After Moore's Law," *The Economist,* 12 March 2016, http://www.economist.com/technology-quarterly/2016-03-12/after-moores-law

By relying upon virtualized, as opposed to physical, infrastructure, NFV-based services provide other benefits such as high availability, ease of scalability, improved performance quality, and more effective network management. NFV is expected to support a wide range of fault tolerance options and enable service providers to employ redundant resources to meet specific high availability requirements.

NFV has proven a popular standard since its introduction and has supported various applications such as virtualization of mobile base stations, platform as a service (PaaS), and content delivery network (CDN). It also forms the foundation of other critical advance such as C-RAN and network slicing. Various NFV products have been announced or built and the ecosystem is forming at a rapid speed.

ETSI discussions of NFV

ETSI has formed an Industry Specification Group for NFV (NFV ISG),[30] which includes representatives of European and international telecommunications operators, to evaluate and discuss standards for the technique. It published its first white paper describing NFV in 2012,[31] and has since produced a series of white papers, as well as reports on standard terminology, potential use cases, and relevant security and regulatory considerations.

4.2.2 Cognitive Computing

Cognitive computing employs data mining, pattern recognition and natural-language processing to mimic the processes of human brain in order to be able to learn. It addresses complex situations where ambiguity and uncertainty exist, usually in a dynamic and information-rich environment where data can also change frequently. The aim of cognitive computing is to offer better insight by synthesizing information, context, and possible influences, and to produce answers in natural language.

Cognitive systems are typically:

- **Adaptive** – They are able to learn as information changes.
- **Interactive** – Especially with users as well as with other processors and devices.
- **Iterative and stateful** – They are able to find extra input information and remember previous interactions.
- **Contextually sensitive** – They are able to understand, identify and extract contextual elements such as meaning, syntax, time, location, regulations, goals, and so on.

Cognitive computing adds an extra layer of intelligence, enabling industry to provide recommendations that are more relevant to customers, proactively and in real time. For example, in the healthcare industry, a physician could make use of more data or attributes in real time to improve the accuracy of diagnosis of a patient, rather than making use of only commonly selected attributes under the conventional method.

Cognitive computing is still a new and developing type of computing. It requires more accurate models of how the human brain senses, reasons, responds to stimuli, and draws conclusions before its full benefits can become widespread. Nevertheless, the technology has the potential to be used in many different industries, especially those that are data-rich. Cognitive computing contrasts with the traditional approach to big data, in which a company hoping to make sense of their data would use data warehouses, meaning insights could not be gained in real time.

[30] European Telecommunications Standards Institute, *NFV Industry Specification Group*, https://portal.etsi.org/tb.aspx?tbid=789&SubTB=789,795,796,801,800,798,799,797,802

[31] ETSI NFV Industry Specification Group, *Network Functions Virtualisation An Introduction, Benefits, Enablers, Challenges & Call for Action,* 22 October 2012, https://portal.etsi.org/NFV/NFV_White_Paper.pdf

Spotlight: IBM and the Cognitive Internet of Things

IBM, which has been developing the technology over the past few years, has worked with partners to implement the technology for healthcare, financial services, and other cross-industry applications. Cognitive computing is also expected to play a key role in real time management of the vast increase in data collection and the complex systems of interconnections generated by the Internet of Things. IBM is already attempting to develop these capabilities through its Watson IoT Cloud.[32] Based in Munich, the project will serve as a test bed of cognitive IoT services, targeting the automotive, electronics, manufacturing, healthcare, and insurance industries.

4.2.3 Delay-tolerant Networking (DTN)

Delay-tolerant networking (DTN) can be employed when networks lack an end-to-end path, for example due to limits of wireless radio range, scarcity of mobile nodes, energy resources, or presence of noise. It accomplishes this by using a store and forward approach, ensuring no information is lost even when a connection is interrupted. The data therefore moves incrementally through the network to reach its final destination.

Many communication environments can benefit from DTN, such as those with intermittent connectivity, long or variable delay, asymmetric data rates or high error rates such as rural areas with poor infrastructure. DTN accommodates long disruptions and delays between and within networks, and supports the mobility and limited power of evolving wireless communications devices. It can also accommodate many kinds of wireless technologies including radio frequency (RF), ultra-wide-band (UWB), and free-space optical technologies.

4.2.4 Self-organizing Networks (SON)

Self-organizing networks (SON) are seen as essential for today's complicated cellular networks that need the ability to self-configure, organize, optimize, and also "self-heal" when fault occurs. The following are some of the key features of a SON:

- Self-configuration enables simple plug-and-play of newly deployed nodes. For example, the nodes are expected to configure aspects of themselves such as the cell identity, transmission frequency, and power. This facilitates faster cell planning and roll-out.
- Self-optimization includes optimization of coverage, capacity, handover, and interference to improve capacity. To accomplish this, load level and information on available network capacity need to be maintained and exchanged between the network nodes.
- Self-healing includes features for automatic detection and removal of failures and automatic adjustment of parameters.

SON techniques are increasingly popular among operators, who can benefit from significant improvements in capital and operational expenditure. It can reduce costs by reducing the level of human intervention needed, optimizing the use of resources, and protecting the network by reducing errors. It may require larger upfront investments from the operator initially, however the returns are expected to be even larger and could be essential to long-term growth. To users, SONs can help provide lower costs and better network performance.

[32] IBM, *Watson Internet of Things,* http://www.ibm.com/internet-of-things/

4.3 Radio and Antenna Technologies

4.3.1 MIMO

Multiple-input and multiple-output (MIMO) is an antenna technology for wireless communications in which multiple antennas are used at the source transmitter as well as the destination receiver. This method multiplies the capacity of a radio link and is also able to exploit multipath propagation.

In conventional wireless communications, a single antenna is usually used at the source and at the destination. One of the common problems this approaches faces is multipath effects, whereby obstructions such as a hill or buildings scatter signal wavefronts, causing it to travel in many different paths to reach its destination. These signals will therefore arrive at different times and wave phases, fading each other and causing errors and a reduction in data speed. The use of multiple antennas on the other hand takes advantage of this phenomenon by allowing signals to be transmitted along multiple paths, bouncing off walls, ceilings, and other obstructions to reach the antenna at different angles and at a slightly different times. By enabling the antennas to carefully synchronize and add these data streams, MIMO can increase capacity, reliability, and range. This can be done by handling the multi-path signals of spatial multiplexing MIMO using orthogonal frequency-division multiplexing (OFDM) or orthogonal frequency multiple access (OFDMA).

The use of MIMO has already been incorporated into the latest mobile communications standards such as 3GPP and 3GPP2, Long-Term Evolution (LTE) and High-Speed Packet Access Plus (HSPA+). It is expected to be integral to future IMT-2020/5G standards, especially the use of massive MIMO at the base transceiver station. This usually employs a large number of antennas, typically more than 64, and will be key to achieve the performance targets for IMT-2020/5G.

4.3.2 Beamforming

Beamforming is a signal processing technique realized by transmitters and receivers that use MIMO technology. Antennas employing beamforming focus their radiations toward the source (or destination) instead of spreading out into the atmosphere in all angles as in omnidirectional transmission and reception. This is done by a beamformer that controls the phase and relative amplitude of the signal at each antenna, creating an intended radiation pattern.

Conventional beamformers use a selective and fixed set of weightings and phasing to combine the signals in the array. The adaptive beamforming technique on the other hand is able to automatically adapt the beamforming according to different situations. Adaptive beamforming antennas, also referred to as a “smart antennas,” can support more than one user on the same frequency, as long as they are in different directions, by steering the separate antenna beams at each user, hence focusing the energy in the respective directions. This allows concurrent transmission in one area, reducing interference to other users and increasing the energy efficiency and network capacity of cellular systems dramatically.

This capability is particularly important for IMT-2020 networks, where interference needs to be carefully controlled to support high throughput for a large number of users. Newer technology such as field-programmable gate arrays (FPGAs) are able to handle high data rates in real-time using reconfigurable interconnects, using a combination of hardware and software technology, making it particularly suitable for handling high-speed applications in IMT-2020 systems.

4.3.3 Cognitive Radio system

The terms Cognitive radio system (CRS) are defined in Report ITU-R SM.2152 as follows: “A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained." A Device using CRS would then be able to configure itself to certain radio frequencies and operating parameters taking into account reliable information available from the regulatory Authority allowing the use of these frequencies for this purpose.

A CRS generally consists of an adaptive, multiband software-defined radio (SDR, also defined in Report ITU-R SM.2152) that supports multiple air interfaces, multiple protocols, and is reconfigurable through software. An SDR contains hardware components such as mixers, filters, and amplifiers that are activated and controlled by means of software on an external computer or embedded within the radio. An adaptive radio monitors its own performance and uses closed loop actions (inclusive of machine learning capabilities) to optimize its performance by automatically selecting the appropriate frequencies and channels. These mechanisms allow it to adapt to the changes of the environment, and use available frequencies at given time and area, and use a common set of radio hardware.

ITU frameworks and cognitive radio

The Report ITU-R SM.2152-0 (09/2009)[33] defined:

- *Software-defined radio (SDR):* A radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard
- *Cognitive Radio System (CRS):* a radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained .
- The operation of cognitive radio systems (CRS) is defined by the ITU. It shall respect the Radio Regulations (RR), the international treaty providing allocations of radio frequency bands to more than 40 defined radio services and the associated regulatory provisions for their use in a targeted interference-free environment. It shall also respect national spectrum regulations. WRC-12 considered that the current international regulatory framework can accommodate software defined radio and cognitive radio systems[34], by following the guidelines stablished on Recommendation 76 (WRC-12), "*Deployment and use of cognitive radio systems*" [35] recognizing that: (a) any radio system implementing CRS technology needs to operate in accordance with the provisions of the Radio Regulations; b) the use of CRS does not exempt administrations from their obligations with regard to the protection of stations of other administrations operating in accordance with the Radio Regulations . With respect to the national regulations, the RR require in particular that no transmitting station may be established or operated by a private person or by any enterprise without a license issued in an appropriate form and in

[33] Report ITU-R SM.2152 (09/2009): *Definitions of Software Defined Radio (SDR) and Cognitive Radio System (CRS)*; http://www.itu.int/pub/R-REP-SM.2152-2009

[34] Speech by ITU-R Director Francois Rancy, speech on 13 December 2013, Tunis, Tunisia, ITU Radiocommunication Seminar for Arab Countries, RRS13-Arab.

[35] Recommendation 76 (WRC-12): *Deployment and use of cognitive radio systems*. Radio Regulations, Edition 2012, Volume 3: Resolutions and Recommendations. http://www.itu.int/pub/R-REG-RR-2012

conformity with the provisions of these Regulations by or on behalf of the government of the country to which the station in question is subject (see RR No. 18.1)[*]. Within that international regulatory framework, it rests entirely in the hands of national regulators the decision to develop national a regulatory framework enabling the use of cognitive radio systems.

In addition to existing ITU-R publications[**] on this subject and to further ongoing ITU-R studies, which shall be in consistence with the Radio Regulations provisions cited above, the ITU-R and ITU-D Joint Group on WTDC Resolution 9 (Rev. Dubai, 2014), "Participation of countries, particularly developing countries, in spectrum management" is currently developing a report that will examine dynamic spectrum access approaches using cognitive radio technology based on a few recent national experiences, mainly in the UHF band, as well as the regulatory impact and challenges, and the long-term feasibility of projects using these technologies.[36]

The most commonly used cognitive radio systems rely on geolocation databases that contain information on the location, frequency, power output, and other technical characteristics of spectrum users. Wireless devices operating on these frequencies must report their location information and then query the database for the available frequency channels and the operating parameters. Geolocation databases have been implemented and are currently operated as a part of TV white space (TVWS) systems in the United States, the United Kingdom, Canada, and Singapore.

Further, other spectrum sharing mechanism such as the Spectrum Access System (under development in the United States) and Licensed Shared Access (developed in the European Union[37]) contemplate using geolocation databases to ensure non-interfering operation on shared frequencies. These different new regulatory frameworks are also under study within ITU-R towards providing a set of relevant solutions to national regulatory Authorities that would facilitate the share use of the spectrum and encourage its efficient use by allowing applications of different and/or similar nature to coexist in an identified spectrum environment. These different solutions may provide different level of protection and quality of service to the new service applications according to the needs.

Spectrum sensing is an alternative to the geolocation database approach, where dedicated sensors are used to measure the radio environment and enable wireless devices to commence operations on a non-interference basis. Spectrum sensing techniques have the potential to provide crucial information of the actual spectrum usage environment in specific locations as well as ensure optimum usage of the available spectrum. However, taking into account the difficulty to obtain with basic sensing equipment reliable information on incumbent users, sensing alone could not enable spectrum sharing without the support of other technologies such as geolocation databases.

[*] The term "licence" should be understood in its broad acceptance and means that the use of spectrum must be explicitly permitted.

[**] See relevant ITU-R Report in the M series and SM series.

[36] http://www.itu.int/net4/ITU-D/CDS/sg/rgqlist.asp?lg=1&sp=2014&rgq=D14-SG01-RES9&stg=1

[37] Licensed Shared Access (LSA), Feb.2014, http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP205.PDF

5 Emerging and Evolving Applications

Enabled by these new technological innovations, delivery platforms, and network architectures, new classes of applications are being developed which are already having an impact on society and the economy. In many cases, these applications are built upon existing wired and wireless connectivity services – terrestrial and satellite – however enhanced platforms and architectures enable these technologies to deliver new types of capabilities. For example, Machine-to-Machine (M2M) sensors have been in use for many years. However, the varied ways in which they are now being deployed and how the data is used are anticipated to transform the way we live and work. Geospatial imagery satellites have also been in use for many years, but new ways to put this data to use are coming out of age. More importantly, the volume and expected growth of these deployments are causing policymakers across all facets of government to consider how to address a world increasingly powered by ICTs.

What are these new applications, and how are innovators finding new ways to apply technologies to address the challenges of social and economic development and build the Smart Society? How can regulators look ahead and ensure they put in place the right spectrum management, regulatory, and policy frameworks to allow these applications to flourish, encourage innovation, and stimulate investment in the economy?

5.1 Internet of Things (IoT) and Machine to Machine (M2M) – Applications for a Smart Society

Everyone has been hearing about the Internet of Things (IoT) transforming everything. Nevertheless, what does it mean and what are the technologies behind the IoT? In many cases, the connected devices that encompass M2M and the IoT are not new – in fact, telecommunications providers have been providing M2M services for many years, for example through the use of low-cost, low data-rate sensors or RFID chips in the manufacturing and fleet management sectors. The transition to the IoT involves greater innovation and interconnection of these devices, an intersection between M2M and Machine to Person applications (M2P), and improved cloud services and Big Data analytics, all intimately linked to the development of IMT-2020, common standards, and other new delivery platforms. M2M – and more broadly the Internet of Things – has been growing exponentially and the number of connected devices is forecast to be 26 billion by 2020.[38] This increase in volume is raising questions regarding the potential impact on society and the economy and about the policy and regulatory environment that will best enable the IoT.

The IoT has wide-ranging regulatory implications such as licensing, spectrum management, standards, competition, security, and privacy – only some of which are squarely under the mandate of telecom regulators.[39] Maximizing the benefits of the IoT will likely require more coordination across all sectors, with telecom/ICT regulators working closely with their counterparts in data protection and competition, but also with officials and other stakeholders in emergency services, health, highway authorities, or other sectors.[40] The sections below will address sector-specific implementations of the IoT, as well as some basic technical and regulatory considerations.

[38] Gartner, *Predicts 2015: The Internet of Things,* 26 January 2015, http://www.gartner.com/newsroom/id/2970017

[39] ITU and Cisco, "Harnessing the IoT for Global Development," *Report for the UN Broadband Commission on Sustainable Development*, 2015, https://www.itu.int/en/action/broadband/Documents/Harnessing-IoT-Global-Development.pdf

[40] Ian Brown, "Regulation and the Internet of Things", *GSR-2015 Discussion Paper*, www.itu.int/en/ITU-D/Conferences/GSR/Documents/GSR2015/Discussion_papers_and_Presentations/GSR_DiscussionPaper_IoT.pdf

It is important to think of the IoT both as something new and emerging, but also recognizing that the underlying connectivity of devices to the Internet or other networks may not be new at all. Applications run across diverse wireless technologies and platforms – terrestrial and satellite, narrowband and broadband, long-range and short-range, which are already operating via existing regulatory and spectrum management frameworks.

Wireless IoT devices connect to the Internet or other networks using both unlicensed and licensed spectrum, and operate across a wide range of frequency bands, depending on requirements for the specific devices or systems. For example, IoT devices often connect via standard mobile (IMT, GSM, 4G/ LTE, etc…) and satellite (Mobile Satellite Service (MSS) and Fixed Satellite Service (FSS)) connections. Where licensed spectrum is used, regulators should examine whether existing licensing rules support – or possibly constrain – deployments of the IoT. In some cases, e.g. when new spectrum is not required and protection of existing systems is ensured, no regulatory changes may be needed since the underlying technology is the same. Short-range, low power IoT devices frequently operate using unlicensed Industrial, Scientific and Medical Bands (ISM) frequency bands, under the principle of no interference (to other radio stations))/ no protection (from other radio stations); authorized bands vary in terms of national and regional allocations (see Report ITU-R SM.2153). An example would be devices that connect using Wi-Fi, ZigBee, and Bluetooth in the 2.4 GHz or 5 GHz frequency bands. In these cases, authorizations are already in place, and developers are creating new applications using already harmonized spectrum. Wireline technologies such as fiber, DSL/copper or cable - each with varying capabilities of range, power, and bandwidth - also play a role. Global Navigation Satellite Systems (GNSS) such as GPS allows for the location services already underpinning many M2M and IoT devices.

Flexible, market-based policies for use of spectrum – implementing both licensed and unlicensed approaches – may allow for growth of these devices without a need for dedicated spectrum. One challenge will be to ensure sufficient spectrum once anticipated IoT deployments are made. The United States Federal Communications Commission's expert IoT Working Group has predicted that the IoT will add significant load to existing Wi-Fi and 4G mobile networks. Regulators are recommended to give continuing attention to the availability of spectrum for short-range IoT communications, the capacity of backhaul networks, as well as encouraging the rollout of small-cell technology and 4G. Assuming these conditions are met, the Working Group did not expect that new spectrum authorizations will be needed specifically for IoT communications.[41]

Flexible licensing approaches also allow migration to new technologies possibly without the need for regulatory changes. In some cases regulators are reviewing existing spectrum frameworks to adjust rules to take account of the growth of the IoT and allow for future developments while protecting existing services. For example the UK just created a new "IoT" license in the VHF band to better clarify that this spectrum could be used for such devices, which were previously licensed more simply as "radio licenses". Australia has also proposed changes to remove a technical barrier to the operation of narrowband low powered wireless networks in the Radiocommunications (Low Interference Potential Devices) Class Licence 2015 in the 900 MHz, 2.4 GHz band and 5.8 GHz bands.[42]

Regulators and policymakers should also consider developing an overall IoT strategy or plan, to help take account of the broad picture of the IoT – including support for standards development, research and

[41] US FCC Technological Advisory Council IoT Working Group, *Spectrum: Initial Findings, FCC TAC meeting update*, 10 June 2014, http://transition.fcc.gov/bureaus/oet/tac/tacdocs/meeting61014/TACmeetingslides6-10-14.pdf

[42] Australian Communications and Media Authority, *Easier Access to Spectrum for the Internet of Things,* 15 March 2016, http://www.acma.gov.au/Industry/Spectrum/Spectrum-planning/About-spectrum-planning/easier-access-to-spectrum-for-internet-of-things

development, and review of issues like privacy, security, spectrum, cross border data flows or data localization requirements.

ITU and Internet of Things (IoT) Standardization

The international community has been working across diverse standards development organizations (SDO's) to agree IoT standards. Standards are important for future developments of the IoT to allow for more interoperability across devices and systems. The ITU has defined the IoT as "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies" (Recommendation ITU-T Y.2060). In 2015, the ITU Telecommunication Standards Advisory Group (TSAG) approved the creation of Study Group 20 on the IoT and its applications, including smart cities and communities (SC&C).[43]

ITU-T SG20 is tasked with developing international standards to enable the coordinated development of IoT technologies, including machine-to-machine communications and ubiquitous sensor networks. A central part of this study is the standardization of end-to-end architectures for the IoT, and mechanisms for the interoperability of IoT applications and datasets employed by various vertically oriented industry sectors. SG20 will assist government and industry in capitalizing on the opportunities presented by the IoT, providing a unique platform to influence the development of international IoT standards. "[44]

Further to the approval of Resolution ITU-R 66 at the Radiocommunication Assembly RA-15 (Oct. 2015), ITU-R Study Groups are studying wireless systems and applications for the development of IoT, which may also benefit from the ITU-R studies to achieve harmonization for short-range devices (Res. ITU-R 54).

5.1.1 Smart Cities

National and local governments everywhere are racing to promote development of model 'Smart Cities'. The UAE, Republic of Korea, the United States, and Singapore are just some examples of countries that have launched Smart City initiatives, seeking to support research and development, promote investment, and stimulate innovation in use of technology to help reduce traffic congestion, fight crime, foster economic growth, adapt to climate change, and improve the delivery of government services. While a Smart City would implement technologies broader than what is considered part of the IoT, the IoT is an integral component of the Smart City.

ITU, Smart Societies and Smart Sustainable Cities

ITU is exploring new activities related to the development of the Smart Society. ITU-D Study Group 2 Question 1/2 is examining the technologies and case studies that will help developing countries enable the "Smart Society." Recognizing that ICTs will have a crucial role in 'smart sustainable cities' particularly in water, energy and waste management, and intelligent transport systems (ITS), the ITU-T established a Focus Group on Smart Sustainable Cities which concluded its work in May 2015 with the approval of 21 Technical Specifications and Reports. The FG brought together the key stakeholders – such as municipalities; academic and research institutes; non-governmental organizations (NGOs); and ICT

[43] ITU-T, *Focus Group on Smart, Sustainable Cities,* http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx
[44] ITU-T, *Study Group 20 at a glance,* http://www.itu.int/en/ITU-T/about/groups/Pages/sg20.aspx

organizations, industry forums and consortia – to exchange knowledge in the interests of identifying the standardized frameworks needed to support the integration of ICT services in smart cities.

The ITU-T has adopted the following definition of a Smart Sustainable City based on the work done by the Focus Group and the United Nations Economic Commission for Europe":

"A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects".[45]

Early Smart City initiatives offer regulators and policymakers a great opportunity to preview new and innovative technologies, support test beds for wireless innovations, build dialogue and collaboration with key stakeholders, and evaluate how current spectrum regulations and allocations will allow for a wider adoption of the Internet of Things. Spectrum and telecom regulators should evaluate current spectrum management practices, and collaborate with other Ministries and regulators who are leading on Smart City Initiatives and who have a role in identifying ICT requirements of their specific sectors. Additionally, as countries develop infrastructure such as roads, airports, bridges, and energy grids, countries may also consider how to make these "smart" through embedded sensors to take advantage of the IoT at the outset.

5.1.2 Smart Manufacturing and the Industrial Internet of Things

The manufacturing sector is one of the leading adopters of M2M and IoT applications. IoT applications have been transforming manufacturing, allowing companies to increase efficiencies, identify workforce gaps, and improve services. The Industrial Internet of Things (IIoT) will transform many industries, including manufacturing, oil and gas, agriculture, mining, transportation, and healthcare. Oxford Economics predicts that collectively, these account for nearly two-thirds of the world economy. By using sensors embedded in equipment, manufacturers can monitor systems, identify and remotely address maintenance issues, and collect data to help improve productivity. Fleet tracking can further improve the efficiency of supply chains. Industrial IoT is challenging traditional business models and forcing businesses and governments to adopt the IIoT in order to remain competitive.

Sensors and ubiquitous connectivity are behind much of the Industrial Internet of Things, with data analytics and software enabled services playing an important role in helping put the great amounts of data collected from the sensors into use. Manufacturers can use such sensors and software capabilities to support predictive maintenance, increasing efficiencies and cost savings. Additionally, agricultural companies can use this new data to calculate how many bushels of wheat can be produced on a given piece of farmland with a particular mix of seed, fertilizer, water, soil chemistry, and weather conditions. By combining analytics software with connected tractors, tillers, and planters, they can apply the precise mix of seed and fertilizer to maximize crop yield at harvest.[46]

The applications of the IIoT are as varied as the industries and companies they support, and are already being implemented. How can regulators support the continued growth in use of the Internet to allow industries to remain competitive and to support, particularly in developing countries, adoption of new IoT applications? Regulators and policymakers should continue supporting communications infrastructure

[45] ITU-T, *Focus Group on Smart Sustainable Cities,* http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx
[46] The World Economic Forum 2015, *Industrial Internet of Things: Unleashing the Potential of Connected Products and Services*, January 2015, http://www3.weforum.org/docs/WEFUSA_IndustrialInternet_Report2015.pdf

development to allow for the robust and ubiquitous connectivity requirements of the IIoT. Telecommunications and ICT regulators should collaborate with industrial Ministries and regulatory authorities to ensure that existing regulations allow for the benefits of the IIoT to be realized across industries. They should also ensure that the specific ICT needs of certain sectors – like healthcare, transport or manufacturing – are addressed by ICT regulations, including measures regarding privacy and security as appropriate to enable the benefits of these technologies while protecting rights.

5.1.3 Intelligent Transportation Systems and Connected Cars

Intelligent transport systems (ITS) is a term that refers to transportation networks that fully integrates technology. ITS applications may encompass self-driving cars, connected vehicles, or smart sensors for traffic flow management. ITS can make road transportation safer, reduce environmental impact, and reduce congestion.

Both vehicle-to-vehicle and vehicle-to-infrastructure applications are being developed and deployed rapidly. BI intelligence estimates that by 2020, 75% of the cars shipped globally will have the capability to connect to the Internet, and that most of these will be through embedded connections, independent of other devices like a smartphone.[47] However, due to the lack of other supporting infrastructure and services, most vehicles globally with the capability will not be in use. In order to unlock these capabilities, then, the introduction of these new technologies needs to be well coordinated, including addressing regulatory challenges.

Work on ITS within the ITU-R was initiated in 1995, due to a significant increase in traffic on the roads, along with the growing need to integrate new technologies into land transport systems.

Spectrum, standards, and interoperability are especially important given the safety aspects of connected cars and ITS. WRC-15 agreed to two measures related to ITS. The first is the allocation of the spectrum Band 77.5-78 GHz to Radiolocation Services, in a co-primary basis, limited to short-range radar for ground-based applications, including automotive radars[48][49]. This allocation provides a globally harmonized regulatory framework for automotive radar to prevent collisions, which will improve vehicular safety and reduce traffic accidents. The second measure is the adoption of the WRC-19 agenda item 1.12 on harmonizing ITS spectrum[50][51]. This item considers possible global or regional harmonized frequency bands, to the maximum

[47] John Greenough, "THE CONNECTED CAR REPORT: Forecasts, competing technologies, and leading manufacturers," *Business Insider,* 7 January 2016, http://www.businessinsider.com/connected-car-forecasts-top-manufacturers-leading-car-makers-2015-3

[48] Recommendation ITU-R M.2057-0 (02/2014): *Systems characteristics of automotive radars operating in the frequency band 76 81 GHz for intelligent transport systems applications*. http://www.itu.int/rec/R-REC-M.2057/en

[49] Modifications to Radio Regulations, Article 5: Frequency Allocations; decided by the WRC-15, with the addition of a new footnote: **5.559B**: *The use of the frequency band 77.5-78 GHz by the radiolocation service shall be limited to short-range radar for ground-based applications, including automotive radars. The technical characteristics of these radars are provided in the most recent version of Recommendation ITU-R M.2057. The provisions of No. 4.10 do not apply* (Final Acts WRC-15, page 51 : http://www.itu.int/pub/R-ACT-WRC.12-2015/en)

[50] Resolution 237 (WRC-15): Intelligent Transport Systems applications (Final Acts WRC-15, page 294 : http://www.itu.int/pub/R-ACT-WRC.12-2015/en)

[51] Resolution 809 (WRC-15): Agenda for the 2019 World Radiocommunication Conference, item 1;12: to consider possible global or regional harmonized frequency bands, to the maximum extent possible, for the implementation of evolving Intelligent Transport Systems (ITS) under existing mobile-service allocations, in

extent possible, for the implementation of evolving ITS under existing mobile-service allocations. Since 1995, a number of Recommendations and Reports have been published to reflect the above. Most recently Report ITU-R M.2228 provides characteristics, requirements and status of advanced ITS radiocommunications in various countries.

The ITU's Standardization Sector (ITU-T), in strict collaboration with ITU-R, maintains a collaboration group that is striving to create a complete, coherent, and effective package of security frameworks and standards for use within ITS communications. They are also investigating regulatory and legislative actions necessary to facilitate the deployment of ITS communication products and services based on the ITS communication standards being developed.

Ministries or departments of transportation typically lead connected-cars and ITS initiatives. Because of new technological aspects, this also requires closer cooperation with telecom/ICT ministries and regulators, as well as auto manufacturers, ICT manufacturers, and telecommunications service providers. Consideration of regulatory and spectrum requirements must also be undertaken in coordination with these multiple stakeholders both in government and in the private sector.

5.2 Unmanned Aircraft Systems (UAS)

Unmanned aircraft systems[52] offer enormous social and economic benefits – with new commercial and non-commercial uses developed continually. Current and emerging applications for UAS include weather forecasting, 3-D mapping, precision agriculture, protection and conservation of wildlife, search and rescue, and border patrol. Companies such as Amazon.com are exploring options for using drones for delivery services. UAS can properly been seen as part of the broader ecosystem of the future Internet of Things, with drones providing another means for collecting data from remote regions, and supporting automation and efficiency within organizations. Regulatory frameworks around commercial uses of UAS are still developing, with civil aviation authorities in the lead. What pressures will the expected increase in use of UAS place on aeronautical, terrestrial, and satellite spectrum resources?

There is a wide variety in types of unmanned aircraft. There are smaller 'hobby' type aircraft; commercial line of sight operations; autonomous/unmanned systems; and remotely piloted beyond line of sight (BLOS) systems. UAS generally require spectrum for control of the device and for downlinking data collected from the device, such as video or other images. There are multiple considerations for UAS spectrum depending on the type of aircraft – whether line of sight or beyond line of sight. ITU has been studying these matters for several years, with WRC-12 agreeing on aeronautical mobile (Route) service (AM(R)S) allocations in the 5030-5091 MHz band for line of sight (LOS) and BLOS control as well as non-payload communications (CNPC). Most recently, WRC-15 agreed on the regulatory conditions and framework to pave the way for the use of commercial fixed satellite service (FSS) spectrum for UAS BLOS communications by 2023 and help ensure that the future demands for UAS BLOS spectrum can be met, while also ensuring the safety of flight[53].

---

accordance with Resolution 237 (WRC-15) (Final Acts WRC-15, page 426 : http://www.itu.int/pub/R-ACT-WRC.12-2015/en)

[52] Defined by ICAO as an aircraft and its associated elements, operated without a pilot on-board. ICAO Circular 328 (2011) provides an overview of UAS in support of integration into non-segregated airspaces. https://www.trafikstyrelsen.dk/~/media/Dokumenter/05%20Luftfart/Forum/UAS%20-%20droner/ICAO%20Circular%20328%20Unmanned%20Aircraft%20Systems%20UAS.ashx

[53] Resolution 155 (WRC-15): Regulatory provisions related to earth stations on board unmanned aircraft which operate with geostationary-satellite networks in the fixed-satellite service in certain frequency bands not subject to a Plan of Appendices 30, 30A and 30B for the control and non-payload communications of

Regulations and frameworks enabling UAS spectrum use for civil aviation purposes are addressed both by the ITU and ICAO internationally, as well as nationally by spectrum regulators and civil aviation authorities. There should be close collaboration among these bodies as ICAO develops international standards and national civil aviation frameworks implement them. Telecom regulations and spectrum management frameworks should also incorporate the most recent WRC decisions to allow for international development of these systems and applications.

5.3 Healthcare

ICTs have long been used to support healthcare. Telemedicine applications – for example broadband video connections – have been used to enable remote connections between patients and doctors where in person consultations are not possible.

Much like other applications, e-health and m-health applications are transforming healthcare. Wearable devices can connect patients to doctors who can monitor vital signs and address symptoms in real-time; m-health applications can be used to favorably influence patient behavior, for example by reminding them to take medications; SMS messages can support public health campaigns. Mobile applications and services can include, among other things, remote patient monitors, video conferencing, online consultations, personal healthcare devices, and wireless access to patient records.

Such applications can be particularly valuable in developing economies where access to medical services may be more limited.

The variety of applications also means a variety of spectrum resources are used to support them. Mobile networks drive many personal health applications – but systems can also rely on fixed or mobile satellite technologies for telemedicine video conferencing in remote areas. Wireless medical devices or wireless medical telemetry also rely upon both spectrum bands designated for ISM or licensed spectrum bands (by means of specific tools for monitoring devices). Regulators should collaborate with health ministries to ensure that ICT regulations are consistent with requirements of the health sector, and address potential overlapping or conflicting regulations pertaining to cross-cutting issues like security or privacy.

5.4 Geospatial Technology

Geospatial and location based services underpin much of the Internet of Things and the Smart Society. Applications like 'friend finder' and location marketing are important market drivers for defining and documenting the mobile Internet as well as the associated standards infrastructure enabling location-based services (LBS). More importantly, information sharing on a global basis about the natural and man-made environments is crucial to addressing humanity's most pressing problems.[54]

Geospatial technology refers to all of the technology used to acquire, manipulate, and store geographic information. These include remote sensing and earth observation satellites used to collect images from space in the Earth Exploration Satellite Service (EESS), Geographic Information Systems (GIS) or the software tools to map and analyse geographic data, GNSS (GPS) systems for determining precise locations, and other Internet mapping technologies such as Google Earth. UAS are also used to collect mapping data. Importantly, there are a number of scientific missions that collect data about the earth and the environment

---

unmanned aircraft systems in non-segregated airspaces (Final Acts WRC-15, page 238 : http://www.itu.int/pub/R-ACT-WRC.12-2015/en

[54] ITU and Open Geospatial Consortium (OGC) ITU-T Technology Watch Report "Location Matters: Spatial standards for the Internet of Things (IoT) http://www.itu.int/dms_pub/itut/oth/23/01/T23010000210001PDFE.pdf

and make it available for public use. Enhanced software tools help maximize value from this geospatial data. These technologies and tools offer great promise for understanding the environment and climate, predicting and responding to natural disasters, promoting good health through consumer wearables and disease outbreak mapping, or to support humanitarian aid activities.

As geospatial technologies advance, regulators should consider both the connectivity requirements, for example, to support higher bandwidth needs for higher resolution images, or the broader security and privacy considerations associated with increased collection of location data.

The ITU WRC-15 recently agreed to a new allocation in the frequency range 7 190 - 7 250 GHz to Earth-Exploration Satellite (in the path: Earth-to-space), in a co-primary basis; its use shall be limited to tracking, telemetry and command for the operation of ESS Spacecraft[55]; this allocation allows to uplink large amounts of data for operations plans and dynamic spacecraft software modifications. These functions will eventually lead to simplified on-board architecture and operational concepts of spacecraft for future earth-exploration satellite services (EESS). Furthermore, WRC-15 also agreed to new allocations in the frequency ranges 9 200 – 9 300 GHz and 9 900 – 10 000 GHz to Earth-Exploration Satellite (active, i.e., radars), in a co-primary basis[56], which lead to the development of modern broadband sensing technologies and space-borne radars on active sensing EESS. Scientific and geo-information applications will provide high quality measurements in all weather conditions with enhanced applications for disaster relief and humanitarian aid, land use, and large-area coastal surveillance.[57]

[55] Modifications to Radio Regulations, Article 5: Frequency Allocations; decided by the WRC-15; Final Acts WRC-15, page 5 : http://www.itu.int/pub/R-ACT-WRC.12-2015/en

[56] Idem 51

[57] ITU, "Press Release: World Radiocommunication Conference allocates spectrum for future innovation," 27 November 2015, http://www.itu.int/net/pressoffice/press_releases/2015/56.aspx#.Vx4Zc3pzvOk

6 Implications for Business Models

The technological advances discussed above are having a transformative impact on business models, not just of ICT and telecommunications companies but of companies across diverse sectors. In the near term, companies of all types will form more partnerships both within and across industries as they strive to assess future demand, make strategic investments in new services, and find their place in a developing ecosystem of interconnectivity. Many new classes of companies are also finding that they have a stake in ICT and telecommunications regulation and will increasingly assert themselves in these discussions.

6.1 Greater Competition to Connect Everything

We are moving into a richer ecosystem of connectivity, in which multiple delivery platforms with different technical characteristics and capabilities will compete with one another to provide services. Though it is certain that connectivity will become omnipresent, it is not clear at this point who will play the leading role in linking the devices of the IoT together. In connecting the developing Internet of Things, businesses and customers will have many options among which to select.

The providers and operators of many types of platforms are currently jockeying to fill this role.

Mobile networks, including IMT-2020 are expected by many to carry a significant amount of this traffic. These expectations encompass many different criteria, largely but not all of which may be satisfied by IMT-2020 standards. How a IMT-2020 network would function in a future IoT ecosystem is therefore difficult to anticipate. It will doubtless have a major role to play, especially in dense urban environments, but to what extent it will predominate is not yet clear.

Satellite networks, including new geostationary high throughput satellites and low earth orbit constellations may also have an important role to play. These systems have the capability to provide global coverage in a manner no terrestrial system can and may find an important role complementing these networks. However, they may be able to do so at lower capacity than terrestrial networks and – the case of the geostationary satellites – at relatively high latency.

Traditional fiber networks, especially backbone and backhaul systems, will retain a crucially important role. Fiber is also almost certain to remain cost-prohibitive in many regions, however. The prospect of hard-wiring a large number of newly connected devices would likewise prove overly difficult and costly.

License-exempt spectrum applications they self-promote as being able to connect the largest number of devices. TVWS ventures affirm that a large portion of connections –as high as 50 percent – may be uneconomical to connect using traditional mobile networks[58] and also consider that applications like TVWS radios (discussed below) or Wi-Fi mesh networks, can be deployed more cheaply and rapidly relative to licensed mobile broadband networks, and they will be indispensable in unlocking the value of these connections. While likely necessary at small scale, these applications may not be sufficient to satisfy high data demands over longer distances. Furthermore, there are still plenty of regulatory and commercial challenges they shall firstly solve if they like to guarantee its long-term sustainability.

All of these systems will find a role to play in the IoT ecosystem, however the relative importance of each is less clear. A richer ecosystem will mean greater competition to provide services, leading to greater innovation and consumer satisfaction. Greater use of license-exempt spectrum would foster a more

[58] Richard Thanki, "The Economic Significance of License-Exempt Spectrum to the Future of the Internet," *Microsoft Research,* 2012, http://research.microsoft.com/en-us/projects/spectrum/economic-significance-of-license-exempt-spectrum-report_thanki.pdf, p. 63.

competitive landscape for smaller players, who would not have to depend on mobile network operators (MNOs) as the gatekeepers to access customers., but long-term sustainability remains a big question for players appealing to this technical approach.

6.2 Established Telecommunications Operators Are Evolving

Traditional providers of telecommunications services face both significant challenges from greater competition, but also new opportunities as the IMT-2020 ecosystem takes shape and billions of new potential connections are available in the Internet of Things. These factors place significant pressure on established business models and will force major transformations by 2020.

Though the specific outlines of future IMT-2020 and IoT systems are not yet clear, some aspects of these systems are already apparent. They will be expected to deliver vastly greater amounts of data, connect many more devices in different ways, be more flexible in the end-to-end delivery of services, and be capable of delivering different kinds of services for different types of end-users. In meeting the technical challenges posed by these expectations, cloud infrastructure, softwarization, virtualization, and more complex network structures featuring differently sized cells all will assume key roles.

This has a number of consequences for the way operators run their businesses. Though these solutions can increase efficiencies and lower operational expenditures, they do so at the expense of higher initial capital expenditures. Capital costs are compounded by efforts that are still required to develop these technologies. Consequently, operators are already or will soon begin making large investments in these types of capabilities, and these strategic decisions will have a significant impact on their longer term performance. Regulators who want to support this process and incentivize investments in new networks need to be aware of this, and provide stable regulatory environments that give the private sector the confidence to make long term investments.

The billions of new connections that will create the IoT also offer both enormous opportunity as well as challenges to telecom operators. While the aggregate value of these connections will be enormous, the individual value of most of these connections will be quite low, making them difficult to monetize under traditional billing methods. These connected objects will increase the load on networks, but do so in different ways from traditional mobile broadband subscriptions, meaning that networks will need to adapt to different types of connectivity needs.

In the near term, many expect that competition from over-the-top services (OTT)– which may cut into traditional telecom services – will push operators towards adding value through greater

Whither MVNOs?

As the mobile telecommunications system evolves to become more service-oriented, mobile virtual network operators (MVNOs), whose model traditionally relies upon cost competition, may be under threat. As MNOs develop more data-rich services – either proprietary or in partnership with OTTs – and capital investments in new network infrastructure rise, MNOs may be less inclined to sublease their capacity. Alternatively, as MNOs develop more complex and managed core services, they may be more willing to allow smaller players to capture the basic, low-cost end of the market.

Not weighed down by legacy network infrastructure or the need for large new capital investments, mobile virtual network operators (MVNOs) may be well placed to react nimbly to market changes and develop new services. Enabled by recent advances in network architectures, some have begun to speculate regarding the development of network-as-a-Service (NaaS) or RAN-as-a-Service (RANaaS) systems which may transform the mobile network environment. In a RANaaS model, mobile network infrastructure and network access can be sold on a wholesale basis, while multiple consumer-facing services are delivered virtually through a number of different operators. If it becomes widespread, this could make the MVNO model more standard and widespread in mobile operator markets.

digital services and media offerings as well as a stronger customer experience management focus. Given the expected increase in consumption of digital streaming services, it is likely telecoms will seek to further capitalize on data-rich services enabled by the capacity. However, it is not yet clear whether the trend towards development of proprietary services will continue or whether operators will generate revenue through other methods.

The different network requirements posed by the IoT will also incentivize the development of increased B2B offerings and managed services in industry verticals. Some early estimates project that the potential value of managed services integrating back-end data analytics to be up to ten times the value of IoT data traffic alone.[59] MNOs will therefore begin to look to monetize the IoT through packages of services – at minimum for certain specialized users, if not for general subscribers, and move away from traditional data rates.

6.3 More Companies Are Now "Technology" Companies

At the same time as telecommunications providers are adapting their business models, applications of new technologies are spreading through many diverse industries. The prospect of constant connectivity, the growth in big data analytics and new computing capabilities, and the developing IoT will impact large swaths of the economy, generating new value but also new vulnerabilities and changing the nature of products and services.

As discussed above, recent advances open the door to broad new applications in sectors such as automotive, transportation, health, infrastructure, and manufacturing. While enabling new capabilities and unlocking new value, the increasing incorporation of telematics, software, and connectivity dramatically expands the scope of these companies and alters the profile of goods and services they offer. Vendors of physical goods will increasingly package their products with additional services such as cloud-based data analytics.

Durable goods and industrial equipment produced by many companies in these sectors represent significant investments and are generally expected to have a longer shelf life than the ICT products that accompany them, however. This creates an asynchrony between product life cycles, whereby the equipment may last for 20 years, but the integrated hardware and software may be obsoleted in a fraction of that time. Companies may seek to address this difficulty by making their products more reliant on upgradeable software-defined and cloud-based functionality. This may bring added versatility, but also makes such devices dependent on constant and reliable connectivity and could introduce additional security vulnerabilities.

[59] Machina Research, quoted in "Rise of the machines: Moving from hype to reality in the burgeoning market for machine-to-machine communication," *Economist Intelligence Unit*, 2012, http://www.sdn.sap.com/irj/scn/go/portal/prtroot/docs/library/uuid/f0788e6a-1ced-2f10-0eb0-ccda452468d3?overridelayout=true

Licensing, ownership, and "Fair Repair" in the United States

The increasing integration of connectivity and software-based analytics into products may also have implications for traditional ideas of ownership. Overlapping licensing and intellectual property regimes imposed on these new products may pose challenges to an owner's control of their property. While sale may transfer control of physical property, integrated technology may be licensed for use under restricted terms. A farmer, for example, can purchase a piece of agricultural equipment, however they are not permitted to duplicate, repair, or otherwise alter integrated software, as they may with physical components. In modern agricultural and industrial equipment, hardware and software are difficult to distinguish, and both are critical to equipment's functioning. Agreements with telecommunications and other electronic service providers – for example to support telematics – may further limit the owners' control.

Disputes are already beginning to arise regarding the integration of software into vehicles and agricultural equipment in a few countries. Legal action regarding the right of equipment owners to affect software modification – described by its defenders as "fair repair" – have been launched in the US, and legislative debates on the appropriateness of this right have begun in several US states.[60] This issue will only increase in importance as new classes of goods will be subject to the rights of actors besides the formal owner with power to dictate how goods are used.

6.4 More Have a Stake in ICT and Spectrum Management Discussions

With more devices connected and more data being collected, stored, and analyzed across multiple industries, new players are being confronted with policy and regulatory challenges more familiar in telecommunications and technology sectors.

An increasing number of companies will begin to find that their products and services are affected by rules governing the treatment of data traffic, including net neutrality regulations, mandated features to enable law enforcement access, and restrictions on international data transfers. Similarly, new types of products and services, as they collect, combine, and analyze more data, will need to comply with privacy and data protection standards. These aspects are increasingly relevant for new companies and expose them to different types of risks.

An array of new entities will also find that they have a stake in spectrum management discussions. As discussed above, spectrum management is already being impacted by the development of new delivery platforms. Many of these innovations are backed by technology giants such as Google and Facebook, previously concerned primarily with data and software. In order to secure regulatory approval to deploy these projects, they had to engage more deeply with spectrum management regulatory discussions.

This is also true for sectors which will deploy applications that are reliant on telecommunications services. The automotive and transportation industry, for example, is coming to understand the importance of active engagement in spectrum regulation to their future revenues as plans for autonomous vehicles, connected cars, and more advanced telematics become the norm. In the United States, for example, proposals to open frequencies long set aside for vehicle dedicated short range communications (DSRC) for other uses has forced the industry to formulate a response and engage more closely with spectrum policy processes.[61]

[60] "Copyright Law Restrictions on a Consumer's Right to Repair Cars and Tractors," *Congressional Research Service,* 18 September 2015, http://www.crs.gov/LegalSidebar/Details/1382

[61] Auto Alliance, "LETTER TO THE ADMINISTRATION FROM V2V INDUSTRY STAKEHOLDERS," 10 September 2015, http://www.autoalliance.org/index.cfm?objectid=ED665740-57C1-11E5-A252000C296BA163

Others who want to make greater use of drones, such as some retailers and logistics providers, as well as new small and amateur nanosatellite operators may soon discover the same.

Consequently, non-tech companies need to begin to grapple with these challenges and undertake proactive efforts to understand their future business interests and emerging risks in order to remain competitive. They are increasingly in need of relationships with ICT policymakers and of forward-looking engagement strategies.

6.5 New Partnerships Will Emerge to Explore New Opportunities

Use cases and future consumer demands in the IoT are unclear. Similarly, technological capabilities and standards are still evolving. Consequently, companies in various sectors are forming diverse partnerships both within and across industries in an effort to explore new perspectives, diversify their capabilities, coordinate standards, and build sector specific service offerings.

Difficult-to-anticipate market changes means that agile business models and a diverse set of capabilities in the near term will be key to adapting to future needs. To develop a greater portfolio of these capabilities and service offerings and move away from a purely capacity-based model, telecommunications providers have already begun to develop innovative partnerships. Recent examples of both inter-industry and intra-industry partnerships include: AT&T cooperating with IBM on a smart cities program, as well as with Telefónica to offer a building and home-control IoT product; Orange UK teaming up with Nespresso and Coca-Cola to launch an M2M system; India's Bharti Airtel partnering in a joint venture with the State Bank of India to develop a mobile banking app; Sweden's TeliaSonera investing in Zound Industries, a provider of electronics accessories; and Australia's Telstra investing in digital signature company DocuSign and video platform Ooyala.[62] These deals represent the leading edge of a new wave of partnerships and collaboration as companies try to find their roles in a new ecosystem.

Partnerships will also be increasingly important to build and promote uniform standards for wider uptake of new technologies. Currently, the lack of interoperable standards is one of the primary barriers to greater update of the IoT and other technologies such as cognitive radio. National and international bodies, as well as private sector companies are often competing to establish M2M and IoT standards, hoping that theirs will become most widely adopted. While action is required to advance the issue and may confer a first-mover advantage for some, the net effect is a profusion of different protocols and standards. Consolidation of these different approaches is necessary to enable wide deployment. Several private sector consortia have been formed recently with the purpose of doing this and efforts are ongoing in international standards organizations, including the ITU.

[62] Roman Friedrich, Steven Hall, and Bahjat El-Darwiche, "2015 Telecommunications Trends," *PWC,* 2015, http://www.strategyand.pwc.com/perspectives/2015-telecommunications-trends

7 Spectrum Management Considerations

The technologies discussed in this report have significant implications for spectrum management, whether directly – in the case of new technologies that require spectrum resources – or indirectly – in the case of new complementary technologies which may impact the capabilities and usage patterns of spectrum technologies. In order to begin planning future spectrum policies, regulators need to understand what tools are at their disposal to respond to changing demand. It is also important for regulators to examine whether any changes are needed not just to spectrum allocations but to their established frameworks and practices for managing these allocations. In order to adapt to change, greater flexibility of regulatory approaches and spectrum sharing solutions may be required. These considerations and other relevant challenges faced by national spectrum regulation authorities, are deeply analyzed in the recent update of ITU Handbook on National Spectrum Management (Edition 2015).[63]

7.1 Evolving Trends

There is rising demand for spectrum resources due to the rapidly expanding application of wireless access technologies, and the spiraling increase in remotely-delivered services. Many activities – commercial and domestic – that were provided by fixed connections ten years ago are now routinely delivered wirelessly. The importance of managing spectrum efficiently is paramount in order to adapt to this rising demand.

At least three major trends are driving this increasing spectrum demand:

- **The Internet** – Twenty years ago, the Internet was a novel application of computer networking, only recently liberated from its academic roots. Ten years ago, it began changing our domestic routines as we adapted to online shopping and social networking; today it continues to reach into every aspect of our lives with the Internet of Things (IoT). What was once termed a "revolution" has become an accepted tool of communications for government, business, and domestic life, swelling in size as more and more demands are placed upon it. The ultimate strength of the Internet is the fact that it is, at heart, a simple data network that reliably conveys simple text messages on the same channel as complex entertainment – the bounds of its adaptability have not yet been reached. Because of this, it has become a significant element of the infrastructure of almost every society. Although the backbone runs predominantly across fiber-optic fixed networks, universal access to it demands increasing use of wireless technologies.
- **Mobility** – Since the spread of the mobile phone during the 1990s, businesses and consumers have increasingly expected the information and services available to them in their homes or at their desks to be accessible wherever they are. The advent of 3G networks brought an Internet access portal to our hands, and our expectations for that portal have grown with the Internet itself. Businesses are increasingly adapting to the mobility of their customers, offering dedicated services tailored for consumption on mobile devices. Even commercial shipping fleets and long-haul aircraft, as they travel to the most remote corners of the world, today routinely offer phone and internet connectivity to their crews and passengers via satellite connection.
- **Bandwidth creep** – The first wired computer networks typically operated a bandwidth of 1 Mbps; today's wired networks typically run more than a thousand times faster. The first GSM networks offered a modest 9.6 kbps data option, compared to the heady 15 Mbps promised by today's 4G networks. Each iteration of our communications infrastructure

[63] ITU Handbook on National Spectrum Management, Edition 2015; http://www.itu.int/pub/R-HDB-21-2015

increases the available bandwidth, but the services – and our expectations – grow at a faster rate. While most consumers were content with dial-up Internet speeds when they were browsing simple websites and sending text-only messages, they quickly demanded wireless broadband as they became familiar with multimedia messaging and video conferencing. Businesses are using video conferencing tools where a few years ago they might have simply held audio conferences. High Definition TV is quickly displacing earlier lower-resolution media.

Behind these three trends is a further inexorable force – growth in the connected population. At the end of 2015, more than 43 percent of the world's population were connected to the Internet and the number of mobile-cellular telephone subscriptions was over 7 billion or the equivalent of 97 percent of world's population. Twenty years ago, both of these figures were less than 1 percent[64].

7.2 Current Spectrum Management Techniques

Historically, spectrum management has been conducted on a "command and control" basis: National regulators carve-up the available radio spectrum, and license slices of it to network operators to use on highly-specific terms. Spectrum regulators have found themselves in an increasingly difficult dilemma, as more and more users demand access to spectrum, with less and less clarity on the relative merits of each proposed usage. In some cases, regulators have resorted to auctioning slices of spectrum to the highest bidder (for example, to mobile phone operators) but even this has its drawbacks – some operators have found themselves burdened with the debt from the auction, and have been unable to fully commercialize the promised network. However, this has not stopped the auction approach from being widely adopted for the most desirable spectrum. Report ITU-R SM.2012 provides detailed information on the economic aspects of spectrum management.

A notable exception to licensed use of spectrum has been the rise of so-called "unlicensed" or "licence-exempt" frequency bands "Unlicensed" does not imply the absence of a licence but actually means a general licence issued to radiocommunication devices. Most of the "unlicensed" frequency bands are used for low power or short-range radiocommunication devices (SRD)[65]. They have no requirement for an individual licence since they normally use the radio spectrum on a non-interference and non-protection basis. Recently, a large number of these frequency bands have been harmonized globally or regionally in ITU administrations for common usage, and boast some of the highest and most efficient occupancy rates of any band. The most well-known is the 2400 MHz Wi-Fi band, which is accessible by virtually every broadband router, smartphone, and laptop computer in the world. Less than 90 MHz wide, it is shared every day by billions of people around the world. Three factors make this band a successful candidate for sharing: the lower power and relatively short physical propagation characteristics mean that signals in this band typically do not propagate more than a few tens of meters, limiting the potential numbers of users interfering with each other, universally harmonized frequency allocations achieved by administrations and technical standards were established and adopted by equipment manufacturers, ensuring homogenous usage.

In an effort to manage the globalization of spectrum usage more efficiently, regulators have attempted to harmonize their allocations and standards as much as possible. This can be done at the regional level with for instance the approval by European countries of relevant ECC Decisions. At the international level, this is

[64] www.itu.int/itu-d/ict

[65] Recommendation ITU-R SM.1896 "Frequency ranges for global or regional harmonization of short-range devices"; and Report ITU-R SM.2153-4 "Technical and operating parameters and spectrum use for short-range radiocommunication devices".

done by the ITU WRCs with the approval of globally or regionally allocated bands to radio services (see for instance the worldwide allocations to the mobile service that are identified for IMT or automotive radars), as well as by the ITU-R study groups with the approval of ITU-R Recommendations for instance on the frequency arrangements for the implementation of the terrestrial component of IMT in bands identified for IMT in the RR.

7.3 Spectrum Management Tools

Developing an effective response to emerging technologies requires understanding not just their technical requirements, but also their likely use cases and social value. All spectrum management choices involve trade-offs. Determining which trade-offs will result in the most productive use of spectrum requires careful comparison of capabilities and potential value.

7.3.1 Flexibility

Regulators are faced with the need to critically evaluate not just what changes to spectrum allocations may be needed, but also whether their own procedures are sufficiently flexible to adapt to future needs. Historical spectrum management approaches may be too static and therefore insufficient to meet these changing needs. In addition to sometimes contributing to underutilization of spectrum resources, historical approaches of exclusive licensing can also create barriers to implementing more responsive spectrum management practices that can accommodate changing needs.

There is no single spectrum management approach or technique that will be appropriate for all countries in all contexts. However, flexible frameworks that adapt to changing needs are indispensable. Policy-makers must continually question whether historical uses of certain frequencies remain most productive, and assess whether those uses can coexist with new services and technologies. It should be recognized however that these historical approaches may still be useful to accommodate specific needs (such as for some scientific services for instances). It should be noted that ITU-R Study Group 1 carries out regular studies in that respect.

Regulatory Challenge: striking the right balance between licensed and unlicensed approaches

The current spectrum management approach consists in establishing the right balance between licensed and unlicensed spectrum.

The current evolution of spectrum requirements calls for more sharing.

This may be done through unlicensed devices sharing with licensed users, such a RLANs sharing with meteorological radars in the 5 GHz band (since WRC-03 decision) or TVWS. It may also be done through licensed shared access (LSA).

The exclusive licensing approach through which national administrations authorize the use of frequency blocks for specific operators provides benefits in the form of security of tenure for long term investments, clarity and predictability and ease of administration at the national level.

The unlicensed approach through which globally harmonized bands are authorized by national administrations for any device compliant with essential requirements also offers benefits in the form of clarity and ease of administrations, mainly for large amounts of small investments (e.g. WiFi).

Sharing spectrum between licensed and unlicensed devices represents a challenge in that it requires a strong control of the market of unlicensed devices to ensure their compliance with the essential requirement intended to protect the licensed users. Most regulators may not have the resources to carry out this level of control.

7.3.2 Harmonization

Harmonizing frequency allocations – both on a regional and global level – can be an important prerequisite for the deployment of many different technologies. ITU-R "*IMT Vision* - Recommendation ITU-R M.2083, the Recommendation R-0 (09/2015) "*Framework and overall objective for future development of IMT 2020*" recognizes that "The benefits of spectrum harmonization include: facilitating economies of scale, enabling global roaming, reducing equipment design complexity, preserving battery life, improving spectrum efficiency and potentially reducing cross border interference."[66]

Given the complex set of frequencies likely to be required for future mobile networks such as IMT-2020, technical approaches may have to assume that specific spectrum resources are not available in all countries. Emerging technologies that may be implemented based on a license-exempt regime, may also benefit from harmonization – of either available frequencies or device standards (see for instance the on-going ITU-R studies in response to Resolution ITU-R 54). Establishing device parameters that match prevailing global standards facilitate access to international markets and can help a new technology achieve greater scale, therefore reducing costs to end users. The global success of Wi-Fi is a testament to this approach.

Regulators may need to carefully examine domestic frequency allocations, and evaluate when divergence from regional or global practices is necessary to enable particular services, and when it may function as a barrier to accessing new technologies.

7.3.3 Alternatives to Device Licensing

The integration of radio equipment into new products promises to bring millions of new devices potentially within the scope of telecommunications regulations. This coming explosion in devices presents a challenge to licensing frameworks. It is impossible to license all of these devices individually and undesirable to try to do so due to the administrative burden it would place on regulators and the barriers it would present to deploying new technologies.

Rules-based and license-exempt treatment of some frequencies may be an alternative means of accommodating demand, especially for the large number of IoT connections under certain conditions, e.g. on a non-interference and non-protection basis. Such a system manages interference – either to licensed operators in those frequencies or to fellow license-exempt devices - by setting appropriate and pre-established operational parameters to be used by the license-exempt devices, which are not protected against interference from the licensed operators. This approach frees both regulators and end-users of wireless services from the burdens of individual licensing and can enable large deployments quickly. Regulators, however, still need to rule its operation through a general license (blanket license-exempt devices) fixing conditions of its use.

[66] Idem 5

7.3.4 Spectrum Sharing

As policy-makers explore ways to make use of spectrum more efficiently, spectrum sharing offers important solutions to increase the intensity of spectrum utilization. Though spectrum is finite, spectrum usage need not be zero-sum, or defined solely by exclusive blocks of frequencies.

Granting regulatory approval can be more effectively conceptualized as granting a right to use radio technologies in certain ways, defined by frequencies as well as by factors such as time period, power output, and geographic location. Depending on the needs of particular technologies, multiple uses of the same frequencies can, under the right technical and regulatory frameworks, be able to coexist effectively.

There are several potential approaches to spectrum sharing that may rely on different technical mechanisms. As such, they may be suitable for different purposes. One such technique, dynamic spectrum access (DSA), relies on cognitive radio technologies discussed above to dynamically identify and operate on unused frequencies. It can take a number of licensing forms – which range from fully licensed to license-exempt – and be deployed for many end-uses.

Some argue that dynamic spectrum access may also be an option to make more spectrum available without the long and difficult process of clearing and reallocating. Currently two major dynamic spectrum access systems are being developed or actively used internationally, usual license-exempt approach, for example for the TVWS in UHF band, and tiered access spectrum sharing mechanisms (SAS or LSA).

7.3.4.1 Television white space (TVWS)

Television white space (TVWS) technology is a practice to enable license-exempt sharing of unused television broadcast frequencies (VHF and UHF) in a certain area and at a certain period of time.). First tested and then ruled in the United States, regulators in the United Kingdom, Singapore, and Canada have implemented regulations to enable this technology. Several other jurisdictions including South Africa, Malawi, Ghana, the Philippines, Jamaica, and Colombia are currently exploring similar rules.

> ***ITU spectrum sharing principles***
>
> ITU-R provides general guidance on spectrum sharing principles. "General principles and methods for sharing between radiocommunication services or between radio stations" Recommendation ITU-R SM.1132-2 (07/01))[67] describes different sharing principles including frequency, spatial, time, and signal separation techniques, and lists technical modes by which they are implemented. Revised in 2001, this recommendation is currently undergoing further revision by Working Party 1A of ITU-R in order to reflect recent changes in spectrum sharing techniques. ITU-R Working Party 1B is also studying innovative regulatory tools such as LSA to support enhanced shared use of the spectrum and the infrastructure of telecommunications network.

TVWS has received particular attention because analogue TV frequencies often have significant gaps in usage, both geographically and temporally. TV frequencies in UHF band also have particularly favorable propagation characteristics which allow them to travel long distances and penetrate walls, foliage, and other obstacles effectively. These characteristics make the frequencies especially attractive for applications such as broadband deployment in rural areas, but also increase the risk of interferences. Given the unified global allocations for VHF and UHF to the broadcasting service and the ongoing transition from analogue to digital, TVWS is promoted by its ventures to be used as a technology enabling for spectrum sharing to help bridging the digital divide in the short term. However, as mentioned before, TVWS projects are still in test phases,

[67] ITU-R, *General principles and methods for sharing between radiocommunication services or between radio stations (SM.1132)*, July 2001, https://www.itu.int/rec/R-REC-SM.1132/en

and their long-term sustainability has not yet proven, as key technical, regulatory and financial challenges remain unsolved.

However, according to the CEPT ECC Report[68], the White Space concept is by nature opportunistic, which implies that no guarantee can be given regarding to the availability of spectrum for use by white space devices. White space devices should be operated on a non-interference and non–protection basis and need to take into account possible future deployment of primary services in the same band and area in accordance with national spectrum policy.

7.3.4.2 Tiered Access spectrum sharing mechanisms (SAS or LSA)

Tiered access spectrum sharing mechanisms seek to enable more intensive use of spectrum by creating a system of secondary licensing. In these systems, the incumbent spectrum rights holder is generally allowed to continue its unfettered access to its licensed frequencies. Secondary licensees are allowed to access the same frequencies when and where they are not in use by the incumbent. While these secondary users can neither claim protection from nor cause interference to primary stations (current or future) they can claim protection from interference caused by other future users of the frequency band. This approach can be compared to the definitions of primary and secondary radio services having same frequency band allocated in the RR.

One example of tiered access is the Spectrum Access System (SAS) in the United States, which uses a geolocation database approach to allow three different tiers of users, each with different requirements and progressively lower levels of protection. These are the incumbent, the secondary Priority Access Licenses, and the license-exempt General Authorized Access users. The system is initially being developed to allow sharing of the 3.5 GHz band, however it may later be extended to other frequencies.

The Licensed Shared Access (LSA) system in the European Union represents another framework (see ECC Report 205). Current draft ITU-R definition for LSA is as follows: "*A regulatory approach aiming to facilitate the introduction of radiocommunication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the Licensed Shared Access (LSA) approach, the additional users are authorized to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorized users, including incumbents, to provide a certain Quality of Service (QoS)*". This two-tiered system has been designed first to allow mobile broadband use in countries that wish to maintain their incumbent use in a long term in the 2.3-2.4 GHz band.

[68] Guidance for national implementation of a regulatory framework for TV WSD using geo-location databases, May 2015, http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP236.PDF

8 Considerations and Recommendations for Regulators

The regulatory treatment of new technologies requires careful consideration including whether existing regulation may already cover new technologies or applications. The cross-cutting nature of ICTs demands that regulators collaborate with other competent authorities to understand new technological deployments and how regulations will affect their use. While such increased collaboration may challenge established practice, it will also empower policy-makers with new tools to attain their goals.

8.1 Using New Technologies to Support Existing Policy Goals

The Sustainable Development Goals demonstrate that nearly all countries share the goal of extending the benefits of connectivity and information technology at an affordable cost to citizens. Governments often pursue this goal through national broadband plans, specific targets for expanding access, and comprehensive infrastructure investment plans. ICT connectivity can, in turn, also help support a wide array of policy goals in diverse areas such as healthcare, education, agriculture, financial services, or disaster response.

- **Recommendation 1:** *Policy-makers need to keep abreast of different types of technologies for delivering broadband, their costs, benefits, and technical capabilities to understand what services they may enable for citizens and how regulatory frameworks will enable, inhibit or put at risk current access to emerging technologies or continued innovation.*
- **Recommendation 2:** *National broadband plans and policies should strive for technological neutrality, to allow the deployment and future evolution of different types of services and the development of innovative business models.*
- **Recommendation 3:** *Policy-makers should consider how to take account of policy objectives in other sectors and how ICTs may support those objectives when developing frameworks for the introduction of emerging technologies.*
- **Recommendation 4:** *Policy makers should take account of best practices to promote access through new technologies, including through ITU regulations, studies and resources.*

8.2 Developing Effective Regulatory Approaches

Many emerging applications pose challenges to the traditional exercise of regulatory authority. As telecommunications regulators update outdated rules or identify whether new ones are appropriate for new applications and technologies, other regulatory bodies may also be working on frameworks to address introduction of ICTs into their sectors. Such fragmentation or overlap may pose a challenge to wide deployment and adoption of new technologies. Improved coordination across various competent authorities may help facilitate innovation and investment.

- **Recommendation 1:** *Government departments, ministries, and regulatory authorities should identify appropriate methods for collaboration and coordination on common cross-sector issues to support more effective policy and regulatory frameworks (for example, through the creation of high-level inter-ministerial working groups), taking into account the diverse stakeholders in the deployment and use of ICTs.*
- **Recommendation 2:** *Policy-makers should seek to avoid duplication of regulation to alleviate challenges from complying with differing or competing regulatory requirements*.

For further discussion of these issues, please see the GSR 2016 paper on collaborative regulation.

8.3 Creating the Environment for Investment and Innovation

The economic benefits of Internet and broadband penetration are well documented, and support economic growth, productivity gains, and development.[69] Deployment of broadband and advanced network technologies often requires high capital investments. In order to stimulate investment, countries should create an *enabling environment*. This means that regulators and policy-makers need to provide stability, predictability, and transparency regarding any regulatory requirements. Further, test beds and direct support for research and development can stimulate innovation and investment in new technologies. Such projects also allow for adaptation of new technologies to local requirements.

- **Recommendation 1:** *Support the work of ITU as well as of other globally recognized standard development organizations on international regulations, harmonization of spectrum use and standards.*
- **Recommendation 2:** *Promote and support pilot projects and test beds for new technologies, and consider incentives to promote adoption of ICTs.*
- **Recommendation 3:** *Policy-makers should create a positive and stable enabling regulatory environment – across all domains – in order to attract investment in new technologies and allow for innovation while not jeopardizing the operation and future evolution of other networks.*

8.4 Managing Spectrum Resources

Many emerging technologies rely upon spectrum. Predictions of large-scale deployments and enhanced bandwidth requirements are expected to put pressure on limited spectrum resources. Regulators will need to examine spectrum management frameworks to evaluate whether and how they may accommodate new wireless technologies without endanger current and planned radio services and stations. Increasing flexibility in spectrum management, via both licensed and unlicensed approaches, will allow for innovation and evolution of technologies and services, while balancing the needs of incumbent users.

- **Recommendation 1:** *Spectrum regulators should ensure that spectrum management practices keep pace with technology developments and that sufficient spectrum resources are available to support those that serve the public interest.*
- **Recommendation 2:** *Spectrum management should be increasingly flexible in order to accommodate (and reap the benefits of) new technologies, secure investment, stimulate innovation, and enhance spectrum efficiency, while balancing the needs of current and planned users.*
- **Recommendation 3:** *Regulators should take steps to understand current spectrum usage patterns, including through spectrum inventories, setting up spectrum observatories to measure real-time frequencies usage, and addressing any attempts at commercial or government spectrum warehousing*.
- **Recommendation 4:** *Spectrum models and rules to facilitate access as well as to minimize unused frequencies could be implemented as an important aspect of meeting demand for this finite resource*

[69] Qiang, CZW, World Bank. "IC4D: Extending Reach and Increasing Impact," Economic Impacts of Broadband, 2009. Chapter 3 and ITU, "The impact of broadband on the economy", 2012, https://www.itu.int/pub/D-PREF-BB/en

For additional discussion of spectrum management issues, see the previous GSR 2014 discussion paper on spectrum licensing.[70]

8.5 Building trust and confidence

New wireless technologies and applications will enable many new connections, as well as an explosion of new means for collecting ever-increasing amounts of sometimes sensitive data. Additionally, the increased number of interconnections between devices – both wireless and wired – as well as more complex networks increase potential points of failure. Trust and confidence in new and emerging technologies is fundamental, and must be designed into the systems from the outset. Two key components to ensure trust and confidence are privacy and security.

- **Recommendation 1:** *National strategies to protect privacy must take into account a range of risks from a variety of different sources, and adapt to existing regulations.*
- ***Recommendation 2:*** *Regulators should stay abreast of the challenges posed by cyber threats, including the types of devices and information at risk, and their ever-changing nature.*
- **Recommendation 3:** *Addressing cybersecurity challenges requires multi-pronged approaches including: (a) strong public-private cooperation, (b) embracing international collaboration and best practices, (c) stronger domestic laws, governance systems and capacity, and (d) education efforts.*

For further discussion of these issues, please see the GSR 2016 paper on privacy and data protection.

8.6 Developing Standards

Standards are critical for broad deployment and adoption of new technologies. They assist regulators and policymakers in establishing frameworks for the marketplace that allow for interoperability and that sustain competition. They provide manufacturers an opportunity to achieve economies of scale in production that can translate into lower costs for end-users. Facilitating industry-led development of standards can be an effective approach to ensuring that standards become acceptable to major stakeholders and are best-suited to emerging technologies. The ITU has a rich history in the development of standards that are contribution-driven and consensus-based. The ITU notes with pride that in a world with over 300 bodies working on some aspect of ICT standards, they are able to provide focus, clarity and leadership.[71]

- **Recommendation 1:** *Regulators should avoid unique national standards for emerging technologies and should strive to promote internationally compatible standards for technology.*
- **Recommendation 2:** *Policy-makers should encourage and support industry cooperation to develop standards in addition to and in coordination with established international standards-making bodies.*

---

[70] John Alden and Catherine Schroeder (Freedom Technologies, Inc.) ,"GSR Discussion paper: New frontiers in Spectrum Licensing," *ITU-D*, 2014, http://www.itu.int/en/ITU-D/Conferences/GSR/Documents/GSR2014/Discussion%20papers%20and%20presentations%20-%20GSR14/Session4_GSR14-DiscussionPaper-SpectrumLicensing.pdf

[71] ITU-T, *FAQ: Why do we need international standards in telecommunications?*, http://www.itu.int/net/ITU-T/info/answers.aspx?Fp=faqs.aspx&Qn=2&ewm=False

9 Conclusions

This report has outlined some of the key changes in technology that will be affecting telecommunications and spectrum regulators in the coming years. Platforms for delivery of broadband and communications services are changing rapidly as familiar technologies improve their capacity, coverage, and technical capabilities, while entirely new systems such as IMT-2020/5G and high altitude platform stations are developed. As they compete to provide converging services, these platforms will together contribute to an ecosystem of constant connectivity.

Underpinning and enabling these technologies are significant advances in network architectures and software, including cloud computing, software defined networking, and network function virtualization. These new techniques are transforming the way that operators, particularly mobile network operators, develop and deploy their services. MNOs are discovering that technologies such as Cloud-RAN, network slicing, and heterogeneous network structures allow them to provide a higher quality of service, operate more efficiently, as well as develop and deploy services more quickly. These technologies will not only be integrated into future IMT-2020/5G networks, whose outlines will not be clear for several years, but are being deployed now to augment the capabilities of existing 3G and 4G networks which will be under strain.

As new services are developed and connectivity becomes ubiquitous, other industries are integrating new technologies. The integration of communications and data analytics capabilities into new goods creates new value for consumers and businesses, but it also exposes these businesses to new risks – including security failures – and increases their sensitivity to changes in ICT and spectrum regulation. Regulatory treatment of these goods and services frequently cuts across jurisdictional boundaries, meaning that regulatory coordination is key to creating effective frameworks. Regulators also need to be aware of and include the wide array of stakeholders that are increasingly relevant in technology and spectrum management discussions.

Changing technologies pose challenges. The increasingly interconnected and quantified world that these technologies unlock raises questions regarding how trust to ensure trust in their operation and what policies are most appropriate to speed their deployment. Resolving some of these questions is key to accessing the benefits of these technologies. This means that regulators must be develop approaches that balance legitimate concerns and policy goals with the need to operate in a global context. These advances also place strain on both existing spectrum allocations and the ability of regulatory frameworks to adapt to rapid changes. In the near term, regulators need to undertake steps to understand how current spectrum management frameworks are suited to meet these rising challenges.