



Policy Paper

FROM 5G TO 6G GOVERNANCE

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Executive Abstract:

As telco technologies evolve from 5G to 6G communications, the governance challenges – along with benefits and costs – will change yet again. The ecosystem will become even more complex adding new stakeholders, new applications for consumers and in new industry verticals. Some 5G technologies will mature and yet new 6G technologies will emerge and be adopted, including Terahertz communications, visible light communications, split compute architectures, convergence with satellite networks, integration of communications and sensing, wide adoption of AI, brain-network interfaces, etc.

This position paper focuses on looking into the future to identify and analyse the key issues that will arise, including but not limited to: What challenges will the emergence of 6G and other new technologies create for governance? What challenges will arise due to the transition from 5G to 6G? What is the potential for new use cases in different vertical sectors and the involvement of new stakeholders? What governance models might need to be extended or created to deal with these new challenges? What might be appropriate roles of governments, industry organisations, the market and other interested parties? How would the need for national and global coordination change in the face of the new technologies and use cases?

Our main findings are as follows: The transition from 5G to 6G will follow the same trend as previous transitions in telecoms allowing us to predict the performance capabilities with high fidelity. The extremely high 6G performance is being enabled by more spectrum and a range of disruptive technologies which will mature by the time 6G will be deployed in 2028-2030. Powered by those developed gigabit connections, 6G will enable three classes of usecases, notably consolidating the “more-of-5G” applications but also underpinning exciting emerging applications as well as yet-to-emerge applications.

As a result of all these developments, the overall ecosystem will experience substantial changes which require careful governance. To this end, we make five recommendations related to technology, regulation, skills and human-centredness which we hope will not only serve the 6G ecosystem but can also become a blueprint for addressing other technological and societal challenges at national and international stage.

1. Introduction

Telecoms has become an integral part of our digital fabric, at par with the wider Internet. It powers a wide range of applications, from finance to communications to health [1,2]. And it has important societal impact with connectivity shown to be strongly correlated to the national GDP [3], and even wellbeing. And whilst consumers and industries enjoy the “front-facing” capabilities of wireless communications technologies, an enormous amount of work has been happening “behind the scenes” over past decades.

With focus on governance, this position paper examines the mechanisms which needs to be put in place over the coming years to enable further growth and consolidation of future telecommunications technologies despite natural market commoditisation and recent international geo-political fragmentation.

The mobile industry has indeed enjoyed tremendous growth over past decades, a growth which is attributed to open innovation, market competition and appropriate regulation. As a result, the industry has evolved from a niche technology, embodied by an analogue first generation (1G) voice system, to a fully fledged Internet on the move, embodied by an end-to-end digital 5G system. With so many generations of mobile now deployed globally, the technology is starting to become commodity and is naturally experiencing market pressure underpinned by shrinking margins and higher competition.

It is hence useful and timely to pose the question on the future of mobile, a future which goes beyond 5G and the associated standards releases. Notably, we would like to understand which technology, regulation and governance disruptions are required to enable mobile not only to survive but to thrive in an increasingly competitive technology and business landscape.

We will base our argumentation on some irrefutable trends which have been materialising over the past years in telecoms. These trends allow us to identify the technical capabilities of the next generation, i.e. 6G. Open issues, however, remain on how these capabilities are met and what applications they will power. These aspects along with the required governance requirements will be examined in this position paper.

To this end, the structure of the paper is as follows. We first examine above-mentioned trends and patterns in telecoms (Section 2). That allows us to identify the capabilities of 6G (Section 3) and the thus realisable applications (Section 4). We then examine the underlying technologies (Section 5), a section which can be skipped by readers not interested in deep technological developments. We then dwell on governance (Section 6) needed to materialise those capabilities and recommendations for specific next steps (Section 7).

2. Trends & Patterns in Telecoms

The key performance indicators (KPIs) of cellular have evolved in a rather consistent way from generation to generation. There are two trends which stand out, i.e. i) the *growth trend* and ii) the *consolidation trend*. Both are illustrated in Fig 1.

Concerning the growth trend, we observe that each generation has improved important KPIs, such as data rate, in very consistent ways. For instance, the downlink data rates evolved in steps of 10-100x from 2G to 5G respectively from 100kbps to 10Gbps; the number of devices from hundreds of devices to thousands of devices per km²; and the latency has been reduced from almost 300ms to 1ms. 6G and the evolutions thereafter are likely to follow the same trend, with predictions on some KPIs given in the subsequent section.

Concerning the consolidation trend, we observe that the vision of untethered phone calls was introduced with 1G but not perfected until 2G; the vision of an untethered Internet was introduced in 3G but did not mature until 4G; and the vision of an all-encompassing network for both consumers and industry was introduced with 5G but may not consolidate until 6G. Looking into the future, 7G may introduce the notion of a fully self-synthesising network which will only mature in 8G; and as a result, any subsequent generations will become redundant. Our prediction is thus that 8G will be our truly last G.

Returning to the present, 5G has commenced an important transformation in telecoms in that the networking and compute infrastructure is now entirely software controlled; this will be further consolidated in 6G. Furthermore, we see an increased trend of open architectures and commoditisation of hardware (Open RAN), of federation (introduction of edge clouds), atomisation (introduction of microservices) and automation (increased use of artificial intelligence). As a result, innovation can happen at much quicker innovation cycles where new features and capabilities can be introduced in a few years/months, rather than a decade. This has a profound impact on industries, start-ups, standards and regulators – the role of which needs to be re-examined in 6G.

Furthermore, it will enable another important shift, the shift from a device-centric architecture to a more human-centric architecture. Indeed, the telco ecosystem has evolved from an initially cell-centric architecture with designs driven by cell coverage and thus basestation placements. Today's device-centric architecture is driven by capacity which is directly linked to the amount of high-quality links the mobile terminal sees at any given time. Both designs are very static and do not allow us to address use cases like we have seen now during the times of Covid, where entire regions experienced massive shifts in digital usage patterns within weeks. An even more flexible architecture, which we expect to see in 6G, will hopefully enable a human-centric design with human needs put at the centre of the network's capabilities.

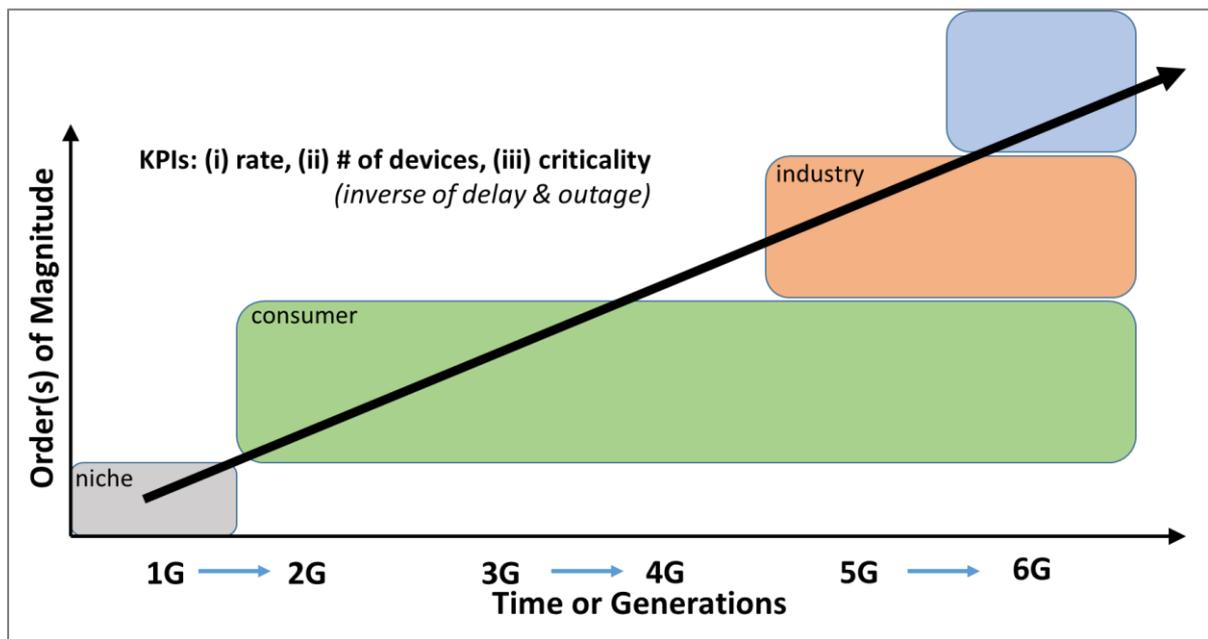


Fig 1: Evolution of telco generations with two important trends in growth and consolidation, with the blue box indicating a prior unseen application space.

3. 6G Capabilities (“What”)

The International Telecommunication Union (ITU) will shortly commence shaping the requirements as part of their generation-led IMT (International Mobile Telecommunication) developments. The naming is yet undecided but could be “IMT-2030” [4]. While the recommendations still have to emerge, we can extrapolate some KPIs from the different use cases and applications.

In particular, for 6G the average experienced downlink (DL) data rates will be 100Gbps, the number of devices per km² will be 10⁹, and the latency of 100us for extremely low latency use cases, etc. These KPIs need to be examined from an energy consumption point of view allowing the community to address global net zero targets [5].

Underpinned by Fig 2, let us examine the most important KPIs. With respect to the users' *average* experienced data rate, 4G has seen 10Mbps, 5G 100Mbps and 6G is thus expected to yield around 1Gbps. That is a very high data rate, for which viable applications have to be invented yet and we will discuss these in a subsequent section.

With respect to user plane latency, 4G could achieve 10ms, 5G 1ms and 6G will thus be able to yield latencies of 100us. Again, the use cases requiring such low latencies exceed human capabilities and thus still need to be designed; however, it certainly would allow for a much stronger and stable interaction between machines, control loops and precision processes.

Parameter	IMT-Advanced (4G)	IMT-2020 (5G)	Networks2030 (6G)
Peak data rate	DL: 1Gbps UL: 0.5Gbps	DL: 20Gbps UL: 10Gbps	
User experienced data rate	10Mbps	100Mbps	1Gbps
Peak spectral efficiency	DL: 15bps/Hz UL: 6.75bps/Hz	DL: 30bps/Hz UL: 15bps/Hz	
Mobility	350km/h	500km/h	
User Plane latency	10ms	1ms	0.1ms
Connection density	1 000 devices/km ²	1 000 000 devices/km ²	
Energy consumption	1 (normalised)	1/10x of 4G	<i>Machine Age, as humans cannot absorb that data</i>
Mobile data volume	0.01Tb/s/km ²	10Tb/s/km ²	10Pb/s/km ²

Source: 5G-PPP

Fig 2: Technical evolution of parameters from 4G to 5G and (likely) 6G.

Last but not least, the data density is worth discussing. 4G enjoyed a density of 0.01Tb/s/km² which was upped in 5G to 10Tb/s/km². 6G is thus expected to yield around 10Pb/s/km². That is a data density which humans have no means to generate and/or absorb. This is yet another strong indication that 6G may herald the dawn of a new user which we discuss below.

4. 6G Applications (“Why”)

We envisage three broad classes of applications to be served by 6G networks, notably

1. more-of-5G applications;
2. currently emerging applications; and
3. yet-to-be designed applications.

Concerning the more-of-5G applications, we envisage 6G to help consolidate 5G high-bandwidth applications as well as low-latency applications [6-8]:

- **XR-Applications:** VR, Augment Reality (AR) and Mixed Media Realities (XR) are not only bandwidth hungry but also require edge-cloud capabilities. Whilst 5G caters for all, it is likely only 6G which will see this consolidated to the degree that consistent Service Level Agreements (SLAs) can be offered, in particular toward the creation of multi-user, fully interactive XR environments.
- **Industry 4.0:** 5G’s Ultra-Reliable Low-Latency Communication (URLLC) is a set of features that provide low latency and ultra-high reliability for mission critical applications found in Industry 4.0 settings. 6G is likely to consolidate that capability, and we will see a surge of industry sites upgrading to untethered 6G systems.

Concerning emerging applications, worth noting are two technologies which have been introduced in the 5G era but do require 6G capabilities:

- **Internet of Skills:** Introduced as a concept by Prof M Dohler in 2015 [9], it merges concepts in networking, robotics and AI to create the next generation Internet which will allow the transmission of physical skills. It envisaged a future where “teleported” digital twinning would enable the remote execution of work. It relies on a very low and stable latency, and consistent data rates. It will enable a society of remote robotic surgery, remote artistic performances and the emergence of Synchronised Realities [9].
- **Holographic Society:** Powered by an emerging set of volumetric capturing and holographic display technologies, one can imagine a swath of applications to power a future Holographic Society [7]. If a human body, for instance, is mapped in holographic tiles with colour/depth and then transmitted, then this will need a data rate of 4.32Tbps which is currently not achievable with 5G. (Note, however, that recent AI-powered technology has shown that prediction at the edges allows lowering the data rate significantly.)
- **Digital Twins:** 5G is providing a first insight on how Digital Twins can be realised by enabling a single platform for sensing, data, processing and visualisation. 6G will further advance the application of Digital Twins through full cyber-physical convergence and therefore accelerating digital transformation of the economy and society [6].

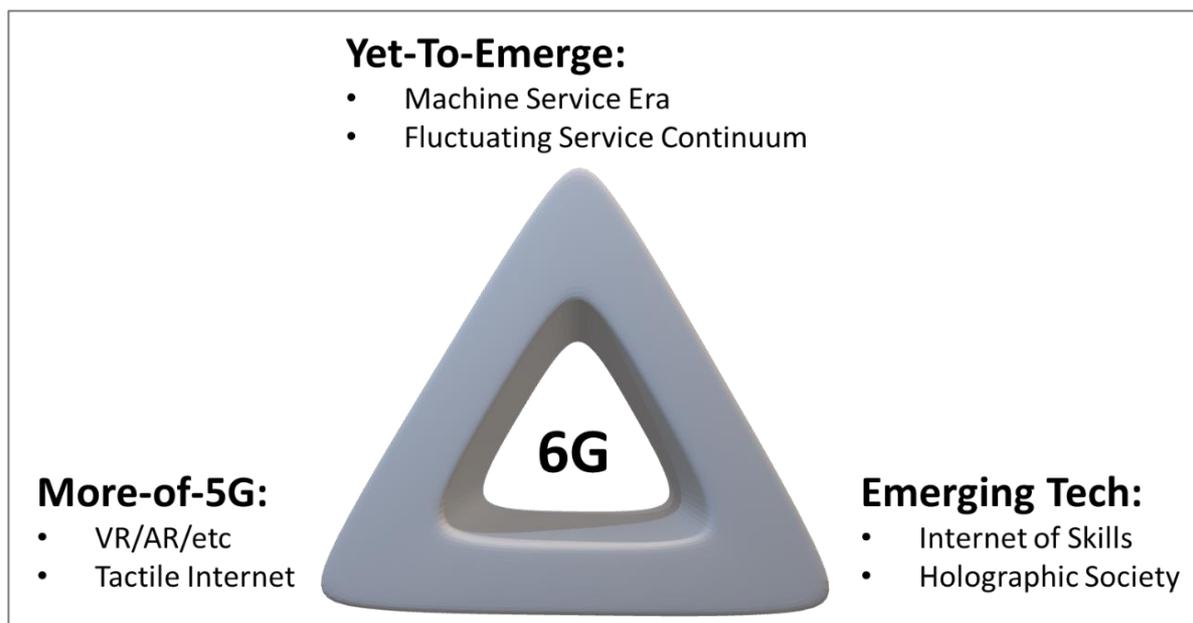


Fig 3: 6G’s service and application triangle, showing that 6G will cover a wide range of legacy, emerging and yet-to-emerge services.

Concerning yet-to-emerge applications, only bold predictions can help here. We predict that it will be the dawn of a Machine-Driven Era. It will be an era, where we won’t define applications/services anymore; it will be autonomously done by machines. And these services will likely appear and disappear in milliseconds. With this, our current era of discrete services will be replaced by a continuous spectrum of highly volatile services.

5. 6G Technologies (“How”)

Uncertainties naturally remain on how above vision will be made reality, but some technology capabilities are already emerging, and these are discussed w.r.t.:

1. 6G Spectrum
2. 6G Radio Technologies
3. 6G Networks and Architecture
4. Important 6G Technology Enablers

Note that many more excellent publications and whitepapers are available discussing 6G technologies and applications in a varying degree of detail [6-12].

Concerning **6G Spectrum**, we will see the closing of the gap between typically cellular GHz bands and visible light communications. Illustrated in Fig 4, the spectrum opportunity is in the 100GHz-1THz region with the aggregate of the spectrum windows W1-W7 yielding 100s of GHz of spectrum. The most promising band for 6G is Window 1 (W1) at 140-350GHz, which also allows for Ultra Massive MIMO at a reasonable form factor. However, the co-existence between civil and astronomer and other services will be a huge challenge at the next World Radio Conference, WRC 2023. Another challenge is hardware as limits on sampling architectures currently only allow low-bit sampling approaches.

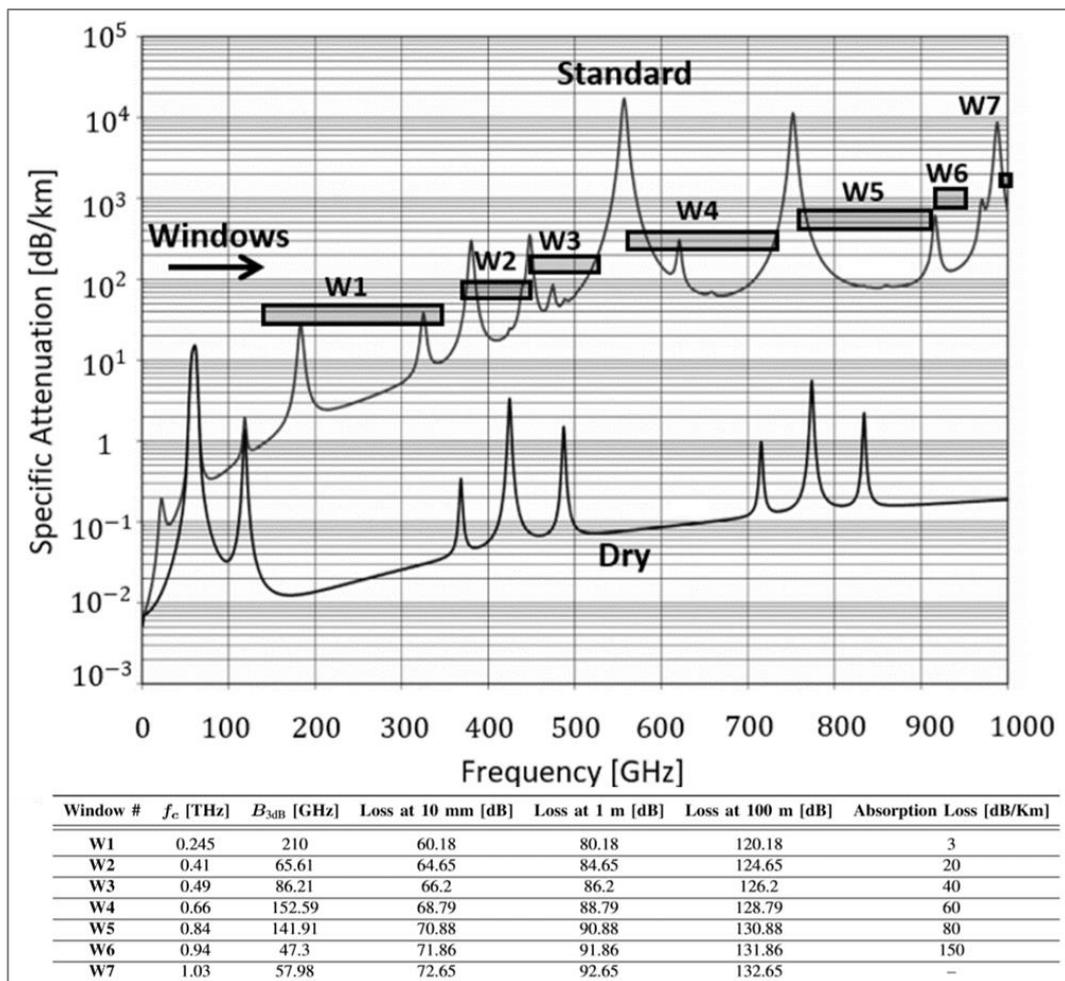


Fig 4: Potential 6G bands at spectrum windows W1-W7 where attenuation is reasonably low.

Concerning **6G Radio Technologies**, we will see the emergence of novel modulation forms, such as orthogonal time frequency space (OTFS) modulation, spin angular momentum (SAM) and orbital angular momentum (OAM) as well as exciting AI-designed schemes; these novel coding schemes will be able to trade block size, latency, re-transmission and energy consumption. Furthermore, we will witness the emergence of Virtual Massive MIMO [8] and Ultra-Massive MIMO with 10s of thousands of antenna elements; the trade-offs here will be in terms of digital vs analog vs hybrid beamforming as well as implementing distributed and cell-free MMIMO. MMIMO will be enabled through emerging Large Intelligent Surfaces (LISs) where e.g. a building's surface can be used as an ultra-massive MIMO array; here, trade-offs in terms of economic viability, reliability and visual impact will need to be reached. Last but not least, novel multiple access schemes will need to be deployed, such as non-orthogonal multiple access (NOMA), rate splitting (RS) or emerging AI-driven approaches. Beyond classic radio, 6G will see widespread use of Visible Light Communications, specifically for indoors deployments, as the technology matures and considering the benefits regarding bit-rates, energy efficiency and security.

Concerning **6G Networks and Architecture**, there is opportunity to 1) *consolidate convergence* where non 3GPP-native networking and radio systems will form an integral part of 6G. Emphasis here will be on mutual or 3GPP-driven security and authentication of said converged network segments, including the deepening of convergence we see in 5G and emerging satellite constellations. This will greatly aid with traffic balancing due to the ability to onboard and offload traffic between networks of different loads; it will support resilience since traffic delivery can be hedged between different technology families.

Embrace 2) *open and vendor agnostic networking* by expanding learnings and practices from Open RAN adoption into the transport and core segments of future cellular networks. Further, we have the opportunity to introduce 3) *non-IP based networking protocols* with IPv6 now being decades old with calls for standardisation of entirely novel networking protocols growing. Indeed, the body of research on protocols beyond IP is rich and several solutions are currently being investigated by European Telecommunications Standards Institute (ETSI)'s Next Generation Protocols (NGP) Working Group as possible candidates for such a disruptive approach.

Also, 4) *Information-Centric and Intent-Based Networks (ICN)* are emerging as an active research area allowing for separation of content and its location identifier. Rather than IP addressing, content is addressed using an abstract naming convention. A new ITU-T focus group has been established to guide the requirements for the network of 2030 [4].

Yet more transformative approaches are emerging, such as 5) *the call to completely "flatten" the compute-storage-transport capabilities of 6G*. A possible scenario is where transport is virtualized over existing fiber but isolated using modern SDN and virtualization methodologies. At the same time, the networking functions are packaged into a microservice architecture and enabled on the fly using containers or server-less compute architectures. To underpin novel 6G applications, we will also see a clearer split between central processing unit (CPU) and graphics processing unit (GPU) instructions sets, allowing each to be virtualized separately and leading to the paradigm of "split compute" [7]. For instance, the GPU instructions are handled locally on the phone whilst the CPU instructions executed on a nearby virtual MEC.

Also, there are calls to 6) *reduce if not remove the traditional transport network*. Unknown to many, the transport is in fact a legacy artefact from the 2G era because back then the internet was not able

to provide the required QoS. However, today the transport fiber infrastructure is really well developed and there is no reason for operators to maintain their own private “LAN at national scale”. A complete rethink may thus give the opportunity for the cellular community to solely focus on the wireless edge (air interface + radio access network + control plane to support all); and simply use a sliced Internet fiber infrastructure to carry the cellular traffic. Whilst it requires some policy and operational changes, the technologies to support this are there.

And last but not least, there is likely a need to 7) *introduce a new Plane for AI* into the 3GPP architecture. Indeed, current User Plane (used for transporting the actual user data) and Control Plane (used for controlling the entire system) may not suffice with the emergence of machine/AI-driven control and data consumption. We refer to this new plane as the A-Plane, for AI-Plane. The high-level view of a resulting approach is illustrated in Fig 5.

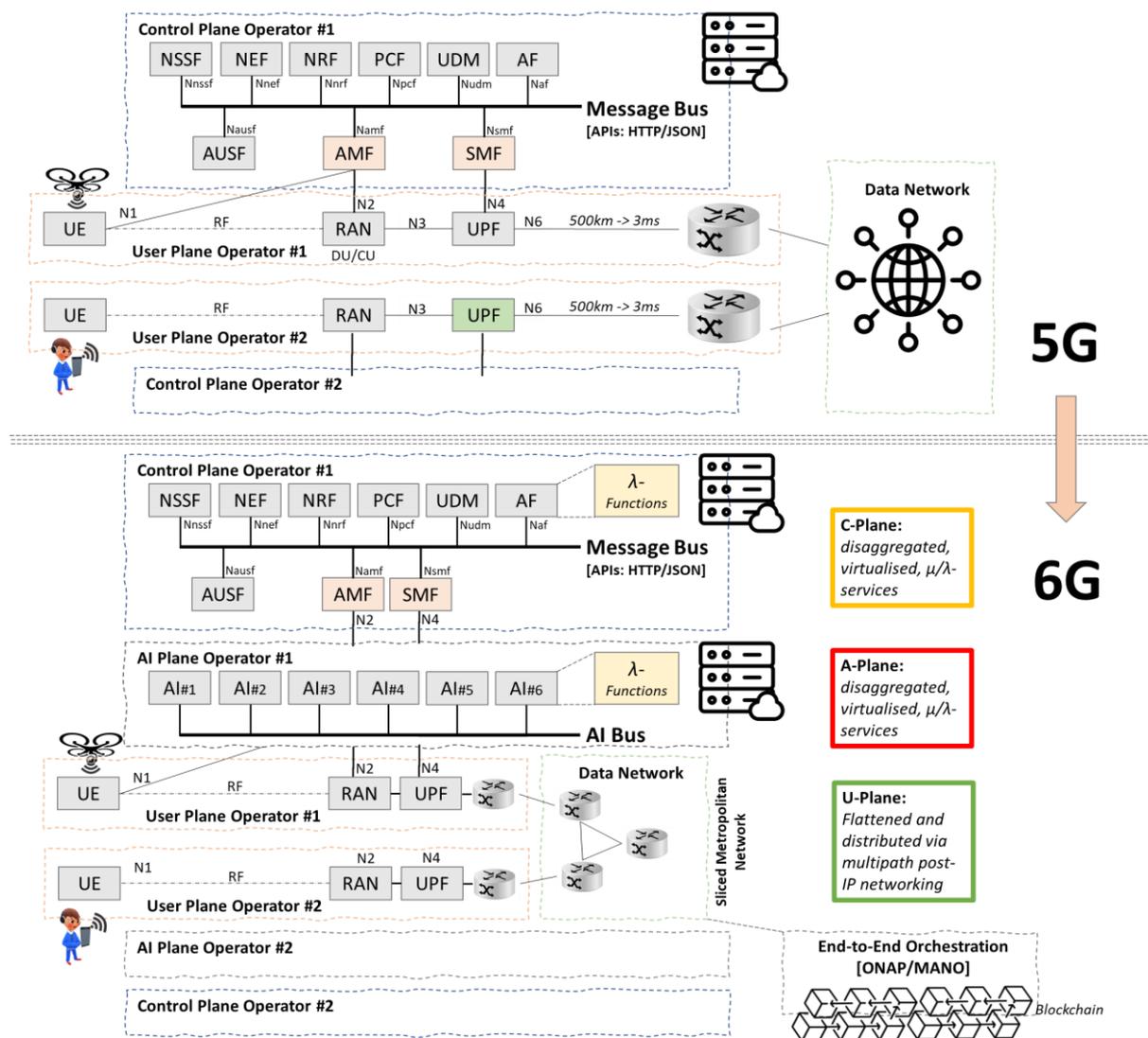


Fig 5: Federated and micro/lambda-serviced system architecture with reduced transport, flattened compute-storage-networking capabilities and the introduction of a new plane [© 6G IEEE paper by Dohler *et al*].

Concerning important **6G Technology Enablers**, a large swath of novel technologies and features is constantly appearing, the introduction of which into the telco architecture often takes decades. Examples of such technologies today are quantum and post-quantum security, distributed ledger technologies (DLT) and AI. Tomorrow, another set of technologies will appear. All these ought to be embedded quicker and more efficiently which is why 6G needs to cater for mechanisms allowing not-yet-invented technologies to be embedded into the overall functional architecture.

Concerning 1) *quantum technologies or even post-quantum cryptography*, the exciting feature is that it can be used to make the 6G infrastructure tamperproof and compatible with the emergence of quantum computing systems. It can be used for cryptographic key exchanges and thus enabling a much more secure infrastructure. Furthermore, quantum computing enables NP-hard optimization problems to be solved in linear time, thus allowing network optimization problems to be solved and executed in much quicker (if not real) time.

Concerning 2) *distributed ledger technologies (DLTs)*, they enable data provenance in that data, transactions, contracts, etc, are stored and distributed in an immutable way. This proves useful in a large multi-party system with little or no trust between the involved parties. Whilst DLTs raised to fame in the financial world with the emergence of Bitcoin, the same industry dynamic applies to telecoms where different suppliers feed into the vendor eco-system, vendors into operators and operators serve consumers. DLTs allow for a much more efficient execution of all these complex relationships. For instance, a vendor feature approved by one operator with the approval stored on a given DLT, should make other operators trust the feature without the need for lengthy procurement processes. Another example is where consumers can create their own market place to trade data plans, or other assets as part of the telco subscriber plan.

Finally, 3) *Artificial Intelligence (AI)* has been used within telecoms for years, but mainly to optimize consumer facing issues, such as churn, network related issues, or the optimal base station antenna array tilt combined with the optimal transmission power policies. However, with the emergence of distributed and more atomized networks, novel forms of AI will be needed which can be executed in a distributed fashion. Furthermore, consumer-facing decisions will need to be explained thus calling for Explainable AI (xAI) concepts which are able to satisfy stringent regulatory requirements.

6. Governance & Policies (“Who”)

From above, a few important governance issues arise which are better addressed earlier than later. We group these into technology, governmental and societal governance issues. An actionable policy framework ought to be established to ensure that these issues are addressed, with more specific set of recommendations given in the concluding section of this paper.

Technology Governance:

- *Native Open-Source Support*: For economic and security reasons but also reasons related to quicker innovation cycles and thus quicker time-to-market, open source will be an ever-growing constituent of a 6G eco-system. This is corroborated by recent announcement of tier-1 operators going to use open source not only for their core network but also parts of the radio access network. This presents an opportunity for the entire communications and computer science community, as features can be contributed to at scale. Furthermore, not only open source (input) but also open data (output) will be instrumental in unlocking the potential of 6G. Many if not most design and operational decisions in 6G will be taken by some form of algorithms. Said algorithms need to be trained which requires a huge amount of data.

The telco ecosystem has been historically conservative in opening up operational data, such as the amount or type of traffic carried over various segments of the control and data planes. Automated mechanisms will need to be created in 6G which allow access to important data, whilst not compromising security of the network nor the privacy of the customers.

- *From Big Data To “Big Action”*: 6G will be accumulating a lot of data allowing for real-time Big Data insights to optimise the networks, performance and services. Whilst the benefits of Big Data are well understood, 6G offers another important opportunity: the software-driven architecture allows for insights to be actioned in real-time, thus closing an important design loop and offering what we refer to as “Big Action”. Policies ought to be put in place which encourage, if not incentivise, any gathered data to be analysed and any analysed data to be responsibly actioned.
- *Native Framework for AI/Machines*: Machine Learning and AI have been part of telecom standards ever since the introduction of self-organizing networking (SON) in Release 8 [13]. However, the degrees of freedom, the high dynamics, the high disaggregation of 6G networks as well as more stringent policies will almost certainly require a complete rethink of how AI is embedded into the telco eco-system. 6G is an exciting challenge for the AI community as there is no global technology eco-system which has such stringent design requirements on spatial distribution, temporal low-latency and high data volumes. Emerging paradigms, such as distributed AI, novel forms of transfer learning as well as ensemble techniques, need to natively fit the overall telecom architecture. Importantly, consumer-facing decisions taken by AI need to be compliant with various consumer-facing policies around the world, such as Article 13 in Europe’s general data protection regulation (GDPR). This requires the disclosure of any “meaningful information about the logic involved, as well as the significance and the envisaged consequences of such processing for the data subject”. As a result, novel paradigms such as Explainable AI will need to natively sit within 6G. And, as discussed in more details in an adjacent governance paper on digital technologies and AI, we urgently need to develop a platform which allows observing and keeping provenance of the actions/impact of AI. Only such framework will ultimately enable a viable human-machine coexistence.
- *Transport Infrastructure Sharing*: There is a growing case for ensuring efficient usage of all available digital infrastructure [14]. For instance, across the UK and in many other countries, a strong fibre network is already in existence. And whilst it is owned by a complex range of organisations working in isolation from each other, the technology allowing for business-centric infrastructure sharing should be prioritised. Examples could be the combination of software-defined networking and blockchains. In doing so, a much more cost-efficient deployment of 6G can be achieved in that not only access but also transport networks are converged.

Government-driven Governance:

- *Smart Procurement*: Innovation is driven by a competitive market and ensures the best deal for consumers. The role of the regulator is to ensure that these innovative forces remain in place. Innovation is typically brought to market via procurement where the cheapest product/service meeting the minimum requirements is being selected. A milestone study [15], however, has found that Smart Procurement is more sustainable long-term where not only the minimum requirements are met but where long-term capabilities are also assessed. Market and/or regulatory mechanisms ought to be put in place that incentivise the use of Smart Procurement
- *Trade Barriers and Business Certainty*: One needs to recognise that a highly complex system like 6G cannot be built by one nation alone. Therefore, to stimulate innovation and competition, geo-political trade barriers are not helpful as they cause long-term structural imbalances and yield uncertainty to businesses that rely on certain technology components.

Concerns regarding country of origin, features and service capabilities should be addressed prior to procurement and deployment. That is, a proper 360 risk assessment ought to be conducted prior to procurement and mechanisms put in place that are able to mitigate any considerable risks. Failing in doing so risks the emergence of two or more geo-political bubbles with technological incompatibility, and thus reverses the very essence of the success of mobile: a truly global interoperability.

- *Government-as-a-User:* Governments around the world typically account for about 1/3 of the domestic GDP [16]. There is therefore a unique opportunity for governments to fill some demand uncertainties. One could imagine that internal procurements will stimulate the use of modern technologies when applicable, such as 6G and/or the IoT, and therefore create entire new supply chains and industries. Government should think about implementing mechanisms today that will allow for a Smart Procurement of 6G into government as an end user; for instance, for health, security, government-internal operations or maintaining public services.
- *Public Street Furniture:* There are over five million publicly owned streetlamps in the UK alone, and thousands of other structures that are suitable for the siting of 5G and 6G networking equipment. Street furniture, therefore, offers a unique opportunity to roll out such a network at scale, if a coordinated approach to leveraging these assets nationally is developed [14]. Currently, 5G development and implementation are still occurring in silos with projects being led by a range of organisations. 6G offers an opportunity where public street furniture is a foundation that can ensure a cost-efficient deployment. Understanding the complexity with public real-estate, we recommend the development of best practices and incentives for city councils, local authorities, government departments and regulators to show the benefit of a polycentric governance at national level.
- *Piggyback on Large Infrastructure Projects:* A substantial cost to operators is the deployment or lease of the transport network, a fiber network which spans the country. Compared to other infrastructure deployments, such as roads, electricity masts, etc, the cost of fiber is by several orders of magnitude cheaper. It thus would make sense to mandate the rollout of fiber with every national infrastructure project. Several models for operating that infrastructure could be developed, including but not limited to government operated, private lease or sales. We therefore recommend an early and mandated interaction between pertinent government departments, notably the IPA, BEIS, DFT and DCMS.
- *Skillset Development:* There needs to be a national approach to building skills in telecommunications [14]. However, skills to leverage on the potential benefits of even 5G are currently in short supply, and will become an urgent necessity in 6G. This issue has been recently highlighted by other technological developments – such as cyber security, artificial intelligence, big data, and the internet of things – where significant effort has been expended to ensure that skills catch up with the demands of these sectors. Worth highlighting is the UK’s success in building world-class skills in cyber which has been enabled by a strong leadership and “ownership” by several national agencies and centres [17]. We therefore recommend replicating that approach with 6G in that a “home” for 6G skills development is found or created through e.g. national centres of excellence. Building a strong and sustainable foundation of suitable 6G skills is central to supporting, growing and driving innovation across the telco ecosystem in the UK.

Societal Governance:

- *Carbon Footprint Framework:* The impact of the ICT sector on the global energy consumption and thus carbon footprint is very large, in both negative but also positive ways. Notably, ICT now consumes about 4% of the global energy [18] whilst – and that was amplified with the Covid crisis – enabled remote working and thus savings in carbon footprint linked to

commutes and travels [19,20]. A consistent framework to assess that trade-off is not available to-date but ought to be established with urgency. Various technology standards and alliances, such as the NGMN [21], have commenced assessing the impact but purely from a technology point of view. A larger, society-centric framework is entirely missing which clearly hampers meeting the UK [22] and UN Sustainability Goals [5].

- *Human-Centricity*: The network-centric design in 2G and 3G had been superseded by a device-centric design in 4G and 5G. 6G has the opportunity to be user (citizen)-centric in that it is societally aware and technologically adaptable, so that important societal needs or Black Swan events can be dealt with more efficiently and effectively. A fundamental change is vital as today's networking infrastructures have become too fragmented and heterogeneous to meaningfully support societal challenges. Examples of these shortcomings were laid bare with the ongoing COVID-19 crisis: a massive shift of networking resources from corporate premises to private homes was needed but unattainable; privacy concerns over tracing apps emerged but could not be dispelled since privacy was not fundamentally embedded into the infrastructure but rather provided through T&Cs; a significant increase in security breaches was reported by various agencies around the world. 6G will further consolidate a hyper-connected world [23], where large telco and service companies are impacting daily realities without any notable input from the very communities they transform [24]. That lack of transparency and engagement will lead to an increasing lack of privacy/dignity and potentially undermine social cohesion. Principles need to be put in place for 6G and across the wider range of emerging technologies which ensure ethics, responsibility and human-centredness.
- *Fundamental Change to Privacy*: Whilst security-by-design is now a well understood design approach, privacy is still being solved at "consent" level. A novel approach is needed which we refer to as Privacy-by-Engineering design. It will ensure that privacy mechanisms are natively built into the protocols and architecture which would e.g. prevent the forwarding of information if not certified to be privacy-vetted. For instance, a security camera will only be allowed to stream the video footage if certain privacy requirements are fulfilled at networking level and possibly contextual level, i.e. understanding who is in the picture and what privacy settings they have enabled. These privacy settings are context dependent and much research is needed to enable such advanced systems. Whilst such developments are technological by nature, a strong societal and regulatory push is needed to commence developing such systems which have the potential to change today's Internet for a more society-friendly digital fabric. Furthermore, to protect privacy, security must not be compromised. The call by various nation states to weaken security for backdoor access is ill-advised and will only lead to an explosion of cybercrimes. Access to suspected criminals should be governed by Lawful Intercept (LI) which is a well-established field in standardisation bodies. Discovered security loopholes, such as the recently discovered ability to track users whilst they roam using some Control Plane messaging, ought to be closed with urgency. We recommend for standards bodies to establish an emergency protocol for such security flaws to be fixed at highest urgency.
- *Addressing Public Perception*: The telco eco-system has been notoriously complacent in communicating the impact of new technologies on health and well-being. As a result, each new generation is being greeted with dooms-news which is not helpful to consumers nor the industry. 6G has the potential to revert this by spending considerable efforts not only analysing the impact of the frequency bands to be used onto human health and well-being but also communicating findings through easy-to-understand messages. Ofcom is currently (Q4 2020) doing excellent outreach work by developing such simple messages to the wider population and public authorities which explain the benefits of 5G [25]. Phrases, like "microwave", "beamforming" or "Massive MIMO", are explicitly omitted as they were found to cause anxiety in the wider population. We therefore recommend for government and telco regulators to partner with health authorities, psychologists and marketing companies to deliver simple yet truthful messages about 6G well before the release of the technology.

7. Recommendations & Next Steps

6G will have a profound impact onto businesses, innovation cycle and the skills landscape of telecoms, providing a phenomenal opportunity for growth at national and international levels. Above-discussed governance issues however highlight that important work needs to be done to ensure the best possible conditions for 6G to evolve from 5G and to thrive from a business but also societal point of view. Subsequently, we outline recommendations which we deem vital for unlocking success. A high-level drawing of the recommendations is also shown in Fig 6.

Recommendation 1: Cross-Government Technology & Infrastructure Task Force

- *Establishment Timeline:* 2021/2022
- *Responsibility for Formation:* government departments, DCMS Barrier Busting Team, IPA
- *Objective:* Establish a national task force which provides recommendations and governance on technology co-deployment with large-scale infrastructure projects, transport infrastructure sharing and efficient re-use of any other national and private digital assets, an economic use of public street furniture, continuous innovation of spectrum regulation and usage thereof, and general market assessments, recommendations on regulation and governance of emerging technologies.

Given the significant investments in telecommunications and networks already made and recently announced (Q4 2020) by the UK government and other governments around the world, a cross-government task force will ensure inclusiveness on some core aspects of 6G. This is vital to counter the fragmentation of existing technological, geopolitical and regulatory regimes, and thus allowing for an effective coordination of the opportunities and risks around 6G on a national as well as global levels.

Indeed, 6G governance risks being weakened because of various interdependent developments: first, telecoms governance overlaps more and more with other large regulatory domains (such as cyber, AI, content regulation, etc.) and, second, geopolitical rivalry is growing which consumers and businesses cannot afford.

To address these mid- and long-term structural imbalances, the three main forces of market competition, systematic competition and technology determinism [24] that limit the effectiveness of governance need to be addressed through this unifying task force. It ought to be permanent and chartered, thereby enabling national and global coordination through meta-governance mechanisms.

Recommendation 2: Cross-Domain Regulatory Sandpits

- *Establishment Timeline:* 2022/2023
- *Responsibility for Formation:* government, industry, regulators
- *Objective:* Establish regulatory sandpits which allow for the development of innovative and trusted solutions among all market and societal players (regulator, large companies, SMEs, universities, consultants, civic organisations and the third sector etc), and well before procurement takes place. Focus should also be on cross-regulatory sandpits, such as between the FCA and Ofcom, underpinning emerging technology solutions of e.g. mobile micro payments. Further, mechanisms ought to be put in place which ensure that regulators remain innovative themselves.

Regulatory sandpits address the two common problems of over-regulation and under-regulation. Regarding the former, industry is hampered and innovation stifled thus depriving consumers of innovative products and services; regarding the latter, industry is granted a free reign thus potentially jeopardising long-term societal values.

We also have to acknowledge that our dependency on technology prevents nowadays simple switches distinguishing between “good use” and “bad use” of tech [24], something a regulatory sandpit environment can address.

Importantly, a sandpit environment allows all involved parties to understand each other’s concern well before they are carved into legislation, contracts or business logics. It could potentially prevent £bn in misaligned legislation and technology development roadmaps.

Recommendation 3: Centres of Excellence for Telecom Skills

- *Establishment Timeline: 2022/2023*
- *Responsibility for Formation: government, industry alliances, universities, schools*
- *Objective: Establish virtual and physical centres at national and scale to incubate 5G, Beyond-5G/6G skills, encompassing technical skills, interdisciplinary skills (e.g., sustainability and ethics), leadership and also skills enabling the engagement with the demand side.*

Skills shortage has long been identified as one of the major blocking stones towards the establishment of native industries. Whilst each nation may focus on a specific part of the skills spectrum, one should not require a nation to develop skills at all levels. For instance, the UK has a strong track-record in B2B software and service creation, thus calling for intensifying the creation of skills around software programming for 6G services and infrastructure, as well as skills in 6G business development.

Creating an entire industry from scratch should be handled with care as the three moving parts of supply, demand and skills need to be carefully orchestrated; poor governance here can potentially lead to inefficient and ineffective use of public money.

Thus, the development of a national skills roadmap should be developed carefully, taking strengths and weaknesses at national level into account. Once finalised, the roadmap should be implemented through a permanent/chartered body which shall oversee the implementation at industry, SME, university and school levels. Start-up incubation programs should also form part of this initiative.

Importantly, curricula need to be adapted and the framework governing the creation of curricula made more flexible so that the ecosystem can adapt easier to an environment of accelerated change. Certification processes, similar to those conducted for cybersecurity in the UK, ought to be implemented specifically for telecoms. Furthermore, student placements in industry, SMEs and government need to be mandated and streamlined; that will ensure a proper knowledge exchange and skills creation across all involved stakeholders.

Recommendation 4: Human-Centric 6G Task Force

- *Establishment Timeline: 2022/2023*
- *Responsibility for Formation: government, industry alliances, consumer alliances*
- *Objective: Ensure that design principles in 6G are truly human-centric and inclusive; establish principles which ensure responsible innovations towards the development of 6G; put in place an effective communications which transparently conveys the opportunities and risks of 6G to the wider population; ensure the establishment of a framework for assessing the end-to-end carbon footprint of 6G; etc.*

Given the pervasiveness and constant proximity of mobile devices to humans and their importance to society at large, there is indeed a unique opportunity to shape a more human-centric agenda for generations to come. This would mimic important developments at national and international levels in other domains, such as AI, and is perceived to be long overdue for the telecommunications sector.

Such an initiative should be governed by principles of responsibility and human-centredness. It should not be a central entity but rather rely on polycentric governance, representing a broad spectrum of stakeholders but most importantly the voice of citizens and society. Importantly, it should reconcile a rather structural fragmentation between current stakeholders and find alternatives to the established logic of economic efficiency which has provenly led to unemployment, underemployment and labour displacement.

The task force should reinforce social cohesion, rather than weaken it. It should counter the increasing lack of dignity and privacy citizens and society experience in this hyperconnected world. Growing issues around physical and mental wellbeing must be addressed, well before 6G will be deployed.

Furthermore, with focus on sustainability, the task force should develop a quantitative and qualitative framework allowing energy consumption and carbon footprint of 6G to be assessed and, importantly, predicted. One should strive for meeting the national and UN sustainability goals.

Last but not least, the task force needs to develop contingency measures for the risks arising from 6G and the hyperconnected world it will enable. For instance, cyber or remote-controlled robotic attacks can be carried out at ease and without any trace due to the ultra low latency capabilities of 5G and 6G. Lawful intercept and forensic mechanisms need also be discussed as part of such measures.

This task force ought to be chartered, permanent, fair and transparent, and have sufficient operational means and executive mandates.

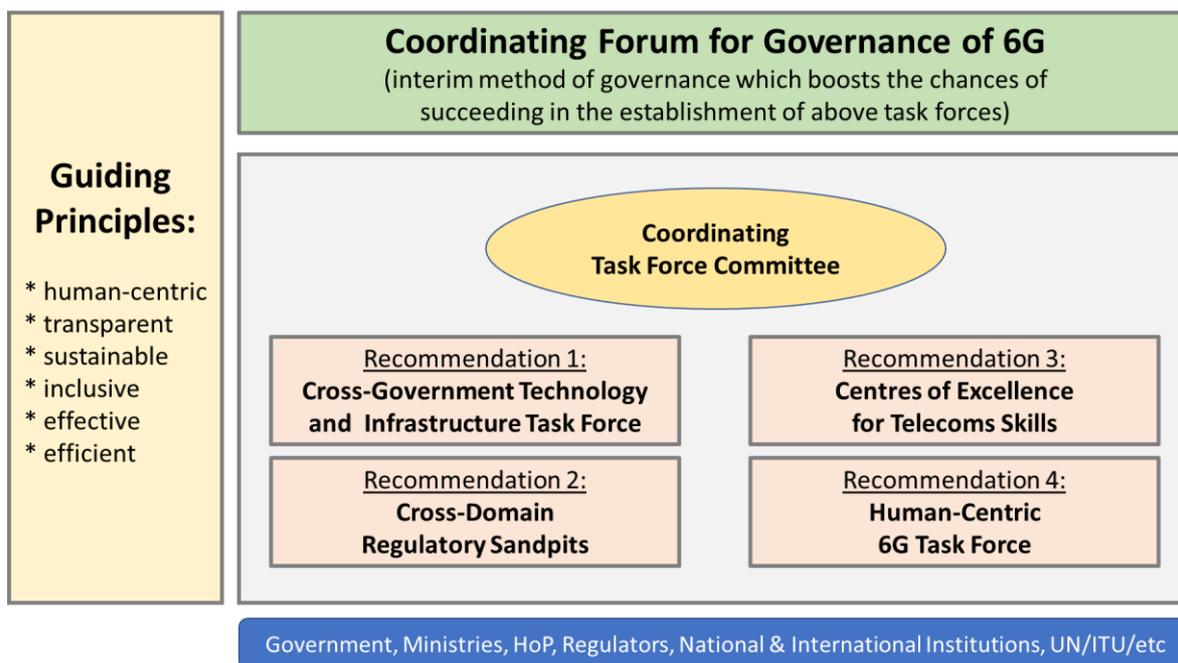


Fig 6: High-level overview of the guiding principles, a forum coordinating the establishment of a task force committee which in turn establishes the task forces as per above recommendations.

Recommendation 5: Coordinating Forum for Governance of 6G

- *Establishment Timeline: 2021/2022*
- *Responsibility for Formation: government*
- *Objective: Establish an interim method of governance which boosts the chances of succeeding in the establishment of above task forces. It should have the mandate to convene all stakeholders to form above task forces. The process and activities of that coordinating forum should be transparent, efficient and effective.*

Such coordinating forum ought to ensure that each of above recommendations is addressed in equal parts, where Recommendation 1 addresses the demand side, Recommendation 2 the supply side, Recommendation 3 skills and Recommendation 4 the societal view.

Similar to suggestions made in [24], said coordinating forum should meet on a regular basis with senior representatives of all stakeholder groups. It should coordinate the planning of the task forces and help establishing the mandate of each.

Should the government adapt the proposed recommendations, this could also serve as a blueprint for addressing other technological and societal challenges at national and international stage. It would aid in refocusing the current landscape of geo-political rivalry and profiteering to a more cooperative and civic approach.

8. About the Authors



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Bibliography

- [1] "Mobile industry has never been more important to world's citizens and global economy," GSMA, 26 March 2020; online: <https://bit.ly/345VVSG>.
- [2] "Telecommunications Market Data Update Q2 2019," Ofcom, 31 Oct 2019; online: <https://www.ofcom.org.uk/research-and-data/telecoms-research/data-updates/q2-2019>.
- [3] "Why Infrastructure Connectivity Matters," OECD Japan G20 Development Working Group, January 2019; online: <https://bit.ly/3gFiVgk>.
- [4] "Focus Group on Technologies for Network 2030," ITU Focus Group; online: <https://www.itu.int/en/ITU-T/focusgroups/net2030/Pages/default.aspx>.
- [5] "United Nation Sustainability Goals," UN; online: <http://www.undp.org/content/undp/en/home/sustainable-development-goals.html>.
- [6] "A research outlook towards 6G," Ericsson 6G White Paper, 2020; online: <https://www.ericsson.com/en/reports-and-papers/white-papers/a-research-outlook-towards-6g>.
- [7] "6G. The Next Hyper-Connected Experience for All," Samsung 6G White Paper, 2020; online: <https://research.samsung.com/next-generation-communications>.
- [8] "5G Evolution and 6G," Docomo 6G White Paper, 2020; online: https://www.nttdocomo.co.jp/english/info/media_center/pr/2020/0124_00.html.
- [9] Mischa Dohler, *et al*, "[Internet of Skills, Where Robotics Meets AI, 5G and the Tactile Internet](#)," EuCNC 2017.
- [10] "6G Wireless Systems: Vision, Requirements, Challenges, Insights, and Opportunities" by Harsh Tataria, Mansoor Shafi, Andreas F. Molisch, Mischa Dohler, Henrik Sjöland, Fredrik Tufvesson; <https://arxiv.org/abs/2008.03213>.
- [11] "Key Drivers and Research Challenges for 6G Ubiquitous Wireless Intelligence," Oulu University 6G White Paper, Sept 2019; online: <http://jultika.oulu.fi/Record/isbn978-952-62-2354-4>.
- [12] "6G wireless: A new strategic vision," University of Surrey 6G White Paper, 2020; online: <https://bit.ly/3makHqU>.
- [13] "Self-Organizing Networks," 3GPP; online: <https://www.3gpp.org/technologies/keywords-acronyms/105-son>.
- [14] "Government must ensure the UK does not cede its 5G leadership," M Kleinman & M Dohler for Public Technology; July 2018; online: <https://bit.ly/3na83cN>.
- [15] "Restarting Britain: design and public services," UK Design Council, 2013; online: <https://www.designcouncil.org.uk/resources/report/restarting-britain-design-and-public-services>.
- [16] "Total public sector current expenditure as a share of gross domestic product (GDP) in the United Kingdom (UK)," Statista 2019/2020; online: <https://www.statista.com/statistics/298478/public-sector-expenditure-as-share-of-gdp-united-kingdom-uk/>.
- [17] "UK cyber security community," Wikipedia; online: https://en.wikipedia.org/wiki/UK_cyber_security_community.
- [18] "Beyond the Energy Techlash: The Real Climate Impacts of Information Technology," ITIF, 2020; online: <https://itif.org/publications/2020/07/06/beyond-energy-techlash-real-climate-impacts-information-technology>.
- [19] "Homeworking: helping businesses cut costs and reduce their carbon footprint," Carbon Trust, 2014; online: <https://bit.ly/3oFurv6>.
- [20] "Why working from home might be less sustainable," BBC, 2020; online: <https://www.bbc.com/worklife/article/20200218-why-working-from-home-might-be-less-sustainable>.
- [21] Next-Generation Mobile Networking alliance; online: <https://www.ngmn.org/about-us/vision-mission.html>.
- [22] "UK becomes first major economy to pass net zero emissions law," UK Government, 2020; online: <https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law>.
- [23] "The Hyperconnected World of 2030–2040," Institute for the Future, 2020; online: <https://www.iftf.org/hyperconnectedworld/>.
- [24] Jelinek, T., Wallach, W. & Kerimi, D. Policy brief: the creation of a G20 coordinating committee for the governance of artificial intelligence. *AI Ethics* (2020). <https://doi.org/10.1007/s43681-020-00019-y>.
- [25] "Cutting through the Covid-19 confusion," Ofcom, 2020; online: <https://www.ofcom.org.uk/research-and-data/media-literacy-research/coronavirus-resources>.