Ericsson White Paper
GFTL-20:001402
November 2020

Ever-present intelligent communication

A research outlook towards 6G

Content

Introduction — 5G and beyond

In 2020, we have so far seen a strong expansion of 5G happening throughout the world, with networks providing new communication capabilities and services that are set to transform society. As we continue to witness this success, we should remember that the first steps toward 5G were taken a decade ago even as 4G was just being rolled out and while it was still hard to identify needs beyond that time.

There is no doubt that the ongoing transformation will eventually give rise to challenges beyond what 5G can meet. In 2030, for instance, society will have been shaped by 5G for 10 years, and new needs and services will have appeared. Even with the built-in flexibility of 5G, we are beginning to see the horizon where further capabilities are needed [1]. This calls for continued evolution — following the pull from society's needs and the push from more advanced technological tools becoming available — that must be addressed for a 6G era around 2030.

Future networks will be a fundamental component for virtually all parts of life, society, and industries, fulfilling the communication needs of humans as well as intelligent machines. To make the best out of it, we — the industry and research community — should contribute together towards a common vision.

Four main drivers will emerge for the 2030 era: trustworthiness of the systems that will be at the heart of society, sustainability through the efficiency of mobile technology, accelerated automatization and digitalization to simplify and improve our lives, and a limitless connectivity meeting the demands for intensifying communication anywhere, anytime, and for anything.

In this white paper, a vision of ever-present intelligent communication for 6G in 2030 will be outlined, taking a research angle on what future networks should be able to deliver and what candidate technologies should be developed to get us there.

The 6G world of 2030

We can expect the society of 2030 to have transformed around increasingly advanced technologies, where 5G plays a key role and the future networks act as the communication and information backbone, allowing anything to communicate anywhere and anytime.

Pull from increasing expectations

Trustworthiness	Sustainable world	Simplified life	Application demands
trusted communication and computing for industry and society relying on critical information	communication and networking as part of and enabler for sustainable development	massive use of AI across systems for optimal assistance and efficiency	extended and new services requiring extreme connectivity performance

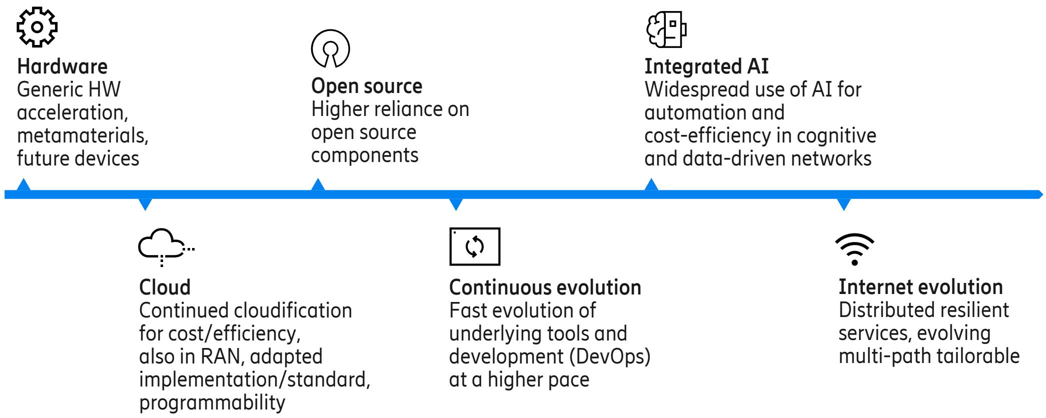
As wireless connectivity becomes an integrated, fundamental part of society, trust in the data delivered through connectivity as well as in the connectivity itself (along with data services and the compute platform functionality) will become even more important. Society must be able to rely completely on networks delivering critical services while being able to ensure the integrity of the information. People as well as industries must be able to rely on verified data and identities even as they enjoy full privacy.

Sustainability is at the top of all agendas, and all sectors of society need to work towards the UN's Sustainable Development Goals (SDGs) [2]. Wireless communication already plays an important role here, and there is clear potential to further accelerate its contribution in enabling increased efficiency in the use of resources and support of new ways of living, making it a tool for sustainable change.

With artificial intelligence (AI), it is possible to optimize and simplify many processes and improve operations by reducing the need for human participation and supervision. Following this development forward, we should expect a dramatic increase in the use of AI to further optimize society and simplify our lives. To enable this, networks need to be based on a data-driven architecture using massive data to support AI across systems, designed for the highest security and explainability.

Today, there is a strong increase in highly demanding applications, where very low latencies and very high data rates are required to enable applications such as virtual, augmented, and mixed reality as well as remote control of sensitive operations. Going towards 2030, we can expect this evolution to continue with even higher demands placed on the performance that networks should deliver.

Push from technology advancements



Beyond 5G, many new technological tools within and outside of the information and communications technology (ICT) domain will become available. These innovations will make the leap from 5G possible and enable more powerful networks in the future.

Today, hardware continues to evolve at a rapid pace and will become increasingly capable in terms of processing speed, energy performance, and size. In parallel, the emergence of new meta materials may encourage radically new approaches to (for example) antenna implementation. Smaller, simpler, low-power devices will make it possible to embed connectivity everywhere.

Cloud and virtualization technologies will continue to ensure improved cost-efficiency and adaptability, and internet-era methods (like DevOps for all layers and open-source code) are speeding up the development. The integration of AI into fully programmable networks promises to turn complexity into efficiency.

New use cases

Triggered by the drivers, new application areas will appear, calling for new capabilities in the networks of the future. Equally important is the future of the existing applications and closing the remaining digital gaps.
Although early, starting with services that can meet future expectations allows us to see the contours of some new use cases.

A digitalized and programmable world, for example, will deliver full representations of the physical world. This may lead to billions of embedded sensors and actuators represented in digital, interactive 4D maps of whole cities that are precise in position and time and can be simultaneously accessed and modified by large numbers of humans and intelligent machines for detailed planning of activities. Such cyber-physical service platforms can issue commands to steerable systems, like public transport, waste handling, or water and heating management systems.

The advent of precision healthcare, enabled by miniature nodes measuring body functions and capabilities to issue medications and physical actions, will be supported by a digital representation that can be continuously analyzed. Such high integration of technology in our lives will only increase the importance of trustworthiness through availability, security, and data privacy and requires new device types that can be embedded virtually anywhere and that are capable of maintenance-free deployments, efficient and distributed data processing and management, and representation with high rates and low latency.

An automated society would harvest all the benefits of AI assistance for improving our welfare and simplifying our lives. For instance, collaborative industrial AI partners could perform many challenging tasks involving manual labor more safely and efficiently as well as act autonomously and adaptively. Such high-trust cyber-physical systems should be able to smoothly cooperate with groups of humans and other intelligent machines, which will require extreme reliability and resilience, precise positioning and sensing, low-latency communication, and AI trust and integration.

Building a sustainable world requires efforts throughout society, all aiming at digital inclusion on a global scale. This includes diverse elements, such as support of smart automation services everywhere on the planet, connectivity for global sensors monitoring the statuses of forests and oceans, access to digital personal healthcare for everyone, and access to high-end services for institutions (such as schools and hospitals) everywhere. Through global, end-to-end life cycle tracking of goods, autonomous supply chains can accelerate a full circular resource economy. Taken together, this requires truly global coverage with excellent energy and cost-efficiency, embedded autonomous devices and sensors, and a network platform with high availability and security.

Immersive communication will deliver the full telepresence experience, removing distance as a barrier to interaction. The advent of mobile extended reality (XR) technology [3] with complete human-grade sensory feedback will require very high rates and capacity, spatial mapping from precise positioning and sensing, and extremely low latency end to end with edge cloud processing. One example will be the ubiquitous use of mixed reality in public transport, offering separate virtual experiences for each passenger, like being able to run virtual errands, getting XR guidance, and having games overlaid on the physical world.

Going further still, communication will approach a fully merged reality, where all senses and holograms can be translated across physical and digital worlds. Devices capable of precise spatial mapping and body interaction will allow access to experiences and actions far away, with extreme data rates and low latency ensuring an immersive perception. In the future, we could even better support the communication needs of people (the importance of which has become especially clear during the ongoing COVID-19 pandemic) and, at the same time, welcome completely new interaction opportunities requiring integrated compute and strict control over access and identities.

The 6G platform

The increasing expectations set a clear target for us in the industry and research community — 6G should contribute to an efficient, human-friendly, sustainable society through ever-present intelligent communication.

Needed capabilities

To serve as the platform for a vast range of new and evolving services, the capabilities of future wireless access networks need to be enhanced and extended in various dimensions compared to the networks of today. This includes having classic capabilities (such as achievable data rates, latency, and system capacity) as well as new ones (with some being more qualitative in nature). We must also prepare for the unknown by ensuring as far as possible that the future networks serve as a platform for innovation, supporting the services not yet envisioned.

Starting with the classic capabilities, the focus must remain on higher achievable data rates in all relevant scenarios. This includes the possibility to provide several hundred gigabits per second and sub-millisecond latency end to end in specific scenarios. Equally important is the possibility to provide high-speed connectivity with predictably low latency end-to-end and low jitter rate.

These future wireless access networks should be able to serve an exponentially growing traffic demand without increasing overall costs. Higher spectral efficiency of radio access technology is one component to this, with access to additional spectrum being naturally another. Even more important, though, is the cost-efficient deployment of dense networks.

There is a need to continue the expansion of wireless communication and target full global coverage — closing the digital divide to remote areas — while supporting a dramatically higher number of devices that will be embedded throughout society. As a fundamental principle to allow for further digital inclusion, the total cost of ownership should be on a sustainable level.

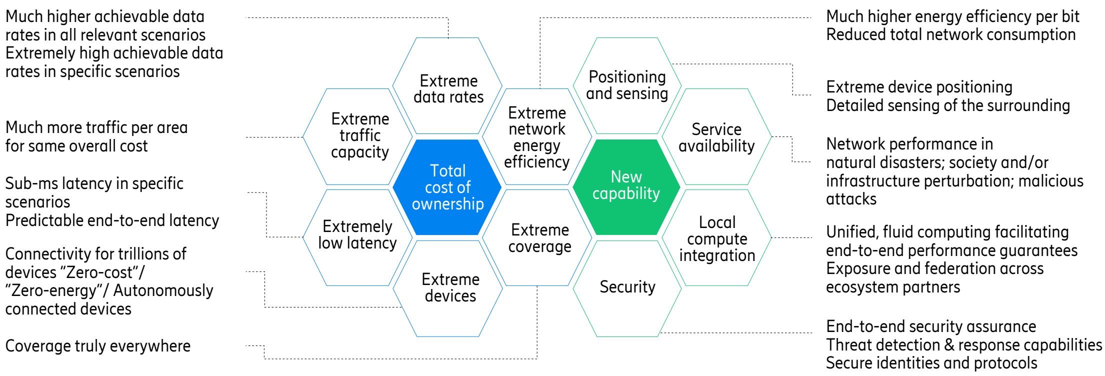
Network energy performance played an important role in the development of 5G, and it will be even more important for future wireless access solutions [4]. An acceleration in traffic should not mean accelerated energy usage.

As wireless networks increasingly become critical components of society, resilience and security capabilities are crucial. The network must be able to provide service when part of the infrastructure is disabled due to natural disasters, local disturbances, or breakdowns in society, and it must offer robust resistance against deliberate malicious attacks.

In terms of trustworthiness, these networks should also be able to leverage new confidential computing technologies, improve service availability, and provide enhanced security identities and protocols with end-to-end assurance.

These networks will need the capabilities of local compute integration, infrastructure enabling distributed applications and network functions to be swiftly developed and deployed, and services for data and compute acceleration can be delivered throughout the network with performance guarantees.

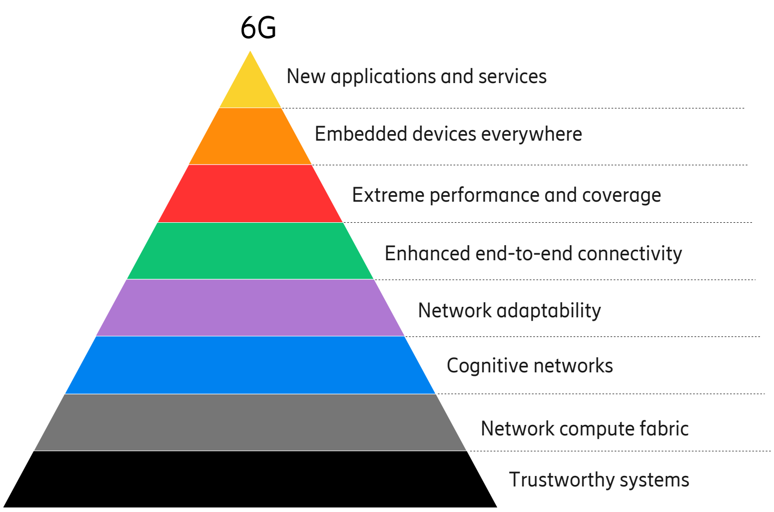
Finally, to power the full digitalization and automation of society, networks need high-precision positioning and detailed sensing capabilities from their surroundings.



Foundations of 6G

For the 6G networks of 2030, we should consider a broad range of promising technologies. The study of these potential elements of 6G will be a key topic of research in the coming years.

Taken together, the elements of 6G will form one seamless system, having all the needed capabilities and empowering the vision of ever-present intelligent communication. With a foundation of trustworthy systems and a highly efficient compute fabric with built-in cognition capacities, the networks of the future will deliver limitless connectivity for upcoming applications and services. This will make 6G a broad platform for innovation and the information backbone of the society.



Technology elements of 6G

Network adaptability

By increasing the adaptability of networks, several key efficiencies can be addressed. These might be related to cost of deployments, energy consumption, network development and expansion, and management and operations.

Dynamic network deployment

Mechanisms to ensure dynamic network deployments will be key to supporting the cost-effective deployment of high capacity, resilient networks in the future. This will make an operator more agile when handling new business opportunities and new emerging use cases. The key challenge is to seamlessly integrate traditional service provider-deployed network nodes with complementing ad-hoc, temporary, user-deployed, mobile, or non-terrestrial nodes.

The possibility for multi-hop communication — already partly introduced in 5G through integrated access backhauling (IAB) — will be an important component to enabling such dynamic network deployments. We expect this to further evolve, ensuring seamless multi-hop wireless connectivity with low costs and high flexibility. This will also partly erase the distinction between wireless access links to devices and wireless backhaul links between network nodes, creating a unified framework for wireless connectivity.

A factor that is common to all future deployment scenarios is the requirement for a superior transport network to be flexible, scalable, and reliable in order to support demanding 6G use cases and novel deployment options, such as a mixture of distributed radio access networks (RAN) and centralized/cloud RAN. This is achieved by AI-powered programmability enabled by software definition, multi-service abstraction/virtualization on heterogeneous networks, and closed-loop automation to keep transport networks flexible and manageable.

Device and network programmability

Previous generations of cellular networks have relied on clearly specified device behaviors controlled by network configurations. While this does provide consistent device behaviors, it also has a key limitation: new features cannot be applied to legacy devices, limiting the speed of development.

Device behaviors can be made more programmable, making devices more future-proof and ready to support more advanced network functionalities by replacing hardcoded device behaviors with a more programmable environment (for example, defining them by different application programming interfaces

— APIs). This, in turn, would enable networks to be more programmable, since it would now be possible to fundamentally change both the networks and the devices, enabling new functionalities(such as, for example, allowing service providers to download AI models to both the devices and the networks, optimizing the overall network performance or customizing the device behavior targeting specific vertical use cases). Another aspect is that this could lead to faster feature development and time to market, faster bug fixing, and more DevOps-type operations.

Network simplification and cross-RAN/CN optimizations
With the expectation of networks becoming a more and more integral part of society comes the requirements of higher availability and resilience. Over the years, however, networks have continuously grown in functional richness as well as complexity. This has led to them supporting many different functions and sometimes addressing similar (or the same) problems, increasing the overall level of complexity. Future deployments will be less node-centric and both RAN and Core networks (CN) will have more common platforms. This removes some of the reasons to duplicate functionalities, having RAN rely on the CN as a "data store" for idle devices. Consequently, it is important to revisit some architecture assumptions behind today's functional separation between RAN and CN.

A smart choice when it comes to the right set of RAN and CN functions and interfaces is needed to provide the best performance, use cases, and deployment versatility while at the same time keeping development efforts and network operations manageable. A set of multi-vendor interfaces needs to be selected carefully so that it ensures openness in networks and the ecosystem while minimizing system complexity, ensuring the development of agility and a robust and resilient network.

Enhanced end-to-end connectivity

Future applications need to leverage high-performance connectivity, fulfilling required bandwidth, dynamic behaviors, resilience, and further demands. Network capabilities need to be available end-to-end and match the evolution of applications and internet technology. This affects, for instance, application—network collaboration, resilience mechanisms, evolution of the end-to-end transport protocols, and ways to deal with latency.

Network collaboration
Applications and networks can benefit from collaboration to ensure that the most suitable networking services are provided for different applications. The increased need for protected communications implies that any collaboration needs to be explicitly agreed, with both parties benefitting from and consenting to it.

Resilience
Network resilience will need to be addressed from different perspectives. Applications that demand resilience, both for their connectivity and their end-to-end communication, need to be supported. Similarly, the necessary internet infrastructure needs to be available, resilient, and resistant to commercial surveillance. A distributed architecture ensures that not all information (and not all risk) is centralized among a few parties.

Evolved protocols
The recent rapid evolution of web and transport protocols has resulted in the internet protocol stack becoming easier to change (for example, we can now update transport protocols without impacting operating system kernels). At the same time, we expect future communications to employ more multi-access technology and applications to come with even stricter requirements. This is an opportunity to build solutions that can handle multi-path communications, resilience, and congestion control in mobile networks more efficiently.

Predictable latency
Experience has shown that many of the (initial) use cases with stricter latency requirements often have a maximum latency that they tolerate. Achieving predictable latency will open up opportunities for testing additional use cases and support both distributed and more centralized deployment models.

Extreme performance and coverage

The future wireless access solution must provide truly extreme performance in a multitude of dimensions and in all relevant scenarios in order to enable future in-demand services at acceptable costs. This includes, for example, extreme data rates and latency performance when so required, extreme system capacity to be able to deliver the services to a massive number of users, and truly global coverage of the wireless access. The key to enabling dense deployments with extreme system capacity in a cost-effective way is to introduce packet fronthaul and new wireless transport technologies, such as relay and mesh networking, free-space optics, and further integrated access and backhaul.

Enablers for sensing/positioning
Cellular networks are widely deployed to support wireless connectivity, where the propagation of the radio waves depends on many factors in the environment. Using data analytics on the radio signals received, it is possible to sense and estimate quantities impacting the radio propagation. (For example, the received signal quality in microwave links is affected by the presence of rainfall — information that is valuable for weather forecasting.) Active sensing, where radio signals are transmitted solely for the purpose of sensing, is also possible, allowing a base station to act as a radar system in addition to serving the communication needs of an area. This can be used to build and continuously update a map of surrounding areas to, for example, detect changes in road traffic or set off alarms if a person enters a restricted area in a factory hall. Reusing cellular systems for sensing can provide more cost-efficient sensing compared to the dedicated systems specifically deployed for sensing only.

Flexible spectrum usage
Spectrum is — and will continue to be — an essential resource for wireless connectivity. Access to additional wideband spectrum as well as efficient utilization of the existing spectrum is of critical importance, and both licensed and unlicensed spectrum are of interest.

The lower frequency bands (up to around 6GHz) are currently used by 4G/5G but will remain important in the 6G era as well (to provide, for example, wide-area coverage). Since very little (if any) new spectrum is expected, it is essential that 6G radio access be able to share spectrum with the previous generations. The mmWave frequency bands in the 24–52GHz range, pioneered by 5G and likely to soon be extended up to 100GHz, will naturally be used by 6G as well.

The 7–24GHz range is currently used for other purposes than cellular communication but can be exploited for 6G by deploying advanced sharing mechanisms. Above 100GHz, there are opportunities for relatively large amounts of spectrum, but, given the very challenging propagation conditions, it is mainly of interest for very specific scenarios requiring extreme traffic capacity and/or data rates in a dense network deployment condition.

Non-terrestrial access
Extending the conventional terrestrial access to also include a non-terrestrial access component will be necessary to realize truly global coverage for future wireless connectivity. Such a complementary non-terrestrial access component may be provided by different means, including, for example, drones, high-altitude platforms (HAPS), and/or satellites. It will be an integrated part of the overall wireless access solution, providing seamless coverage truly everywhere.

Multi-connectivity and distributed MIMO
In order to enhance robustness and performance as well as ensure more consistent quality in wireless connectivity, multi-point connectivity is expected to become common in the future. Already today, technologies such as multi-radio, dual-connectivity, and multi-point transmissions are available for 5G, but we expect them to expand in the future. This might include, for instance, massive multi-connectivity on the physical layer, where devices have simultaneous physical links to a large number of tightly coordinated network transmission points (sometimes referred to as "distributed MIMO"), or multi-RAT connectivity, where devices have simultaneous connectivity to a network using different radio access technologies that may provide different simultaneous services in a more optimized way (or just improve the robustness of the overall connectivity).

Embedded devices everywhere

Future services will require connectivity everywhere and in everything. 6G networks can support trillions of embeddable devices and provide trustworthy connections that are available all the time.

"Zero-energy" devices
Today's massive machine-type communication provides data rates up to a few hundred kilobits per second, serving applications such as remote meter reading. Although their battery life can be up to ten years in some cases, battery replacement or charging limits the applicability of these devices. Energy harvesting — where a device's energy is obtained from ambient energy in the form of light, vibrations, temperature differences, or even radio waves — opens up the possibility for devices to not need battery replacement or charging. The amount of energy possible to harvest is typically very small, though, implying that extremely energy-efficient communication protocols need to be developed. Given the minuscule amounts of energy available, the amount of information that could be transmitted will be small — in many cases, only a couple of bytes per hour. For applications such as asset tracking, though, this is sufficient, and radio-based technologies could be a more appealing choice than the current solutions, such as the optical reading of bar codes or facilitating communication with items out of direct sight.

Ultra-short-range networks
Highly miniaturized devices, leveraging advances in nanoelectronics, can enable micro networks with extremely low power and range. Micro devices could be ingested or implanted to enable proactive medical care and augment human organ functionality and are expected to be built up from bio-compatible and bio-stable materials. These micro networks would consume extremely low power and could route to a full network using ultra-low-power wireless connectivity (for example, by using the 400MHz ISM band) through surface hubs that further securely communicate through an always-available link. These micro networks could be used, for example, to monitor drug dosages or the wear and tear of machine parts.

Cognitive networks

To realize future networks without accelerating levels of cost and complexity, we must raise the level of intelligence of these networks. Cognitive networks will help improve energy efficiency and ensure service availability. We expect this to occur in two ways: in optimizations that are difficult to achieve with traditional algorithms, where AI machine learning (ML) can support, and in evolving the operations systems to handle most of today's system management tasks autonomously, where AI machine reasoning (MR) can play a vital role.

Intent-based management
Humans will be able to control what systems do by stating operational goals in the form of intents. This intent-based, automated management requires a higher level of abstraction in the human-machine interface as well as the systems' ability to interpret and reason around such goals. There is a need to understand abstract knowledge and draw conclusions from existing knowledge and data sets by the use of MR techniques. Knowledge and experience will be gathered both from humans and from analytics algorithms, represented in a common knowledge base. These varying elements would then be used by a cognitive network to understand the different situations, identify suitable corrective measures and plan the best courses of action for their implementation in the network.

Autonomous system
Such an approach also implies that the system becomes more and more autonomous. A cognitive system requires native capabilities to adjust to its environment, constantly observing and learning from previous actions. Learnings from operations and service performance are fed back in short cycles or in near real time to improve configurations, processes, and software. Within the network logic, we will see a continuous improvement in algorithms driving run-time decisions distributed across physical locations and logical functions. This continuous optimization will make the system much more dynamic compared to today's system. Intelligence, in different forms, will be available all over a geographically distributed network.

Explainable and trustworthy AI
An autonomous system can only be successful if it is trusted by humans. This involves several aspects. Firstly, the system needs to be able to explain its actions and why it ended up in its current state. Secondly, the intelligent system should act lawfully, respecting all applicable laws and regulations; ethical, respecting the right principles and values; and technically robust while considering its social environment [5]. Thirdly, the system must involve humans when needed.

Data-driven architecture
Intelligence involves making decisions based on facts or data, and with more data available, better decisions can be made. Data-driven architecture is infrastructure for AI algorithms that make decisions. Such infrastructure supports data pipelines that take care of moving, storing, processing, visualizing, and exposing data from inside service provider networks as well as external data sources in a format adapted for the consumer of the pipeline.

Network compute fabric

6G will bring all physical things into the realm of compute. It will act not only as a connector but also as a controller of physical systems — ranging from simple terminals, complex and performance-sensitive robot control, and augmented reality applications — hosting computing intertwined with communication in a network compute fabric for the highest efficiency.

Service providers can utilize their assets by integrating compute and storage into increasingly virtualized networks to provide applications with maximum performance, reliability, low jitter, and millisecond latencies [6]. The network-compute fabric will thus provide tools and services beyond connectivity, such as accelerated compute and data services for customer segments and verticals, including enterprises and industries.

Ecosystem enablers
Such a system can only be realized via the collaboration of a broad set of actors working in the same federated ecosystem. Network and cloud providers, application developers, service providers, and device and equipment vendors all have a role to play. Much of the interaction between the players will happen in software, where a broker-less marketplace will help the ecosystem to scale, featuring automated contract negotiation and fulfillment supporting sales, delivery, and charging operations. Such an ecosystem can be viewed as a combination of the existing ecosystems around the air interface, the internet, and cloud services.

Unified, fluid computing
Applications developed to interact with physical reality need to be highly distributed in order to be close to data sources and data consumers, such as sensors and actuators, in the cases of (for example) radio beamforming, closed-loop control of mission-critical processes, and intelligent aggregation of large amounts of data. This poses several new challenges to computing. New ways of combining, placing, and executing software are needed to meet real-time deadlines even in the face of user mobility or failures. Stringent energy requirements will also have to be met by (for example) exposure and optimal utilization of energy-efficient, specialized computational hardware.

Application development, on the other hand, must be easier than ever. There will be a need for the ecosystem to develop new, innovative applications once more things get connected. More development flexibility will be required to meet the increasing need for highly customized applications. Common APIs and abstractions, together with new programming concepts and simplified models, will be part of the solution. Other elements of the solution will mandate DevOps-inspired ways of working across ecosystem partners, including tracing, logging, observability, and debugging capabilities for distributed applications.

A converged network compute fabric with fluid computing capabilities will complement 6G connectivity performance to reach true end-to-end guarantees for applications. The network compute fabric will offer unified interfaces for the simplified development of distributed applications along with accelerated hardware and system software infrastructure. Application deployment will happen seamlessly on this fabric, spanning central cloud, network edge, and all the way out to the devices. This will turn 6G into a true innovation platform.

Trustworthy systems

The ability to withstand, detect, respond to, and recover from attacks and unintentional disturbances is a cornerstone in designing trustworthy systems. The four important building blocks for trustworthy systems are use of confidential computing solutions, secure identities and protocols, service availability, and security assurance and defense.

AI is expected to have a major impact on future technology evolution as well as security and is expected to help in all the four areas mentioned above. At the same time, the trustworthiness of AI components also becomes important.

Confidential computing
Today's systems offer strong protection for data in transit, but data being processed and stored is less protected. For protecting data while being processed and stored, confidential computing is becoming a strong paradigm. In cloud computing, it provides hardware-based isolation for the processing of payloads, which a cloud provider cannot tamper with. It also allows remote cloud users to verify the isolated environments in which they want to place their payloads, and the verification and attestation procedures are carried out by the compute hardware itself, preventing a bypass by the cloud provider owning the hardware. The basis of these confidential computing features is part of the root-of-trust (RoT) mechanism.

Confidential computing also has the potential to enhance the security of network slices. Slices can be cryptographically isolated from each other by combining data in transit protection mechanisms and confidential computing technologies for protecting data being processed or stored. The path to secure identities and protocols depends on establishing trusted identifies for infrastructure, connectivity, devices, edge, and network slicing functions. This can be enabled by means of RoT mechanisms for identities that are established for every physical component, software function, and interface. The end goal is to create a system that offers privacy for all deployed software as well as the protection of data from unauthorized access.

Service availability
Service availability can be offered by attention to details that improve the reliability and resilience of networks as a whole. The radio link is a critical part of meeting availability requirements. Radio resilience can be improved by provisioning of adequate capacity, redundancy of coverage, and use of the diversity of connectivity and medium access control. Resource provisioning for critical services across RAN, transport, and core can be designed to allow variable grades of service and service guarantees in terms of meeting near-real-time deadlines in industrial scenarios or other critical control functions.

Another aspect of availability is to build in automated recovery mechanisms by analyzing and aggregating data from all parts of the communications system. This means that a distributed and hierarchical approach for improved observability of performance must be designed, with intermediate analytics that can validate that requirements are being met on a real-time basis. Furthermore, AI has a role to play in integrating data-driven observability to infer the end-to-end validation of service availability. Real-time analytics based on AI can similarly offer the ability to improve network resilience to dynamic changes in traffic load and radio environments, thereby providing further assurance of the reliability of performance in relation to the needs of various network slices.

Security assurance
Today, security assurance and certification are receiving a lot of attention. One example is the EU Cybersecurity Act, under which certification schemes are currently being created. Current state-of-the-art security assurance schemes (such as GSMA NESAS, for example) are good tools for providing security assurance for a specific version of a product; however, some areas need further development. Enhancements for virtualization and cloud computing, continuous integration and continuous delivery processes, and AI need to be considered. An essential aspect to consider here is that security has a much wider interpretation than just product security. Today, security assurance schemes concentrate on product security. In the future, they should be amended to increasingly consider all aspects of the system, including networks in operation. When creating security assurance schemes, it is important to establish well-defined requirements and processes that are accepted by all stakeholders. This is preferably achieved in line with global standards.

Conclusion

There is a strong upcoming need for communication on the 2030 horizon, with the transformations begun by 5G spurring increasing expectations in society, accelerated by advancements in enabling technology, and leading towards new services and use cases that will improve our lives.

Development is ramping up in formulating capability targets for the 6G era and investigating a range of promising technology components that may become part of 2030 networks. The key elements for this transformation will be the extreme performance of radio access network adaptability with global as well as pervasive reach. Going beyond connectivity, 6G should become a trusted platform for data and compute, encouraging innovation and serving as the information backbone of society.

This is the right time to initiate advanced research on 6G technology aimed at expanding the capabilities for the needs of 2030. The advancements in technology and system design can enable ever-present intelligent communication. This journey towards future networks should naturally build on the strengths of 5G, which continue to evolve in new releases, and should be taken in collaboration with the academic community and other industry partners aiming at a globally aligned way forward.

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