FIVE NETWORK TRENDS

TOWARDS THE 6G ERA

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The pivotal role that the digital infrastructure plays in delivering critical societal, economic and governmental functions has become clearer than ever before as a result of the COVID-19 pandemic. There is now a high level of awareness in both business and society that availability, reliability, affordability and sustainability are all essential aspects of the digital infrastructure that must be ensured in both the short and long term. At the same time, the cyber-physical convergence is picking up speed, highlighting the need for advanced network technologies to support use cases that blur the boundaries between physical and digital realities.

The rapid acceleration in the adoption rate of digitalization during the pandemic would not have been possible without the existing capabilities of both the mobile and the fixed communications infrastructure. Going forward, 5G will be the main digital infrastructure for consumers with mobile and fixed wireless residential access supporting augmented/virtual reality and artificial intelligence (AI) based services. For enterprises – and particularly those that are already moving to cloud services – 5G provides higher performance, edge computing, built-in Internet of Things optimization, workflow automation and network slicing for Service Level Agreement-based QoS. The desire for more advanced use cases in which the physical and digital worlds converge can already be seen in 5G and will be even more evident in the development of 6G. For example, the Internet of Senses (IoS) will augment our senses beyond the boundaries of our bodies. The network will provide cost-effective and trustworthy solutions for these use cases.

Increasing reliance on cloud technologies is going to be essential. Many network operators have already started to include cloud-native technologies in their networks – examples include the use of cloud-native standalone core and cloud RANs with an open layered architecture. Future development in this area depends on the existence of high-performance digital infrastructure functions that ensure an open, interoperable, trustworthy, secure, efficiently automated and safe physical world. Beyond exposing traditional communication services, the network will provide new features such as multisensory digital representations including context awareness and observability to support users with insights and reasoning. The distributed functions of the communication network, such as ubiquitous connectivity embedded with intelligent, real-time compute, will work in synergy with the distributed endpoints and the cloud infrastructures, forming the future capabilities of the digital infrastructure.

The foundational principle for the evolution of the digital infrastructure will be openness in technical and business interfaces, guaranteeing an open marketplace. This openness will be instrumental for independent innovation both within and on top of the digital infrastructure, enabling the future business platform. The ecosystem will evolve through business-driven investments, strong partnerships and openness in the digital infrastructure.

In last year's technology trends article, I stressed the importance of the network as the spinal cord of the digital infrastructure and argued that it is the ideal platform for innovation for an intelligent, sustainable and connected world. This year's article focuses on the fundamental network functions related to digital representation that enable the communication paradigm for the networked reality. I have grouped all of these functions together in trend 1, under the heading digital representation for the networked reality. Trends 2-5 are the main network building blocks that will ensure the provision of the required capabilities and services, namely: adaptable limitless connectivity, integrity of trustworthy systems, federated cognitive networks and a unified network compute fabric.

TREND #1:
DIGITAL REPRESENTATION FOR THE NETWORKED REALITY

With 5G, we already enable physical and digital worlds to converge into an augmented reality that serves communication needs for humans and machines. As humans and physical objects are only able to experience the physical world in a local context, the local presence of sensors, actuators and networks is a crucial enabler. The convergence of physical and digital worlds is enabled by digital representations of both humans and physical objects as well as their environments.

Data from embedded sensors and actuators enables the digital observability of the environment and physical assets. The future network will provide low-level processing of billions of different data streams from sensors and prepare them for applications. The preparation will handle aggregation, filtering and fusion of the data streams. Processes are monitored in real time, and actuators will enable autonomous operations. To further improve observability, the network will generate sensory data such as identity, positioning, time stamps and spatial mapping information. While 5G enables the basic functions, 6G will provide enhancements across these domains. The following functions and capabilities are the most crucial in the development of the future network platform.

Network-aware rendering and synchronization

Some use cases require upper-bound guaranteed end-to-end latency. As the network is context aware, from the capabilities of spatial mapping and dynamic object handling, rendering algorithms provides the dynamic latency and control required to optimize the quality of the user experience. The optimization includes synchronization between all sensory modalities and digital objects in the physical environment.

Collaborative contextual awareness and observability

Connected intelligent machines rely on contextual awareness and observability to relate to, and cooperate with, other machines nearby. This includes the registration and tracking of physical trajectories, intents and capabilities, for example. The network will serve intelligent machines through a context fabric of contextual information including real-time

KEY USE CASES

Three key use cases are driving the networked reality: the digitalized and programmable physical world, the Internet of Senses (IoS) and connected intelligent machines.

1 THE DIGITALIZED AND PROGRAMMABLE PHYSICAL WORLD

In the future, every physical object – including intelligent machines, humans and their environments – will have a digital representation, and the physical world will be fully programmable and automated. The digital representations will manage and process data both individually and collectively for prediction and planning in relation to the physical world. The generated insights will impact the physical world through orchestration, actuation and reprogramming.

2 INTERNET OF SENSES

The IoS makes it possible to blend multisensory digital experiences with local surroundings and interact remotely with people, devices and robots as if they were nearby. Essential components to realize digital sensory experiences close to those experienced in the physical world are visual, audio, haptic, olfactory (smell) and gustatory (taste) sensing and actuation technologies.

3 CONNECTED INTELLIGENT MACHINES

Connected intelligent machines are physical objects and software agents operating and performing tasks in both the digital and physical realms. They are connected to applications, users and each other in collaborative and aggregate structures. As collaborative capabilities advance, the need for communication capacity and functional capabilities increases exponentially, and new digital and diverse interaction patterns will be generated. Further, connected intelligent machines will be increasingly dependent on awareness of both the physical and digital contexts in which they act.

processing of such contextual information. The context fabric thus provides validated information to the collaborative machines about their personas and capabilities, as well as contextual data.

Interoperability among machines and devices

Diversity among connected intelligent machines and devices leads to heterogeneity in terms of semantic descriptions and information formats, and mediation and interoperability are thus required between them. The optimization of communication between machines and devices calls for syntactical and semantic interoperability, as well as programmability between different protocols and models. The network communication stack will provide support for this, thereby off-loading the issue of interoperability.

Real-time positioning

Physical and logical positions as well as time observations will be essential for relating the digital representations to the physical world, thereby generating digital context awareness. Such context-aware data needs to be presented in a uniform and standardized format to enable usage across platforms and to operate and manage systems of systems. This also enables marketplaces for continuously updated observations, models, lessons learned, insights and other digital representations in real time.

A key network feature is the coordination of safe, collaborative autonomous operations by real-time positioning of physical objects in a dynamic environment. The network also provides secure identification and authentication of objects and their related data for integrity and privacy. This enables the secure control and actuation of physical objects, taking into consideration regulations, policies and roles. These network abilities will be key enablers in the foundation of a trustworthy cyber-physical world.

Spatial mapping

Spatial maps are created by collecting and fusing sensor data from all network-connected devices – such as cameras, lidars, radars, gyroscopes, accelerometers, level sensors and pressure sensors. These network-generated maps are used to correctly position the digital objects to the physical environment, thereby enabling multiuser interaction. This network feature will handle relevant spatial mapping processing to reduce form factors, power consumption and cost on IoS devices. Spatial maps will initially focus on visual representation and will, over time, be extended to spatial sound, touch, smell and taste.

Dynamic object handling

Based on spatial maps, the network will perform dynamic object handling and real-time tracking to merge the physical environment and digital content. Dynamic object handling will be particularly important for advanced occlusion, un-occlusion and the continuous update of moving objects in high-resolution spatial maps. For example, in a fire-rescue operation, un-occlusion of smells and temperature could be used to localize a trapped human. Other features include the ability to collect spatial data to generate personalized user experiences and enable context-aware communication.

Embedded data processing and enrichment

A fundamental capability of the future network is a lightweight pervasive data-processing fabric providing the right data pipeline and compute characteristics. As the connected intelligent machines, devices and sensors will generate massive data and information streams, the network will provide adequate processing for the preparation of data, metadata extraction and annotation. Further, in-network stream processing and enrichment such as event detection, filtering, inferencing and learning, as well as sensor fusion, will be provided and exposed. This in-network stream processing will be supported by specialized hardware acceleration embedded in the network. Data formats and new compression algorithms will be optimized for the need of machines rather than for human consumption and processing. The necessary transcoding and compression algorithms will be embedded in the network.

In addition to the network functions and capabilities described above, the realization of digital representation for the networked reality at scale will also require end-to-end solutions across the digital infrastructure of devices, edges, networks and clouds. As digital representations can include sensitive information, standardized, interoperable and secure use of collaborative spatial maps are prerequisites to build trust, making them a good example of an area that will benefit from ecosystem collaboration and innovation. We will promote openness and close collaboration within the global ecosystem to form the future business platform for innovation.

Technological advances in four key areas are essential for the future network to support the convergence of the physical and digital worlds, namely: limitless connectivity, trustworthy systems, cognitive networks and the network compute fabric (trends 2-5).

TRENDS 2-5:

BUILDING BLOCKS OF THE NETWORKED REALITY

TREND #2: ADAPTABLE LIMITLESS CONNECTIVITY

One of the primary goals of 6G access is to deliver adaptable limitless connectivity that ensures the development of an agile, robust and resilient network. Users and applications should focus on the task at hand anytime and anywhere, while the network should be able to adapt and support their needs. Multi-vendor interfaces will ensure openness both in networks and in the ecosystem at large while minimizing system complexity.

Network adaptability

Solutions that ensure dynamic and flexible site deployments are essential for future high-capacity, resilient networks. Different types of nodes, including ad-hoc and non-terrestrial ones, will be seamlessly integrated. For smaller sites with limited reach, the network topology will evolve with multi-hop routing capabilities leading to cost-effective network densification, as dedicated transport links will not be needed.

High-performance, flexible, scalable and reliable transport will allow heterogeneous deployment scenarios for the whole network. For example, it will simplify the integration of distributed and centralized radio access, as well as public and non-public networks. To keep transport networks flexible and manageable, AI-powered programmability will be used for closed-loop automation and multi-service virtualization.

Device and network programmability

Devices will become more future-proof and be able to leverage more advanced network functions through programmability. Device programmability will include downloadable software stacks and configurable AI models. At the same time, the programmable network functionality will support updated and new device features, resulting in optimized customization of individual devices for specific use cases, as well as faster feature development and time to market.

End-to-end availability and resilience

To meet availability and resilience requirements, the network will be simplified, with fewer node-centric deployments and functional separations between the radio access and core. Standardized multi-vendor interfaces will ensure ecosystem openness while minimizing complexity.

Networks and applications will collaborate to ensure end-to-end performance and the provision of the most suitable services to different applications. Resilience mechanisms and end-to-end transport protocols are good examples of functions that support collaboration with applications. These end-to-end support functions will evolve with the needs and requirements of the applications, such as transport protocols that can handle multi-path communication and intelligent congestion control. To support upper-bound latency application requirements, the network will provide predictable latency with low latency variation.

TREND #3: INTEGRITY OF TRUSTWORTHY SYSTEMS

6G networks will support trillions of embeddable devices and provide trustworthy, always-available connections with end-to-end assurance to mitigate the widened threat space. An essential feature of the network will be to provide secure services by managing and verifying compliance to security, safety, resiliency and privacy demands. Automation that utilizes AI technologies will be used in the whole product life cycle covering development, deployment and operations. AI technologies will also be used for automatic root-cause analysis, threat detection and response against attacks, as well as unintentional disturbances. These technologies will also enhance service availability.

Confidential computing

Secure cloud and edge systems have strict protection requirements for the execution of sensitive code and data in virtual execution environments. Trustworthy confidential computing features will provide isolated execution environments using encryption and cryptographic integrity protection. This will require specialized hardware and remote attestation by users to verify that their applications execute on genuine and properly configured hardware, enabling hardware root-of-trust and secure bootstrapping of the virtual execution environment.

Evolving technologies like homomorphic encryption, which permits users to perform computations directly on encrypted data, as well as multiparty confidential computation, where data privacy between participating parties is secured, will become available.

Confidential computing technologies can also be used to overcome privacy concerns when performing processing on the cloud and edge.

Secure identities and protocols

The network will provide root-of-trust to secure identities in the highly dynamic and distributed virtualized environment. Secure identities form the baseline for identity management and enhancements to privacy-preserving protocol stacks, which will enable the monitoring and compliance verification of the entire network as well as all connected physical objects and software agents.

Zero-trust architecture

A zero-trust architecture is foundational for facilitating secure access to network resources that is limited to authorized and approved clients. Zero trust is an identity-centric approach by which dynamic policy authorization is executed in runtime. Humans supervise the integrity and security posture of all owned and associated assets.

Service availability assurance

Service availability starts with ensuring the integrity and reliability of the hardware and software components and the consistency of behavior of each service in the operating environment with the assigned network resources. One example is the trade-off between system capacity and performance in the radio access to mitigate the effects of environmental and traffic variability for critical services.

A predictive analysis framework for data-driven operations and real-time policy management will provide real-time composite metrics to secure service availability and to inform critical services about functional safety risks. In addition to the network metrics, users can also share their intentions to further enhance their service availability.

TREND #4:
FEDERATED COGNITIVE NETWORKS

Continuing along the 5G network automation path, the future network will become cognitive by observing and acting autonomously to optimize its performance. Cognitive 6G networks will enable full automation of network management and configuration tasks, allowing operations and maintenance personnel to supervise the network.

A set of distributed intent managers will be embedded in the network. Each intent manager is controlled by intents that specify expectations including requirements, goals and constraints. An intent manager includes cognitive functions that observe the environment under control and draw conclusions from the acquired data. This implies a reasoning process with the purpose of taking action to fulfill the expectations of the intents. Humans will express intents to control the network.

The cognitive functions use AI features to draw conclusions from raw data. Examples of such features include machine-learning models that can produce insights and machine-reasoning capabilities to execute on intents. Further machine-reasoning and multi-agent reinforcement-learning technologies are candidates to enable collaborative closed-loop functionality.

Trustworthy AI ensures that transparency is built into the network, so that humans can understand why certain actions are taken or why certain conditions cannot be met. One technology for implementing trustworthy AI is Explainable AI, an approach that aims to provide an easily understandable explanation of what an AI outcome is along with the rationale behind it. The implementation of cognitive functions is enabled by an underlying data-driven architecture that includes efficient and secure data ingest. An essential part of the intent manager will be the knowledge base, which is where the knowledge of the cognitive functions resides.

TREND #5:
A UNIFIED NETWORK COMPUTE FABRIC

The convergence of internet, telecom, media and information technologies will lead to the creation of a unified, global system of interconnected components. The network compute fabric facilitates unification across ecosystems, application management, execution environments, and exposure of network and compute

PROOF OF CONCEPT

Ericsson is engaged with the automotive industry in a proof of concept for automated transport robots on a wireless factory floor. The solution will move relevant application-related processing from the connected devices into edge compute capabilities. The cloud-based software stack and related services have been significantly adapted for deterministic real-time performance. To fulfill the industrial requirements on availability and reliability, the integration of the solution into the 5G connectivity network is underway. The network compute fabric is embedded with deterministic computation capabilities to manage event-to-actuation in a fault-tolerant manner for safe and accurate operations.

capabilities. 6G will act as a controller of the network, covering applications ranging from simple devices to advanced cyber-physical systems. At the same time, 6G will integrate storage, compute and communication to create a distributed unified network compute fabric. This fabric will give service providers access to tools and services beyond connectivity that can be made available to the open marketplace.

Future use cases such as the IoS and connected intelligent machines will be highly distributed with demands on guaranteed low deterministic latency, high throughput and high reliability. The network will complement the connectivity offering with an embedded, unified execution environment that hosts and manages these types of use cases. Hardware and software acceleration, time-sensitive communication technologies such as time-sensitive networking and ultra-reliable low latency communication, as well as timing-aware features will enable guaranteed end-to-end timing and reliability.

Considering the billions of sensor and actuator data streams, in-network stream processing will be provided by deterministic compute capabilities available through interoperable application programming interfaces. In conjunction with the preparation of information such as the provenance of data, metadata extraction and annotation, a lightweight pervasive data pipeline and compute fabric will be provided. Further, the network will provide application deployment, scaling and resource allocation in a serverless fashion to support the execution of all the possible sensor and actuator functions of the future.

This compute fabric will evolve around a federated ecosystem involving actors and users of the air interface, the internet, cloud services and devices. The scale of the ecosystem will require wide usage of bilateral agreements between ecosystem actors. The compute fabric will offer a decentralized and broker-less exchange for virtual services, including identity and relations handling. Smart contract technologies such as distributed ledgers will automate contract negotiation between parties supporting as-a-service delivery models like automated sales, delivery and charging.

Current roaming models for voice and data will expand to include smart contracts for the federated ecosystem. Together with our academic partners, we are conducting research to address the security, confidentiality, privacy and provenance of these types of broker-less exchanges.

Conclusion

The digital infrastructure enabled by 5G and 6G has a critically important role to play in enabling the emerging cyber-physical convergence, particularly with respect to its ability to reach a massive scale. Advanced capabilities and features embedded in the network, such as full real-time spatial mapping and context-aware user data, will be foundational to the next wave of digital transformation. The worldwide system of interconnected physical objects and software agents that emerges as a result will make it easy to integrate entities from different domains to form various systems of systems.

The digital infrastructure will enable the continuous optimization of all digitalized solutions for the benefit of society and business, not only to continuously improve efficiency and comfort, but to minimize environmental impacts as well. With all of this in mind, I foresee unprecedented growth and adoption of digitalized solutions in the years ahead, across virtually every sector of business and industry, as well as in the consumer and public domains. The digital infrastructure will grant access to new and increased revenue streams for all enterprises and industries on a global scale.

It is important to note, however, that the innovation required to develop the capabilities to enable intellectual exchanges between humans, machines and software agents demands new forms of collaboration across the ecosystem. Reaching the full potential of this networked reality will therefore require new collaboration frameworks between vendors, industries and society to ensure fairness, trustworthiness and interoperability. 6G offers a broad platform for innovation and is ideally suited to become the information backbone of society.

The networked reality will be based on a global platform with the responsibility to guarantee performance, integrity and openness in technical and business interfaces, ensuring an open marketplace. It will evolve through business-driven investments and collaborations. Ericsson's investments in 5G and 6G represent our primary contribution in the realization of the networked reality. With regard to collaboration, our approach is driven by our firm belief that the development of the future business platform for a converged cyber-physical world requires deep, long-term engagement with the ecosystem. At Ericsson, we are committed to working together with partners old and new to make this happen.

As Group CTO and Head of Technology and Strategy, Erik Ekudden is responsible for setting the overall strategy and direction of technology leadership for Ericsson. In 2017, he relocated to Kista, Sweden, after nearly seven years in Santa Clara, California.

His focus for the group is on strategic decisions and investments in mobility, cloud, artificial intelligence and the Internet of Things. This builds on his decades-long career in technology strategies and industry activities with leading customers and partners from 2G to 5G and beyond. Ekudden first joined Ericsson in 1993 working on mobile systems, but rapidly moved into leadership within research and technology. He has served as research area director and vice president of technology strategy, standardization and industry.

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Further reading

- Ericsson white paper, A research outlook towards 6G, available at: *https://www.ericsson.com/en/reports-and-papers/white-papers/a-research-outlook-towards-6g*
- Ericsson Technology Review, The network compute fabric – advancing digital transformation with ever-present service continuity, June 30, 2021, Sefidcon, A; John, W; Opsenica, M; Skubic, B, available at: *https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/network-compute-fabric*
- Ericsson, 10 Hot Consumer Trends 2030, available at: *https://www.ericsson.com/en/reports-and-papers/consumerlab/reports/10-hot-consumer-trends-2030*
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