# Network 2030

## A Blueprint of Technology, Applications and Market Drivers Towards the Year 2030 and Beyond

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## Executive Summary

The decade preceding 2020 witnessed not only an Exabyte of data transmitted over networks, but more importantly the advent of autonomous vehicles, beginning of an era of sensors, IoT, and an onset of immersive media. Collectively, it created billions of new connected end points, with varying sensitivity to different kinds of resource requirements. It exposed several deficiencies in current network technologies, especially in wireline networks. As a society we strive for the possibilities of high-resolution immersive multimedia over the Internet, smart IoTs, factory automation, and autonomous vehicles to become real. The role of Network 2030 is to identify the right set of network technologies required to deliver these applications. To be exact, it is scoped to serve up the communication needs of our society in the year 2030: its purpose remains to address new capabilities of both public and private wireline or fixed networks.

The fusion of digital and real worlds across all dimensions is the driving theme for Network 2030. We expect to see lots of automation. A hyper-scale of things will operate at the system level, not in isolated environments such as private networks: this will demand coordination of distributed intelligence all over the connectivity fabric. It will be necessary to deliver information in fractional units of time between machines, robots, and their virtual counter parts to support autonomous operations safely.

The question then is, can we continue doing more of the same and still deliver the promise of new verticals? Perhaps not. The shape of the Internet hasn't changed much since the 1980s, but the manner in which it gets utilized is an ongoing race between the cost and complexity of delivering services. It is known that the Internet does not support fundamental services, such as those requiring strict performance, that are essential for the above suite of applications.

One of the key differences between today's networks and future networks is that the latter will be based on entirely new technologies, in both hardware and software. These will need to be interoperable with the current generation and forthcoming generations and new formations of space networks. Network 2030 is an abstraction, both above and across different types and generations of communication technologies.

The scale of the challenge means it's unlikely that a single telecoms operator or content provider will be able to manage the entire process, from researching and testing through to implementation. Simultaneously, the boundary between IT and telecommunications is disappearing. The proliferation of individual public and private networks, in many cases created and delivered by non-traditional Converged Service Platforms, further amplifies the complex nature of networking well into the future. The successful development of network 2030 and beyond capability therefore, requires access to large scale physical and virtual development and testing facilities, with embedded state of the art measurement.

Without cross-industry and cross-sector collaboration there is a real risk that future network technology deployment is undertaken in an un-coordinated way, where the impacts are evidenced in live network failures, in siloization and performance issues, through impediments to the adoption of digital services, in lowered productivity, and through the undermining of public confidence. Strategic cross-sector collaboration between operators, technology companies, vendors, service providers, academia, standards bodies and forums, and government agencies will be essential, as well as access to the necessary facilities and resources to develop the future network's capability.

This white paper describes the Network 2030 initiative and provides a comprehensive analysis of the applications, the network, and the infrastructure in that context.

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# 1 Introduction

In recent years, the innovation in the field of cloud computing, high-resolution multi-media, mobile networks, sensors technologies etc. facilitated an entirely new set of applications and industry verticals. Today, a year short of the next decade, we find ourselves at the transformational stage where application developers do not hesitate to use technologies from as many disciplines as possible. They do not discriminate whether those applications will be used by human beings, or by physical, digital, or virtual objects.

In the age of rapid advances in technologies, network community is grappling with a persistent challenge to comprehend what are the demands of each market segment and how to identify what networks need to do in order to meet the asks from new industry verticals that did not even exist just three years ago.

We cannot possibly list every single requirement from the applications that will emerge from Industry 4.0, entertainment, autonomous communications systems, smart cities, remote healthcare etc., and claim with confidence that the current network can support them without major changes. This is where Network 2030 comes in.

The Network 2030 initiative steps back and studies what role networks will play in our society few years down the road. What are the applications that are expected to mature and be realistically available in the time frame of next ten years or so?

Yet, the most critical challenge is to project a decade ahead how our society will absorb the next steps in digital transformation and the interplay of human and machine intelligence. What applications will use technology for the betterment, safety, and well-being of human life?

Network 2030 initiative does this groundwork. It does so by examining three independent characteristics relevant to the networks. The first characteristic is the emergence of new verticals powered by autonomously operating machinery in the industry and by near-real-time experiences in personal communication using holograms as new fundamental media-objects.

The second characteristic is about the development of new communication services: Network 2030 develops a model to offer new type of in-network services that enable applications to interact with networks more intelligently and with high-precision. Today, the network resource demand is of basic connectivity and capacity. For emerging applications this, alone, is not sufficient; the network needs to be concerned with time as well because the success of several new verticals will depend on timeliness of data arrival times. A formalization of new services is the key differentiator of Network 2030 versus the current network.

The third and final characteristic relates to a harder discussion about the emergence of new network infrastructures – terrestrially, over the air, and in space. The goal is not to examine these technologies, but to grasp what constraints or opportunities a user would need to be aware of when retrieving information.

We hope that the standards developing organizations, public-private partnerships and industry alliances understand the significance of planning ahead with the Network 2030 capabilities and identify opportunities for themselves: that they build strategies to innovate and lead new markets; perhaps that they use new technologies with Network 2030 for increasing productivity and operations in their business.

# 2 Emerging Applications and New Business Cases

The next frontier in multimedia after Augmented Reality and Virtual Reality (AR/VR) will include Holographic media and multi-sense including haptic communication services. Soon our experiences with AR/VR will determine that they are not real-enough, calling for a new media, unencumbered by HMDs, that is far more engaging and realistic because of its true rendering of an object. Holographic media applications are not limited to the realm of entertainment and teleconferencing, but more interesting applications begin to emerge, some of which are life-impacting (such as tele-surgery) while others provide a superior engaged experience (remote holographic presence).

## 2.1 Holographic Type Communications

Holographic display technology has made significant advances in recent years, from lightfield displays to different kinds of HMD. With the science and technology to construct and render holograms being well understood, the holographic applications are well on their way to becoming a reality. Those applications will involve not only the local rendering of holograms but networking aspects, specifically the ability to transmit and stream holographic data from remote sites, referred to as "Holographic-Type Communications" (HTC).

Far from being just a technological gimmick, HTC has plenty of useful applications. For example, holographic telepresence will allow remote participants to be projected as holographic presences into a room. Conversely, **immersive holographic spaces will render artefacts from a distant location into a room, rendering local users into the remote location**. Remote troubleshooting and repair applications will allow technicians to interact with holographic renderings of items at remote and hard-to-reach locations, such as on an oil drilling platform or inside a space probe. Holographic signage which renders holographic content that is centrally managed and distributed presents a natural next step for digital signage. Training and education applications can provide remote students with the ability to engage with the objects and other pupils for active participation in the classroom. In addition, possibilities abound in the areas of immersive gaming and entertainment.

Figure 1:Pervasic Holographic Media

For HTC to become a reality, there are multiple challenges that future networks will need to address. They need to provide a very high bandwidth due to the large data volumes involved in the transmission of high-quality holograms. The "Quality" of a hologram involves not just colour depth, resolution, and frame rate as in video, but it also involves the transmission of volumetric data from multiple viewpoints to account for shifts in tilt, angle, and position of the observer relative to the hologram ("Six Degrees of Freedom"). The streaming of underlying volumetric data and image arrays imposes additional synchronization requirements to ensure smooth viewing transitions for the user.

Going beyond the streaming of holographic information itself, some applications may additionally combine holographic images with data from other streams. For example, holographic avatars may be able to combine a holographic image with an avatar. This allows an entity to not just be projected or rendered from a remote site, but to feed information back to that entity from that remote viewpoint. For example, a video and audio stream may be derived from the point of view of where the hologram is projected. This could be accomplished by superimposing holograms over corresponding cameras, microphones, or other sensors. For this to work requires tight synchronization across multiple data streams, but the result will be applications that provide an even more realistic sense of user interactivity.

A second set of extensions concerns combining HTC with tactile networking applications, allowing users to "touch" a hologram. This opens up new possibilities for applications such as the ones mentioned for training and remote repair. Tactile networking applications impose requirements of ultra-low delay (to provide an accurate sense of touch feedback) on underlying networks and, in particular as far as mission-critical applications such as remote surgery are concerned, tolerate no loss. Coupling tactile networking with HTC introduces additional high-precision synchronization requirements to ensure all the various data streams are properly coordinated.

## 2.2 Multi-Sense Networks

When discussing networking applications that involve not only optical (video, holograms) and acoustic (audio) senses, but touch as well (tactile), the question arises: why stop there; what about the other senses? Indeed, to create fully immersive experiences, it would make sense to also involve the senses of smell and taste.

Unlike vision and hearing, smell and taste are considered "lower" senses. They generally do not command focus of attention or guide human activity, but are more related to feelings and emotions. These are "near senses" in that their perception involves a direct (chemical) reaction of the agent that is being perceived with a receptor. In contrast, far senses (hearing and sight) allow perception from sources that are remote, with artefacts transmitted by waves, not chemical or physical reactions. The fact that chemical reaction is involved creates a significant hurdle to overcome, namely the problem of how to construct effective actuators. Some limited successes have been achieved using "digital lollipops"[1], devices inserted into the mouth that deliver small currents and differences in temperature to the tongue's papillae (taste sensors) to simulate sensations such as sourness, saltiness, or sweetness. Smell constitutes an even more challenging problem. Some researchers have proposed "transcranial stimulation", i.e. a set of electrical magnets (e.g., incorporated into a headset) to deliver stimuli to areas in the brain responsible for creating sensory sensations.

Even more than the networking industry, the food industry is very interested in breakthroughs in this area. For example, the ability to generate "digital sweetness" promises the ability to cut down on the use of sugars or artificial sweeteners. While true breakthroughs in actuators that convey a digital sense of smell and taste seem at this point far away, assuming those hurdles can be overcome, there will clearly be interesting potential networked applications. For example, remote learning solutions as well as digital advertising may exploit the fact that memory retention can be improved by association with smells and tastes. Digital experiences can be enhanced, in particular as smells and tastes can evoke or amplify emotions. For example, certain images could be associated with a certain scent. Cloud-based medical

[1] http://www.nimesha.info/lollipop.html#dtl

solutions could generate bitter tastes from remote locations to prevent the intake of certain foods at certain times as part of a dietary regimen.

In contrast to the actuator problem, requirements imposed by sensory applications on the network can be expected to be reasonably straightforward to support. To communicate data for taste and smell, it is sufficient to communicate the data that is actually in contact with the taste or smell receptors – the taste and smell in and by itself, not the taste and smell as emitted by any one of many objects in an environment. For example, to communicate a particular taste in a scene, it is not necessary to communicate what every "pixel" of every object potentially tastes like. This is different from vision, where every object in a scene will reflect light that is perceived by the end user. Although there are additional factors that influence the sensation of taste, such as texture, given that the number of receptors in a tongue (around 8000) is about 4 orders of magnitude fewer than the number of receptors in an eye's retina (around 150 million), the volume of "taste" data that needs to be transmitted will be dramatically lower than what is required for the communication of images. In addition, as detection of a taste in the human body can take as much as a second, no particular requirements are imposed concerning support for ultra-low latency. Similar considerations apply for scent data, despite the fact that the delay involved in detecting scents by a person is significantly lower.

## 2.3 Time Engineered Applications

Human intelligence naturally adapts to disruption and unpredictable events and can tolerate some delays in the delivery of information. We have adapted to best-effort network services, waiting for reconnections, and retrying upon failures, and we are able to handle voice or video communications that suffer lost packets or considerable jitter. However, during past decades as technology has advanced, our dependence on communication networks has grown. As we incorporate more devices and gadgets, quick responses and real time experiences have become the prime factors for smooth functioning in daily routines.

In particular, when we consider market drivers such as industrial automation, autonomous system, and massive networks of sensors where humans are not an endpoint, the time-factor becomes even more significant since **most machines are not programmed to adapt: they are purpose built for specific tasks and deterministic control loops**. Precision engineering does not require learning, the devices in the system must comply to timeliness. That is why, time-engineered communication has to be a prominent theme of Network 2030.

What indicates a higher degree of difficulty is the type of time attributes Network 2030 is concerned with. It is not just about relative characteristics like fast or slow, but concerned with the precise time of an event or data delivery.

Energy efficiency and machine utilization are extremely relevant to the economics of manufacturing in industry automation. Utilization is maximized when wait time of each piece of equipment is close to nil, and energy is saved as retries are eliminated. The tiny connected entities in the industrial Internet, such as Programmatic Logic controllers (PLCs), sensors, and actuators have to perform with time accuracy in the lower digits of 10 milliseconds, and many times sub-millisecond accuracy may be required.

Similarly, autonomous traffic systems, even in a small radial distance of two miles, will have connected endpoints in the order of tens of thousands of vehicles, traffic signals, content, and other components. To harmonize the operation of such densely inter-connected machinery, the on-time delivery of information is necessary. In this case, knowing at what exact time the information arrives is useful: anything arriving early or late is meaningless.

Creation of identical digital environments in multi-party applications like online gaming or remote collaborations will require true synchronization of objects in the frame of reference at multiple sites. A new set of challenges emerge when movement of a physical object will need to be coordinated in time across sites served by communication links that operate with varying latencies.

As the boundaries between digital and real-world objects blur, **we need a communication system that can coordinate between different sources of information such that all the parties involved have synchronized view of the application**.

## 2.4 Critical Infrastructure

Critical infrastructure refers to those essential assets that are considered vital to the continued smooth functioning of the society as an integrated entity.

While cyber- and IoT security are the focus in current ICT systems, expectations to protect and safeguard society from emergency situations by means of technological advancements are anticipated to grow in the next decade to the extent that new capabilities will need to ensure the safe rescue of the subjects in any place at any time in the event of any kind of emergency. Identifying those capabilities is also one of the primary goals of Network 2030. Looking ahead, the critical safety operations need to consider all the features of the subjects who are in the emergency area. For example, to always have location available until rescued, pointing it at the subject's networked device with reference to an area map, accessed via a safe-path navigation capability, and providing the necessary courses of action.

In particular Network 2030 must identify how a subject associated with a terminal (such as a phone or a tablet device) will use services developed by specialists of those emergency situations for this subject and for this type of emergency. Obviously, time centric services mentioned earlier are the enablers; in addition, it has to be further studied what is entailed to develop such services over heterogeneous, independent infrastructures. The problem that such services could solve becomes more acute and more urgent every year equally for developed and developing countries. This is due both to natural causes and to the main directions of development of the world: there is an observed increase in the activity of global processes, such as earthquakes, floods, etc.; there is a trend towards urbanization of populations; there is deepening in cooperation within and between nation states, which intensifies the counter flow of goods and population; and there is a growth in the use of the territories of countries located in the subtropical and tropical zones as resorts and recreation areas.

The systems[2] developing such services are looking at advanced applications such as remote holographic presence, augmented reality and virtual reality, and tactile networking applications. They also benefit from involving the senses of smell and taste, etc.

# 3 Network 2030 Impetus

There is an increasing emphasis on the '**Digital Society**' and the importance of the Internet technologies in such society began as early as 2014[3]. More recent initiatives such as on the Next Generation Internet[4] places the **citizen** and **humans** at the very center of future communication network research, i.e.,

[2] Sarian V., Nazarenko A. Presentation «Mass service of individualized control for the population rescue in the event of all kinds of emergency situation», 2019

[3] Networld2020 European Technology Platform, "5G: Challenges, Research Priorities, and Recommendations", available at https://www.networld2020.eu/wp-content/uploads/2015/01/Joint-Whitepaper-V12-clean-after-consultation.pdf, 2014

[4] https://www.ngi.eu/

increasing the penetration of network technology in all aspects of human interaction with an increasing focus on new media, including holographic approaches, driving the need for more capacity and increased network capability. Current evolutions in both fixed and radio access networks, play a crucial role in having leaped from Over-The-Top (OTT) Internet approaches in previous generation (e.g., with the optimization of video OTT experiences in current 4G networks) to deep penetration into networked verticals, many of which are not part of the (public) Internet yet utilizing internet (working) technologies, many of which stem from the Internet area. *We strongly believe that this penetration is going to increase with almost every part of today's life being impacted by networked technologies with a need to think about the new communication services and infrastructures supporting those for Network 2030.*

## 3.1 A Stalling or Invigorated Market

What drives the penetration of networking technologies is the ever-increasing **bandwidth** capability at the local level but also new capabilities, on lower **latency** and higher **reliability**, targeting interactive as well as industrial use cases. Advances are being made in all types of access technologies, such as Passive Optical Networks (PONs), DOCSIS, DSL, cellular communications, and satellite-based communication. *We see this evolution of different access technologies as likely to continue, driving the need for a unified way of offering new capabilities as described later.*

Cost of providing communication solutions has always been critical, both at the CAPEX and OPEX level. On the one hand, the increasing softwarization of previously specialized hardware capabilities, e.g., with the advent of software-defined networking (SDN), has aimed at driving the OPEX reduction through faster software updates (rather than costly hardware replacement) and utilizing the programmability to address wider use cases with the same hardware platform, while the utilization of common-off-the-shelf (COTS) hardware has targeted CAPEX reduction by allowing to move away from specialized hardware platforms in parts of the network infrastructure. On the other hand, communication technologies have increasingly contributed to the overall energy consumption, increasing the pressure for cost-effective and energy-reducing solutions. *We believe that this cost and energy pressure will only increase in future communications.* The above situation creates an **increasing chasm** between the desire to push communication technologies into all aspects of life, while being increasingly conscious of the price to be paid in terms of energy and cost as well as the ability to provide suitable communications to accompany the evolution of the ever-richer communication technologies.

This dichotomy is captured in the figure on the right through a situation where we see the trend of increasing penetration of communication either **stalling** or being **invigorated** by innovations in the right communication technologies

*We strongly believe that relying on the current network technologies will accelerate the stalling, while addressing crucial shortcomings of the Internet will ultimately lead us towards realizing the use cases for Network 2030.*

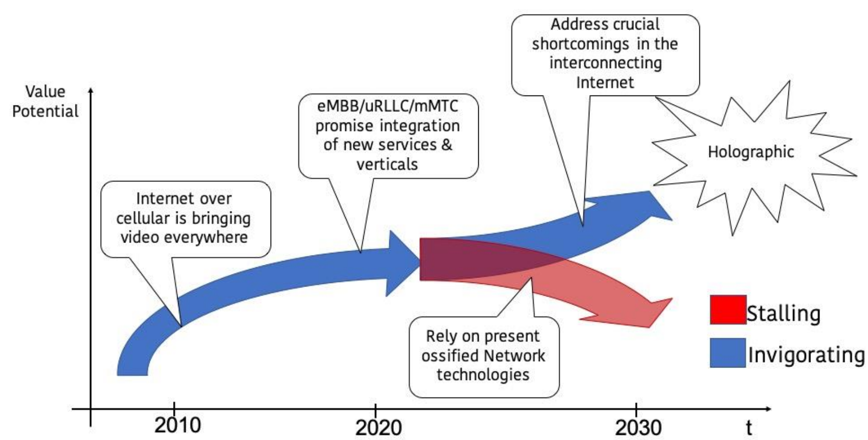

Figure 2: Opportunities of Challenges towards Network 2030

## 3.2 Gaps & Challenges in Today's Communication Services

The Network 2030 initiative is a structured approach to defining the capabilities of networks and corresponding communication services for the decade following 2030. The goal is to have networks ready for the market verticals that will utilize emerging technologies in 2030. Network 2030 extrapolates from what we know about technologies and develops a vision of the new media, new services, and new infrastructure. For this, we outline a few areas of importance to address towards building this vision.

**Lacking service-network interaction:** Failure to find an ordered and healthy relationship between the applications and the network has been a sticking point. Connectivity is just one of the workflows involved in application logic. It is a service consumed, with reachability being the only explicit means of setting up the application behaviour in the networks. However, a number of services offered by networks are not obvious to the end user. These include reliability of the network fabric, broadcast or multicast, integrity and security of data delivered, and network level awareness of congestion, capacity, and latency. Accommodating for such capabilities directly in the networks have been much of the focus of industry for the past thirty years. *Due to lack of direct support for such services through proper interfaces to the network, application developers have been left in a limbo, designing for every conceivable possibility of network failures and outages*. Many of these services are controlled over end-to-end interfaces between the endpoints using the transport (TCP) layer which is another example of free-form evolution aiming to solve the problems of the network without sufficient assistance from the networks.

**Readiness for Holographic and multi-sense media:** The amount of data necessary to stream holographic media can easily approach the scale of gigabytes per second even after compression. The challenge with commoditizing holographic media-aware applications (holo-apps) involves several stake-holders. Almost every conceivable use of holograms requires network connectivity. Besides on-premises generation and display of holograms, the applications will need to locally render a dynamic and complex remote setting. For an end-user, it is not just a bandwidth problem. There is an additional ask from networks to provide reliability and timeliness to eliminate any jitter since that will immediately degrade an interactive application's behaviour. It is even tougher for network service providers as they plan for such bandwidths at the scale of hundreds of thousands of subscribers. A reconsideration of protocol designs and service customizations for high-density metropolises will be especially needed. Here, exploiting edge-caching will not help with real-time traffic directly, but will certainly offload capacity by moving not-so-live data to the edges. Yet the biggest challenge is more fundamental, i.e. what "on-the-wire" capabilities need to be added to the networks, so that applications could ask for holographic streams with specific characteristics.

**Precision of time in services:** Most market segments are striving to be operationally autonomous and automated, both being time-bound functions. The fact that automation in factories aims to eliminate down time, improve quality, and be cost-efficient relies heavily on every single sensor, actuator, cyber physical system, and robot to perform with extreme accuracy of the order of few milliseconds. Similarly, self-driving cars are highly-desired, but the safety of passengers in the vehicles and the surrounding environment are absolutely necessary. Unlike flying planes with flight plans in autopilot mode, road driving has many more unpredictable events to respond to often in the orders of a few milliseconds. The accuracy of the time delta between the event's occurrence and notification determines the safe outcome of the action taken by the self-driving systems. Both automated and autonomous systems certainly have a higher dependence on time. Time is critical to scenarios such as automotive, factory floors, and audio/video productions and networks to support these scenarios are built separately with purpose-built protocol stacks such as TSN, AVB[5], PROFINET, EtherCAT, SERCOS, etc. This is obviously a limitating approach on a large-scale network and providing a generalized, application friendly mechanism becomes absolutely necessary to demonstrate the potential of a fully automated future, in which manufacturers can adapt fast with shorter lead times.

**A richer access network:** Access networks have traditionally been a facility to merely access the Internet, with a more recent evolution for those services being located in the many cloud platforms that make up the (mostly web) services we all use. Inter-domain networking or local points-of-presence (POPs) provide the service capability towards those customers connected to the customer/access network. However, the proliferation of ever more powerful computing and communication resources at the 'edge' of the network has turned such access networks into a possibly rich service provisioning and access platform. Hyper-local services, such as interactive virtual reality scenarios and many others, do not require connectivity to distant service platform but, instead, often perform better with local service access due to decreased latency when accessing a nearby service instance. While efforts like Mobile Edge Computing (MEC) in ETSI and other 5G-oriented efforts address service termination in access networks*, reconciling those approaches with the ones used for many years in (data centre based) Internet services is still crucial for a truly end-to-end and access network agnostic service deployment solution for Network2030.* Section 4.3 presents the necessary aspects of study in relation to those increasingly richer access networks.

**Moving beyond best effort and coarse-grained QoS:** Incubating a new set of network services that enable smooth deployment of applications is the driving theme. While extensions towards quality of service have been extensively studied, standardized, as well as implemented, the vast majority of the networks can still support best effort or limited number of QoS levels, without being able to offer specifically tailored network treatments. However, for a number of future use cases, guarantees for timely delivery, both in bounding latency but also jitter, will be necessary for successful realization. *A holistic approach for a full end-to-end realization of such use cases that would include an interconnecting Internet, is still missing.* Section 4.1 elaborates on the aspects relating to addressing this challenge.

**ManyNets, a seamless coexistence of heterogeneous network infrastructures:** Networks overall, not only at the edge, have become increasingly richer in terms of *technology*, *ownership* and *end user participation*. Quite likely there will not be just one, but many public Internets. New technologies further widen the constraints for transmitting packets through the utilization of infrastructure-based wireless, wireless mesh, satellite, fixed line technologies (such as fibre optics), all of which must be accompanied by the fundamental packet transfer solution, while adhering to the underlying ownership relations when traversing those different networks. *As a consequence, the end-to-end realization of services across those many internet environments need strong consideration for Network2030 and is an increasing departure from the structures of networks as we see today.* Section 4.3 elaborates on the necessary focus of work in this area.

## 3.3 What is Network2030?

As discussed above, the Internet is reaching its limits. It may sustain more of the same applications of today but falls way short of achieving a fully-connected Digital society. We believe that the gaps and challenges set out in Chapter 3.2 will need thorough consideration in order to move us towards the new use cases for Network2030. With this in mind, we can characterize Network2030 as a network that

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[5] IEEE 802.1 Audio Video Bridging Task Group and Time - Sensitive networking task Group

1. Supports new emerging use cases that will drive the Digital Society towards 2030 and beyond, including new (holographic) media, digital twins, and many more, with suitable application-network interaction that allows for specializing service delivery to the needs of the applications. ***A Network2030 network will provide a rich set of mechanisms to allow for interaction between the applications and the infrastructures beyond naive datagram delivery***.
2. Provides a suitable, **performant** interconnection of ever-**richer** access and edge networks which in turn will be utilized by new verticals with **stricter** as well as more varying **boundaries** for latency and capacity. ***A Network2030 network will embrace this edge/access proliferation, accompanied with a thinned yet function-rich interconnection between those ever-richer edges of the network***.
3. Enables those new verticals through means for tight resource control with strict time awareness and guaranteed services. ***A Network2030 network will have moved beyond the current best effort Internet foundation, providing extreme high-bandwidth and rich time-engineered communication services for new use cases***.
4. Supports the much richer interconnectivity of future infrastructures, driven by the proliferation of new connectivity technologies, including satellite, space networks, and end user provided networks, as well as by new ownership structures, including private and public as well as end user provided networks. ***A Network2030 network will have embraced multi-access and internet at the level of infrastructure integration and communication service support***.

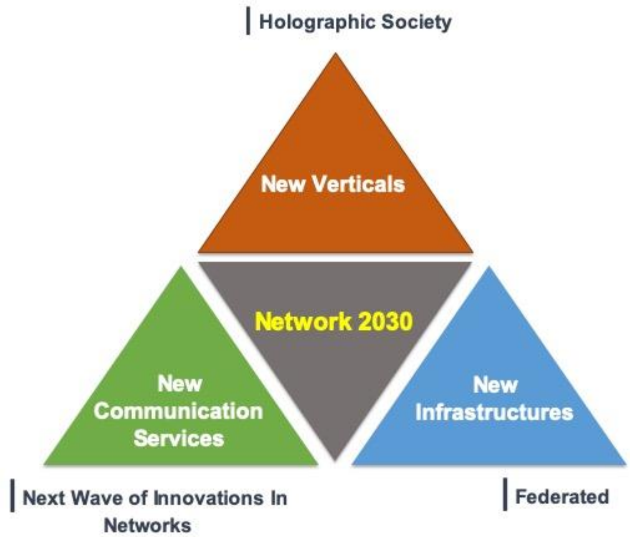

Figure 3: Network 2030 Vision

We illustrate the scope for Network2030 with Figure 3 the ***artefact that enables new verticals within the emerging holographic society***, ***a* future digital society empowered by holographic technologies *through a wave of innovations in networks to provide new communication services over federated*, *new infrastructures***.

## 4 Key Focus Areas for Network 2030

In the next decade, ubiquitous connectivity will be more pronounced; among everything, by which ever means and everywhere. While some connecting entities will get smaller than what we see today, others will become more independent in decision making, and the remainder will render digital replicas of objects in real world.

The key enablers will be the new capabilities in networks offered to the end users in different market segments which in turn offer potentials to create new types of verticals and opportunities. Network 2030 formalizes such capabilities with time as a vital attribute and holograms as new media objects. The time-engineered capability will help decide when to schedule for information and when to expect it to arrive.

Just as important is the capability to identify when partial information is better than not receiving anything at all at a specific period of time.

The new type of media does not limit itself to entertainment, but creates new verticals in the personal, entertainment, healthcare, and education segments. This should enable building a holographic society in which, by and large, all the barriers associated with physical distance start to diminish.

The network infrastructure perspectives must evolve as well. There is a continuous shift to consume all types of media (predominantly video, voice, text) as data over the Internet. In particular, the satellite industry is at the brink of creating a new Internet in space, but cloud/content providers have invested heavily in building private infrastructures. A case can be made that new kinds of networks will begin to emerge and flourish independently, which raises the question of how to honour policies of different types of users in different interconnected systems.

## 4.1 Time Engineered Communications Services

One of the key principles of Network 2030 is the guarantee and assurance of services. Timeliness of data delivery will be central to the success of new kinds of application and several of the scenarios covered in section 3.3.

Current networks can provide assurance of bandwidth and reliability. Bandwidth is obvious, because any information carried over the network is packetized and consumes transmission media capacity. Network 2030 externalizes the time as a central property for the scenarios described above. That is, the support for precision of time in data delivery as a fundamental communication service must be provided by the networks. The above scenarios may be classified in one of the following types of basic time-engineered services (Figure 4).


Figure 4: Net2030 Focus: Time Engineered Services

**IN-TIME SERVICES** supply data for real-time applications a-priori that allow a bounded time of arrival of data packets, i.e. packet arrives ahead of a specific time. Typical multi-media applications can buffer in the order of one hundred millisecond's worth of data, but on industry floors controller-to-field-unit feedback control-loop responses are under ten milliseconds. Both situations are similar in that a late arriving packet is useless and the behaviour demands bounded arrival times. To appreciate the relevance of time-constrained delivery, compare with an email or web-based service: slow performance causes degraded experience, but the data is still relevant. **ON-TIME SERVICES** expect data-arrival at a specific time with tolerance for only a very small difference. On-time service guarantees are served by accurate time with the smallest resolution of measurable time (in the order of one millisecond). For example, when several operations are quasi-synchronized, a set of jobs must operate in sequence determined by a precise time for each job. This is particularly relevant to safety response applications such as moving autonomous objects (cars, drones), where in-time service delivery could cause unpredictable outcomes, but on-time services will assure that the system behaviour is precisely controlled. An absolute time stamping is required in the finance market sector in order to establish fairness across trading operations. **COORDINATED SERVICES** demand timeliness of delivery of packets from multiple flows (from the same or from multiple sources). For example, holo-sense enabled applications may source different senses over separate flows. In general, smell and touch do not have the same level of sensitivity as video but they must still be synchronized with respect to visual rendering in order to deliver near real experiences.

The Table 1 below shows relevance of new services corresponding to certain use cases and clarifying criteria.

**Table 1: Time-engineered service criteria**

| Time centric | Criteria | Use cases | Time scales |
|---|---|---|---|
| **In-time service** | no later than requested time | Manufacturing automation<br>Remote surgery | t ~ 1-10 ms |
| **On-time service** | at a requested time | Instantaneous response to emergency situation<br>Synchronized operations such as drone swarms | Δt ~ 1 ms |
| **Coordinated service** | Relative time | Multi-sense communication<br>Autonomous Traffic communication | t < 5ms |

## 4.2 Communication Services with Complex Constraints

There are communication services that are dependent on more than a single constraint. Applications that demand both time and data-rates of varying granularities are described as compound services. To this effect we consider holographic type communications and Tactile Internet as examples of compound services because they get realized using specific combinations of different time-engineered guarantees, reliability of new time-centric services and bandwidth guaranteed services that already exist. Tactile Internet is a combination of low latency delivery and response to haptics, whereas ***holographic-type services*** are a combination of very high bandwidths, multi-sense coordinated streams, and lower than 20 millisecond latencies.

Network 2030 also introduces **QUALITATIVE COMMUNICATION SERVICES**. Networks often drop packets due to congestion or due to media errors even when they are just a bit flips, because the fundamental unit of transmission is packet. However, for time-engineered services loss of packet is always undesirable. Qualitative services bring the notion of discriminating different parts of a packet, by associating significance to different parts. Then, as a network node determines that a packet is time-sensitive and may get dropped, it can decide to send only the most important information, dropping the remainder of the packet and scheduling the packet ahead of those with larger payload sizes. The idea is to avoid retransmission penalties over the network. Inception of such services will be tremendously useful with web-browsing applications (that prefer to drop less important information in favour of more valuable information) or high bandwidth multimedia applications, where certain patterns on screen with less significant information can use lower resolution.

***Network 2030 strongly believes holographic media and full-sensory immersive experiences will lead to new application opportunities in a range of market verticals.*** The idea of supporting holograms over the network entails the combination of several attributes and services with varying constraints and are therefore, a compound network service. Such a service will require a high bandwidth stream dedicated for the video, perhaps low bandwidth to encode smell and flavour-type of senses, and a time sensitive haptics stream for applications where haptic feedback is a significant functionality. Similarly, tactile communications are a compound service that carries the feedback control loop specifications in the streams. Coined as Digital Teleportation, another compound service is envisioned for the year 2030 and beyond. In fact, having a full 3D digital projection of an individual with a multi-senses involved, truly simulates remote presence.

The Table 2 below shows relevance of compound services corresponding to certain use cases and clarifying criteria.

**Table 2: Compound Services**

| Compound Service | Criteria | Use cases | Time scales* |
|---|---|---|---|
| **Qualitative Service** | Conditional to network state | High throughput multimedia such as Holographic applications | ~ 40 ms |
| **Holographic Type Communications** | Coordinated, time dependence and high bandwidth | High bandwidth requirements, different encoding for teleconferencing vs 3D medical imaging | ~30 ms |
| **Digital Teleportation** | Coordinated, synchronized, | Digital replicated live-environment | ~30ms |
| **Tactile communications** | Time dependence and reliability (zero packet-loss) | Variable encodings of haptics, optionally high bandwidth requirements, fast responses. | < 10ms |

*note: Time scales depend on physical distances between the end points; numbers here represent general guidelines

## 4.3 Coexistence of Heterogeneous Network Infrastructures

The fact that global scale connectivity must go through the public infrastructure now remains an outdated conjecture. More recent changes in the infrastructure happened at a much faster pace than it had been anticipated due to the compelling business needs to scale in different market segments. The change has been both organic (faster optical speeds) and inorganic (public clouds and distributed data centres, edge densification). There will be a need to connect and provide the new infrastructures in a way that handle legal, billing, security and trust related issues of the users.

**Proliferation of private transits:** The observed trend nowadays for large scale content providers has been to deploy and build their own private transits[6] and reducing the number of points of presence. This has been proven to be more economical by eliminating the cost of paying service providers for east-west type of data movement across data centres. The consequence is much higher penetrations in private networks and the percentage of data that once used to transit the Internet backbone has shrunk tremendously.

**Space communications:** Beginning to emerge as space internet[7], low-earth orbit (LEO) satellite-based access technologies help overcome the latency of the Internet providing feasible broadband scenarios with latency toleration up to 30 ms. The contrasting nature of the difficulty of providing a common means of connectivity to the end user and convergence with fixed networks will require infrastructure built for being resilient to both delays and losses.

**Densification of distributed edges:** The optimal organization of data in content delivery networks has been caching centric. Newer verticals as in self-driving networks, smart home, and smart cities have

[6] https://www.itu.int/en/ITU-T/Workshops-and-Seminars/20181218/Documents/Geoff_Huston_Presentation.pdf
[7] https://extranet.itu.int/sites/itu-t/focusgroups/net-2030/_layouts/15/WopiFrame.aspx?sourcedoc={451092C1-A1F5-4532-88E2-89DFD31874BC}&file=ITUT-Network2030-LEO-Network.pdf&action=default

unique regulatory and functional requirements, and the majority of data is dynamic due to the continuous changes in environment.

Collectively, it is difficult to think in terms of a single backbone. We anticipate islands of Internet to become more self-serving to their customer needs and operating autonomously. In contrast the users would need the capability to switch from one island to the other or to be part of several of those islands on as needed basis. The most difficult part is resolving the regulatory patterns; The simplest one we know of today is based on geographies and national boundaries that an internet could span, but the new harder regulatory patterns are where the regulations among two or more Internets will need to track when their users move between these networks. The challenge is in **finding innovative ways to solve accounting, diverse capability, and reachability problems, providing classes of citizenship and safe harbor to users and their assets**. Emergence of such ***federated networks*** will be imminent and Network 2030 undertakes this challenge to identify requirements in network technologies to understand this behaviour and provide dynamic regulatory-binding mechanisms.

## 4.4 New Verticals

The connected Digital Society 2030 will be based on new kinds of verticals entering the markets. Figure 5 illustrates relationship between the opportunities stemming in different verticals due to innovations in the communication industry. Network 2030 aims to boost the horizontal ICT sector by enabling **new services which in turn will foster creation of cutting-edge applications in a wide variety of industries**, even leading to emergence of new segments such as holoportation[8], digital avatars, self-operating factories, digital food sampling etc, built solely from newly available features and capabilities such as high-precision, holographic media, digital-senses over the networks. For example, a new form of education-segment with immersive learning, enables remote participation of students and must support a holographic type service. This allows students to be more engaged in their curriculum by being holographically (in real-time and space) present in the class. Top to bottom specialized education verticals can then be customized based on the subjects, geographies, student's capabilities.

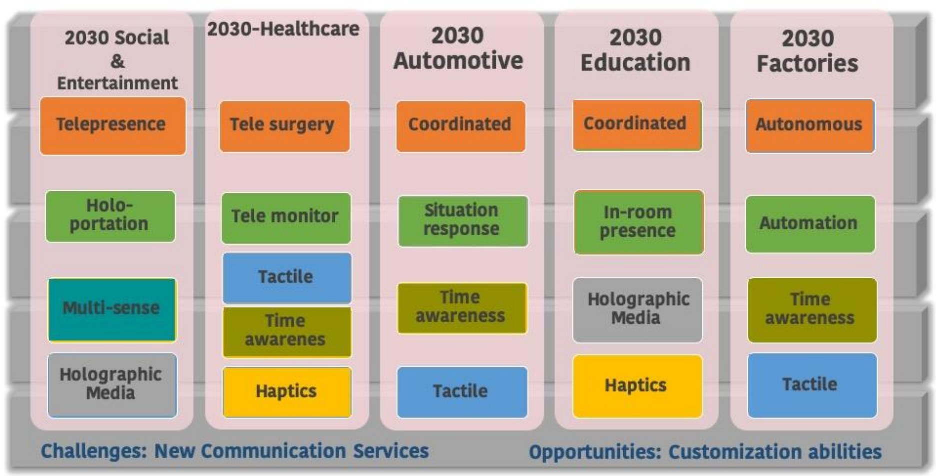


Figure 5: Enabling Vertical Markets with Network 2030

Key to this customization is the **flexibility** achieved through **customization** and **programmability** of the utilized resources. Such customization spans across communication as well as computing/storage resources in order to fulfil the requirements of the new verticals, such as for high bandwidth, localization, low latency and others. Integrated storage and compute in networks will pave the way for pushing programmability down to the transport networks to support the widening requirements defined by current

8 https://www.itu.int/en/ITU-T/Workshops-and-Seminars/20190218/Documents/Rahim_Tafazolli_Presentation.pdf

and future verticals. Through this, we expect that the network communication industry itself will receive a tremendous boost from Network 2030 by widening the applicability across many vertical markets, not only focusing on current Internet markets.

## 4.5 Relation to Next-generation Mobile Technologies

It is expected that in 2030s, several new initiatives such as beyond 5G and/or the sixth generation[9] (6G) mobile technologies will emerge elsewhere. Then the positioning of Network 2030 needs to be clarified vis-à-vis advances in mobile communications. Network 2030 is a fixed network related technology. It will take a more *end-to-end* view on the future network evolution, keeping in mind the applications and services relevant in that time frame and beyond.

On the other hand, we can still envisage some early synergies between Network 2030 and future mobile and wireless generation initiatives. First of all, both will be driven by future networked applications and services which may not have been foreseen or sufficiently supported by the 5G capabilities. Many such examples were elaborated in this white paper. In addition, new networking paradigms involving protocols and mechanisms developed within the context of Network 2030 can be potentially applied in future 6G network environments where appropriate, as fixed/mobile network convergence continues to progress in the next decade.

Similarly, 5G will continue to prosper from this time onwards, in the form of Beyond 5G (B5G) initiative. Here, Network 2030, in particular time engineered services, maybe used to provide tangible fixed network backhaul approaches to close the link between end users and applications requiring low-latency guarantees.

Network 2030 is an abstraction of network technologies required to deliver advanced applications in 2030 and the decade after. It aims to coexist with deployed infrastructures, incrementally inserting the new capabilities in the networks. However, the focus and expertise of Network 2030 will remain within the fixed networks domain.

[9] https://www.6gsummit.com/

## 5 Concluding Remarks

Globally, many governments identify that world-class communications networks are, or will become, an intrinsic component of their critical national infrastructure and essential to ensuring that citizens can take full advantage of increasingly pervasive digital services across the plethora of existing and emerging use cases and verticals. This will underpin data-driven innovation, industrial automation, AI deployment and the ensuing social and economic opportunities across economies, and increasingly between economies, for example the European Union's developing Digital Single Market[10], or if considering how an autonomous system might operate across borders.

Communications network technologies are entering a period of unprecedented change and opportunity. In particular, the impact of the Network 2030 initiative on the distribution and management of network functionality will deliver a massive increase in network flexibility. These combined developments will result in a paradigm shift in how future networks are conceived, designed, built, and operated for decades to come.

Due to the need and nature of seamless and borderless communications and networks it's not unreasonable to suppose that the development and delivery of future networks could and should consolidate into a significant international endeavour. The Network 2030 initiative could be the enabling network platform for other large- or small-scale initiatives. For example, the United Kingdom is developing an initiative, the Future Networks Research Initiative, where such collaboration and innovation will be front and centre, responding to the challenge outlined above in a strategic and coordinated fashion. Other notable activities include the CENGN (Canada) and SFI Connect (Ireland) are two other smaller scale initiatives underway.

As first steps, currently the ITU-T Focus Group Network 2030 (a) identifies relevant use cases, (b) describes key communication services and technologies, and (c) recognizes infrastructure evolutions. Through this exercise comprehensive requirements will be, or are being developed. FG-NET-2030 has already held a series of workshops that brought froth limitations from different markets and helped in providing inputs to requirements for the new communication technologies.

The undertaking is ambitious and involving the right partners from different geographies and multi-disciplinary fields will be necessary to provide the appropriate focus. The Focus Group Network 2030 welcomes you to join and participate.

https://itu.int/en/ITU-T/focusgroups/net2030/Pages/default.aspx.

[10] https://ec.europa.eu/commission/priorities/digital-single-market_en

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