

What digital infrastructure for the future?

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CROSS-SECTIONAL ELEMENTS ON CONVERGENCE

- 09 **From network services to digital platforms
and multi-sector services**
Francis JUTAND & Daniel KOFMAN

We are entering a new phase of the digital transformation. Continuing a transformation in silos, by sector of activity, we are moving to a phase which opens the way to multi-sector services, transversal to the various verticals. The enormous potential for value creation has been identified and will continue to develop given the potential for innovation which is thus opened; the risks for the actors and for the sovereignty of the countries are multiple.

This evolution is made possible by a series of new paradigms, including the softwarization and virtualization of infrastructures, the progressive convergence between networks and the cloud, the evolution of interfaces, digital twins and AI, as well as the opening of networks and systems to external actors. This last point transforms digital infrastructures into service platforms enabling the design and establishment of new services in real time, orchestrations components from different players, to dynamically respond to specific and evolving needs.

In this article we present an integrated vision of these various developments.

- 15 **The cloud in the digital industrial value chain**
Quentin ADAM

In the age of digital transformation, France and Western Europe are facing a major economic revolution. Digital technologies, and cloud computing in particular, are profoundly transforming the way we create and distribute wealth. This digital transformation represents an unprecedented opportunity, but also a major challenge for France, which has to juggle technological innovation with digital sovereignty. Unfortunately, this subject does not always receive the necessary attention, and the major impacts of this revolution are often downplayed.

- 25 **From manufacturing to infrastructure:
implications for regulation**
Pierre-Jean BENGHOZI

In the space of a few decades, digital technology has become an essential component of our societies. The regulation of digital infrastructures, such as telecommunications networks and data platforms, represents a major strategic challenge. They require massive investment and raise complex issues of sovereignty, equitable access and the distribution of value. Regulation must also adapt to rapid technological and market change, while managing the systemic risks associated with

cybersecurity and network reliability. This article examines these challenges and suggests ways forward for effective and fair regulation.

**31 Convergence of digital infrastructures:
an economic perspective**

Laurent BENZONI

Telecommunications operators (TELCOS) operate on a territorial basis, whereas the major content and application providers (GAFAM) operate on a global basis. The result for TELCOS is smaller size, higher debt and lower profitability. With convergence, the GAFAMs are moving down the digital infrastructure value chain to offer integrated services and capture greater value. They are getting closer to TELCOS but staying away from the local loop. Each TELCO subscriber requires a considerable investment compared with the services of a GAFAM.

While TELCOS have failed to move up the value chain, the emergence of slicing provides an opportunity to offer differentiated connectivity and to rebalance the conditions of access to their networks and subscribers. However, compliance with net neutrality and the use of artificial intelligence to implement these offers will limit TELCOS' room for manoeuvre. Convergence of digital infrastructures: an economic viewpoint.

40 Water in the clouds

Sylvain BOUVERET, Aurélie BUGEAU,
Anne-Cécile ORGERIE & Sophie QUINTON

In this article, we look at the environmental impact of digital infrastructures through the particular prism of water-related issues in the data centres (DCs) that make up clouds. We attempt to draw up an overview of the use of water in DCs, structured according to direct uses, for cooling and humidification, and indirect uses for power generation, production and the end-of-life of electronic equipment. This overview is illustrated with figures, mainly from the cloud service providers themselves, to give some orders of magnitude on water consumption and trends. The aim is also to discuss these figures, the relevance of the usual indicators and the associated potential impact transfers, and to recall the major spatio-temporal issues and conflicts of use linked to water resources.

48 A European digital perspective

Emmanuel DOTARO

Europe's digital future will be shaped by 6G, which, although it is a continuation of 5G, is characterised by the opportunity to bring together in an unprecedented combination disruptive innovations in all areas of digital technology. By understanding these components, technologies and architectures, we can identify the key issues that need to be addressed if Europe is to benefit from these transformations. The convergence between connectivity and computing, the uses of artificial intelligence, the integration of 3D architectures extending into space, cybersecurity and, lastly, the development of value through the control of digital consumption in the form of services are all areas in which Europe has a legitimate role to play and must be competitive. Economic development and the defence of societal values, where Europe is in the vanguard, can be achieved by combining investment in Research and Innovation, the federation of players and regulatory tools.

**TECHNOLOGIES AND ARCHITECTURES
FOR THE INFRASTRUCTURE OF THE FUTURE**

58 6G: promises and challenges for 2030

David GESBERT

This article takes a quick look at certain expectations of 6G that seem to have reached a consensus to date. We also shed light on the scientific concepts that will play an important role in these future wireless networks, such as intelligent reflective surfaces, artificial intelligence, spatialization of information and ISAC (integrated sensing and communication). Finally, we are addressing certain social challenges that will determine the success of 6G, such as computer security, the right to digital privacy, and the ecological impact of these wireless systems.

64 Communications networks on satellite constellations

François BACCELLI

This article, which is based on the Académie des Sciences report « Grandes constellations de satellites : enjeux et impacts », aims to describe the organisation, functionalities and prospects of communications networks using satellite constellations. It focuses on broadband communications functionalities. It describes the architectures used and the general characteristics of the satellites that make up these constellations. It also describes the principles governing communications between the various elements of the network. It reviews the longer-term prospects for this class of network.

**72 Managing complexity in 6G -
The stochastic geometry approach**

François BACCELLI

6G is based on the use of several new types of network elements, frequencies and architectures. Mastering the resulting complexity of radio coverage requires the development of new design and analysis tools. The aim of this article is to describe the principles of the stochastic geometry approach to these issues and the prospects for its use in the context of 6G.

**77 Cyber-physical systems and digital twins:
triggers and conditions for accelerated adoption**

Pascal BROSSET

The cyber-physical systems (CPS) terminology, which appeared contemporaneously with Industry 4.0, has been the topic of many academic publications about its potential in domains ranging from industry to healthcare. As a reminder, the term was introduced in 2006 by Dr Helen Gil of the US National Science Foundation. This concept was developed to describe the integration of computing with physical processes, where embedded systems and networks allow to monitor and control physical processes, including feedback loops between both.

The convergence of socio-economic factors and accelerating progress as far as artificial intelligence result in an acceleration in the adoption of CPSes, often bundled with digital twins. This article explores, from a manufacturer's point of view, the reasons of this acceleration and its implications.

84 The benefits of Gaia-X
Anne-Sophie TAILLANDIER & Pierre GRONLIER

Gaia-X, created in 2020 by the German and French governments, aims to create a federated data infrastructure guaranteeing data sovereignty and transparency, thereby supporting Europe's digital economy. With over 300 members, Gaia-X promotes interoperability and security through a standardised framework, facilitating data sharing while maintaining control and compliance with European regulations such as the RGPD. It emphasises technical, operational and legal autonomy, encouraging multi-cloud strategies to reduce dependency on non-European suppliers. The Gaia-X architecture relies on standardised vocabularies, encrypted verifiable references and a trust registry to ensure secure and verifiable data exchanges. The initiative also supports the development of AI by ensuring data traceability and consent, in line with regulations such as the AI Act.

Going forward, Gaia-X aims to integrate future regulations, providing comprehensive coverage for data providers and consumers, fostering a trustworthy digital ecosystem.

94 Virtualised networks: promises and challenges
Fabrice GUILLEMIN

Virtualisation technologies have revolutionised telecommunications networks in recent years. Aside from the technical advances and the considerable flexibility they bring, this breakthrough in network design poses a number of challenges, particularly with regard to the underlying cloud infrastructures and network operations. The aim of this article is to take stock of these sensitive issues for network operators and identify possible solutions.

99 The softwarization of networks and its technical and economic impact
Emmanuel PUIG

Softwarization, or the migration of IT functions from hardware to software, marks a key technological development in which increasingly powerful CPUs enable software solutions that were previously impossible. This transition, visible in a variety of fields such as video games and telecoms, is driven by economic and operational benefits such as flexibility, cost reduction, and access to a wide range of open source tools and resources. In telecoms networks, although network cores are already largely "softwarised", radio access is still predominantly hardware-based, but the trend is changing with the rise of private networks and technologies such as 5G, favouring more flexible solutions tailored to small volumes. Companies that embrace this transformation at the right time can gain a significant competitive advantage.

104 New optical technologies: what impact on tomorrow's augmented reality systems?
Jean-Louis de BOUGRENET DE LA TOCNAYE

Augmented reality (AR) has often progressed thanks to technological leaps. This has been the case with the miniaturisation of displays, pico-projectors and combiners. Will the latest advances in the design/manufacture of surface-effect optics (e.g. meta-surface, -lens and -shape) have the same impact on the projection devices of future AR systems? Progress has already been made in this area with freeforms. Similarly, will the development of holographic AR, driven by the growing

popularity of smart glasses in the consumer sector, impose this choice on all AR devices? These are all questions that will be briefly addressed in this article, which focuses on the optical layer of AR systems. Finally, in this ongoing race towards ever greater immersivity and closer proximity to the eye, will contact lenses be the future of hyper-immersive AR? What are the ultimate dimensions that can reasonably be crossed? These are just some of the questions we'll be tackling here.

113 **Metavers: beyond virtual reality headsets**

Guillaume MOREAU

Since Mark Zuckerberg's speech on the "metaverse" in 2021, it has to be acknowledged that the claimed generalization has not taken place yet. While immersive technologies have notably improved and reached price levels compatible with a wide audience, some challenges, more or less related to the tradeoffs on the interfaces, remain to be addressed. Not only must the software part adapt to the tradeoff between mass, energy, network bandwidth and computing power but authoring tools must also improve. Those systems are far from reaching human perception features and generate aftereffects that may have some consequences on human health. At last, it is important to study the ethical questions raising from those technologies that are mixing together with artificial intelligence.

119 **Cyber security**

Hervé DEBAR

Cybersecurity has become a major challenge for digital infrastructures. The threat carried out by attackers that are highly skilled, motivated and tooled leaves no doubt to the fact that digital infrastructures, current or future, will be under attack. Despite the best care, some of them will be compromised. Therefore, cybersecurity best practices need to be deployed in all these digital infrastructures, to understand and analyze risk, to protect these infrastructures from malicious activities, and to detect and mitigate the impact of these activities as early and efficiently as possible. While there has been progress in both cybersecurity methods and tools, we need to ensure that cybersecurity aspects are taken into account in the management and operation of these digital infrastructures. Ensuring this will increase the efficiency and trustworthiness of these digital infrastructures, and benefit all users and stakeholders.

127 **Components for digital infrastructures**

Dimitri KTÉNAS & Dr Denis DUTOIT

In this paper, we take a closer look at the components that make up digital infrastructures, first from the point of view of computational infrastructures, then from that of communications infrastructures.

Key components of the computational infrastructure of digital systems include intelligent sensors, application processors, and any xPU providing computational capacity. These components create a heterogeneous, flexible and scalable digital processing infrastructure, capable of meeting growing computing needs.

On the other hand, the telecommunications sector has become the keystone of the Western economy. It appears that 6G, currently being defined, will require new dedicated components, notably due to the rise in frequency, which is likely to render current silicon components inoperable. A real breakthrough is therefore on the horizon in this field of microelectronics.

SECTORAL IMPACTS

134 Contribution of the Agdatahub data sharing infrastructure to the agri-agro sector
Sébastien PICARDAT

France's farms are highly connected and generate a huge amount of data. The Agdatahub data-sharing infrastructure is the trusted third party for the agricultural and agri-food sector, enabling data to circulate in compliance with the European regulatory framework. The French platform is a technological and operational tool that meets the objectives of sustainability, innovation and sovereignty pursued by players in the sector. As a data intermediary, a status enshrined in European regulations and French law, Agdatahub simplifies and secures the circulation of agricultural data, and addresses priority use cases such as animal genetics, carbon reduction, environmental labelling, etc.

142 Digital challenges in electricity distribution
Claire WAAST-RICHARD, Claudine RABILLARD & Yves BARLIER

The power distribution network is, all over the world, at the crossroads of many transitions. The energy transition is already a reality and has a strong impact on the network which, in its turn, adapts. The digital is one of the key success factors. Deployments of smart meters, IoT, data processing, AI and simulation allow Enedis to generate performance; to support its customers in their energy transition; and allow the electricity system and market players to operate more precisely. The continued growth of decentralized renewable energy installations, the generalization of electric mobility, the development of hydrogen will have an increasingly profound impact on the way the network is managed. The future system will be much more complex and more decentralized. This will not happen in a day. The transition will be achieved thanks to digital technologies but also thanks to commitment of all the players in the sector, with a "smart regulation" and with all employees mobilization.

149 Cooperative intelligent transport systems for urban mobility policies
Éric MONCEYRON

Connectivity now makes it possible to integrate the vehicle with its immediate environment, and to provide new safety aids for the driver, including the promotion of peaceful cohabitation with other modes of transport, as well as new opportunities for road and traffic managers. This assistance is implemented in particular by Cooperative Intelligent Transport Systems (STI-C), based on the instantaneous exchange of data between vehicles (V2V) and infrastructures (V2I).

After intensive standardisation work, the European Commission launched a decade of successive pilot projects to deploy ITS-C. These projects have enabled us to come to terms with operational realities and have now reached the production stage, as demonstrated by the final seminar of the InDiD project (Digital Infrastructure of Tomorrow - June 2024).

This article highlights the contribution of ITS-C to the urban nodes of the trans-European transport network, integrating vehicles into reactive multimodal management of global mobility, particularly on the outskirts of city centres where the modal share of the car remains dominant.

**161 Pleading for the great forgotten:
public data-sharing infrastructures**
Laura LÉTOURNEAU

What if the infrastructures of the future were not so much those with spectacular underlying technologies as those that help us to meet the challenges of the future? Data-sharing infrastructures organise the fluid and secure circulation of information within a given circle of players. Ecological transition, pandemic management, improving the education system, security... Infrastructure of this kind is actually necessary whenever a large number of public and private players need to work together to solve societal problems. What could be more important? Yet the subject suffers from a deleterious asymmetry of attention in favour of “sexier” technologies such as AI. This paper explains why these infrastructures are essential and sets out a collective and ambitious guide to help support them, in the belief that we can collectively move faster in the next 3 years than we have in the last 20.

173 Healthcare systems
Michel BARTH

Digital technology is investing in and transforming the healthcare sector, and this trend shows no signs of slowing down, particularly with the development of high-speed internet, cloud computing, mobility and connected objects (Internet of Things or IoT). Beyond the obvious rationalization and efficiency of care enabled by the digitization of organizations and processes, digital health also brings a qualitative promise of increasing patients’ chances of being accurately diagnosed as early as possible, and then being treated and rehabilitated effectively, while streamlining care episodes, especially for hospitalizations and long-term or chronic conditions. All generated data is transmitted over fixed and mobile networks for various purposes in support of the patient care journey. This results in a continuously growing need for fixed and mobile digital infrastructures to support these flows.

184 The evolution of commerce thanks to digitisation
Leonardo ÁLVAREZ

Electronic commerce is a key element in the digitisation of our society and a major factor in economic growth. After putting the subject into historical perspective, we will define the general concept of digital commerce and present its current reality. We will consider the factors that have contributed to the growth of this industry, analysing the context that is catapulting its current and future development. Finally, we will reflect on the trends, solutions and concepts that seem to be shaping the future of this industry, and we will open a debate on the players who will eventually control digital commerce in the future.

FORWARD-LOOKING STATEMENTS

**192 The role of AI in the evolution
of the digital infrastructures of the future**
Francis JUTAND & Daniel KOFMAN

Faced with the rapid growth of complexity and the dynamic, even at very short time scales, of digital infrastructures, digital intelligence will bring critical tools for their modelling, design, planning, monitoring, analysis and exploitation, with

the dynamic creation and demand of new services and applications, and therefore for the overall management of the operation of these infrastructures. The availability of such tools represents a “game changer” in the evolution of infrastructures and services they make possible. In this sense, they also represent a key element of sovereignty and a vector to promote a strong positioning of France in the extremely competitive context we live. AI will therefore play a key role in regulation, innovation and competition in digital infrastructures, the potential for development of national economies and societies depends more than ever on these.

199 Meaning in Networks

Laurent CLAVIER & Marios KOUNTOURIS

Communications networks are designed and operated on the basis of information as defined by Shannon, stripped of its meaning and context. While this basis has enabled networks to evolve incredibly, it is now showing certain limitations in terms of coping with both increasingly demanding applications and planetary limits (sustainability). The theory initiated by Shannon has enabled the development of ever more efficient solutions, but without regard for the reason why information is transmitted. Performance is measured in terms of throughput and spectral or energy efficiency, but not in terms of effectiveness for the intended purpose. Putting the meaning of the information, the reason for its transmission, at the heart of network design and orchestration, will make it possible to achieve the same objectives, or even to fulfill more functions, while limiting, or even reducing, the quantity of data transmitted and therefore the environmental impact of the network. Less is more.

Issue editors

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