AIOTI

Strategic Foresight Through Digital Leadership

IoT and Edge Computing Convergence

IoT Research Working Group

Ovidiu Vermesan, Chair

October 2020

Contents

Executive Summary

This paper examines arguments, observations, experiences and reflections from relevant events and documents that underline IoT and edge consumer, business, industrial sector-specific perspectives based on a review of technology trends. It also recognises potential new innovative concepts and possible obstacles to future research and innovation. In summary:

- Internet of Things (IoT), Industrial Internet of Things (IIoT) and edge computing are at the core of digitalisation, with key industrial sectors seeing great potential in these technologies.
- New IoT and edge capabilities drive the decentralisation of architectures and topologies and accelerate the decarbonisation of applications in industrial sectors.
- Edge computing has triggered a paradigm shift in cloud computing. There is a clear need to orchestrate resources to create a "computing continuum".
- We are seeing calls for a new operating system at the edge for decentralised IoT/IIoT computing architectures and real-time processing.
- Open industrial IoT edge computing platforms must strive for leadership to address the challenges of the evolving digital age.

The ideas and trends identified have been consolidated into four main recommendations.

1. **Europe must build on its strengths** in electronic control systems, safety-critical systems, sensing and automation, mechatronics and microelectronics/microsystems, privacy-preserving technologies, and intelligent connectivity.
2. **A single market for IoT/IIoT edge computing is required**. There is a need for a single market for IoT/edge devices and systems founded on open standards, able to connect seamlessly and on a plug-and-play basis to the edge and the cloud.
3. **Europe needs a trustworthy infrastructure that builds on flexible federation and a "fair business offer" to manage vast amount of IoT-generated data and change how ownership and location of data are treated**. The EU needs to identify the catalysts that may speed up innovation at the edge, to scale-up and invest in infrastructure, enable orchestration across relevant players in the value chain, and facilitate coordination on horizontal issues such as interoperability and open standards.
4. **Europe needs to capitalise on the shift of value creation to the edge**. It can do this by further accelerating the technological developments of IoT and edge computing, and support the convergence of technologies such as artificial intelligence (AI), digital twins, distributed ledger technologies (DLTs) and intelligent connectivity at the edge by creating large-scale open edge IoT projects.

State of Play

The synergy and integration of IoT/IIoT and edge computing is part of the paradigm shift from centralised solutions to decentralised and distributed computing architectures, in which information processing is located close to the edge, where "things" (e.g. sensors/actuators, devices, machines and humans) produce and utilise that information, knowledge and related experience.

The IoT and IIoT have become catalysts in the convergence of different technologies and in the creation of new applications and services in different sectors: enablers for addressing societal challenges and sustainable development goals and critical pillars for digitising industries. Convergence has brought about significant changes in how data and information are collected, exchanged, processed, and analysed. We have seen a shift from centralised systems to edge decentralised, distributed and hybrid solutions, integrating IoT/IIoT and edge computing as a central component of the complex interconnectedness in the computing continuum that is addressed by IoT/IIoT applications within and across different industrial sectors.

With the increased concentration of data value at the edge, edge computing has become a vital component of the processing layer of the IoT architecture: to advance the real-time processing of large-scale IoT applications deploying edge computing units with storage, computational, connectivity and intelligence capabilities to implement newly decentralised IoT solutions.

The exponential growth of IoT/IIoT devices and applications that generate terabytes of data also requires accelerating and adapting the development of critical edge computing technologies. This is necessary to address the challenges of the new decentralised computing continuum for more efficient, reliable, and secure processing of data at the edge. With new edge computing technologies, IoT is expanding beyond static monitoring to active device automation, based on real-time processing of data usage, edge processing, AI, mesh connectivity and end-to-end security. By bringing responsiveness and innovation to where it is needed, intelligent IoT devices accelerate the convergence of information technology (IT) and operational technology (OT) and fuel the digital transformation of areas including energy, agri-food, automotive, mobility/transportation, manufacturing, smart cities and communities, while addressing the sustainable development goals and accelerate the decarbonization of all aspects of the economy.

The European IoT community has identified and followed these trends. This includes organising multiple workshops and webinars [9][10][11][12] bringing together experts from industry, research and academia in 2019-20 to identify research and innovation priorities, and the actions required to implement new initiatives and programmes. The Alliance for Internet of Things Innovation (AIOTI) has been working in collaboration with H2020 projects, financed under the IoT European Large-Scale Pilots Programme, IoT Security and Privacy Cluster, and the new Large-Scale Pilots in areas such as energy, agriculture and healthcare. AIOTI ran a series of online events [3][7][8] including "IoT and Edge Computing: Future Directions for Europe" [2] and "IoT - Driving European Technology Leadership" [1].

Driving Strategic Foresight in Europe

Presentations and discussions at AIOTI events underlined and complement the findings of the *2020 Strategic Foresight Report* [4] published by the European Commission in September 2020. This report highlighted 5G connectivity in combination with IoT as critical elements of an open strategic autonomy that is key to develop Europe's digital economy, particularly as hyperconnectivity continues to accelerate, with physical-digital integration.

The study on *Emerging Technologies in Electronic Components and Systems (ECS)* [5] published in August 2020 identified that growth in the industrial and robotics, automotive, aerospace/defence, telecoms and health sectors are grouped and led by IoT technologies and applications. The report emphasises that *platforms for edge computing and IoT represent an opportunity for the EU to compete with the foremost global leaders in the innovation race*.

Furthermore, the report on *Strengthening Strategic Value Chains for a future-ready EU Industry - report of the Strategic Forum for Important Projects of Common European Interest* [19] states that the Industrial IoT is at the core of the digital transformation of Europe's industry. It highlights *"a huge market potential for the EU [that] lies in leveraging Industrial IoT, exploiting AI in industry and making the most out of high-quality data. Unlocking such potential benefits requires specific solutions to reduce fragmentation of data production, to overcome data silos and to minimise data lock-in"*. This would lead to a *"common European Industrial IoT and data ecosystem"*. Among other action, the report recommends investments in *"building common European industrial IoT and data ecosystems in key industry sectors, including manufacturing, agriculture, transportation/mobility, energy, and utilities."*

Last but not least, European Council conclusions in October 2020 called for stepping up the assistance to the existing Important Projects of Common European Interest (IPCEI), *"to those being developed by Member States and industry in the context of various alliances (such as on the Internet of Things, …)"* to surmount market failures and enable breakthrough innovation with maximum impact and scaling up opportunities. In this context, European Council invites the EC to support the Member States to *"develop new Important Projects of Common European Interest. Furthermore, it calls for further strengthening synergies between the use of EU and national funds as regards key technological projects, while ensuring transparency and open participation of SMEs."* [6]

Perspectives for IoT and Edge Computing

The findings from these events and reports underline the industrial sector-specific perspectives, based on reviewing technology trends while identifying obstacles and possible innovative concepts. In particular, the events provided extensive opportunities to explore and discuss future directions for research and innovation in the data economy, emphasising the essential role of IoT and edge computing. The following sections highlight the main takeaways for a clearer and more robust IoT/IIoT and edge computing strategy at the European level.

1. **IoT/IIoT and edge computing are at the core of digitalisation, with key industrial sectors seeing great potential in these technologies.**

IoT applications are advancing in manufacturing/industrial domains, with verticals such as transportation/mobility, energy, retail and healthcare reporting benefits from more and distributed intelligence and autonomy at the edge. Innovative edge solutions translate into new business opportunities and structural changes. For example, decentralised energy grids, autonomous driving, automated food chains and more efficient farming, and new healthcare remote monitoring and treatment systems. IIoT is transforming the rules of manufacturing, accelerating the evolution of digital manufacturing, and enhancing operational performance by creating synergies on data processing and operations across sectors.

Currently, there is a separation of solutions and standardisation activities focusing on IT and OT. Digitising industry requires the convergence of IT and OT as enabling technologies to accelerate the integration of technological and business enablers, to address the global challenges across the entire industrial value chain. A more holistic end-to-end approach is therefore critical for the socioeconomic success of digitisation across industrial sectors, building on expertise in IoT sensing/actuating hardware, IoT systems integration, communications, edge and cloud processing, storage, AI-based analytics, and IoT applications built on the convergence of these technologies.

2. **New IoT and edge computing capabilities drive the decentralisation of architectures and topologies, and accelerate the decarbonisation of applications in industrial sectors.**

Decentralisation triggers a structural and regulatory change in main industrial sectors and intelligent infrastructures to achieve greater flexibility, agility to match demand/supply and responsiveness, while optimising resource consumption. These new capabilities support energy efficiency and sustainability of edge applications deployment for implementing green and circular economy principles in and across various industrial sectors.

The platforms for IoT and edge computing are involved in the transformation towards decarbonisation, digitisation, and decentralisation by applying digitally enhanced low-carbon technologies. Embedded AI and neuromorphic computing will lead to new design challenges for physical and functional integration into devices and smart systems due to rapidly evolving concepts like requirements for AI inference, distributed edge computing and collaboration across intelligent edge nodes, mobile 5G, and mesh network functionality.

3. Edge computing has triggered a paradigm shift in cloud computing.

The ubiquitous nature of IoT devices has triggered a change to the models of managing and controlling the flow and transmission of data. The new concepts are moving from the widespread use of cloud-based infrastructure models, which are dominated by leading Internet companies, towards IoT edge mesh distributed processing, low latency, fault tolerance and increased scalability, security, and privacy. These trends crystallise a future strategy for industrial and consumer products and systems innovation. New research is required to address the challenges of orchestrating resources in a comprehensive ecosystem where IoT, edge/fog and cloud converge to form a computing continuum.

These changes bring a paradigm shift for IoT with advanced edge computing capabilities, from static monitoring to active IoT device automation, based on real-time edge processing using AI, advanced mesh connectivity and end-to-end security implemented based on outcome-driven platforms. New architecture concepts for edge and sensors/actuators systems integration are emerging to deal with intermittent connectivity, volatile devices, resources to support the increased autonomy and more intelligent sensing to reduce latency. IoT leverages edge computing to reduce bandwidth costs by processing data locally to improve agility through the real-time on-premises decision to allow edge devices/processes to function autonomously. The new generation of collaborative IoT edge nodes integrates AI and machine learning (ML) as a distributed intelligence topology involving algorithms for hardware implementation, with energy-efficient computing power and architectures to dispatch edge control and swarm intelligence. The new topologies and architectures of distributed intelligence will be beneficial to increase privacy and confidentiality by keeping valuable data closer to its origin, but at the same time will rise the need for new collaborative and privacy-preserving AI techniques in order to realise the full potential of data combined from multiple sources. These novel architectures are based on edge concepts such as fog computing, dew computing, multi-access edge computing (MEC, formerly mobile edge computing), the deep edge that encompass distributed computing, the use of advances in AI chips used for inference and learning, DLTs, and innovative sensing/actuating concepts.

4. Orchestrating resources to form a "computing continuum"

IoT/IIoT and advanced edge computing technologies are emerging as key components in the computing continuum, ensuring the real-time link between the edge control and automation systems, multiple clouds, and data centres. Edge computing functions can be hosted on a micro modular edge device, a gateway, micro server or other processing units where the edge server operates as a decentralised processing unit or an extension of the centralised cloud in the context of an overall application or workflow that is managed in the edge or cloud and executed at the edge.

Future edge infrastructure concepts are interest-driven; cloud-edge concepts target to reinforce edge visibility in the cloud. An example is the effort made by Tech Giants (e.g. Google, Amazon, Facebook Apple, Microsoft) to target edge applications through the creation of the Voice Interoperability Initiative. MEC is a key element of 5G that extends virtualised infrastructure into the radio access network (RAN) and utilises the network functions virtualisation (NFV) infrastructure to create small clouds at the edge. MEC is seen as a key technology to enable the hosting of applications in the 5G access networks and is used with cloud RAN in different applications.

The cloud infrastructure offers a centralised architecture for IoT applications, while edge computing implements a decentralised computing orchestration that generates new concepts for data centre deployments and innovative methods to balance computing loads for clouds/data centres. The emerging ecosystems for IoT and edge computing are centred around Intelligence Sensing (e.g. sophisticated perception systems for IoT devices) and embedded AI technologies that accelerate the development of new concepts such as Internet of Things Senses (IoTS), Tactile Internet of Things (TIoT), Internet of Robotic Things (IoRT) and Artificial Intelligence of Things (AIoT) to establish seamless, intuitive, context-driven interactions with future Internet resources. These trends are supported by new business models and start-ups (e.g. exploit X as service models, foster an app economy) with high growth potential that can bring new IoT and edge products and services to the market.

5. A new operating system at the edge for decentralised IoT/IIoT computing architectures and real-time processing

In the new IoT edge paradigm, edge compute functions can be an extension of the centralised cloud, or it can be a new device edge architecture where intelligent edge computing functionalities are integrated into intelligent devices such as sensing/actuating industrial nodes, smartphones, drones, robotic things or connected vehicles. Intelligent edge computing enables the adoption of high-level capabilities such as AI and analytics, abstract from the underlying complexity of heterogeneous sensors and system environment, virtualisation, and network resources. These conceptual changes require new architectural concepts and an underlying operating system at the edge.

Automotive companies such as Volkswagen have called for a modular meta operating system for vehicles of the future to manage processing at the edge and federation with the cloud infrastructure.

In the energy sector, experts called for a smart energy operating system as a framework to enable flexibility in energy consumption by controlling the power load in IoT-enabled systems, while addressing decentralised consumer-driven business models. Smart sector integration calls for greater orchestration and coordination across energy sector recognising the pivotal role of digitisation.

New concepts are being proposed to address the challenges of the new computing architectures, such as having a "guardian angel" as a personal assistant, sitting at the edge of federated personal devices to provide seamless device and resource management across distributed edge nodes (trans continuum).

6. Striving for leadership in open industrial IoT edge computing platforms

The convergence of technologies calls for new ecosystems, partnerships, and cooperation mechanisms to deal with interoperability and standards. The proliferation of edge applications across a growing number of market segments causes an increase in the complexity of the overall edge ecosystem and the integration of IIoT digital production platforms with streamlined data exchange in the industrial edge.

European actors have a clear opportunity to establish markets and services where other stakeholders from other continents have started to explore markets yet to mature. This requires moving beyond simple send-data-to-the-cloud lacking automation service levels.

The new frontier for IoT and edge computing applications demands solving societal challenges including energy consumption, decentralisation, and decarbonisation, while preserving security, safety, and privacy by developing modular building blocks, open architectures, and standards for advanced knowledge platforms.

Recommendations

The digitisation of industrial sectors comes with new challenges and opportunities. IoT/IIoT and edge computing convergence have the potential to bring radical change to technology paradigms, opening the way for new applications, creating new revenue streams, and generating growth and new industrial opportunities in Europe. Our recommendations are as follows:

1. **Europe must build on its strengths**

in electronic control systems, safety-critical systems, sensing and automation, mechatronics and microelectronics/microsystems, privacy-preserving technologies, and intelligent connectivity. Europe has to retain its sovereignty and autonomy in these sectors for the provision of critical components and systems. Indeed, Europe must rely on its industrial strength to benefit from its scale and the diffusion of IIoT and edge computing technologies across supply chains to advance digital transformations.

2. **A single market for IoT/IIoT edge computing is required**

There is a need for a single market for IoT/edge devices and systems founded on open standards, able to connect seamlessly and on a plug-and-play basis to the edge and the cloud. This will enable a thriving edge ecosystem for the real-time systems integration and federation of multiple edge and multiple cloud topologies where open platforms are used across vertical silos to help developer communities, SMEs and start-ups to innovate.

3. **Europe needs a trustworthy infrastructure that builds on flexible federation and a 'fair business offer' to manage vast amount of IoT-generated data and change how ownership and location of data are treated**

The EU needs to identify the catalysts that may speed up innovation at the edge, to scale-up and invest in infrastructure, enable orchestration across relevant players in the value chain, and facilitate coordination on horizontal issues such as interoperability and open standards. This will avoid fragmentation of edge infrastructure and enable synergies with open source software frameworks and hardware platforms, development tools, governance, and coordination at the EU level as well as an open level playing field for newcomers, start-ups and opportunities to address the challenges of the new frontier of technologies.

A major focus should be given to the role of global standards in ensuring cross-device, cross platform, and cross-vertical interoperability, as well as developing an open market for IoT and edge computing products and services. A global IoT certification should be established to allow all actors to assess solution compliance and interoperability to foster global trust from industry and end users. Privacy-preserving AI and ML technologies can be leveraged to simultaneously guarantee the highest trust levels without hindering gaining the full potential of data in the distributed IoT data ecosystem.

4. **Europe needs to capitalise on the shift of value creation to the edge**

It can do this by further accelerating the technological developments of IoT and edge computing, and support the convergence of technologies such as AI, digital twins, DLTs and intelligent connectivity at the edge by creating large-scale open edge IoT projects. These can leverage the strengths of networking between stakeholders and technological applications centred on diffusion across industries, value chains and value networks.

References

[1] AIOTI Signature Event 2020 – Webinar: IoT – Driving European Technology Leadership – 29 September 2020, Online Webinar

[2] IoT and Edge Computing: Future Directions for Europe – 11 September 2020, Webinar

[3] Advancing the Digital Transformation of European Industry Webinar 2020 - The role of standards in accelerating innovation – The case of IoT/IIoT

[4] 2020 Strategic Foresight Report EC, September 2020

[5] Emerging Technologies in Electronic Components and Systems (ECS) - Opportunities Ahead, EC, August 2020

[6] Special meeting of the European Council (01-02 October 2020) – Conclusions

[7] Data Sharing in Agriculture – 10 June 2020, Webinar. Smart Networks and IoT – Common topics for research and innovation in Horizon Europe, 5G IA and AIOTI, October 2019

[8] Navigating IoT Architectures and Standards Days – 19-21 February 2020, Brussels, Belgium

[9] Policies to Support Open Data Marketplaces – 29 January 2020, The Hague, The Netherlands

[10] European Industry Partnerships Lighthouses to Thrive in the New Digital Age – 05 November 2019, Brussels, Belgium

[11] European Industry Partnerships for New Digital Age Event – 12 September 2019, Brussels, Belgium

[12] European Industry Partnerships Collaborative Event – 17 April 2019, Amsterdam, The Netherlands

[13] AIOTI response to public consultation on European Partnership for smart networks and services (Horizon Europe programme)

[14] Joint 5GIA-AIOTI Vision on Future Networks, Services and Applications – High societal and economic impact potentials for a collaborative approach in the Horizon Europe Programme, March 2019

[15] AIOTI – Research and Innovation Priorities for IoT – Industrial, Business and Consumer

[16] Advancing EU IoT Research and Innovation – AIOTI's position on Horizon Europe and Digital Europe

[17] Innovation in Europe – Changing the game to regain a competitive edge, McKinsey Global Institute, October 2019

[18] The Five Myths of 5G – Misconceptions holding back the 5G market, and the facts you need to know. ABIResearch 2019

[19] Strengthening Strategic Value Chains for a future-ready EU Industry, Report of the Strategic Forum for Important Projects of Common European Interest, November 2019

[20] Project GAIA-X, A Federated Data Infrastructure as the Cradle of a Vibrant European Ecosystem, Federal Ministry for Economic Affairs and Energy (BMWi), Berlin, Germany, October, 2019

About AIOTI

AIOTI is the multi-stakeholder platform for stimulating IoT Innovation in Europe, bringing together small and large companies, start-ups and scale-ups, academia, policy makers and end-users and representatives of society in an end-to-end approach. We work with partners in a global context. We strive to leverage, share and promote best practices in the IoT ecosystems, be a one-stop point of information on all relevant aspects of IoT Innovation to its members while proactively addressing key issues and roadblocks for economic growth, acceptance and adoption of IoT Innovation in society.

AIOTI's contribution goes beyond technology and addresses horizontal elements across application domains, such as matchmaking and stimulating cooperation in IoT ecosystems, creating joint research roadmaps, driving convergence of standards and interoperability and defining policies. We also put them in practice in vertical application domains with societal and economic relevance.