NETWORKED INTELLIGENCE

A Wider Fusion of Technologies That Spurs the Fourth Industrial Revolution—Part I: Foundations

Alexandros Stavdas

Alexandros Stavdas is Full Professor in the Department of Informatics and Telecommunications, University of Peloponnese, Greece. He has authored over 180 journal and conference papers. He has also served as the Technical Program Committee Chairman and a Member of the Technical Program Committees in various International Conferences. Email: alexandros.stavdas@uop.gr

Abstract: In this article, it is argued that the Fourth Industrial Revolution (I4.0) is the result of a technology fusion between the following factors that define an economic epoch: (a) The production systems and the type of tools these systems are employing; (b) The communication technologies as well as the means used for information storage, processing, sensing and knowledge creation: the information and communication technologies (ICT); (c) The energy generation and distribution systems used, and (d) The biotechnology. The thesis of this article is that ICT is the predominant factor in the context of the Fourth Industrial Revolution. To justify this claim, the progress of the scientific fields of which this factor consists is elaborated, and its impact on other factors is highlighted with emphasis on the societal impact. It is claimed that the eventual fusion of these factors leads to a single technological continuum. The eventual fusion of all factors is made possible because they all exploit a common material base while we are entering the era where we can regulate and superintend a vast number of heterogeneous technologies via open software. The eventual fusion of these factors will lead to a single technological continuum, and it will redefine the notions of "production" and "work," as it will allow overcoming the over-fragmentation in specialization, while it will reshape our cities, our personal lives and our relationship with science.

Keywords: technology; production; production systems

Introduction

Today, the so-called Fourth Industrial Revolution (I4.0) is the subject of heated discussions among scientists and engineers worldwide. However, what is really remarkable is that the interest in I4.0 extends well beyond the small circle of scientists: today, it is at the epicenter of government long-term investment plans, and it is at the top of the agenda of world organizations, like the World Economic Forum and G7 meetings, like the one held in 2017.

This broad interest comes as no surprise as I4.0 will affect all forms of social interaction and primarily all spheres of production. The debate on how a technological revolution has an impact on our society is not a new one. It has tantalized philosophers and economists repeatedly over the last two centuries or so. In this regard, scholars have previously identified I4.0 as the “third industrial revolution” (*The Economist* 2012; Rifkin 2012) and, much earlier, as the “third wave” (Toffler 1984). These differences in nomenclature, apart from the unavoidable personal interpretations and inclinations, manifest the absence of a systematic methodology that allows us to differentiate between the various stages of social evolution, in a consistent way.

To contribute to these debates, the main thesis of this article is that *economic epochs* are distinguished by virtue of their unique *technosphere*, which is fully determined by a number of scientific/technical factors. In fact, it is the interaction between these factors that define the economic epochs and their corresponding stages. Regarding the industrial epoch, it is argued that, indeed, I4.0 is a new stage in industrialization with clearly differentiable characteristics to previous industrial stages (that are codenamed as I1.0–I3.0, hereafter). Actually, the main characteristic of I4.0 is the convergence between technologies, a process that made its debut first in the ICT sector. This convergence in ICT led to a rapid paradigm shift fueling technology convergence in other fields until the eventual fusion of the technologies in all factors into a single technological continuum.

I4.0 not only revolutionizes the hitherto existing mode of production, but it also has long-reaching economic and social consequences: a) it provides the means to overcome the fragmentation of skills and professions due to the division of labor; b) it creates the technological framework that allows the human operator to appropriate his own general productive power and to subordinate and master the forces of science, so the labor work becomes truly abstract. Through these advances, the human operator maximizes the power of the processes he superintends or the agencies he sets in motion, giving a quantum leap in productivity and, eventually, completely reshaping our relationship with nature.

The Framework

The starting point of our analysis is that each economic epoch has a one-to-one relationship with its unique technosphere. A technosphere is completely defined by means of the four factors, which are listed in Table 1. For simplicity, the factors are identified, hereafter, with their initials as F1–F4.

Table 1 The Factors That Define the Technosphere of an Economic Epoch

First factor	(F1)	The production systems and the type of tools these systems are employing
Second factor	(F2)	The means of communication as well as the means used for information storage, processing, sensing and knowledge creation
Third factor	(F3)	The energy (power) generation and distribution systems used
Fourth factor	(F4)	The biotechnology providing the means to affect and/or modify the living environment

These factors are common in all epochs, so what makes a technosphere unique during a specific era is:

The relative technological progress of a factor against the other factors. It is important for our analysis to point out that each factor consists of a number of technical or scientific fields (identified as fields, hereafter), so the relative progress may refer to the factor, as a whole, or to the fields this consists of.

The mode of interaction between the factors, that is, through the specific technological features that define each factor and its evolution in time, the extent and the strength (strong or weak) of the interactions between these factors, and/or the interactions between the fields of which each factor consists. This is schematically illustrated in Figure 1.

The two aforementioned parameters define:

- The predominant factor of an economic epoch: this is the primary factor that fosters the new relationship between humanity and nature.
- The relative importance of a particular factor (or factors) over a specific period of time/evolutionary stage. The importance of a factor is not time-invariant. It does change in time. This is because, within a given economic epoch or the stage within it, a factor might be either at its peak or, on the contrary, it is technologically immature or at a primary phase of its development, so it might play a minor role, at that particular moment, to the formation of the technosphere.
- A systematic analysis of the interrelations between the factors and/or the fields within them that take place during each epoch is key to comprehending the role the scientific innovations play in social evolution.

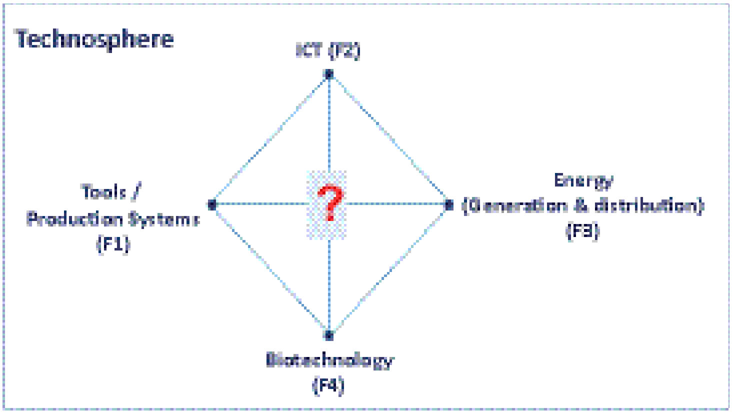

Figure 1 The Interrelationship between the Factors That Define the Technosphere of an Economic Epoch

The Early Stages of Industrialization

It is widely accepted today that the first industrial revolution (I1.0) was sparked by the mechanization of the textile industry. The enormous leap from empirical to scientific knowledge made possible the interaction between F1 and F3 and set the conditions for I1.0. The scientific progress in the separate scientific fields empowered F1 and F3 to exist on a new technological framework and enabled them to converge and complement each other. On the contrary, as progress in the fields of F2 is not yet in sight, this factor played only a minor role in the formation of I1.0. This role is only of local significance, that is limited to the coordination of the working force using native languages, some limited printing facilities, as well as primitive postal message exchange. This is schematically shown in Figure 2, where only F1 and F3 produce a strong resonance.

During this era, the worker acted/operated only in specific locations due to the physical restrictions imposed by the power system employed (initially horses and waterfalls and then internal combustion engines) or by the internal structure of the mechanisms and/or the production tools the workers were using. In any case, the physical presence of humans and/or machines in specific-purpose locations (e.g., Factories, agricultural fields) was an unquestionable necessity.

The second industrial revolution (I2.0) was characterized by *mass production* and the concentration of a vast number of special-purpose machines to a few very specific and single-purpose locations (like factories, construction sites, enterprises, etc.), leading to unprecedented urbanization as cities expanded around these locations. As before, production was possible only if the workers were

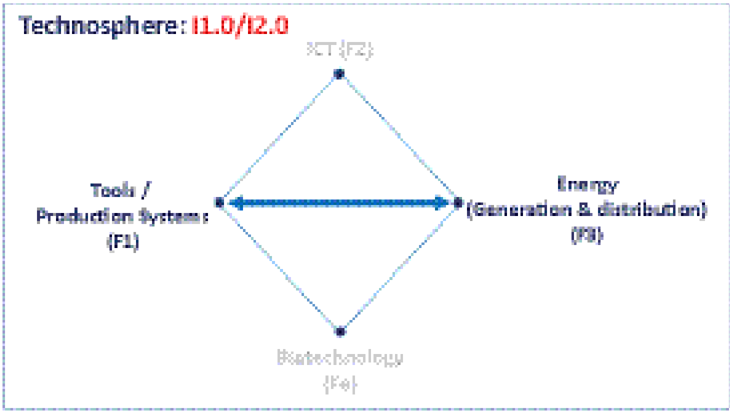

Figure 2 The Synergy between F1 and F2 Shaped I1.0 and I2.0

assembled into these specific locations, where they spent a considerable part of their day, in order to cooperate and coordinate between themselves and with the machines. The workers merely became an additional element of the machines since their actions were defined by and limited from the functions the corresponding machines provided or required. It was the period of extreme specialization. The scope of industry then became *mass production* aiming for *mass consumption*. To carry out these goals, a vast number of distribution networks of gigantic proportions were necessary for the creation and the transportation of goods, so we had the birth of railways, motorways, electricity power transport networks, etc. The scientific progress in F2 was making rapid steps, but the corresponding technologies remained limited in scope and fragmented while the activities in F4 were almost exclusively empirical. F2 remained decoupled from F1 and F3 while when, at a later stage, the agricultural machines (tractors, combines, etc.) were made available, designating that F1 and F4 were on a course of primitive convergence, the quality of life was enormously improved in the respective areas of the world where these innovations were applied.

Social life during this period followed exactly the same pattern to which the technologies were introduced and established in production sites: a plethora of special-purpose institutions like schools, theaters, hospitals, libraries not only proliferated but, in fact, their widespread availability was synonymous with progress. By closely looking at the way these institutions operated, one can observe that they all had a distinctive feature, i.e., that citizens had to actually convene at these very specific-purpose locations where these institutions were founded. The character of these institutions, as special-purpose, was eye-striking regarding their clearly and uniquely identified role, e.g., a “theater” may never be a “library,” or within a "school" there could be a place (e.g., a building or a room) that was called a "library" or "theater" but this was clearly designated and separated.

Nevertheless, the personal freedom of citizens improved, compared to the previous period, as a number of "forced localization" barriers were gradually lifted or disappeared, albeit this was done within the boundaries set by the structure and the mode of operation of the specific-purpose technologies and the organizations that were erected upon them (enterprises, factories, theaters, schools, etc.).

The Dawn of I4.0

The progress being made in science—primarily in physics—in the first half of the 20th century was the underlying incubator of the changes in the technosphere during the second half of the century. In particular, the scientific progress that led to the emergence of *Integrated Circuits (ICs)* and *Microelectronics* was the material base upon which *digitization* was built. This was a turning point in human history similar to the Bronze or Iron Age as our entire technosphere was exclusively built upon this technology now, given that digitization is unthinkable without it. This technology was the point of departure for the third industrial revolution (I3.0), which was a new phase in the industrialization with acute contradictions: on the one hand, the fields of F2, like Telecommunications and Information Technologies (IT), both relied on ICs to develop their systems (and, thus, they relied on Moore's Law to continuously increase their functionality and versatility at affordable prices). This sets up the grounds for a convergence between the two sectors. On the other hand, the technical advances in one sector were largely decoupled from the progress being made in the other, limiting the efficacy of this convergence.

The primary reason for this contradiction was that the incumbent corporations in the sector, in their quest to maximize their profitability and also to dominate the market by kicking-out competitors, launched products based on proprietary technologies providing limited or no interoperability between different vendors. As such, the convergence within the fields of F2, or between the other factors, never reached the level needed to become the driver of change. The I3.0 digitization was always of a limited extent and impact. As is the case with I1.0 and I2.0, the developed technologies in I3.0 were still of limited scope and of a local significance, even when aspects of it were networked, restricting the cross-fertilization.

The fact that both I3.0 and I4.0 exploit: a) ICs as their underlying technology and b) digitization as their fundamental process, as the material base for all forms of social interaction, fuel discussions for the differentiating characteristics between the two industrial stages. What contributes to the ambiguity is that I4.0 is shaping up in front of our eyes—it is not a historically set stage—meaning that the features and the interactions between its constituent parts are neither completely formed today or even, some they may have not even emerged yet.

This article argues that, indeed, there are substantial differences between I3.0 and I4.0, which are centered on the role, the extent, and the consequences the convergence in technology sectors has had. During I4.0, convergence is completed not only within the fields of F2, but also because of this process and through it, the convergence of technological sectors spreads to embrace technologies across all factors. This level of convergence was unthinkable during the previous industrial stages, so the thesis of this article is that:

> I4.0 is the stage of development where the *fusion* of all four factors that characterize an economic epoch is completed. It is this characteristic that differentiates I4.0 from the previous industrial stages. As such, the *fusion* of the factors *F1–F4* into a single technological continuum will mark the completion of the third distinctive epoch in human's civilization. In other words, I4.0 will designate the end of the industrial epoch and, simultaneously, it will mark the dawn of a completely new epoch.

Figure 3 depicts in a schematic way this convergence. It is pointed out that Figure 3 only illustrates the main milestones and a possible time sequence of this convergence where the emphasis is given to the technologies that feed the process. Even though this sequence should be interpreted with caution as the advances in this or the other field may change the chronological order the convergence stages take place. However, what remains clear is that a technological convergence that originates within the fields of ICT further spreads out and ignites the convergence between all

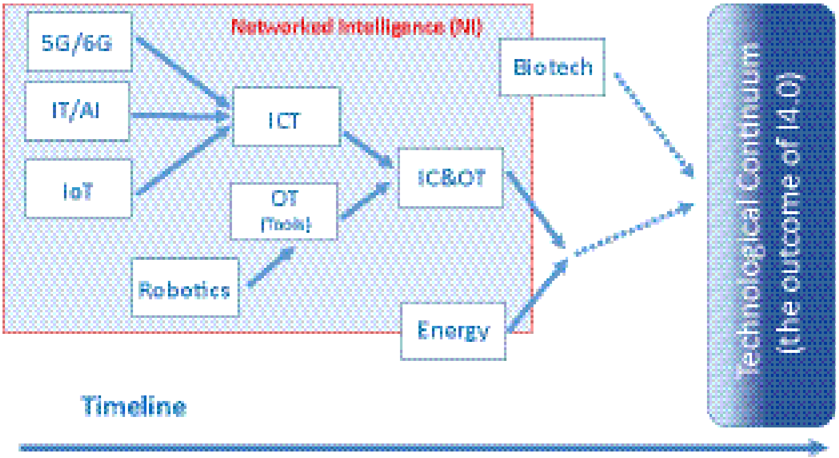

Figure 3 A Schematic Timeline for the Formation of the Networked Intelligence and Technological Continuous as the Outcome of I4.0

factors, leading to a technological continuum. This level of interaction and interdependence between the factors is unique to human history and the differentiating characteristic of I4.0 with all previous industrial stages where the progress of the technologies in each factor was made, more or less, independently of each other.

The catalyst and the starting point of the transformations that formulate the I4.0 is the upcoming integration of the currently distinctive technological fields in F2. We will see in the next section that there are objective reasons that set in motion this new round of convergence in technologies. In particular, during the first stage of this internal process, Telecommunication Networks and IT technologies (referring to data storage and processing as well as their applications, like the Artificial Intelligence [AI]) are forming up in the so-called *Clouds*. Further, the convergence of the Internet-of-Things (IoT) technologies with Clouds (see the next section) link the Clouds with a myriad of applications that are associated with I4.0, either directly or indirectly. In the second stage, technology convergence further spreads to incorporate fields from other factors like the *Operational Technologies* (OT) in F1 and then with F3 to form the *Networked Intelligence* (NI). The formation of NI is a landmark as this is the stage where all forms of intelligence are interconnected seamlessly in a pervasive and ubiquitous way. Through NI, the interconnected "*intelligence*" becomes an "ambient" and "fluid" entity, i.e., it is not localized in space and time while its effectiveness increases with the number of interconnected elements.

Nevertheless, there is no doubt that the ultimate outcome, i.e., the fusion of all factors, is a longer-term process that may span a whole historic period: as the scientific advances in every factor may not progress at the same speed, elements of I4.0 coexist—for many years to come—with their I2.0 and I3.0 counterparts.

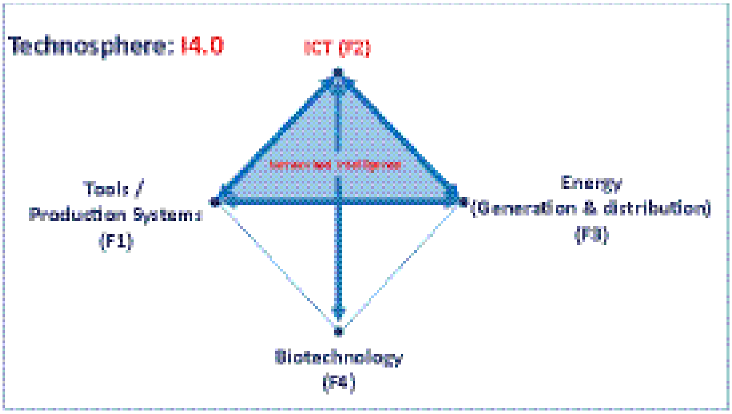

Figure 4 ICT Is Ushering in Networked Intelligence That Shapes I4.0

The fact that F2 becomes the central linking institution of I4.0 constitutes a paradigm shift in industrial development. This is schematically shown in Figure 4, which portrays the pivotal role the ICT play in the progress of F1, F3, and F4. The next section elaborates the reasons why ICT becomes the key enabler for this transformation and the contradictions the current ICT framework is facing. Part II of this article focuses on the convergence of ICT (F2) and production systems (F1) that will give substance to a new production mode (IC&OT).

The Convergence in the ICT Fields Lays the Foundations for I4.0

Journalists and advertisers—but not only them—often argue that 5G is the main driver of I4.0. Despite the critical role of telecommunication networks in the formation of I4.0, this approach undermines and obscures the role the convergence in technologies is playing. Actually, it is the convergence of the three industrial sectors that will establish I4.0. These are:

> *Connectivity*—These are the telecommunications networks, both fixed-line and mobile. During recent years, these networks have been identified with the short name *5G* and today with *6G*. Although this code name is "catchy," it is also a misleading one in many respects (see further down in this section for the reasons why).
>
> *IT Processing and Storage*—These are the IT infrastructures that in recent years have appeared in the form of Datacenters of different sizes and scopes. They can be found everywhere: as distinctive entities, they can be found in Internet incubator's corporate premises, as part of telecommunications network nodes, in laptops, etc.
>
> *Sensing and probing*—These are the IoT platforms that consist of diverse types of sensors and actuators; they also incorporate elements of connectivity, processing, and storage. IoT terminals either generate a vast amount of data (so-called "Big Data"), or they provide the means to modify the physical state or value for a large number of appliances. The generation of Big Data is a phenomenon of such magnitude that scholars argue it manifests a paradigm shift in science (Agrawal and Choudhary 2016). Regardless of whether one agrees or not with this claim, the availability of Big Data and the need to have them processed is an additional driver for the convergence between the technical fields of ICT.

Each of the aforementioned industrial sectors made its debut in different periods of time and as a discrete scientific and technical discipline, having little relevance to the other sectors. For example, telecommunications technologies as well as sensors and actuators did exist during the later period of I2.0 as analog technologies, so they were built on an entirely different material base that was not scalable, etc. To reflect this origin, the factor F2 in Table 1 consists of the corresponding fields viewed as clearly identifiable branches.

In the context of I3.0, the first round of convergence between these three technical fields took place. This was made possible because all three technical disciplines relied on semiconductor technology and ICs, something that allowed them to exist over a single technological foundation. As pointed out in the previous section, market protectionism prevailed over the need for fully interoperable systems, and this contradiction limited the extent of this convergence stage. Today, these fields are at a crossroads again, featuring the second round of convergence. The reasons are the following:

1. The rapid scientific progress made during the last 30 years or so led to an accelerated depreciation of capital and a fall of the profits the telecommunication operators, system vendors, and internet service providers were making. For them, the need to expand their activities and to invest in new sources of revenue became acute. Moreover, the need for operators to reduce their capital and operational expenses (CapEx/OpeEx) made it a necessity to reduce their dependence on system–vendor monopolies. The vendors are selling to the operators' systems consisting of a large number of proprietary and specific-hardware network elements with limited (if any) interoperability with the systems from other vendors. On the contrary, the operators were looking for systems with fewer elements that were fully interoperable. This "tug of war" between operators and vendors reshaped the status quo within the ICT sector, as this was established during I3.0.
2. A considerable fraction of services and applications for smartphones—mainly targeting entertainment and leisure time—required advanced processing and storage, which was found in abundance in datacenters.
3. During the same period of time, the cost of data transportation was decreasing at a slower pace compared to the cost of IT. Therefore, the distribution of processing and storage services in many geographic locations—at relatively shorter distances between them—and the interconnection using advanced networks made better sense than carrying traffic back and forth in longer, indirect, routes to a single host location where warehouse datacenters were. After all, enterprises operating on a global scale needed to exploit local caching and mirroring, anyway, because this was the essence of their business plan. The process of distributing intelligence at network periphery was already on its way.

4. The accelerated deployment of IoT infrastructures and services created vast amounts of data that needed to be transported and processed. This gave a further incentive to migrate datacenters closer to the end-terminals and to employ advanced connectivity networks to interconnect them.

As a result of these developments, a new landscape emerged where the interoperability between *connectivity networks, IT*, and *IoT* systems became a necessity. Researchers from the field of connectivity networks proposed two innovative approaches to materialize this interoperability. The first is termed Network Function Virtualization (NFV) (ETSI 2012), according to which a large number of special-purpose proprietary hardware elements, from which the connectivity systems are built, are consolidated by fewer general-purpose technologies. The second is the Software Defined Networking (SDN) (Van der Merwe et al. 1998; Casado et al. 2007) that disassociates the deployment of software from the underlying hardware; this allows the joint orchestration of heterogeneous connectivity systems by means of open software. Earlier efforts to achieve the same goal—via the predecessors of SDN like the "active networking"—were not successful for the reasons elaborated as discussed above regarding the exclusions market protections create. Since their first introduction, these two innovations have evolved to become forces of unification and the means used to integrate the technical fields of F2: intense research efforts are made to provide a framework for the joint orchestration of ICT resources and, then, to allocate a slice of them to a given service, application, or user.

The initiatives of SDN/NFV clearly show the path that leads to the eventual convergence between the technical fields in all factors. Now it is not really that hard to trace the path of the formation of NI: a framework along SDN/NFV principles is used to ensure the interoperability and the joint orchestration of the resources of the already converged fields with the new ones. This process is repeated, as it is shown in Figure 3, until the formation of the NI is complete.

Contradictions and Challenges in the Contemporary ICT

Despite the giant step forward being made with the SDN and NFV initiatives, existing contradictions in the fields of ICT curtail faster progress. "Networked Intelligence" is defined by two intertwined categories: the "Intelligence" that appears either in the advanced form of Artificial or Augmented Intelligence (AI or AuI) applications or by means of the many primitive forms associated with simple IT storage, processing, or computational processes. In the context of NI, none of them is considered in isolation as a standalone entity. On the contrary, it is the "Networked" context and dimension that allows the "Intelligence" to become a key enabler for I4.0.

Currently, there is an uneasiness that the relationship between the two pillars of NI can still be derailed back to the practices followed during I3.0, the market protectionism practices. In particular, the danger is to keep trying to implement outdated arguments when it comes to connectivity networks and to adopt schemes that jeopardize the "open" character of the deployed platforms, as is detailed below:

> *Silos in ICT*: The rush of cloud and e-commerce enterprises to penetrate the markets is forcing them to adopt, quite often, compartmentalized platforms and other proprietary single-purpose solutions. These are usually codenamed as silos. If this practice is widely adopted, it may lead to the deployment of multiple platforms in parallel, which are all tasked to perform, more or less, similar tasks. Although this mode of operation serves a faster early-day deployment of specific applications, a large number of parallel and isolated infrastructures in silos will incur tremendous costs to the digital economy as a whole at a national level. Actually, these compartmentalization initiatives contradict the philosophy of SDN/NFV as these keep exploring the pathway of single-purpose and over-fragmented platforms where no cross-fertilization is possible.
>
> *Rationalization of Connectivity Networks*: Around the globe, there are frequent reports of the stunning breakthroughs of 5G-enabled applications and services. These advances are often accompanied by misconceptions and exaggerations that range from the extent of the 5G deployments to the actual abilities of this technology. Without trying to downsize these advances, the reported achievements may not necessarily be as remarkable as it is claimed they are, or they may not apply under different conditions or application environments. Clearly, the deployment of 5G is not without complications. In parallel, partially reflecting the truth that many of the promises 5G has made turned out to be void, researchers are probing the characteristics of 6G, which is regarded as the next evolutionary phase in connectivity networks.

Regarding next-generation connectivity networks, attention needs to be paid to dissociate ourselves from the very questionable rationale adopted during the current 5G deployments: there is a bias in 5G for the primacy of cellular mobile wireless technology over all other technologies. In fact, the very name of 5G contributes to the misconception as 5G directly refers to the fifth-generation technology standard for broadband cellular networks.[1] In reality, the connectivity networks to serve I4.0 need to be technology-agnostic, i.e., to be based on systems that exploit the whole range of existing and emerging communication technologies. An inclination toward the opposite is more due to the uneasiness of corporates (operators and system vendors) to penetrate the market, using marketing arguments, than a sober technical or techno-economic analysis. Moreover, it is evident that none of the I4.0 goals can be met by resorting only to a "local" optimization model, which is exactly what cellular mobile wireless technologies do. For connectivity networks to serve the purpose of I4.0, as a production platform that overcomes localization barriers, wireless technology cannot be—by any means—the sole technical solution as wireless networks are of a local-only significance.

Conclusively, if I4.0 is to transform production as we know it, then these ICT solutions should demonstrate that they are *scalable*, i.e., the approach still works regardless of the extend of the application, over in a number of key-performance-indexes (KPIs) including but may not be limited to:

- The *number of users* a solution may support. The term "users" here refers to both humans and machines.
- The *geographic coverage*, which extends from the local neighborhood across the national borders and beyond in order to become a "global" platform.
- The *Quality of Service (QoS) performance* a solution may guarantee. The term QoS is defined in terms of parameters such as capacity, latency, jitter, error rates, packet loss, etc.
- *Cost-effectiveness*, i.e., any solution should provide the requested performance at an affordable cost when estimated at the scale of a national economy.

Currently, there are *no* 5G solutions that *simultaneously* satisfy *all* these KPIs; claims for the opposite are just wishful thinking. Reversing the argument, with a sufficient level of funding, any solution could demonstrate an adequate performance over one and, maybe, over two of the above KPIs. However, under the predominant 5G framework, the rollout of 5G at a national scale featuring an outstanding performance over all *KPIs* will incur a colossal cost on the national economy. In this case, the consequences are gloomy: under the current 5G mindset, either the connectivity network will cripple the national economy or—this is more likely—the KPIs will not be met, jeopardizing the path of I4.0.

The Longer-Term Implications of the Convergence in Technologies

Inevitably, one is wondering: where this technological revolution will leave us when it is over? Which are going to be the longer-term social implications? The changes will be colossal, and it seems that, although pieces from the puzzle are still missing, we have today sufficient evidence for some relatively safe predictions regarding the far-reaching consequences. There are two processes in parallel that reinforce each other:

"Delocalization"—the death of distance: The technologies we develop to serve I4.0, will have, as their by-product, the liberation of mankind from all these constraints that are forcing us to be "local," i.e., from any technology-induced restriction compelling us to operate only within certain geographic boundaries. As discussed above, we have seen that the previous industrial stages, I1.0–I3.0, never had this dimension in sight: this was neither feasible, and some might say nor even desirable. This liberating and democratic feature of I4.0 is schematically illustrated in Figure 5, where the I4.0 technologies set the grounds for the *delocalization*: humans will not be obliged anymore to have a physical presence in a specific place (like factory, enterprise, agricultural field, etc.) to fulfill most—if not all—working tasks. As a result of the convergence in the fields in F2, all forms of social interaction are initially "digitized," and through the "softwarization" of SDN/NFV, they are replicated and reproduced in many places at the same time and/or they are implemented and coordinated remotely. This delocalization will be a universal phenomenon leading to what Bell Labs describes as: "a new phase of nomadic, distributed human existence" (Weldon 2016, 10).

The connectivity networks play the primary role in this "death of distance" that make possible this "nomadic existence." Through this process, the centuries-old antagonism between the *rural* and the *urban* areas is eventually overcome as, currently, the former is the place where the population is concentrated since this where the factories, the production, the culture, and the opportunities in life are, while the latter demonstrates just the opposite fact, the isolation and separation. But since the very own reasons that made cities what they cease to exist, i.e., to be the preferred place for production, then humans in their free will decide their own fate, not an external force that is imposed on them.

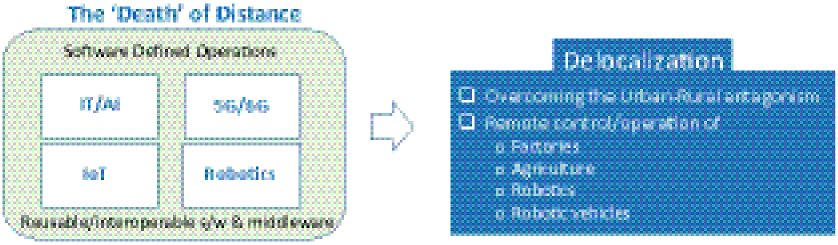

Figure 5 The Effect of Delocalization as the Final Result of the I4.0

The Death of Specialization—the general-purpose platforms: As presented in detail in Part II of this article, generalized or *general-purpose production machines* will replace the vast number of special-purpose ones in the I4.0 technosphere. The existence of a large number of narrow-scope machines, tools, methods, etc., lead to over-fragmentation and coordination complexity in production, while it is the main cause behind the division of labor that is monstrously expanded during the previous industrial stages. The term "general-purpose" is used here to describe *a system* of production machines and/or agents that emerge as a result of the IC&OT technology convergence (Figure 6).

These general-purpose systems may consist of a sizable number of single (ASICS) or general-purpose (FPGA-like) IC devices, other sub-systems, as well as a number of other heterogeneous platforms. Hence, the term general-purpose is used here to designate a ubiquitous and pervasive system that is reused to accomplish dissimilar tasks, or it may mean a generic platform that is reconfigured, at will, to carry out dissimilar tasks. Therefore, when a general-purpose production machine is examined in isolation, this should be able to reconfigure its part and/or to transform itself in order to complete, as a standalone entity, all necessary tasks of a working activity.

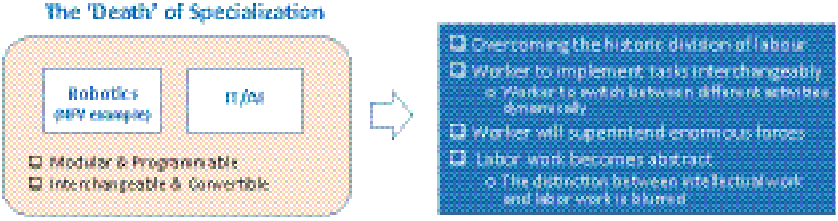

Figure 6 The Death of Specialization as the Final Result of the I4.0

The above does not mean that specialization disappears. On the contrary, it constantly reappears in all new innovations: specialization continues to be the primitive form of change and/or the preferred platform whenever extreme performance requirements prevail over efficiency.

Conclusions

We are entering an era of the deep transformation of all aspects of human activity and in forms of social interaction. The main characteristic of this era is the convergence and eventually the fusion of those technologies that define our technosphere into a single technological continuum. The drivers of this convergence are clear, and they make I4.0 a distinctive industrial stage. The upcoming fusion of these factors, at the end of this long road that is expected to last an entire historic period, will result in the emergence of ubiquitous, general-purpose technologies that will allow us to overcome the hurdles that limit the horizon and the experience of humans. This era will redefine the notions of "production" and "work," and it will reshape our cities, our personal lives, and our relationship with science.

Note

1. See https://en.wikipedia.org/wiki/5G.

References

Agrawal, A., and A. Choudhary. 2016. "Materials Informatics and Big Data: Realization of the 'Fourth Paradigm' of Science in Materials Science." *Apl. Materials* 4, no. 053208.

Casado, M., M. J. Freedman, J. Pettit, J. Luo, N. McKeown, and S. Shenker Ethane. 2007. "Taking Control of the Enterprise." Association for Computing Machinery—Special Interest Group on Data Communication, ACM SIGCOMM no. 07.

ETSI (European Telecommunications Standards Institute). 2012. "Network Functions Virtualization—Introductory White Paper." *ETSI*, October 22.

Rifkin, J. 2012. *The Third Industrial Revolution*. Chicago: Griffin Publishers.

The Economist. 2012. "The Third Industrial Revolution." *The Economist*, April 21. https://www.economist.com/special-report/2012/04/21/a-third-industrial-revolution.

Toffler, A. 1984. *The Third Wave*. New York: Bantam Books.

Van der Merwe, J., S. Rooney, I. Leslie, and S. Crosby. May 1998. "The Tempest: A Practical Framework for Network Programmability." *IEEE Network* 12 (3): 20–28.

Weldon, M. 2016. *The Future X-Network: A Bell Labs Perspective*. Boca Raton: CRC Press.