# Agentic AI in 6G: Revolutionizing Intelligent Wireless Systems through Advanced Semiconductor Technologies

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**KEYWORDS**

*Agentic AI, 6G, intelligent wireless systems, advanced semiconductor technologies, autonomous networks, edge computing, ultra-low latency, real-time decision-making, AI-driven communication, neuromorphic computing, energy-efficient hardware, intelligent connectivity, massive MIMO, mmWave, terahertz communication, adaptive signal processing, AI-enabled base stations, smart transceivers, distributed intelligence, self-optimizing networks, quantum semiconductors, AI hardware acceleration, embedded AI, network slicing, dynamic resource allocation, chip-scale integration, AI-chip co-design, next-generation wireless, AI-native infrastructure.*

**ABSTRACT**

Agentic capabilities are believed to become a baseline feature of all Artificial Intelligence capability layers, leading to a paradigm shift in technology as well as business models towards commercially exploitable technology components and value-added services. With IWOs together with heterogeneous advanced semiconductor devices forming the capability backbone of 6G intelligent wireless systems, an unprecedented magnitude of intelligent wireless services can be enabled. Although next generation intelligent wireless systems, such as 6G, are integrated naturally into the previous generation system hierarchies and service domains, it is expected that 6G and beyond will bring an unprecedented abundance of intelligent mobility supporting diverse human and machine work. In this chapter, we provide an outlook on advanced semiconductor capabilities tailored to face the ensuing challenge for revolutionizing intelligent wireless systems in 6G.

Semiconductor technologies have been the hidden backbone for large-scale capacity growth in intelligent wireless systems and the development of the wireless services ecosystem. Agentic Artificial Intelligence capabilities, integrated at various capability layers ranging from low-level AI microcontrollers powering intelligent wireless objects to high-level AI engines optimizing the end-to-end system, will credibly unveil the long awaited vision of Asynchronous and Volumetric Mobility. 6G is expected to bring an unprecedented abundance of intelligent mobility services, spanning diverse user categories. To accelerate the capabilities expansion of devices and the democratization of intelligent services, 6G intelligent wireless systems must exploit every area of the performance landscape, enabled by advanced semiconductor technologies that are combined and packaged intelligently..

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## 1. INTRODUCTION

The future wireless networks, beyond the current 5G, are referred to as 6G networks. These networks are anticipated to exploit new paradigms and technologies, such as artificial intelligence and internet of things (IoT), in order to provide ultra-high speed, ultra-low latency connectivity, while supporting an unprecedented number of devices and enabling new innovative applications and services. Thus, advanced wireless edge and core networks are envisioned. These networks will be deployed at different frequency bands, from sub-1GHz up to THz frequencies, and will incorporate advanced intelligent technologies. Intelligent wireless networks will have a life cycle that is different from the typical 5-10 years life cycle. Instead, the cycle life of intelligent wireless networks should adapt the emerging new wireless applications and services by being flexible, agile and software-defined.

Both present and future intelligent networks will rely more and more on the layers of nano-, micro- and macro- semiconductor devices at the physical layer. These semiconductor physical layer devices and associated microwave and optical chips, either miniaturized or consolidated should support lower latency, faster processing and higher throughput of the millimeter, sub-THz and THz waveforms. In this context, advanced semiconductor technology is the missing ingredient for building intelligent wireless systems capable of supporting the future demand for data anywhere, anytime and with any quality of service. Thus, future intelligent wireless systems will combine three concepts. Firstly, a radical increase of the volume of data of the intelligent wireless networks, with respect to the current intermediate 5G networks. Secondly, the introduction of parallel processing and/or 6D communications with novel created degrees of freedom, such as spatial and resource-less MIMO, quantum and THz services. Thirdly, the implementation of intelligent wireless systems capable of decision and decentralized processing at nano/microscale thanks to nanomaterial solutions and nano-products.

## 2. Overview of 6G Technology

The roadmap of full-fledged realization of six generations (6G) of wireless communication technology provides opportunities toward achieving the vision of ubiquitous connectivity, supporting huge number of communicating devices, enabling very high data rates and ultra-low latency, autonomizing intelligent wireless systems and realizing sustainable operation of future communication infrastructure. These information and communication technology (ICT) capabilities as well as their broader economic and social impact makes 6G as one of the most disruptive and transformational technology of future. As life moves to a concrete supplement of virtual reality, it is desired to achieve the metaverse vision that demands shaping and evolving the network infrastructure toward immersive holographic communication experience being supported by ambient sensory communication environment in engaging styles targeting at the individual levels. There is also a push toward realization of "everything-as-a-service" mission to facilitate the unlearnable experiences of nature through local dynamics provisioning synthesized by advanced intelligence gradient. For this, the real-time intelligent capabilities enabled by artificial intelligence (AI) frameworks are expected to evolve toward agentic artificial intelligence (AAI) that advances the communication infrastructure toward being able to sense, act, aware, learn and interact.

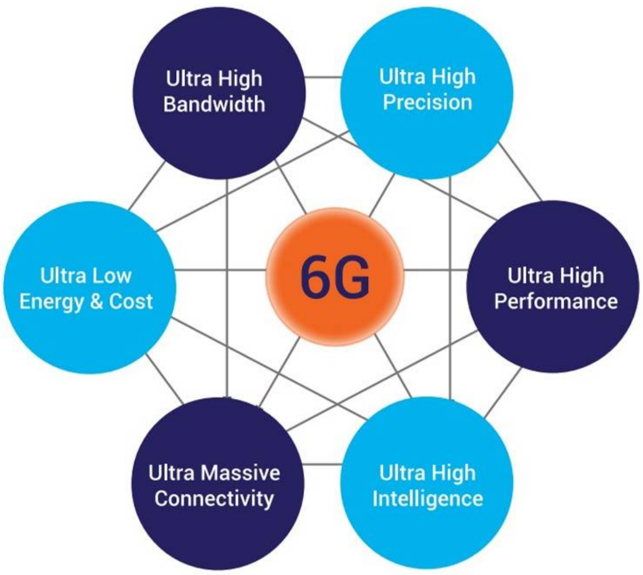


**Fig 1 : 6G network? What are its advantages**

To accomplish the vision of 6G, there are outstanding challenges. The complexity of network infrastructure is increasing dramatically, while the resources are very limited. Further, the demand of high energy efficiency is becoming critical tenet for network operation. Ubiquitous sensing of the environment can grab the attention from intelligent functions, while advancement of new types of devices creates the ecosystem with low size and cost. Recent advances in semiconductor technologies have opened opportunities involving capable semiconductor devices and circuits that ease the fulfilling of challenges through establishing synergies among hardware, wireless and AI. Advanced semiconductor circuits, sensors, actuators and devices are enablers to augment the network intelligence and autonomize the network functioning toward AAI-driven 6G. This chapter envisions a new paradigm that shapes the integration of advanced semiconductor technologies with the agentic intelligence foundation, while offering a perspective on the framework of realizing the intelligent wireless systems (IWS) concept.

### 3. The Role of Agentic AI

The mission-oriented nature of wireless systems is highly compatible with the objectives of agentic AI, and agentic AI can greatly enhance the capabilities of future wireless systems. Through the agentic AI driving and choreographing the 6G wireless systems, the cognitive AI-empowered agents need higher level of AI intelligence and capabilities. First, agentic AI-enabled 6G systems can greatly aid the improvement of the performance of wireless systems by achieving intelligent mapping and understanding of the interactions between the wireless systems and their surroundings, along with the multi-scale design and optimization of the artificial electromagnetic environments. Second, the intelligence and cognitive capabilities of wireless systems supported by agentic AI can extend from coordinating the energy, bandwidth, and hardware resource of wireless systems to orchestrating a continuous and enhanced symbiosis between the wireless systems and their mission environments. Third, while the critical communication and computing infrastructures from lower reach to higher nodes in the communication and decision-making hierarchies from real physical world to virtual cyber world are provided by 6G wireless systems, the utilization, routing, and management of the critical resources in the physical world are carried out by the agents that are driven and guided by agentic AI. The cognitive AI-powered agents themselves can be either operated in mission-specific collaborative group-based forms or controlled by agentic AI. 5G could achieve more than 50 times performance increase over LTE. And yet with 6G, in addition to wireless system-empowered intelligence, intelligence-empowered wireless systems are expected to have their performance further improved by 100 times.

### 4. Advanced Semiconductor Technologies

The semiconductor technology becomes extremely important, because the First Pillars of Intelligence are in between the computing and semantic materials utilized to facilitate the communication between the Stupified AI Devices and Operation AI Servers. But the semiconductor technologies are facing several roadblocks. It is an open question whether the extension of the scaling paradigm through the Fin-FET, the Gate-all-around FET, or the Tunnel Field Effect Transistors is enough to provide sufficient speed at low power supply and low supply noise, and high Internal Bandgap energy to properly fabricate the driving logic for each of the many semiconductor Material Sensors that will enable the Stupified AI at the edge.

**Eqn 1 : Carrier Transport Models**

$$J_n = qn\mu_n E + qD_n \nabla n$$

$$J_p = qp\mu_p E - qD_p \nabla p$$

Where:

- $\mu_n, \mu_p$: Electron and hole mobilities
- $D_n, D_p$: Diffusion coefficients
- $E$: Electric field

It is known that the semiconductor devices cannot be properly scaled beyond the 5nm node, with the natural limitations imposed by the number of atomic layers in the channel. This imposes serious limitations to vertically stack more logic and memory devices. It is important to note that a proper geometric scaling of semiconductor devices does not imply a scaling of the supply voltage. Because of the statistics, silicon bipolar transistors have a thermal voltage of around 26mV at room temperature, which must be larger than the threshold voltage of both logic devices and memory devices. Therefore it can be safely stated that an exponential geometric scaling of semiconductor devices will not be possible in the future, even if advanced semiconductor technologies will be able to keep proper current handling capabilities.

### 5. Integration of AI and Semiconductor Technologies

The existing semiconductor design and fabrication chain for modern devices used in intelligent wireless systems like 5G or IoT involve various time-consuming and data-intensive steps. These existing workflows may benefit significantly from an introduction of intelligence at key stages from the research-and-development budget to the effort required for manufacturing and debugging at-scale production chips. Rapid advancement in AI algorithms could help mitigate this complexity, and create novel solutions that can optimize performance and reduce cost in shorter design cycles and lower energy consumption chips. In this sense, integrating AI for-chip design, fabrication, and testing would mark a significant advance in any globalization of semiconductor design and manufacturing toward an eventual product realization cycle, custom or general-purpose. At the same time, the exploding field of AI itself dramatically increases the demand for high-performance and custom semiconductor chips, and advanced architectures, that the AI increasingly relies on for processor-driven convolution engine acceleration of both the learning from multi-level and multi-modal data and the day-to-day low-latency in-production inference. Chipmakers have recognized their heightened opportunity to leverage and capitalize on their capabilities in design and manufacture of miniaturized and optimized semiconductor solutions at reasonable price points-supporting increasingly diverse and demanding applications that utilize AI for-a host of industries and services.

### 5.1. AI Algorithms for Semiconductor Design

What if chips could learn how to become smarter during their life cycles? What if we could teach chips how to learn to dissipate less power? What if we could put miniatures of the most optimal semiconductor devices in a chip and optimize them continuously – not only at the design time, but also during its life cycle to achieve zero defect lifetime? That might sound science fiction, a dream drawn by midideists, but the advancement in various branches of artificial intelligence today can pave the way to make it come true. Therefore, this section elaborates on the opposite direction: We review the recent works where advanced machine learning and AI algorithms are utilized to design semiconductor devices and chips to bring the next performance boost, with less power and area or advanced computations. Satisfying all these characteristics is a multi-objective optimization problem, and thanks to the limitation of available computational power, similar challenging problems are solved using various approximations.

Machine learning has been applied, although on a limited basis using simple algorithms and rule-based systems, for many design tasks ranging from PDK generation through synthesis, layout, circuit, reliability, and physical verification. Recently, with the advancement of deep learning, its use in various semiconductor design tasks has been proposed as it enables the performance of previously inaccessible sophisticated approximations. These relatively formalized design tasks include photolithography, many aspects of SoC design, especially layout, such as DRAM floorplanning, signal routing, placement, cell synthesis and layout generation, synthesis of analog circuits, design exploration, simulation, and modeling, reliability checking, and chip testing, and yield management. Therefore, what if we could teach chips how to learn to dissipate less power?

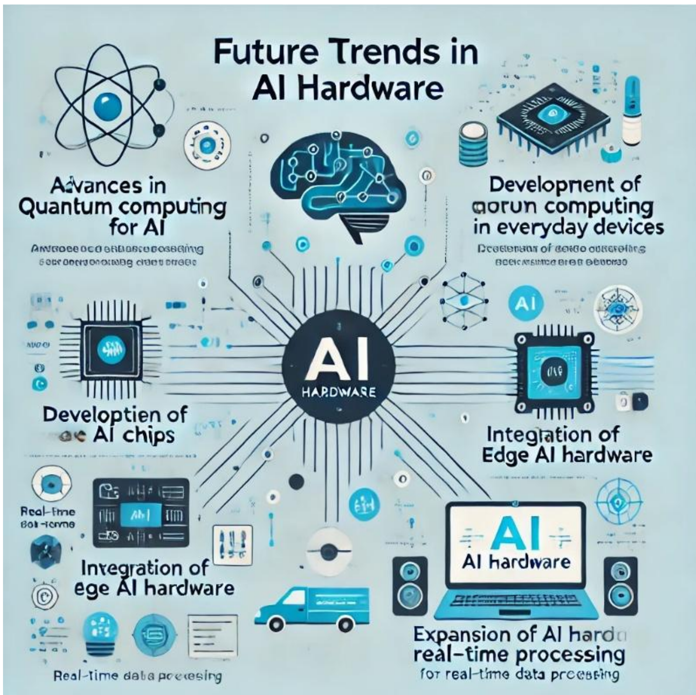


**Fig 2 : Artificial Intelligence Hardware – What is Required to run AI**

### 5.2. Machine Learning in Chip Manufacturing

The rapid development of machine learning technology and its wide adoption have revolutionized many industries and boosted productivity growth. We have seen the success of ML-powered applications such as image classification, machine translation, and complex decision-making in the fields of computer vision and natural language processing. The semiconductor industry is the foundation of both the AI computing platform and the AI chip itself. Hence, it is natural to see the impact of AI and ML on data-driven applications back to the semiconductor industry. Companies have started to invest their resources to explore the novel AI/ML technology to accelerate the chip manufacturing workflow, which is traditionally dominated by human experience and expertise.

Traditionally, chip manufacturing is done with hand-crafted rules based on the expertise accumulated in years of experience. The huge parameter space makes the chip manufacturing extremely time-consuming, and the expert rule-based system is difficult to adapt to various designs and situations. ML has the potential to mimic the experienced experts and automate chip manufacturing workflows. Thanks to the many years of development of semiconductor process, EDA tools have accumulated a wealth of records made during past silicon tape-outs. These EDA tools have recorded important design and fabrication information, such as the manufacturing process, design rule checks, optical proximity corrections, layout-to-drift mismatch, yield, and so on. ML is a data-driven approach which can use the rich history records to build models to predict and optimize the different chip manufacturing processes, effectively make the chips work better, and save time and costs.

**6. Impact on Wireless Communication Systems**

Advancements in semiconductor design and technology to realize agentic capabilities will have a fundamental impact on future wireless communication systems. The capability to independently acquire knowledge, take action, and form and change internal representations of a complex external wireless communication environment will greatly enhance the capacity of sophisticated intelligent wireless communication systems. Initial concepts for various technology subsets have been proposed, including technology components necessary to achieve such agentic AI systems to be utilized at the user terminal, at the network service provider, and at the wireless channel itself. To date, the impact of such advanced intelligent systems on wireless communication systems of the future has only been qualitatively discussed.

In this section, we delve deeper beyond the qualitative description of agentic AI to note how existing communication system concepts are impacted, in order to provide guidelines on and yield further insights into what these components and design considerations should be to achieve agentic intelligent wireless communication systems of the future. In general, it has been recognized that the intelligence applied to wireless communication systems of interest are targeting various levels of the wireless stack. Typically, transport protocol, network layer, and upper levels of the wireless stack are targeted for intelligent solutions that make predictive decisions towards improving throughput and latency, assist in mitigating vulnerabilities, and selecting antenna patterns to provide predictable and minimized latency for intelligent agentic systems, including the service allocation of users to prediction-assisted communication and sensing services.

**6.1. Enhanced Signal Processing**

Much of the state-of-the-art signal processing was designed for conventional wireless systems, where parameter knowledge (at least at the receiver) is assumed. Consequently, the performance is limited when such knowledge is not available. However, actual wireless propagation is much more complicated than what we can analytically model, leading to limited engineering choices. Also, the general gap between engineering models and real system behaviors can only be bridged by data.

**Eqn 2 : Array Signal Processing (Beamforming)**

$$y(t) = \sum_{n=1}^{N} x_n(t - \tau_n)$$

- $x_n(t)$: Signal from the $n^{th}$ sensor
- $\tau_n$: Delay applied to align signals

On the bright side, many novel techniques, such as deep learning, have demonstrated drastic improvements in many wireless signal processing tasks. This capability is mainly based on the strong universal approximation property of deep networks and the ability of such models to leverage large scale datasets for training. Naturally, since wireless channels are actually functions of space, or time and space, it is reasonable to attempt to utilize these datasets to train dedicated engines for model-based physical signal processing to construct such interference rejection and performance boosting capabilities as intelligent reflecting surfaces. These capabilities cannot be achieved solely by hardware advances; even with extremely advanced hardware, without these sufficient empirical training optimizing some task performance, the AI engine would be too general to achieve the robust performance required for real task constraints, such as user experience and resource efficiency. Therefore, training dedicated deep signal processing engines, on the foundation built by wireless hardware and efficiency, is essential to guarantee a good tradeoff between system performance and service latency.

Additionally, individual signal processing engines employed in different parts of the system for diverse tasks, such as data detection, channel estimation, or feedback channel design, could be designed and efficiently implemented using a neural network architecture for optimal parameter interrelationships, in a collaborative either end-to-end or cooperative learning framework, thus offering efficiency improvements for the data-driven AI methods as well. Devices could cooperate through a distributed learning framework taking advantage of the latest techniques.

### 6.2. Improved Network Efficiency

Despite considerable advances accomplished by existing technologies, global wireless communication networks are continually challenged by growing traffic demands on dependable and efficient operation. A need has emerged for improving the operating efficiency of current wireless networks while assuring effective support of the projected multi-terabit/second wireless data service requirements of the sixth-generation systems. Thus, smart radio access and core networks capable of dynamic configuration, sensing, resource allocation, and learning are an important building block of the envisioned intelligent wireless systems. To be able to accommodate the tremendous data rates at practical energy and latency costs, the forward wireless access links will heavily rely on resource and ID/spectrum/timeliness multiplexed ultra-massive multiple input multiple output. In such systems, diverse scatterers are overly utilized to generate a fully populated multi-dimensional data space allowing distributed MIMO communicators to overcome excessive fading and multipath dispersion and achieve the projected capacity gains. At the core of the capacity multiplexing is the need for timely acquisition of the channel estimate, knowledge of which can be expressed via polynomial functions providing a predictive capability able to accommodate dynamically changing propagation conditions.

The anticipated very high mobility and associated rapid scattering dynamics at the optical carrier frequencies used in the forward wireless access link of the systems dictate the use of closed loop transmission realizations. In such cases, the response of the radio channel is referred to as the channel impulse response or channel response, which describes the time-varying transfer function mapping inputs to outputs at various spatial locations of the transmit and receive arrays. Providing estimates of the CIR on a timely and continual basis for the anticipated THz frequency-based networks is impractical with the currently used access strategies that employ comparatively long time durations to compute the required estimates.

### 7. Challenges in Implementing Agentic AI in 6G

Intelligent wireless networking systems capable of providing distributed seamless and autonomous services for numerous resident users based on the users' contactable devices and their expectations is the vision of 6G technology. The 6G intelligent wireless network system will become the basis of our intelligent space, and moreover, work and life environment. To enable distributed intelligence technologies like agentic AIs, integrated photonics and terahertz wireless communication systems will be exploited. We present vision and related technical areas toward intelligent wireless systems with agentic AIs, which are capable of multiple layers of abstraction with agentic perception, cognition and action through tightly integrated smart devices in semantic association with physical objects and orchestration of decentralized wireless networks.

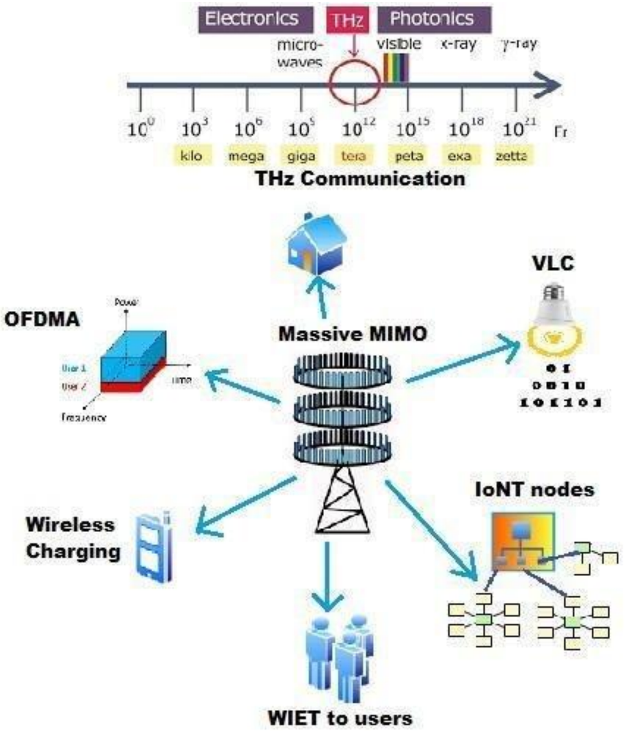


**Fig 3 : The challenges in 6G Wireless technology**

Despite the potential and opportunities promised by the future Agentic Artificial Intelligence technology and Agentic Intelligence aided intelligent networks, there are still many challenges in implementing the related technology in 6G Wireless Communication Systems. First, existing physics and based semiconductor technologies as well as devices like Von Neumann computing architecture cannot unleash the computing, storage and sensing system with necessary speed, efficiency and capacity to enable the agentic AI technology. Second, enabling trust between the humans and machines to service autonomously in a decentralized manner and between the machines themselves to cooperate effectively is essential as there is lack of transparent decision guidelines for the AIs in making decisions. Third, there is a lack of understood ethical governance in incorporating realigned reward functions into training cycles of the machines since accountability cannot be assigned when errors happen during a duty cycle, especially when the installed AI is an agentic one acting in the physical world.

### 7.1. Technical Limitations

As a stepping stone toward practical implementation of agentic AI in 6G, it is required to deeply understand important technical limitations and related efforts. The most important special requirement of 6G as an enabling technology is high reliability at ultrahigh throughput. As a centuries-old wish of human beings, bringing such a reality depends on large-scale deploying Intelligent Wireless Systems (IWSs) having interaction and overlap with human activities, realize fool-proof operation in daily lives in an all-encompassing manner, and always keeping alert for any major troubles even in the loss of power sources. With such a characteristic, IWSs differ from existing telecommunication systems and have special problems which cover not only the AI itself but also the carrier devices, networking, semantic understanding, human-system interaction, and payload processing platforms for agentic AI.

When we focus on AI itself, how to enhance reliability of AI firmware against the inaccurate behavior and malfunction is an important task. Suppressing false, sensitive, irrational, and logical mistakes of machine learning is a valuable important challenge. The currently available AI techniques are completely based on data-driven machine learning. For real-life security, augmentation learning using negative data feedback should be required. Historically, the hitherto proposed AI processing including semantic understanding, robot watching, NLP, and condition provision has been always tried for redundancy and huge backup data. This result on one hand is praised as the success on huge scale, on the other hand is said on the collapse of the grid caused by the enormous needs for computing and storage resources.

The above-mentioned demands on the data processing by AI firmware will cause unavoidable losses on network reliable throughput, latency, and initial delay. The trade-off is resolved by augmenting physical stimuli by wireless transmissions, such as guiding the conversation monitoring for gesture expression recognition through haptic broadcasting, and preparing infrastructure for hinting important information beforehand.

### 7.2. Ethical Considerations

Concerns about the ethical implications of using AI technologies pervade various fields. These concerns arise from potential impermissible actions that an agentic AI may take, the inability of AI to distinguish between right and wrong, the incapacity of AI to comply with moral principles, and the fact that AI replaces humans in conducting certain activities. A society that values autonomy recognizes that the exercise of deliberate control over one’s life is an integral aspect of one’s humanity. Agentic AI raises particular concerns in this respect, as it may replace certain aspects of human agency. Recent AI-assisted healthcare technologies, for instance, commingle human agency with machine influence in uniquely challenging ways. They utilize predictive techniques that estimate health outcomes for individual patients, thereby delivering personalized recommendations for treatment. Yet these algorithms do not and cannot have knowledge of the individual’s history, particulars of the case, and values in play that are critical components of the decision-making calculus regarding treatment. It is not clear whether a recommendation that is blindly followed on the basis of an algorithm’s predictive capabilities serves an individual’s agency; if it does not, this is a significant problem from an ethical point of view. The problem becomes far more acute when we consider algorithms that recommend high-stakes decisions where factors that are irrelevant to predictive performance loom larger than prediction in the underlying causal structure: such situations are likely to arise in contact tracing or the remotely monitored recovery of patients.

**Eqn 3 : Moral Risk and Harm Modeling**

$$H_{exp} = \sum_{i=1}^{n} P(a_i) \cdot D(a_i)$$

Where:

- $P(a_i)$: Probability of action $a_i$
- $D(a_i)$: Degree of moral harm caused

Therefore, a significant ethical concern arises in regard to agentic AI systems that collaborate with humans in decision-making processes. The fact that recommendations by AI can affect but not serve specific individual goals raises ethical questions as to when, and to what extent, it is appropriate to prioritize algorithmic recommendations over human reasoning.

## 8. Case Studies of Agentic AI Applications

In this section, we describe two exemplary applications of agentic AI in practice, which are pervasive in society today or are expected to play a pivotal role in the future: smart cities and autonomous vehicles. We analyze these application areas in detail in order to derive guidelines and architectural principles for future agentic AI systems.

Smart cities have been touted as an effective solution to alleviate some of the problems faced by modern society. To improve the quality of urban life, ensure its sustainability, and ameliorate the efficiency of urban services, smart cities utilize sensor networks and ubiquitous connectivity to gather data about the urban environment and its internal dynamics; then, through intelligent agents of varying degrees of autonomy, analyze this data to identify and model problems such as traffic congestions, air pollution, or noise pollution; and finally, provide a solution for the optimal use of urban resources, often in real-time. Information generated in this cycle can be shared with citizens and used to enhance their engagement in the city life as well as create applications and services that benefit city residents. Using concepts initially borrowed from business, the “smart city” paradigm proposes that cities not only provide the services, engage the citizenry in its operation through participatory budgeting, for example, but are also a commercial partner in the efficient delivery of city services through private-public partnerships.

Autonomous Vehicles (AVs) carry potential for a radical improvement in transportation efficiency and reduction of GHG emissions, traffic accidents, and congestion. To deliver this promise, AVs must have an intelligence that allows them to make good driving decisions under high levels of uncertainty. Optimization-based approaches that assume perfect knowledge of all other traffic participants' behavior fail when used for a limited-time horizon. Rule-based AI as historically used in the context of AVs has fallen short due to the difficulty of formalizing a long set of usually tacit rules. Recent developments in deep learning give promise that data-driven methods can effectively learn to replace rule-based AI; however, in principle they suffer from the same fundamental problems with generalization seen in other applications of AI, as well as additional complications arising from the need for highly reliable performance.

### 8.1. Smart Cities

As nations transitioned from industrialism into a new, quasi digital age, business practices and strategies that had dominated economic output began to shift on mass from company-driven growth focused on decentralizing and offshoring labor spending to the singular vision of cities where vast sums of money were poured into urban renewal and revitalization. The original vision for Smart Cities foresaw a shimmering, sexy, dustslemashing vision of the future. Fleets of autonomous delivery drones mapping and managing busy urban environments with low stress, recordsetting speed, while commercial freight traffic is handled by specialized, self-driving trucks. Exempt from traffic, looking down on the silently chugging, driverless electric taxis sorting their clumps of happy tourists and successful businesspeople from one appointment to the next would be massively braced vertical farms, standing side-by-side with a legion of stepped roofs topped with tiles facing directly into the sun and fielding power for urban electric plants beaming their surplus into the grid. Housing, schools, and office buildings would be powering themselves, overeducating local knowledge workers who would spend their working hours in collaborative offices made to encourage the sharing of big ideas, and their leisure time wandering through an alluring landscape of parks, solar trees, and ponds.

The special feature of these smart cities would be the ubiquitous presence of agentic Artificial Intelligence units, either moon-beaming energy from huge solar concentrators above, or receiving gigahertz laser fire from ground-side concentrators. These units would be enabling civil engineers and urban planners tasked with enhancing these municipal jewels to engage in planning that was active, immediate, constant, and highly interactive. The cost of enhanced fiscal need, driven by increased opportunity for value-adding investment, would be borne by mostly digital taxes on taxes. Automated commerce would be stripping the traditional coffers bare, and everything from transaction taxes to inheritance levies would see squads of tax accountants chasing down corporate evaders, but only big deals would get missed, pass the bucket, and enter the sort of blackmarket that all economies sport.

### 8.2. Autonomous Vehicles

With anticipated cars and trucks equipped with Agentic AI, then the road will become their both Integral and decorrelated environment of chance. Autonomous models will act following their local capacities without needing to give answers to the external questions, such as: what is the road status for you now? Is it raining for you during your travel? Is your external connectivity good enough? Possible solutions will require nobody to connect each car with the outside communication networks. All possible solutions will ask nobody to connect external sensors to all the possibilities of interactions. As cars will belong to several Local Autonomous Environments (LAEs), possible scenarios will be LAE without networks of connexion. All the smart support necessary for IA without communication will be proposed. From their travels to the road or its coast, possibly from simple action to goal valorized by simple reactions without networked connexion, all autonomic walking scenarios will not use the vehicle communication system.

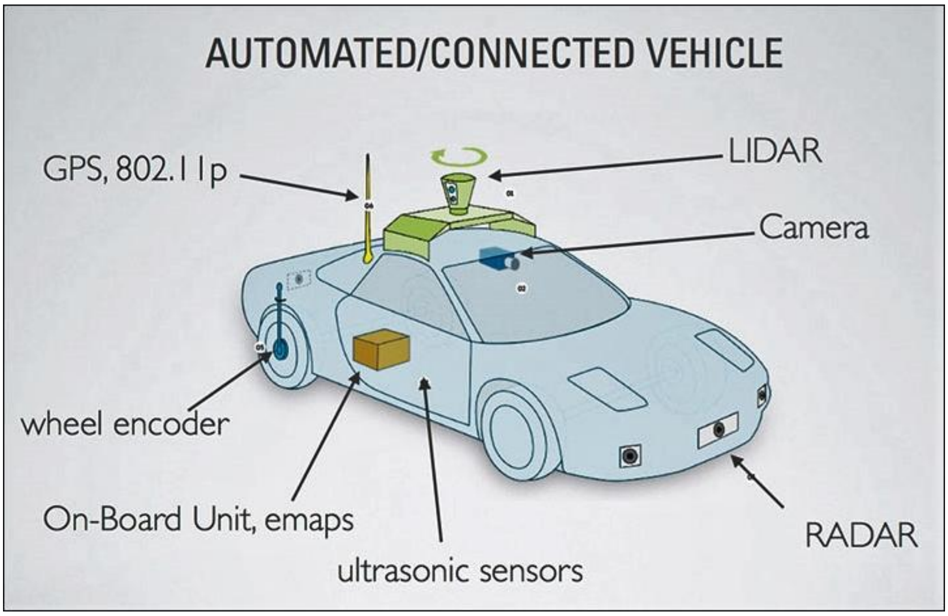


**Fig 4 : Embedded - The role of artificial intelligence in autonomous vehicles**

With help of some of these LAEs principles, reliable, safe, secure and trusted solutions could be offered to all temporal dynamics of urban, rural and life-critical mobilities. Possible agentic principles will concern vehicles which will be totally partner-solutions of all journeys, without waiting master-orders, master-communication or complex inter-facts. Their travel will be automatically scheduled with other vehicles without networked connexion. Let us stress that principles exposed here deal with autonomous systems with potential support for agentic foundations. Such discussions are bound concerning several others living systems their travels.

Trucks will move similarly. Deprived of any transport order, secure and trusted transport over movements will offer trusted and secured road transport. Without anticipated transport order, trucks will retrieve packages and unload them. Movement of transport will be done without informing customers. Security and trust will be commonly guaranteed, offer trusted transport.

### 9. Future Trends in 6G and AI

The mobile communications landscape is poised at the very brink of an exciting new chapter spanning the entirety of the 6G Era. New technologies such as RF DNA, intelligent surfaces, holographic radio, and THz comms are some of the exciting tools needed to fulfill the lofty vision of 6G. As benign operating frequencies grow, and the automation of our daily lives swells to heights never before envisioned, new responsive and agile tools and novel ways of integrating them must accompany these new frontiers. Recent spirals in technology advancement along Moore's Law, as well as post-Moore progress anticipated near the end of this decade will catalyze further advancements in the field of semiconductors, and likely result in unforeseen consequences for fields as diverse as AI, wireless comms, and beyond. Here, we delve into these opportunities.

6G goes well beyond raw bandwidth efficiency. It must seamlessly unite the demands of AI with the unique needs of multi-sensory information transfer for multiple uses and multiple users rich enough to enable an immersive experience. AI can continue its evolution into its next agentic chapter, where its unique capabilities displace near-equilibrium tools of current weak-AI, while assisting humanity in its deepest endeavors. The aspiration toward such an evolution of AI requires three different components: support for deep, perceptual exploration, founded on multi-sensory rich transport; knowledge transfer from AI to humans; microscopic transfer of discrete sensory data between agents of all orders of magnitude, with real-time latencies supporting the sensoria of the unified mind.

#### 9.1. Emerging Technologies

6G systems will require advanced communication technologies that utilize Intelligent Surfaces to deliver extreme security, energy efficiency, and coverage. These antennas will require advanced materials and semiconductor processes to fabricate and be manufactured at a low cost but with high radiation pattern quality, low insertion loss, and other desired figures of merit. Therefore, novel materials engineered at the nanoscale with low dielectric loss need to be found, novel integrated circuit technologies need to be developed that work for the THz frequency band, and new methods of studying the electromagnetic properties of circuit materials also need to be developed. In particular, the challenges presented specifically at THz frequencies will require new or modified device technologies that are capable of obtaining gain and low noise figures.

Hybrid and integrated photonic-electronic systems will need to be developed for optical communications. New optoelectronic devices will need to be developed for THz generation, detection, optical communications, and new sensors. Novel nanoelectronics devices and integration processes will need to be developed for low power computing. Optoelectronic devices will also have to perform photodetectors, electroabsorption modulators, coherent optical transceivers, highly absorbent and efficient solar cells, quantum dot based lasers, and biosensors, as well as quantum cryptography. Achieving these goals will require a concerted effort from researchers in a wide variety of fields including allied areas such as photonic nanostructures; spintronics, photonic integration circuits; quantum optics; and nanobiophysics.

**9.2. Predicted Developments**

The sixth-generation networks are anticipated to be launched in 10 years and are expected to cover several promising advanced technologies such as augmented and virtual reality, enhanced mobile broadband, intelligent sensors, tactile Internet, extreme automation, and massive, ultra-reliable, low latency communications. As the expression "sixth generation" and the "G" letter claim, the sixth generation of wireless systems will cover several promising paradigms also addressed by the first, second, third, fourth, and fifth generations. Notably, the 6G network is conceived to extend the 5G capabilities towards trusted and extremely-improving solutions for services, users, application, privacy, security and trust, and the well-being of humanity, favouring the invention of novel paradigms able to radically influence the human experience.

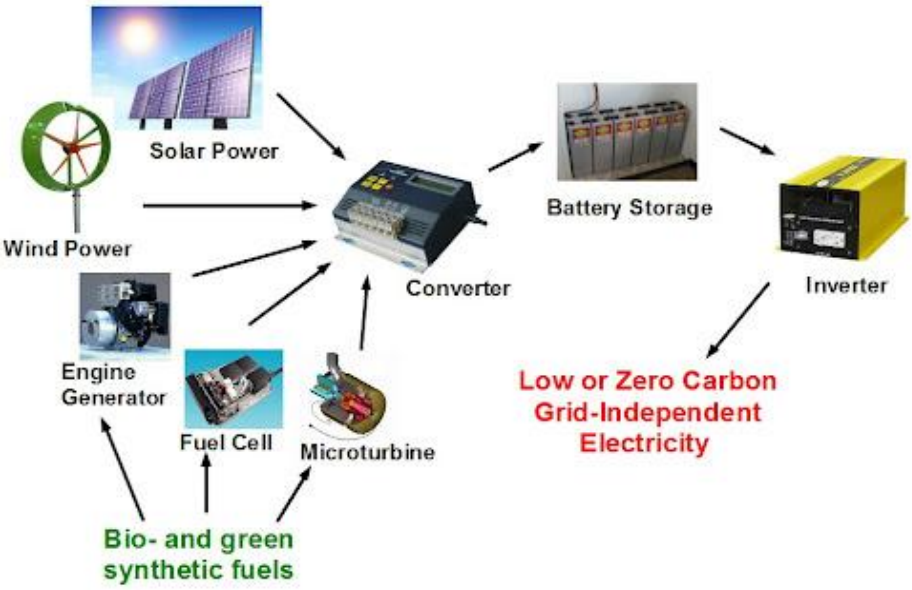


**Fig 5 Emerging Technologies**

To imagine what will come in 6G, even in terms of core technologies for advanced semiconductor nodes, let us think logically on what are the potential limitations of 5G. First of all, we have a crescent capability of real deploy what named as XR, that are notoriously bandwidth-consumed and latency-sensitive. Then, we have the need of an extreme number of edge and IoT devices able to communicate among them in a privacy-oriented sight. These examples and applications below root to develop extreme lowering of management times. In order to manage distributed intelligence and communicate hastily and safely information on smart devices acting together, we need the space of numbers able to support the novel standards and a microelectronic and photonic arena able to support these waves: fiber optics are however able to manage only few signals. Intelligent semiconductors able to enhance or realize novel solutions will have to coherently communicate and process them quick and safely. These domains with their synergic interactions will have to enable the "fifth" element of haute couture smart systems: safety.

**10. Regulatory and Policy Considerations**

In this section, we analyze the regulatory and policy considerations that will be raised through the advent of agentic AI since these topics are usually excluded from a general scientific discourse but are of utmost importance when approaching the future of wireless communication systems. There are various proposed standardization bodies that might pursue the advancement of 5G or 6G research and set the goals of the technology. The currently most well-known consortium provides the technical specifications for all parts of the mobile telecommunications industry. Other well-known international standards organizations are involved in the standardization process. These organizations assigned to 6G the massive data throughputs, low latency, low energy consumption, and ubiquitous connectivity at low cost.

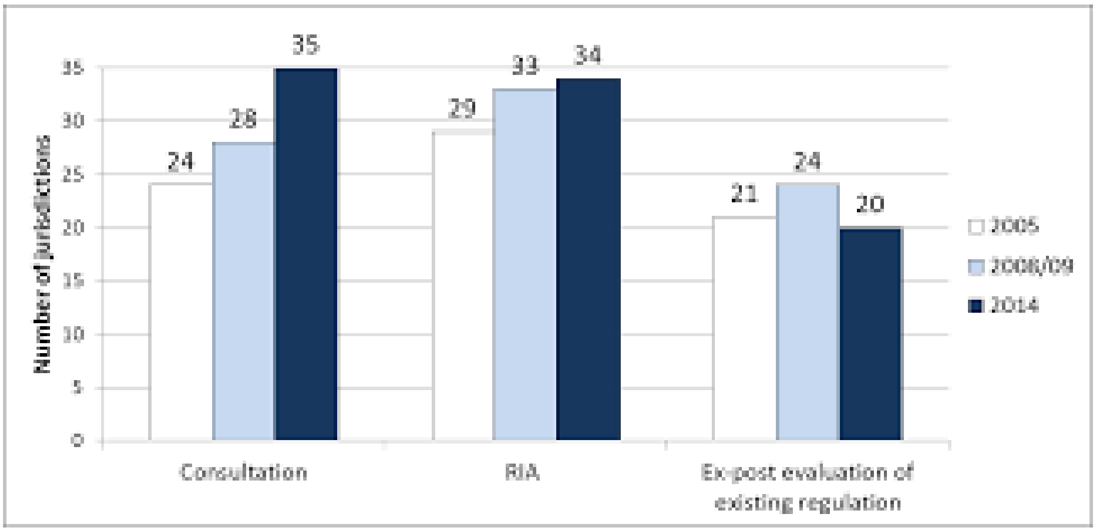


**Fig : International Regulatory Cooperation An OECD perspective APEC Economic Committee Workshop**

While the requirements of the target technology are well defined, the actual use cases differ vastly among different developing countries, and in fact the use case may differ in regions of the same country, as the development times and paths are dependent on the local societal, economics and democratic considerations. This gives rise to the question of whether the heterogeneity of the stakeholder ecosystem must be represented at the policy committee level or if certain actors, be they private or public, should be favored. Further, the combination of commercial with public interests needs to be defined as many of the designed research projects will have a public impact, i.e., they take actions with a public interest or impact consumers, but companies cannot be expected to conduct research or even construct infrastructures without immediate monetary compensation.

### 10.1. Global Standards for 6G

The rapid development of 6G technologies will require collaboration among various companies, universities, and research organizations from around the world. In particular, collaboration among development teams in different countries will allow for improved communication and a reduction in duplicated efforts. Furthermore, by tapping into each other's innovations and resources, coordinating different industry and service activities will help to decrease development times and costs. Trade policies must reflect this need for collaboration, providing a supportive environment for joint innovation between nations. To fully enable advanced semiconductor technologies and novel communication and computing paradigms, policies from various governments must support open business models that encourage the sharing of technologies, know-how, and talent among companies, but also academia. National government policies must therefore prioritize the development of trusted global standards for innovative, intelligent wireless infrastructure and devices for 6G networks.

Setting common standards for 6G equipment and networks is crucial in order to ensure the rapid development and accessibility of key technologies. The substantial investment needed to develop specialized manufacturing technologies will be driven by market demand, but that demand is only present if 6G services have been widely deployed. Moreover, setting international agreements during the first phases of development provides an early and safer business model for those companies considering riskier investments in novel technologies, enabling them to recoup their expenses while providing the necessary services that support market demand. International standards allow for improving economies of scale and are also very helpful for users, who benefit from interoperability between different manufacturers' devices.

### 10.2. Data Privacy and Security

"Trustless" framework eliminates the need to trust the proxy while verifying the data integrity without client's local copy. We must note that although the trustless framework requires specialized hardware components, many existing 6G devices such as smartphones and tablets already have Trusted Execution Environments allowing for the implementation of a trustless protocol. Other devices can also have support for TEEs in the future and/or receive firmware updates to enable TEE support. Throughput challenges and possible implementation issues such as requiring periodic data inconsistency checks by the proxy can be addressed by performing the consistency checks in a burdened cloud through an intrinsic "check in" feature of the trustless protocol. Involving a burdened cloud will completely offload the burden of the proxy during protocol checks while also allowing the burdened cloud to act as a fail-safe for stale data in case the proxy is held captive for a prolonged period of time or requires more time to undergo an ongoing cleanse during specific triggers such as receiving multiple aggression-denoting signals.

We must also emphasize that according to the trustless framework we have designed, although the overhead on the system burdened cloud increases, client privacy is not compromised. Further note that the protocol is capable of doing all checks through the query and return flow between the proxy and the burdened cloud and during the state check-ins done by users on the proxy. Data privacy laws mandate this degree of privacy assurance.

**11. Economic Implications of 6G and AI Integration**

The 6G ecosystem is expected to create new markets, enhance existing markets, and amplify the economic impact of various sectors driven by advanced AI-6G synergy. The existing mobile network has already indirectly supported the global economy by enabling a significant percentage of the global GDP, directly contributing a substantial amount to the mobile ecosystem, globally supporting millions of jobs in the ecosystem, and globally connecting a notable percentage of mobile broadband users. Mobile uses of connected devices represent the fastest path towards becoming digital-first for most retailers and are relied upon equally by both online-first and omnichannel brands, pushing the need for a mature mobile ecosystem. Smart factories, leveraging mobile innovations used throughout the manufacturing workflow, represent another industry sector spending a high percentage of their GDP on mobile solutions.

The telecom industry is ripe for disruption and although the large mobile operators have excellent profitability and capital discipline, the industry as a whole is an opportunity for 6G investment. The new focus on sustainability will increase demand for mobile solutions in lower income countries as they go digital-first. The Internet of Behaviors, adding a new dimension to the Internet of Things, will create a huge investment thesis for new semiconductor solutions that address entire absent behavioral patterns. Industrial APIs for mobile services will open a huge addressable market for industries that need to embed location aware services in their unconnected experiences. Integration between 6G and AI will augment the wireless technology stack to accommodate these new applications and provide users with services that have surprising new capabilities that make them an essential part of their lives. The role of the wireless industry enabling these capabilities will expand and the addressable market for mobile services will grow dramatically to become an essential part of the world economy.

**11.1. Market Opportunities**

Both the AI and 6G wireless communication technology markets are expected to grow massively by the end of the decade. The 6G market is expected to reach $2.6 trillion by 2030, growing at a 76.6 percent CAGR. It will enable hundreds of use cases, including mission-critical services, sensing and imaging, and digital twinning. Such services are required for a variety of sectors, including transportation, healthcare, energy, and manufacturing. AI is needed for data identification, modeling, and analyzing network behavior patterns to assist dynamic slicing in 6G. It is also used for managing non-terrestrial networks with space, terrestrial, airborne, and maritime assets. To further enable generative AI, it is anticipated that by 2030 the global generative AI software market will reach $110 billion, expanding at an exponential growth rate of 46.2 percent. Generative AI, with its enhanced efficiency and upward propagation of productivity, is expected to impact a variety of sectors, including marketing, healthcare, education, gaming, software development, and entertainment.

The collective impact of AI in 6G is thus a multi-trillion dollar opportunity. The ICT industry is always seeking a greater impact and higher efficiency. Generative AI is a technology that offers enormous upside potential that can assist ease the current cybersecurity and niche talent shortfalls. It is mandatory for web3, the next generation of the internet that is built on decentralized blockchain principles. Since the 6G architecture is meant to be the backbone of web3 and subsequently the backbone of the digital economy, investing in this digital ecosystem of the communications layer makes sense. Telecommunications firms and their investors must pursue generative AI to reap the benefits of lower operational and capital budgets and more economic services for customers if they expect to optimize emerging revenue and profit pools at scale.

**11.2. Investment Trends**

Major technological advancements often correspond to notable shifts in technology investments, including the emergence of new venture capital firms and new sources of funds as capital flows to key areas positioned to take advantage of new trends in the supporting fiscal ecosystem. The development of 5G as well as renewed interest in artificial intelligence prompted a new level of investment in those sectors over the past few years. The convergence of AI and 6G is at the forefront of a new wave of capital spending, setting the stage for the next generation of start-ups. The impact of these technologies on venture capital is notable: Generative AI, deep tech, and space & satellite are the breakout areas. Generative AI is hot, but investment is concentrated among a handful of startups; funding in the next year will likely focus on best-of-breed technologies. Deep tech at multiple levels - including semiconductor manufacturing and 3D modeling technologies - is still attracting funding, although industries dependent on the widespread availability of new models have experienced a downturn. Aerospace startups still dominate the Space & Satellite vertical, especially those related to logistics, broadband, and satellite imagery. Investment in the Next-Gen Internet ecosystem is cooling off, as firms that previously focused on blockchain and crypto pivot to AI infrastructure.

The global AI in Telecommunication market is set to compound at a staggering 19.07% per year for more than a decade, taking it above a sizable new threshold of $7.438 billion by 2030. It is worth noting that the telecom market is crucial for general AI market growth, as it is expected to compound at more than 34% for nearly two decades, nearing $900 billion by 2030. Winning companies and business models will be in place by 2025, thanks to the first movers in the eventual economic transition phase, due to the crucial asymmetric integration of AI and Telecommunications transforming edge and networks systems and AI models for DeFi and security, smart cities, advanced autonomous enterprises, digital twins and the metaverse.

## 12. Interdisciplinary Collaborations for 6G Success

Interdisciplinary collaborations across various research domains, industry sectors, and implementation agencies will be paramount to 6G innovation success. New and complex system interoperability challenges of 6G wireless systems enables establishing the pretext for unique new partnerships. Partnerships between more traditional carriers, content providers, consumer products manufacturers, hardware equipment manufacturers, software service providers, and transportation providers are being formed to ensure a successful 6G vision. In industry, partnerships are forming between competitive organizations to jointly invest in a shared vision of an open, broad, versatile, secure, and trustworthy 6G implementation framework. Designers at all collaborative levels, delivery partners, and regulatory agencies will need to be involved to successfully realize the ambitious 6G vision. Interdisciplinary partnerships and synergies in academia among the graduate students, faculty experts, and associated joint industry partners that teach, mentor, advise, and guide today's technology innovation pipeline of future leaders, innovators, and research principal investigator teams will be essential to propel innovation in the adult collaborative research and design phases of bringing faster to market new technologies and solutions to complex world problems. Academia industry partnerships are not new drives to accelerate into the adult research and innovation phases, but the intense funding now moving through the available industry and government grants and contracts has created a now unique and vital opportunity for academia-industry partnerships. Federal governments recognize that to not fall behind in the expanding knowledge economy race into the mid-century, they must invest heavily in the research engine phases so that the new leaders that will run the next wave of adult innovation in the next two to three plus decades are found, formed, and nurtured.

### 12.1. Partnerships between Academia and Industry

Introduction to Interdisciplinary Collaborations for 6G Success The main goal of this chapter is to address how, and in what context, interdisciplinary collaborations may help accelerate the development and commercialization of key hardware systems needed to realize 6G intelligent wireless systems, which are envisioned to play a dominant role in a wide range of global digitalization solutions. We are focused on three key aspects of wireless intelligent systems: Artificial Intelligence (AI) that enables and powers the smart functions, Agentic forms of AI that learn-driven interactive functions, and Hardware Systems built on advanced Semiconductor technologies that are essential for real-time low-power AI processing. 6G is accelerating toward an incredible growth trajectory; become an essential framework for every country to grow, develop new business models and become economically attractive. It will enable and support a vibrant digital economy, boost the development of smart cities, factories and homes, increase digital connectivity and accessibility to infrastructure and businesses. 6G is not just a tool to achieve these goals, but a fundamental part of the journey, creating new business, economic and social value. 6G communications are also essential to enable how to harness the potential of emerging industries that rely on getting, analyzing and acting on data from the physical world. Processing real-time data is key for industries such as logistics, transport, manufacturing, healthcare, defence and critical infrastructure. National governments and the global private sector are collaborating to accelerate the 6G research agenda within trustworthy, open, and secure ecosystems. These partnerships between academic research and industry innovation and product development are focused on the research roadmap for technology policy and the security risks posed by widespread introduction of 6G.

### 12.2. Role of Government in Innovation

Innovation is crucial to the continued growth of the semiconductor industry, but this is a global dilemma. Significant risks in developing new products lead to increasing hesitation in establishing development investments within the industry in the world's semi leading countries. The general solutions applied to respond to this paradox consist of the collaboration between market actors: 1) Forward and backward collaborations between and within the semiconductor design and foundry sectors, such as incentive programs to motivate the design houses and the use of tools, tool hermeticity, and the standards for the specialized tools, and 2) Innovation and financial collaborations since semiconductor design and foundry partners may also be from the same country or region. In this sense, the collaboration between companies and foundry companies in Taiwan aims at consolidating Taiwan's leadership position in the fabs market.

Moreover, not only the decision-making agencies at the microeconomic level but also those at the macroeconomic level in the host country should make suitable policies, that is, technical support policies. Such policies should ensure pertinent funding to encourage both innovation and free-for-all market competition. While growing national pressure is put on stimulating a domestic economy through public investments in infrastructures, the global semiconductor industry's growth depends mainly on import policies regulating the transnational trade of services and products provided by design houses, equipment supplies, foundries, or companies. The continuation and expansion of free trade agreements, along with public efforts to create a climate of confidence within partnerships, become a powerful complement to territorial growth.

**13. Conclusion**

The 6G era is ushering in technological and societal innovation cycles that have the potential to radically improve the quality of life, while realizing the promise of Intelligent Connected World. This Third Industrial Revolution is, on one hand, impelled by scientific and technological advances resulting in a myriad of new applications and connections. On the other hand, it is also submitted to the Road to Sustainable Development constraints and challenges, namely climate change and the necessity of reducing CO2 emissions. The development of semiconductor technologies, supported by a dedicated research agenda, is at the very foundation of the 6G vision. The Controlled Quantum States paradigms, empowered by Moore's Law during the two previous Industrial Revolutions are also key enablers for the fulfillment of the 6G vision. Besides direct 6G requirements, which drive the investigation of advanced semiconductor building blocks that deliver higher performance, higher spectral and energy efficiency, higher CQS coherency and delivery features, these technological advances are expected to impact other SOS functional area innovation cycles.

These SOS innovation cycles shift the role of wireless communications from a mere connectivity and broadband delivery to a proactive role where wireless mechanisms and capabilities can be leveraged to enhance and improve the very performance of several SOS functional areas. We argued along these conclusions that Advanced Semiconductor Enhanced Agentic AI is a key enabler for such shifts to happen. However, Agentic AI goes beyond these two roles as it may disrupt the current technology focus by shifting attention also regarding the design requirements and considerations that technology architects and functional area system architects have traditionally followed along the development of systems and system-enabled functionalities and services. Agentic AI has the potential to provide system designers and architects not only real-time feedback on the evolution of such development processes and the on-line testing of completed subsystems and components but also to remotely monitor and alter de facto the behavior of the deployed systems

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