Internet of Skills, where Robotics meets AI, 5G and the Tactile Internet

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***Abstract*—Capitalizing on the latest developments in 5G and ultra-low delay networking as well as Artificial Intelligence (AI) and robotics, we advocate here for the emergence of an entirely novel Internet which will enable the delivery of skills in digital form. We outline the technical challenges which need to be overcome to enable such a vision, i.e., on the development of a 5G Tactile Internet, standardized haptic codecs, and AI to enable the perception of zero delay networks. The paper is concluded with an overview on the current capabilities, and the standardization initiatives in the IEEE 5G Tactile Internet standards working group as well as the IEEE 5G Initiative.**

***Index Terms*—Internet of Skills, 5G, Tactile Internet, AI, Robotics.**

I. Concept Vision

Each Internet generation was believed to be the last, with designs pushed to near perfection with the best to-date network technologies supposed to deal with the traffic-to-come. To the first and original Internet, numerous changes followed to reach the current virtually infinite network of computers as we know it and we use it nowadays. What is important to note is that, from the very beginning, the Internet was a paradigm changer and went on to define the global economies of the late 20^{th} century [2]. After that Internet, came the Mobile Internet, allowing connectivity while moving to billions of smart phones and laptops. Again, this redefined entire segments of the economy in the first decade of the 21^{th} century [3]. Today, we witness the emergence of the Internet of Things (IoT) [4], soon to connect billions of objects and starting to redefine yet again various economies of this decade [5].

Underpinned by zero-delay networking paradigms in the network and the Tactile Internet [6] at the wireless edge, above embodiments of the Internet will be dwarfed by the emergence of industrial local area networks ("Industry 4.0" [7]) and - believed to be a true paradigm shift - by the **Internet of Skills** ("Human 4.0").

By enabling the delivery of physical experiences remotely (and globally), the Internet of Skills will revolutionize operations and servicing capabilities for industries and it will revolutionize the way we teach, learn, and interact with our surroundings for consumers. It will be a world where our best engineers can service cars instantaneously around the world; or anybody being taught how to paint by the best available artists globally. At an estimated revenue of $20 trillion per annum worldwide (20% of today's global Gross domestic product, GDP), it will be an enabler for skillset delivery - thus a very timely technology for service driven economies around the world[1].

II. Addressing Societal Challenges

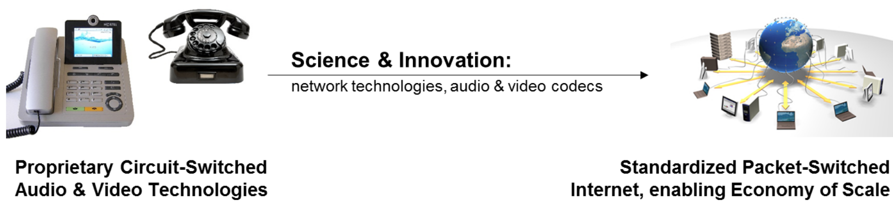
The potential global *impact of the Internet of Skills would be phenomenal* and instrumental in conquering some of the world's biggest challenges. The Internet of Skills will open several new possibilities ranging in heterogeneous sectors, such as:

- important disaster operation applications such as remote monitoring/surgery of people in need (e.g., applicable in Ebola hit areas);
- remote education that is beyond sharing knowledge but also sharing skills (e.g., a child in Gaza is taught painting);
- industrial remote decommissioning and servicing capabilities (e.g., the remote reparation of a broken car in Africa);

and above reported examples are only a very limited set of possible ones. Any possible skill can be delivered to any area of the planet where the Internet of Skills will be available. We now go into the details of the benefits brought by the Internet of Skills from various angles and by using two examples.

United Nation's Ebola response. We are confident that some of the basic and frequent manual operations like spraying antiseptics on equipment and health-care workers, communicating with patients through gestures, pictures, or animations can be done using commercially available light tactile robots. Medical experts will move the hands and grippers of an exact replica of the remote robot to send commands and receive feedback via the Internet of Skills.

[1] An abridged version of this article has been published in a non-copyrighted blog of the IEEE Communications Society [1].



(a)

(b)

Fig. 1. (a) Visualization of the fundamental transformation from a proprietary intranet to a scalable Internet. (b) The foundational blocks of an "internetization" of the haptic paradigm, i.e., enabling the transformation from today's very expensive haptic edge technologies to a standardized Internet of Skills.

This will allow aid workers and medical experts to contribute to the Ebola response operation without risking their own lives, or bringing the virus back home.

Remote servicing. Operational costs (OPEX) are one of the largest expenditures for industries to date, with inefficiencies due to sub-optimal/wrong skill being one of the largest contributors. The Internet of Skills will allow matching specific needs in one physical location with the best skill in another location. Broken cars and airplanes can thus be serviced remotely; industrial plants inspected and repaired; high value manufacturing supervised - all in a significantly more efficient and effective manner, with minimal carbon footprint.

The Internet of Skills will thus be an **enabler for remote skillset delivery and thereby democratize labor the same way as the Internet has democratize knowledge**.

III. Technical Ambition

Whilst haptic communications has been around for a long time [8] and the communications principles of the zero-delay Internet/Tactile Internet have been laid out in e.g., [6], [8]-[9], the design of an Internet of Skills requires some ground-breaking cross-disciplinary approach in combining:

- *telecommunication engineering*, involved in developing solutions related to communications and networking;
- *computer science*, especially regarding applications such as artificial intelligence (AI) and, more in general, data science;
- *mechanical engineering*, where kinesthetic robotics need to answer fascinating scientific questions around the viability of the Internet of Skills.

To accelerate the design of the new Internet of Skills, we aim to borrow insights from the development of today's Internet. Indeed, as shown in the Fig. 1(a), the Internet took several decades of networking and codec innovation to transit from a heavily proprietary circuit-switched audio/video paradigm to today's standardized packet-switched software-based Internet enabling economies of scale. The fact that looking at Internet's development is an interesting and effective exercise is testified by ongoing activities of Mobile Internet, which is targeting the shift from hardware-based to software-based networks [10] allowing a faster re-configuration, lower costs and thus enabling economies of scale.

Similarly, it is our ambition to lay foundational blocks (depicted in Fig. 1(b)) in integrated end-to-end low-latency networking and haptic codec design to enable a similar transformation from today's proprietary and expensive haptic edge-technologies to a truly global, standardized and scalable Internet of Skills. By keeping in mind the goal of achieving a standardized and scalable Internet of Skills, we will derive the requirements and the features of the Internet of Skills in the following Section.

IV. Technical Realization

The components of the Internet of Skills are depicted in Fig. 2. The actual technology thus needs to be innovated around three major areas:

1) agile networking and communication protocols;
2) artificial edge-intelligence;
3) standardized haptic data digitization and encoding.

A proper skill-oriented design of above areas would allow a reliable haptic experience around the globe, i.e., a true Internet

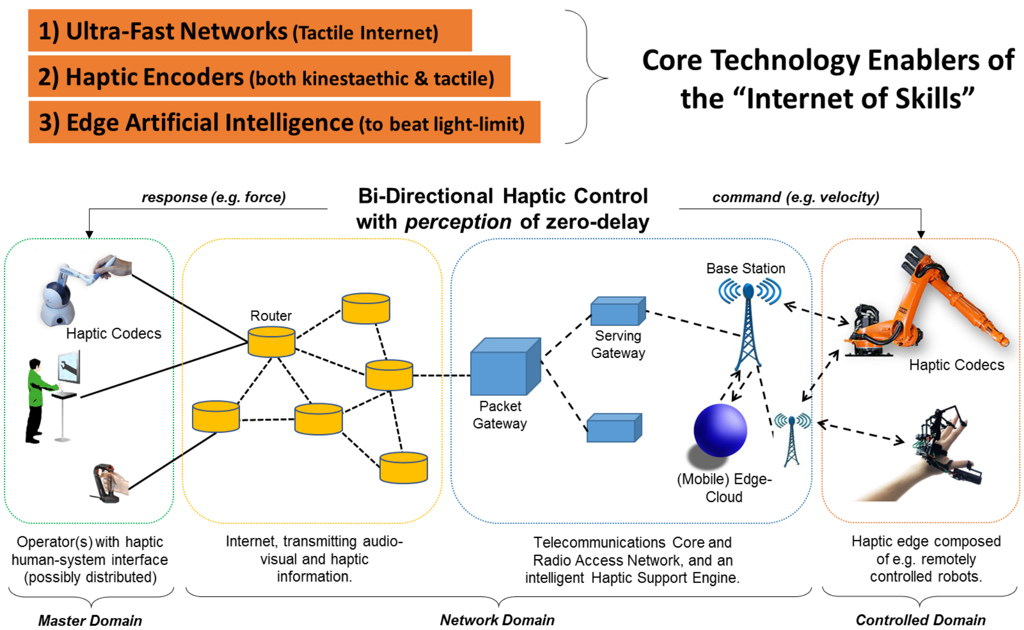


Fig. 2. High level architecture of the Internet of Skills, and required building blocks.

experience. Above listed areas are now discussed in more details.

A. Networking and Communication Protocols

The designed network has to have the following characteristics:

- be *ultra-reliable* since many critical tasks will be executed remotely;
- be of *zero perceived delay* since the transmission of kinesthetic (movement) data requires closed control loops to support action and reaction and long delays yield system instabilities;
- rely on *cheap edges* to enable true scale.

As a summary, the network able to deliver the Skills needs to have the lowest possible delay whilst being extremely reliable and robust.

To achieve low delay and stability during a session, *end-to-end path reservation* from master to slave needs to be supported, where path reservation means that all traffic going from master to slave and vice versa will be treated (in terms of routes to follow, priority, etc.) according to some rules defined during the establishment of the Internet of Skills session. Network slicing [11], [12] will be an enabler of reliability and low-latency. With network slicing, the Internet of Skills will have its own logical core network which will not be affected by the other traffic in the physical network. By implementing isolation of resources, network slicing provide reliability and robustness to Internet of Skills as it will guarantee stability of performance during an ongoing session. Network slicing will be implemented through Software Defined Networking (SDN) and Network Functions Virtualization (NFV) [13], where the former will manage the physical communication infrastructure (i.e., switches, links among network entities, path management) while the latter will manage the network functions needed to properly handle the Internet of Skill session. SDN and NFV are two fundamental building blocks of next-to-come 5G networks, where such technologies are expected to provide flexibility to the network to accommodate a wide range of service with heterogeneous QoS needs. Network functions, data paths, queues at network switches, mobility tracking, service location and all other functionalities needed for data communication will be instantiated and managed by SDN and NFV. Such technologies need to be extended to assure low-latency and, more in general, the QoS needed by the Internet of Skills. More in details, SDN needs to implement effective solutions to handle QoS, especially in terms of guaranteeing low latency packet delivery while NFV needs to implement light network functions allowing data packets to be managed as quick as possible to avoid further processing delays. In addition, SDN and NFV need to handle the traffic in a dynamic way by reacting to changes of network/traffic conditions. As an example, SDN can be instructed by end-user initialization to provide the QoS figures needed for a particular type of traffic, where the QoS can be modified on-demand during the ongoing session [14]. Similarly, NFV can dynamically move network functions from overloaded network entities to other less utilized in order to cut processing delays. Above described features will allow the network to dynamically allocate resources in all segments of the network (i.e., access, core, backbone) avoiding under-utilization with thus benefits allowing economies of scale. As a final note on SDN and NFV, such technologies need to be extended to quickly react to changes due to mobility. We could for instance think to a scenario where a patient is on an ambulance, thus moving towards the hospital. In this case, the delivery of an adequate quality of Internet of Skills is based on the possibility of fast reacting to user/device mobility. In this scenario, not only network re-configuration but also prediction of user/device mobility patterns would be beneficial to guarantee stability during an ongoing session [15], [16].

It is important to underline that master and slave could potentially be located into two networks managed by two different Internet Service Providers (ISPs). This means that end-to-end path reservation should be implemented with multi-domain capabilities in order to deliver the Internet of Skills around the planet. The design of protocols for multi-domain path reservation is thus another enabling feature of the network to be designed for the Internet of Skills. SDN may come in handy by allowing operator domains to negotiate traffic policies [17] in the route from the master to the slave, thus guaranteeing effective end-to-end path reservation.

Furthermore, some fundamental changes are however required to cut over-the-air delay as well as to increase reliability in order to exploit the benefits of the utilization of wireless access. These aspects are currently considered in the design of 5G new radio interface [18], [19], [20], with particular interest towards transmission reliability, faster procedures traffic resource allocation as well as hybrid automatic repeat request (HARQ) in both downlink and uplink directions.

Such advances on the wireless interface, together with above discussed advances in the core and backbone network, will deliver the effective low-latency high-reliable Internet of Skills network.

B. Artificial Edge-Intelligence

AI, together with networks, play an instrumental role in giving the perception of zero-delay networks. Indeed, one ought to use model-mediated teleoperation systems to have AI predict movement on the remote end and thus give enough time for the signal to reach the other side of the planet. The haptic control loops typically require a delay of 1-10ms, which translates to 100-1000km range under typical networking conditions; a range which can be extended by model-mediated approach to the tens of thousands of kilometers needed to cover the entire planet. Open research problems here pertain to environment modeling (geometry and physical properties); stable force rendering on the master side; standardized database of environmental models and cloud placement of intelligence and functionalities.

C. Haptic Codec

Finally, the haptic codecs will enable scale in the future as it will avoid vendor lock-ins. Here, we envisage the combination of tactile (touch) and kinesthetic (movement) information into the already available modalities of video and audio. Open challenges here are to develop a haptic mean opinion score (h-MOS); find trade-offs for joint tactile and kinesthetic information; trade-off studies for integration with other codecs; and possibly see if we could use compressed sensing solutions.

V. Prototypes, Standardizarion and other Initiatives

All these exciting developments are being tested in our 5G lab at King's College London (KCL), as shown in Fig. 3.

We now describe the equipment and the network configuration available in this lab to test the Internet of Skills. Notably, the Glove One high-degrees of freedom (DoF) tactile glove is integrated into a Phantom low-DoF kinesthetic device. One acts as a Master (left-hand side) and the other as a Slave (right-hand side). It is worth underling that both roles can be interchanged instantaneously, i.e., a *bidirectional* "touch & feel session" can be maintained. The haptic signals go through compander and data reduction in the embedded edge (i.e., in the glove and/or phantom) or it is outsourced to the local cloud; or a hybrid thereof. The haptic equipment is connected to KCL Software Defined Radio (SDR) testbed which transmits wirelessly to its SDR counterpart (not shown here) which, in turn, is connected to KCL SDN network. On the wireless side, our network can also transmit on an Ericsson RBS 6501 4G base station. The SDN manages the network hosting Cloud-RAN and Edge-Cloud capabilities. The latter hosts part of or the entire haptic codec, which is composed of compander, reduction and AI-capabilities. That reduced data is then routed through KCL Core Networking (CN) equipment where NFV is are used to establish quick paths and influence delays. The above described powerful experimental platform allows us to test important concepts of the Internet of Skills.

Our platform is enriched with hybrid access capabilities, allowing devices to simultaneously exploit different access technologies as well as to move from one access to another. The hybrid access is also supported by Hybrid Access Gateway (HAG), acting as anchor point of both wired and mobile networks. A customized implementation of multipath TCP (MPTCP) is used to enable hybrid access, which is as important for the Internet of Skills as the availability of multiple paths, in increasing traffic reliability and allowing the network to select the best available path for delivering the best performance.

As a community, much of the work is also carried out by various standardization bodies. You are most welcome to joining us at the IEEE 5G Tactile Internet working group [21] as well as the overall 5G Roadmap [22], [23] which we are currently developing. The IEEE 5G Tactile Internet working group, P1918.1, is currently developing the application scenarios, as well as definitions and terminologies. The current focus also includes a reference model and architecture, which defines common architectural entities, interfaces between those entities, and the mapping of functions to those entities. Given the significance of standardized haptic codec in the success of the this new generation Internet, a complete subgroup is focused on the haptic codec.

VI. Concluding Remarks

In this paper we presented our vision on a novel Internet generation, the Internet of Skills, where advanced ultra-low delay, AI and robotics will enable the delivery of skills in a reliable and cost sustainable way across the World. We discussed the societal challenges related to the Internet of Skills, highlighting the novel enabled opportunities from either a business and a societal point of view. We then discussed the technical requirements of the Internet of Skills and we

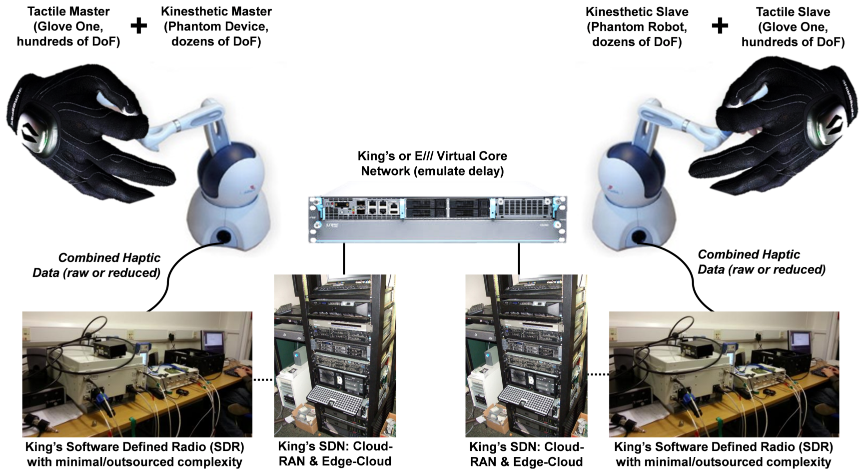


Fig. 3. Displayed is the KCL 5G Tactile Internet working lab.

analyzed how our vision can be reached with network, AI and haptic codes advances. We also presented the capabilities of the 5G lab at King's College London, with the aim to show that the building blocks needed to enable testbeds on the Internet of Skills as well as our ongoing works in this direction.

VII. Acknowledgement

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