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Graphene-based integrated photonics for next-generation datacom and telecom

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The evolution of mobile communications: the 5G network

The evolution towards 5G will influence and define the amount and nature of data traffic in all network segments. Hence we discuss 5th generation wireless network concepts and not just component technologies aiming at high performance optical networks.

Fig.1a outlines the structure of a telecommunication network, highlighting the major segments: “Access”, “Aggregation” with local-, metro- and regional networks, and “Core”. Based on the traffic characteristics and topologies, these network segments have very different requirements in terms of cost, performance, quality and unit count for the devices which operate in them. This has consequences for their components and the underlying physical technologies. The data traffic is aggregated from the network edges (access) to the network core. The routers in the nodes of the core network need to process high bit rates ~several tens Tbit/s. At present, devices at the network periphery like, e.g., user equipment and residential home network terminations, usually need to deal with data rates of several tens to hundreds Mbit/s, and need to be affordable for the end-user and produced in billions of units. The predicted strong growth of data traffic over the coming years is mainly fuelled by the increasing demand for high definition (HD)-video applications, such as e.g. HD-content streaming, -virtual reality, -augmented reality and - gaming. Today’s users expect ubiquitous and anytime availability of these applications, which requires broadband wireless connections supporting extremely high bit rates to the user equipment (UE). 5G will address these demands for high bandwidth, together with the requirements coming from a different category of applications based on highly reliable low latency networking technologies described by the terms IoT or “Machine to Machine Communication, M2M”[1,2]. Typical applications are autonomous driving, industrial automation (“Industry 4.0”), smart-X (i.e. smart grid, smart home, …), e-health (Fig.1b). This class of applications is characterized by requirement of low transmission latencies down to 1 ms, high security and reliability, and low or moderate data rates (kbit/s) per device (sensor or actuator). However, the expected vast abundance of these devices (projected worldwide counts are hundreds of billions[1,2]) will give a significant contribution to the total traffic increase expected for the coming years. The 5G system will extend beyond previous generations of mobile communications, while ensuring a seamless upgrade for operator networks and quality of experience for the final users, with new services and enhanced network performance. To enable 5G, all the available network infrastructures should evolve with new levels of flexibility and automation (i.e. networks performing self-operations, optimization and healing), with higher priority given to network optimization, security, energy and cost efficiency[3,4]. 5G is designed to deliver, in a feature-rich network, more diversified services with respect to previous generations.

Like its predecessors, the realization of the 5G network involves *wireless* as well as *fixed* link technologies (i.e. Cu-wire or fibre). Wireless links are present in the access part of the network, connecting radio antennas mounted on small- and large-cell stations with single connection, or interconnected peer to peer, end-users devices via radio waves or mm waves (wireless access links), point to point interconnections between high power cell towers and small cell stations, and amongst small cell stations (*i.e.* wireless fronthaul link).

There are two ways to have access to the 5G network: one is through a traditional access node, already defined in the previous generation of mobile communications, and the other is through a virtual access node. The latter is defined by the installation of a dedicated cell for industries or private applications, where wireless connectivity and mobility is performed with uniform industry-wide or private policy and mobility requirements. 5G through virtual access nodes can deliver more customized and dedicated network services with the quality and network performance settled by the final user.

Wireless access networks are composed of cell sites (hexagons in Fig.1a), divided into sectors, sending data through radio waves[5]. 4G long-term evolution (LTE) wireless technology is the foundation for 5G. Whereas LTE supports data rates up to ~150Mbit/s, LTE Advanced supports peak data rates up to ~1Gbit/s in the downlink. The practical individual user experience, limited by a number of technical constraints, usually is lower at several tens of Mbit/s for LTE. Unlike 4G, which requires mainly large, high-power, cell towers to radiate signals over longer distances (large towers in Fig. 1), 5G wireless access signals are for efficiency reasons transmitted also via a larger number of small cell stations located in places like light poles or building roofs (small towers in Fig. 1).

Cu-wires and/or optical fibres provide "fixed access" to buildings (like e.g. residential homes and industrial premises) or are part of the wireless infrastructure when connecting detached remote antenna heads to their base station controllers. Fixed links are present in the core and aggregation (metro) networks (defining the backhaul network, where telecom grade networks are connected directly with remote datacom or IP networks to have access to high computational resources), and close to the access networks (defining the wired fronthaul network, where telecom grade networks are directly connected with datacom networks, closer to the final user, so to be fast and responsive in delivering latency-sensitive services to the final user) (Fig. 1a). Typically, optical fibres ensure broadband connectivity from the core up to radio antennas and end-user premises (*e.g.* house, office, buildings, campus and stadiums).

Two main scenarios are seen in the 5G network evolution. 1) Mobile wireless cloud networks (represented in Fig.1b by a cloud icon encompassing several mobile devices) leading to the concepts of Smart City, Smart Industry, and Smart Life applications. These are evolving and need to ensure high mobility and network scalability, while supplying enhanced connectivity. 2) Dedicated networks for end-user premises applications (represented by the house in the top right of Fig.1b, encompassing mobile and smart interfaces). These leverage both broadband connectivity based on optical interconnections to the rest of the network and pervasive wireless networks (*e.g.* WiFi; Visible Light Communication Systems, such as Light Fidelity (LiFi); Mobile Indoor Localization Systems).

In the mobile wireless cloud network the worldwide available connections can transmit on average 100Mbit/s per user. The download of one HD movie (*e.g.* 1500Mb) can take less than two minutes. The dedicated networks to the final user premises enable the worldwide access to a 5G network with an average capacity of 1Gbit/s per user, thus, the download of an HD movie can take ~10 seconds.

5G networks will give people access to a networked society, where anybody will want to communicate with more people, in more contexts and for more reasons than ever before. In the networked society, communications will matter even more than in the past, since the global economy will increasingly depend on our ability to communicate. 5G enables the telecom and datacom networks to provide new services to the benefit of operators and their customers. A huge number of new communication services will be created to satisfy the increasing demand for new ways to communicate. As a consequence, new communication services will be continuously proposed and new network models will be assessed.

To track the 5G shift, several trends illustrating the impact on communication services are represented in Fig 1.

1) Strong growth in the number of connections through subscription in emerging markets, with an increase in the number of devices per person (13Bn by 2021: smartphones, laptops, tablets), as well as an increased number of machines and equipment connected, with the rising IoT (number of IoT devices expected to grow by 15Bn by 2021)[6]. A large number and different types of objects with IP address will be controlled, monitored, connected through the network. Thus, the IoT aggregate data traffic will overcome that of traditional voice and data communications.

2) Smarter and more capable devices, including smartphones and tablets, as well as Smart TVs. Each has the potential to radically increase our ability to communicate in different ways. Smartphones are the new global standard. Tablets also serve as communication hubs in the home. Smart TVs opened new forms of communication in a previously unexplored context.

3) Consumer demands for communication continuously increasing, as people come to expect high quality and coverage for less money. They are also communicating more than ever before, but not always using traditional voice or SMS channels. As the internet is becoming communication-centric, communication channels have started to blur, and consumers will be more open to migrating traditional phone-related behaviour to other technological platforms.

4) Expansion of communications into ever more contexts through social media interactions, ubiquitous video and, increasingly, machine-to-machine with the IoT rise.

With 5G there is an opportunity for telecom and datacom operators to put communications in different contexts with new business models. They can reach out to users not in their customer base (through service exposure, context-based and machine-to-anything communications). E.g., within the automotive sector, if a car crashes, the release of the airbag could trigger a direct connection to the emergency services, as well as to a towing service and garage. The user would pay for the service, with the operator acting as frontend or interface. There could be similar situations with communications included in home alarms, gaming, transport, mobility and in-web communications, smart trash collection and reuse (*e.g.* in Fig. 1b the scheme at the bottom right indicates the advent of services such as smart trash and wireless-connected cars).

Today people are better informed, have more choices and are in a better position to be demanding to their service providers. This puts greater pressure on operators to offer consumers more value for money. At the same time, the phone is becoming a multi-communications device that includes all communications trends.

Smartphones have made the use of complex services controllable for everyone. Besides the price, flexibility and accessibility define the service quality perception. Operators' networks need to evolve on performance and flexibility to support this reality of rich, varied, and often free, services. A leading example is the evolution of domotics and home security, influencing everyday life. 5G networks could enable automation and reliable remote control in real time of the main basic home functionalities, from the optimization of energy and resource utilization, to lowering the impact of domestic waste by performing optimized recycling processes through automated waste selection and proper packing.

The 5G network also supports interactive and portable media players (e.g. mp3 reader, iPod), mobile equipment with sensors (e.g. environment monitoring or body temperature and blood pressure sensors), mobile wireless cameras to take pictures or video with high definition or for surveillance purposes, all devices capable of offering HD-video streaming, webmail delivery and any kind of internet connection. With 5G, specifically tailored services can be delivered, such as those dedicated to automotive, autonomous vehicles, including cars or buses, and apps for entertainment, traffic monitoring, chartering on demand of usual and unusual paths. To support users with time- and energy-optimized travel management, internet connectivity will be available even for users travelling with fast moving vehicles for public and private transportation, like airplanes or trains, thus redefining the concept of transportation as functional smart transportation (Fig.1b).

The evolution of 5G is creating ecosystems bringing different partners together offering different services (e.g. infrastructure, transport and building services) leveraging on the combined use of different technologies. All current and future companies can be influenced by the diffusion of capillary telecom and datacom networks, giving rise to an interconnected industrial evolution. Innovation and related business can be generated by ecosystems where small, medium and large enterprise interests proactively converge on 5G.

Finally, we consider the example of smart grids, where renewable and not renewable energy production, transmission, transformation, distribution and delivery are performed in networked infrastructures. E.g., environmental energy harvesting (clean energy from natural sources, such as sun and wind) and delivery needs to be optimized, adapting the network infrastructure performance to the real energy availability and final user demand. 5G IoT solutions introduce full control, manageability and surveillance (e.g. through sensors and smart meters, dedicated data centres for data storage and real time analytics) at sustainable cost and energy efficiency for operability of each element in the network (solar cells and energy collectors, electricity pylons, power lines equipped with sensors and transceivers for system monitoring), to the advantage of all industries, from primary electric suppliers over the national grid, to medium and small utility companies for local and regional infrastructures. The smart grid enables telecom operators to install 5G networks powered by renewable and clean energy sources, reducing the telecom and datacom network environmental footprint.

This industrial evolution towards smart manufacturing is enabled by robotics, machine intelligence and 5G, to improve productivity, while ensuring sustainable growth margins and speeding the delivery of new services for industry and people. The factory is going to be redefined through the digitization of the manufacturing process and plants, enabled by 5G networks, thus realizing new industrial scenarios where real-time communication between humans, robots, remote controlled machinery, factory logistics, and products are key[3].

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