Future of Mobile

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***Abstract*—We are the last global eco-system which still advances its entire technology family in generations, having started as a 1G-niche and now entering the transformational era of 5G. The typical 10-years innovation cycles between generations, the "Gs, worked well in the past but are unfortunately not adequate for the future. Based on some past trends, the aim of this paper is to develop a technology and innovation roadmap for the mobile ecosystem. Notably, required technology disruptions to the cellular infrastructure are discussed as well as much-needed changes in the overall innovation landscape suggested, which would enable a massive shift from selling the cost of connectivity to co-creating value in ubiquitous connectivity.**

***Index Terms*—5G, Next Generation, Radio Access, Core Networks, Business Models**

I. Introduction

The mobile industry has enjoyed tremendous growth over the past decades. It has evolved from a niche technology, embodied by an analogue first generation (1G) voice system, to a fully fletched Internet on the move, embodied by an end-to-end digital 4G system. With so many generations of mobile now deployed globally, the technology is starting to become commodity and is naturally experiencing market pressure underpinned by shrinking margins and higher deployment costs.

It is hence useful and timely to pose the question on the future of mobile, a future which goes beyond 5G and the associated Third Generation Partnership Project (3GPP) releases. Notably, we would like to understand which technology disruptions are required to enable mobile not only to survive but to thrive in an increasingly competitive technology and business landscape.

Understanding that technology disruption is tightly coupled to innovation, we examine which changes in the innovation landscape are required to enable such technology transformation. This in turn will also change finances, business models and value chains in mobile.

All these suggestions, however, are based on solid observations on trends in mobile. Notably, we construct our hypothesis on past developments which seem to be fundamental to our trade, and which thus allow us to draw meaningful conclusions on future developments in cellular.

II. Inevitable Trends in Cellular

Decades of mobile development, deployment and usage allows us to draw three fundamental trends, as follows, that are then described in the remainder of this section.

1) Increase in orders of magnitude of the system KPIs.
2) Small cells contribution to the support of high data rates.
3) IEEE vs 3GPP complementary strengths.

A. KPI Orders of Magnitude between Generations

The key performance indicators (KPIs) of cellular have evolved in a rather consistent way from generation to generation. The most important ones are rate, number of devices and delay/latency. Illustrated in Fig. 1, each of these have increased or decreased by one to two orders of magnitude. Notably, the downlink data rates evolved from 2G to 3G to 4G respectively from 100 kbps to 170 Mbps to 1 Gbps; the number of devices from hundreds of devices to 10^5 devices per km^2; and the latency has been reduced from almost 300 ms to 100 ms to 10 ms.

5G and the evolutions thereafter are unlikely to follow a different trend. The International Telecommunication Union (ITU) is shaping the requirements to be fulfilled by the future mobile generation in the IMT (International Mobile Telecommunication system)-2020 programme [1]. While the recommendation is still being discussed, we can extrapolate some KPIs from the different use cases and applications. In particular, for 5G downlink (DL) data rates will be 10 Gbps, the number of devices per km^2 will be 10^6, and the latency of 1 ms for ultra low latency use cases [2]. For the first time, these numbers overstep some fundamental thresholds which make 5G very interesting for stakeholders which traditionally were not associated with cellular technologies.

Indeed, the extremely high number of devices (and optimised power consumption) allows 5G to enable the emerging Internet of Things (IoT) which requires billions of end-points to be connected. Given the global coverage, along with mobility and roaming support, 5G is hence consolidating as a serious candidate to enable the IoT.

Furthermore, the very low latencies and ultra high reliability, enables critical applications to be serviced. Given the ability to offer service level agreements (SLAs), 5G is hence also consolidating as a serious candidate to enable Industry 4.0 applications.

B. Contributors to Million-fold Capacity Increase

The breakdown on the increase of wireless capacity over the past three decades is shown in Fig. 2. It is based on

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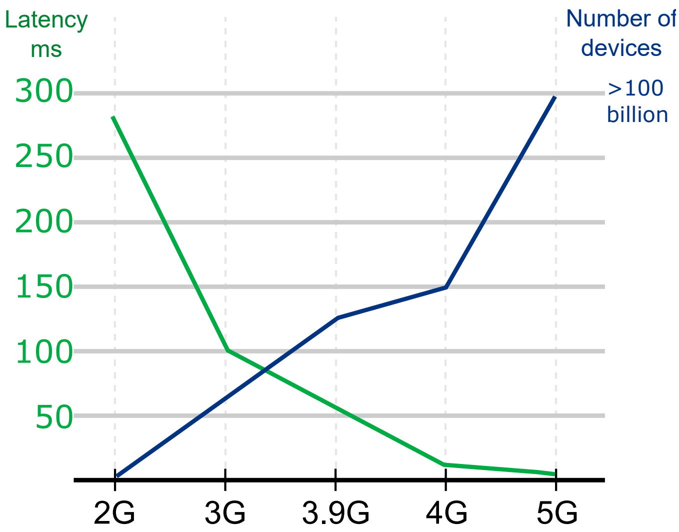

Fig. 1: Evolution of KPIs throughout the different generations

Fig. 2: Contributors to capacity increase

Martin Coopers law which says that wireless capacity doubled every 30 months over the past 100 years with overall million-fold increase in capacity since 1957, the breakdown of these gains being: 5 times due to the physical layer enhancements, 25 times due to the efficient use of spectrum, 1600 times due to the massive deployment of reduced cells and 5 times due to other influencing factors [3]. Overall, it indicates that smaller cell sizes are by far the biggest contributor, followed by the availability of spectrum; all the other factors however remain negligibly small. In particular, the physical layer has only contributed roughly 0.3% to increase in capacity when compared to that of the smaller cell sizes, whereas spectrum accounts for 1.5%. It is due to these smaller cell sizes that cellular has become much more heterogeneous, and this trend is to continue, if not accelerate with 5G and beyond.

C. 3GPP versus IEEE Link Rates

As per Fig. 3, at any time, IEEE link capacity has always been one to two orders of magnitude higher than 3GPP link capacity. At the same time, the 3GPP was always better in capturing the value of wireless connectivity by offering billing and service capabilities, in addition to mobility and roaming. With mobile cells becoming smaller and being at par of Wifi coverage, the order of magnitude difference(s) between both technology families will become more and more predominant. How the 3GPP ecosystem can turn this to their advantage is explored in the subsequent sections.

III. Required Technology Disruptions

To be able to keep up with the above trends over the next decades, some fundamental technology disruptions are required. In the following, we describe those we have identified.

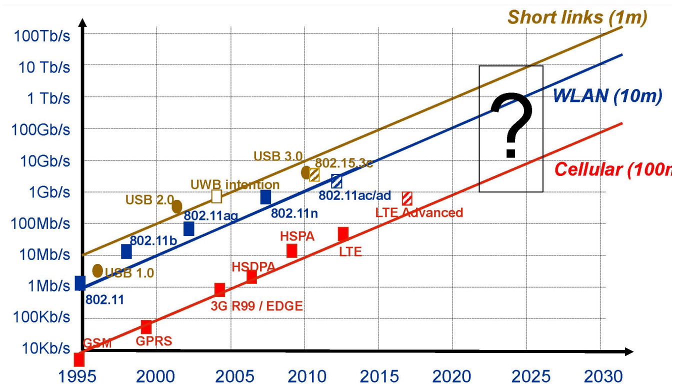

Fig. 3: Approximate link capacity of IEEE versus 3GPP systems over past years, with different ranges from 1 meter to 100 meter. ©G.Fettweis

A. From KPIs to Perception of KPIs

With decreasing cell sizes and increasing traffic demand, it will become more and more difficult to offer satisfactory designs on rates, outage or delay. Therefore, we advocate for a fundamental change in the design approach where systems are not designed and regulated based on the measured KPI but on the perceived KPI.

Let us take the example of rate. In a future 5G system, the majority of the capacity will be provided via some high capacity small cells using for example millimetre wave technologies. However, providing ubiquitous radio frequency coverage to satisfy such capacity increase is both technically challenging and economically prohibitive. One possible solution here is to use predictive analytics on different metrics, such as: user data usage behaviour, user movement behaviour or speed of movement. That would allow one to implement, for example, enhanced chaching techniques which allow to provide service continuity in the case of a coverage hole, and buffer the to-be-watched Netflix/Youtube video until the next access point is reached. Several disruptions are needed here, with the most notable being that application layer needs to communicate with lower layers so as to execute the best strategy. Strategies based on the use of software defined networks (SDN) dynamic QoS management can be further enhanced with predictive analytics to provide accurate on demand resource allocation [4].

B. Atomized and Decoupled Architecture(s)

The breakdown on the increase of wireless capacity over the past three decades, as discussed above, indicates that smaller cell sizes are the biggest contributor. This in turn translates to more heterogeneous architectures, which have to be managed in a novel way. 3GPP has proposed to decouple control and user planes (CP and UP, respectively) via phantom-cell approaches [5] but in latest research has shown that further enhancements in the small cell features can lead to massive improvements in the UP transmission. Cell selection based on the reference signal received power (RSRP) result in imbalance problems, since the DL coverage of the MCell is much larger than that of the SCell, this principle is illustrated

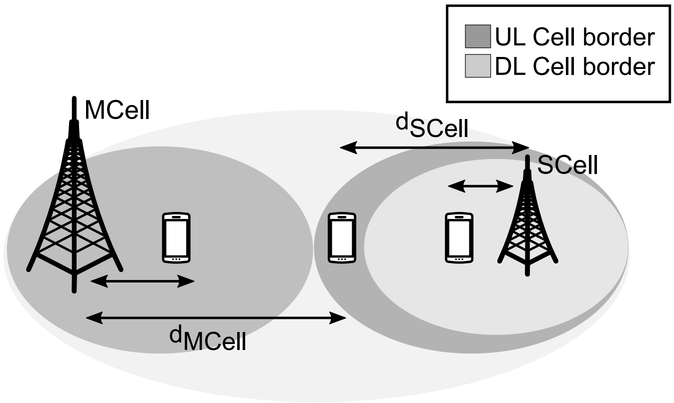

Fig. 4: Principle around the decoupled up and downlink architecture, yielding an order of magnitude improvements in throughput and two orders of magnitude improvements in reliability

in Fig. 4. One strategy that can address this problem and bring some fairness to the UL is the cell Range Extension (RE), however recent studies [6], [7] have shown that using high RE offsets increases the DL interference levels. Alternatively, a full decouple of UL and DL allows to bring similar UL fairness while reducing the RE interference problem in the DL. Works in [8], [9] show performances with much higher throughputs and, above all, smaller UL outages.

Continuing this trend, a challenge will be to design a completely decoupled architecture, i.e. decoupled in CP/UP and UL/DL, enabling ultra-low latency and ultra-reliable communications. Work in [10] shows that to enable complete flexible transmissions in both CP and UP, centralised architectures with low latency fronthaul connections allows to maximise the performance improvements.

C. Thinning of the Core Network Infrastructure

Scalability in 3GPP architectures is hugely limited by the physical infrastructure of the Core Network (CN). For instance, a typical operator in a country like the UK has only about a handful of packet gateways (PGWs) to serve the entire's country mobile traffic. The CN is in fact an artefact of pre-Internet times as it was introduced in 2G because none of the operators believed that there will ever be a general Internet which is able to carry the voice traffic. 30 years on, we still use the CN and thereby greatly limit the scalability of the wireless edge, which because of above discussions limits the rates to be delivered.

Capitalizing on this insight as well as recent trends to virtualize the enhanced packet core (vEPC) functionalities, the next step ought to be to push the entire cellular CN system to the edge: first, into the emerging Cloud-RANs; and later into the edge devices. This contraction of functionalities to the cloudified edge and eventually onto a device edge is illustrated in Fig. 5. Important to note here is that the CN fiber infrastructure could be leased (or long term even sold) to Internet service providers (ISPs); and in return, more CN fibre capabilities can be leased when needed. This approach would allow to scale and importantly significantly decrease the end-to-end delay between operators.

D. 3GPP-as-a-Control-System

As per Fig. 3, at any time, the IEEE standards link capacity has always been one to two orders of magnitude higher than 3GPP link capacities. At the same time, it is well established that the ratio between control-to-data packet size is about one to two orders of magnitude in typical communications systems.

Based on this observation, we suggest exploring if combining the best of both worlds allows one to achieve prior unseen performance gains. Notably, one needs to research the architectural and protocol approach to have 3GPP act as a control channel/system for all wireless systems available globally. Going well beyond todays LAA, cellular would be responsible to coordinate various Wifi and other systems to ensure best possible link performance whilst offering mobility/roaming as well as billing. This work is already gaining increased interest in the context of fixed and mobile converged networks in 5G, where the broadband forum and the 3GPP architectures are merged to obtain the best of each technology [11].

E. Self-Designing Cellular Systems

With advances in artificial intelligence (AI), software defined radio/networks (SDR/SDN) and robotics, there is no reason why cellular system couldnt evolve their own design and deployment. Whilst research on best possible technology solutions can still be conducted by humans, future cellular systems should be able to scout the publication/innovation databases, extract the most promising solutions, self-upgrade these (using SDR/SDN) and/or self-deploy them (using autonomous drones, for example). This would allow the standardization cycles to be shortened from years to days if not minutes.

Bringing the principal of SDN to the mobile CN can deliver the similar benefits in terms of agility, and evolvability as it has delivered to e.g. the Datacenter networking. Works in [12], [13], [14] and [4] elaborate on improvements that programmability and abstraction of SDN can introduce in lowering the signalling overhead, increasing reliability during handover, and improving agility in dynamic configuration of network paths, consecutively.

IV. Innovating the Innovation Ecosystem

For above technology disruptions to take place, we examine the current design approach in cellular industries, and concluded that some changes in the underlying innovation ecosystem are advisable. These are discussed in the following subsections.

A. Industry Vertical Co-Design

With 5G breaking into the needed performance thresholds for industries to use mobile for industry-grade operations, a much stronger co-design is required between industry verticals and the telecommunications industry. Such a co-design should be articulated through a joint establishment of requirements

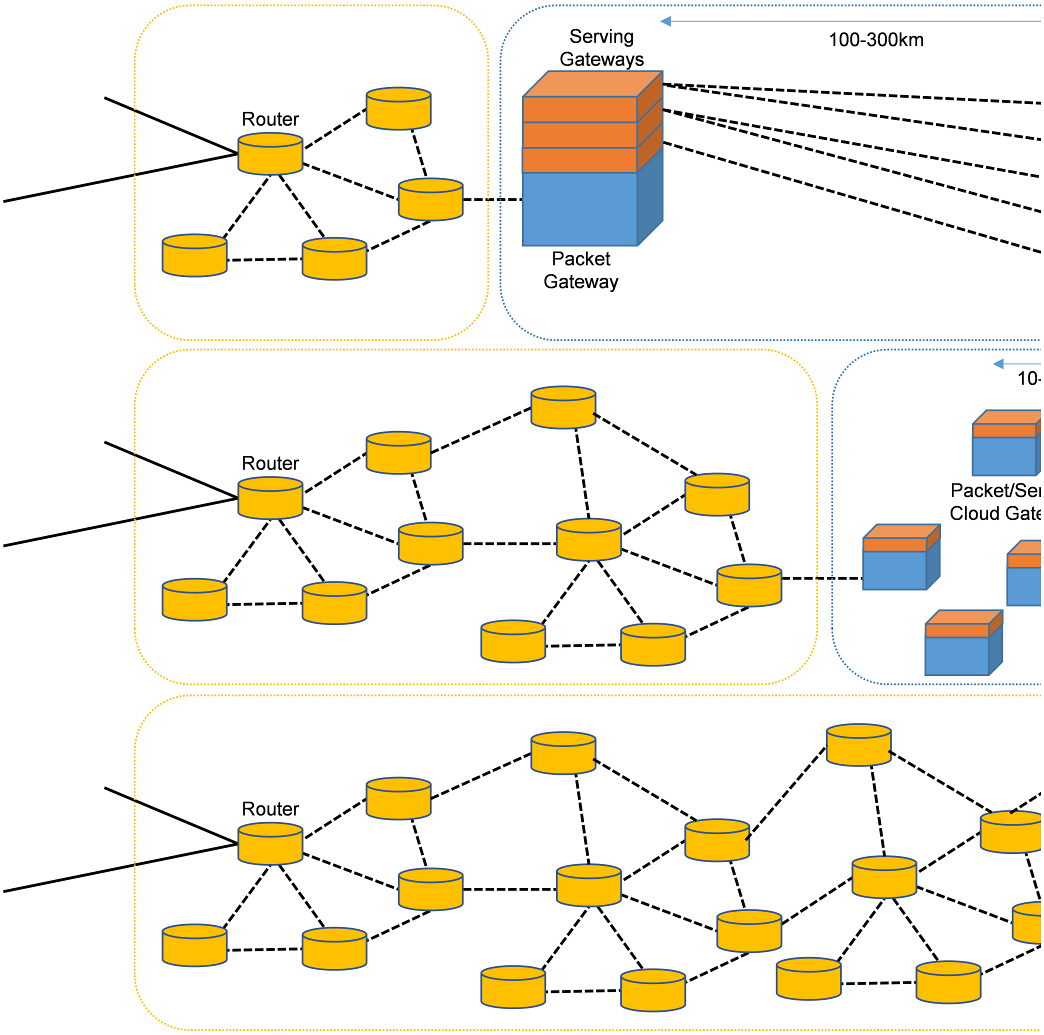

Fig. 5: Conceptualization of the “things of the core networking infrastructure, whilst keeping all of the core network functionalities in virtualized form at the edge

and joint design of future architectures. It would allow the telecommunications industry to get knowledge of the true requirements of these industries; as well as evangelize the developed technology. And it would ensure for the verticals not to question the cost of the technology but rather see its value [15].

B. Opening Up Standards

3GPP, which is the underlying standard development organizations (SDOs) for cellular, has successfully standardized complex and global systems. However, the time it takes to advance from generation to generation is far too large for our times. In addition, the 3GPP innovation power houses of the past have shrunk considerably thus leaving the entire ecosystem in a much weaker position w.r.t. innovation capabilities and capacity. To this end, it is advantageous to open up the 3GPP design process and procure innovative solutions in a different form that currently done. Different avenues are possible, such as crowdsourcing standard solutions by only specifying the APIs; or breaking up 3GPP into different standards bodies so as to ensure a more agile standardization process. Finally, the 3GPP may also consider using IEEE as its “innovation arm and only work on architectural “glues to combine the link and system level designs of the IEEE.

C. Changing Regulations

The regulatory frameworks will also need to undergo a substantial change, not least because of the large time frames for regulatory changes to take place which are not adapted to our fast-changing world. There are three important items which stand out.

First, to absorb the quickly growing density in required access points, street furniture (i.e. lamp posts, street signage, etc) need to be deregulated the same way as the telecommunications industry had been deregulated. The single most important factor preventing base station roll-outs at scale are the difficult discussions with city halls, building owners, etc, regarding the usage of their public-facing real-estate. A simple government regulation could completely change this dynamics and pave the way for the much needed increase in base station densities.

Second, data and control may need to be regulated separately in the future. This would allow the usage of 3GPP to control any wireless system globally; and it would also allow a separate billing on the usage of the services over the data or control planes.

Third, with industry entering 5G as an end-user, the current operator model may not suffice. A higher density of micro operators will be required for which entirely novel spectrum management methods will be vital [16]. Whilst current TV White Space approaches have laid a good foundation, the sheer scale of potential micro operators will need a more scalable approach. To this end, combining spectrum management with distributed ledger technologies (such as used for Bitcoins) seems an adequate way forward. Much research, however, is still needed here.

V. Concluding Remarks

We have discussed some fundamental trends which underpin the mobile industry. Notably, we have established that the key KPIs always improve by one to two orders of magnitude on each generation, that the most important contributor to capacity over the past decades has been a decrease in cell sizes, and the massive deployment of these, and that the IEEE generally offers a link capacity one to two orders of magnitude larger than 3GPP at any point in time.

Based on these trends, we have suggested some disruptive technology changes from the radio and frequency aspects to architectural enhancements that allow to cope with the increase in mobile traffic. Fully flexible CP and UP transmission, along with a lighter CN architecture empowered by cloudification are some of the concepts discussed.

This, however, does not suffice to enable the much needed change. We have thus also proposed some fundamental changes to our innovation eco system. Notably, we have underlined the importance of co-creation aspects with the industry verticals, outlined the advantages of teaming up with other SDOs to strengthen the outcomes for 5G, and finally discussed the advantages of changing regulation aspects to ease the future network deployments.

All these items have very important impacts on the business models of mobile networks, which have not been discussed here and are left as future work. However, it is worth outlining that the value chains will transform slowly where we see telecommunications operators transit from consumer focused business models to business focused ones.

Acknowledgement

This work has been partially supported by the 5GPP VirtuWind (Virtual and programmable industrial network prototype deployed in operational wind park) project, as well as by the 5GPP 5G NORMA (5G NOvel Radio Multiservice adaptive network Architecture) project.

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