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5G and the Internet of EveryOne: Motivation, Enablers, and Research Agenda

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***Abstract*—As mobile broadband subscriptions grow twice as fast as the fixed ones and the Internet of Things comes forth, the 5G vision of the Internet of Everything (people, devices, and things), becomes a substantial and credible part of the near future. In this paper, we argue that the 5G vision is still missing a fundamental concept to realize its societal promise: the Internet of EveryOne (IoEO), *i.e.*, means and principles to overcome the concerns that the current 5G perspective raises for the digital divide and the network neutrality principle. We discuss open-source software and hardware, Community Networks, mobile edge computing and blockchains as enablers of the IoEO and highlight open research challenges with respect to them. The ultimate objective of our paper is to stimulate research with a short-term, lasting impact also on that 50% (or more!) of population that will not enjoy 5G anytime soon.**

***Index Terms*—Internet of EveryOne, community networks, 5G, mobile edge computing, network neutrality, community cloud computing.**

I. Introduction

5G, or the next big thing in Internet connectivity, plays a key role in the transition toward ubiquitous connectivity, and currently drives both research agendas and standardization work [1], [2]. Notably, 5G is not described as *just* a specification for the next mobile cellular network, but rather as a game changer in Internet usage for two main reasons. First, it is intended as the communication layer of the so-called *Internet of Everything (IoE)*. The IoE consists of billions of connected entities (devices, processes, etc.) constantly exchanging and processing data to revolutionize many of the daily activities we are immersed into. Second, 5G promotes a vertically integrated service delivery paradigm. According to it, service providers would partner with network operators through service-level agreements to control how data packets are processed in the 5G network or place services directly into it [3].

However, there are gray zones in 5G, raising justified concerns that 5G may end up amplifying the digital divide and accentuating existing inequality and power asymmetries in the Internet ecosystem [4]. Developing this analysis we propose another model: The Internet of EveryOne (IoEO). Whereas the current 5G vision is oriented at connecting "everything", we are instead interested in the social change that can be achieved connecting (and empowering) "everyone".

"Everyone" counts no less than 7 Billion people, including the 50% currently disconnected ones living primarily in the developing world. They cannot afford super-connectivity, and they do not constitute a profitable case for highly remunerative investment in market terms; yet, the social and development impact of including them is huge. 5G will not provide benefits to them and risk hampering social development. Hence, as researchers, we pose the question: *is it today more urgent to invest in more bandwidth for those that are already well connected, or to invest in having more people connected?* The two objectives are not mutually exclusive, but we have to accept that if we design technology that fulfills only the former objective, we are not necessarily tackling the latter. This paper wants to stimulate research with a short-term, long-lasting impact also on all those (and they are more than 50%) who will not enjoy 5G anytime soon, maybe never.

The vertical integration of applications and networks is another key feature of 5G that requires further analysis. One of the primary reasons that Internet has evolved in an open way up to now, is the end-to-end principle (*aka* keep the network core simple and place service intelligence at the edge). This principle (that is informally referred to as "network neutrality") prevents operators from adopting a business model based on the discrimination of traffic. Operators cannot make a profit signing deals with service providers to prioritize *their* traffic over the rest. Vertical integration clearly contrasts with transparency and network neutrality. If vertical integration is promoted to the "de jure" way of deploying new applications, network operators and incumbents are endowed with tremendous power and the risk is high to make the entrance barrier impossible for newcomers in the service provision, thus ossifying both the network and the services and blocking any future evolution.

With the IoEO term, proposed in this paper, we refer to a set of low-cost technologies that make connectivity affordable for everyone and enlarge the number of connected people. We show that grassroots organizations and individuals can run large distributed networks with a governance model that puts the rights of the user at first place, and thus minimizes power asymmetries and social/market control. Introducing the IoEO we draw the attention of the research community on the fact that networks built with openness in mind and a participatory governance can be the field for the growth of innovative applications, and that research in this field can achieve the benefits of vertical integration without sacrificing the user's rights: Technology at the service of society!

II. The Gray Areas of 5G

5G is a vision for future wireless communications and a realization path to it. The ambition of the 5G vision is most clearly reflected in the key performance indicators (KPIs) that accompany it [5]:

- 1,000-fold increase of the aggregate network capacity coupled with 10-fold decrease of the latency compared to 4G;

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- Provision of 100Mbps access speed to 95% of the users;
- Support for up to 10,000 connected devices per Base Station;
- Strong reduction of the *per link* infrastructure cost in order to compensate for the higher density of users.

Technically, the realization of the vision entails the extreme densification and diversification of the radio network access points, both in terms of radio technology and cell size (from macro down to femto cells). More specifically, to cater for the required capacity volumes, 5G aims at enabling wireless communications in the millimeter wavelength range (30–300 GHz). Radio communications in these bands need to overcome technical challenges such as high pathloss and the high sensitivity to obstacles, so that a dramatic increase of the density of BSs is inevitable. Eventually, there will be more points of access per home and even more outside, pushing WiFi home networks out of the market. At the same time, the vertical integration of applications and networks will allow the management (storage and/or processing) of part of the traffic directly in the network, so as to reduce the traffic on the backhaul network. Such an integration will ideally enable new applications, but it will also consolidate the control of the network and the applications into a single entity with arbitrage control, which historically means blocking innovation and not opening new opportunities.

These two directions are strategic in the current 5G agenda, as this is expressed in both standards and policy documents. In the remainder of this section, we analyze their negative implications and the concerns they raise.

A. The huge 5G infrastructure cost and questionable returns

One open problem in 5G is to find a cost-effective technology to sustain the aggregate throughput in the network. The backhaul network could use wireless technologies in the 6-80 GHz bandwidth, but there are still several technical challenges to be solved [6]. Given that the 5G deployment is planned for early 2020, the only available technology for the backhaul network is optic fiber, essentially calling for a fiber-to-the-home (FTTH) deployment [7]. Yet, FTTH is very scarcely present even in developed countries. As an example, as of Sept. 2016 the average penetration of FTTH over the 28 EU states is 9.4%, with large countries like Italy or Germany below 5% [8].

To realize the vision of 5G, a major infrastructure investment is needed. In urban areas of developed countries such investment is currently undergoing, though often subsidized, but it is unlikely that suburban and rural areas will experience similar investments in FTTH. The following figures give an idea of how unlikely this would be:

- The cost of deployment of fiber in rural areas in USA are in the order of 4,000-10,000$ per household when the number of users per linear mile of fiber ranges from 65 to 5, and skyrockets up to more than 25,000$ for less then 5 users per mile [9].
- The cost of deployment of fiber in rural areas in UK can reach 12,000£ [10].

The largest portion of the cost is due to civil works, so that the improvement of ICT technology can hardly reduce this cost. These numbers indicate that deploying FTTH is not profitable even in certain areas of highly industrialized countries, let alone in developing countries.

Even if one of the goals of 5G is to reduce the cost per connected device in order to cope with their increased number, it does not provide any concrete path to achieve it. To put it simply, there is no plan to make 5G profitable in rural and suburban areas. As a consequence, 5G is not expected to bridge the gap between the connected and the unconnected. It will instead enlarge it, giving even better connectivity to those who already have it (and can afford it) and making the cost barrier higher for the others [11].

One may argue that *over time* the price of 5G technology will decrease, and it will become affordable for a larger portion of humanity. However, this optimistic approach has never worked well enough to reduce inequalities. As researchers we are compelled to ask ourselves in a critical manner: What is the best thing to do *now* to have the largest impact on society? Whereas there is large evidence that the transition from analog or zero connectivity to DSL-style connectivity (always on, offering a few Mbit/s) has a strong societal impact, there is lack of data to support the theory that the economic impact increases with further increase of the broadband speed. Available studies show that the most positive effect is attainable when the access speed ranges between 4 and 8 Mbit/s, further increments producing marginal impact [12].

B. Vertical integration of network and services and its pressure on network neutrality

Whereas the scientific literature focuses on the technological advances needed for 5G, the major mobile operators produced a business-oriented point of view in a very instructive white paper [3]. As said, operators intend to partner with service providers to let them access advanced in-network functionalities that will make new kind of applications possible. Using "open APIs" the partner service providers will be able to control how data packets are processed in the network, or they may place services directly into the 5G network. All these functions will be regulated by service level agreements.

This model overlaps, if not fuses completely, with the popular (in research) Mobile Edge Computing (MEC) paradigm: A set of technologies that enables the dynamic placement of services close to the users [13]. The description of 5G as an "end-to-end system" rather than a specification for the access network, makes this mapping rather obvious.

This design marks a serious paradigm shift in the way services are delivered and *de facto* breaks network neutrality, which has been one of the key aspects of the ability of the Internet to support evolution compared with the vertical integration model of traditional Telco (ISDN-like) networks. In the past years, network operators have been challenging the provisions of network neutrality requesting a relaxation of network neutrality terms so that they could negotiate with service providers fees to gain a competitive advantage against competitors. This claim has so far been rejected by the majority of the national regulators, which stated multiple times that neutrality is a principle needed to defend user rights, but the FCC in the US has recently moved away from this position.

Hence, the vertical integration of networks and services as promoted by 5G, can be viewed as another attempt of introducing arbitrage positions in the communications service market, thus preventing, de-facto if not de-jure, its evolution. Besides the legal implications, we argue that network neutrality, whose value has been largely debated in the last decade [14], is to be preserved for technical and societal reasons. This is especially true if we consider

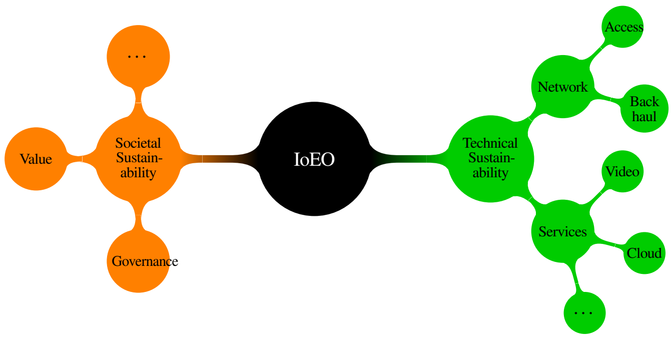

Fig. 1: A conceptual map of the IoEO

the current trends for centralization of network resources, data, and power in the hands of a few service and network providers.

III. Enablers for the IoEO

Fig 1 presents a conceptual map of the IoEO paradigm. in the following subsections we discuss the enablers that make this paradigm not only feasible, but indeed preferable to many others (5G included) for the Internet of the future.

A. Low-cost access networks

While 5G will rely on new physical layer standards that are to be defined, the previous generations of cellular access technologies are becoming accessible at reasonable prices, and WiFi already supports most of the wireless access at negligible costs. This is happening along mainly two different paths.

The first one is the development of free software that can be run on existing 2G, 3G or LTE base-stations. This is the case with the OpenBTS and OpenBSC open source software. These products emulate the radio interface and replace the whole voice back-end protocol stack of the cellular networks with equivalent functionalities of the IP stack in the well known open source Asterisk PBX implementation. Over time, the open source community was also able to take advantage of Software Defined Radio (SDR) and implement the radio component, removing dependencies on old, end-of-life base stations. Today, a 3G BS can be implemented with the SDR approach at a cost of few thousand Euros, while a full open source LTE solution is under development[1]. Several community-based projects have been bootstrapped using open source cellular solutions such as Rhizomatica.org[15].

The second approach consists in using Wi-Fi for the access network and extend its reach via meshing. The rationale behind this approach is that in low-income regions the penetration of Wi-Fi enabled smartphones is high, but there are no operators available to set-up the necessary access and backhaul infrastructure. The Serval project [16] realized low-cost devices that use UHF frequencies to create a backhaul mesh network and then expose an 802.11 access point. Using dedicated smartphone applications, the users can access voice and messaging services. A similar approach is taken by the LibreRouter project, launched in Argentina by the Altermundi NGO. The goal of the project, which has received funding from different sources, is to produce a fully open source multi-radio access points, with support for 802.11n and other wireless access technologies (it has a plug-in TV White Spaces communication module)[2].

B. Low-Cost Backhauling

Wireless Community Networks, or simply Community Networks (CNs) have been around since the early 2000s. In the last few years they received new attention from several research projects, especially in the FP7 and H2020 programs[3]. They initially used omnidirectional antennas or handmade directional antennas to create Wi-Fi mesh networks that could scale up to a few tens of nodes. Today, low cost outdoor 802.11ac (802.11n) devices make it possible to build 1 Gbit/s (450 Mbit/s) links spanning several kilometers with less than 2000 € (200 €). Directional antennas and proprietary extensions to the MAC layer, as implemented by many vendors, greatly reduce radio interference; and, the use of multiple gateways, together with bandwidth-aware routing metrics, greatly improves their scalability. Bottom-up communities today create CNs that scale up to hundreds of nodes and connect thousands of people [17], [18]. Some sufficiently well-organized CNs even deploy their own optic fiber cables. We already mentioned that deploying fiber is generally very expensive and that the majority of the cost resides in roadworks, licenses etc. Communities, especially in rural areas, are able to cut down on the cost of fiber traversing private land and pooling a sufficient amount of interested people in order to gather the required resources. A relevant example is B4RN, a bottom-up organization that provides an already-made business plan for communities that want to invest in fiber connections, and claims to be able to cut down the price of deployment down to 1100£ per property [19].

C. Edge computing or community clouds

Fog [20] and edge computing [21] have been proposed to enable a new type of cloud services at the network edge, essentially complementing large data centers with an edge cloud infrastructure. Fog computing migrates cloud computing to the edge of the network, where, through edge networks, more decentralized services are expected to replace centralized cloud services. Edge cloud computing is well suited to perform local data processing for the Internet of things (IoT).

An evolution of these paradigms consists in the provision of edge cloud services by communities of citizens. A *Community Cloud (CC)* is a deployment model in which a cloud infrastructure is built and provisioned for use by a specific community of consumers with shared concerns and interests. There are proprietary remote public cloud solutions offered by the major players [22]; closed-source CC solutions; and full stack open-source products in the market like OpenStack or OpenNebula, intended for rack or data-center class computing clusters.

Cloudy [23] is a community cloud software distribution, which exemplifies the infrastructure, platform and application services of the community cloud system. It unifies the different tools and services

[1] OpenBTS: http://openbts.org, OpenBSC: http://osmocom.org, OpenLTE: http://openlte.sourceforge.net, Asterisk: http://asterisk.org

[2] https://www.internetsociety.org/sites/default/files/blogs-media/18_LibreRouter_Innovative-Technologies.pdf

[3] See http://confine-project.eu, http://clommunity-project.eu, http://rife-project.eu and http://netcommons.eu.

of the cloud system in a Debian-based Linux distribution. It is open-source and can be downloaded from public repositories[4]. Cloudy provides custom decentralised services for network management and service discovery, which enable the orchestration of distributed services for the provision of platform and application services.

D. Blockchain-enabled mesh networking

Blockchain technologies (not necessarily Bitcoin!) have given fresh momentum to decentralized wireless mesh networks. The idea of using tokens, or other virtual credit mechanisms, to give value to individual user contributions to the network and preventing/mitigating free riding phenomena is not new. Yet, the related proposals almost never progressed beyond the level of academic exercise. Blockchains, on the contrary, present a tested-in-practice machinery to record and validate transactions in distributed manner. As such, they have taken not only the ICT community but also many professionals by storm, who try to apply them in many different activity areas.

Two relevant projects for our context are Althea and AMMBR[5] that try to implement a sustainable distributed wireless network, both relying on blockchains. The two projects are in their early stages, so it is hard to predict the importance they can have in the IoEO concept, but they serve as an incentive to stimulate research in this field. Althea uses crypto-currency transactions to incentive peering agreements between nodes. In short, neighbouring nodes, during their link-level negotiations agree on a price-per-byte to be paid in Ethereum (a well-known crypto-currency), so that nodes have incentive to offer connectivity to new nodes and not remain leaf nodes forever. The AMMBR blockchain instead is a dedicated ledger to keep track of many potential exchanges in the network and related applications: pricing, metering, billing, payment, reconciliation, reporting and auditing. Both projects wish to create a distributed marketplace to foster participation, cooperation and competition among those who want to act as service providers or network providers. They consider blockchains as the missing instrument to easily encourage, coordinate and automate this participation and thus, they design blockchain-enabled network nodes. A recent proposal pushes this concept further and try to merge the network and the blockchain itself [24].

IV. Elements of a research agenda for the IoEO

Many research directions stems from the IoEO vision and its enabling technologies in Sect. III. We discuss a subset of them that is neither exhaustive nor exclusive to IoEO: There are clear overlaps with research treads currently active in the 5G community, and this clearly indicate that 5G can be much more, simply changing some of its targets.

Low-cost SDR platforms. We have mentioned how important it is to have open source implementations of the 3GPP standards. For the IoEO case, it is imperative that while developing the standards and technologies for 5G, the same technologies be made available for low-budget scenarios. To this end, we need SDR platforms that operate in the mmWave range, and open source implementations of the 5G stack. Some efforts are ongoing on this front, [25], [26] but much more research is needed.

[4]https://github.com/Clommunity/

[5]See http://altheamesh.com and http://ammbr.com

Backhaul sharing solutions and meshing. Having enough bandwidth in the backhaul network is necessary but not sufficient to operate a properly working network with a distributed approach. As in 5G, the themes of QoS, infrastructure sharing and network reconfiguration are of paramount importance and need technical solutions that are (as in 5G) not fully available and call for more research effort. Currently, we know that in small scale scenarios wireless backhauling is able to deliver the necessary QoS to support 3G applications in rural areas [27] and meshes can scale well [28]. Yet, the scalability of these approaches and how they cope with the challenges posed by dynamic networks are not well understood. Likewise, there are models that make it possible to share the backhaul network and transform it into a real distributed Internet Exchange Point [29]. But, again, we need more research to understand how this approach can scale and become dynamic. Software defined networking and wireless network virtualization are key enablers towards efficient infrastructure sharing since they provide the substrate for creating virtual images of network resources. Whereas SDN is heavily researched upon in 5G, it has been only partially explored in the context of mesh networks [30], [31].

Novel business models for service provision. One of the strategic aims of IoEO is to keep the Internet open to small service providers and P2P applications. This is better served by non-vertically integrated telecommunication service models; this is well reflected in EU [32] and ITU [33] policy documentation promoting infrastructure separation and sharing through legislation, regulation and subsidies, with concepts dating back many years [34]. Ideally, the roles of physical network infrastructure provider (PIP), network (NP) and service provider (SP) would be separate. For instance, in remote underserved areas, grassroots CN initiatives could undertake the role of PIP, and small, possibly cooperative, ISPs could serve as NPs. The charging models for the infrastructure use, the trading of resources and services between PIPs, NPs and SPs, as well as possible incentives for motivating the investment of PIPs and/or NPs and SPs on infrastructure building are only a few of the open research questions. At a fundamental level, the call is for solid theoretical models from the network economics area, which would also be applicable in practice. These would define cost and revenue functions and viable ways of sharing the costs of operating the infrastructure and the profits incurred from the service provision. Cooperative business and organizational models based on the concept of open commons are being developed and formalised as well as security, privacy, and collusion prevention mechanisms for such P2P systems [18], [35], [36], [37].

Local service provision. Services offered locally can be cost effective [23], moreover, local processing make them subject to lower network latency and more resilient to networking problems. However, there are also issues with the added complexity from deployment, coordination and management. Anyway, local services have a better potential for local customisation, and more control on the privacy of users, especially when run in trusted environments both by service providers and consumers.

Compensation mechanisms in local networks. The economic sustainability of cooperative networking infrastructures depends on a balance between consumption and contribution in terms of CAPEX to expand the network, OPEX to operate it, with the consumption of connectivity and the provision of services [38].

Blockchain-based technologies are being developed to automate these compensations and payments, in terms of tokens exchanged to account for these contributions and consumption. The use of smart contracts and digital decentralized autonomous organizations (DAO) makes it possible to automate the implementation of decentralised and self-organized business and governance models, without the need of an operator acting as a centralized firm, more like a cooperative or competitive market.

V. Conclusions

In the industry white paper on 5G [3] there is one page (over a total of 125) dealing with a "scaled down" version of 5G that will address the needs of areas with extremely low average revenue per user. We deem this too short, if such areas account for roughly 50% of the world population. In this paper, we have presented IoEO, as an attempt to develop that missing part of the 5G agenda, which has been largely overlooked by the scientific community.

We have tried, in particular, to sketch a complementary research agenda that would set as primary objectives to narrow (rather than increase) the gap between served and under-served areas, between developed economic markets and subsistence economies, between economic impact and social impact, between centralization in operators and decentralization in small local initiatives, between participants acting as providers and consumers, and to blur (rather than sharpen) the power asymmetries between the people-end users and the top-notch application and network providers. To this end, we identified what technologies could serve as enablers and the main challenges that relate to them.

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