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ON REGULATIONS FOR 5G: MICRO LICENSING FOR LOCALLY OPERATED NETWORKS

ABSTRACT

Future 5G networks aim at providing new high-quality wireless services to meet stringent and case-specific needs of various vertical sectors beyond traditional mobile broadband offerings. 5G is expected to disrupt the mobile communication business ecosystem and open the market to drastically new sharing based network operational models. 5G technical features of network slicing and small cell deployments in higher carrier frequencies will lower the investment barrier for new entrants to deploy local radio access networks and offer vertical specific services in specific areas and allow them lease the remaining required infrastructure on demand from mobile network operators (MNO) or infrastructure vendors. To realize the full vision of 5G to benefit the society and promote competition, innovation and emergence of new services when the 5G end-to-end network spans across different stakeholders administrative domains, the existing regulations governing the mobile communication business ecosystem are being refined. This paper provides a tutorial overview on how 5G innovations impact mobile communications and reviews the regulatory elements relevant to 5G development for locally deployed networks. This paper expands the recent micro licensing model for local spectrum authorization in future 5G systems and provides guidelines for the development of the key micro licensing elements. This local micro licensing model can open the mobile market by allowing different stakeholders to deploy local small cell networks with locally issued spectrum licenses ensuring pre-defined quality guarantees for the vertical sectors' case specific needs.

Keywords: 5G, licensing, micro operator, mobile network operator, small cell, spectrum sharing, regulation

1. INTRODUCTION

New generation of wireless network technologies known as 5G is expected to revolutionize the traditional mobile communication business ecosystem by connecting billions of devices and ultimately digitizing the entire society. This development will be based on dense deployments of small cell networks in specific high demand locations to complement the traditional macro cellular deployments. Policy makers have globally recognized the importance of widespread deployment and timely take-up of very high capacity networks as being the key enabler for realizing the full economic and social benefits of the digital transformation (EC 2016a; FCC 2016a).

In particular, it is of utmost importance to realize that 5G will be available to organizations, communities and individuals as a development and production means, to carry all sorts of activities and capture the value created through them. To date the roles of network and service providers and end users have been much separated, but they will become blurred and occasionally even reversed. One could consider this either as the last remaining corner of digitalization of mobile communication networks or as the platform economy hitting the business sector in case, but the expected results are the same – grand opening of the mobile communication ecosystem as a whole, with entirely new opportunities and threats to its participants.

Traditionally, a small number of Mobile Network Operators (MNO) has dominated the mobile connectivity market with high infrastructure investments and long-term spectrum licenses as described e.g. in (Li & Whalley, 2002; Al-Debei et al., 2013; Cricelli et al., 2011; Ahokangas et al., 2013). The mobile communication sector has recently gone through a transition where the MNO market dominance has been shaken with the advent of over the top (OTT) services that became substitutes for MNOs' money making voice and text services leading to decreasing revenues for MNOs as described in (Feasey, 2015; Weber & Scuka, 2016; Peitz & Valletti, 2015). These internet services can operate independently of the infrastructure, leaving the MNOs to act as bit pipes to provide the mobile broadband connectivity for the various OTT services that the end users are enjoying. This substitutability of services has shifted MNOs' revenue streams to internet giants and MNOs' attempts to create closed walled garden services emphasizing security and safety and restricting what was made available for end users have failed.

Regulations on the other hand have not evolved along with the technical and market developments resulting in different regulatory requirements for the strictly regulated mobile connectivity domain and the loosely regulated internet domain as pointed out in (GSMA 2016). The difference is quite remarkable, but in fact it is not just the question of public versus private regulation, but the actual situation is more complicated and will develop further due to the emergence of 5G. On the mobile connectivity side short-range communication has been loosely regulated, compared to the MNOs' territory, for quite some time. More strictly speaking, it has been privately regulated, covering means from corporate control, contractual agreements and community rules to individual practices. The same holds for the internet domain, with a note that community-based governance has been adopted in many cases in combination with market-based commercial governance. Many known social media examples illustrate the point. This kind of regulation is basically missing from the mobile communication domain.

5G is expected to disrupt the mobile communication market to connect objects, processes and business models in new innovative ways in various vertical sectors (5GPPP, 2016). Even more importantly and following the old slogan, it will "connect the people". In other words, individuals and communities can and will rush to the domain. Indeed, 5G is seen as the major enabler for economic and social benefits of digital transformation by significantly contributing to widespread deployment and take-up of very high capacity networks (EC 2016a). Future 5G networks are expected disrupt the traditional mobile communication market by lowering the entry barrier to new entrants to the market by sharing of required resources with technical advances to operate on higher carrier frequencies and end-to-end network slices (5GPPP, 2016; Agiwal et al., 2016; Samdanis et al., 2016). The telecommunication sector is seen as the major enabler for the entire digital economy and society. Regulators are currently in the process of adapting their regulatory mechanisms for the adoption of next generation networks. For example, the European Commission (EC) is developing the new directive of the European Electronic Communications Code (EC 2016c) to provide tools to address the increasing complexity of networks with changing stakeholder roles.

Considering that the mobile communication market is at the advent of adopting a new generation of networks that can open the market for new entrants to deploy different parts of the end-to-end networks, the goal of this paper is to identify the regulatory implications of 5G in order to realize the full benefits of the next generation mobile networks. The paper specifically seeks to address how spectrum authorization should be done for the future 5G networks to increase competition, innovation and emergence of new services to benefit the society.

The rest of this paper is organized as follows. In Section 2 we summarize the key 5G innovations including expected applications, technical elements, and spectrum considerations. Section 3 describes the evolution of the mobile communication ecosystem towards 5G with the advent of new stakeholder roles. Section 4 identifies regulatory implications of 5G and Section 5 introduces the notion of micro licensing to the regulatory discussions on spectrum authorization for 5G. Finally, conclusions are drawn in Section 6 with a future outlook.

2. 5G INNOVATIONS

5G networks are expected to bring reliable wireless connectivity to serve the versatile needs of different vertical sectors, in addition to many other more generic communication needs that include what internet of things (IoT), virtual reality (VR) and augmented reality (AR), and big data and artificial intelligence will bring along, not to speak of block chain. This means that 5G enabled services will have many and partially conflicting requirements that must be met with the new system architecture and deployment options. This calls for innovations in both technologies and business models.

2.1 Expected applications

5G is expected to drive industrial and societal transformations and economic growth by offering gigabit mobile broadband services and supporting new types of applications connecting devices and objects in the IoT as depicted in e.g. (5GPPP, 2016; EC 2016b; RSPG 2016). The well-known usage scenarios for 5G (or IMT-2020) from the International Telecommunication Union Radiocommunication (ITU-R) sector forming the global targets and foundations for 5G system development include Enhanced Mobile Broadband, Ultra-Reliable and Low Latency Communications, and Massive Machine Type Communications (ITU-R 2015). These three high-level scenarios encompass a wide variety of applications that span across multiple vertical sectors such as automotive, health, manufacturing, logistics, energy, safety, media and entertainment that are discussed in more detail in (5GPPP, 2016; EC 2016a; EC 2016b; ECC 2016). This will result in versatile and increasing application requirements in terms of data rates, mobility, latency, connection density, spectrum efficiency, traffic capacity, and energy efficiency which are the key parameters from (ITU-R 2015).

Provisioning of high quality connectivity infrastructure in specific locations such as schools, transport hubs, public service providers' units, and enterprises has become a key societal objective as the enabler for new services, see e.g. (EC 2016a). This highlights the location specific needs for wireless connectivity in the different facilities to provide drastically new services in the coming decades that cannot even be envisaged today. Different business cases for the deployment of 5G networks will arise in specific high-demand locations including e.g. being a neutral host that provides connectivity services to traditional MNOs' customers in specific building instead of all MNOs deploying their indoor networks separately as discussed in (Ahokangas et al. 2017). Additionally, local closed 5G networks can be deployed and operated to serve a restricted set of customers such as machines in a factory environment. Ultimately, 5G networks will support these distinct business cases or a mix of them resulting in different regulatory requirements for operations according to the business case. As an example, VR, AR and integrated mixed reality based services can find applications in the different sectors and locations resulting in stringent bandwidth and latency requirements that require 5G with mobile edge computing capabilities to reach their full potential. Massive deployment of IoT with billions of connected devices and objects is increasingly seen to use 5G networks as the delivery mechanism (EC 2016b). Moreover, IoT is expected to transform from a sensor-driven paradigm focused on uplink machine-type communication into active systems complemented by actuators, drones and robots which sets increasing requirements for both uplink and downlink directions in terms of end-to-end reliability, latency, and energy consumption that are addressed in 5G (Condoluci et al., 2016). Overall, 5G is expected to work with enormous number of users, variety of devices and diverse services, yet resulting in significant improvements in users' perceived quality of service (QoS) (Agiwal et al., 2016).

2.2 Disruptive technical features

Development of 5G networks aims at meeting increasingly stringent requirements for higher capacity, higher data rate, lower latency, massive device density, and reduced capital and operational costs. Moreover, 5G networks are expected to be deployed in a wide range of frequency bands with different characteristics including spectrum below 1 GHz, spectrum between 1-6 GHz, and spectrum above 6 GHz in the millimeter wave range (EC 2016b; ECC 2016; FCC 2016a; RSPG 2016). This requires that 5G networks are flexible, scalable and reconfigurable towards different deployments which calls for a major paradigm shift in the entire network design.

5G is expected to lead to the shift to ultra-dense small cell deployments, flexible network deployment and operation, multi-connectivity, dynamic traffic steering and resource management, intelligent use of network data, users participating in storage, relaying, content delivery and computation within the network, coexistence of heterogeneous networks and local stand-alone 5G systems, and the use of smart antennas to help in capacity and interference mitigation, and operations in higher (millimeter wave) frequencies (Agiwal et al. 2016; Marsch et al., 2016; Rost et al., 2016). In fact, very dense deployments of small cells that are connected with high capacity backhauls are expected to be a key operational mode in 5G and can be deployed by the facility owner as discussed in (Zander, 2017). Regulators have started to take actions to remove barriers for the installations of small cells for speedy and cost-effective deployment (EC 2016b).

In terms of radio access, it is not possible to develop a single 5G air interface that would meet all application requirements in all scenarios operating a wide range of frequency bands but several new optimized air interface variants will be needed (Marsch et al., 2016). New spectrum sharing opportunities will emerge to allow operation in the various 5G frequency bands under different spectrum authorization regimes (ECC 2016; Bhattarai et al., 2016; Gupta et al., 2016; Tehrani et al., 2016) which can benefit from network-side interference management to be complemented by user equipment side interference management to improve spectrum usage efficiency (Nam et al., 2014). In particular operations in the millimeter wave bands requires the use of smart antenna technology to overcome the problem of high propagation loss at high frequencies which at the same time makes spectrum sharing easier by limiting the interference distances (Kim et al., 2016; Gupta et al. 2016).

In the network infrastructure side 5G is expected to take a leap from traditional network sharing between MNOs (Khan et al., 2011) aimed at cost reductions towards an ultimate goal of on-demand multi-tenancy for hosting totally new services to specific customer segments. There the network slicing functionality will be a critical new technical feature to enable multi-service and content aware adaptation of the network to different applications in vertical sectors through dynamic creation of network slices on top of a common shared infrastructure (Samdanis et al. 2016; Richart et al., 2016; Rost et al., 2016). These slices including both radio access networks and core network sides could span across the administrative domains of several stakeholders and be operated separately for the provisioning of services for specific vertical customers.

2.3 Spectrum considerations

The key spectrum related regulatory consideration for 5G will be the identification of suitable spectrum bands for mobile communications and making them available for the potential stakeholders deploying the 5G radio access networks in a timely manner. In 5G this includes finding opportunities in bands with existing allocation to the mobile service as well as new potential bands covering a variety of bands below 1 GHz, between 1-6 GHz, and above 6 GHz. Identification of new 5G spectrum at the global level in ITU-R focuses on the frequency range of 24-86 GHz including supporting regional activities in preparation for the World Radiocommunication Conference in 2019 (WRC-19). Moreover, a key task for the regulators is the development of spectrum authorization models for granting access rights to use 5G spectrum among the applicants in an objective, transparent, non-discriminatory, and proportionate way. In 5G these applicants not only include existing MNOs but also new entrants have expressed their wishes to deploy local 5G networks in specific areas such as manufacturing companies in their factory sites.

The growth of mobile communications has increased the rivalry between different radio services competing over access to spectrum as discussed in (Cave & Pratt, 2016). Regulators globally see the 5G networks as an important enabler for new businesses and are committed to making new spectrum available in a timely manner (EC 2016a, EC 2016b, FCC 2016a, RSPG 2016). Ensuring sharing and compatibility with other spectrum users will, however, need to be guaranteed as traditionally between any radio services. Advanced spectrum sharing techniques (Bhattarai et al., 2016; Tehrani et al., 2016) are expected to play an increasingly important role in 5G protecting the possible incumbent spectrum users in the bands, allowing MNOs for more dynamic sharing-based operations and opening the market to new entrants. In its 5G Action plan (EC 2016b), the EC states that the potential for spectrum sharing, including license-exempt use, should be maximized as it generally supports innovation and market entry. In its communication towards a European gigabit society (EC 2016a), the EC specifically promotes shared use of spectrum, either on the basis of general authorisation or individual rights of use, as an enabler for more efficient and intensive exploitation of spectrum especially in the new millimetre spectrum bands.

In addition to potential new spectrum identifications for 5G in the higher frequencies, there are several bands already allocated to the mobile service that are planned for 5G use as discussed in (EC 2016a; RSPG 2016). These bands typically encompass other type of incumbent usage and spectrum sharing mechanisms will be needed to access the bands to avoid their time-consuming clearing from the current use. In fact the lessons from the development of new spectrum sharing models adopted in regulation, including Licensed Shared Access (LSA) in Europe (ECC, 2014) and three-tier sharing model for Citizens Broadband Radio Service (CBRS) in US (FCC, 2016b), are available to allow efficient coordination of interference between existing and entrant 5G systems as well as between entrant 5G network deployments as summarized e.g. in (Tehrani et al., 2016, Bhattaraj et al., 2016). These different spectrum sharing models adopted in regulation were seen to consist of similar high-level steps were identified including regulatory preparations, access rights to shared spectrum, deployment, operations and release in (Mustonen et al., 2017).

The LSA model in Europe introduces additional licensed users while protecting the incumbent spectrum users in the given band resulting in quality guarantees for both entrant and incumbent systems. Prior work on LSA in the European regulation has focused on the protection of the incumbents and left out defining of LSA licenses as it is a national matter for the regulator to decide (ECC 2014) and not deployed in any country yet. The architecture and procedures for LSA in the 2.3-2.4 GHz band were defined in standardization (ETSI 2013; ETSI 2017a) from the perspective of the dominant MNO to be the LSA licensee without considering new entrants. In fact, the entire objective of the prior work on LSA has been to provide more spectrum for existing MNOs (ECC 2014; ETSI 2013) but new LSA work has started to address locally deployed high-quality 5G networks with temporary spectrum access (ETSI 2017b). With the advent of addressing vertical sectors' needs with local 5G networks, the current LSA framework is being expanded to address admitting of new entrants to the market.

The Federal Communications Commission (FCC) in the US has taken concrete actions in its report and order (FCC 2016a) by adopting new licensing, service, and technical rules for several specific 5G bands in the millimeter wave range including sharing between entrants' systems and the protection of incumbent spectrum users. The Federal Communications Commission (FCC) has introduced a three-tier sharing model for providing CBRS on a shared basis in the 3.5 GHz band (FCC 2016b). This model introduces second priority layer of priority access licenses (PAL) in specific geographical areas called census tracts for currently three year license periods while guaranteeing that first tier incumbent federal users remain free from harmful interference. The model also introduces a third priority layer of General Authorized Access (GAA) users that need to guarantee that higher priority layer incumbents and PAL license holders remain free from harmful interference from them. GAA users can access parts of the band without paying license fees but they are not guaranteed interference protection from other users.

After global and regional harmonization of suitable spectrum bands, the main mechanism in mobile communication spectrum assignment in the national level to grant access rights to competing MNOs has been exclusive licensing awarded through spectrum auctions that are extensively discussed in (Cramton, 2013; Cave & Pratt, 2016). This mechanism has traditionally come with stringent obligations on e.g., coverage, and resulted in high spectrum fees limiting the potential licensees to be the existing MNOs. In 5G, regulators aim at complementing the traditional exclusive licensing will also general authorization (license-exempt) and sharing based models (EC 2016a; FCC 2016a), which will in practice open the Pandora's box and is a concrete justification for regulatory developments. In fact the US three-tier sharing model for the 3.5 GHz band presented in (FCC, 2016b) already introduces a mix of individual access rights and general authorized access clearly indicating the change in regulation towards opening the market by granting local access rights to new entrants. In the LSA model, the procedures for defining and awarding LSA licenses is a national matter left to the NRAs to decide and has not been discussed yet (ECC 2014). Overall, the different spectrum authorization regimes can be characterized with the degree of QoS guarantees, level of spectrum access guarantees, spectrum license fee, and spectrum utilization efficiency (Tehrani et al. 2016). New licensing models are studied in the research domain to allow more flexibility by taking into account operations in shared bands by finding a balance between license fee and the admitted interference (QoS), see e.g. (Kliks et al., 2015).

Spectrum considerations in the development of 5G have received a growing interest and importance as the enabler to open the market compared to previous network generations where the main goal was merely to make new spectrum available for the existing MNOs. Spectrum authorization methods and decisions taken by the regulators eventually shape the business ecosystem and competition environment through the allocation of a certain number of licenses and conditions, thus restricting the stakeholders who actually can deploy mobile communication networks and enter the business. There has been a growing pressure to increase the competition in the mobile market by adding versatility to the potential spectrum license recipients (EC 2016a; FCC 2016a). With the new 5G features, such as the networks slicing spanning across multiple stakeholders' domains, the operation of 5G networks is no longer restricted to existing MNOs but new entrants can more easily start operating parts of the network, such as the radio access network in specific areas, taking advantages of the sharing-based operational models.

3. CHANGING MOBILE BUSINESS ECOSYSTEM

Mobile operator business is currently highly regulated indicating that the regulators have a significant influence on shaping the mobile communication business ecosystem. The mobile market has evolved from state owned monopolies toward a competitive environment through the adoption of new regulatory mechanisms that aim at promoting competition and sharing of infrastructure. The business ecosystem has particularly been shaped through the mechanisms regulators are using to allocate spectrum, directly concerning operators and indirectly other stakeholders in the ecosystem. At the same time, the ecosystem has however greatly evolved based on evolution outside the mobile connection and communication domain, including on one hand developments that have led to increasing horizontalization of technologies, and on the other hand a massive opening of access to and services based on digital data created, consumed and shared by individuals and businesses.

3.1 From operator dominance to service provider outperformance

Traditional business ecosystem in mobile communications has been extensively studied and described e.g. in (Li & Whalley, 2001; Al-Debei et al., 2013; Grove & Baumann, 2012; Peitz & Valletti, 2015). Typically the following stakeholders and roles have been identified: content providers, pure service providers that do not operate their own infrastructure, integrated operators covering both infrastructure and service provisioning, content and service aggregators, internet service providers as local access network providers, infrastructure vendors, and device makers with their distribution channels in addition to end users.

Regulators have held a significant influence on the competitive situation in the mobile markets when making decisions on allocating spectrum to MNOs (Lundborg et al., 2012). In the past decade spectrum management reform initiatives have focused on promoting more efficient use of existing spectrum bands used by the MNOs by introducing technology and service neutrality (refarming) and by allocating more spectrum to mobile communications (Frias et al., 2016). Refarming by allowing upgrades to newer technology on bands originally awarded for other technology (e.g., from 2G to 3G) may lead to competitive distortion due to uneven distribution of spectrum between MNOs (Lundborg et al., 2012). This has implied a risk to competition if the spectrum allocations favor the leading operators to secure their strong market positions. In fact auctions have become the main mechanism for granting rights to use the mobile spectrum which has limited the potential licensees to those who can afford high license fees and fulfill coverage obligations. While auctions introduce objectivity to the process (Cramton, 2013; Cave & Pratt, 2016), they may favor existing MNOs that have already invested in the infrastructure and prevent competitors from entering the market (Lundborg et al., 2012). In addition to spectrum decisions, regulators' have set requirements for interconnection and interoperability for the services, which has shaped the ecosystem for the benefit of end users and allowed a smaller network holder to gain access to the users and benefits of the larger network (Feasey, 2015) and prevented big firms to from charging too much or denying access. This has been an important step in opening the market for competition.

Even more importantly, competition has come outside the mobile communication domain and has not been caused by small entrants, but by very big companies. Feasey (2015) and Weber and Scuka (2016) have described the path how the MNO market dominance has been shaken by internet giants who make money by offering OTT services. These OTT services can operate independently of the networks over with the services are run and remain outside the operator domain which has led to the decoupling of infrastructure and services. Pure OTT service providers that do not operate their own infrastructure have overtaken the money making role from operators over the past decade (Grove & Baumann, 2012). Some of the services provided by OTT players using the operators' infrastructure have directly competed with traditional MNO offerings, such as voice and SMS, leading to decreasing profits for MNOs. As pointed out in (Peitz & Valletti, 2015) the increasing role of OTT players requires a fresh look at the market forces shaping the mobile communication industry. This involves also and perhaps especially regulation, because the new entrants have not needed to build their positions during many years and in a strictly controlled environment. On the contrary, they have enjoyed the opportunity to grow they service offerings without the burden of infrastructure investments and governance.

Interestingly, however, to further blur the roles of the traditional stakeholders, there has recently been a growing interest of internet giants to build networks, but in unlicensed bands to take up the operator role as discussed in (Feasey, 2015), and a tendency of MNOs to offload in unlicensed bands (Weber & Sucka, 2016).

As a summary, consumers can today use different overlapping access networks as substitutes for one another or as a mix, depending on their location. This fact together with the mentioned new entrants' strategies has, in essence, paved a road for a situation where the well-established, regulated and orchestrated mobile access, connection and communication ecosystem is in quite a shaking state despite that it is obviously still far from collapsing. Although the situation is not quite similar to Uber providing services without much of any transportation infrastructure costs, it is an alarming change from the viewpoint of those, who have invested a lot in mobile networks and organized their businesses around the capacity to build and manage them. While it is not yet possible to state who will be the biggest winners and losers, it is likely that changes in regulation are needed and that they will offer opportunities both to the existing and new parties in the ecosystem. MNOs themselves, for example, will apparently not stand still waiting for their networks to become a costly burden, while service cash-cows and value creating end-user communities are booming elsewhere.

3.2 Emergence of new roles in 5G

5G is envisaged to result in changes in the traditional mobile business ecosystem and be the enabler for a wide range of new services in various vertical sectors (5GPPP, 2016a). While the roles of infrastructure and service provisioning have grown apart in the era of the OTT services substituting traditional MNO services, they could be partially recoupled in 5G to provide new mix of tailored services for specific verticals' needs. More importantly, the roles of traditional stakeholders in the mobile business are expected to change with the advent of 5G that will open up the traditionally closed mobile value chain. Figure 1 summarizes the trends of change with 5G.

Facility owner's role is becoming increasingly important in 5G with the shift from macro coverage to the deployment of ultra-dense small cell networks in specific locations such as schools, hospitals, sports arenas, industry plants, and malls (Zander, 2017). In the mobile business ecosystem the local players that have a "natural monopoly" over the space where they are will play an important role in future service provisioning. Other roles are also foreseen to change leading to e.g. closer collaboration between MNOs and various local service providers in the form of co-investments between operators and content providers as discussed in (D'Annunzio & Reverberi, 2016). A good example of this is AT&T's acquisition of Time Warner (Trainer, 2016).

Moreover, 5G could also provide new network slicing based service provisioning opportunities to infrastructure vendors and constructors to offer networks or parts of the infrastructure as a service, and it may also boost new local content services and the monetization of context-specific big data or user data. The emergence of a new network slice broker role in 5G was proposed in (Samdanis et al., 2016) to enable different stakeholders such as mobile virtual network operators (MVNOs), OTT service providers and vertical sector market players to request and lease network resources on-demand from infrastructure providers such as MNOs or directly infrastructure vendors.

New ecosystemic connectivity services, content services, context services and commerce platforms business models are expected to emerge in 5G to allow different stakeholders to exploit the new opportunities opened up by technical innovations (Ahokangas et al., 2016; Ahokangas et al., 2017). With 5G the disruption in business is expected especially at the higher layer context and commerce platform service business models, as context-specific local services and commerce platform services will increasingly be available and also needed in 5G. 5G can also be seen to bring the elements of sharing economy to the mobile business ecosystem, thus highlighting the role of collaborations and value sharing regarding infrastructure and spectrum.

In fact 5G can open totally new roles in the future mobile ecosystem. A micro operator (uO) role for locally deployed and operated small cell radio access networks is expected to emerge in (Ahokangas et al., 2016; Ahokangas et al., 2017; Matinmikko et al., 2017a) to offer tailored services to complement the traditional MNO offerings. A micro operator as described in (Ahokangas et al., 2016) can be considered as an entity that offers 1) mobile connectivity combined/locked with specific, local services, is 2) spatially confined to either its premises or to defined (but narrow) area of operation, and is 3) dependent on appropriate available spectrum resources. From regulatory perspective the emergence of the uO role will be of fundamental importance to allow different stakeholders, such as facility owner or tenant, to take the operator role in specific location/facility. This has traditionally been possibly only for MNOs under the individual authorization regime while other stakeholders wishing to operate wireless services have had to resort to unlicensed bands without quality guarantees. Due to the comparatively small size and limited resources of the uOs, the most likely uOs to emerge with required scale and scope of operations have either to serve a specific and necessary purpose and/or have a large enough user base. A uO should also collaborate closely with other operators so that to provide connectivity to internet and other mobile networks.

Because 5G will be associated not only with services, but also with many kinds of verticals, IoT and digital data processing solutions, plenty of new stakeholders will enter the outskirts of the ecosystem, if not the center. As the emergence of OTT service providers, first without many worries for the wireless mobile infrastructure, but then an increasing interest in grasping their own share also from the network indicates, it is not said that the new stakeholders would stay in their initial positions. Digitalization has already led to the adoption of completely new businesses by existing actors, such as banks running health-care services. Indeed, oblique moves will be introduced that cut across the existing ecosystem relationships and boundaries, connecting it in new ways to other domains (Iivari et al., 2016). Regulation can be seen and may be used to boost it or slower it down. From the viewpoint of promoting fair competition, innovations, and new services, 5G is a true cornerstone of the digital future, and the latter is not an option.

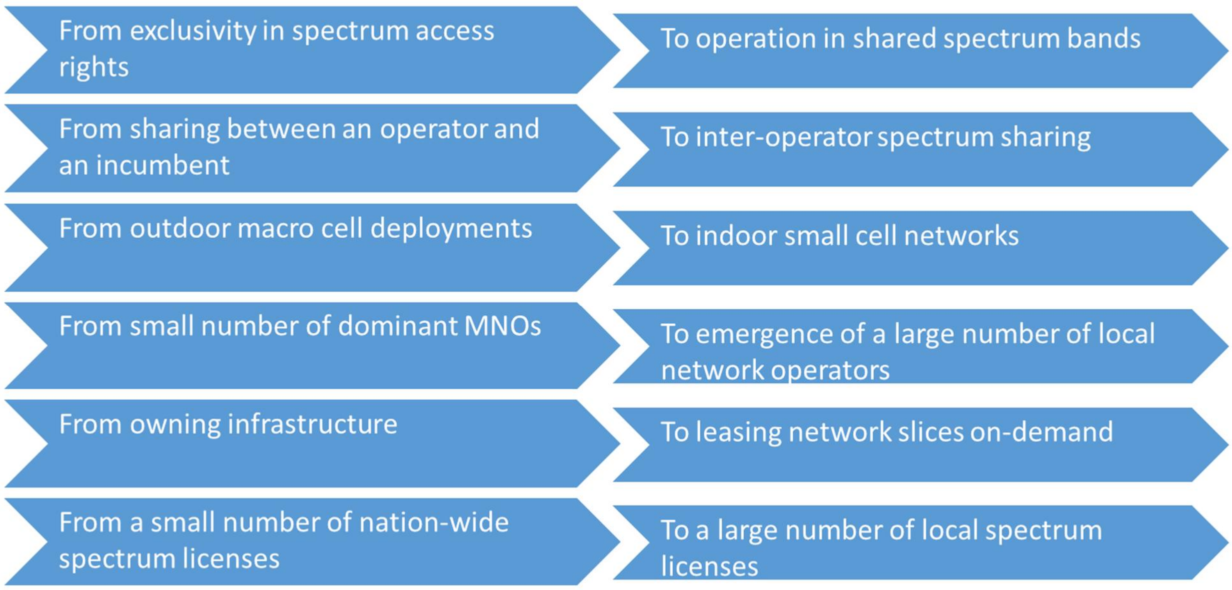

Figure 1. Trends of change in 5G business ecosystem.

4. REGULATORY IMPLICATIONS OF 5G

The extent to which 5G networks can fulfill the bold visions for transforming industries and the society and change the entire mobile communication ecosystem depends on the regulatory actions taken. The regulatory framework consist of different levels including national, regional, and international levels. It is important for regulations to support profitable long-term investments for all major stakeholders including both entrants and incumbents while promoting competition, innovation and emergence of new services.

4.1 Review of regulatory elements

In order to examine the regulatory implications of 5G, we first identify the key influential regulatory elements. The electronic communications market is highly regulated at national, regional and international levels. Especially spectrum matters require regional and global coordination and harmonization for the movement of people and goods and creation of economies of scale. While there are wide variations in the national regulatory approaches there is also harmonization. For example in Europe, the member states of the European Union (EU) are governed through EU level regulations to which the national regulations needs to be aligned. These are now being revised in EC's development of the new European Electronic Communications Code (EC, 2016c). Here we use the EU level regulations as the basis to identify general regulatory elements, while noting that there are also national differences.

Bauer (2015) has identified the general elements of regulation of the mobile communication ecosystem including spectrum policy, competition, access to networks, infrastructure and content, price regulation, facilitation of coordination, harnessing societal benefits, and industrial policy. From the operator perspective GSMA (2016) has pointed out the following regulatory elements: access regulation, consumer protection, competition enforcement and economic regulation, intellectual property, privacy and data protection, resource management, network security, taxation, and universal service and accessibility. The EU level regulation considers regulation of broadband markets, access and interconnection (wholesale access), authorization and licensing, spectrum management, access to passive infrastructure, consumer issues (privacy, security), universal service, and net neutrality (QoS) (EC 2002; EC 2016a; EC 2016c). Based on this, we identify the following highly interdependent regulatory elements: access regulation, pricing regulation, competition regulation, privacy and data protection, and authorization of networks and services which are summarized in Table 1 together with their roles in 5G.

Access regulation refers to the obligations for interconnection and interoperability requesting that operators offer connectivity to virtual operators and to other operators that lack part of the network as discussed in (Briglauer et al., 2017; Cambini & Jiang, 2009; Peitz & Valletti, 2016). *Pricing regulation* aims providing a minimum set of services to all end users at an affordable price and ensuring that wholesale and transfer prices do not distort competition, see e.g. (Briglauer et al., 2017; Cricelli et al., 2012). *Competition regulation* aims at ensuring that competition in the market is not restricted to reduce economic welfare and innovation, see (Briglauer et al., 2017; Peitz & Valletti, 2015; GSMA, 2015). *Privacy and data protection* refers to ensuring the rights of users to the processing of their data and privacy to protect confidentiality as well as security of services. Finally, the *authorization of networks and services* defines the ways how rights to use radio frequencies are granted and is essential to the development of the market and of innovative products and services, and to the proper functioning of competition and the achievement of various societal goals, see (EC, 2002).

To expand regulation, governance in general can be divided into public and private endeavors and that in addition to written or common law there exists a plethora of private controlling means. These include not only internal corporate governance and contracts made freely by market actors, but also relationship-based mutual agreements and community alias bazaar governance. In general, governance is becoming associated with networked settings and more integrated, so that multiple mechanisms may co-exist (Johnston 2001;

Faems et al., 2008). Community governance has been both advocated and studied (Demil & Lecocq, 2006; Forte et al,. 2009), but it is far from any dominant approach yet. Moreover, some authors claim that governance and control of collaboration would need to be developed to match with the jointly developed and utilized assets (Hoetker & Mellewigt, 2009).

4.2 Regulation of 5G networks

After identifying the key regulatory elements we move on to analyze how the current regulations support the vision for 5G depicted in (5GPPP, 2016; EC 2016b). Regulations need to promote investment in the new technology as discussed in (Briglauer et al., 2017; D'Annunzio & Reverberi, 2016). The European Council has called for very high-capacity fixed and wireless broadband connectivity across Europe, as a precondition for future competitiveness, and for regulatory reform to incentivise major network investments while promoting effective competition and consumer rights (EC 2016a). The role of private investment in the internet connectivity networks and the role of a stable regulatory framework are essential in encouraging and enabling stakeholders to invest.

An important question is whether regulators should apply same rules to entrants as were applied to incumbents or reduce regulation on incumbents. For sharing based economy, there are suggestions that regulators should relax old rule on incumbents and new entrants should only face minimal regulatory requirements, see e.g. (Koopman et al., 2014). The regulatory decisions taken for 5G should consider the time perspective of 5G as a long-term solution which calls for considering dynamic approaches. Prior work on challenges of designing effective governance for the mobile broadband sector by Bauer (2015) highlights that more adaptive approaches to governance are needed combining regular monitoring of performance metrics with a reassessment of the prevailing policies and their modification or abandonment. These could benefit from international comparisons as long as different national conditions are sufficiently captured. Adding dynamics to regulations becomes key to incorporate technical advances.

The five identified regulatory elements and their envisaged roles in 5G are further summarized in Table 1. Access regulation in 5G should continue to allow access to network infrastructure for those who do not have it, which becomes increasingly important with a large number of local small cell radio access network deployments operated by different entrant stakeholders. Pricing regulation and competition regulation should promote the emergence of new operators by guaranteeing connection to other operator networks with reasonable prices to ensure end-to-end connectivity from local 5G small cell deployments and the outside world. The importance of privacy and data protection will increase in 5G as more and more data is collected and processed into new service offerings. The goal for the governments in making authorization decisions including spectrum allocation and assignment should be efficiency by ensuring that those who can put the spectrum to its highest use get it, instead of revenue maximization, see (Cramton, 2013). Competition which ultimately will lead to greater innovation and better and cheaper services will likely generate greater government revenues in the long-run. The traditional ways in mobile communications including the granting of individual access rights via auctions with high obligations and general authorization with limited transmission powers and no quality guarantees will continue to be applicable in 5G as outlined in (EC, 2016 a; EC 2016b; FCC, 2016). However, there is a growing demand for locally operated high capacity networks in specific areas as studied in (ETSI. 2017) for which the two main assignment methods are not applicable as such in the newly envisaged 5G bands to realize the full benefits. In particular, the spectrum authorization in 5G will need to be complemented with new local licensing models to allow the technical innovations of network slicing and operation in higher frequencies to provide versatile applications in different vertical sectors.

It is clear that 5G regulation must be expanded or associated with the presently non-regulated or loosely regulated areas that will become parts of the emerging business ecosystem. Standardization might help in creating rather stable starting point, be it related to the fundamental network characteristics, interoperability between and accessibility to services and resources. A special need is to provide a solid regulatory foundation for locally established 5G networks as a starting point to the governance of presently less-regulated or non-regulated areas, to prevent losing the momentum of fair competition based on 5G solutions and to harvest its value. We will next discuss a specific proposal for authorization including “micro licensing” as a means to allow different stakeholders to deploy local 5G radio access networks.

Table 1. Regulatory elements and their roles in 5G.

Regulatory element	Description	Role in 5G
Access regulation	Interconnection and interoperability requirement to allow access to infrastructure for those who do not have it.	Network slicing and providing network as a service spans across multiple stakeholdes and local 5G small cell radio access network deployments need to connect to other operator networks to ensure end-to-end connectivity.
Pricing regulation	High quality services should be made available for end users with affordable prices. Retail and wholesale prices between operators need to be non-discriminatory and reasonable.	Local 5G networks need to be allowed to connect to other networks with reasonable prices to ensure affordable prices for end users.
Competition	Holders of significant market power should not be allowed to abuse their dominant position.	Regulations should promote competition by the establishment of local operators to serve vertical sectors’ specific needs in specific areas.
Privacy and data protection	Service providers need to safeguard the security of their services and protect the privacy and data of users as well as confidentiality.	Role of data collection, analysis and usage will increase in 5G service provisioning which calls for regulatory actions to define rules for data ownership and exploitation.
Authorization of networks and services	Spectrum authorization decisions regarding granting of access rights to use frequency bands including rights and obligations (licensing models).	New local licensing models will be needed to complement existing models to allow different stakeholders to establish local 5G small cell radio access networks with guaranteed quality.

5. MICRO LICENSING MODEL FOR LOCAL 5G NETWORK DEPLOYMENTS

The authorization mechanisms to assign the access rights to the radio spectrum among those requesting it will be a critical design factor shaping the future 5G mobile communication market. These mechanisms need to open the market beyond existing MNOs while ensuring fair competition environment for both incumbents and entrants and encouraging them for investment. The value of a spectrum band to an operator depends on its previous spectrum portfolio indicating that gaining access to a new spectrum band is more valuable to an operator that has less spectrum (Frias et al., 2016). 5G networks are expected to be deployed in a wide range of spectrum bands including bands with existing mobile allocation in the lower frequency bands and in the potential new higher frequency bands spanning from 24 GHz to 86 GHz expected from WRC-19. Due to the high signal attenuation due to radiowave propagation in the higher frequencies, the 5G networks can only provide service over limited local coverage areas, such as inside specific buildings, see (Gupta et al. 2016). The traditional spectrum authorization models used in mobile communications of granting individual access rights and general authorization will need to be complemented with new sharing based models that consider the specificities of 5G network deployments that are inherently local and address the needs of specific verticals in parallel with traditional mobile broadband offerings.

5.1 Micro licensing elements

The notion of *micro licensing* presents a means to grant local access rights to deploy and operate 5G networks in a specific places such as sports arenas, hospitals, shopping malls or factories as discussed in (Matinmikko et al., 2017b). Micro licensing is a form of granting individual access rights with a predefined level of protection from interference from other spectrum users. The exact conditions and awarding procedures can take forms from both individual authorization with mainstream auctioning mechanism and general authorization admitting a large number of entrants to the market. The traditional elements defining a spectrum license in auction mechanisms include license duration, carrier frequency, bandwidth, maximum transmission power, coverage obligations, how much paired and unpaired spectrum per operator and altogether, allowed level of infrastructure sharing, amount of spectrum for the new entrants that dominant stakeholders cannot bid (spectrum set aside), and time when network needs to be up and running (use it or lose it) (Mochon & Saez 2016; Cramton 2013).

In Table 2 we present a summary of the elements defining a spectrum license and what form they could take in the 5G micro licensing model. The micro licensing model is here intended for the mobile service but the same principles are already applied in other radiocommunication services where local access rights are issued. Micro licensing can benefit from the spectrum sharing techniques developed for mobile communications (Bhattarai, 2016; Tehrani et al., 2016) which can then be expanded to other radio systems too. Figure 2 summarizes the micro licensing, traditional exclusive licensing and general authorization models and presents their high-level comparison. The micro licensing model combines benefits from the other two models by admitting a larger number of stakeholders to gain access to spectrum that can provide quality of service guarantees. However, it is a more complicated regulatory procedure which requires careful defining of the various micro icense elements which are discussed next.

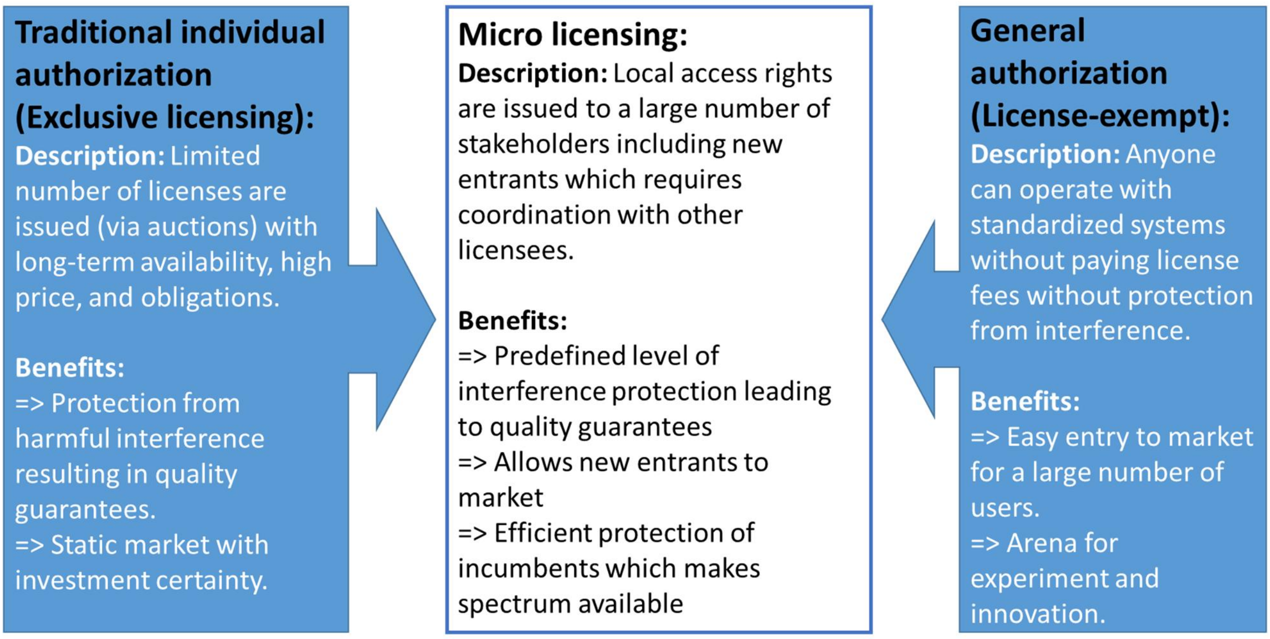

Figure 2. Comparison of micro licensing with individual authorization and general authorization.

In terms of who is eligible to get a micro license, the potential stakeholders should not be limited but the market should be made open for entrants while deciding who is an eligible licensee. They are foreseen to adopt a shorter license duration in the order of some years as the investment in local network deployments is lower than in a country-wide infrastructure and the renewability of the license could be made possible case-by-case. Although 25 year license durations were still promoted in (EC 2016a), there is a trend towards shorter time-scales (FCC 2016b). The renewability option and lower cost on infrastructure will not raise the possibility of stranded investment. In terms of license area, current country-wide licenses will be replaced by smaller license areas which helps in the protection of potential incumbent spectrum users by defining license areas that take incumbent activity into account as well as allows micro operators to focus on high-demand locations. Smaller license areas go hand in hand with the deployment of small cell technology in the higher frequency bands envisages for 5G.

Technology neutrality will continue in micro licensing to allow the license holder to select what technology to deploy. Transmission parameters in this licensing model will defined by the regulator similar to traditional licensing through block edge masks that define the maximum allowable transmit power levels within the spectrum block and outside it. However, in micro licensing they could be defined based on the actual deployment by allowing higher transmission power levels for indoor usage where the building entry losses restrict the interference distances to others. Furthermore, these specifications could even be relaxed based on mutual agreements among the neighboring micro licensees. The awarding of micro licenses needs to treat the applicants in a fair and transparent manner taking into account that getting spectrum access rights is more critical for new entrants than established stakeholders with existing spectrum assets. Sharing rules and conditions need to be known to the micro licensees beforehand to find the balance between license fee and interference conditions. Pricing of the micro licenses should not aim at maximizing profits for the government but promoting competition and innovation by admitting a larger number of stakeholders to gain individual access rights with reasonable price levels. This would leave room for investment to encourage rapid development of new services and deployment of technology for the betterment of the society.

Obligations in micro licensing will differ from country-wide licenses as traditional coverage obligations can only address local areas. However, micro licensing offers the opportunity to define service obligations for indoor coverage which today is a bottleneck as outdoor deployed cellular networks do not provide extensive indoor service coverage everywhere due to high building entry losses. In terms of interference coordination, micro licensing calls for more dynamic approaches that not only protect potential incumbents but efficiently handle interference coordination between a larger number of local micro license holders within local license areas and potentially different levels of protection. Interference coordination will be critical in the micro licensing model to guarantee operational certainty for the license holders. Micro licensing will exploit horizontal spectrum sharing to protect micro licensees from harmful interference within their licensed area from other micro licensees. Thus micro licensing results in a predefined level of interference protection within the license area. In addition depending on the frequency band in question, vertical spectrum sharing can be realized to protect incumbent spectrum users in the band. The exact protection mechanisms need to be defined case-by-case taking into account the incumbents' characteristics.

Table 2. Micro license elements.

License element	Description	Role in micro licensing
Eligible licensee	Company or entity that can apply for and obtain a license.	There can be a wide variety of potential license holders beyond traditional MNOs.
Purpose of use	Type of services to be offered.	Micro licensing is targeting the mobile service with the advanced interference management techniques developed but the idea is already used in other radio services.
License duration	Time duration of a license. Extension of license duration and renewability of a license.	Micro license durations are shorter (~years) than traditional exclusive licenses (~20 years). Extension of license duration and renewability could be made possible.
License area	Geographical area where licensee can operate: -Country-wide or local -Indoor and/or outdoor usage	Local license area needs to be defined which is considerably smaller than in current exclusive country-wide. Role of buildings needs to be considered in defining license areas.
Technology neutrality	License holder can select the actual technology that implements the rules imposed in regulations.	License holder can select the technology that implements the rules imposed in regulations.
Transmission parameters	Block edge masks that define the maximum transmit power levels within the spectrum block and out of the block.	Maximum transmit power levels could be dependent on the deployment: indoor small cell networks could have building-specific maximum transmit power levels.
Awarding of micro licenses	Selection criteria should be objective, transparent, non-discriminatory and proportionate. There can be spectrum caps to balance the amount of spectrum for each.	New awarding mechamisms needed for efficient handling of local licenses to a larger number of stakeholders. Awarding mechanisms should consider existing spectrum allocations and promote competition by considering well-estalished stakeholders' assets.
Pricing	Fees the licensees need to pay for access rights: -Auctions traditionally used to determine prices	Pricing of micro licenses does not aim at maximizing revenues for the regulator but promoting competition and innovation. Lower prices can take place due to local availability of spectrum. Pricing can consider entrants vs. established stakeholders.
Transferability of rights	Entitlement and conditions to transfer the rights of use to others: - Which parts (frequency, area) can be re-sold/sub-leased? - Is approval needed from NRA?	Rules to transfer local rights of use need to be defined: - Can you take your micro license with you when you move? - Re-sell rights of the micro license or parts of it
Obligations	Criteria to be fulfilled by the licensee: - Time frame to deploy the wireless system - Coverage (e.g. how much population must be covered?) - How much network must be deployed alone and how much infrastructure can be shared from others?	Country-wide coverage obligations are inappropriate in micro licensing. There can be coverage obligations within the license area. Rules for micro operator's own deployment and shared deployment are needed.
Interference coordination	License holders are guaranteed protection from harmful interference.	Micro licensees need to protect incumbent spectrum users from harmful interference. Interference coordination between potentially a large number of micro license holders is needed to guarantee predefined level of interference protection for micro licensees.

There are similarities between the micro licensing model described here and in (Matinmikko et al., 2017b) and the US three-tier sharing model developed by the FCC for the 3.5 GHz band to provide CBRS. The US model (FCC, 2016b) introduces a layer of second tier priority access licenses (PALs) that are assigned to stakeholders in census tracts through an auction mechanism for considerably shorter duration than traditional exclusive licenses. The PAL layer is a concrete example of micro licensing. The main difference between the two models is that the three-tier model introduces the GAA layer where part of the band is reserved for license-free operations without fees and quality guarantees. Although introducing a third tier of users will encourage more new entrants to the market, this layer is absent in micro licensing. This is because the third tier is not guaranteed protection from harmful interference from higher layers and the same tier users. Hence, delivering 5G services that require high QoS like VR and AR is quite challenging using the GAA layer. In fact having the GAA layer can discourage to invest in PAL licenses as it is possible to access spectrum without a PAL through by being a GAA users, albeit without quality guarantees. Instead in the micro licensing model we encourage more entrants to become license holders with interference protection so they can reliably deliver high-quality 5G services.

In the European LSA model (ECC, 2014), the protection of incumbents can lead to unavailability of spectrum for the LSA licensees throughout the entire country which results in the need for assigning the LSA licensees in certain locations. To this end there have been no discussion on the awarding of LSA licenses as it is a national matter and not taken place yet. In fact, micro licensing is a suitable model for LSA because the LSA licenses will be geographically restricted due to exclusion zones and protection zones to protect the incumbents. The LSA license conditions need to be defined such that they guarantee that incumbents are protected from harmful interference from the licensees which can be done with micro licenses that are issued locally with rules and conditions that take the incumbents into account.

While a micro license is essentially a contract to operate a local 5G network, it can at the same time be seen as a valuable and tradeable intellectual property. In fact, the evolution of the information and communication technology industry shows very clearly the importance of licensable assets, remembering that also the more recent community-driven developments rest on open licenses. It is important to identify the elements of micro licenses, to build a process for awarding them, and to ensure their proper use. We expect that the management and deployment of micro license based activities will become a key activity in creating and nurturing the 5G business ecosystem.

5.2 Micro licensing procedure

The micro licensing model will consist of a step-wise procedure as the development of any spectrum sharing model that is summarized in (Mustonen et al., 2017). We outline the micro licensing procedure for awarding of and managing the micro licenses with six steps as depicted in Figure 3 together with some guidelines for defining each step. First, suitable bands for micro licensing need to be determined. Micro licensing with local access rights is particularly suitable for the operations above 6 GHz bands because propagation losses limit the network coverage and interference to local areas. Operation in lower bands below 3 GHz is more complicated resulting in larger safety margins in terms of e.g. separation distances between micro licensees due to propagation characteristics. Then, the band needs to be partitioned according to a specific band plan to determine how the available bandwidth in each defined location is going to be split up into lots where a lot is a particular frequency band covering a particular geographical area. Factors to be taken into account when determining the band plan include making the lots suitable for high data rate technologies, harmonization with other band plans, and guaranteeing that each licensee can deploy a functional high-quality network with the band plan.

In the third step the micro license parameters and sharing rules and conditions need to be defined including the technical details of maximum transmission powers, spectrum masks, and criteria and methodologies for the protection of incumbents. The license awarding mechanisms need to be designed to fulfill the regulatory criteria of assigning the micro licenses to the applicants in a fair and transparent way. For example, this can be done through an auction which is suitable when there are more entrants competing over fewer resources. In some areas micro licenses can attract only a limited number of applicants and thus the awarding mechanism should also result in high spectrum use in this setup. After micro licenses are awarded and networks are deployed, monitoring the use of the micro licenses is needed in a way that it covers the issues raised by license providers and license holders and spectrum sharing arrangements. As experience is gained from micro licensing, the model can be further developed.

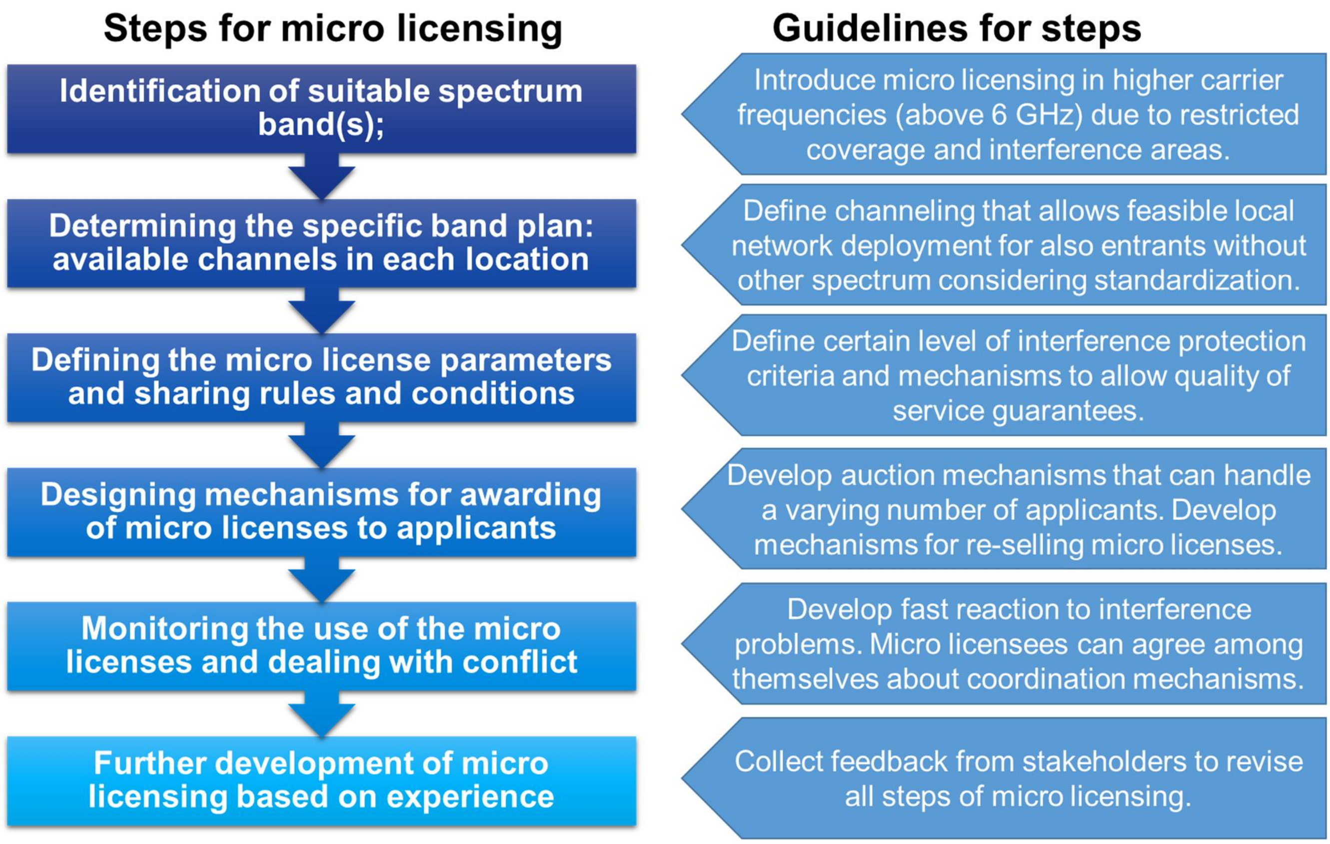

Figure 3. Procedure for micro licensing and guidelines.

6. CONCLUSIONS AND FUTURE OUTLOOK

Development of 5G networks calls for a fresh look on making the regulatory decisions to take these networks into use. In this paper we have reviewed 5G innovations that depict a landscape for the future wireless world that cannot be realized to its full extent with existing regulatory regime and spectrum authorization models. We have identified a number of influential regulatory elements around 5G that contribute to the promotion of competition, innovation and new services in the future mobile market. To dwell deeper into the authorization of networks and service in 5G, this paper has presented the local micro licensing model from regulatory perspective to complement the existing individual authorization and general authorization models by combining their benefits. Micro licensing would allow different stakeholders to use 5G spectrum locally on a shared basis. It allows the establishment of a large number of local small cell radio access network deployments by different stakeholders such as facility owners to meet the versatile needs of vertical sectors in specific places with quality guarantees. The model opens the mobile connectivity market by allowing new stakeholders to become micro operators and enter the market that currently do not have spectrum licenses, which can positively contribute to competition, innovation and new services.

The limitations of this research include focusing on the development of the new local micro licensing model from regulation perspective while leaving out the technical details about its implementation. Our study has mainly focused on the European regulatory situation noting that similar principles are present elsewhere but there are differences in the different regulatory elements and details of regulations and specifically authorization mechanisms. Prior research on the development of new spectrum authorization models for 5G for local licensing is scarce, which results in very little empirical data available other than in the US three-tier model. This has placed constraints on our research. Moreover, the 5G technology is not yet fully defined, which impacts the proposed model. The business ecosystem around 5G is still about to form and thus, there is uncertainty about the feasibility of the proposed model.

There are several open questions in the development of regulatory frameworks, policies and flexible for promoting innovation and competition in 5G and particularly small cell network deployments context that contribute to social welfare with dynamic and minimum control regulations for 5G. Our attempt to define a micro licensing model to complement the existing spectrum authorization models used for mobile communications to consider the specifics of 5G networks operating in the higher frequency bands serves as the starting point for these discussions. This model can help to increase competition in the mobile market by promoting new market entry but its efficiency depends on the suitability of spectrum bands for micro licensing. While admitting a larger number of license holders to access the spectrum, the spectrum efficiency of micro licensing could be lower compared to exclusive country-wide licensing with a single MNO deployment due the requirement for interference coordination between micro licensees. However, the operations in higher frequencies makes interference coordination easier. Characterization of interference between micro licensee networks taking into account the propagation specifics of the different 5G bands and their impact on the network performance requires further studies in order to define the micro license conditions.

Another open question for the future is the management and further development of micro licensing model to define the exact the detailed micro licensing elements including license areas, durations, obligations, and protection criteria for co-channel and adjacent channel usage between micro licensees and possible incumbents. Techniques for interference coordination need to be studied by taking ideas from both individual and general authorization regimes to allow dynamic adaptation to changing interference conditions and different levels of interference protection. Moreover, fair and transparent mechanisms and technologies implementing these mechanisms are needed for awarding the micro licenses to potentially large number of different applicants in different geographical areas. If an enterprise with multiple separately located facilities would like to operate 5G small cell networks in all of its premises, it would be desirable to obtain micro licenses in all the desired locations. One potential approach to implementing micro licensing for improved transparency and efficient handling of transactions is to use block chain technology. Block chain introduces transparency in the spectrum transactions that could become numerous with a large number of local licenses with shorter time durations that will need an efficient market place. Moreover, the valuation of spectrum in the case of micro licensing is an open topic for future noting that gaining access to a new has different value depending on the stakeholders' current spectrum holdings. Micro licensing as any other spectrum sharing model would benefit from trialing activities using practical systems before its actual launch to showcase the feasibility of operations of micro licensee deployments. Finally to conclude, we recommend that when making the regulatory decisions for the adoption of 5G networks, the regulators would consider new innovative approaches in order to ensure the bold visions for 5G as the true enabler for realizing the full economic and social benefits of the digital transformation.

REFERENCES

5GPPP (2016). 5G empowering vertical industries: Roadmap paper. The 5G Infrastructure Public Private Partnership (5GPPP). Brussels.

Agiwal, M., Roy, A. & Saxena, N. (2016). Next generation 5G wireless networks: A comprehensive survey. *IEEE Communications Surveys & Tutorials*, 18, 1617-1655.

Ahokangas, P., Matinmikko, M., Yrjölä, S., Okkonen, H. & Casey, T. (2013). ”Simple Rules” for mobile network operators' strategic choices in future cognitive spectrum sharing networks. *IEEE Wireless Communications Magazine,* 20, 20-26.

Ahokangas, P., Moqaddamerad, S., Matinmikko, M., Abouzeid, A., Atkova, I., Gomes, J., Iivari, M. (2016). *Future Micro Operators Business Models in 5G.* Paper presented at 6th International Conference on the Restructuring of the Global Economy (ROGE), University of Oxford, 20-21st June 2016, UK.

Ahokangas, P., Matinmikko, M. Yrjölä, S. & Atkova, I. (2017). *Disruptive revenue models for future micro operator driven mobile business ecosystem*. Paper presented at 24th Nordic Academy of Management Conference (NFF), 23-25 August 2017, Bodo, Norway.

Al-Debei, M. M., Al-Lozi, E., Fitzgerald, G. (2013). Engineering innovative mobile data services: Developing a model for value network analysis and design. *Business Process Management Journal, 19*, 336-363.

Bauer, J. M. (2015). Governing the mobile broadband ecosystem*. International Telecommunications Policy Review, 22*, 1-26.

Bhattarai, S., Park, J. M. J., Gao, B., Bian, K., & Lehr, W. (2016). An Overview of Dynamic Spectrum Sharing: Ongoing Initiatives, Challenges, and a Roadmap for Future Research. *IEEE Transactions on Cognitive Communications and Networking, 2,* 110-128.

Briglauer, W., Cambini, C., Fetzer, T., & Hüschelrath, K. (2017) The European Electronic Communications Code: A critical appraisal with a focus on incentivizing investment in next generation broadband networks. *Telecommunications Policy*, (in press). http://dx.doi.org/10.1016/j.telpol.2017.07.011.

Cambini, C., & Jiang, Y. (2009). Broadband investment and regulation: A literature review. *Telecommunications Policy, 33*, 559-574.

Cave, M., & Pratt, N. (2016). Taking account of service externalities when spectrum is allocated and assigned. *Telecommunications Policy, 40*, 971-981.

Cramton, P. (2013). Spectrum auction design. *Review of Industrial Organization*, *42*, 161-190.

Cricelli, L., Grimaldi, M., & Ghiron, N. L. 2011. The competition among mobile network operators in the telecommunication supply chain. *International Journal of Production Economics*, 131, 22–29.

Condoluci, M., Araniti, G., Mahmoodi, T. & Dohler, M. (2016). Enabling the IoT machine age with 5G: Machine-type multicast services for innovative real-time applications. *IEEE Access*, 4, 5555-5569.

D'Annunzio,A & Reverberi P. (2016) Co-investment in ultra-fast broadband access networks: Is there a role for content providers? *Telecommunications Policy, 40*, 353–367.

Demil, B. & Lecocq, X. (2006). Neither market nor hierarchy nor network: The emergence of Bazaar governance. *Organization Studies, 10,* 1447–1466.

EC. (2002). Authorisation of electronic communications networks and services. Directive 2002/20/EC of the European Parliament and of the Council.

EC. (2016a). Communication from the Commission to the Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Connectivity for a Competitive Digital Single Market - Towards a European Gigabit Society. European Commission, COM (2016) 587 final.

EC. (2016b) 5G for Europe: An Action Plan. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. COM(2016) 588 Final, Brussels, 14th September 2016.

EC. (2016c). Proposal for a Directive of the European Parliament and of the Council establishing the European Electronic Communications Code (Recast). COM/2016/0590 final - 2016/0288 (COD), Brussels

ECC. (2014). Licensed Shared Access (LSA). ECC Report 205. Electronic Communications Committee Committee (ECC) of European Conference of Postal and Telecommunications Administrations (CEPT).

ECC. (2016). CEPT Roadmap for 5G. Electronic Communications Committee of European Conference of Postal and Telecommunications Administrations. ECC(16)110 Annex 17.

ETSI. (2013). Mobile Broadband services in the 2300-2400 MHz frequency band under Licensed Shared Access regime. ETSI RRS TR 103.113.

ETSI. (2017). Reconfigurable Radio Systems (RRS); Information elements and protocols for the interface between LSA Controller (LC) and LSA Repository (LR) for operation of Licensed Shared Access (LSA) in the 2 300 MHz - 2 400 MHz band. ETSI RS 103 379.

ETSI. (2017b). Reconfigurable Radio Systems (RRS); Feasibility study on temporary spectrum access for local high-quality wireless networks. Draft Technical report.

FCC. (2016a). Report and Order and Further Notice of Proposed Rulemaking. Federal Communications Commission, FCC 16-89.

FCC. (2016b). Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band, Order of Reconsiderations and Second Report and Order. Federal Communications Commission, FCC-16-55.

Faems, D., Janssens, M., Madhok, A., & van Looy, B. (2008). Toward an integrative perspective on alliance governance: Connecting contract design, trust dynamics, and contract application. *Academy of Management Journal, 51,* 1053-1078.

Feasey, R. (2015). Confusion, denial and anger: The response of the telecommunications industry to the challenge of the Internet. *Telecommunications Policy*, *39*, 444-449.

Frias, Z., Gonzales-Valderrama, C. & Martinez J. P. (2017). Assessment of spectrum value: The case of a second digital dividend in Europe. *Telecommunications Policy, 41*, 518-532*.*

Forte, A., Larco, V. & Bruckman, A. (2009). Decentralization in Wikipedia governance. *Journal of Management Information Systems, 26*, 49-72.

GSMA. (2015). Competition policy in the digital age: A practical handbook. GSMA Association.

GSMA. (2016). A new regulatory framework for the digital ecosystem. GSM Association.

Grove, N. & Baumann, O. (2012). Complexity in the telecommunications industry: When integrating infrastructure and services backfires. *Telecommunications Policy*, *36*, 40-50.

Gupta, A. K., Andrews, J. G. , & Heath, R. W. (2016). On the feasibility of sharing spectrum licenses in mmWave cellular systems. *IEEE Transactions on Communications, 64*, 3981-3995.

Hoetker, G. & Mellewigt, T. (2009). Choice and performance of governance mechanisms: Matching alliance governance to asset type. *Strategic Management Journal, 30,* 1025-1044.

Iivari, M. M., Ahokangas, P., Komi, M., Tihinen, M. & Valtanen, K. (2016). Toward ecosystemic business models in the context of industrial Internet. *Journal of Business Models*, *4,* 42–59.

ITU-R (2015). IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond" ITU-R Report M.2083. International Telecommunications Union.

Johnston, E. 2010. Governance infrastructures in 2020. *Public Administration Review,* 122-S128.

Khan, A., Kellerer, W., Kozu, K. & Yabusaki, M. 2011. Network sharing in the next mobile network: TCO reduction, management flexibility, and operational independence. *IEEE Communications Magazine*, 49: 134–142.

Kim, Y., Lee, H.-Y., Hwang, P., Patro, R. K., Lee, J, Roh, W. & Cheun, K. (2016). Feasibility of mobile cellular communications at millimeter wave frequency. *IEEE Journal of Selected Topics in Signal Processing, 10,* 589-599.

Kliks, A., Holland, O., Basaure, A. & Matinmikko, M. (2015). Spectrum and license flexibility for 5G networks. *IEEE Communications Magazine, 53,* 42-49.

Koopman, C., Mitchell, M. & Thierer, A. (2015). The sharing economy and consumer protection regulation: The case for policy change. *The Journal of Business, Entrepreneurship & the Law,* 8.

Li, F. & Whalley, J. (2002). Deconstruction of the telecommunications industry: From value chains to value networks. *Telecommunications Policy, 26,* 451–472.

Lundborg, M., Reichl, W., & Ruhle, E. O. (2012). Spectrum allocation and its relevance for competition. *Telecommunications Policy, 36*, 664-675.

Marsch, P., Da Silva, I., Bulakci, Ö., Tesanovic, M., El Ayoubi, S. E., Rosowski, T., Kaloxylos A. & Boldi, M. (2016) 5G radio access network architecture: Design guidelines and key considerations. *IEEE Communications Magazine*, *54,* 24-32.

Matinmikko, M., Latva-aho, M., Ahokangas, P., Yrjölä, S. & Koivumäki, T. (2017a). Micro operators to boost local service delivery in 5G. *Wireless Personal Communications, 95*, 69-82.

Matinmikko, M., Roivainen, A., Latva-aho, M., & Hiltunen, K. (2017b). *Interference study of micro licensing for 5G micro operator small cell deployments*. Paper accepted for presentation at Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom), 20-21 September 2017, Lisboa, Portugal.

Mochon, A. & Saez, Y. (2016). A review of radio spectrum combinatorial clock auctions. *Telecommunications Policy, 41,* 303-324.

Mustonen, M., Matinmikko, M., Holland, O. & Roberson, D. (2017) Process model for recent spectrum sharing concepts in policy making. *Telecommunications Policy, 41,* 391-404.

Nam, W., Bai, D., Lee, J. & Kang, I. (2014). Advanced interference management for 5G cellular networks. *IEEE Communications Magazine*, *52,* 52-60.

Peitz, M., & Valletti, T. (2015). Reassessing competition concerns in electronic communications markets. *Telecommunications Policy*, *39*, 896-912.

Richart, M., Baliosian, J., Serrat, J. & Gorricho, J. L. (2016). Resource slicing in virtual wireless networks: A survey. *IEEE Transactions on Network and Service Management*, *13,* 462-476.

RSPG (2016). Strategic roadmap towards 5G for Europe. Radio Spectrum Policy Group. European Commission. RSPG16-032 FINAL.

Rost, P., Banchs, A., Berberana, I., Breitbach, M., Doll, M., Droste, H., ... & Sayadi, B. (2016). Mobile network architecture evolution toward 5G. *IEEE Communications Magazine*, *54*, 84-91.

Samdanis, K., Costa-Perez, X. & Sciancalepore, V. (2016). From network sharing to multi-tenancy: The 5G network slice broker. *IEEE Communications Magazine*, *54,* 32-39.

Trainer, D. (2016). *AT&T Time Warner Acquisition A Rare Deal That Makes Economic Sense*. Forbes 2016: Nov. 15. http://www.forbes.com/sites/greatspeculations/2016/11/15/att-time-warner-acquisition-a-rare-deal-that-makes-economic-sense/#1160cd395b69

Tehrani, R. H., Vahid, S., Triantafyllopoulou, D., Lee, H. & Moessner, K. (2016). Licensed spectrum sharing schemes for mobile operators: A survey and outlook. *IEEE Communications Surveys & Tutorials*, *18,* 2591-2623.

Weber, A., & Scuka, D. (2016). Operators at crossroads: Market protection or innovation? *Telecommunications Policy*, *40*, 368-377.

Zander, J. (2017). Beyond the ultra-dense barrier: Paradigm shifts on the road beyond 1000x wireless capacity. *IEEE Wireless Communications, 24*, 96-102.