Scalability and Replicability of Spectrum for Private 5G Network Business: Insights into Radio Authorization Policies

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Abstract. New spectrum bands are being released to respond to the growing need for locally deployed industrial and private networks. This calls for new licensing schemes and spectrum sharing approaches. New challenges are faced from the ever-increasing variety of released spectrum bands with different technical and operational requirements and the increasing fragmentation of spectrum management approaches. While the standardization is progressing and technical solutions are developed for the new networks, less attention has been paid to the radio product related regulation, including equipment authorization frameworks. With roots in engineering, policy and economics, this paper looks through the lenses of business model framework at scenarios of wireless equipment authorization related to novel spectrum management approaches. This paper provides an overview of radio authorization for mobile communication networks and develops a conceptual framework to depict and analyze authorization policies. The results indicate the strong impact the authorization frameworks have on the scalability and replicability of the business. This calls for novel models of governance and regulation that highlight utilization of harmonized, widely employed frequency bands and the associated technical requirements.

Keywords: Business model · Cognitive radio · Private networks · Radio authorization regulation · Spectrum policy · Spectrum sharing · 5G

1 Introduction

The deployment of 5th generation (5G) mobile networks aims at significant increase of the efficiency and productivity of industries, logistics, agriculture and other vertical sectors. Key technical elements will be the wide employment of Internet of Things (IoT), possibility for very low network latencies and highly increased transmission capacity [1]. Depending on the use cases and their requirements there may be a need to allow the enterprises and industries to deploy private networks without relying on communication service providers networks [2]. The industrial use cases can be significantly different

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from those supported by public mobile networks, especially related to requirements on guaranteed network performance, trustworthiness, security and privacy [3]. If an enterprise intends to deploy a private network as a local operator [4], it needs an authorized timely access to affordable quality spectrum [5, 6].

To date only a limited number of countries have released dedicated spectrum for private networks. Required spectrum availability, sharing and authorization models for local 5G networks were discussed in [7], locally and temporarily shared spectrum in [8] and micro licensing and the associated regulatory framework in [9]. Reference [10] reviewed several frameworks based on local deployments utilizing geographical sharing and cognitive radio techniques like the US three-tiered Citizens Broadband Radio Service (CBRS) and the license exempt 5 GHz shared Radio Local Area Network (RLAN) bands. Furthermore, it introduced a method for assessing spectrum management approaches applicable to private industrial networks and assessed the suitability of the recent frameworks below 5 GHz to use cases of private industrial networks.

In addition to valid use cases and access to affordable spectrum, the timely availability of radio equipment is essential. Applicable radio equipment needs to be authorized in order be placed on the market and be used. Information on radio equipment authorization is mainly discussed and available as standards and as regulatory documents, e.g., [11]. Engineering overview of type approval is discussed, e.g., in [12–14] and national authorization frameworks are presented by commercial entities in [15–17]. To the best of the authors' knowledge there is no preceding research assessing the radio authorization approaches in the context of locally deployed private networks and novel spectrum regulation frameworks.

This cross-disciplinary paper looks at business aspects related to novel spectrum management approaches, particularly scenarios of wireless equipment authorization through the lenses of business model framework [18] focusing on scalability [19], replicability [20], and sustainability [21]. Scalability can be categorized based on the five mutually exclusive causal factors: technology, cost and revenue, legal regime adaptability, network effects and user orientation [22]. Replicability, on the other hand focuses on how firms replicate their successful business models across geographical markets [20, 23]. The research discussing localization of the mobile communication services has recently emerged in the business model literature. Matinmikko et al. [4] and Ahokangas et al. [24] defined the local operator concept, stakeholders, and related business models. Regulatory requirements were explored in [25], and the challenge in spectrum management revealing a new level of complexity that stems from the variety of spectrum bands and spectrum access models with different levels of spectrum sharing and cognitive radio techniques in [26]. Business opportunities for local private network operators found in [4] were hosting for mobile network operators (MNOs), secure and private local service provisioning for industrial enterprises, offering differentiating service level agreements, and expanding service to data and application governance [4].

This study widens and enhances the earlier research via focusing on radio product availability and examines radio equipment authorization approaches as antecedents to private industrial 5G networks deployment. In order to assess the scalability and replicability of the radio authorization approaches, the radio product test and certification processes and regulation in the 27 European Union (EU) countries and in 67

other countries have been studied. The countries were chosen based on their relevance for private mobile network business, cognitive radio spectrum management approaches and availability of detailed regulatory data. Special attention was paid to the US and the EU/European Telecommunications Standards Institute (ETSI) radio authorization frameworks applicable in multiple countries globally. This study is based on the direct communication with selected national regulatory authorities, and data collected from governmental web pages.

The rest of the paper is organized as follows. In Sect. 2, the theoretical foundation and key concepts are presented. The radio authorization frameworks are presented and discussed in Sect. 3, and conclusions are drawn in Sect. 4.

2 Theoretical Foundation and Key Concepts

This section discusses the key concepts and frameworks utilized in the study: concept of business model, radio spectrum requirements for private 5G networks and the radio equipment authorization processes as depicted in Fig. 1.

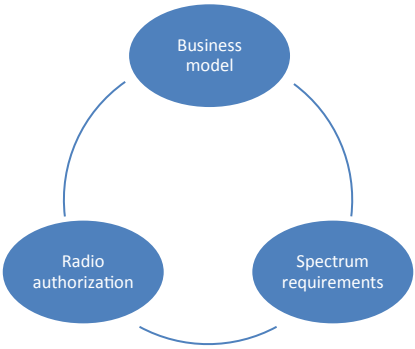

Fig. 1. Key concepts and frameworks.

2.1 Business Model Framework

The contemporary business model research has evolved towards value creation, value sharing and value capture discussion [27] from traditional activity view [28]. Furthermore, recent studies stemming from ecosystem perspective [18] do not presume a focal firm and sees business model to "*create value through the exploitation of business opportunities*". In addition to value and opportunity, the exploration and exploitation of competitive advantages form strategic business choices of company [27, 29–33]. In studies analyzing the antecedents of the prosperous business, three strategic implication were found: capabilities to *scale* [19], *replicate* [20], and *sustain* [21]. This paper focused on analyzing radio product regulation and its relation to scalability and replicability as growth related factors of business models. Scalability can be defined as the

ability of a network to be extended in a capable flexible manner [34] where the augmentation of resources results in increasing returns [35]. Organizational flexibility [36] allows agility to cope with changes in the industrial environment such as competitive and regulative landscape or macro-economic pressures [36]. Scalability can be categorized based on the five mutually exclusive causal factors: technology, cost and revenue, legal regime adaptability, network effects and user orientation [22]. Replicability, on the other hand focuses on how firms replicate their successful business models across geographical markets [20, 23] in order to maximize value [37]. The replication strategy stems from company's dynamic capabilities to choose, refine, transfer and maintain the necessary elements of their business model components to allow successful replication in applicable geographies [23].

2.2 Private 5G Network Spectrum Requirements

For the fourth generation (4G) public mobile networks, radio frequencies were generally allocated and assigned utilizing competitive awarding, i.e. via auctions, and the same approach is most widely used with the 5G spectrum release [38, 39]. However, several countries have already introduced regulatory frameworks aimed at deployment of individually authorized, locally deployed private 4G or 5G networks [40]. In most cases dedicated spectrum has been released under local licensing, allowing for local network deployments through basic geographical sharing, assuming that in each location there is only one network. However, there are also regulatory frameworks utilizing specific technical and operational cognitive radio requirements to facilitate sharing with incumbents and other users, for example in the US for the CBRS band [41], in the UHF broadcasting band for TV White Space (TVWS) [42] use and for the European Licensed Shared Access (LSA) concept [43]. As the demand for spectrum for local deployments increases, spectrum management frameworks with operational requirements related to more dynamic spectrum access and cognitive technical capabilities are to be defined and employed.

Many industrial use cases have very specific technical and operational requirements which call for specific network implementations that are best realized though deployment of a private network [44]. The spectrum related preferences of private network deployments were studied in [10] and [45]. The preferences aim at gaining from economies of scale for lowering the equipment cost and at minimizing the spectrum and regulatory costs. In case of public mobile networks, the large market size and the utilization of harmonized 3GPP spectrum bands allows for economies of scale for equipment, while for private networks the case is very different due to fragmented bands, specific technical and operational requirements, as well as due to limited in-country market size. Furthermore, the fragmentation is reflected in fragmentation of the radio equipment authorization requirements. Therefore, approaches increasing the geographical availability (replicability) and applicability (scalability) of the authorization frameworks have become important antecedents of successful business. The proposed replicability and scalability assessment framework comprised of the following elements and preferences, adapted from [45], as shown in Tables 1 and 2.

Table 1. Replicability related preferences.

Replicability (Geographical availability)	
Characteristic	Preference
Band availability	Widely available for ecosystem and economies of scale
Radio authorization	Widely utilized framework employed (FCC, EU/ETSI)

Table 2. Scalability related preferences.

Scalability (Applicability)	
Characteristic	Preference
Bandwidth	Sufficient for wideband applications
Network deployment	Both indoor and outdoor
Max transmit power	Sufficient for indoor and/or outdoor deployments
Interference protection	Yes
Co-existence mechanisms	No complex technical or restrictive operational requirements
Regulatory certainty	Predictable framework and schedule, fast time-to-air
Spectrum cost/pricing	Fee, administrative one-off or annual fee, per license/area
Standards maturity	Standardizations process mature in IEEE and/or 3GPP
Radio availability	Yes

Especially the interference protection and co-existence mechanism related technical and operational requirements are closely related to possible spectrum sharing, employed cognitive elements and dynamic spectrum use. Currently, radio equipment for the US CBRS band, the LSA band, TVWS band or any other band where cognitive capabilities or band specific requirements are required must conform to specific technical requirements in the compliance testing.

2.3 Radio Equipment Authorization

In this section radio authorization processes used in the analysis are discussed in more details. Only locally authorized radio products are allowed to be placed on the market and be used [11, 46]. The radio equipment authorization is achieved by verified conformance to local requirements and regulations resulting in a certification issued by the local regulator or by a body authorized by the regulator. The radio authorization requirements and the approval and certification procedures vary by region or country. This must be taken into account as there may be a need to go through extensive and very specific type approval testing process in the target country to obtain certification before the equipment can be placed on the market and taken into use. Moreover, the equipment authorization process can be very complex and time consuming, especially in case novel spectrum management frameworks are utilized.

Product authorization may be achieved through Type Approval (TA) or by Supplier's Declaration of Conformity (SDoC). Most countries require a TA of radio products to demonstrate the conformance. TAs may comprise of laboratory testing against the national technical requirements/standards and certification including product labeling and may require in-country laboratory tests or be partly or completely based on submitted documents. It is also possible that a document-based application process must be complemented by submission of product samples and verification of their performance. In the EU and certain individual countries, SDoC allows placing the products on the market.

Mutual Recognition Agreements (MRAs) are agreements established between countries for the purpose of mutual recognition of conformity assessment of regulated products. The benefits of the MRAs arise from removal of duplicated inspection or certification. Where a product intended for two markets may still have to be assessed twice (when technical requirements or standards are different), the assessment cost will be lower when carried out by one body. Furthermore, the time to market and business is reduced since contacts between the manufacturer and the single conformity assessment body, and a single assessment, speed up the process. Even where the underlying regulations are harmonized, for example because they refer to the same international standard, the need for recognition of certificates remains, and in such cases the benefit will be clear: the product is assessed only once against the commonly accepted standard instead of twice. Wireless product authorizations require typically demonstrating compliance also with requirements in other areas than radio/wireless, such as compliance with Electromagnetic Compatibility (EMC), energy efficiency, safety, and environmental requirements. Based on the global radio authorization method data, the following framework was developed to characterize radio product authorization, as summarized in Table 3.

Table 3. Radio product authorization characterization.

Product authorization characteristic	
Scheme	Employed approval scheme (Type Approval, Supplier's Declaration of Conformity…) and description of required process, including possible requirement for laboratory tests and required documentation
Local presence	Requirement for local applicant/representative
Process costs	Costs and payment instructions
Process timing	Prior information on duration of the authorization process
Technical requirements	Applicable standards
Test facilities	Requirement for in-country testing or usage of accredited in-country or international test laboratories
Foreign test applicability	Mutual recognition agreements (applicability of foreign test results, especially FCC and EU related tests)
Marking and documentation	Requirements for product labeling and documentation
Authorization duration	Validity period of authorization, renewal conditions

3 Analysis of Radio Authorization Frameworks

This section presents collected data and analyses the main aspects of radio authorization frameworks in the European Union covering Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, in the US and in 66 other countries, covering Andorra, Angola, Argentina, Australia, Bahrain, Bosnia and Herzegovina, Botswana, Brazil, Cambodia, Canada, Chile, China, Colombia, Egypt, Equatorial Guinea, Gabon, Guatemala, Hong Kong, Iceland, India, Indonesia, Israel, Ivory Coast, Japan, Jordan, Kenya, South Korea, Kuwait, Lebanon, Liechtenstein, Macau, Malaysia, Mexico, Moldova, Montenegro, Morocco, Mozambique, Namibia, New Zealand, Nigeria, North Macedonia, Norway, Panama, Peru, Philippines, Puerto Rico, Qatar, Russia, Rwanda, Saudi Arabia, Serbia, Singapore, South Africa, Taiwan, Tanzania, Thailand, Tunisia, Turkey, Uganda, Ukraine, United Arab Emirates, United Kingdom, Venezuela, Vietnam and Zimbabwe.

3.1 European Radio Authorization Framework

In the EU, the Radio Equipment Directive (RED) provides the essential requirements for placing radio equipment on the market [47]. The essential requirements address safety and health, electromagnetic compatibility and the efficient use of the radio spectrum. All radio products in scope of this directive and placed on the EU market must be compliant with the RED. Only compliant radio equipment may be sold and used in the EU. The essential performance requirements and use of radio spectrum are laid down in Articles 3.2 and 3.3 of the RED [47]. The RED allows manufacturers to self-declare that their equipment meets the applicable ETSI harmonized standards, which at the same time indicates compliance with the essential requirements of the RED, and to affix the CE mark, so the equipment can be placed on the market in those countries where the harmonized standards apply. If there are applicable harmonized standards, there is no requirement for TA testing by the regulator or associated accredited bodies. But if there is no applicable harmonized standard then manufacturers can use any technical specification to demonstrate that the radio equipment complies with all necessary requirements, upon their own responsibility. The results must, however, be certified by a Notified Body, if alternative specifications than harmonized standards are applied. The EU has MRAs currently in force with Australia, New Zealand, the United States, Canada, Japan and Switzerland.

In Europe, seven countries, Finland, France, Germany, the Netherlands, Norway, Sweden and the UK, have designated spectrum for private 4G or 5G networks, and several countries are considering doing so. Even if a variety of band is employed, the common radio authorization framework applies. However, there are country specific technical requirements, for example in the UK, for the utilization of the 2390–2400 MHz, 3800–4200 MHz and 24250–26500 MHz bands [48], which limits the replicability of the equipment authorization related to those bands.

3.2 US Radio Equipment Authorization Framework

All electrical equipment marketed in the USA requires authorization. Intentional radiators, including radio transmitters, are required to be tested at an authorized test laboratory and the technical file reviewed by an independent body before a certificate is granted and details listed on the Federal Communications Commission (FCC) website. The FCC has two different approval procedures for equipment authorization: Certification and Supplier's Declaration of Conformity. The required procedure depends on the type of equipment being authorized as specified in the applicable rule part. In some instances, a device may have different functions resulting in the device being subject to more than one type of approval procedure. Telecom products having a radio transmitter, such as mobile phones or RLAN equipment are to be certified. Technical rules are generally specified in applicable parts of [49], and the administrative rules for equipment authorization, including the process are described in [50]. The US has MRAs for conformity assessment of telecommunications equipment in place with Asian Pacific Economic Cooperation (APEC), Inter-American Telecommunications Committee of the Organization of American States (CITEL), the EU, Israel, Japan and Mexico.

The band 3550–3700 MHz has been made available in the US for CBRS [41] and it is expected to become the main band for enterprise networks. The band accommodates currently the prioritized incumbent users (tier 1) protected from the potential interference originated from the lower tiers. The rules provide two paths for local industrial spectrum: tier 2 Priority Access License (PAL) and tier 3 General Authorized Access (GAA). The FCC allows the PAL licensees to lease their spectrum, which is within their PAL area, but beyond their deployment coverage. For example, in an industrial area a PAL holder may lease one or more of their channels to industrial enterprises. The General Authorized Access (GAA) users can access the portions of the CBRS band in 3550–3650 MHz that are unused by the incumbents and the PAL users and the portions of the band in 3650–3700 MHz that are unused by the incumbents. The GAA usage is also suitable for enterprise usage in case the spectrum availability is not critical. There are CBRS band specific requirements for radio equipment. Specific requirements also extend to authorization of other related network elements, as applies for example to the Environmental Sensing Capability (ESC) entities and Spectrum Access System (SAS) in the CBRS band [41]. Employment of specific requirements limits the scalability of the authorization frameworks and creates new challenges to authorization of radio products for private networks.

3.3 Comparison of FCC and EU Radio Product Authorization Processes

Table 4 presents and compares the FCC and EU radio product authorization processes. The major difference is that the FCC process builds on testing at authorized test laboratory and certification granted based on application, while the EU process builds on manufacturer's self-testing and self-declaration of conformity.

3.4 Radio Authorization Frameworks in Selected Countries

In addition to the EU and US radio authorization frameworks addressed in the previous section, approaches in 66 selected countries were analyzed. Radio authorization

Table 4. EU and FCC product authorization process comparison.

Radio product authorization	FCC	EU
Approach	Testing and certification	Self-testing and Supplier's Declaration of Conformity
Preparations	Determine applicable rules, e.g. in CFR Title 47	Determine applicable ETSI Harmonized Standards (ETSI HS)
Testing	Compliance testing at an authorized testing lab	In case ETSI HS covers product: manufacturer's own tests are sufficient. In case ETSI HS does not (fully) cover product: tests required at Notified Body
Approval	Apply for Certification	Prepare Supplier's Declaration of Conformity
Labeling	Attach FCC Certification Number, include compliance info in manual	Label product (CE mark), include compliance info in product documentation
Outcome	Product ready for US market	Product ready for EU market

frameworks in nine countries together with examples of relevant spectrum bands are presented in this section, as an example. Countries were selected based on private network opportunities, novel spectrum management approaches and different authorization frameworks.

Australia

In Australia spectrum has been reserved for private network deployments for example in the 5.8 GHz band and in 24 GHz. The 5.8 GHz band is available under general authorization for private networks. The requirements are partly similar to the FCC requirements, but partly country specific. A portion of the 24 GHz band will be available as licensed band, and another portion under general authorization, without a license, both suitable for local network deployments. The technical requirements for the 24 GHz band would be at least partly country specific.

The radio equipment authorization in Australia is based on Declaration of Conformance. Compliance with Australian ACMA technical standards for telecommunications customer equipment, radiocommunications devices, electromagnetic radiation, and electromagnetic compatibility is required. The process is document based and no in-country test is required. A local representative is required, either the manufacturer, importer or agent. Evidence of transmitter compliance to ACMA technical standards may be demonstrated by providing a complete ETSI or FCC test report. The Australian importer or supplier is required to make the declaration of conformity and hold a product description and compliance records. Compliant products should also be labelled with the Regulatory Compliance Mark (RCM). The validity period of the authorization is unlimited. The

wireless and EMC requirements are similar in Australia and New Zealand, therefore the approval applied in Australia also indicates similar compliance in New Zealand and vice versa [51].

China

Spectrum management in China follows largely the traditional way to make the mobile bands available for major MNOs and countrywide deployment of public mobile networks. The recent development in Chinese Belt and Road Initiative (BRI) is exporting China originated frequency and radio standard variants into several South American and African counties targeting in particular the utility verticals, e.g., on 200 MHz and 450 MHz spectrum bands.

All radio transmitter devices in China require Radio Type Approval (RTA) issued by the State Radio Monitoring Centre of the Ministry of Information (SRRC) [52]. The approval process includes in-country testing at the State Radio Monitoring Centre (SRMC) and a certification application to the SRRC. A local applicant/representative is required. Approved radio equipment must be marked with a certificate number (CMIIT ID) that must appear on products or labels. The validity period of the authorization is 5 years, and one renewal is possible. A Network Access License (NAL) is required for all telecommunications equipment that connects to public network. Safety and EMC testing and The Restriction of Hazardous Substances (RoHS) certification is also required.

Hong Kong

The band 27.95–28.35 GHz has been made available on a geographically shared basis for locally provided, innovative wireless broadband services targeted towards specific groups of users. The deployed networks are based on the 5G or other advanced mobile technologies. This is a country specific spectrum opportunity for deployment of private networks.

Radio equipment shall meet the minimum requirements of the Hong Kong Communications Authority (HKCA) [53]. The requirements are described normally in the form of HKCA specification. Radio equipment which has been evaluated against the relevant HKCA specification and is compliant with the requirements may be authorized. Local certification bodies and foreign certification bodies have been accredited or recognized to provide type-approval of radio equipment. The certification is done under the Hong Kong Telecommunications Equipment Evaluation and Certification (HKTEC) Scheme. Under the scheme, radio equipment is classified under the Voluntary Certification Scheme (VCS) or Compulsory Certification Scheme (CCS). Radio equipment classified under VCS can be used or marketed in HK without type approval. Generally, mobile equipment is under VCS, but for example LTE base stations are under CCS.

India

Spectrum allocation in India follows largely the traditional approach where mobile bands are made available for MNOs. However, the 5.8 GHz band allows for deployment of private networks, and the technical requirements are largely similar to the FCC requirements. The same 5.8 GHz band is available in more than ten countries globally.

All wireless equipment shall be type approved [54]. The Wireless Planning and Coordination Wing, Ministry of Communications and IT, Department of Telecommunications (WPC) issues approval of radio devices operating in licensed and unlicensed frequency

bands. For radio equipment operating in licensed frequency bands the importers, dealers and users of the equipment must obtain licenses from WPC. An application with essential documents and test reports must be sent to the relevant agencies by the manufacturer. India-based representative is required. Generally, the approval is document based, i.e., based on application and review of foreign standard test reports and approval certificates. FCC or EU/ETSI test documentation may be utilized. Online filing is possible for all types of license applications, followed by hard copy submission of the application. Certain products must be tested in-country. Approved equipment must be labeled with TEC label. The validity of the authorization is unlimited.

Japan

Japan has made the band 28.2–28.3 GHz available for locally deployed 5G networks. The eligibility is connected to the land ownership or right of use. The existing MNO's are not granted access to the band. Both indoor and outdoor use are allowed. The aim is to make adjacent band, i.e. 28.3–29.1 GHz available in late 2020, when the sharing studies on the conditions allowing sharing with incumbents are completed.

Testing radio equipment to be used in Japan to conform to Japan's radio standards may be conducted by properly recognized laboratories. and they must be certified by one of several private MIC Recognized Certification Bodies (RCB) [55]. The EU – Japan MRA enables appointed certification bodies in the EU to grant approval for certain radio equipment enabling fast access to the Japanese market. The details of the approval process depend on the category in which the product falls under. No in-country testing is required and no local applicant is required. Approved equipment must be labeled with MIC certificate. The validity of the authorization is unlimited.

South Africa

South Africa follows largely the traditional operator model, where most of the mobile bands are assigned to public mobile use. The 5.8 GHz band is available for Fixed Wireless Access (FWA) use and satellite spectrum in 2.4 GHz is being made available for private terrestrial use, similarly to several African countries. Similarity between the South African and European spectrum allocations and radio equipment authorization documentation will be a benefit if the regulator ICASA designates spectrum for private use.

All radio equipment is subject to type approval by ICASA [56]. In many cases the ICASA will issue approval based on review of foreign standard test reports that demonstrate compliance with South African technical standards. The RED directive applies, and EU/ETSI test documentation may be utilized as ICASA accepts reports on product tests conducted based on the relevant EN standards, if the testing has been performed at an accredited test lab. The applicable technical standards are found in the technical regulations as defined in the TA regulations. Applications can be submitted by manufacturers, importers, distributors, and any South African registered company. The TA certificate will only be issued to South African registered companies. The approval usually takes 30 days, from submission of all necessary documents. Equipment must be labeled with ICASA type approval label. The validity of the approval is unlimited.

Canada
The Wireless Broadband Service is allowed to use the frequencies 3650–3700 MHz in Canada. The deployed technologies include WiMax and LTE, adapted to comply with the band specific requirements. Both fixed and mobile network deployments are allowed. In practice, the band is largely used for local industrial networks.

The regulator ISED requires certification for telecommunications terminal equipment and radio devices [57]. The product must comply with Canadian regulations and ISED standards. Applications for certification are submitted to recognized certification body or ISED. A Canadian representative is required for certifications or registrations. Testing to demonstrate compliance with Canada's technical standards can be conducted at many recognized laboratories: globally there are 37 Test laboratories and 40 certification bodies recognized by ISED. Approved equipment must be labeled with product ID info and ISED registration number. The validity of the approval is unlimited.

Mexico
Mexico does not have licensed bands for enterprise use. However, the 5.8 GHz band is available under a general authorization. The allocation is similar to the US, but the technical requirements are partly country specific. Leasing spectrum from MNOs could be another option.

All radio products must be certified by the regulator IFT [58]. Compliance with the official Mexican standards and technical provisions is required. In-country testing in accredited laboratories is required, as well as a local representative. Submission of two samples of certain parts is required, as well as employed test software, product specifications and installation and operation manuals. The FCC approval only helps as provider of additional info. Testing and certification of each product and model is required separately. All approved products should be labeled with IFT label. Validity of provisional certification is one year, renewal is unlimited.

Argentina
The 450 MHz band has been made available for regional use out of the major cities to cover 373 areas in 15 provinces. This could be an opportunity for private networks in rural areas.

The regulator ENACOM requires that all radio products comply with the national requirements [59]. There are two approval processes Homologación and Codificación. The former is related to approval related to Argentine standards and the latter related to approval in case no local standard exists. Equipment testing must be performed in-country at an accredited test laboratory. Foreign test reports are not accepted, but they may be helpful as provider of additional info. An Argentinian representative (applicant) is required. The importer or distributor must be registered with ENACOM in order to obtain certification. The approved products must be labeled with a CNC ID. The validity period of the approval is 3 years.

3.5 Discussion

This section summarizes the findings of radio authorization frameworks addressed in this study and assesses their impact on scalability and replicability of the business.

Summary of Radio Authorization Frameworks Globally

In all countries only locally authorized radio products are allowed to be placed on the market and be used. The application process is typically country specific, and involves submission of forms and other national documents, often in the local language, interaction with different authorities, usually at least with the local regulator, and payments. Most countries require TA of radio products to demonstrate the conformance to national requirements. TAs may comprise of laboratory testing against the national technical requirements/standards and certification including product labeling. In-country laboratory tests may be required. The approval may be partly or completely based on submitted documents. The study shows that TA/certification is required in 40 countries. In the EU and certain individual countries, such as Australia, New Zealand, Hong Kong, and Lebanon, Supplier's Declaration of Conformity allows placing the products on the market. Applicable standards are usually specific national standards or specifications, which may refer to international standards. A local applicant is required at least in 30 non-EU countries, in-country laboratory tests are required in 14 non-EU countries. Product labeling is required in 38 countries and the EU27. The validity period of certification/approval is unlimited in the EU and 36 other countries, while in 27 countries the validity periods very between 1 and 5 years.

Replicability and Scalability of Radio Authorization Frameworks

In many cases the national standards refer to a few key technical and operational requirements, which usually have similarities to ITU-R requirements. For example, for ITU Region 1 countries both the spectrum allocations [60] and the spectrum related requirements are very similar, thus the technical requirements may be similar to European requirements and the results of product tests based on ETSI standards are valid in many countries also outside of Europe, especially in Africa and in the Middle East, all belonging to ITU-R Region 1. The same applies to the ITU Region 2, especially in the Latin-American countries the national spectrum use, and the related requirements have similarities with the US spectrum use and FCC requirements. Therefore, the national technical requirements in many countries globally have similarities to or are identical with ETSI or FCC frameworks and requirements. On the other hand, in most countries the ETSI or FCC product authorizations are not sufficient as such for local product authorization. However, in the authorization process it is possible to utilize EU/ETSI documentation in 38 countries outside of EU and the FCC documentation in 8 countries. A pre-requisite for this is some degree of commonality between the local technical requirements and applicable standards and ETSI/FCC requirements. Figure 2 shows the global replicability of FCC and EU authorization test results in the countries addressed in this study.

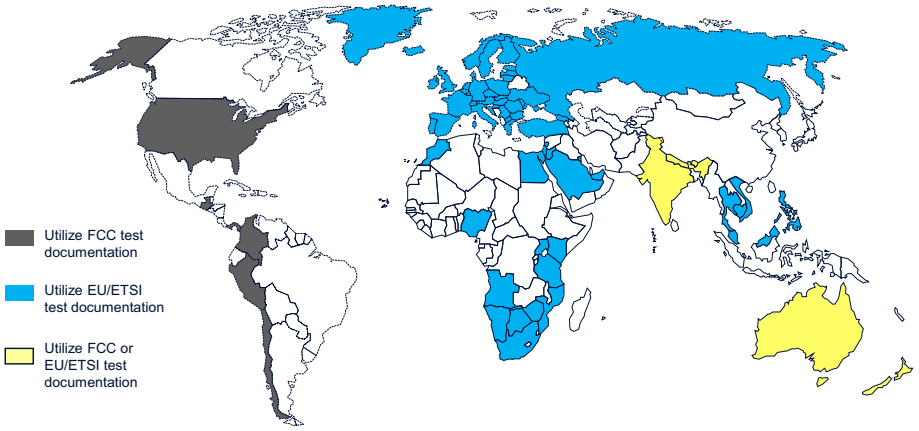

Fig. 2. Global replicability of FCC and EU/ETSI radio product authorization test results.

4 Conclusions

To date, only a few countries have introduced novel spectrum management frameworks to allow local private LTE or 5G networks to access individually authorized exclusive spectrum. Furthermore, the spectrum bands, allowed radio standards and the technical and operational requirements vary country by country. In addition to timely access to affordable spectrum, the key element for implementation of any private mobile network is availability of radio equipment that meet the use case requirements and business needs. The mandatory local authorization of radio products is achieved by verified conformance to local requirements and regulations, certified by the local regulator or by a body designated by the regulator or through supplier's self-declaration. Moreover, as the use cases and the markets of private networks are fragmented, and limited in size, the diversity of the product authorization frameworks is an issue, and the replicability and scalability of existing frameworks become important.

Extant research on radio authorization in the private network context is still scarce, and this paper represents the first attempt to depict the impacts on business. Utilization of harmonized, widely employed frequency bands and the associated technical requirements widen the replicability of the radio authorization frameworks. This can be enhanced by mutual recognition agreements between the countries. By employing similar technical and operational requirements to those of the FCC or EU, the scalability and replicability of the radio authorization frameworks can be further increased, leading to economies of scale.

Variety of spectrum bands and fragmentation will keep increasing in 6G, which calls for novel approaches in spectrum management and product authorization. With rapid technology developments and business driven needs the timely network deployment is essential and calls for more dynamic and forward-looking radio product authorization strategies. Since the 5G evolution towards 6G may be expected to be decisive for the competitiveness and sustainability of our economies, this paper sees the key future research challenge to be as follows: what kind of novel regulation, standardization, and

governance models might emerge and be competitive in future 6G environments enabling successful scalable, replicable and sustainable business models both for nationwide mobile network operators as well as multiple local operators serving the long tail of enterprise, vertical and community customer needs.

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