24st European Regional ITS Conference, Florence, 20-23 October 2013

Title:
The Validity of Unlicensed Spectrum for Future Local High-capacity Services

Du Ho Kang
Wireless@KTH
KTH Royal Institute of Technology
Electrum 229
S-164 40 Kista
Sweden
dhkang@kth.se

Ki Won Sung
Wireless@KTH
KTH Royal Institute of Technology
Electrum 229
S-164 40 Kista
Sweden
sungkw@kth.se

Jens Zander
Wireless@KTH
KTH Royal Institute of Technology
Electrum 229
S-164 40 Kista
Sweden
jenz@kth.se

Abstract

Unlicensed spectrum indeed initiates high-data rate wireless services with the combination of the great success of Wi-Fi technology. Interestingly, the local high data rate services are mainly deployed and invested by non-traditional local actors, e.g., mostly facility owners who build local fixed line infrastructure. Motivated by the great success of the Wi-Fi eco-system, there are growing interests from various regulatory initiatives on short-range indoor shared spectrum access to continuously foster new business innovations and local investment by new players. Despite of flexible spectrum access and almost no regulatory management overhead, it is still not so clear that the traditional unlicensed approach can work for future high-capacity services where extremely dense nodes are deployed. In this paper, we aim to discuss the validity of the traditional unlicensed approach for the new local operators for future indoor high-capacity services. We compare traditional Wi-Fi in unlicensed band and a hypothetical local cellular-like network with regulatory coordination in terms of total deployment cost. We found that the traditional node-level etiquettes in unlicensed band work as system design constraints, leading to too conservative full distributed systems such as Wi-Fi. Thus, regulatory technical conditions need to designed to allow intra-network coordination such as cellular-like technologies with certain inter-network regulation. .

1. Introduction and Motivation

Mobile broadband (MBB) service markets are rapidly growing, leading to exponential increase of mobile data traffic [1]. One of main enablers to achieve such high data rate MBB services in a reasonable cost was the use of Wi-Fi infrastructure at 2.4 and 5 GHz utilizing unlicensed band [2]. Unlike a wide-area network in exclusive licensed band, it is characterized as spectrum access by anyone in anywhere anytime. Thanks to the flexible spectrum accessibility, significant local infrastructure investments have been made by non-traditional types of local network operators (LNOs), e.g., facility owners or 3rd party network-only providers, with various purposes [3,4]. As shown in Figure 1, their interests are particularly focused on service provisioning in limited areas with far higher data rates than outdoor services by traditional mobile network operators (MNOs), e.g., public indoor areas or professional working environments. For instance, the facility owners have wireless access for better customer relations and private companies may support their employees by establishing high-capacity wireless connections.

By being stimulated by the Wi-Fi eco-system, we see now that there are growing interests of having more shared spectrum for indoor short-range services in a regulatory side to keep continuing the business innovation and encourage the local high-speed network deployment by such non-traditional players. For instance, USA recently encouraged FCC to release new unlicensed band at 470-698 MHz as a secondary basis [5]. Swedish regulatory PTS also recently announced a part of 1800MHz under the condition of an indoor purpose. This regime can be the most flexible authorization with respect to accessibility and lowest regulatory management overhead. However, it is also true that there is still a serious concern about unknown interference by deploying more and more access points (APs) and hand-held devices in an uncontrolled manner, which typically enforces node-level coexistence requirements. In addition, this does not have any specific bureaucratic control on when to or not to access spectrum as long as technical conditions are met. Thus, it may be very difficult to reallocate afterward if there will be problems in future, i.e., the risk of junk spectrum. In contrast, traditional exclusive licensing with the a contract on license allocation/termination is very limited with respect to spectrum accessibility at the gain of almost no need for interference protection as compared in Table 1.

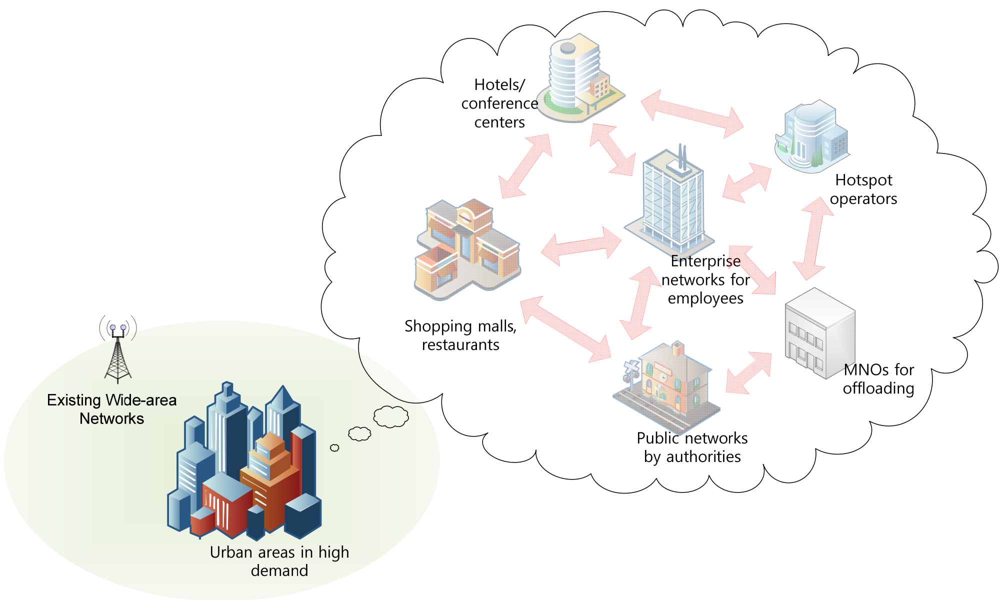

Figure 1. In-building wireless infrastructures by facility owners and 3rd party local network providers

Table 1. Pros and cons in traditional binary licensing

	Spectrum Access Flexibility	**Coexistence Design**
Unlicensed	(+) Open to everyone (MNO, new market players, end-users)	(-) Robust interference protection from unknown transmitters
Exclusive licensing	(-) Limited to single MNO	(+) No co-channel interference

In the presence of tradeoff between spectrum accessibility and interference controllability, several countries currently investigate non-traditional 3rd way of licensing, e.g., light-licensing, in order to resolve interference issues while ensuring flexible spectrum sharing for social benefits [6,7,8]. Nevertheless, their actual implementations are different and a country by a country, leading to no consensus on the concept of novel shared spectrum access methods. For instance, a registration scheme was proposed in the U.S for use of the 3650 – 3700MHz band for fixed wireless access. Thus, spectrum access rights is basically not limited to a specific group of operators and dynamically allocated or terminated. Licensees are mutually obliged to cooperate and avoid harmful interference to one another. In contrast, the UK regulator Ofcom awarded twelve low power concurrent rights of use of the frequencies 1781.7-1785MHz paired with 1876.7-1880MHz through auction. The number of operators is fixed. Licensees are expected to co-ordinate their use of the spectrum to avoid harmful interference.

Research Questions

From a research perspective, it is highly valuable to analyze potential consequences of using unlicensed spectrum both in technical and business perspectives and identify key regulatory considerations to design future spectrum policies for the LNOs. The purpose of this paper is to suggest key regulatory decision making to foster future local investment by non-traditional local operators with the minimal concern of interference. In this paper, the following questions are asked:

1. *Can traditional unlicensed authorization regime still work for future indoor high-capacity services by non-traditional local operators?*
2. *What will be key regulatory considerations in future indoor short-range spectrum sharing?*

2. Related Work and Study Approach

Shared spectrum has been one of hot research topics in both telecom policy and technical studies. Several spectrum sharing schemes are investigated with different terminologies and motivations, potential target scenarios [14]. A co-primary shared access model is typically considered when primary license holders agree on a joint use of their licensed spectrum in order to reduce license fee or overcome the failure of license acquisition. The technical coexistence conditions is mostly based mutual agreements between sharing partners while regulatory technical conditions are not so much involved. Sharing with non-communicating incumbents, namely License Shared Access (LSA), is also under discussion. Differently from the co-primary access, the existing incumbents have access priority than LSA licensee. More liberalized licensing without exclusive access rights, so called light-licensing regime. It involves much simpler simplified procedure of issuing spectrum license than previous two approaches. It is typically used when severe and immediate interference concerns are not so highly expected by the means of coordination or sparse deployment. Although their shared access models are proposed in different context, explicit and clear boundaries are not well understood and agreed yet.

Besides of the regulatory framework, authors in [2] quantitatively assessed the economic benefit of unlicensed band in today's life. In a technical perspective, the different forms of coexistence mechanism are studied in vast studies. [10] investigated dynamic license allocation by the means of technologies advances, a so-called spectrum broker. In [4], the author investigated thoroughly new business opportunities in local deployment and growing interests of having private networks by non-traditional actors. Regarding regulatory initiatives on future spectrum sharing for MBB services, there are recent several public reports available about future shared spectrum policies. The document from [8] well summarized different practices in European countries about light licensing. The others focused more on secondary spectrum sharing at existing non-telecom incumbents [9]. A recent report from European commission discussed more general spectrum usage for future IMT systems [7]. In technical studies, authors in [11] theoretically studied interference issues between random access networks.

Different spectrum sharing schemes and technical solutions are required depending on the potential usage and operator scenarios which makes extremely challenging to bring up one solution to fit all scenarios. In this study, we particularly focus on future indoor local operators and discuss the validity of traditional unlicensed spectrum for the indoor short range spectrum sharing. Regulatory decision making is intrinsically a complex task since it involves not only technical aspects but also business and social aspects. Our study approach is followed. We first define a LNO and identify their key requirements both in technical and non-technical aspect in Section 3. Then, Section 4 proposes the model of regulatory decision domains and their linkages with wireless system design for a more systematic analysis. Afterward, a Wi-Fi example is taken and technical problems related to the unlicensed authorization are discussed in Section 5. Regulatory implications on future shared spectrum policy making are drawn in Section 6. Then, we conclude Section 7.

3. Who Are Local Operators and What Are Their Fundamental Requirements?

We in this section define a LNO and their requirements on spectrum policies and system design. A LNO is defined as a network provider which deploys a wireless network at particular small geographical area. According to this definition, LNOs do not necessarily exclude traditional MNOs who have typical exclusive license for voice coverage at a country level. If they are interested in local business, e.g., enterprise services or offloading in hot-zones, they still can be considered as local operators. Nevertheless, if they make an roaming agreement with 3rd party network providers, they may not be considered as local operators since they do not control and deploy a network to require local spectrum access. Especially in indoor cases, we can easily find many practical examples of network sharing among multiple service providers in tradition cellular networks [12]. In this case, there will be a 3rd party network-only provider involved which provides wireless access to end-users of multiple outdoor operators and need spectrum access.

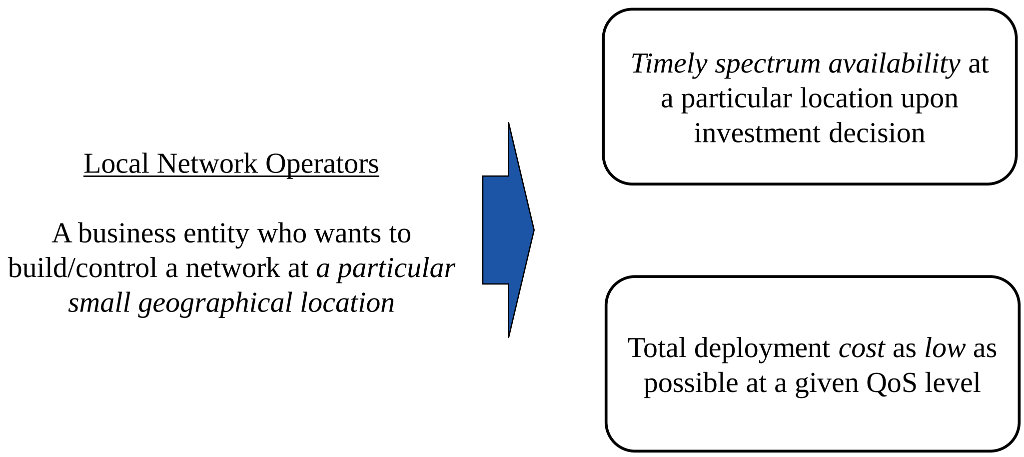

Figure 2. Definition of local network operators (LNOs) and high-level requirements

For those LNOs, two fundamental high-level requirements are identified for local capacity provisioning shown in Figure 2. First, it is essential that spectrum should be accessible as soon as they decide to install networks. Unlike wide-area services which typically accompany the quick roll-out of network deployment with huge investment to ensure nation-level coverage in short time, the investment decision of local operators will be very case specific since it is highly dependent on individual local needs and service purposes. Secondly, future local wireless systems should be cheap enough to provide high-capacity services to be invested under a budget constraint. Although spectrum policies allow timely spectrum access rights to LNOs, the future local network systems should be economically feasible to fulfill high-capacity services.

Along with the spectrum and system requirement, interference protection at network boundaries is highly important as shown in Figure 3. In traditional unlicensed band, too severe interference experienced at a particular node likely to happen even in co-located areas due to fully unexpected user positions and completely random deployment. However, we assume that there is only one LNO in a given local area of interest. This assumption can be justified by a fact that most of indoor sites are controlled by facility owners unlike traditional outdoor deployment where site may not be fully controlled by single entity, e.g., public outdoors. Although the co-located deployment may be avoided at the deployment decision moment by site control, interference leakage to neighbors is still problematic for QoS services. The main challenging task of regulations will be how to deal with such interference protection at network boundaries.

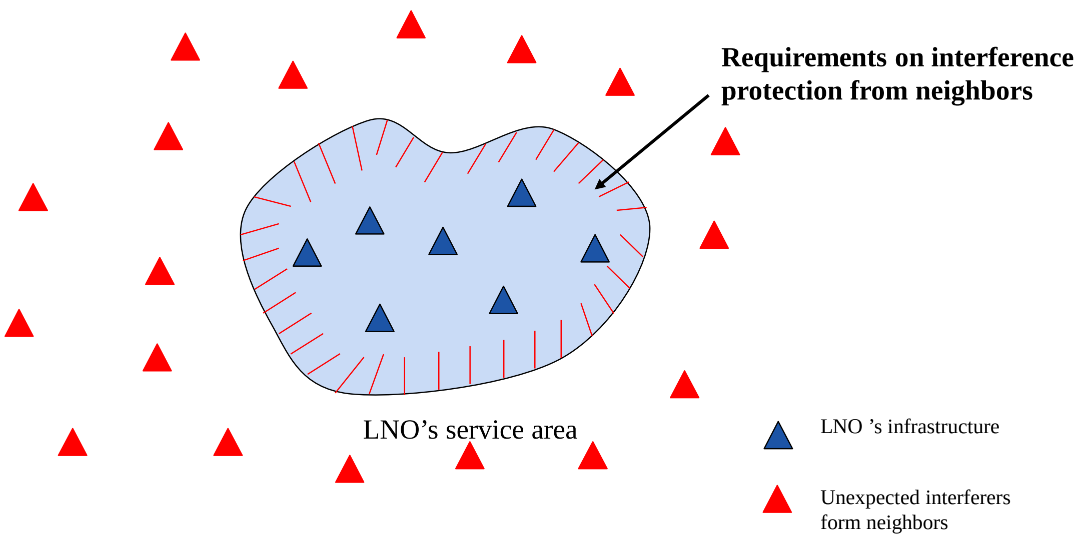

Figure 3. Coexistence requirements for interference protections at network boundaries.

4. Model of Key Regulatory Decision Making

The analysis of regulatory decision making itself is a complex task and its impact to business and system design is also not trivial. Especially, this becomes more non-trivial when shared spectrum is considered due to additional complexity on operator coexistence. In this section, we discuss such complicated procedure of regulatory decision making in more details. We particularly identify three key decision domains which are interconnected with spectrum flexibility and technologies: 1) authorization, 2) regulatory coexistence rules, 3) operator-specific commercial system design.

The authorization is about who will have access rights and how they are authorized, e.g., license allocation/termination/period. We strictly differentiate spectrum authorization from technical decision domains. The decision in authorization ultimately affects spectrum accessibility and flexibility by controlling the number of operators in the same frequency and its predictability. For instance, in a traditional unlicensed case, any organizations as well as individual end-users or devices can have implicit permit to access the spectrum without explicit access request procedures. This leads to no limitations on the number and types of operators. The FCC approach taken at 3.5 GHz has a mean to control the access rights by mandatory pre-registration with small usage fee. This method at least prevents access from anonymous end-user devices and may end up hundreds of operators in unexpected places although the history of spectrum access can be recorded. In UK, more conservative shared licensing was adopted at 1800 MHz by giving only twelve operators access rights. Thus, the number of operators can be limited and expected/known before network deployment. The license allocation to a limited number of operators also ensure a national regulator to have a control mean in future to reallocate the spectrum for a different purpose based on the future change of spectrum needs. Nevertheless, it may limit the investment opportunities of new players who fail to acquire licenses and market competitions among network providers at the advantage of reducing the uncertainty in the number of operators.

Authorization as a Precondition for Technology Design

In a technical aspect, the authorization works as a precondition for designing coexistence rule design. For example, co-channel coexistence is not an issue in the traditional exclusive licensing. However, when multiple operators are allowed to access, technical solutions are essential to prevent the worst case interference situations where no communications are feasible. Various technical means to enable coexistence among (known or not) operators have been studied and some of them were commercially implemented [5]. It could be traditional simple etiquette based approaches or server-based centralized coordination, e.g., database or spectrum brokers. In any cases,

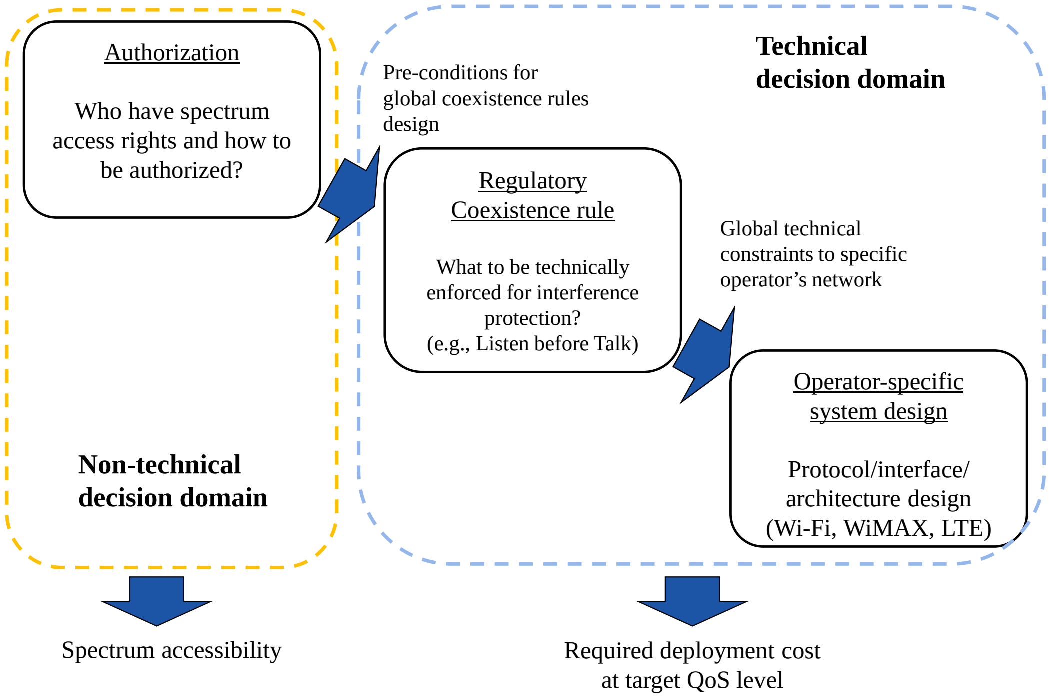

Figure 4. Model of Regulatory Decision Making

coexistence rules will be applied to *all* operators in the shared spectrum. Then, a commercial wireless system which can (but not necessarily) be specific to one operator's requirement can be standardized/implemented subject to technical constraints from the common coexistence rules. Although standardization can be done general enough to apply all types of operators, individual deployment and network configuration which at the end decide the overall network capacity will be operator-specific. Such technical solutions both from regulatory decisions and system design solutions will finally decide network performance and are converted into required deployment cost.

5. Deployment Cost of a Wi-Fi System for Future High-capacity Services

In this section, we exemplify the required deployment cost of Wi-Fi system in unlicensed band for future high capacity services based on a simplified system-level simulation. This can guide us to discuss the potential barriers in unlicensed band.

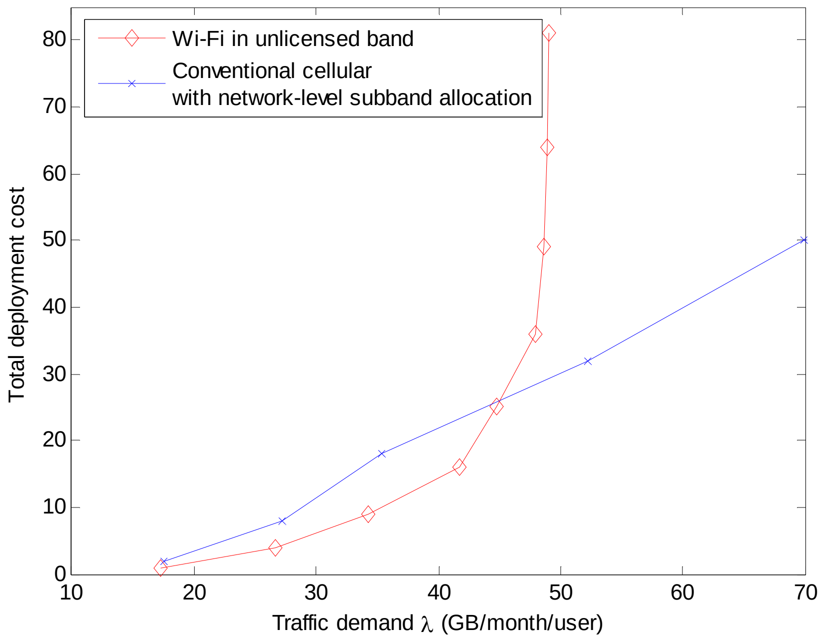

Figure 5. Total deployment cost comparison between Wi-Fi in unlicensed band and a conventional cellular system. The cellular system is assigned the half of spectrum by 3rd party spectrum broker to avoid inter-building interference while Wi-Fi system fully access whole spectrum based on CSMA/CA.

Wi-Fi Deficiency – Technology or Regulatory Bottleneck?

In traditional unlicensed band such as 2.4 GHz and 5GHz, anyone can access spectrum as long as transmitters follow predetermined technical conditions, e.g., EIRP limit, since no pre-procedure on authorization is required. Thus, coexistence rules are only a regulatory mean to control shared spectrum access. There are several coexistence rules currently in use [5]. Transmit Power Control (TPC), Dynamic Frequency Selection (DFS) and Listen Before Talk (LBT) can be some of examples. It is noticeable that such rules apply for any individual transmitters no matter who owns and deploys in order to ensure communications in unlicensed band. Therefore, such regulatory requirements naturally ends up a fully distributed system design which does not explicitly have control plane architecture, working in a self-organizing manner. Such fully distributed coordination protocols was also adopted in commercially successful Wi-Fi systems. In Wi-Fi technology, individual AP makes a transmission decision based on a detected energy level, so-called CSMA/CA [13]. If a shared channel is considered busy, an AP takes a conservative decision, i.e., waiting although actual transmission can transmit data successfully. Without any architectural support, common carrier sensing threshold is given by W-Fi standard in order to coexist with other transmitters including even mobile end-users. Although the probability of interferences from end-users or ad-hoc like sensors are sometimes very low in certain environments, globally fixed rules and relevant threshold, e.g., carrier sensing threshold or maximum backoff window size, were used in IEEE 802.11 standard as a mandatory requirement. Similar design approach was widely adopted in many other communication standards in unlicensed band, e.g., IEEE 802.15.1/4.

We evaluate supportable traffic demand with increasing Wi-Fi access point deployment density in a typical office environment in order to see the impact of such conservative design to deployment cost. As shown in Figure 5, as capacity requirement grows, required deployment density rapidly grows after a certain demand level. The coexistence requirements with anonymous mobile users make Wi-Fi densification redundant to let them wait until others do not use channels although the others are the part of one operator's network. Although specific numerical results are dependent on actual simulation parameters, e.g. the considered network geometry of office areas, such trend will be maintained. Technically, the Wi-Fi deficiency may be easily resolved by centrally coordinating all APs at the same time in the unlicensed spectrum as traditional cellular systems. However, this may not be allowed if regulators enforce listen before talk as a basic coexistence requirement in the unlicensed spectrum.

The key issue is how the regulations should be made to allow such cellular technologies to overcome Wi-Fi deficiency. One of naïve approach could be divide whole spectrum into several subband and coordinate subband allocation between networks to avoid excessive interference at network boundaries (shown in the blue curve at Figure 5). Then, each local cellular network operates at the allocated subband. However, the shortcoming is this may access less amount of whole spectrum at a given time unlike traditional Wi-Fi. The gain is of course that individual operator can fully control multiple APs in their own network since fixed node-level etiquettes were avoided by central spectrum coordination. The key difference from traditional single operator exclusive licensing is that the subband is repeatedly reused by other operators which is not the closet interferers. This centralized operator coordination and subband allocation are also observed in recent data based approach in TVWS to coordinate aggregate interference at a primary receiver. Therefore, adopting cellular technologies in local areas can reach future high capacity far beyond Wi-Fi system although Wi-Fi can be cheaper at a relatively low capacity requirement due to full spectrum access.

6. Discussions on Future Local Spectrum Sharing Policies

In this section, we discuss future spectrum sharing policies for indoor short range services by local operators. Both technical coexistence design and authorization perspectives are considered.

Global Node-level Restrictions vs. Network-level Access Coordination

Unlike technical (frequency band, max power, channel access rules…) or operational (e.g. geographical area or time restrictions for the operation of radio stations) requirements, the authorization is of administrative nature and necessitates - as a prerequisite for use - that the user contacts the Spectrum Management Authority to meet its obligation. Without administrative control in unlicensed band, spectrum access is regulated solely by adherence to pre-defined technical conditions, leading the conservative system design against uncertain interference from mobile users at the given locations. As identified in the Wi-Fi example, the unlicensed authorization based on a node-level etiquette possibly leads to unnecessarily conservative wireless system in order to ensure communications even at the worst case where nodes are deployed or stayed in a completely random manner. In order to overcome the fundamental inefficiency of the node-level full distributed approach, the coordination among APs at a given network will be essential. For this, node-level constraints given by a regulator need to be relaxed to allow more network-wide control by operators. However, in order to resolve the interference at network boundaries, regulator-driven centralized inter-network coordination may be inevitable.

Limited Several vs. Potentially Many Operators?

The number of access rights may seriously affect the scene of business and local investment, e.g., competition in B2B markets or speed of infrastructure investments. In society perspective, fast and wide local investment is desirable and can be better fostered by giving spectrum access opportunities to more operators. In this regard, there are two different approaches in authorization. One is simple and flexible license allocation without predetermined restrictions in the operator group. This theoretically allows unlimited number of operators. The other one is more limited by allowing pre-fixed several operators. A key difference between two approaches is the uncertainty in the number of operators. In a technical perspective, a fixed licensing approach and flexible registration-based approach could result in the similar level of interference uncertainty at a given local operator since the amount and uncertainty of interference is dominated by technical parameters, e.g., network deployment and site density, than the number of operators. More flexible license allocation is desirable for fast local investment by a number of non-traditional operators, compared with more rigid shared license, e.g., auction-based contract, since the uncertainty in the number of operators is not so dominant as site density and geometry of deployment of one operator in n an interference protection perspective. Such approach will potentially lead to many operators which may need government-driven network-level coordination instead of purely relying on individual operator's agreement with neighbors.

7. Conclusions

We discussed the future indoor short-range spectrum sharing polices for non-traditional local operators compared with a traditional unlicensed approach in the presence of tradeoff between spectrum access flexibility and interference uncertainty. We developed a model to investigate complex regulatory decision domains and their relations with both business and technologies. We evaluated the deployment cost of Wi-Fi systems for future high-capacity services and identified the potential problems of the unlicensed approach. We answered the following two research questions:

RQ1: Can traditional unlicensed authorization regime still work for future indoor high-capacity services by non-traditional local operators?

> Maybe 'No' for very high-capacity services. From the local operator perspective, the unlicensed band may lead to too much conservative coexistence rules e.g., the fixed node-level etiquettes, in order to prevent the worst case situations. From a local wireless system design perspective, this requires a fully distributed system such as Wi-Fi systems without any inter-node communication supports. It may significantly sacrifice overall network performance and eventually increase the order of magnitude more deployment cost than a traditional single operator cellular system in exclusive band.

RQ2: What will be key regulatory considerations in future indoor short-range spectrum sharing?

> A traditional transmitter access control approach, e.g., node-level etiquettes, needs to be avoided for ensuring network-level controllability by individual operators. Nevertheless, network boundary interference protections should be in place. In this regard, regulatory focus should be moved from traditional node-level etiquettes to network boundary interference controls. In addition, this may be backed up by explicit license control by registration or notification to at least

remove the interference uncertainty at the given place from mobile devices/end-users as a necessary condition.

Although we showed one possible solution which at least can yield lower cost than unlicensed Wi-Fi, recent technological advances may help to increase efficiency in shared spectrum. Studies on the efficiency and feasibility of new coordination technologies, e.g., dynamic spectrum pooling, for enabling local operator coexistence will be a next step.

Acknowledgements

Part of this work has been performed in the framework of the FP7 project ICT-317669 METIS, which is partly funded by the European Union. The authors would like to acknowledge the contributions of their colleagues in METIS, although the views expressed are those of the authors and do not necessarily represent the project.

References

[1] “Cisco visual networking index: Global mobile data traffic forecast update, 2010-2015,” White Paper, Cisco, 2010.

[2] Richard Thanki , “The Economic Significance of Licence-Exempt Spectrum to the Future of the Internet,” White Paper, 2012

[3] Cisco, “Cisco Service Provider Wi-Fi: A Platform for Business Innovation and Revenue Generation,” White paper, 2012, available at http://www.cisco.com/en/US/solutions/collateral/ns341/ns524/ns673/solution_overview_c22-642482.html

[4] J. Markendahl, M. Nilson, “Business models for deployment and operation of femtocell networks; Are new cooperation strategies needed for mobile operators?,” 21 European Regional ITS conference, Copenhagen, 13-15 Sep. 2010

[5] K. Berg, M. A. Uusitalo, and C. Wijting, “Spectrum access models and auction mechanisms,” in Proc. IEEE International Symposium on Dynamic Spectrum Access Networks (DySpan), Bellevue, Washington, USA, Oct. 2012.

[6] S. Forge, R. Horvitz and C. Blackman, “Perspectives on the value of shared spectrum access-Final report for the European Commission,” Feb. 2012.

[7] J. S. Marcus , J. Burns, F. Pujol, and P. Marks, “Inventory and review of spectrum use: Assessment of the EU potential for improving spectrum efficiency,” WIK-Consult Final report, Sep. 2012.

[8] Electronic Communications Committee (ECC), “Light Licensing, License-exempt and Commons, the European Conference of Postal and Telecommunications Administrations (CEPT), Moscow, Jun. 2009

[9] J. Khun-Jush, P. Bender, B. Deschamps, M. Gundlach, “Licensed shared access as complementary approach to meet spectrum demands: Benefits for next generation cellular systems,” ETSI Workshop on reconfigurable radio systems, Dec. 2012, Cannes France

[10] B. Jabbari, R. Pickholtz, and M. Norton, “Dynamic Spectrum Access and Management,” IEEE Wireless Communications Magazine, 2010

[11] R. Etkin, A. Parekh, and D. Tse, “Spectrum Sharing for Unlicensed Bands,” IEEE Journal on Selected Areas in Communications, 2007

[12] C. Beckman, and G. Smith, “ Shared networks: making wireless communication affordable,” IEEE Wireless Communications, 2005

[13] IEEE 802.11-2012, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications*, IEEE std., 2012.

[14] “Intermediate description of the spectrum needs and usage principles,” public deliverable D5.1, Document Number: ICT-317669-METIS/D5.1, Aug. 2013, [Online available] https://www.metis2020.com/documents/deliverables/