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

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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 deployed and invested by non-traditional local actors, e.g., facility owners who have 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 require extremely denser deployment than today. In this paper, we aim to discuss the validity of the traditional unlicensed approach for the new local operators in an economic aspect. We evaluate the required deployment cost of conventional Wi-Fi system and compare it with a hypothetical cellular-like system with marginal regulatory coordination. We found that the traditional node-level etiquettes in unlicensed band work as system design constraints, leading to too conservative full distributed systems. Although the current unlicensed band approach is the lowest cost solution for relatively low-capacity services, it may not be work at future high-capacity provisioning. Thus, regulations need to be designed to allow more coordinated systems 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 far higher data rates than outdoor services in particular areas, e.g., public indoor areas or professional working environments. For instance, the facility owners may want high-capacity 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 in 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, traditional regulations in unlicensed band do not have any specific bureaucratic control on who (or not) to access spectrum as long as technical coexistence 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 based on license allocation/termination contract is very limited with respect to spectrum accessibility at the gain of almost no need for interference protection as compared in Table 1.

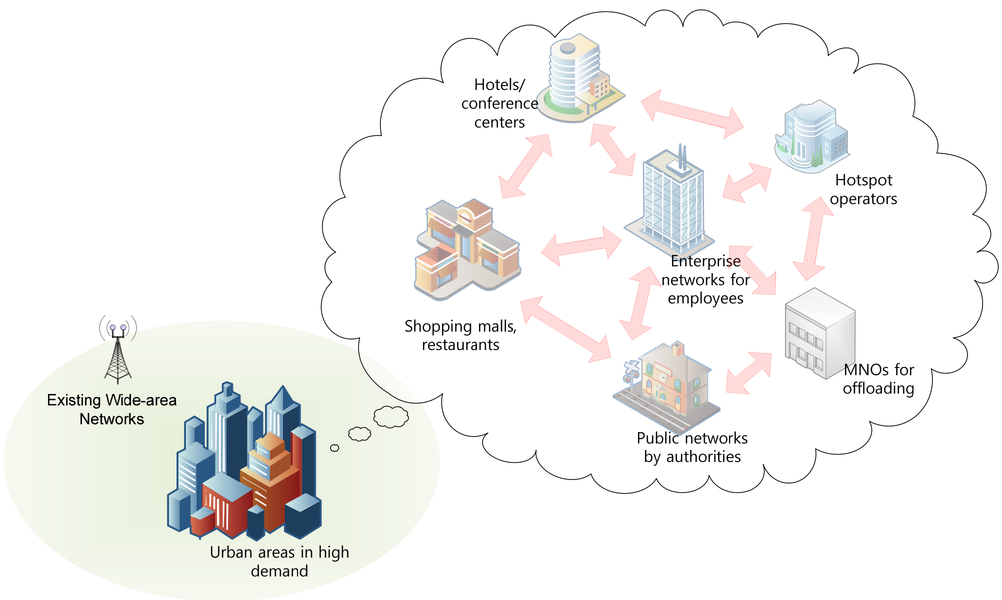

Figure 1. In-building wireless infrastructures by non-traditional facility owners and 3rd party local network providers

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, license shared access (LSA), in order to resolve interference issues while ensuring flexible spectrum sharing for social benefits [6,7,8]. Even if most of them are still in a conceptual level and evolves, there are several examples which are already implemented. Nevertheless, their actual implementations are different and a country by a country. 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 growing interference in traditional unlicensed spectrum and identify key regulatory considerations to design spectrum policies for the LNOs. The purpose of this paper is to suggest some key regulatory decision making to foster future local investment by LNOs with reasonable cost. In this paper, the following questions are asked:

1. *Can traditional unlicensed approach 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, motivations, and 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 and the technical coexistence condition among secondary operators are still under discussion. 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. Compared with previous two approaches, the spectrum access is in principle not limited similar to unlicensed band. However, license allocation history is maintained for regulatory management purpose. It is typically used when severe or immediate interference concerns are not so highly expected. Although their shared access models are proposed in different context, explicit and clear boundaries are not well understood and agreed yet.

Besides of different regulatory frameworks, 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 may be 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 characterize and define a LNO and identify their high-level 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 geographical area. According to this definition, LNOs do not necessarily exclude traditional mobile network operators (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 a roaming agreement with 3rd party network providers, they may not be considered as local operators since they do not directly 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 traditional 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. They can be also considered as local operators.

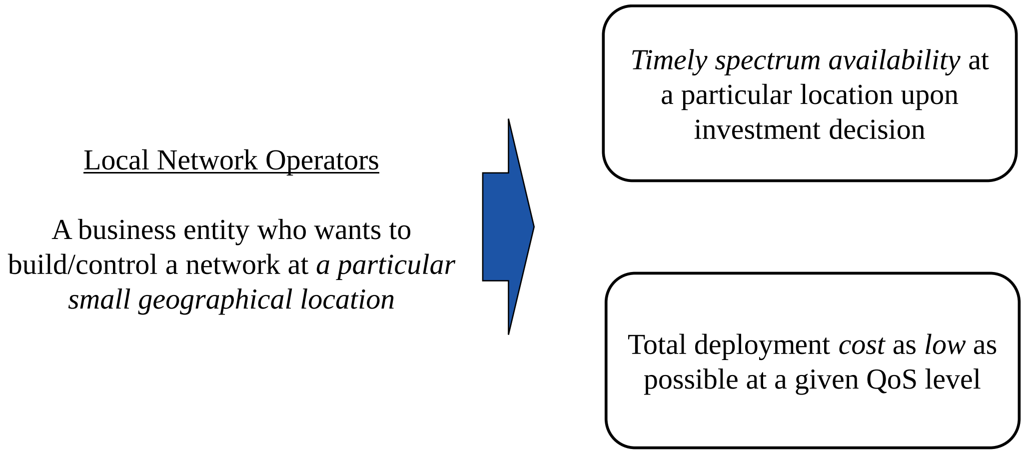

Figure 2. Definition of local network operators (LNOs) and high-level requirements

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 by flexible licensing, the future local network systems should be economically feasible at a given high-capacity service.

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 areas. Although the co-located deployment may be avoided at the deployment decision moment by the 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.

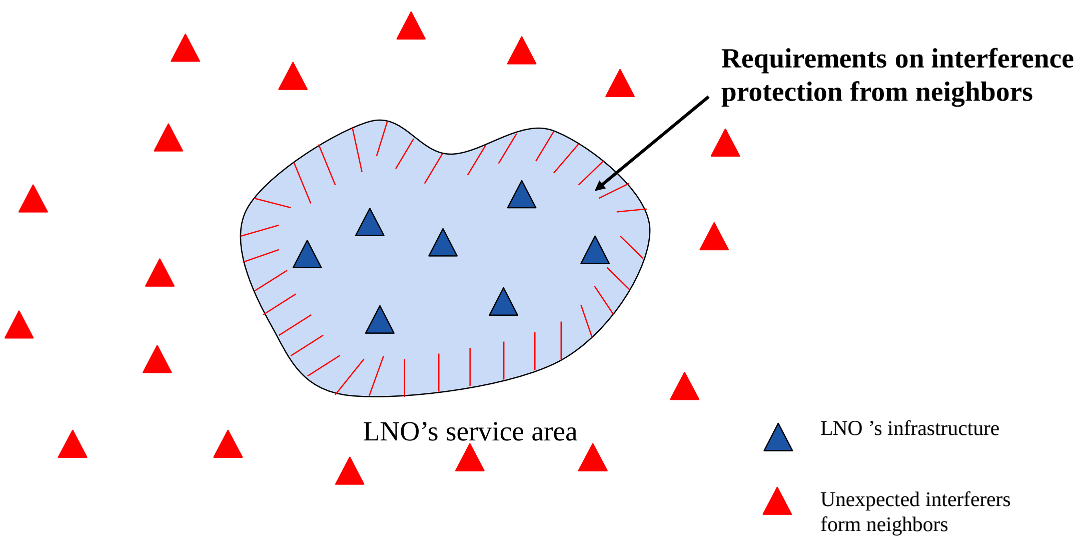

Figure 3. Coexistence requirements for interference protection at network boundaries.

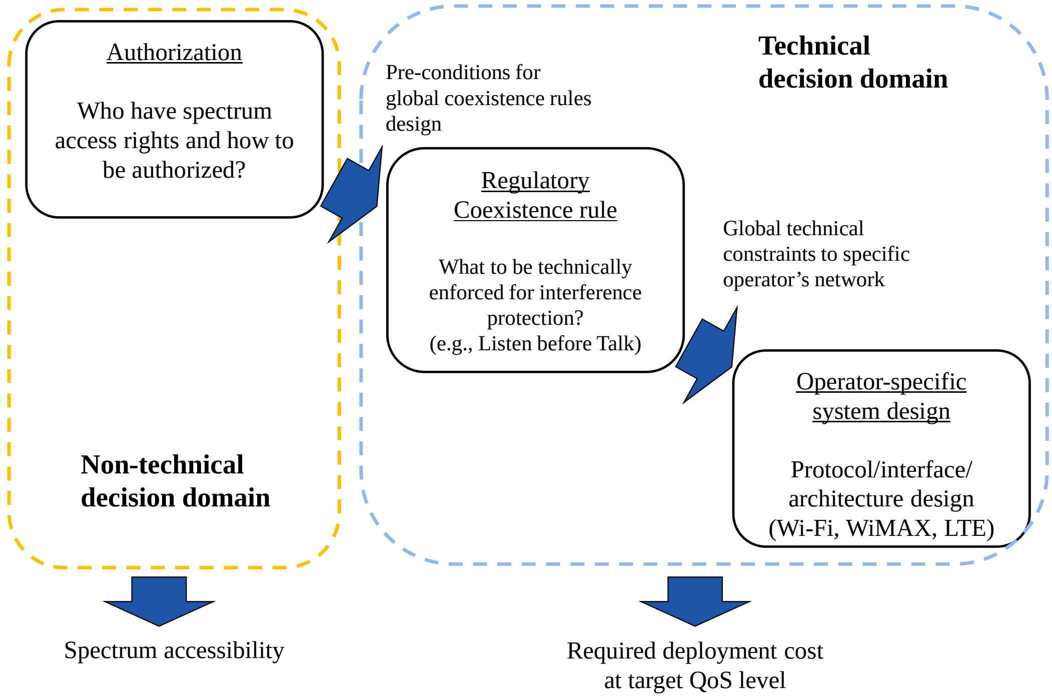

Figure 4. Model of Regulatory Decision Making

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. In Figure 4, 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 the technical decision domains although it 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 rules and future radio systems. For example, co-channel coexistence is not an issue in the traditional single operator 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, 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 regulatory technical constraints. 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 future system design 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.

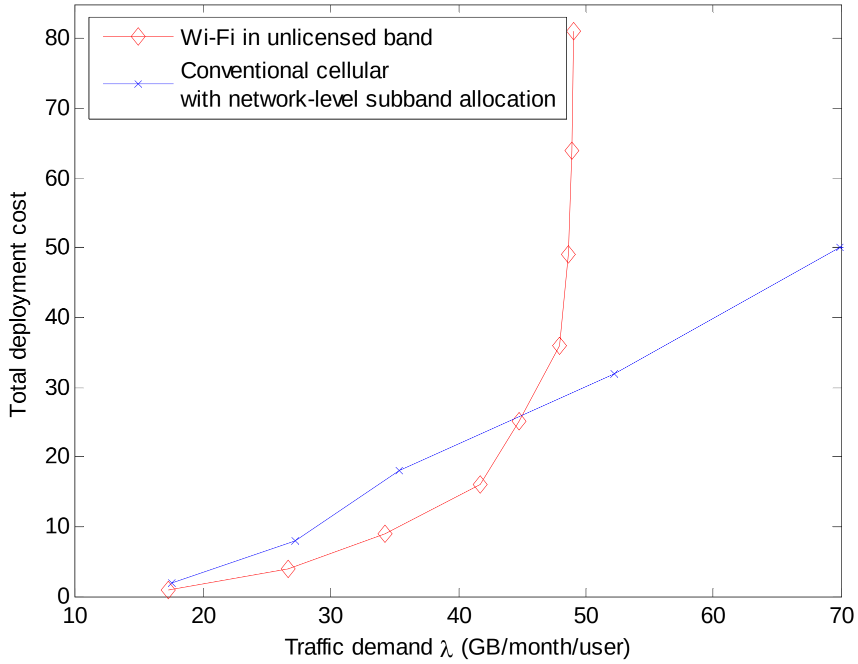

Figure 5. Total deployment cost comparison between Wi-Fi in unlicensed band and a conventional cellular system. The cellular system is assigned the half of spectrum by 3rd party spectrum broker to avoid inter-building interference while Wi-Fi system fully access whole spectrum based on CSMA/CA.

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 since no pre-procedure on authorization is required. Thus, coexistence rules are only a regulatory mean to control shared spectrum access. Typical approaches were based on node-level etiquettes [5]. Transmit Power Control (TPC), Dynamic Frequency Selection (DFS) and Listen Before Talk (LBT) are some of examples. Such regulatory requirements naturally ended up a fully distributed system design which does not explicitly have control plane architecture, working in a fully self-organizing manner. This also applied to the commercially successful Wi-Fi system. For instance, 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 as a mandatory requirement in order to coexist with other anonymous transmitters even including mobile end-users. Although the probability of interferences from co-located areas are very low in most cases, all individual nodes should follow globally fixed rules , e.g., common carrier sensing threshold or maximum backoff window size. 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 AP 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 at very high-capacity 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 at the level of local areas instead of a traditional nation-level and coordinate subband allocation between networks to avoid excessive interference at network boundaries (shown in the blue curve at Figure 5). Thus, the subband is repeatedly reused by other operators which is not the closet interferers. One shortcoming of this approach is that each local network accesses less amount of whole spectrum. However, the gain appears when very high-capacity is required by allowing that individual operator can fully control multiple APs in their own network. Therefore, a local cellular-like system with the combination of regulatory network-level coordination may be needed for very high-capacity services.

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 of network deployment) requirements, the authorization is of administrative nature and necessitates - as a prerequisite for use - that an operator contacts the Spectrum Management Authority and meet its obligation. Without administrative control in unlicensed band, spectrum access is regulated solely by adherence to pre-defined technical conditions. 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. Such approach may work relatively low capacity services and be cost-effective. Nevertheless, the coordination among APs at a given network will be essential if LNOs aim much higher data rate services than today. First, node-level constraints given by a regulator need to be relaxed to allow more network-wide control by operators. Equally importantly, regulator-driven centralized inter-network coordination is inevitable for mitigating network boundary interference.

Limited Several vs. Potentially Many Operators?

Besides of technical conditions in spectrum policies, the number of access rights may also 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, rather 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 network deployment in 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 traditional unlicensed approach.

From the local operator perspective, the unlicensed band with too much conservative coexistence rules e.g., the fixed node-level etiquettes, will lead to a fully distributed system without any inter-node communication supports. It may significantly sacrifice overall network performance at very high capacity region and eventually increase the order of magnitude more deployment cost than a traditional cellular system in exclusive band. Thus, a traditional transmitter access control approach, e.g., node-level etiquettes, needs to be avoided for ensuring network-level controllability. In addition, regulatory focus needs to be moved from traditional node-level etiquettes to more adaptive coordination to protect interferences at network boundaries to support future high-capacity services.

Although we showed one plausible technical coexistence solution which at least can yield lower cost than uncoordinated Wi-Fi at a high-capacity region, 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

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