Scenario Making for Assessment of Secondary Spectrum Access

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***Abstract*—Secondary spectrum access, through which secondary users opportunistically access the under-utilized radio spectrum, has emerged as a solution to cope with the perceived spectrum scarcity. The potential of the secondary spectrum has therefore attracted industry players and regulators worldwide. To assess the real-life benefits of the secondary spectrum, it is crucial to estimate the amount of spectrum available for secondary use. This estimation requires a well-defined set of models and parameters, which are collectively termed a 'scenario'. In this article, we demonstrate the importance of scenario making in the quantitative assessment of secondary spectrum access. We first describe the elements that constitute a comprehensive secondary access scenario, namely a primary system and spectrum, a secondary system and usage, and the methods and context of spectrum sharing. Then, we demonstrate how the assessment results of the spectrum availability differ depending on the scenario elements. We also illustrate the crucial aspects of a scenario in the business analysis, which, together with the technical assessment, is the input for the regulatory decision.**

***Keywords*—Secondary spectrum access, quantitative assessment, business analysis, scenario**

I. INTRODUCTION

The secondary use of already-licensed but under-utilized spectrum has emerged as a promising solution to cope with the rapidly increasing demand for the radio spectrum. It is the most feasible form of dynamic spectrum access (DSA) and has attracted spectrum regulators and industry players, as well as academic researchers (see, e.g., [1]-[3]). Although it is generally believed that secondary spectrum access has the potential to significantly increase spectrum utilization, its true benefit has not yet been fully revealed. The EU FP7 project QUASAR [4] quantified the opportunities of secondary access with regard to its technical, business, and regulatory aspects.

Based on experience with the QUASAR project, we learned that the amount of available spectrum depends on many factors, including primary and secondary systems, their interaction, and geographical features of secondary usage. Therefore, a quantitative analysis of secondary access is not feasible without specifying these factors. This analysis requires a well-defined set of models and parameters, which we term a *scenario*. Scenario making is essential for understanding where and how secondary spectrum access can occur. A comprehensive scenario enables us to derive relevant *'what-if'* questions, the answers to which are valid for making decisions for regulatory and business purposes.

In this article, we demonstrate the importance of scenario making in the quantitative assessment of secondary spectrum access. As a first step, we describe three elements that constitute a complete secondary access scenario, namely a primary system and spectrum, a secondary system and usage, and the methods and context of spectrum sharing. The conditions needed for these elements to be candidates in the scenario are also explained. Then, using a sample scenario, we demonstrate how the availability of secondary use differs depending on the elements of the assessed scenario. Crucial aspects regarding business feasibility analysis are also discussed.

II. WHAT IS A SCENARIO?

A scenario is an outline that details a specific event. When we consider secondary access to a primary spectrum as an event in the radio resource domain, specific and detailed descriptions of the event are needed to investigate the effects of the new technology. In this article, we refer to the set of those descriptions as a *secondary access scenario*.

A secondary spectrum access scenario is composed of the following three elements: a primary system and spectrum, a secondary system and usage, and the methods and context of spectrum sharing. To protect the legacy system already in use, we should have an extensive knowledge regarding the characteristics of the target primary system and spectrum. This also applies to the secondary systems, which have some possible use cases. The ways in which the spectrum is shared should also be justified in the scenario. These elements will be described in detail in the subsequent sections.

After defining the elements in a comprehensive manner, a secondary access scenario can be evaluated not only with respect to its technical feasibility but also with respect to its business potential. With the scenario, we can predict the effectiveness of secondary spectrum access by hypothesizing what can occur during the technology implementation based on the current status. The results of both technical and economic analysis are fed back into the scenario during the assessment process. Then, either each element or the entire structure of the initial scenario may be changed, and the refined version of the scenario is investigated again. Through this iterative refinement of the scenario, the spectrum availability and the benefits of secondary access are better quantified, and finally, decisions regarding regulation and business investment can be made. Therefore, the scenario is an analysis and decision tool, as illustrated in Figure 1.

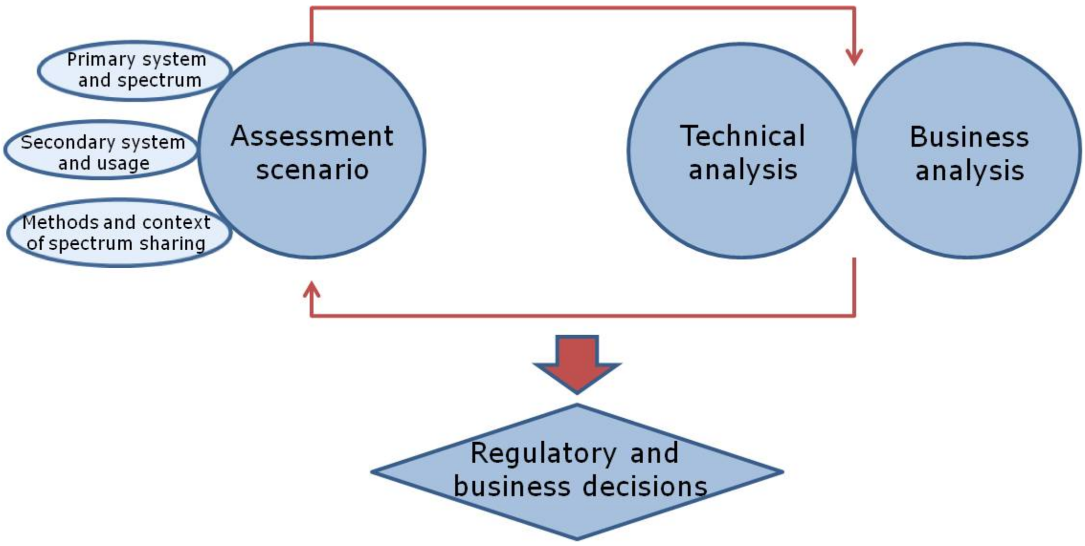

Figure 1: Iterative analysis and decision process based on an assessment scenario.

III. PRIMARY SYSTEM AND SPECTRUM

The primary system must be protected from the potential harmful interference generated by secondary usage. At the same time, secondary users must maximize spectrum utilization to benefit from the secondary access. Therefore, precise knowledge of the primary system is a prerequisite for secondary spectrum access. It is also important to understand the characteristics of the primary spectrum for a sanity check on business feasibility.

A potential primary spectrum is required to have the following attributes to make a secondary access scenario successful. First, the secondary system should achieve economy of scale, i.e., a large chunk of frequency band is allocated to the primary system that is usable by the secondary system in many parts of the world. Second, the propagation characteristics should be compatible with the desired secondary usage. The UHF band (300 MHz to 3 GHz) has been considered the most valuable for wireless communications. Third, there should be a technical means to discover and exploit the opportunities of secondary access without incurring excessive cost.

By examining the international frequency allocation table, one can easily find several candidate primary frequency bands. Examples of these include the bands used in

- Terrestrial TV broadcasting (470-790 MHz) [3,5]
- Aeronautical radionavigation (960-1215 MHz) [6]
- Radar for air traffic control (ATC) and meteorological aids (e.g., 2700-2900 MHz) [7]
- IMT cellular communications (e.g., 790-960 MHz, 1710-2025 MHz).

It is desirable to have a preliminary assessment of the candidate primary frequency bands before performing a detailed availability analysis. Here, we provide assessment criteria and present a qualitative evaluation of the above-mentioned frequency bands.

- **Spectrum occupancy**: A high level of spectrum occupancy is an indicator of a low opportunity for secondary usage. The cellular spectrum is the worst in this sense because its usage is already high. On the contrary, aeronautical and radar bands show a low occupancy in terms of both time and space. TV broadcasting band exhibits a moderate occupancy in general but tends to show a higher occupancy in urban areas.

- **Interference tolerance**: Radars and aeronautical devices suffer from high interference susceptibility and a stringent protection requirement. Although TV receivers have better tolerance than radars, it is difficult to know where the victim TV receivers are located. Cellular systems can cope with much higher interference than other systems. However, they are also vulnerable to unknown interference because they are carefully engineered for planned intra-system interference. It should be emphasized that legacy systems were not designed to tolerate interference from secondary users.
- **Regulatory difficulty**: Aeronautical devices and ATC radars are associated with safety-of-life functions and thus are strictly controlled from a regulatory perspective. However, the secondary use of the TV broadcasting spectrum has already been approved by regulators in some countries, such as the USA, UK, and Korea. In the IMT spectrum, the willingness of incumbent operators to take part in secondary access business will play a critical role in its regulation. The cellular industry will be hesitant about providing secondary access unless it provides some benefits to existing businesses.
- **Global coordination**: The globally coordinated spectrum has the advantage of achieving economy of scale. The aeronautical spectrum has strong global coordination due to the nature of aviation operations. TV broadcasting and the cellular spectrum provide reasonably good levels of coordination to support mass manufacturing and the deployment of a secondary system. The radar spectrum maintains poor coordination. Although the 2.7-2.9 GHz band is globally allocated to radars, each country employs quite diverse technical specifications and radar frequency assignments.

Table 1 summarizes the above discussion. The TV broadcasting band is the most feasible and favorable spectrum for secondary access. The radar and aeronautical spectrums show great potential for secondary access due to their low occupancy rates. However, the regulatory circumstances associated with these spectrums are challenging. The cellular spectrum is already heavily utilized. Mobile broadband service as a secondary usage does not seem promising, but machine-type applications that make use of the existing cellular infrastructure may be interesting candidates.

Table 1: Qualitative evaluation of potential primary spectrums

Primary system	Terrestrial TV	Aeronautical navigation	Radar	IMT cellular system
Frequency band (MHz)	470-790	960-1215	e.g., 2700-2900	e.g., 790-960 and 1710-2025
Occupancy rate	Moderate	Low	Low	High
Interference tolerance	Moderate	Bad	Bad	Moderate
Regulatory difficulty	Low	High	High	Moderate
Global coordination	Good	Good	Bad	Good

IV. Secondary System and Usage

The feasibility of secondary spectrum access depends not only on the primary system and spectrum but also on the characteristics of secondary systems. For a secondary access scenario to be promising, there are two basic conditions that should be met by the secondary system and its usage. First, secondary users who have a strong demand for more spectrums in their existing or future systems are needed. For example, secondary access will be attractive to mobile broadband providers who currently suffer from the capacity limitations.

Second, orthogonality between the primary and secondary services should be guaranteed in the scenario. This means that the usage pattern of the secondary system should be spatially and/or temporally dissimilar to that of the primary system. When the secondary usage type is different from that of the primary system in terms of the coverage area, propagation characteristics, and therefore quality requirements for services, this service differentiation will facilitate the sharing of the spectrum that is under-utilized by the primary system. In the QUASAR project [4], we consider the following types of deployment as candidate secondary use cases: short-range and low-power wireless access, indoor and hotspot broadband access, wide-area wireless access, backhaul and relay, and machine-type communication. These use cases feature different system structures and physical constraints, providing various services.

- **Short-range and low-power wireless access**: Short-range point-to-point communications between devices are typically used in personal area network (PAN) and body area network (BAN) applications. The devices transmit with a low power at a close distance, and the signal propagation is assumed to be line-of-sight. The devices can form a network without any infrastructures, but self-coordination protocols have to be defined to enable their communications. In this type of secondary system, there possibly exist a number of devices as secondary users and the aggregate interference caused by them may do harm to the primary systems, even though they use low transmission power.
- **Indoor and hotspot broadband access**: End-user devices communicate with indoor base stations (BSs) or access points (APs), which are attached to a central network. Because it is expected that indoor data traffic will explode in a few years, this type of data off-loading can be regarded as a promising secondary service. This use case is suitable for femto- or pico-cell deployment (small cells) in urban areas. The range of wireless connections will be just a few meters with low transmission power, which will provide better protection to the primary system. Indoor and hotspot networks can be controlled by a central unit to enable reliable interference management.
- **Wide-area wireless access**: In contrast to the use case described above, this type of secondary access considers macro-cellular system deployments. It can be implemented by incumbent operators to extend capacity and coverage or by new entrants as a way of obtaining spectrum. In this case, the issue of how the regulators manage the licensing schemes should be incorporated, because the secondary operators may require an exclusive secondary license to justify their

infrastructure investment to guarantee quality of service (QoS). The high transmission power of the macro BS should also be scrutinized to prevent harmful interference to the primary system.

- **Backhaul and relay**: A wireless link is often used for the connections between a BS and the central network or between a BS and relays. Because backhauling and relaying require a high level of reliability, their operation as secondary systems should be static after the completion of a carefully planned deployment. Collaboration with the primary system is feasible because the location and signal structure of the secondary system allow for accurate interference prediction. This type of planning, however, still faces challenges regarding the design of secondary access, which can be damaged by slight changes in the primary system.
- **Machine-type communication:** Machine-to-machine (M2M) communication will emerge as an important application in the coming years. M2M differs from the other use cases in the sense that the requirement for the data rate is not strong. However, the number of machine terminals is significantly high, and careful interference management is needed. Challenges also arise with respect to connectivity and scalability. Because secondary usage in this case is bursty, however, the temporal exploitation of the primary spectrum provides an interesting challenge.

V. METHODS AND CONTEXT OF SPECTRUM SHARING

In a secondary access scenario, how the primary and secondary systems co-exist within a given spectrum should be detailed in terms of both technical and regulatory aspects. Spectrum sharing between the primary and secondary systems is realized through sharing techniques and opportunity discovery schemes. Licensing and medium access control (MAC) schemes then specify the type of sharing among the secondary users. Based on them, the behaviors of the secondary system are defined and the interference footprints in a secondary access scenario are determined. This affects the performances of both primary and secondary systems, and consequently the feasibility of a scenario is assessed. Note that the regulators can be involved in setting the scene of the spectrum sharing.

- **Sharing technique**: The following three techniques are usually considered in spectrum sharing between the primary and secondary systems: overlay, interweave, and underlay. Detailed descriptions of the concepts can be found in [8]. Regulators mostly consider interweave as a means of implementing secondary access. In the interweave approach, the secondary system transmits only on a spot not causing harmful interference to the primary system. Such a spot should be found in a three-dimensional space consisting of spectral, temporal, and spatial dimensions.
- **Opportunity discovery**: Secondary users can detect primary signals via spectrum sensing, which can be implemented by energy detection or other methods. However, detecting the primary transmitters does not guarantee the protection of the primary receivers. Sensing can be a useful tool for discovering secondary access opportunities only when knowledge of the primary transmitters is directly applied to the primary receivers (e.g., radar). The use of a geo-location database is a more popular method of opportunity discovery. Database managers make decisions regarding the available spectrum and permissible power use in response to a query from a secondary user. The decisions are based on primary system information and propagation data. This database-driven scheme can be further enhanced by spectrum sensing functionalities because the propagation environment can be estimated more accurately with the aid of this sensing.
- **Spectrum licensing**: The concept of spectrum commons, according to which any secondary user abiding by the regulatory rules can have access to the primary spectrum, is currently accepted by regulators. However, other types of secondary licensing schemes, such as exclusive secondary licensing and multiple-secondary sharing licensing can also be considered to ensure the quality of secondary services. The regulators can give a secondary system an exclusive license so that no other secondary systems are allowed to use the spectrum in a specific region. In multiple-secondary sharing licensing, however,

the spectrum opportunities are shared within a certain group of secondary systems, which is defined by the regulators or the spectrum trading process of the primary license holder.

- **Secondary MAC**: The primary spectrum is shared not just between the primary and secondary systems but also among the secondary users. Efficient MAC protocols of the secondary system are essential for achieving fair and successful secondary access. The secondary MAC also has a large impact on the aggregate interference that the secondary system gives to the primary system.

A secondary access scenario is completed when all of the elements described so far are put into the context of geographical area. The deployment of the legacy primary system is location-dependent. Propagation characteristics are also determined by the terrain and buildings in the area. The demographics of the region are good indicators of the secondary usage demand and can further serve as input for the analysis of business feasibility.

VI. Scenario-dependent Secondary Access Availability

Whether a particular frequency band is available for secondary access depends on the above-mentioned scenario elements. Even a slight variation in some of the elements can make a large difference in the availability. For example, the spectrum available for a short-range secondary service may not be accessible to a macro-cellular system. Likewise, the fact that a secondary service is technically feasible in a certain area does not necessarily guarantee its viability elsewhere. The impact of scenarios on secondary access availability should be carefully examined to evaluate the true benefit of the secondary spectrum. Thus, we demonstrate, from a technical perspective, how the assessment results differ depending on variations in the scenario elements. Here, our focus is on the secondary usage and the opportunity detection method.

Let us consider an ATC radar operating in the 2.7-2.9 GHz band as the candidate primary system. It is assumed to be located at an airport. A secondary system located downtown near the airport wants to share the same frequency band. Because the radar is highly susceptible to interference, a sufficient separation distance is required between the primary and secondary systems to protect the radar. Thus, the secondary access availability can be measured in terms of the minimum required separation distance. For brevity, a single secondary transmitter is considered.

Due to the random nature of the radio propagation, the requirement for the protection of radar receivers is expressed as a probability:

$$\Pr\left(I_{su} \geq THR_{rad}\right) \leq \beta \, , \tag{1}$$

where I_{su} is the interference power received at the radar from the secondary user, THR_{rad} is the interference threshold of the radar, and β is the maximum allowable probability of interference violation. Note that THR_{rad} and β are regulatory parameters that depend on the level of protection required by the primary system. The received interference I_{su} can be calculated as follows (in dB):

$$I_{su} = EIRP_{su} + G - PL(d) + X_{shad} + X_{rayl} \, , \tag{2}$$

where $EIRP_{su}$ denotes the equivalent isotropically radiated power (EIRP) of the secondary user, and G represents other gains and losses. $PL(d)$ is the path loss when the secondary user is d km away from the radar. X_{shad} and X_{rayl} denote the variations in the received power due to shadow fading and Rayleigh fading, respectively.

We consider two types of secondary systems:

- **Macro-cellular BS**: In a macro-cellular system, the BS emits high EIRP, particularly in the worst case, i.e., the BS antenna points toward the radar. The antenna is usually above rooftop level, which requires a longer separation distance.
- **Indoor AP**: This has a considerably lower EIRP than the macro BS. In addition, its transmitter height is comparable to that of hand-held devices. Thus, it is expected to have a much greater availability.

We also consider two different methods of opportunity detection:

- **Database-only**: The secondary user is attached to a geo-location database that decides whether it can use a particular frequency band. The decision is based on the distance between the secondary user and the radar. We assume that the database does not have any knowledge of the fading components, which leads to a large margin for compensating the fading effects.
- **Database + sensing**: In addition to the database, the secondary user detects the radar pulses and estimates long-term propagation loss by exploiting the feature of the radar that the receiver is collocated with the transmitter. Although the instantaneous propagation variation still remains uncertain due to the fast fading, the required fading margin is significantly lower than that present when relying only on the database.

Figure 2 depicts the minimum required separation for combinations of secondary usage and opportunity detection method. A detailed description on the primary system and the analysis method can be found in [9]. It is observed that the separation required under the database-only method sharply increases as the constraint of interference violation becomes stricter, i.e., β becomes smaller. Additionally, the macro BS requires approximately 40 dB more separation than the indoor AP under the same opportunity detection method. The required separation is converted into distance[1] in Table 2. The table shows that the macro-cellular use of the radar band requires several hundred kilometers of separation, which effectively eliminates the opportunity for such secondary access. On the other hand, providing indoor broadband access on the radar spectrum appears feasible considering that most airports are several kilometers away from downtown areas, where the demand for secondary access exists. In particular, the auxiliary sensing capability significantly increases the availability of indoor secondary use. Note that the results presented here reflect only a few possible scenarios regarding the secondary use of the radar spectrum. Taking other aspects into account may produce different results.

[1]The COST-Hata model is employed to calculate the path loss. Although the radar spectrum (2.7-2.9 GHz) exceeds the applicable range of the COST-Hata model, it provides a rough estimate of the required separation distance.

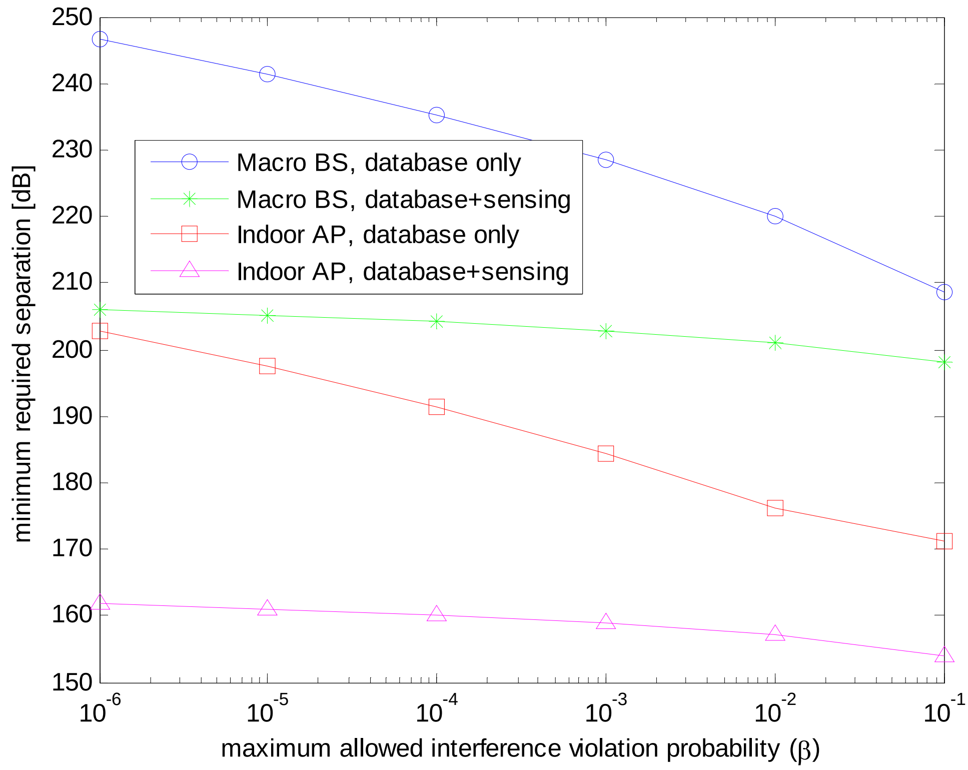

Figure 2: Minimum required separation between the secondary user and the radar; the EIRPs of the macro BS and indoor AP are 54 and 10 dBm, respectively.

Table 2: Minimum required distance between the secondary and primary systems in kilometers; the transmitter heights of the macro BS and indoor AP are 20 and 1.5 m, respectively.

β	**Macro BS Database-only**	**Macro BS Database + sensing**	**Indoor AP Database-only**	**Indoor AP Database + sensing**
0.0001%	2248.20	169.04	22.08	1.97
0.01%	1094.09	151.21	11.27	1.78
1%	414.90	124.97	4.56	1.49

VII. Scenario Elements Affecting Business Feasibility

For the scenarios deemed technically feasible, a business analysis is the next step. The foregoing three elements also affect the business feasibility of a secondary access scenario, especially with the following specific factors: 1) spectrum license ownership by the primary, 2) spectrum license ownership by the secondary, and 3) service differentiation between the primary and secondary systems. Spectrum license ownership indicates the level of exclusiveness in the spectrum license of interest. Depending on the license ownership, the primary spectrum can be traded in a free market or managed by particular regulators. If it is clear who has the license of the primary spectrum, the leasing or sublicensing of the spectrum is easily implemented; this implies that a greater business opportunity exists with that spectrum. The spectrum license ownership by the secondary also affects on the opportunities for secondary business. Imagine that the secondary access rights are open to anyone and that the spectrum is shared; in this case, it is hard to provide any services requiring a certain level of QoS guarantee.

With these spectrum ownerships, service differentiation between the primary and secondary systems is important as well. In service differentiation, the temporal and spatial correlations between customer groups of the primary and secondary services, as well as the differences between the service types, are considered. When there is a large overlap in their service areas and targets, the primary license owner is reluctant to lease the spectrum to the similar competing services provided by the secondary operators, even if these competing services are technically promising. However, if there is clear separation with respect to the target services and customer groups between the primary and secondary systems, both parties may mutually benefit from their spectrum sharing.

Based on the above three factors, we can draw a cubic diagram that assesses the business opportunity of a secondary access scenario, as depicted in Figure 3. The business opportunity of a scenario may be maximized when the primary- and secondary license ownerships are high and there is a large difference in their services. As an example, we conclude that short-range/indoor broadband service is the most promising one in secondary business, when it operates on primary spectrums, such as TV white spaces or radar bands controlled by regulators with light licenses. The M2M service on the cellular spectrum is also a good example, which opens a new market, but there is a great deal of excess capacity in the traditional licensed bands. In contrast, wide-area cellular system as a secondary service may be possible in some rural areas, but its technical feasibility is too limited to motivate long-term investments.

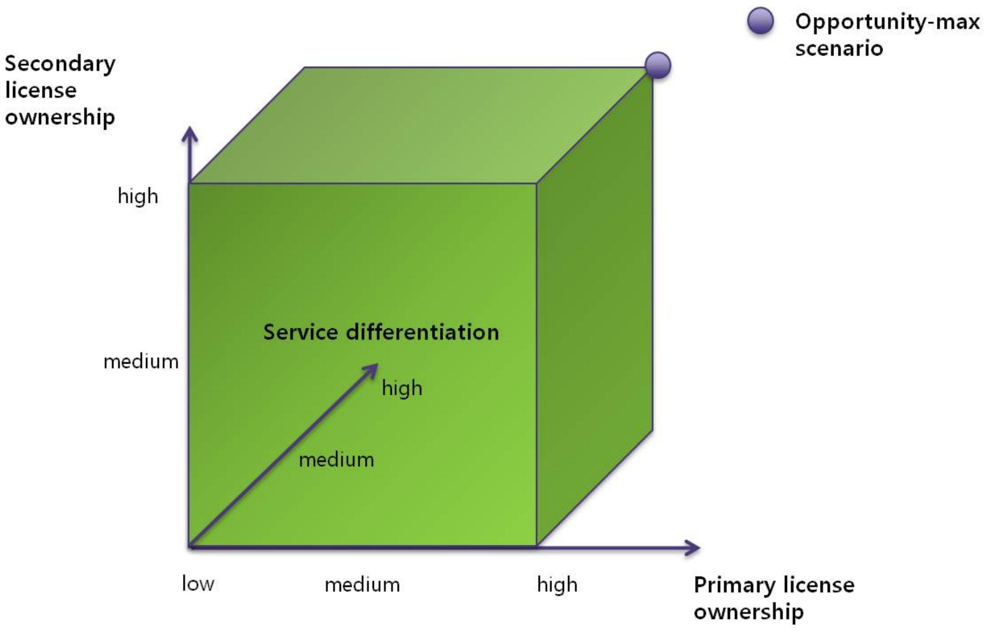

Figure 3: Ideal scenario elements for business opportunities.

VIII. CONCLUSION

In this article, we demonstrated the importance of scenario making in the quantitative assessment of secondary spectrum access. A scenario refers to a set of models and parameters that describes secondary spectrum access in a comprehensive manner. A scenario consists of three elements: a primary system and spectrum, a secondary system and usage, and the methods and context of spectrum sharing. By iteratively assessing and refining a scenario, proper decisions regarding the regulation of spectrum access and business investments can be made. This process and the decisions will facilitate the optimal exploitation of valuable spectrum resources.

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