Feasibility Assessment of License-Shared Access in 600~700 MHz and 2.3~2.4GHz Bands: A Case Study

Yao-Chia Chan[1], Ding-Bing Lin[1], and Chun-Ting Chou[2(✉)]

[1] Graduate Institute of Computer and Communication Engineering, National Taipei University of Technology, Taipei, Taiwan
yaochia.chan@gmail.com, dblin@ntut.edu.tw

[2] Graduate Institute of Communication Engineering, National Taiwan University, Taipei, Taiwan
chuntingchou@ntu.edu.tw

Abstract. License-Shared Access (LSA) has been regarded as a feasible solution for spectrum sharing. In LSA, regulators coordinate the spectrum use between incumbents — the users who hold the licenses and have the exclusive access to the spectrum — and secondary licensees that need authorization before their access. In the midst of 2014, Taiwanese government proposed a draft of Frequency Provision Plan, in which 600~700MHz and 2.3~2.4GHz bands are considered to be opened for more flexible usage, presumably including LSA. The benefit that secondary licensees obtain from LSA depends on the behaviors of the incumbents. This paper evaluates the feasibility of LSA in these bands in Taiwan. Our experiment is based on a 26-day spectrum measurement in Taipei, Taiwan. The behaviors of the incumbents are analyzed in both temporal and spectral domains. The results show that in 600~700MHz band, only narrowband incumbents were detected during small and sporadic time intervals. No incumbent activity was observed in 2.3~2.4GHz band. The experiment shows that low spectrum usage in these bands allows LSA licensees to provide services with predictable quality of service (QoS).

Keywords: Spectrum observation · License-Shared Access (LSA) · Spectrum sharing

1 Introduction

The demand for frequency spectrum has never been higher since broadband wireless communication becomes an integrated part of our daily life. Operators require more bandwidth to support higher data rates and service more clients. The regulation of the spectrum, unfortunately, falls way behind such a trend. Under the current spectrum regulation, the Ultra-High Frequency (UHF) band is sliced into fragments, where some of them are allocated to satellite, civil, and military uses. The spectrum frag-

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mentation makes contiguous bands scarce and even unavailable, thus preventing the adoption of new wireless technologies that need higher bandwidth.

The frequency bands allocated for licensed uses scatter in the UHF band. Most of them are used in restricted areas or within limited time spans of a day. The rest of the time in most of the areas can be regarded as idle, and could be reused without causing interference to incumbents. Spectrum reuses at fixed locations during predictable time periods are most suitable for License-Shared Access (LSA) [1]. Proposed and developed in Europe in the last few years, LSA improves the utilization of licensed bands by sharing the frequency bands with regulated secondary users. According to the architecture proposed in European Communication Committee (ECC) report [2], LSA involves three parties including regulator, incumbents and secondary licensees. The first coordinates the band usage between incumbents and secondary licensees based on predefined rules, which not only guarantee the availability of licensed bands for incumbents, but also offer a predictable level of QoS to secondary licensees.

In midst of 2014, Taiwan Ministry of Transportation and Communication announced a draft of Frequency Provision Plan, in which the UHF sub-bands may be released for commercial mobile communication [3]. In addition to these bands, the draft also includes some bands that have never been licensed for commercial communication, including 608~698MHz band and 2.3~2.4GHz band. These bands, if being used in an integrated way, could provide a considerable amount of spectrum for mobile communication without incurring a formidable expense in spectrum refarming/reclaiming, if the idea of LSA can be applied.

The feasibility of LSA relies heavily on the behaviors of incumbents. Such behaviors vary with the bands and the regions where the incumbents are located. In [4], spectrum usage from 30MHz to 3GHz in Chicago, US, had been studied from 2007 to 2010. The results of the three-year observation are used to not only assess the long-term trend in spectrum usage, but also capture significant events such as the release of digital dividends in 700MHz band after the analog-digital TV conversion. Their results confirm the presence of some TV white spaces in 30~1000MHz band. In a six-month spectrum observation in 300~4900MHz band in Bristol, UK, [5] the usage is divided into three categories including continuously occupied, permanently free, and temporally occupied, according to the temporal occupancy pattern. Their measurement shows that TV broadcast bands contribute most of the temporally-occupied usage. In [6] and [7], cellular radio and ISM bands had been observed at multiple locations in London, UK, for a week. The results suggest that GSM bands are less occupied in suburb areas or during the weekends. In [8], the measurements of 2.3~2.4GHz bands were carried out in Chicago, US, and in Turku, Finland, respectively, for two weeks. This band in Turku, according to the results, was occupied in an unpredictable manner due to wireless cameras, while in Chicago the occupancy pattern was relatively stable. The results suggest that even though only a smaller proportion of the band is available in Chicago, the more stable occupancy patterns make LSA a feasible solution in that area.

However, to the best of our knowledge, few reports regarding the usage of 600~700MHz or 2.3~2.4GHz bands were made available to the public in Asian countries. In this paper, we present the results of a 26-day spectrum measurement in

Taipei, Taiwan --- a typical modern Asian metropolitan area. The received power and the time duration of the spectrum usage in 600~700MHz and 2.3~2.4GHz bands were recorded. The behaviors are analyzed in time and frequency domains to assess the feasibility of LSA in these bands. The results show that in 600~700MHz band, only some narrowband incumbents were detected during small and sporadic time intervals. No incumbent activity was observed in 2.3~2.4GHz band. The experiment shows that low spectrum usage in these bands allows LSA licensees to provide services with predictable QoS in Taipei, let alone other areas in the rest of Taiwan.

The rest of the paper is organized as follows. The architecture of LSA proposed by European ECC is introduced in Section 2. The settings of our measurement are presented in Section 3 along with a snapshot of the spectrum usage in these two bands. The spectrum usage of both bands are analyzed in both time and frequency domains in Section 4. The feasibility of LSA is also discussed. Finally, conclusions are given in Section 5.

2 A Review on the Architecture of LSA

The concept of LSA is intended to accommodate users within a licensed spectrum in different time or locations, so that they may share the spectrum and operate with some QoS guarantee. Users are usually divided into two categories including incumbent users and secondary licensees. Their spectrum usage is coordinated by the regulator based on some predefined rules. Incumbent users are licensed to use the spectrum. From the perspective of traditional regulators, incumbent users are the only legitimate users in the designated bands. In the architecture of LSA, they still have the highest priority in using the spectrum. Secondary licensees do not have the license as the incumbent users. They can use the spectrum only when they are authorized by the regulator and when no incumbent user is present. Whenever an incumbent user reclaims the spectrum for its own use, all licensees are required to evacuate within a short time, thus keeping the spectrum clear.

The relationships between regulators, incumbents, and secondary licensees are depicted in Fig. 1. In addition to the three parties, two more components are needed in the architecture: LSA repository and LSA controller. The LSA repository is a database containing the information of incumbents and licensees, including their geo-locations, radio-frequency (RF) characteristics, and intended operation frequencies and times. The LSA controller, on the other hand, is served as a gatekeeper between licensees and the repository. The controller receives queries from the licensees, and releases the information of the vacant bands and the spectrum-sharing authorization to the licensees. It also sends evacuation requests to the licensees whose authorizations are reclaimed on the (re)entry of incumbents. In addition to message delivery, the controller also protects the fidelity of the database content from being erroneously or even maliciously modified.

The licensees are authorized to use LSA-regulating bands based on the policy of regulators, the status of incumbent spectrum usage, and the locations and RF characteristics of the licensees. A licensee sends its location and RF characteristics (such as transmitting power, antenna type, etc.) along with its query for vacant bands to the repository through the controller. The regulator replies the licensee with candidates of bands. The licensee selects one or several bands from the candidates and obtains the authorization. If a nearby incumbent emerges and sends a request of an immediate use of the authorized bands, the regulator recalls the bands even if such a request is not in repository schedule. The authorization is reclaimed, and the licensee is required to evacuate within a short time. The status of LSA-regulating bands is updated in the repository whenever they are authorized or reclaimed.

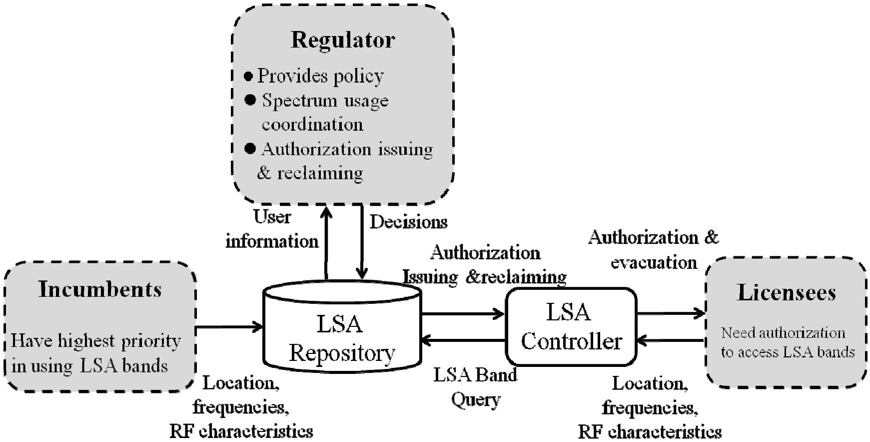


Fig. 1. The architecture of LSA

Although LSA licensees are free from contention when compared with licensed-exempt access, their transmission quality heavily depends on the behaviors of the incumbents. If the behaviors are stable or even predictable, the licensees may plan their usage of the authorized bands in advance without sudden evacuation. In contrast, if the incumbent usage is dynamic, the time interval in which the licensees can share the bands becomes unpredictable and the licensees will be subject to frequent evacuation and service disruption. Such uncertainty in using the authorized bands could void the advantages of LSA as it not only incurs radio resource management overhead but also reduces the utilization of the authorized bands.

As indicated in [9], incumbents can be divided into two types including government and commercial. These two types of users have distinct behaviors of spectrum usage. Government incumbents such as national defense, public safety, meteorology, and science do not have individual rights to access the spectrum. Instead, they share the spectrum to perform their duties. Their access to spectrum is coordinated and regularly reviewed by the regulators and usually is sporadic in both time and spatial domains. In contrast, spectrum usage for commercial incumbents is more contiguous. In general, the spectrum with government incumbents is favorable for LSA. In this paper, we evaluate two spectrum bands that are currently allocated for government incumbents in Taiwan. The goal is to not only characterize the usage pattern of these bands but also provide regulation insights to the regulator based on our quantitative measurement results.

3 Measurement Setup

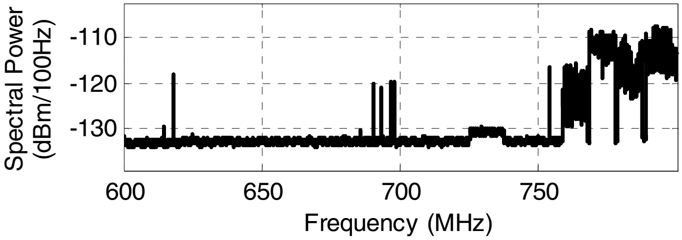
Although the identities of the users in 600~700MHz and 2.3~2.4GHz bands in Taiwan are not fully revealed by the regulator, both bands are not licensed for commercial use. The activities of the incumbents affect the potential advantage of the licensees under LSA. To gain better knowledge regarding the incumbent activities, we conducted a 26-day spectrum measurement from 09/13/2014 to 10/08/2014. A spectrum observatory is set up on the rooftop of Barry Lam Hall, National Taiwan University, which is located in the center of Taipei metropolitan area.

Our observatory consists of a spectrum analyzer (Rohde & Schwarz FSV-4), a wideband antenna (Rohde & Schwarz HE500), and a computer for control and storage. In order to provide better frequency resolution, resolution bandwidth was set as 100Hz with a noise floor of approximately -133dBm. The root-mean-square detector of the analyzer was chosen to measure the average spectral power within signal acquisition. The control computer recorded spectral power measurement in the respective bands every 3 minutes. As a result, a total of 12,500 records were collected for each band.

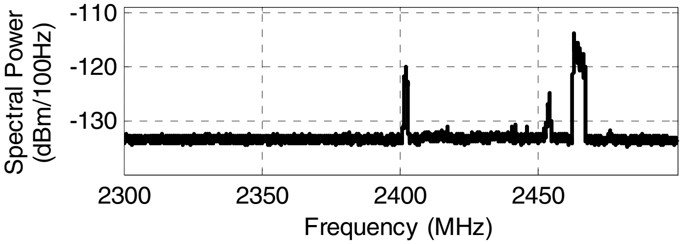
Fig. 2 show a two-second snapshot of our spectrum measurement for both bands. Their neighboring bands were also measured and are plotted for comparison. For example, the neighboring 700~800MHz band is also given for comparison with the 600~700MHz band as shown in Fig. 2(a). While the identities of the incumbents in 600~700MHz band are unclear, their neighboring band mostly belongs to commercial use in Taiwan. For example, 703~748MHz and 758~803MHz are licensed to 4G Long-Term Evolution (LTE) operators, and the rest (i.e., 748~758MHz) is assigned to unlicensed wireless microphones [10]. Compared with the occupancy patterns in the 700~800MHz band, the 600~700MHz band is rather vacant with some scattering spikes. The spikes indicate the presence of narrow-band incumbents in the band. The sparse spikes confirm the existence of relatively clean bands that are potentially available for LSA.

Fig. 2(b) shows a two-second measurement snapshot of the 2.3~2.4GHz band and its neighboring 2.4~2.5GHz band. The latter is globally known as the Industrial, Scientific, and Medical (ISM) band, in which wireless local area networks (WLAN) and Bluetooth devices operate. As shown in the figure, this band is occupied with several wideband WLAN signals, and one Bluetooth signal somewhere near 2.4GHz. In contrast, no spectral activity except noise was detected in the 2.3~2.4GHz band. The results show that either the incumbents of this band remained silent during our measurement period, or there was no incumbent at all. In any case, the band is perfect for LSA to provide predictable QoS support.

Although Fig. 2 suggests the potentials of LSA in these bands, a more long-term spectral observation is needed as the behaviors of incumbents may vary at a larger time scale. In what follows, our complete (26 days) measurement results are presented and analyzed.

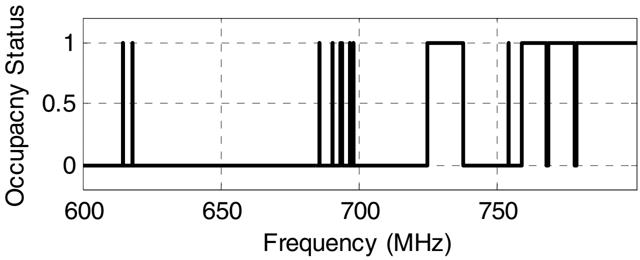


(a) 600~800MHz

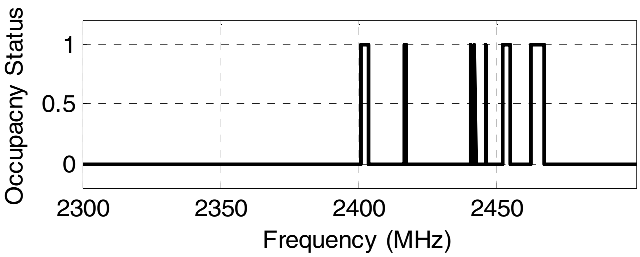


(b) 2.3~2.5GHz

Fig. 2. Snapshots of the measured spectrum



(a) 600~800MHz



(b) 2.3~2.5GHz

Fig. 3. The corresponding spectrum occupancy status of Fig 2 (1 for occupied and 0 for vacant)

4 Variation in Spectrum Occupancy

In order to quantify the incumbents' behaviors based on the measurement results, the occupancy state of a measured spectrum must be determined first. Since there is no prior knowledge about the RF characteristics of the incumbents in these bands, energy detection is applied to determine the occupation status. The measured spectral power at each frequency is compared with the noise floor. The noise floor is estimated with Forward Consecutive Mean Excision (FCME) [11]. Since the spectral power of an incumbent signal may vary within its transmission bandwidth, direct comparison between the spectral power and the noise floor leads to an underestimate in spectrum usage. Therefore, the occupancy status is determined with Localization Algorithm with Double-thresholding and Adjacent Channel Clustering (LAD-ACC) [12]. Take the spectrum snapshots in Fig. 2 as an example. The corresponding occupancy status determined with LAD-ACC is shown in Fig. 3.

The spectrum of the incumbents may vary in both time and frequency domains. To capture the statistics of spectrum occupancy in each domain, we define so-called temporal and spectral occupancy rates as follows. Let $O(f, t)$ be the indicator of occupation status at frequency f ($f = 1, 2, \ldots, N_F$) and time t ($t = 1, 2, \ldots, N_T$). The temporal occupancy rate is defined as

$$R_T(f) = \frac{1}{N_T}\sum_{t=1}^{N_T} O(f,t), \tag{1}$$

which is the proportion of the measurement time occupied by the incumbents at frequency f. On the other hand, the spectral occupancy rate is defined as

$$R_F(t) = \frac{1}{N_F}\sum_{f=1}^{N_F} O(f,t), \tag{2}$$

which is the proportion of the spectrum occupied by the incumbent at time t. It is often referred to as duty cycle in literature [13]. The occupancy statistics in different domains have different interpretations. A high temporal occupancy rate usually indicates frequent incumbent usage. In this case, the licensees may not benefit from LSA due to frequent evacuation. On the other hand, a high spectral occupancy rate indicates that a large number of incumbents operate simultaneously in these bands, or a few incumbents with large transmission bandwidth exist. Either of the cases makes the corresponding bands unsuitable for LSA with predictable QoS support.

The temporal occupancy rates of our 26-day measurement results are calculated for 600~700MHz band and shown in Fig. 4(a). The rate is about 70% at frequencies around 685MHz, roughly 20%~25% at some frequencies in the lower and upper parts of 600MHz band, and is almost zero for the rest of the band. The result shows that the majority of the incumbents in 600~700MHz band used spectrum in a concentrated manner; that is, few of them used other frequencies and the majority of 600~700MHz was left unused during the 26-day observation. The rates evaluated in 2.3~2.4GHz band are uniformly zero, as shown in Fig. 4(b). The uniformity implies either the incumbents remained dormant, or there were no incumbent near our observatory.

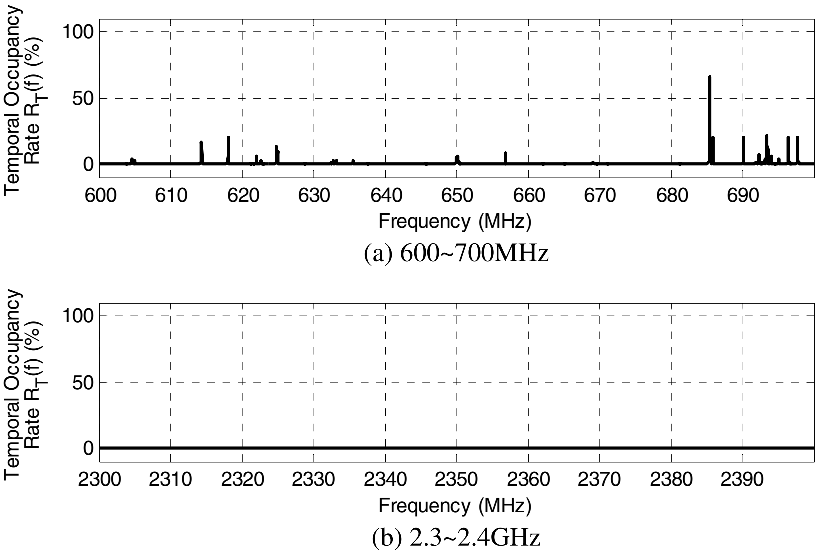


Fig. 4. Temporal occupancy rate

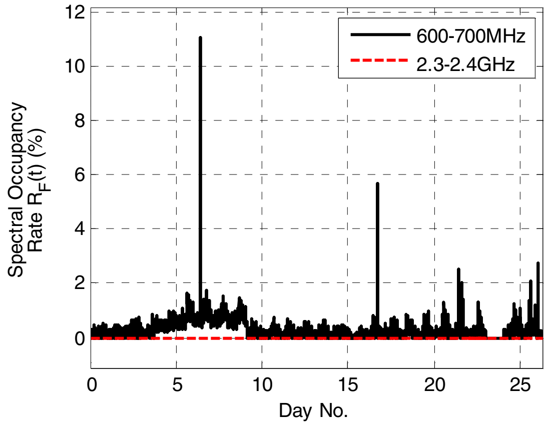


Fig. 5. Spectral occupancy rate

The spectral occupancy rates are also evaluated with all the 26-day records of spectrum measurement. Fig. 5 shows the result in a chronological order with two traces corresponding to the respective bands. The spectral occupancy rates in 600~700MHz fluctuate with a period of roughly a day. The rates are higher from Day 4 to Day 9, but they remain below 3% except for two days, which are less than 12%, on Day 7 and Day 17. The low occupancy in the frequency domain for most of the observation indicates there was no wideband incumbent user observed during our 26-day measurement period. On the other hand, the spectral occupancy rates are zero in 2.3~2.4GHz band. The zero rates in spectral occupancy, together with the zero rates in temporal occupancy in Fig. 4(b), confirm the absence of the incumbents in this band during our measurement.

As mentioned in Section II, the incumbent behaviors significantly affect the performance of LSA. Based on the temporal and spectral occupancy rates observed in 600~700MHz, it is found that the incumbents occupied less than 2% of this band for most of the time. The concentration of the incumbents in spectrum usage shows that the licensees could benefit from LSA in these white spaces without frequent evacuation. In addition, zero occupancy in 2.3~2.4GHz indicates no active incumbents found during the measurement period. The result shows that LSA licensees can provide predictable QoS or even guaranteed QoS in this band in Taipei and presumably the rest of Taiwan.

5 Conclusion

Both 600~700MHz and 2.3~2.4GHz bands, according to the draft of Taiwan Frequency Provision Plan, are considered to be opened for commercial mobile communication in the near future. The two bands are currently assigned or licensed to some incumbents. Given that the expense of spectrum refarming/reclaiming is very high, LSA seems to be a good alternative for efficient spectrum usage. The usage behaviors of the incumbents, however, determine the feasibility of LSA. To assess the feasibility of LSA in Taiwan, we conducted a 26-day spectrum observation in Taipei, Taiwan, in the midst of 2014. Our measurement results show that in 600~700MHz band, the temporal occupancy rates are considered high only at 685MHz (about 70%), moderate at a few others (about 20~25%), and almost zero for the rest of the band. The result indicates that the incumbents only use some fixed frequencies for their narrowband transmission. In 2.3~2.4GHz band, both temporal and spectral occupancy rates are zero throughout the 26-day observation period. The results of this band indicate that the entire band is purely white space. Such low spectrum usage, along with predictable patterns in temporal and frequency domains, makes LSA an economic and feasible solution in Taiwan.

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