On Second Thoughts: finding a value for shared spectrum

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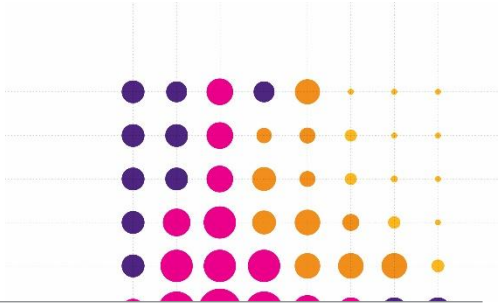


With an ever-increasing demand for bandwidth and capacity on telecommunications networks, and continued or increased use of spectrum for science, navigation, military and monitoring, the question of spectrum sharing has never been more important. New sharing mechanisms are being developed to maintain access to spectrum for existing users, while making sure that frequencies are being used to their maximum effectiveness. Sharing itself is not a new concept, but with the advent of more dynamic sharing systems – and the cost of implementing and monitoring them – it is increasingly uncertain how this secondary use of spectrum should be charged for. This paper explores the different ways in which spectrum can be shared and how this will impact on its value, not just for the new user but also for the incumbent.

Before we look at value, it is important to understand how spectrum may be shared between users. If two users attempt to transmit using the exact same frequency at the same time in the same geographic area, the resulting interference will mean that the signals will be unintelligible for all. To mitigate this, the two users must liaise, either to determine an encryption and decryption algorithm which allows the signals to be combined and separated after transmission, or to share the frequency in terms of time and location.

In unlicensed spectrum bands, this "liaison" can take place automatically, with (for example) WiFi devices avoiding interference by using adjacent frequencies based on a sense and detect approach. With sufficient spectrum bandwidth, all nearby WiFi users can be accommodated at required speed and reliability. However, increasingly crowded spectrum threatens this availability (see the boxout on Spectrum Commons opposite), and the lack of guarantees on quality or connection availability mean that this spectrum is not suitable for critical users or even standard commercial networks, giving it significantly lower value.

For these users, licenced spectrum provides a higher guarantee of quality and availability, and the cost of the licence can reflect this. Mobile network operators, for example, rely on their spectrum holdings being available and free from interference constantly. PPDR requires guaranteed availability when needed but this may not be the case all the time if it is shared – and the commercial price that can be paid for this spectrum does not reflect the social benefit that it realises.

Unfortunately, there is a finite amount of spectrum available, particularly in bands that are suitable for most uses. There is certainly not enough available for all users to have full access to enough spectrum for all potential expansion of demand. In the past this has led to situations such as PMSE using TV white space spectrum, but increasing amounts of sharing and new approaches are needed to meet current and future spectrum demands.

Types of sharing

In the past, sharing of spectrum bands has been done in three ways: **geographically**, with users given precedence in defined regions or areas; **time-based**, with users able to use spectrum at defined periods of the day or month; and **frequency-based**, where an overall band is split into smaller fragments.

Sharing has become more capable – and more complex – with the introduction of dynamic sharing, where users can coordinate

The Tragedy of the Spectrum Commons

In 1968 Garret Hardin published a paper[1] arguing that open pastures and common land would usually be ruined by overgrazing, because adding additional livestock would give a marginal benefit to individuals, and these individuals would not care about the overall loss to society. This paper built on lectures delivered in 1833 by William Lloyd[2], who argued that an open common ground would lead to undernourished livestock because of a lack of maintenance.

Analogies to this situation have long been considered in terms of spectrum, where additional users could theoretically reduce the speed and reliability of the network for all existing users. There is no disincentive for the new user (they are gaining a connection which they otherwise would not have), but there is a loss for all existing users. Since the 1950s there have been calls for mitigation – through ownership of spectrum, licencing, or restrictions on use[3]. The licencing of spectrum alleviated these concerns, but there remain large unlicenced bands which are at risk of overcrowding.

Until recently, such a trade-off had not been experienced, leading to some commentators underplaying the capacity constraints of the unlicenced bands[4]. However, recent increases in devices and services have led to calls for new unlicenced bands – in particular, the upper 6 GHz band, which is fought over around the world by IMT and WiFi users.

and liaise to ensure a fair share of spectrum, potentially with some users having priority over others. It is this situation which we examine here, with there being a primary user for spectrum, accompanied by secondary services who will use spectrum when it is available.

Interference considerations for secondary services

According to the ITU Radio Regulations[5], a secondary service:

- "shall not cause harmful interference to stations of primary services to which frequencies are already assigned or to which frequencies may be assigned at a later date",
- "cannot claim protection from harmful interference from stations of a primary service to which frequencies are already assigned or may be assigned at a later date", but
- "can claim protection, however, from harmful interference from stations of the same or other secondary service(s) to which frequencies may be assigned at a later date."[6]

Unlike primary services, under the ITU's definitions there is no guaranteed protection from harmful interference, which makes it impossible to guarantee a certain quality of service (QoS).

However, secondary services may utilise spectrum based on time or geographic sharing and, although this may constrain the service, this can reduce the risk of interference issues and also enable quality requirements to be met. For example, secondary services may be for land-based use and these can effectively share with maritime services.

Primary and (some) secondary services will normally be authorised on the basis of individual transmitter or spectrum licences with the technical and operational requirements specified to ensure a guaranteed quality of service. This more limited licencing pool means that issues surrounding the use of unlicenced spectrum are reduced, giving added value to the spectrum. To reflect this value to all users of spectrum, and to ensure there is no excess demand, regulators will use fees.

Objectives of setting fees

Best practice requires that spectrum fees be set in a fair, objective and transparent manner without incurring undue administrative costs, while promoting efficient use of spectrum[7].

In general, the two main objectives for spectrum pricing are:

- Covering costs of spectrum management activity (such as assignment, monitoring, investigations, enforcement) – referred to as '**cost recovery fees**'; and
- Reflecting economic value by providing incentives to ensure efficient use of assigned spectrum, particularly in frequency bands or locations where there is excess demand or where demand is expected to exceed supply in the foreseeable future – referred to as administrative incentive pricing (AIP), market-based fees or '**opportunity cost fees**'.

Fees are generally only associated with licences to use spectrum; in the case of unlicensed services there is usually no fee to pay since the costs of day-to-day spectrum management are normally minimal (the majority of the activities being in advance of spectrum becoming available) and there being no measurable opportunity cost since there is no guaranteed access to spectrum.

For mobile network spectrum, where demand exceeds supply, auctions have come to be widely accepted as the standard approach for setting market-based fees, although the reliance on auctions is diminishing as the amount of spectrum used by mobile networks is increasing. For most other services, auctions are less commonly used as the pricing mechanism for various reasons, such as the nature of the service, demand for the frequencies and the complexity of an auction.

Measuring the value of spectrum for primary users

It is noted above that one purpose of fees is to ensure there is no unmet excess demand for spectrum; this in turn will mean that spectrum is being used at its most efficient level. Spectrum users will wish to acquire more spectrum up to the point at which the fees are equal to the value of the spectrum (which will generally decrease on a per-MHz basis the more spectrum that is acquired). Therefore, in order to consider the right level of fees, we must estimate the value of spectrum.

For primary users, this exercise is well-understood. There are multiple ways of understanding the value of spectrum bands, depending on how it is used and the benefits that accrue from it. Where spectrum is a key input, then value can be estimated from the full value of the service provided. If services could be provided using an alternative system – through network densification, for example, or via unlicensed spectrum, then the cost saving or incremental benefit should be used instead. If values are unclear, regulators can look at the value of alternative use of the spectrum, and charge an increment over the opportunity cost.

In recent years, the direct link between value and price has lessened, as regulators have increasingly considered the social value of spectrum applications and adjusted private costs to account for public externalities. Nevertheless, the value for exclusive use of spectrum remains high.

The value of spectrum for a secondary user

Having examined how spectrum is valued by an exclusive user, we can now consider the differences when we move to a spectrum sharer. In general, those looking to share spectrum on a secondary basis will have lower expectations of availability and service quality. The lack of certainty of spectrum availability will reduce the expectations that can be placed on the spectrum within a business plan. For most consumer-facing services, where it would not be acceptable to have a complete lack of

service, the secondary spectrum would need to be used only for additional capacity or capabilities over the baseline service.

In order to accurately estimate the value of spectrum to the secondary user, therefore, we need to consider the following.

- How the spectrum is used: would it only be needed and deployed in restricted circumstances (such as at sports events, during harvesting, or for satellite reconfigurations)?
- How often will the primary service restrict access: it may be that the primary user requires spectrum only in the case of emergency or military action, in which case the spectrum would be available for 99% of the time for secondary use?
- What would the alternative cost be: if the secondary use were not available, would the user need to acquire additional exclusive-use spectrum, or could it use other methods such as network densification?

It is clear that the value of spectrum being used on a secondary basis is considerably lower than spectrum used exclusively. However, the extent to which the value is lower will depend on operational and logistical issues, involving both primary and secondary use. Further, it is likely that this value will be higher than zero, which would be the case absent any sharing.

Impacts of sharing on primary user value

As outlined above the value to a secondary user is significantly lower than the value to a primary user. However, the very act of sharing may impact on the primary user as well, so that the value is lower than it would be if the band were used exclusively.

Even if systems were put in place to ensure the primacy of spectrum use, there is always a possibility of equipment malfunction or incorrect implementation of a database system, which would introduce interference, significantly impacting any critical service. While there is always the possibility of interference from external sources, the secondary use of spectrum would mean that there is more equipment deployed which could cause this interference.

Therefore, despite the fact that primary users should theoretically see no change in their spectrum use due to sharing, there is an inherent increase in uncertainty which leads to reduced value.

Costs of implementation

At the same time as these impacts on value, implementing a spectrum sharing mechanism will also add costs to a business. The form of implementation will mean that costs will initially be incurred by different parties.

A database or register will mean that the regulator (or a funded third-party) will need to pay to build and maintain a system, including providing access for spectrum users. Primary users will incur costs in keeping the database up to date; secondary users will incur costs in liaising with the register and implementation.

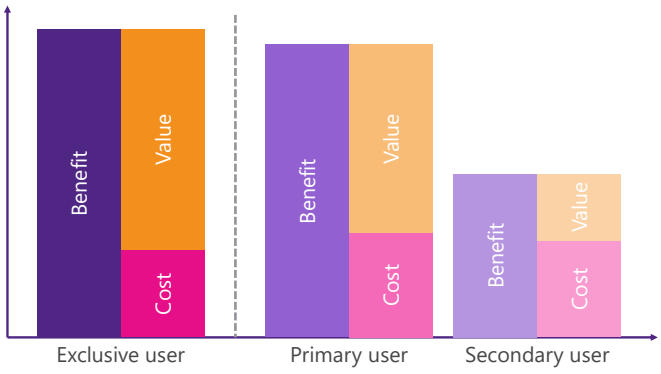
If the system relies on a heartbeat – where the primary user broadcasts their need to use the spectrum, as used in CBRS (see below) – then this broadcast incurs additional cost, as well as the implementation of any system set up to listen for the heartbeat. For more dynamic equipment, much of the cost would be incurred by the secondary user, including sensing equipment in their networks and implementing a stop-switch if other use of the spectrum were detected. However, primary users may still need to upgrade their networks to facilitate the sharing.

There may also be additional costs associated with the mitigation of interference, particularly for the primary user. When sharing is implemented on a geographic basis, for example, the primary user may need to consider how to reduce the footprint of its network, or it may need to implement interference mitigation at the edges of the network.

Overall benefits

With such increases in costs, and reduced benefits to both primary and secondary users, it may seem that sharing will not be beneficial to implement. However, in most cases the reduction in value to primary users will be relatively modest, and there will be a clear value for the secondary use.

Figure 1: Comparison of spectrum value



It can be seen that in this example, there is a small reduction in benefit for the primary user alongside an increase in cost, but the additional benefit and value coming from the secondary user outweighs this, leading to an overall gain. Part of this benefit to the secondary user could be used to compensate the primary user for the loss of exclusivity.

Setting fees for licensed secondary services

The authorisation approach will have an impact on fees for secondary services. Where the secondary use is not licensed then there are limited spectrum management costs and, as noted above, fees would not be justified. However, in the case

where there is a licensing process and the spectrum users and use registered, then there will be management costs. At the same time, as previously noted, fees can be used to incentivise efficient use of spectrum, although this must be adjusted for the ways in which value is reduced through reduced certainty and availability, and increased costs. Fees will be, at the maximum, the value of the licenced primary service, and at the minimum, the zero fees charged for unlicenced services.

Other considerations in setting the fees are as follows.

- Fairness and objectivity mean that fees should be based on objective factors, and all licence holders in a given frequency band should be treated on an equitable basis. However, the difference in utility between primary and secondary use should be recognised.
- Administrative costs will be low if the fee schedule is simple to administer. The simplest fee schedule would be one involving a flat fee payment to cover spectrum management costs for the secondary services. However, this would not necessarily promote efficient spectrum use or allow for compensation to primary users for the loss of exclusivity.
- Auctions may still apply in setting market values, but the expectation would be much lower prices would apply to, for example, spectrum for secondary cellular services if there is no guarantee of QoS.
- One option for setting fees for a secondary service shared on time, could be on the basis of the percentage of time the spectrum would be available. Clearly as the percentage of time access to the spectrum nears zero then there would be limited applications.

It will be important, whatever the basis of the fees, that the approach adopted is transparent and published.

Setting a price

As well as the need for objectivity and transparency, the price will need to reflect the alternatives available in the market. This is a delicate balancing act. If fees for secondary use are set too high, the users are likely to just use unlicenced spectrum, putting further strain on the common resource, or not expand capacity at all, both of which will lead to lower quality of service. If fees are set too low, then this may lead to spectrum hoarding, or an imposition of sharing and higher costs for primary users where it is not justified. Further, if prices are set very low for spectrum where the sharing obligation is less onerous (so there is less geography or time restricted from use), then users may opt to reduce their use of exclusive spectrum.

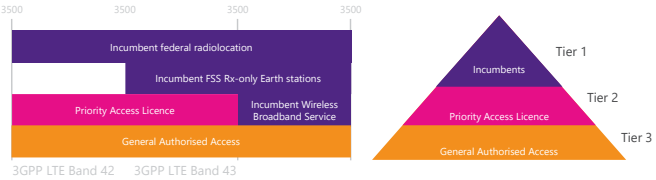
As well as fees, regulators can use non-financial conditions to incentivise use. If secondary users may have spectrum licences revoked if not used, the likelihood of hoarding will disappear. There can also be requirements for network sharing (where, for example, an emergency services network may agree to share its spectrum when it is not used, in return for access to a mobile network in times of crisis), or specific service obligations.

Overall, the value of spectrum to secondary users will be significantly lower than either the value for exclusive use, or the value to primary users. The price must be set taking account of the reduction in overall benefit to the user, but regulators have a number of other considerations to include, as we have noted.

Case study: CBRS in the United States

In the US the Citizen's Band between 3550 and 3700 MHz provides an example of different fees based on the service tier and therefore the level of protection from interference. Tier 3 is for General Authorised Access (GAA) and is "lightly-licensed" with no cost for the spectrum and no pre-defined bandwidth or duration. However, the use is such that interference cannot be caused to Tier 2 (priority access) and Tier 1 (incumbents) and there is no protection afforded from other spectrum users.

Figure 2: CBRS in the US



The Tier 2 priority access licences (PAL) were awarded at auction, with significantly reduced prices, compared to international benchmarks for similar spectrum. There are defined interference protections from other PALs and all GAA. The licences awarded were for one 10 MHz channel in one license area (county).

To discuss how Plum can assist with secondary use spectrum valuation and pricing policies in your circumstances, email us at info@plumconsulting.co.uk

[1] Hardin G (1968): "The Tragedy of the Commons", Science, New Series, Vol 162, No 3859, pp 1243-1248
[2] Lloyd WF (1833): "Two Lectures on the Checks to Population", Oxford University Press
[3] See, for example, Brito J (2007): "The Spectrum Commons in Theory and Practice", Stanford Technology Law Review, from http://stlr.stanford.edu/pdf/brito-commons.pdf
[4] PolicyTracker (2016): "The tragedy of the commons: tragically misunderstood?", from https://www.policytracker.com/blog/the-tragedy-of-the-commons-tragically-misunderstood/
[5] ITU (2024), Radio Regulations Article 5, Section II, para 5.28 onwards
[6] First in time, first in right
[7] For example, see ITU-InfoDev ICT Regulation Toolkit, Chapter 5.5 http://www.ictregulationtoolkit.org/toolkit/5.5