Spectrum Efficiency & Mesh Networks

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ABSTRACT: This paper examines the issues affecting the efficient use of spectrum. It looks at the origins of the current regulatory framework, the technological and economic bases of a proposed alternative model – the use of spectrum as a commons – with particular emphasis on Mesh networks and how they might influence the adoption of this alternative model.

1. Introduction

In recent years, there has been a growth in the variety of uses to which spectrum is put and a corresponding increase in the demand for Radio Frequency (RF) spectrum. Technological and economic changes have spawned debates as to whether the current regulatory framework for the use of spectrum is the most efficient.

Soon after the popularity of broadcast radio spread in the 1920s, the problem of interference became a major concern. If two or more transmitters in the same city choose to transmit on the same (or very close) frequency, they interfered with each other and it was impossible for the receiver to decode any information. It was this problem – the interference caused by the fact that the receivers could only detect the loudest signal from a sea of others – that led to the creation of the property right standard of priority in use where the first user of the RF spectrum "owned the frequency". The allocation of spectrum by administrative fiat arose because of the technological limitation of receivers designed only to 'hear' the loudest transmitters. This meant that two transmitters shouting at the same 'volume' (power) and in the same 'area' (frequency), made it impossible for the simple receiver to hear any of them.

The chaos that followed when the Commerce Department in the United States of America stopped supporting claims of priority in the use of spectrum led many countries in the world (including the UK) to establish national agencies charged with the responsibility of allocating spectrum to various uses and assigning them to users[1]. The prevention of interference became a major concern for regulators and necessitated the controlled use of spectrum. This arrangement however derives from the obsolete structure of radio equipment market in the early 1920's and is neither necessitated by technological or economic parameters.[1]

A major critique to this method of spectrum allocation was made by Ronald Coase (1991)[1] who argued that market forces of demand and supply are far better at allocating resources than the most knowledgeable and well intentioned bureaucrat. His solution was to create sufficient property rights to the use of spectrum that allowed licensees to sell, buy or lease spectrum. He argued that the incentives of licensees to innovate are limited by the degree to which their licenses allow them to use their allocated frequencies for a variety of purposes and that the granting of sufficient property rights to licensees will result in greater innovation and efficiency in the use of RF spectrum.

The fact that the efficient use of spectrum is still being debated is evidence of the fact that:

1. Coase's model for the allocation of full property rights to the use of spectrum has not been fully implemented and the full economic benefits of a market based approach to the allocation of RF spectrum has not been realised or
2. There exists an even better regulatory framework for the efficient use of spectrum than that which allocates 'property' rights to its use.

This paper explores the workability of this alternative regulatory framework for the efficient use of spectrum in the light of recent technological advances.

2. An Alternative Regulatory Framework – the use of Spectrum as a commons

Reed (2001) argues that our understanding of the physics and architecture of the RF spectrum – the fact that the capacity of a fixed amount of spectrum in a fixed volume of space can be made to increase – contradicts the current regulatory framework model which treats spectrum as a 'property' by allocating rights to individuals/licensees. [7]

Benkler argues that the problem lies in the view of spectrum as a 'resource' that must be controlled and that spectrum is not a 'physical' resource like property that one can 'own'.[1] Technological advances – the reduced cost of processors, the increased sophistication of communications equipment and new technologies (UWB, CDMA, Agile Radio, OFDM to name a few) – have enabled transmissions of different technologies co-located within the same frequency bands and necessitate a review of the regulatory framework for the allocation of spectrum.

The effect of these advances in technology and innovation is a shift in the focus of regulators from that of simply preventing interference by specifying in considerable detail how spectrum should be used, to that of regulating the use of RF spectrum in a manner that encourages innovation, efficiency and enhances its use a public good.[2]

It is on this basis that Benkler (2002) advocates for the unlicensed use of spectrum i.e. as a commons. In this approach, the use of spectrum:

- is open to all but subject to government only regulation.
- is highly efficient as consumers are allowed to put their devices to their personal highest valued use.
- is totally flexible and no restriction is placed on content.
- is Co-ordinated rather than controlled to prevent interference.[2]

3. Technological Advances & Mesh Networks

The IEEE 802.11b and the IEEE 802.15 standards as used by WiFi and Bluetooth respectively are the two predominant wireless technologies operated within the 2.4 GHz ISM band. Current regulations limit the operation in this band to Direct Sequence Spread Spectrum (DSSS) and Frequency Hopped Spread Spectrum (FHSS) technologies. WiFi products are based on the DSSS technology and Bluetooth devices are based on the FHSS technology. Regulations governing the operation of the technologies make it impossible to operate both technologies in the same area without interference. The IEEE 802.11b standard allows for two basic network structures namely: Infrastructure-based (in which devices communicate via an access point) and ad-hoc based in which devices communicate by relaying messages through one another.[8]

Mesh networks which can be deployed using the IEEE 802.11b standard, route data, voice and instructions between nodes. They allow for continuous connections and reconfiguration around blocked paths by "hopping" from node to node until a connection can be established. Ad-hoc Mesh networks have no centralised control; can be used co-operatively to increase capacity with more users. They provide us with a framework that can be used to examine the extent to which the adoption of unlicensed spectrum use as a regulatory framework is feasible. Some advantages of deploying mesh networks include:

- Reduced attenuation
- Reduced multi-path problems
- Low set up costs

These advantages are evidenced by the huge growth the sales of WiFi equipment worldwide from under 5million in 2000 to over 30million in 2004. [10]

A number of issues however, are yet to be resolved in the deployment of mesh networks and they are as follows:

- In situation where high data rates are required, the available bandwidth for each device is significantly reduced due to continuous position updates
- Power consumption due to the need for devices to stay awake in order to relay information.
- Maximum number of hops and jumps through which a message is relayed.
- Interference

The crucial problem of interference is not novel. It is a problem in an unlicensed as well as in a licensed environment – perhaps even more so. Interference exists between the 802.11b and Bluetooth devices in the 2.4 GHz ISM band. Yet in spite of all these, the market for these devices continues to grow because working groups for both these technologies, individual consumers, researchers and equipment manufacturers continue to seek ways to enable the co-operative existence of devices using these technologies[10] especially in the development of mesh networks. The NSF Field tests, Metricom's Ricochet Network and Nokia rooftop are examples of the successful deployment of mesh networks within unlicensed frequency bands.[1] These offered huge cost savings and provided consumers with a variety of applications.

These examples show of the practical and successful deployment of mesh networks show that technology has advanced to the point where it allows us to successfully co-ordinate the use of equipment within an unlicensed frequency where rights to the use of RF Spectrum are not owned by any individually or organisation i.e. to use spectrum as a 'commons'. Mesh networks provide the capability to examine the extent to which the adoption of unlicensed spectrum use as a regulatory framework is feasible.

Although the changes in technology appear to be the basis of Benkler's call for a review of the current regulatory framework, the economic value to be derived from the adoption of this model is of critical importance. There is the question of whether the value to be derived from the use of spectrum as a commons sufficiently justifies or exceeds the cost.

4. Economic Considerations for a Change in the Regulatory Framework

The question asked in the previous section was whether the advancements in technology as evidenced by research and the successful practical deployments of mesh networks in the unlicensed ISM Band, are sufficient reasons to justify a change in the regulatory framework.

The huge impact of telecommunications on our economic welfare cannot be over emphasized. The economics of telecommunications are crucial and perhaps even more so than the technology and therefore, a change in any regulatory framework due to any change in technology must therefore be one that is much more economically viable.

A change in the regulatory framework to unlicensed use of spectrum will represent a shift in the control of decision making from government to equipment manufacturers that are sensitive to changes in the consumer market. Benkler (2002) argues that while spectrum owners will make decisions that allow them to increase the value they can appropriate from the sale or lease of their rights to spectrum, the incentive of equipment manufacturers is to maximize the value of equipment they produce by maximizing the value of communications their equipment make possible for end users.[1]

He argues that the designing of spectrum sharing protocols which reward compliant devices for example by giving faster repeated access for each transmission burst to a device that uses no more spectrum than is necessary provides sufficient incentives to equipment manufacturers to produce compliant equipment.[1] For a mesh networked device therefore, incentives might be put in place for example to give faster repeated access to a fridge that communicates with a microwave in a bandwidth efficient manner.

The practicality of this brings into question whether the average consumer is likely to purchase equipment that only incorporates "new, intelligent" technology. The average consumer is not very likely to purchase a fridge just because it can 'talk' to the microwave or 'surf' the internet.

The value which a consumer places in a product/service is dependent on the degree to which that product or service meets an everyday need and makes life simpler i.e. the extent to which it provides value to the consumer. The consumer may or may not be aware of this need until there is a product or service to meet it.

Although a market for equipment alone provides some incentives to equipment manufacturers in terms of revenue generated from the sale of expensive equipment, the incentives are even greater when there is a recurrent income associated with the sale of this equipment. This is because the number of consumers likely to purchase expensive equipment alone, e.g. brand new cars will not generate sufficient recurrent income to ensure its continued economic viability for the equipment manufacturer. The recurrent income allows the equipment manufacturer to subsidise the sale of this equipment since it almost guarantees a growth in the sale of equipment.

A sufficient incentive for equipment manufacturers of mesh network devices and a justification for a shift in the regulatory framework therefore, is when this technology which makes efficient use of spectrum also provides recurrent income for manufacturers.

5. An economic model for the viability of mesh networks

A good example of a technology that creates a recurrent income for equipment manufacturers is the case of PODcasting and Apple's iPod.[5]

Podcasting is a technology which allows users to subscribe to a feed or receive new files automatically and became popular in late 2004 largely for downloading audio files onto a portable audio player or personal computer. Using this technology, independent producers can create and self-publish syndicated “radio shows”. Other users can download these newscasts and radio shows and listen to them on an iPod, computer or portable music player at any time.[4]

Two days after Apple announced the release of iTunes 4.9, to which it added a podcast subscription feature, and a directory of podcasts at the iTunes music store with 3000 entries, it reported 1 million podcast subscriptions. This is a classical example of an equipment manufacturer providing a service that generates recurrent income from the sale of its equipment.[6,7]

A company like Apple which has the structure and expertise to charge for content incorporates a technology that provides its consumers with a service that is almost tailor-made to their needs, and available to them on demand. By doing this, Apple have not only provided consumers with an application that they value, they have created a huge market for iPods and recurrent income from the sale of podcasts subscriptions – the number of people using the iPod is forecast to reach 56.8 million by the end of the decade.[6] Consumers are much more likely to purchase an iPod now, because it can provide them with a service that is a better reflection of their own individual highest valued use of the service.

An example of a similar economic model for mesh networks using unlicensed frequency bands would be a partnership between a manufacturer of “intelligent” fridges and a food retailer. The intelligence built into the fridges will enable them purchase food as and when needed from the food retailer. This way, the equipment manufacturer has generated recurrent income from a partnership with the food retailer and the sale of its fridges and the food retailer is able to service its customers much more efficiently.

6. Conclusion

This paper considered some of the problems affecting the efficient use of RF spectrum. It looked at the current regulatory framework and how this is historically contingent upon the radio equipment market of the 1920’s. An alternative regulatory framework for the unlicensed use of spectrum as a “commons” was considered in the light of current technological developments with special emphasis on mesh networks. Finally, an economic model which provides equipment manufacturers which recurrent income was proposed as a sufficient incentive for the manufacture of spectrum efficient equipment.

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