To License, or Not To License: Tradeoffs and Challenges in 3G Spectrum Management

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***Abstract*— The purpose of this tutorial article is to explore the potential problems in spectrum management for next generation wireless systems. Specifically, we explore the ability of 3G networks to coordinate the use of both licensed and unlicensed spectrum in a highly competitive environment. First, we describe the current state of 3G standards activity. Then, we discuss the tradeoffs in the management of licensed spectrum, followed by an exploration of the tradeoffs involved in the wide-spread deployment of unlicensed wireless networks. In both cases, we argue that the technical difficulties created by these tradeoffs may only be resolved by proper cooperation between competing service providers. Furthermore, understanding the interplay between technical and economic decisions in wireless network deployment will enable both wireless service providers and regulators alike to predict the technology needs and market outcomes and will provide great benefit to the industry as a whole.**

***Index Terms*—3G, licensing, spectrum, interoperation**

I. Introduction

Second generation wireless was largely based on the distribution of licensed spectrum. Companies were required to purchase large amounts, estimating their bandwidth and customer needs, while making a huge investment and taking on significant risk. As 2G wireless technology was widely successful, the spectrum was well utilized, and there were correspondingly significant returns on the investment. However, the ost of spectrum distribution and management remains an industry concern, and has been a motvator for technological advances, such as the development of new techniques to efficiently re-use spectrum, with the goal of increasing the number of customers, while limiting cost. 3G networks are now being designed to increase the bandwidth allocation experienced by each customer, again requiring huge investments in licensed spectrum for each service provider. However, at the same time, 3G wireless local area networks are being developed to provide unlicensed bandwidth to local customers. The use of unlicensed bandwidth enables any entity to establish a wireless access point for Ethernet service, but lacks the coordination of the licensed wireless networks.

In this article, we explore the potential problems created by the diverse options for spectrum management in next generation wireless systems, exploring the ability of 3G networks to coordinate the use of both licensed and unlicensed spectrum in a highly competitive environment. In Section II, we describe the current state of 3G standards activity. Then, in Section III, we discuss the tradeoffs in the management of licensed spectrum, followed by an exploration of the tradeoffs involved in the wide-spread deployment of unlicensed wireless networks in Section IV. Finally, we conclude with a discussion of the benefits of cooperation among competing service providers as a means to overcome the difficulties in spectrum management. Furthermore, understanding the interplay between technical and economic decisions in wireless network deployment will enable both wireless service providers and regulators alike to predict the technology needs and market outcomes and will provide great benefit to the industry as a whole.

II. 3G Standardization

Significant standardization activity is occurring for WLANs within two global 3G standards bodies: the third generation partnership project (3GPP) and the third generation partnership project two (3GPP2). 3GPP has cooperated in the development and production of technical specifications for 2.5 and 3G systems based on GSM core networks. 3GPP2 is a collaborative effort for North American and Asian interests that focuses on advances for the corresponding North American and Asian 2.5/3G standards.

A. 3G Standards Challenges

WLAN systems are expected to provide complementary radio access for 3G, creating challenging open problems for 3GPP2 standardization, such as the inter-working of 3G cellular standards, e.g., UMTS and IMT2000, with WLAN standards, e.g., IEEE 802.11. In particular, some of the open issues for 3G/WLAN interoperation are:

- Defining the functionality and scope of any necessary interworking units (IWU), including the function and location of the IWU interfaces.
- Inter-system location management, i.e., terminal addressing for mobile terminals entering a WLAN network, location awareness of the WLAN system, and authentication and authorization during inter-system handoff.
- Inter-system handoff management, i.e., when and where should the mobile terminal handoff to the 3GWS or WLAN, how will resources be assigned, and how will the mobile terminal gain access in the new network?
- Physical, link, access and signaling layer protocols to achieve the necessary seamless interoperation between different types of networks.

Beyond the interoperation challenges, 3G systems remain challenged with respect to spectrum allocations for the wide variety of global services and standards.

B. 3G Spectrum Allocations

In the early 1990's the World Radiocommunication Conference (WRC) endorsed a preliminary allocation for wireless services for the IMT 2000. In the 1990's, a 170 MHz section of bandwidth was reserved for terrestrial use, while 60 MHz bandwidth was reserved for satellite. The total spectrum was 1885 to 2025 MHz and 2110 to 2200 MHz, while the satellite band was 1980 to 2010 MHz and 2170 to 2200 MHz. (The frequency gaps between 2025 to 2170 MHz and beyond 2200 MHz are reserved for other services such as Remote Sensing, Cable TV Relay Service, Electronic News Gathering and Space Research & Operation.) In 1995, the ITU World Radio Conference changed the frequency assignments. The satellite allocation for Region 2 (the Americas and the Caribbean) was revised to the 1990 to 2025 MHz and 2160 to 2200 MHz frequency bands [1].

In the year 2000, these allocations were updated to provide additional spectrum to the developing 3G IMT 2000 systems. The main motivation was to be able to support the exponentially increasing number of wireless and mobile subscribers and to provide an increasing variety of wireless and mobile services, ranging from mobile Internet to mobile e-commerce. Three bands were added to the IMT 2000 spectrum: 800 to 960 MHz, 1.7 GHz, and 2.5 GHz [2].

Regardless of the current state of spectrum allocation, the important question for industry participants is whether or not to invest, and how to quantify the effectiveness of that investment, considering all of the possible pitfalls. In the next section, we explore the difficulties in managing 3G licensed spectrum.

III. Difficulties with Licensed Spectrum

Licensing spectrum to service providers has been the normal mode of operation for 2G and 3G wireless wide area networks. The benefits of licensing include the orderly, controlled distribution of spectrum, and a built-in protection against competitors crowding into the same bandwidth. To obtain licensed spectrum, service providers may participate in spectrum auctions to purchase the portions of the spectrum needed for the type of wireless service being offered. However, the significant financial commitment required can introduce undue burdens on companies in the wireless industry—particularly when the company does not have a reasonably accurate estimate of a customer base, or when the promised service does not have as large a market as originally predicted. Thus, many techniques are currently being investigated to overcome the drawbacks of spectrum licenses. Beyond the expense of purchasing a license, many issues remain for licensed wireless spectrum, including: interference, cooperation, and inflexibility [3].

In an ideal world, each service provider follows the prescribed rules that provide service protection between adjacent spectrum assignments. In reality, each company is focused on providing the best service possible to their customers, which may result in some violations that impact other service providers. Resolving interference issues becomes a major undertaking, requiring meaningful enforcement, as well as the ability to build a case against a rogue competitor. In the absence of effective policies, service providers must be able to consider other options, such as investing in interference mitigation techniques, or entering into cooperative agreements.

In cooperative agreements, service providers can minimize interference and maximum use of spectrum, by trading, sharing and leasing portions of spectrum to their competitors. Cooperation provides some relief. However, there is a need to be able to quantify that relief when compared to other options, such as investing in the latest technology, or pursuing a certain growing market to increase the customer base. For example, when hot spots of congestion appear in a network, a company can invest in additional spectrum, it can enter into a lease to obtain spectrum from a competitor, it can re-apportion the spectrum at the base stations, through cell-splitting, sectorization, etc. From the perspective of the company experiencing congestion, which option is more cost-effective? From the perspective of the leasing company, what value should be placed on the leased services, in the context of the other options available? In addition, which of the options allow the service provider to be flexible and adjust to changing conditions?

Flexibility is a major problem for licensed spectrum because of the dynamic nature of wireless technology versus the static nature of licensed spectrum management. As mentioned previously, the financial commitments for wireless spectrum are based on estimations of market growth and customer base—two factors that can change very quickly, due to the emergence of a new technology, or a new "hot application," etc. Even if the service provider attempts to keep up with changes in technology, each new generation of wireless requires the deployment of a new infrastructure that must support both the legacy equipment and the new technology. One example of this problem was the emergence of 3G on top of the 2G technology. The expectations were optimistic, but the implementation has taken a decade, and has resulted in a divided standard. Inflexible spectrum management is a hindrance to service providers attempting to adjust to the changing and evolving wireless standards.

Because of the difficulties in managing licensed spectrum, many of the new wireless technologies that are experiencing rapid growth are those that use unlicensed spectrum, such as, Bluetooth, HiPerLAN, and IEEE 802.11 WLANs. The advantage to such networks is their rapid deployment and reduced cost. However, as the deployment of these networks increases, the need to manage the unlicensed users is becoming more and more apparent. In the next section, we explore some of the difficulties in spectrum management for 3G unlicensed wireless networks.

IV. Difficulties with Unlicensed Spectrum

A. Issues with Dense Deployment of Unlicensed Base Stations

Wireless services operating in unlicensed frequency bands are subject to special difficulties because the radio resources are allocated and used in a completely uncoordinated manner. As more and more networks (such as IEEE 802.11) are deployed in the same frequency band, these are likely to begin interfering with one another. Eventually, this *co-channel interference* can pose a severe limitation on the quality-of-service that can be offered. Consider, for example, a downtown area where several independent, adjacent business owners (such as coffee shops or restaurants) are providing WLAN access. Whenever a new provider installs a base station in the area, he may find the ether overcrowded with signals from terminals and base stations in the vicinity; likewise, users connected to his base station will spread co-channel interference that has adverse effects on other access points already established in the area. Because there is no coordination between the different business owners, the users of all networks as a whole may experience a degradation of service — despite the increased number of base stations.

We can illustrate this effect as follows. Consider a small segment of area (such as the aforementioned downtown district) which is populated by neighboring network access points transmitting in, for example, the industrial, scientific medical (ISM) frequency band. For a mobile at a given physical location (x, y), we can measure the quality of the available service in terms of the quality of the best available radio link to any of the base stations (for simplicity, we consider the downlink — i.e., from the base station to the mobile). This radio link quality is usually measured via the carrier-to-interference-and-noise ratio (CINR), which is the ratio of the carrier power (C) received from the base station of interest, to the sum of thermal noise (P) and the power of all received co-channel interference ($\{I_i\}$) from a total of N_i sources:

$$\text{CINR} = \frac{C}{I+N} = \frac{C}{\sum_{i=1}^{N_i} I_i + N} \tag{1}$$

(assuming a 100% channel utilization, which is somewhat pessimistic for most realistic networks). Whenever N dominates the denominator (which typically happens for cellular systems in rural areas), the system is said to be *noise limited*. If I dominates over N, the system is called *interference limited*; most second generation wireless systems are interference limited in urban areas.

To understand how radio propagation phenomena affect the CINR, radio engineers often adopt simplistic propagation models based on statistical assumptions. One popular model is referred to as the *log-normal log-distance* fading model, and can be used to model C and I as follows [4, Ch. 4]:

$$\begin{aligned} C\ [\text{dB}] &\sim N\left(\rho_0 - \eta \cdot 10 \log_{10}\left(\sqrt{(x-x_0)^2 + (y-y_0)^2}\right), \sigma\right) \\ I_i\ [\text{dB}] &\sim N\left(\rho_0 - \eta \cdot 10 \log_{10}\left(\sqrt{(x-x_i)^2 + (y-y_i)^2}\right), \sigma\right) \end{aligned} \tag{2}$$

where ρ_0 is the received power (in dB) at unit distance from the transmitter, (x, y) is the coordinate of the terminal of interest, (x_0, y_0) is the position of the base station currently connected to the mobile, (x_i, y_i) the location of the interfering source (base station) number i, and $N(\cdot, \cdot)$ denotes a Gaussian distribution. The variables σ and η are radio propagation parameters; "textbook choices" of these parameters for outdoor environments are $\sigma = 6$ and $\eta = 4$.

The log-distance log-normal propagation model can be used to illustrate how the radio environment in an unlicensed frequency band behaves in the interference-limited case. Figures 1–3 show the CINR (in dB) for some different base station configurations in the area under study, using the propagation model described in the above paragraph. For illustration purposes, we consider a CINR larger than 20 dB to be sufficient for service to be provided (in reality, a larger value will probably be required depending on the network type). In Figure 1, there are three base stations, providing service to about 22% of the area under study. Base stations A and B transmit with power 5 dB below the maximum power $P_{\max}$ allowed by the standard (which is, for example, about 29 dBm for the IEEE 802.11 standard), while C is using maximal power (0 dB relative to $P_{\max}$). In Figure 2, a fourth base station (D) is installed and set to transmit at nominal power $P_{\max}$. Due to the interference created by D, the coverage of A–C decreases; in fact, the *total* coverage of the area decreases from 22% to 17%. In Figure 3, the power of D is reduced to 20 dB below $P_{\max}$; both the coverage of C as well as the total coverage of the area are now restored to those in Figure 1.

The above example reflects a more general problem associated with the deployment of additional access points in unlicensed frequency bands. From a pure "selfish" perspective, a location owner or service provider entering the market should let her base station transmit with the maximum allowable power: doing so would maximize the area that is covered by that particular base station, and thereby ultimately maximize the provider's revenues. At the same time, as the above example demonstrated, installing a new base station close to other access points already in place will certainly create co-channel interference that decreases the quality of service for several other nodes in the network. This may result in the other operators increasing their transmit power to regain the loss of coverage they experienced when the new vendor first entered the market. Eventually, this can lead to a behavior where all base stations in a dense network are set to transmit with unnecessarily large power, at the same time as the quality-of-service is inadequate

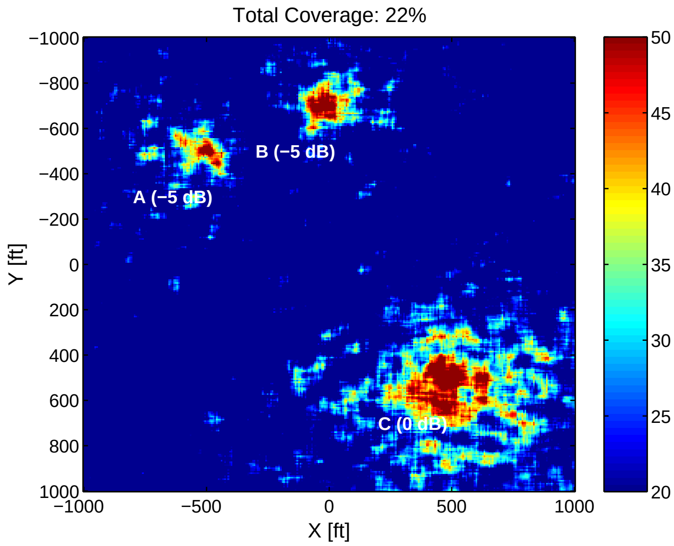

Fig. 1. Three base stations provide service to about 22% of the area under study. Base stations A and B transmit with power 5 dB below the maximum power $P_{\max}$ allowed by the standard (which is, for example, about 29 dBm for the IEEE 802.11 standard), while C is using maximal power (0 dB relative to $P_{\max}$).

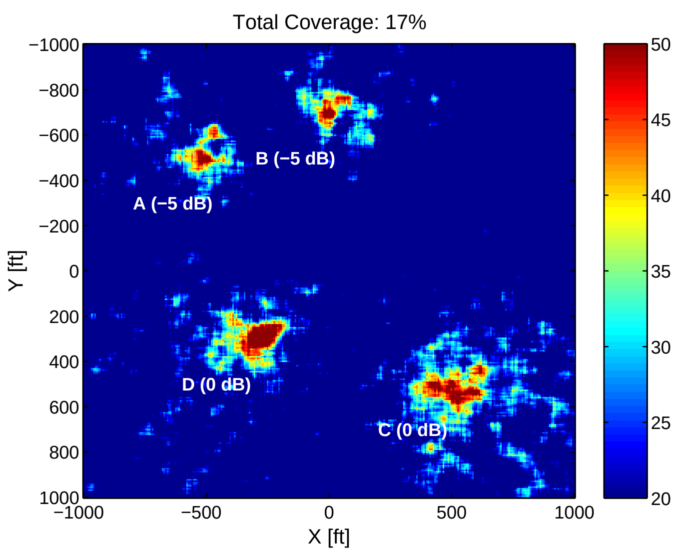

Fig. 2. A fourth base station (D) is installed and set to transmit at nominal power $P_{\max}$. Due to the interference created by D, the coverage of A–C decreases; in fact, the *total* coverage of the area decreases from 22% to 17%.

for many users.

V. Conclusions and Future Work

Many phenomena in economic systems can be understood as the result of a balance reached between the two extremes of fully unregulated anarchistic competition, and a totally controlled operation. For a long time, most economic theory was based on the hypothesis that all individual players in a system act entirely in order to maximize their self-interest. This theory, rooted in a survival-of-the-fittest paradigm, may appear as a natural. Nevertheless, many later studies have shown that actions that appear to benefit the individual may not be the best for

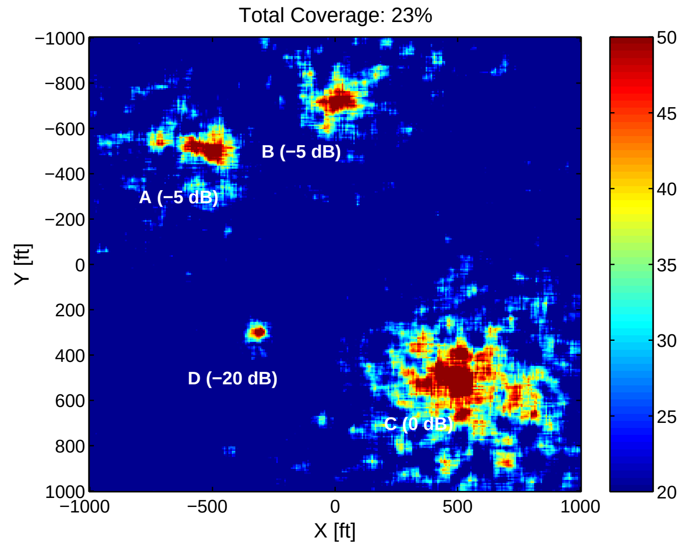

Fig. 3. The power of D is reduced to 20 dB below $P_{\max}$; both the coverage of C as well as the total coverage of the area are now restored to those in Figure 1.

the group — and that what is bad for the group may be defective for the individual in the long run. Hence cooperation that does not appear to immediately benefit an individual may turn out to be the best thing to do in the long run. It is possible that similar conclusions hold for the scenarios that we have considered in this section: because no central frequency planning is performed, for networks to function efficiently, mutual agreements may have to be executed between providers on issues such as base station locations, transmission powers.

Solutions to these problems will most likely comprise a mix of strategies from business and network planning. The spectrum management may lead to contracts where location owners cooperate to make best possible use of the available spectrum resources. From a pure technical point of view, the operation of base stations belonging to different provides could be coordinated in a centralized manner by using a radio-planning tool, or by using advanced power control algorithms rooted in control theory [5]. However, in practice, due to the decentralized nature of access point in unlicensed frequency bands, this may not be realistic and the community must take a more pragmatic approach to solving these problems.

Traditionally, the engineering and economic disciplines have taken separate approaches to technology choices, investment decisions, and regulatory policies. Although this has led to a good understanding of many tradeoffs involved in network planning, such an approach is inadequate to resolve the physical, access, network, and economic implications of a next generation technology. The questions raised here can only be addressed by specifically analyzing the interplay between engineering and economic decisions. At the University of Florida, work is currently underway to develop new methodologies to explore the techno-economical dynamics of wireless network deployment.

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