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Re:	Call for Contributions: Requirements for WirelessHUMAN Systems, submitted 2000-04-10
Abstract	Although unlicensed spectrum has tremendous advantages, it is always possible that an unlicensed wireless system will experience intolerable levels of interference from its neighbors. Before developing products and services for which interference is problematic, strategies must be adopted to minimize this effect. One strategy is to keep utilization low, possibly by allocating excess spectrum, or strictly limiting transmission power. Another strategy is to encourage efficient coexistence, possibly by adopting an effective *etiquette*. Further study is required, and if problems are to be averted, this study should begin soon.
Purpose	To identify some of the challenges of providing quality of service in unlicensed spectrum that is adequate for high-speed metropolitan-area networks, and to suggest useful future studies.
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The Path Towards Efficient Coexistence in Unlicensed Spectrum

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Introduction

Unlicensed spectrum has tremendous advantages over licensed spectrum [1]. There are applications that are best supported, or only supported, with unlicensed spectrum. Unfortunately, adequate protection from interference is not one of those advantages; there is always a risk that too many systems will be deployed in close proximity, and all will suffer. As a result, a company is gambling when it develops products or services using unlicensed spectrum, and the FCC is gambling when it allocates a new block of unlicensed spectrum. This IEEE committee may have the opportunity to improve the odds in those gambles. This will require studies into a variety of pressing questions.

The Challenge

Unlicensed spectrum has two principal advantages. First, because there is no licensing procedure, deployment can be fast and inexpensive. This makes it practical to mass market inexpensive wireless systems for which the cost of a single license would be a significant part of a system's overall deployment cost. Second, unlicensed spectrum is shared. Such sharing is essential for wireless systems that are moved from place to place, like laptop computers that can be connected via a portable wireless local-area network, or devices forming a smart environment [2]. It would not be practical to require the owners of a portable device to acquire a license that covers every place they may ever wish the system to operate. Fixed applications that that transmit sporadically or at fluctuating rates can also make more efficient use of unlicensed spectrum; when one is not transmitting, another can. It has been shown that cellular systems could carry significantly more traffic if they shared spectrum dynamically, provided that competing firms are willing to adopt cooperative strategies that serve their common interest [3]. Metropolitan area networks carrying bursty data traffic could expect even greater efficiency gains, if competing networks can be motivated to adopt such techniques.

One serious disadvantage of unlicensed spectrum is the lack of motivation to conserve shared spectrum. All system designs involve a trade-off between competing goals, such as reducing equipment costs while improving reception quality. In licensed spectrum, where the spectrum consumed is the exclusive domain of the end users, conserving spectrum is an important design goal. In unlicensed spectrum, a designer may adopt a *greedy* approach, where the more a device wastes shared spectrum in favor of its own design goals, the more we consider it to be greedy. For example, when America On Line began offering unlimited Internet access at a fixed monthly cost, subscribers greatly increased usage. Some would remain logged on for hours when not using the system, to avoid the hassle of reestablishing a connection. Similarly, it is possible to reduce access delays or decrease system cost in unlicensed spectrum with greedy access protocols [4]. If many designers adopt such a strategy, performance could be intolerable for all systems in areas where utilization is high. Consumers would complain bitterly, especially if performance was good when they purchased a given product or service, and then performance degraded over time.

This phenomenon may not seem like a problem at the moment, as there are vast new unlicensed bands with low utilization. However, there is also a proliferation of new unlicensed devices on the horizon. Moreover, given the scarcity of licenses, some companies may use unlicensed spectrum for applications that are actually better suited for licensed spectrum, unless there is some deterrent to doing so. We may see no problems initially, but severe problems as utilization increases. This occurred, for example, with CB radios, which are unlicensed to accommodate their mobility. When utilization was low, there was no problem. When utilization became high, and interference great, many users responded by buying radios with greater transmit power. This reinforced the scarcity, causing even more users to increase their transmit power.

The Solution

There are two ways of providing unlicensed devices some protection from interference. One is to keep spectrum utilization low. This could be done by allocating excess spectrum, by imposing strict limitations on transmission power, or by imposing fees on unlicensed devices that are large enough to limit consumer demand.

The alternative is to construct a framework that allows devices to coexist without excessive interference. There are a wide range of choices, which must balance potentially conflicting objectives [2]:

- All devices should have adequate quality of service, where the definition of "adequate" may differ considerably from one application to the next.
- No device should starve, i.e. be blocked from transmission for extended periods. This is a special case of inadequate quality-of-service, but starvation deserves particular attention in an environment where one device may be allowed to transmit indefinitely to the exclusion of others in the band.
- Policies and standards should not inhibit innovation in this rapidly changing field.
- The limited spectrum should be used efficiently, which implies high frequency reuse and some deterrence to wasting spectrum.
- Meeting the imposed rules should not significantly increase device costs.

One promising technique is the adoption of an effective *etiquette*, which places some limitations on when devices can transmit, as well the duration, power, and bandwidth of those transmissions. For example, the unlicensed personal communications services (UPCS) band uses a listen-before-talk approach, whereby a device is not allowed to transmit until it has detected the band "free" throughout a monitoring period. An effective etiquette would facilitate expansion of applications intended for the band, discourage applications that are not well suited to unlicensed and that would interfere with intended use, and encourage efficient use of the band.

The UPCS etiquette is a good example of an *ineffective* solution. Although it has some advantages, devices operating under the UPCS etiquette can still improve their performance by causing more interference for the neighbors than is necessary [4]. One possible solution is to build explicit incentives into the etiquette. We have proposed imposing a *penalty* on devices which is an increasing function of the spectrum resources consumed. Thus, a device that uses excessive spectrum resources would have a higher penalty than other devices. For example, in a listen-before-talk etiquette, a device that has transmitted at high power or duration may have a larger monitoring time, a smaller power limit, or a different definition of what constitutes a "free" channel. It has been shown that this approach has great promise in curbing greed [5].

Next Steps

Just as there are two ways to provide acceptable quality in an unlicensed band, there are two avenues for study. The committee should attempt to predict whether utilization will be high in the unlicensed bands between 5 and 6 GHz, at least in some areas or some peak usage hours. This effort would include

1) Prediction of the types of products and services to be offered, and long-term projections of market demand and penetration.
2) For each of the prominent products and services, characterization of their potential access protocols, modulation schemes, power levels and coverage areas, likely locations, and how often they will be used.
3) Determination of how heterogeneous neighboring devices will affect each other's performance, using simulation, experimentation, or a combination of the two.
4) Evaluation of propagation characteristics of signals at 5-6 GHz, in doors and out.

The committee should also seek effective coexistence techniques in case utilization is high. This would require

- Analysis, simulation and experimentation with existing etiquettes.
- Development of new etiquettes.
- Design of access protocols for important applications when operating under the above etiquettes.

There is a small window in which we can make a difference. Each year, more devices will be produced for this band, so there are more incumbents to block any future attempt to change the rules. Consensus is only possible while utilization is low. If utilization will be large, those who want to provide services where protection from interference matters must demand an effective etiquette while there is still time.

Carnegie Mellon University hopes to work with industry partners who share concerns in this important arena.

References*

[1] J. M. Peha, "Spectrum Management Policy Options," *IEEE Communications Surveys*, Vol. 1, No. 1, Fourth Quarter 1998.

[2] J. M. Peha, "Wireless Communications and Coexistence for Smart Environments," accepted to appear in *IEEE Personal Communications*.

[3] H. Salgado, M. Sirbu, and J. M. Peha, "A Narrow Band Approach to Efficient PCS Spectrum Sharing Through Decentralized DCA Access Policies," *IEEE Personal Communications*. Vol. 4, No. 1, Feb. 1997, pp. 24-34.

[4] D. P. Satapathy and J. M. Peha, "Performance of Unlicensed Devices with a Spectrum Etiquette," *IEEE Globecom*, Nov. 1997, pp. 414-8.

[5] D. P. Satapathy and J. M. Peha, "Etiquette Modifications For Unlicensed Spectrum: Approach and Impact," *IEEE Vehicular Technology Conference (VTC)*, May 1998, pp. 272-6.

*References are available at http://www.ece.cmu.edu/~peha/wireless.html