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Commission Seeks Public Comment on Spectrum Policy Task Force Report	)	ET Docket No. 02-135
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COMMENTS OF FRED MOORE

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Introduction and summary.

I would like to thank the Task Force and the Commission for creating an opportunity to offer my comments on the November, 2002 Report of the Spectrum Policy Task Force.

Basically, I wish to offer some refinements to the discussion of "interference temperature" and then propose that the interference temperature concept be more fully considered as a fourth kind of regulatory model, which I call spectral congestion pricing. Utilizing spectral congestion pricing as an allocation option for certain uncoordinated networks that deliver services to the public promises to overcome some well-known limitations of both the exclusive use and commons regulatory models that have been proposed to date by the Task Force.

The Task Force has stated that the spectral resource is artificially scarce as a result of barriers to access (Report at 37). I discuss the nature and extent of the spectral resource in relation to a key driver I have identified – societal investments in semiconductor lithography. Understanding in what year spectrum could be accessed by low-cost devices is key to addressing the challenges of wise use, mitigation of harmful interference, and making spectrum available for new spectrum technologies.

I touch on the 1995 dissertation of Shepard, urging the rapid evaluation of their ideas. Finally I offer some general remarks on the nature and challenge of the regulation of communications.

Remarks concerning "interference temperature" and overlay service.

In their report, the Task Force defines an interference temperature limit, above which an incumbent licensee would be likely to encounter harmful interference from an unlicensed overlay service (Report at 29, figure 3). While commendable as a strategy for squeezing in more services, there are some difficulties, and one possible modification.

A modification to consider is that the interference temperature limit line be given a slope that is the same as the slope of the declining power of the incumbent signal, as it is the received signal-to-noise ratio (SNR) at a particular receive site that determines whether harmful interference occurs. A sloping interference temperature could be quite handy in an urban setting. If the incumbent transmitter is sited near the population center, then the overlay service can proliferate more freely in the area of highest population density, a natural fit to market need. The overlay service receiver could do a sounding of the incumbent's carrier to cap its maximum power level, in addition to whatever power management features should exist.

One difficulty with this model is that in reality the interference temperature is not a binary, but a continuous variable. What I mean by this is that in actual systems the experience of harmful interference would not have a sudden onset at some exact value of overlay service field strength. Rather, the experience of degradation is somewhat gradual, and varies with the type of encoding used by the incumbent service. At best, with a digital overlay on a digital incumbent[1], there would be an SNR range of just a few

[1]using forward error correction (like, perhaps TDMA voice). A graphical summary of the bit error rate vs signal-to-noise ratio for various digital encoding choices is cited in Moore (1999 at 43, figure 2.1).

decibels over which the incumbent's recovered signal would be degraded. On the other hand, if one were to overlay a digital service on analog television,[2] the situation would be rather the opposite of what the interference temperature model suggests. An excellent quality picture requires an SNR of about 60 decibels, whereas a barely viewable picture occurs at an SNR of about 20 decibels.[3] Thus, there would be a 40 decibel range over which the incumbent user experiences the harmful effect of the externality created by the overlay service.

Not only is the effect of interference varying as perceived by an analog incumbent service, it is ever shifting. In a built-up area, there are multiple reflections of the signals of both the incumbent service and the overlay service transmitters arriving at an incumbent service receiver. These many signals will create constructive and destructive interference, depending on the relative positions of the equipment. There will be certain exact positions where the overlay service interference is greatly enhanced, compared to the incumbent signal. These effects will vary with movements of only inches. They will vary as overlay transmitters go in and out of service, or as overlay transmitters move with respect to each other. For example, in the case of the analog TV viewer, they might need to unpredictably and repeatedly adjust their "rabbit ears." Improvements to incumbent receivers could only partly address this issue.

Another scenario is an analog overlay on a digital incumbent. The overlay service wouldn't stand a chance.[4]

The interference temperature model remains useful for a digital overlay on a digital service. If the incumbent is analog, it might first be possible to incentivize a transition to digital, architecting the services to be most compatible, in order to best approximate a binary interference temperature. Beyond the thinking of the Task Force to use an interference temperature to combine services on the same assignment, might that idea be useful as a spectrum allocation mechanism in the design of wholly new services? I describe my findings below.

A fourth regulatory model: Spectral congestion pricing.

Instead of thinking of interference in the framework that is and must continue to be appropriate for all analog systems, interference in a digital network could be thought of as the marginal deterioration in the quality of service one user experiences as the effect of the presence of other transmitters. If the modulation scheme employed is pseudonoise, then other transmitters appear to the user as an elevated noise floor. In effect, adding users to an allocation increases the noise level, until deterioration in bit error rate

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[2] Thankfully, to my knowledge no one has suggested this.

[3] I am distantly recalling these numbers from my days as a TV service technician, working my way through college.

[4] Several years ago (pre-1996) I observed a Voice of America test of digital HF broadcasting. I was two states away from their California test transmitter, and yet the signal was far more potent than any of the analog transmitters on nearby assigned frequencies, because the duty cycle of the digital voice was so much greater than that of analog speech. Similarly, amateur radio operator experience with MT-63 over SSB voice is that the 2 KHz-wide MT-63 transmission wipes out co-channel voice.

performance sets in. At that point the allocation has become congested with users. The situation is not unlike urban traffic congestion.

I developed another candidate spectrum regulatory model in my 1999 dissertation (Moore at 37-56), based explicitly on the marginal effect of users on others. This new regulatory model, which I call spectral congestion pricing, is the result of an effort to explicitly incorporate the engineering characteristics of uncoordinated networks of multiple pseudonoise transmitters, the economics of congestion pricing in networks, and public interest considerations.[5] Utilizing spectral congestion pricing as an allocation option for certain wireless digital networks that deliver services to the public promises to overcome some limitations of both the exclusive use and commons regulatory models that have been proposed to date by the Task Force.

Spectral congestion pricing might to first approximation be thought of as a blending of the exclusive use and commons models, but with somewhat different distributive implications. For example, an allocation would have the character of a public road, with equal rights bestowed upon all travelers. But unlike the commons model, travelers could have an expectation of not experiencing harmful interference, in part because of a privately managed short-term noise environment, in which they are willing to pay a real time price for their use, based upon their contribution to system noise.[6] Property-like rights would be conveyed, not to individual users, but to service providers. A right of use would be conveyed to service providers, not by auction, but in exchange for their aggregation of dynamic congestion tolls. The intent is to create an economically efficient allocation mechanism, while encouraging low-cost entry and exit of local service providers. Contracting with competing providers to provide redundant network access provides service reliability and competition in backhaul services. The Commission would use long-term noise surveys to ensure efficient use, overall service quality at the industry level, and proper toll collection.

I suggest that spectral congestion pricing be adopted as a distinct model, to facilitate the development of an appropriate regulatory environment for equipment and services. I further describe how spectral congestion pricing might be used to provide wireless voice and data services, and the expected revenue in my dissertation.

The nature and extent of the spectral resource and implications for the reduction of "harmful interference" and the promotion of unlicensed services.

With the adoption of new regulatory models, the scarcity that has impaired our thinking will likely give way to a period of sufficiency. But there remain fundamental engineering constraints. First, speech can be compressed in bandwidth by perhaps a

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[5] A model of spectral congestion pricing was first described in my 1999 dissertation. My dissertation is available in PDF format at no charge at www.qsl.net/wn9i. (When I refer to page numbers in my dissertation, the page number cited is that of a printout of the PDF version.) I include a copy of my dissertation as a supplement to this comment.

[6] In the limit of insignificant congestion, pricing is competitively set by providers, in part to allow for cost recovery for their infrastructure deployment. (Note that one of the problems with a commons is that everyone seems too lazy to pay for improvements. There will need to be service providers, and they will expect compensation though some mechanism.)

factor of eight.[7] Second, semiconductor technology limits the spectrum that can be accessed at low cost to perhaps 225 GHz.[8] We can never really lose touch with our realization that the electromagnetic spectrum is a gift of which we ought to be good stewards.

In pages 159-190 of my dissertation I explain the relationship between our societal investments in making smaller and faster computer chips, and a perhaps unanticipated result: Large new regions of the radio spectrum, formerly accessible only with advanced military technologies, are being opened up to low-cost technologies suitable for consumers. Within a decade, vastly more spectrum will be available for digital networks.[9]

There are certain implications for FCC and NTIA spectrum policy. First, I would correct the dated remarks in my thesis by acknowledging that we have once again moved suddenly and unexpectedly into a time of war. On the consumer side, there are opportunities to utilize the EHF frequencies for computer networking, using a "commons" approach, or a hybrid of it. Certain parties, in particular Motorola (Sharkey at 14-18) have asserted that spectrum below 6GHz is best suited to [urban] mobile users.[10] Should we not immediately cease to promote urban computer networking at and below 6 GHz, which had been established at a time when higher frequencies were not economic, in favor of a well-conceived usage of new EHF commons? There is a brief window of opportunity to make policy concerning UHF-EHF highest and best use tradeoffs.

The military might eventually prefer a "commons" (with more robust link parameters than civilian users) to "exclusive use" for many kinds of its systems, and this might be a basis for harmonizing the work of the FCC and NTIA. The incentive might be that limited "exclusive use" allocations might be traded for much wider "commons," with rights to judiciously despoil the commons in time of war. For example, military ad hoc networks might have a three position software 'switch' that differentiates between peacetime parameter levels (where infrastructure build-out has occurred in a planned way, there is no jamming, and military and civilian users coexist) and two or more wartime parameter levels (unknown support infrastructure, jammers, and civilian users might be interrupted for varying intervals). There might be less need to first set aside blocks of spectrum for government use.

Where the Task Force (Report at 38) gives preference to the "exclusive use" model, they are arguably right below 6 GHz. But above 6 GHz, it might be much wiser to give preference to the "commons" model, with specific exceptions,[11] for the reasons I have stated above. The artificial scarcity that the Task Force has noted in their report seems to me to be mostly a result of parties not coordinating their R&D investments in infratechnology needed to expeditiously bring low-cost extremely high frequency transmitter-receiver chip sets to market. The Commission may be able to aid in such

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[7] See Cox (1996 at 229) or Kucar (1996 at 252-3).
[8] Moore (1999 at 185).
[9] See Moore(1999) at 185 for a timetable of the expanding spectral resource.
[10] Urban mobile users face several distinct challenges, due to peculiarities in signal propagation in urban areas. I summarize these concerns in Moore (1999 at 282-287).
[11] Several other parties have, in their comments, have well explained the need for various exceptions, like radio astronomy or satellite links, etc. The NTIA may have specific needs here, as well.

coordination, which would simultaneously have the benefit of minimizing any need to overlay digital services on incumbent users.

Some apparently believe that EHF frequencies are only useful for very short range communications. This is not true, as I explain in my thesis (Moore at 216-225).[12]

Possible impact of Shepard's 1995 thesis on the work of this Task Force.

In their comments on this Docket, Sharkey (2002 at pp. 4-7) brought to the attention of the Task Force the dissertation of Shepard (1995). While I haven't had an opportunity to read Shepard's dissertation for myself, as Sharkey discusses it, the theoretical developments might greatly affect the need for and nature of the regulatory functions of the FCC. Sharkey relates that it is theoretically possible to construct wireless spread spectrum ad hoc cooperative networks, in which the mutual interference never rises sufficiently to produce harmful interference, and spectrum requirements scale very favorably with traffic. Sharkey calls for more research in this area, years of patient waiting, and ultimately a single network architecture.

I believe that at least three organizations (not including Motorola) already possess the ad hoc network simulation tools, hardware and expertise to definitively and in short order inform the Task Force as to whether Shepard is correct in practice, and if so, under what set of communication link parameters.

If it were possible to make a set of technology choices that ensure that an unlicensed commons won't be despoiled, no matter how many users are present, then no allocation mechanism would be needed. Ad hoc IP networks would no doubt replace many, if not all, existing analog uses of the spectrum. Copper outside plant could be refashioned into jewelry. Even public safety communications might be better served by such a distributed and ubiquitous architecture.

If Shepard's work is not fully realizable, then a range of regulatory models and wise and fair use of the spectrum matter as much as ever. Let's work together to get the questions raised by Shepard's work answered ASAP.

The nature and challenge of the regulation of communications.

In their July 8, 2002 comments on this Docket, Sharkey & Kubik explain that "Real world spectrum management is a blend of technical, economic, and public interest objectives in a way that provides the greatest benefit to the public." That is equally true in the design of wireless services, and yet parties too often focus excessively on just one or another of these three pillars of institutional choice. Each party grasps a leg of the milking stool. In a sense, the three regulatory models (command and control, exclusive use, and commons) are disparate attempts to build a whole stool – no one regulatory model can ever safely be used in isolation.

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[12] If the 'appearance police' would be tolerant of ping pong ball-sized outdoor antennas and T/R units, the utility of EHF for "last mile" delivery would be enhanced.

Moreover spectrum regulation is not simply a domestic concern. There is a fundamental physical reality underlying the nature of the regulation of radio communications – electromagnetic waves know no national boundaries. Alexandrowicz (1971), in surveying the various forms of communication between the nations and the development of thought concerning their regulation, concluded that the regulation of radio communications is the brightest instance of international law and relations. For decades we have been better able to conduct our affairs here through cordial discussions than in nearly any other area of our relations. Indirectly, there is much at stake in any transition away from this regime, and yet there is the promise of expanding democratization – as long as new regulatory models successfully address the three pillars.

By contrast, the behavioral assumption underlying spectral auction theory, the "assumption of rationality" in economics, is that each party maximizes their self-interest, while being indifferent to the welfare of others. Such indifference is fundamentally the opposite of the regard for others that has made possible the first century of progress in spectral resource allocation and in the mitigation of harmful interference. The move toward property rights in spectrum allocation, so well surveyed by Rothkopf & Bazelon (at 1 and 2), while producing efficiency in an economic sense, potentially represents a replacement of a culture of appreciating the other with a culture of indifference. Is this a step forward? Is it a step that needs to be taken to provide for an efficient outcome?

Resource utilization efficiency can in general be achieved through assigning nearly any non-zero price, so that there are likely to be other regulatory models that could be devised that are economically efficient, but not destructive of the public interest leg of the stool. The important thing is that in any new spectrum regulatory models that are adopted, that public and/or private forums be explicitly designed into the approach, in order that we are compelled to perfect our relationships through ongoing dialogue. We need more than an indifferent and impersonal free market mechanism, whether the arena is an auction or a commons.

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