# TRANSITION PATHS IN A SPECTRUM COMMONS REGIME

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**August 31, 2003**

## INTRODUCTION

The Federal Communications Commission (FCC), and the Federal Radio Agency before it, has been determining who and how radio spectrum is used in the USA. There has been a strongly held view in regulation that the radio spectrum has been a scarce resource and hence must be subject to strict licensing for use.

In 1993, the FCC for the first time treated spectrum as a private good and auctioned it. All stakeholders currently admit that the current licensing regime is obsolete and needs to be redefined to enable a more efficient and useful allocation of spectrum. In the past few years, two diverging opinions have formed out of these discussions – one that supports the creation of property rights in spectrum, allowing it to be traded, aggregated and divided like any other property; and the other which would like to see spectrum being used as a commons – where anyone who follows basic rules of etiquette can use spectrum without a fee or license.

The supporters of the commons regime argue that innovation and maximized allocation efficiency will come out of a less restrictive policy, while property rights supporters claim that since spectrum is a scarce resource, it should be handled by a market for optimal welfare and that treating it as a commons would only lead to tragedy.

We believe that a commons regime would do much to benefit the current level of innovation and the establishment of new and interesting services and products in the user-space. However, although we recognize that the commons can fail, we do not feel that it is necessary to discard the commons regime completely. Instead, we propose that the commons would be a better spectrum policy regime, and should be established for most of the spectrum. Only if and when the commons shows signs of failing or heading towards tragedy, should a more restrictive policy structure be implemented.

In order to establish this argument, we begin by listing the relative benefits and limitations of the commons regime, and then move on to an analysis of the possible failure modes of the spectrum commons. Through this, we hope to isolate specific conditions where the commons might fail, and then to grade them according to extent of failure. For each of the failure modes that we find as relevant, we propose responses that could range from technical to policy. In this way, we specify exactly what the different responses should be in each case, and to propose or require transitions only when absolutely necessary.

In this way, we hope to establish a stable and viable commons structure, which would work, and in the case of failure, provide the stakeholders with a pre-defined response in order to minimize disruptions and allow for smooth transitions to more restrictive regimes.

## ALLOCATION: SPECTRUM COMMONS AND OTHER PHILOSOPHIES

Traditionally, the need to regulate the use of the electromagnetic spectrum (spectrum) grew from the problem of interfering transmissions between users. The Radio Act of 1927 was created to control in future the interference that prevented the Titanic's SOS reaching help[1] and the chaos ensuing from the Department of Commerce stopping using priority in determining claims to frequencies used by broadcast stations in 1926[2]. This mission to control interference was coupled with the perception that spectrum was a limited natural resource. This led to greater regulation eventually making the allocation of spectrum a Government responsibility. It also established a licensing regime that specified who could broadcast, and when, where, and even how.

This 'command and control' philosophy has resulted in inefficient spectrum usage[3,4]. It has stifled innovation due to the imposition of high entry barriers, usually in the form of extremely expensive spectrum licenses. An observation often made is that spectrum policy processes have been largely reactive, and not planned[5]. This has negative impacts on the development of wireless services and benefits to the public.

There is a common objective among all stakeholders, including now the FCC, to make the allocation of spectrum efficient and sensitive to advances in technology. However, two schools of thought debate on how this should be done – one group referred to in the literature as the 'engineers' and the other as the 'economists'. The engineers favor an allocation policy that eliminates all barriers to innovation, makes spectrum available to anyone who wishes to use it responsibly, and not define any type of property-rights[6]. The economists want to define property-rights for spectrum and use market transactions for the allocation of spectrum[7].

### Models of allocation

Currently, three models for the allocation of spectrum exist[8,9]. These are the 'command and control' or licensing model currently in use; the 'exclusive rights' or 'property rights' model that the economists are said to favor, and the 'spectrum commons' that the engineers support. We briefly introduce these models below.

*Licensing*: This is the traditional process of spectrum allocation to limited categories of spectrum users for specific government-defined uses. Rules specify eligibility and service restrictions, power limits, build-out requirements, and other rules.

*Property rights*: Spectrum is treated as property, and the owner has exclusive and transferable rights to the use of specified spectrum in an area, with protection against interference. Owners of spectrum can buy, sell, aggregate or subdivide their portions of spectrum like any other type of property. Supporters contend that having such clearly defined rights along with flexibility and transferability ensures economic efficiency. Further, they believe that not having protection against interference will act as a deterrent against investment[10].

*Spectrum commons*: Allows unlicensed users to share frequencies, with no right to protection from interference, and only etiquette expectations to control users and usage.

### Need for hybrid theories

Everyone involved understands that 'one size does not fit all'. To quote the report of the Spectrum Rights and Responsibilities Working Group of the FCC's Spectrum Policy Task Force[11]:

…most commenters and workshop participants supported the proposition that in spectrum policy, "one size does not fit all," and that the Commission spectrum policy should therefore strike a balance between the exclusive rights and the commons models.

### The commons is not open

It is important to understand the difference between the spectrum commons and an open spectrum approach. These terms have similar meanings and some common supporters, but have critical differences. While open spectrum is open to anyone to use as they wish and please, commons spectrum is in fact, not open to everyone freely. To use the commons, one must belong to a group of users who follow certain rules, such as transmission power restrictions, politeness and pre-certification of devices by the FCC. Open spectrum does not have any such restrictions.

The next section will list the benefits and limitations of the spectrum commons.

## BENEFITS AND LIMITATIONS OF THE SPECTRUM COMMONS

The commons has great potential to support innovation and the rapid expansion of new wireless networks and services. However, there exists a camp that does not support the commons despite agreeing to its benefits. They insist that the spectrum commons, like any other, will head to a tragedy at some point, undermining the systems that depend on it and leading to quick fixes that could be more damaging, they say, than implementing a property-rights regime from the start.

It is useful to evaluate both sides of the argument: understanding what the benefits and limitations of both the commons and property-rights approaches are, and then understanding their limitations.

Benkler (2002) has made a lengthy case for the spectrum commons, and in his argument emphasizes the following benefits[12]:

1. Innovation: In a property rights regime, Benkler expects that owners of the spectrum property would not accept innovation unless it fits their revenue models and capacity to own it. In the commons, he says, anyone can innovate, and hence the commons will grow with users innovating, a process that will closely resemble the development of the Internet.
2. Welfare optimization: Benkler proposes that since users will invest in end devices in a commons, and not in a central core of a network, the commons will be able to adapt more rapidly to changes in consumer preferences than a centralized network where changes will be much slower to come.
3. Security: Due to the redundancy and decentralized nature of any open network, it is difficult to sabotage its working, increasing security and reliability. Benkler again refers to the similarities with the Internet, which can work even if major portions of the network fail.

Benkler also states that having a commons regime is choosing a device market rather than an infrastructure market, and not choosing between a market and non-market oriented approach, believing that the commons structure will be able to respond to increases in demand more quickly than a property-rights regime.

On the other side of the argument, Faulhaber and Farber (2002) state[13] that all spectrum should be converted to property, and sold in a market like any other private good. They believe that the government can buy the spectrum it would like to use, including that used for emergency or essential services. They believe that the property-rights regime would lead spectrum to be used by those who value it most. The spectrum that is available in the market can be treated like any other property – bought, sold, aggregated or divided as required and desired by the owner. The believe that spectrum is not infinitely available, and hence, since it is scarce resource, must be allocated by a market. They believe that if the commons is implemented, it will face certain tragedy, and despite the best efforts of engineers, it would ultimately get congested and hence fail.

Peha (2000) also specifies the lack of incentives to conserve shared spectrum space as a major disadvantage[14], explaining that in the commons regime, every device would optimize for cost rather than conserving spectrum. He also voices concern about interference between devices.

We believe that these are valid concerns, but not so critical that the entire idea of a spectrum commons should be rejected on the expectation of congestion or interference that might occur in the distant future. The benefits of the commons as enunciated by supporters leads us to support its implementation as the active and primary spectrum allocation policy. Given that we would like to attract substantial investment, and make the system stable, we would prefer to create a setup where the commons is implemented to begin with, and transitions to a more restrictive regime, such as property-rights, only if it is absolutely necessary. The rest of this paper will elucidate these ideas, first performing an analysis of the expected failures of the commons and then proposing what could be done in each case of failure.

## FAILURE MODES

While proponents point out the resulting dynamic and endogenous allocation and innovation as benefits of the of the commons regime, detractors are quick to respond pointing out that chaos and confusion will soon follow the introduction of any commons regime, and in any case, the number of users will quickly rise and cause congestion and interference at some point of time. They do not object to the commons' proponents claim that commons can greatly benefit innovation, but they foresee an unavoidable failure of such a system and predict that it would inexorably lead us to the kind of situation that prompted the creation of the Federal Radio Commission in 1927. In such a case, it would be damaging to users and service providers to undergo a sudden and unexpected regulatory reaction to mitigate or reverse the failure. It is possible to avoid such a situation by predicting possible failure modes and defining policy responses to these failures. The commons is ultimately headed for tragedy – they say – reason enough not to follow the commons philosophy and to choose the property-rights regime.

However, we argue that it may not be necessary to impose a property-rights regime and loose all possible benefits of the commons regime that have been, as pointed out in previous sections, realized in the FCC's Part 15 or the other unlicensed spectrum elsewhere in the world. It might be possible for regulators to allow portions of the spectrum to remain a commons until the time that the cost of maintaining it far exceeds the benefits. In such a situation, it may then be sensible to address the failure of the commons and respond in an appropriate manner. We will classify these different failure modes – ways in which the commons would fail – and to then propose responses to deal with the failure.

At the outset, we specifically indicate that the entire spectrum need not be converted to a commons. Some portions of the spectrum can be set aside for emergency, navigation, military, and meteorological services. Other parts of the spectrum might be reserved for use by broadcasters, or by the state for future use. In any case, we base our arguments on a spectrum which has a major portion of the spectrum converted to a commons. It is now important to address the different failures that can occur with the commons, and to understand the importance and relevance of these failure modes.

We now assume the establishment of a spectrum commons, and detail the possible failure modes, classifying them, and then providing appropriate responses. In the spectrum commons, we define failure as an inability for users to use the wireless spectrum in an efficient and equitable manner. What this means is that any user on the network should be able to access the spectrum when he or she needs it. This is necessary as the purpose of the commons is to provide such access as long as the users maintain technically correct and polite[a] behavior. It is also necessary to ensure such a system since the ensuing stability is what will drive investment in the creation and use of devices that rely on the commons. Having an inefficient and unequal distribution will hinder investment, and reduce the economic viability of any technology or network that uses the commons for wireless transmission. Furthermore, it is important to enforce the behavior of users to prevent abuse of the commons, and reduce the risk of drowning out emergency or essential services.

However, even though the aim may be to maintain this fair and efficient commons regime, some conditions can occur that disrupt the working of the commons, and we now analyze and classify these failures.

It is important to understand the effect that differences between devices can have on the failure of the commons. If the devices are all equal, failures can be related to failure of the commons itself, and not be confused with failures arising from differences in the capabilities of the devices. This is important because of the very nature of the commons. Since allocation in the commons is not done by any one authority, but by each user requesting use of a part of the spectrum at a certain time, the capability of a user to request and grab spectrum is important, and determines their ability to use the spectrum. It may happen that the commons works fine until a new breed of devices is released, competing with incumbent devices and grabbing spectrum faster, causing transmission delays for the

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[a] Technically correct and polite behavior includes transmitting at a certain power level, using legal methods and not causing harm to other users transmissions

older devices. In this case, it is not a failure of the commons – one of the groups of users is able to function in the commons. It is a case of technological evolution – one device outperforming the other. This should be dealt with differently from the case when the commons itself fails to function efficiently even when devices are all the same. Thus, we classify the failures as belonging either to the equal power or differing power cases.

We now factor the technological evolution in our analysis by dividing failures into two basic cases: the equal device case and the unequal device case. In the equal device case, we assume that all the devices forming the network belong to the same standard, follow the same protocols, or are of similar capabilities. In the unequal device case, we assume that devices can differ by age, capability, or speed.

### Equal Device Case

As explained before, the equal device case is one is which the devices are all the same, and hence, any major loss in efficiency of the system indicates not the inefficiency of the devices, but of the commons spectrum. We illustrate this case with a general example:

> Consider a situation when $n$ devices of type A are able to use the commons at acceptable throughput. Now another device of type A also appears on the network, leading to some loss of throughput for each of the first $n$ devices due to overcrowding. We can easily determine that the average throughput of the system has reduced due to network effects and not device differentiation.

This example and our investigation led us to the most significant failure in the equal device case: the problem of **congestion**.

Congestion occurs in any system when the demand for service exceeds the capacity. Congestion can occur in any combination of three dimensions – spatial, temporal, and spectral. Spatial congestion is caused by an excessive number of users concentrating in a very small geographical area and requesting service. An example is the reduction of throughput at busy airport lounges. Temporal congestion occurs at specific times, such as end of trading on Wall Street when a large number of users might be using their wireless devices. Spectral congestion occurs when there is crowding of services around certain ‘sweet spots’ in the spectrum, especially those portions that support simpler, or legacy[b] system design.

In the equal device case, other failure modes include the failure of devices, something that could cause problems in hop or mesh networks where data transmission depends on the closest nodes to propagate data packets forward – the failure of such nodes can cause disconnection of parts of the network; and vandalism. However, these cases are not of great importance in our analysis, since they are rarely occurring and can be easily detected and dealt with without interrupting the commons. Congestion seems to then be the major and most important cause of failure of the commons.

To simplify the problem of congestion, we look for common properties that can be used to describe the three dimensional types of congestion – characteristics that are effects or causes of all these types. We find that the types of congestion can be judged in terms of the length of the incident, its periodicity (how often it happens) and how harmful or severe its effect is. For analysis, we rename periodicity as predictability of the congestion. Severity indicates the harm caused to the system and the length of the occurrence. Thus, we can classify an incident of congestion as being predictable or unpredictable, and mild or severe in effect, a type of classification that can be used to describe congestion in different dimensions. This classification can be visually depicted in a two-by-two matrix structure as below:

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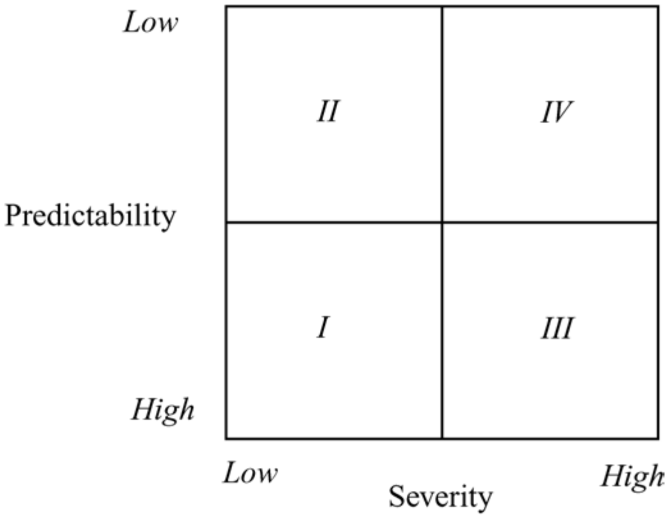
[b] For example, CB radio users will still use their current frequencies



The matrix should not mislead the reader to believe that the boundary between low and high cases of severity, or predictability is defined to transition suddenly. These boundaries are actually fuzzy, and depend heavily on the regulator. However, for the purposes of analysis, we consider the extreme cases as below, the transition lying at some point along the continuum along these extreme cases:

For severity, extremely low severity would be a case when loss of data in transit is minimum, and cannot be immediately perceived as any different from normal losses in propagation due to device limitations. The extreme high severity case would be when the system stops functioning for an extended duration of time, resulting in a major loss of data and is immediately perceived as different from device limitations.

For predictability, extremely high predictability is when a failure is easily predictable, in advance, with sufficient time for a work-around to be established, while an extremely unpredictable situation would occur with no advance warning and be discovered only after the fact.

It is not necessary to consider any more axes, since the complete congestion problem is summarized in these two dimensions. They can be used to describe the three dimensions, as well as the characteristics of congestion in terms of effect. It is not necessary to consider the specific cause of congestion since it does not add any information to the predictability and severity of the incident. For congestions based on the spatial or frequency dimensions, the issue is more when the congestion occurs and if that congestion is predictable and severe. For example, it is important in the Wall Street closing time example to note that the effect might be severe, but it is predictable. Having it happen at Wall Street is no different than having it at Capitol Hill. Another example: if an accident on a highway leads to geographic congestion, it might not be predictable, but it is mild in effect. The accident could happen any time and any place. Frequency congestion too can be condensed to fit this matrix, since the range of frequencies affected will also be affected with some level of severity and at some specific time. The response of the regulator to the failure would depend on 'how bad' the congestion is, triggering a response which then should lead to problem resolution.

We have now established that the congestion problem can be represented in this matrix. It is now necessary to provide examples of the different types of congestion.

Type I: Low severity, high predictability

> In these cases, the severity of the incidence and the loss in throughput experienced is not extreme. Further, it is easy to predict the incident. For example, an increase in the number of users requesting service at the start or end of the business day is easily predictable, and might cause some loss in throughput, but not a complete breakdown of the system.

Type II: Low severity, low predictability

> These cases include minor emergencies, like traffic accidents or increased data exchange due to events like lotteries or online auctions. In these cases, throughput might not decay substantially, but they are harder to predict.

Type III: High severity, high predictability

> Throughput losses in these cases are severe, leading to a loss of service or even breakdown of the system for a finite period of time. Examples include the congestion of control channels – certain frequencies used to coordinate the transmission of data between wireless devices. If the number of users goes beyond the capacity limit for these control channels, the system fails due to the inability of any user to access service – a phenomenon known as blocking.

Type IV: High severity, low predictability

These are the worst type of failures – where the system is affected to a great extent, and which are completely unpredictable. Examples include major emergencies such as earthquakes, leading to a dramatic rise in requests for service by a large number of users; and the occurrence of simultaneous high-volume traffic across different users on the network – file swapping or trading of large datasets. In this type, we also include the final limiting case of congestion – where the number of users and devices accessing the spectrum commons is so large that the system has no way of functioning – some sort of a permanent traffic-jam on a wireless freeway. This is the case that might be considered as the final tragedy of the commons – with too many cows on the field, no grass is left to graze.

Each of these cases has a different probability of occurrence. For example, a Type I failure is more probable than a Type IV. While there is no available quantification of this probability, it is intuitive to expect an order of[c]:

P(Type I) > P(Type III) > P(Type II) > P(Type IV)

Or

P(Type I) > P(Type II) > P(Type III) > P(Type IV)

The order of criticality is also readily deduced as[d]:

C(Type IV) > C(Type III) > C(Type II) > C(Type I)

### Unequal Device Case

Unequal devices have failure modes that are fundamentally different from those in the equal device case. An important failure that has been the basis of most spectrum regulation has been **interference**. Interference is said to occur when unwanted transmissions are intercepted by a receiver, resulting in the loss of clarity of the intended transmission. The **advancement of technologies** may also lead to faster-better-cheaper systems that can

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[c] P(Type x) indicates the probability of occurrence of Type x congestion

[d] C(Type x) indicates how critical the congestion of Type x is

crowd out older technologies and result in unequal spectrum allocation among independent users.

**We do not consider interference to be a failure of the commons**. Interference is caused due to a receiver's inability to distinguish the intended transmission from another unwanted transmission. It is thus a problem that we associate with the device design itself, and not with the network that the device belongs to. As a result, we discard this failure mode as unnecessary at a time when device design is so far advanced, and is only improving with time. Interference does not lead to the failure of the commons, and we believe that it should no longer be used as the basis for decision-making in spectrum policy. We however do agree to a need to reduce interference among devices in the commons, and provide suggestions for this in the following section.

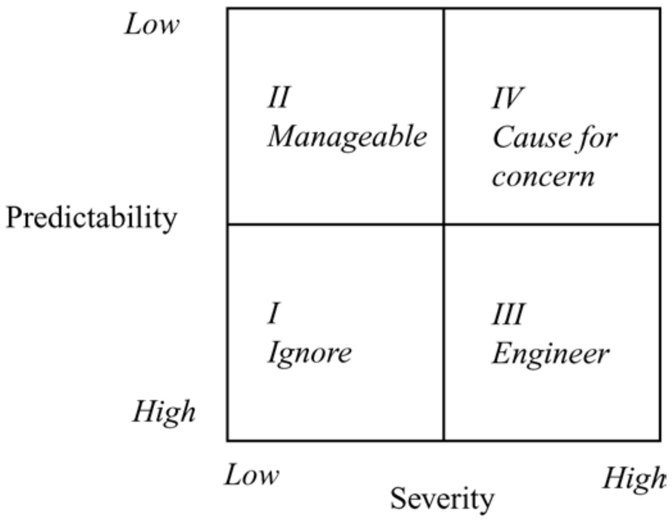
The main benefit of the spectrum commons would be the innovation it affords in the development of wireless devices and applications. We have full faith in the ability of the innovators to develop faster-better-cheaper devices that would be able to utilize the spectrum to a grater extent, and be more efficient at grabbing spectrum to transmit data. This case, where the technological advancement of devices leads to older devices not being able to access spectrum, is not entirely clear. It may be so that the new devices do not impede the older ones in their individual attempts to capture parts of the spectrum to transmit. However, it may also happen the new devices are able to monopolize the grabbing of spectrum and leave the older ones with little or no space. We argue that such evolution is an integral part of the commons regime. It is important to understand that any such new technology would take some finite time to dissipate in the marketplace, and hence, provide users with a fair amount of time to either switch to the new system or adapt the existing system to deal with the changes. By the time the new devices get to be so popular that they pose a threat to older generations, it is reasonable to assume that the number of users of the older devices would be in a minority – similar to the advent of Windows and it overtaking MS-DOS. Thus, we allow for such evolution to occur unabated and do not classify it as leading to failure of the commons due to device differentiation.

In the next section, we propose responses to these failures and conditions to minimize the effect of other problems such as interference.

## PROPOSED RESPONSES

In the preceding section, we discussed the different failures that could occur in the spectrum commons. The two cases were equal device failure, where congestion was the key failure mode, and the unequal device case, where device evolution and interference were key issues, but not failures of the commons. In this section, we will propose solutions to the congestion problem, and address the issues in the unequal device case in order to minimize their effect.

For the case of equal devices, where congestion was the primary failure mode, we classified the types of congestion according to severity and predictability. The matrix we proposed is presented again with the responses appropriate for each type of congestion problem.



Type I Response: Low severity, high predictability

> This is not a critical failure, as it has minimal effect on the working of the commons, and is easily predictable. We do not believe that any special response is necessary for this type of congestion, and it definitely does not need any policy transition.

Type II Response: Low severity, low predictability

These failures are manageable, since they do not affect the system to a great extent. While they might cause temporary malfunction of the commons and the networks using it, these can be attended to and the system returned to normal working. Since these are predictable to a lesser extent than type I congestion, however, they are afforded a greater important, and the system needs to be monitored to reduce the effect of such incidents even further. However, no transition away from the commons regime is required.

Type III Response: High severity, high predictability

High severity problems need to be dealt with at the design stage. While these types of congestion problems are severe enough to cause a complete failure of the commons, it is possible, due to predictability of these problems to address them and engineer the system with sufficient redundancy and spare capacity to overcome the excessive loads when they occur. An example of this is the creation of extra cellular base stations to increase frequency reuse and the capacity of the network. Another method is to design systems considering a blocking probability – the probability that a user is refused service – higher than expected and hence factoring in the excess loads that might cause the increased blocking due to congestion. Since better system design can reduce the incidence of this particular type of congestion, no change in the allocation policy is necessitated.

Type IV Response: High severity, low predictability

This is clearly the case that is a cause for concern. In this case, it is necessary to understand the difference between a one-time event, such as a major emergency that caused excessive loads on the system, and a condition where the commons simply fails – i.e. can no longer work, and must be transitioned to some other regime of spectrum allocation.

In the case of a one-time event, it may be necessary to establish **user differentiation** that would allow for certain services to occupy specific portions of the spectrum. User differentiation can be carried out to provide special privileges to services that must have continuous access to spectrum regardless of other activity. These can include emergency and essential services, which as pointed out earlier, can be separated from the commons portion of the spectrum and hence continue using their current systems without intervention from the commons users, who could also access this part of the spectrum in times of need. This would not undermine the commons regime, but only reserve specific portions of the spectrum for use by these services. In any case, we believe that this is a good practice to follow before the fact, i.e. implement such reservation before a catastrophe occurs. This would minimize the harm to the system and allow for a better setup of the spectrum commons.

If however, a final and limiting failure does occur, where the commons becomes so congested that it is impossible to resolve or reengineer, we must seek out a transition to a different policy structure. It is highly unlikely that such an event of this magnitude would not display symptoms ahead of time, where users loose data packets or the throughput of the system decays. These symptoms, observed over some length of time, can indicate the need for a transition once a decay of a certain level occurs for an extended period of time, pre-empting the total collapse of the commons.

In order to transition smoothly, this point of response must be identified in relation to the ideal working of the system. For example, it may be found that if more than 50% of the data packets transmitted are lost, the problem is serious and falls into this category. We leave these definitions to those who actually design the wireless commons.

Once it is recognized that the commons is bound to fail, it is essential to prepare for a new type of spectrum allocation policy. One of the obvious choices is a property-rights type regime, where different services can be offered at different ranges of frequency. It may also be possible to allocate different ranges of frequencies to

> different user groups, and then allow them to determine whether those frequencies should be a commons or property. It is also possible to create property rights regime with non-interference easements[15]. In this way, it is possible to maximize the potential of the commons while providing the option to convert to a property rights regime, depending on the users needs. A final option is to auction spectrum again, at a time when the true value of the spectrum would be revealed[e]. This would lead to a wholly-property rights regime.

Thus, it is possible to transition to a more restrictive allocation regime only when absolutely necessary, and not before that time. It is highly unlikely that such an event would occur in the near future, as the capabilities of devices in using and sharing the wireless commons improve.

### Dealing with interference

In order to minimize problems arising from interference between devices, we propose that the FCC continue its practice of testing new devices and then approving them for use in the spectrum commons. This would be a similar process to what is now done for the FCC Part 15 devices but would also need to consider the expansion of the range of unlicensed frequencies. By doing this, the FCC can ensure that receiver operation minimizes interference, and hence prevents it from becoming a problem once the devices proliferate. Finally, the concerns about ‘bad’ devices that broadcast over power can be taken care of by good enforcement.

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[e] It is reasonable to assume this, as the service providers would be able to judge how important it is for them to own their own piece of the spectrum

## CONCLUSION

At the end of our analysis and proposals for responses to the different types of failure that a commons could undergo, we find that only in one case – the most severe and unpredictable congestion – is it necessary to transition to another policy regime, where spectrum is allocated in a regulated manner. This proves that the commons regime would be a good beginning to a new spectrum policy, with a condition that if symptoms of a Type IV failure are detected, there might be a transition to a different allocation policy.

This benefits the users of spectrum by allowing for innovation, and the proliferation of new devices and services using the wireless medium – taking full advantage of the benefits of the commons, while still forewarning them about a possible change if and when a failure does occur. As stated before, such *prior* knowledge would encourage investment and foster the growth of networks while ensuring that when the system does fail, a pre-determined and publicly known response will follow. This will allow for system designers and service providers and users to be prepared for such a change.

Through this paper, we have tried to define a setup that harnesses the benefits of the spectrum commons, and heeds the warnings of detractors, benefiting users in the present and future – while keeping its eye on the possibility of failure and providing smooth and pre-determined reactions to problems or tragedies in the spectrum commons.

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