Testimony of

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Chairman Boucher and members of the Subcommittee on Communications, Technology and the Internet, I am very pleased and honored to appear before you today to testify on the topic of radio spectrum management and, in particular, on the issues raised by H.R. 3125, the Radio Spectrum Inventory Act and by H.R. 3019, the Spectrum Relocation Improvement Act of 2009. My name is Dale Hatfield and I am the Executive Director of the Silicon Flatirons Center for Law, Technology and Entrepreneurship at the University of Colorado at Boulder. In the interest of full disclosure, I should also mention that I am on the board of directors of Crown Castle International, a major operator of radio towers for the wireless industry here in the United States and in Australia.

I have been involved in spectrum management issues for more than four decades and, in relation to that involvement, I have had the honor of serving in senior technical and policy positions at both the Federal Communications Commission ("FCC") and at the National Telecommunications and Information Administration ("NTIA") in the U.S. Department of Commerce. Currently, I am serving as the co-chair of NTIA's Commerce Spectrum Management Advisory Committee ("CSMAC"). While my testimony here today is based upon my experience and my current academic research interests, it reflects solely my own views and any recommendations that I offer should not be ascribed to any of the institutions with which I am affiliated.

In my testimony today, I intend to focus on five points or themes:

- *First*, in my opinion, the spectrum scarcity issue is real when viewed through the lens of traditional management techniques and current and forecasted demand for use of the resource.

- *Second*, and on the negative side, some of the basic techniques that we have used in the past to accommodate growth in the demand for the resource will likely have less utility in the future.

- *Third*, on the positive side, there are combinations of newer management techniques and technological advances that can go a long way toward alleviating the shortage in spectrum capacity.

- *Fourth*, the spectrum inventory that would be carried out by the FCC and the NTIA under the proposed legislation is a necessary step in the direction in averting – or at least postponing – that potential shortage.

- *Fifth*, the mandated inventory should be augmented by selected field measurements to gain additional information on actual usage.

Before I address these five points or themes, I would like to provide a little background on the characteristics of this important resource and how we have managed – or, too often, mismanaged – it in the past.

The radio spectrum resource can be shared in its frequency, space and time dimensions by multiple devices or systems but, as a practical matter, there is always a certain amount of interference produced between and among them because of "spillover" in the various dimensions. For example, two cell towers can use the same spectrum or channels but, if they are spaced too close together in geography, unacceptable interference can result – i.e., interference that causes coverage "holes" or dropped calls. In theory at least, additional users can always be accommodated in a given amount of spectrum. But practical constraints in terms of cost and complexity limit the number of uses or users that can be served in a given frequency range in a given geographic area.

Stated another way, as new uses and users are packed evermore tightly into a given amount of spectrum, the overall level of interference increases thereby (1) decreasing the quality and hence the value of the service received by existing users, (2) imposing additional costs on existing users to pay for technical or other changes to mitigate the added interference, (3) imposing additional costs on the new users in order to mitigate the interference they cause to – or receive from – existing users, or (4) resulting in some combination of the first three. It is in this sense that spectrum is recognized and treated as a scarce resource.

By further way of background, I should point out that not all radio spectrum is created equal and that the spectrum between roughly 300 MHz and perhaps 3 GHz or a little more is particularly valuable for technical and economic reasons. I don't mean to imply that higher frequency spectrum is not useful – and valuable – because in some specialized and common applications, it is; but for many critical terrestrial mobile radio systems the more limited 300 MHz to 3 GHz spectrum range I mentioned is much preferred and it is the portion of the spectrum where scarcity concerns are the greatest.

In our market-oriented economy, we traditionally allocate scarce resources among competing uses on a decentralized basis through voluntary transactions carried out by buyers and sellers who react to price signals that are produced by the forces of supply and demand interacting in free markets. However, in the case of the spectrum, we have traditionally managed the resource on a centralized, "command and control" basis wherein the federal government makes the most important decisions regarding how the resource is used. As proven so vividly in the former Soviet Union, it is extremely difficult to manage scarce resources on a centralized manner and it is especially difficult

when – as in the wireless industry today – the market is evolving so rapidly due to exploding demand and revolutionary changes in technology and services. Viewed from the "30,000 foot" level, it is this centralized management of a scarce resource that underlies most of the shortcomings of our traditional "command and control" method of the managing the resource. Said another way, it is extremely difficult – virtually impossible if you will – to sit in Washington, DC and determine how spectrum should be distributed optimally in the remote mountain town of Meeker, Colorado versus a major urban area like New York City.

The shortcomings of the centralized, command and control method of managing the scarce resource have long been recognized and, to its credit, the FCC has taken important and commendable steps in the direction of putting greater reliance on decentralized, marketplace forces to determine the details of how the spectrum is used across the country. Despite these steps, a large fraction of our spectrum is still managed entirely on a centralized, command and control basis or, if not entirely, it is still subject to residual aspects of the traditional regime.

Since the shortcomings of the centralized, command and control approach are well known, I will only summarize them briefly here. First, and perhaps foremost, the traditional approach produces excessive rigidity because it is so hard to change allocations and, in some cases, assignments and technical and service rules to reflect rapidly changing technology and marketplace conditions or, as I touched upon a moment ago, to adjust to differences in supply and demand in different areas of the country. This rigidity is exacerbated by the fact that the traditional approach provides innumerable opportunities for opponents of change to delay the process through long, drawn-out and contentious proceedings that allow them to hold onto their perhaps underutilized spectrum and/or to preclude new, potentially competitive entrants from acquiring spectrum. Finally, the traditional command and control approach often does not provide economic or other incentives for making more efficient use of the resource. For example, the service rules governing a band may prevent or discourage a licensee from introducing a more efficient technology in order to profit from selling or leasing the spectrum that is freed up by doing so.

Because of this excessive rigidity, it is not unusual to find through actual field measurements that large blocks of spectrum or large numbers of channels are unused or only lightly used even in areas of the country and at times when spectrum congestion and scarcity is apt to be most acute. In the spectrum management field, we refer to this form of scarcity as *administrative* scarcity to distinguish it from true scarcity in a physical sense.

Before I turn to the five points or themes upon which I want to focus my attention, I would like to add one further comment relating to this excessive rigidity. The comment is that, in the past, technological limitations associated with wireless devices largely precluded them from moving about from band-to-band in the frequency dimension and adapting their characteristics in order to opportunistically access spectrum that otherwise might not be used at a particular time and/or place. That is, heretofore, the

devices largely lacked the necessary processing power and flexibility to share spectrum on a dynamic rather than static basis. Increasingly this is not the case and even ordinary consumer devices – such as cellular smartphones or Wi-Fi access points – have enormous capability to assist on a more localized, decentralized, real-time basis in the management and utilization of the increasingly precious radio spectrum resource. As I will speak more of in a moment, one of the challenges of modern spectrum management is how to provide the opportunities and incentives for such devices to be introduced to reduce the rigidities associated with the traditional approach to spectrum management that I have outlined.

With that background, I would now like to turn to the five points or themes that I mentioned earlier.

1. The Potential for a Spectrum Crisis Is Real

As indicated earlier, I have been involved in spectrum management for over four decades and it is very clear to me that we are now in the midst of an unprecedented period of demand for access to spectrum in the critical range from roughly 300 MHz to 3 GHz. This increase in demand is propelled by increases in the number of users, increases in the number of uses for the resource, and greater bandwidth requirements per user. Early in my professional career there were actually mobile telephones available – big bulky, vacuum tube units that took up most of the trunk of the car and which sometimes required the modification of the vehicle's electrical system to accommodate the power needed to run the unit. There were only a handful of channels to carry the calls of these pioneering subscribers and it is no wonder that, at the time modern cellular systems began to emerge in the 1980s, there were only about 200,000 of such units in service. Now, of course, CTIA tells us that there are roughly 270 millions cellular handsets in the hands of the public. And a large and increasing fraction of these units are used to access the Internet and, in the process, consume orders of magnitude greater amounts of capacity than traditional voice. Putting it in more technical terms, we are going from perhaps 12 kilobits per second for a voice call to several megabits per second when we, for example, upload or download video clips. This translates directly into demand for more spectrum. On the non-commercial side, to pick just one example, the military is increasingly using drones or Unmanned Aerial Vehicles – UAVs – in their operations and these devices, which hardly existed only a few years ago, need substantial amounts of bandwidth for data collection, guidance and control purposes. Similarly, public safety agencies have increasing requirements for video surveillance and more esoteric systems such as gunshot detection systems. While it may be possible for these public safety agencies to procure the needed services from commercial operators in some situations, the need for the added spectrum capacity remains.

I understand that these increased demands are well known to the Subcommittee and I won't belabor the point further except to say that, in my experience, there are almost an unimaginable set of new devices and services that need access to spectrum and which can contribute enormously to our economic and social wellbeing. For example, I have been encouraging and providing unpaid support to an organization – the Alfred

Mann Foundation – which has a radio-based artificial nervous system that can restore mobility to individuals who have been paralyzed. I am fascinated by the potential of this technology to improve the quality of life of military personnel and others who have become paralyzed due to combat injuries or accidents of various types. But like all radio-based systems, this system requires access to the radio spectrum and these potential benefits will be denied if spectrum is not found to accommodate them. For all of these reasons and others, I conclude that the scarcity issue is real when viewed through the lens of traditional spectrum management techniques and current and forecasted demand for use of the resource.

2. Some of the Basic Techniques Employed in the Past to Accommodate Additional Spectrum Demand May Have Less Utility in the Future

We have faced large increases in demand for spectrum capacity before. In fact, very early in my career (ca.1966) a unit of the Commerce Department published a study entitled "Electromagnetic Spectrum Utilization - The Silent Crisis." As I recall, it dealt primarily with congestion in the shortwave radio bands that were heavily used for military and commercial intercontinental voice communications at the time and with the demands for spectrum to accommodate the growth of two-way mobile radio systems used by public safety and, increasingly, private sector organizations for communicating with units in the field. In my experience, there are five fundamental techniques for accommodating increasing demand for spectrum – five potential solutions to spectrum congestion, if you will.

First, one of the fundamental techniques for relieving spectrum scarcity is to go higher in frequency – that is, extend the upper range of usable frequencies. Indeed, when geostationary satellites were developed that were able to transmit large numbers of telephone conversations or television signals (with concomitant requirements for spectrum capacity) over great distances, they were allocated spectrum above 4 GHz. But as we move higher in frequency, the radio waves behave increasingly like light waves and can be easily blocked by natural or manmade structures and, going even higher, their range may be severely limited by atmospheric conditions such as snow and rain. While such spectrum will continue to be useful – even critical for certain applications – it is generally not useful for mobile/portable/nomadic applications that are currently experiencing such rapid increases in demand. In fact, it is these "laws of physics" effects that make the spectrum below 3 GHz or 4 GHz so valuable and subject to so much intense interest as I explained before.

Second, another fundamental technique for relieving spectrum scarcity is through technological advances that reduce the amount of information that has to be transmitted "over-the-air" (a technique known as data compression) and/or that increase the amount of information that can be conveyed in a given amount of spectrum or bandwidth. While I do not have the time to go into these techniques in detail, there are fundamental technical constraints and tradeoffs in terms of quality and robustness to interference that tend to limit the further improvements that can be expected from them. Perhaps better stated, these techniques can continue to produce incremental improvements in efficiency

(and should be pursued accordingly) but, alone, they are apt to be inadequate in solving the problems associated with orders of magnitude increases in spectrum demand.

Third, still another fundamental technique for accommodating new spectrum uses/users is to reallocate spectrum from a current use to a higher value use. This technique has been used extensively in the past and, consequently, it is well known to the Committee. The most recent example is the reallocation of television broadcast spectrum freed up by the transition to Digital Television ("DTV") to public safety and commercial wireless uses. Of course, it is getting harder to reallocate spectrum in the desirable range from 300 MHz to 3 GHz in part because it is increasingly difficult to identify suitable replacement spectrum for those forced to move and, more fundamentally, because the incumbents are aware more than ever of the value of the spectrum they control. It is unclear at this point what spectrum can and should be reallocated in this critical range but, as I will speak to more in a moment, taking and publishing an accurate inventory of current spectrum allocations in it (as called for in H.R. 3125) would play a necessary and critical role in that determination.

Fourth, another fundamental technique for accommodating new spectrum users/uses is spectrum sharing. Different services can use or "share" the same spectrum (in the frequency, time and/or space dimensions) where the risk of excessive interference is inherently minimal or can be reduced to acceptable levels by various engineering or operational means (i.e., through "frequency coordination"). There are various categories of spectrum sharing. For example, spectrum sharing can be accomplished on a static or dynamic basis. Static – or long term sharing – has been used extensively in the past and it based upon detailed *a priori* engineering studies to minimize interference risk. For example, fixed, point-to-point terrestrial microwave systems can share spectrum with geostationary satellite systems by taking advantage of highly directive antennas that sufficiently isolate the two systems. Dynamic sharing is a more recent development that involves wireless devices or systems that are more aware of their current radio environment though access to data bases and real-time spectrum monitoring measurements. By taking advantage of this more localized, real-time information they are potentially able to access unused spectrum that may be available on a moment-by-moment rather than just a long term basis. I will have more to say about this technique – Dynamic Spectrum Access – later.

Another way to categorize spectrum sharing is whether it is accomplished on an involuntary or voluntary basis. In the past, spectrum sharing between or among various government and non-government/commercial systems has been the result of the FCC or NTIA (or the combination of the two) mandating such sharing in accordance with appropriate rules and regulations to minimize the potential for unacceptable interference. Voluntary sharing of non-Federal government spectrum is a more recent development that has been facilitated by FCC actions to allow certain of its licensees to lease their unused or under-utilized spectrum on a static or dynamic basis. These actions were intended to shift their management of the resource away from the centralized, command and control approach in favor of putting more reliance on localized, marketplace forces to shape spectrum use. When I was the Chief of the Office of Engineering and Technology

at the FCC in the late-1990s, I was a strong advocate of such secondary markets and a supporter of software defined radio and cognitive radio techniques that facilitated Dynamic Spectrum Access techniques. I was a strong advocate because I believed that the resulting, voluntary, spectrum sharing could reduce the administrative scarcity that was a consequence of the traditional centralized, command and control approach to managing the resource.

Fifth, the final fundamental technique for relieving spectrum congestion is frequency or spectrum reuse. When a radio transmitter is operated at high power and the associated antenna is at a great height, the resulting signal – and associated interference in the space dimension – is spread over a wide area. This can be an efficient way of serving less populated areas but in a densely packed urban area with high demand for spectrum, it may mean that a single channel can be used only once in the area. By lowering the power and the antenna height, the interference range is diminished thus enabling the same channel to be used multiple times in an area where spectrum is scarce. This is the capacity increasing technique that is used by commercial cellular carriers and, as demand has increased, the carriers have dramatically increased the number of base station sites in major urban areas to allow additional frequency reuse.

Like some of the other techniques that I have mentioned, frequency or spectrum reuse has limitations. For example, some important systems (such as radar systems designed to track targets at great distances) by their very nature need to emit a large amount of energy over a wide area. Moreover, even with commercial cellular systems, increasing the number of base stations means that they are more dependent upon the availability of broadband terrestrial backhaul facilities to get from the base stations to and from their switching center or other point of traffic concentration. Thus, increased frequency reuse is not always possible because of the nature of the service or it may be constrained by the availability of suitable antenna tower locations and economic backhaul facilities.

To conclude this second point or theme, it appears that going higher in frequency will be of limited usefulness in solving the current spectrum crisis associated with wireless mobile radio systems. It also appears that advances in the technical efficiency of spectrum utilization, while useful, cannot produce the orders of magnitude improvements necessary to accommodate the phenomenal growth in these types of systems and thereby avert the potential crisis. That leaves reallocation, increased sharing and more intense frequency reuse (at least in some services) as potential solutions, albeit ones with challenges of their own.

3. There Are Combinations of Management Techniques and Technological Advances That May Help Alleviate the Looming Crisis

Setting aside reallocation for the moment, the two most promising solutions to the looming crisis appear to be increased spectrum sharing and more intense frequency reuse. In terms of spectrum sharing, I have already noted that the FCC has taken steps to encourage voluntary sharing through a series of decisions associated with its secondary

market initiative and certainly those efforts should continue. In some notable situations associated with non-commercial Federal and non-Federal government licensees or assignees, there may not be sufficient economic or other incentives to share spectrum even in less critical circumstances. A major focus of the Federal advisory committee (CSMAC) that I co-chair is to identify incentives that might be adopted to encourage voluntary sharing and potentially more intense, non-interfering spectrum usage. Where such incentives are lacking or, in the commercial sector, where strategic market behavior may serve to limit voluntary sharing, additional mandated sharing may be necessary. In both the voluntary and involuntary sharing cases, I continue to believe that the technological advances in Dynamic Spectrum Access can play a big part in ensuring that such sharing can be accomplished with an acceptable risk of harmful interference. In short, I believe that a combination of increased incentives (preferably) or mandates (less preferably) for spectrum sharing coupled with more decentralized, more opportunistic, technologically-based techniques governing spectrum access can be of significant help in avoiding the looming crisis.

In terms of increased frequency reuse in those services in which the technique is feasible, I would point the Subcommittee's attention to the connection between (a) the need to drive fixed broadband facilities to the user that is being addressed by the FCC in its preparation of the National Broadband Plan and by NTIA in its grant programs under the ARRA and (b) the need for additional broadband facilities to support the increased wireless backhaul that is associated with more intense frequency reuse. In short, local broadband facilities (e.g., fiber optic facilities) are not only needed to support broadband services to fixed locations such as homes and businesses but to support the phenomenal growth in wireless services as well.

4. Conducting a Comprehensive Spectrum Inventory as Mandated by the Proposed Legislation Is a Necessary First Step in the Direction of Averting – or at Least Postponing – the Looming Spectrum Crisis

I am a strong supporter of conducting the spectrum inventories called for in the proposed legislation because I am a strong believer in the old adage that "You can't manage what you don't measure." More specifically, a comprehensive spectrum inventory is necessary to identify spectrum that could be reallocated – all or in part – for other uses based upon such fundamental information as the type and importance of service being provided and the current extent of usage in the frequency, time and space dimensions. Similarly an inventory is necessary to identify spectrum that could be potentially shared and under what conditions and at what risk. The greater transparency would allow academic and other researchers to better gauge the long-term performance of existing spectrum management processes and to suggest better ways of managing the resource. On a shorter term basis, it would allow entrepreneurs better information on what spectrum might be shared on a voluntary basis and encourage innovators to develop more sophisticated engineering techniques that would promote such sharing. More succinctly stated, a comprehensive spectrum inventory is necessary to support two of the most promising three ways of averting the spectrum crisis – reallocation and increased sharing.

5. The Mandated Inventory Should Be Augmented by Selected Field Measurements to Gain Additional Information on Actual Usage

As I just noted, I am a strong proponent of conducting a spectrum inventory but it must be admitted that there are potential shortcomings in relying upon a purely "paper study" – at least in some spectrum ranges. For example, in some services there may be wide temporal or geographic variations in spectrum usage that may not be revealed in a study of allocation and assignment records. Yet this may be precisely the information needed to gauge the efficiency of current usage and to identify potential reallocation or sharing opportunities. In the mid-1970s – during the first of my two tours of duty at the FCC – I was associated with something called the "Chicago Experiment" which, among other things, involved intensive spectrum occupancy measurements using sophisticated monitoring vans. Those comprehensive measurements revealed spectrum that was lying fallow because the licensee – say a tow truck operator -- had gone out of business and failed to cancel the his or her license. In other cases it revealed spectrum that was unused because the private frequency coordinator given the responsibility of recommending specific frequency assignments mistakenly believed that the channel was unavailable under the FCC's rules. In other cases, the measurements revealed very light usage of a channel or significant variations in usage over time. These usage measurements provided valuable information on the efficiency of existing spectrum utilization. Spectrum measurements in the field can also reveal the presence of illegal or poorly designed devices the proliferation of which may complicate any reallocation or sharing initiatives. For example, spillover or spurious emissions from existing devices/systems in adjoining bands may make usage of what appears to be a lightly used band on paper problematical or it may necessitate substantial and time consuming remedial action to make the band usable.

While I am very much in favor of conducting field measurements of spectrum utilization in order to accurately ascertain the situation "on the ground," I believe they should be done selectively for two reasons. First, in some bands – say the GPS bands – there is no doubt that the associated signals are transmitted continuously and that coverage is nationwide and that the very nature of the service precludes sharing. There would be little to gain from spectrum occupancy measurements in such bands. Second, properly conducted, extensive spectrum monitoring in the field can be quite expensive and time consuming – although the cost is declining with automation and the falling cost of equipment. Because of these two factors, I recommend that the spectrum inventory be augmented by selected field measurements in those bands deemed to be the most likely candidates for reallocation or increased sharing based upon the paper studies. Of course, light use or even no use of a given block of spectrum does not necessarily mean that it should be reallocated or shared as there may be perfectly legitimate reasons that those conditions may hold. On the other hand, light or no use would suggest a starting place for further investigation.

Mr. Chairman that concludes my testimony and once again I want to express my appreciation for being invited to testify here today on these two important pieces of legislation. I would be happy to respond to any questions that you might have.