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R STREET POLICY STUDY NO. 150
September 2018

THE FCC'S 3.7–4.2 GHZ SPECTRUM BAND PROCEEDING: KEY FACTS AND ANALYSIS

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INTRODUCTION

The Federal Communications Commission is considering proposals to expand flexible use of the 3.7–4.2 GHz spectrum band,[1] initiating debate about how this band should be used. Accordingly, the present study seeks to explain why the band is important, discuss why its allocation has become a matter of debate and evaluate proposals for its better allocation.

Briefly, the 3.7–4.2 GHz, a subset of the "C" band, is an excellent range of spectrum for a variety of communications services, such as cell phones or fixed-wireless broadband Internet access. Currently, however, it cannot be used for those services because it is mostly allocated to satellite operations, such as carrying television content. Despite the fact that not every frequency is being received in every area all the time, the band is allocated to satellite operators in such a way as it cannot be subdivided. More extensive use of the band should be possible, but allowing others to use it could result in harmful interference with existing satellite operators. To solve such problems of competing interests, various proposals have been suggested to allow for sharing or reallocation of the band.

As explained in a prior study on spectrum policy, economic analysis is especially effective for understanding spectrum allocation because spectrum rights behave similarly to property rights.[2] Accordingly, this paper applies an economic framework to proposals for sharing of the C-band to identify the benefits and drawbacks of each.

BACKGROUND

The portion of the spectrum in question is the 3.7–4.2 GHz band, which is attractive for a variety of uses and for a number of reasons. First, at 500 MHz wide, it is one of the largest contiguous blocks of spectrum in the country. Contiguous frequencies are beneficial because they allow for the operation of bandwidth-intensive services that are increasingly prevalent in the wireless economy. Second, the frequency range is well suited to modern communications uses. Lower frequencies were traditionally considered "beachfront" in the past because they could travel farther and better penetrate walls, but higher-frequency spectrum is necessary for future dense networks that will send larger amounts of data over shorter distances. 3.7-4.2 GHz is mid-band spectrum

1. "In the Matter of Expanding Flexible Use of the 3.7 to 4.2 GHz Band," Federal Communications Commission, GN Docket No. 18-122, July 12, 2018. https://ecfsapi.fcc.gov/file/07131575002139/FCC-18-91A1.pdf.

2. Joe Kane, "The Role of Markets in Spectrum Policy," *R Street Policy Study* No. 146, June 2018. https://2o9ub0417chl2lg6m43em6psi2i-wpengine.netdna-ssl.com/wp-content/uploads/2018/06/Final-No.-146-for-posting.pdf.

and has some properties of both high and low frequencies. As such, it is attractive to companies like mobile carriers and fixed-wireless broadband providers who would like to have wide channels of mid-band spectrum to provide consumers with fast, reliable service and to upgrade to 5G networks.

Current Allocation

In order to get access to the spectrum, potential new users must deal with incumbents who are already using it. The current users of the 3.7–4.2 GHz band are mostly satellite downlink providers, that is, they send content—generally TV and radio signals—from space to earth. These signals arrive at satellites from places such as a distant studio or a live sporting event. The content is then received back on Earth by cable television "head-ends" or central locations where it is gathered before being sent out to customers.[3]

Changes in the wireless ecosystem, however, make it likely that this spectrum is not currently allocated productively and at least some portion of it would be better used for increased fixed-wireless broadband or mobile service. This is because traditional modes of television viewership are being replaced with over-the-top distribution channels or consumers are switching away from traditional TV altogether. Either way, that video market is converging to IP-based distribution is increasingly the reality in the video market and this likely impacts the optimal allocation of spectrum rights.

Normally, markets for flexible rights in this band could remedy any misallocation relatively easily. For example, businesses that want to use the band for something new could approach the current users and offer to buy access. Such deals would be beneficial to both parties and would likely increase the productivity of the frequencies in question: If the incumbent accepts the offer, this would indicate that the new user expects to make greater profit than the old user. This entails offering consumers services they prefer at lower prices.

However, this band is currently managed in a manner that makes reallocation to efficient uses particularly difficult. Ranges of frequencies are not assigned to individual licensees with only one party holding the right to operate in each one. Rather, the band in governed by a "full-band, full-arc" policy, which means that satellites have the right to transmit over the entire 500 MHz of the band and earth stations can point their dishes at any satellite along the geostationary arc.[4] Thus, at any point, there are many signals from many satellites transmitting over the entire band all over the country.

The result of this arrangement is an "anticommons tragedy," which is defined as an inefficient outcome that results because control over a resource is fragmented or spread out over too many people. As a result, negotiations and mutually beneficial deals cannot be reached because the transaction costs are too high to make them worthwhile.[5] In this case, efficient use of the band is hampered by the fact that property rights are numerous but not clearly delineated. As a result, no entity is able to easily trade away its rights to someone else who wants to use them differently, even if both parties would benefit. For example, if a mobile carrier wanted to purchase the right to transmit on a frequency in this band, it would have to negotiate with every satellite provider, not just one. This causes significant frictions in the bargaining process that preclude the deal from being completed. Solving this problem presents complex economic and technical issues that require serious discussion.

Risks of Interference

The main challenge in repurposing an already-used band is harmful interference with incumbent services. This problem is similar to multiple people having a conversation in the same space:

> If someone is speaking too loudly, information will not reach its intended audience. Likewise, radio signals can overpower each other resulting in service interruptions. In this band, that may look like television or radio station signals dropping out as they encounter interference when they get to a receiver on Earth.[6]

Interference concerns are especially acute in this band because the satellites are in geostationary orbit. This means they do not move relative to the surface of the earth. This

3. "In the Matter of Expanding Flexible Use of the 3.7 to 4.2 GHz Band," p. 6. https://ecfsapi.fcc.gov/file/07131575002139/FCC-18-91A1.pdf. This band is not used for direct-to-consumer satellite television. It sends content to a distributor, which then sends it to the end consumer via cable, fiber or terrestrial over-the-air signals.

4. As viewed from the ground on earth, the orbit of geostationary satellites forms an arc across the sky and geostationary satellites are located every two degrees along this arc. Satellite dishes are oriented at a satellite by a specified elevation, pitch around a horizontal axis and azimuth or the direction they point around a vertical axis. The full-arc policy allows satellite users to utilize any elevation and azimuth rather than single, pre-registered ones. What frequencies are actually in use is managed from the perspective of earth stations, which focus their antenna such that they receive a particular satellite's transmission and then tune-in to the particular channels in that transmission that carry the earth-station operator's content. So, while the satellite is likely sending content on all 500 MHz over the entire country, any given earth station does not "listen to" all satellites at once.

5. Michael A. Heller, "The Tragedy of the Anticommons: Property in the Transition from Marx to Markets," University of Michigan Law School Scholarship Repository (1998). https://repository.law.umich.edu/cgi/viewcontent.cgi?article=1608&context=articles.

6. NCTA – The Internet & Television Association, "Comments In the Matter of Expanding Flexible Use of the 3.7–4.2 GHz Band," GN Docket No. 18-122, May 31, 2018, p. 2 and 11. https://ecfsapi.fcc.gov/file/105318181229999/053118%2018-122%20Comments.pdf.

is advantageous for consistent contact between space and Earth, but it also means that, as a matter of physics, the satellites must be about 22,200 miles away. As such, the signals are relatively faint by the time they get to the ground and they are consequently very sensitive to nearby terrestrial signals of much greater power.[7]

While mitigating harmful interference is an important challenge in this case, minimizing interference at all costs is not and should not be the final goal.[8] No party actually wants to incur the costs that would be necessary to be completely interference free all the time. Instead, the level of interference should be balanced with productivity by means of market transactions. For example, satellite providers may be willing to tolerate more interference if mobile carriers pay them enough to cover or mitigate the costs that result. If this band is actually more valuable for mobile or fixed-wireless broadband than it is for its current use, then new users will eventually buy enough access to provide those services. If the incumbent users turn down such offers, this would indicate that they value it more highly than the newcomers do. In this case, creating the conditions for such a market should be the primary goal of the FCC.

POTENTIAL NEW USES

There are two main uses for the 3.7–4.2 GHz band that would likely be more valuable, on the margin, than the status quo:[9] fixed wireless and mobile. This section describes those uses and the particular problems they face with respect to interference with existing satellite operators.

Fixed-Wireless Broadband

Fixed-wireless service involves providing broadband via towers that send data between stationary points. The word "fixed" refers to the fact that the transmitters and receivers are usually stationary, akin to a television or radio antenna affixed to a roof.

Fixed service already has a limited presence in this band and the challenges presented by its coexistence with satellite users are not extreme. Since both fixed-wireless transceivers and satellite earth stations are generally in static, known positions, fixed services can usually aim their signals to keep out of the way of signals coming from space.

The word "generally," however, conceals a lot. The situation is complicated by the fact that not all earth stations are registered and thus their locations are not always known. A proliferation of fixed services in this band has the potential to interfere with earth stations simply because the fixed providers are unaware of them.

Incumbent satellite users also stress that not all earth stations are immobile.[10] Some move from place to place between, for example, sports stadia.[11] These characteristics further emphasize the need for timely registration and also provide a potential use-case for a database that can be updated with near-real-time location data to allow for more intensive use of frequencies in all geographic areas without interfering with incumbent users. This system would be similar to those proposed for the 3.5 GHz band[12] and TV white spaces in the 600 MHz band.[13]

Mobile Broadband

A more difficult challenge is posed by mobile services in the 3.7–4.2 GHz band. As the name implies, mobile devices move frequently, so the path between them and a radio antenna cannot help but cross through—and likely interfere with—a space-to-earth satellite transmission. For this reason, using the band for mobile services will likely require clearing satellite users out of at least a portion of it so that it can then be dedicated to mobile or similar services.

Here, however, the anticommons tragedy once again applies. Coordinating such a clearance with multiple rights owners presents high transaction costs and the risk of holdups.[14] Even if almost all satellite users can agree on a price to clear a portion of spectrum, one or a handful can hold up the deal by demanding exorbitant prices for themselves. Accordingly, any solution designed to facilitate mobile services in the 3.7–4.2 GHz band must confront this possibility.

7. Satellite Industry Association, "Comments In the Matter of Expanding Flexible Use of the 3.7–4.2 GHz Band," GN Docket No. 17-183, Oct. 2, 2017, p. 36. https://ecfsapi.fcc.gov/file/10022703505533/SIA%20Comments%20on%20Mid-Band%20NOI%202%20Oct%202017.pdf.

8. Ronald H. Coase, "The Federal Communications Commission," *Journal of Law and Economics* 2 (October 1959), p. 27. https://www.jstor.org/stable/724927?seq=1#page_scan_tab_contents.

9. I.e. the next units allocated to fixed wireless or mobile are more valuable than the first units of satellite spectrum that would be cleared.

10. Satellite Industry Association, p. 31. http://www.intelsat.com/wp-content/uploads/2017/10/SIA-Comments-on-Mid-Band-NOI-2-Oct-2017.pdf.

11. Since this band is used for downlink, however, the main, outgoing video feed from a sporting event does not use it. That feed is being sent up to space from the venue using a different portion of the C-band. The 3.7–4.2 GHz band would be used, for example, by an earth station at the site of the event to monitor the feed that was already sent up and to make sure there are no problems with it. But since this function could be performed by other means (e.g. at a central studio elsewhere), one may question whether such rights should be allowed to persist without payment if they preclude other uses of the band.

12. Federal Communications Commission, "Notice of Proposed Rulemaking in the Matter of Promoting Investment in the 3550-3700 MHz Band," GN Docket No. 17-258, Oct. 24, 2017, p. 3. https://ecfsapi.fcc.gov/file/1024196454861/FCC-17-134A1.pdf.

13. Federal Communications Commission, "White Space Database Administration," 2018. https://www.fcc.gov/general/white-space-database-administration.

14. Peter Cramton and Evan Kwerel, "Efficient Relocation of Spectrum Incumbents," *The Journal of Law and Economics* 41:52, (October 1998), pp. 649 and 655. https://www.jstor.org/stable/10.1086/467407?seq=1#page_scan_tab_contents.

EVALUATION OF PROPOSALS FOR REALLOCATION

For the aforementioned reasons, balancing the interests of satellite providers and potential new users requires creative solutions. In light of this, the present section reviews some of those proposals from an economic perspective.

Requiring Registration of Satellite Earth Stations

Knowing the location of operational earth stations is a prerequisite for any revitalization proposal in the 3.7–4.2 GHz band. Registration of receiving earth stations is not currently mandatory under FCC rules, and to do so involves a nine-page form that smaller users may have difficulty understanding and completing.[15] Therefore, the FCC should streamline the registration process to require only the bare minimum of information necessary to identify the location of active earth stations and to adequately protect them. Alternatively, the agency could solicit the help of satellite providers themselves to identify the positions of earth stations. This approach has the advantage of dealing with fewer parties who are likely more sophisticated than the average, unregistered earth-station operator. Either way, registration should be mandatory and after a sufficient grace period, unregistered stations should not receive interference protection.

Creating a Satellite Industry Negotiating Consortium

A classic analysis of tradable rights indicates that when there are significant transaction costs, the initial allocation is important to the ultimate outcome of bargaining.[16] And, in this case, transaction costs are quite significant. But, since scrapping the current allocation framework by regulatory fiat is likely untenable for political and legal reasons, the FCC should aim to reduce transaction costs for rights to operate in the 3.7–4.2 GHz band. This would allow bargaining to clear a portion for mobile service.

A potential solution to the hold-up and anticommons problems has been proposed by members of the satellite industry who suggest that the FCC should empower a consortium of current users to act on behalf of all of them and negotiate deals to clear spectrum for mobile use.[17] This proposal would replace the disparate owners with a single body that is easily identifiable to potential buyers or lessees, thus reducing transaction costs and, hopefully, enabling mutually beneficial trades.

The consortium proposal does have potential shortcomings, however. As a government-granted monopoly over the band, it would have a tendency to bring to market a smaller portion of the band at a higher price than that which would prevail in a competitive market. Moving directly to a competitive market in this band is likely not a viable option at this point, however. Such a move would trigger delays from technical and legal problems that would likely bog down the transition for so long that they could outweigh the inefficiencies of alternative proposals. All stakeholders should therefore avoid rejecting a viable alternative simply because it is imperfect. There are no perfect solutions, only tradeoffs.

The consortium proposal estimates that it could clear 100 MHz for new users with an additional 50 MHz "guard band" necessary to adequately separate mobile users from incumbents to avoid interference.[18] Many interested parties have suggested that this number is too low and argue that up to 400 MHz could be cleared.[19] This issue would be solved by markets in a competitive setting: The seller would supply all the spectrum for which buyers were willing to pay a mutually agreeable price. But since the monopoly consortium will tend to undersupply cleared spectrum, it may be advantageous for the FCC to grant the consortium control over clearing the band, but require it to clear only a minimum range of frequencies—perhaps 300 MHz.

Other Factors That Determine Optimal Clearing

Innovations in incumbent services are another important consideration in determining the optimal amount of spectrum to clear. New compression technologies are gradually being implemented in this band.[20] Such development means that the same content can be transmitted with less spectrum, leaving more available to repurpose for mobile. But compression also improves the quality of current uses of the band. In turn, since they can now receive higher resolution content more cheaply, this could increase the quantity of those services, like video, that downstream users demand. In short, compression technologies have an ambiguous effect on the future use of this band, so market transactions are necessary to reveal the most productive alternatives.

15. Federal Communications Commission, "Sample Application for License of New Earth Station (C-Band Transmit/Receive using U.S. licensed satellites)." https://transition.fcc.gov/ib/sd/se/s312tr.pdf.

16. See Ronald H. Coase, "The Problem of Social Cost," *The Journal of Law and Economics* 3 (October 1960). https://www.law.uchicago.edu/files/file/coase-problem.pdf.

17. Intelsat License LLC and Intel Corp., "Joint Comments In the Matter of Expanding Flexible Use in the Mid-Band Spectrum Between 3.7 and 24 GHz," GN Docket No. 17-183, Oct. 2, 2017, pp. 6-9. https://ecfsapi.fcc.gov/file/1002726526846/Joint%20Comments%20of%20Intelsat%20License%20LLC%20and%20Intel%20Corporation.pdf.

18. Caleb Henry, "SES, Intelsat plead for an extension for C-band dish registration," *SpaceNews*, June 19, 2018. https://spacenews.com/ses-intelsat-plead-for-an-extension-for-c-band-dish-registration.

19. "Statement of Commissioner Michael O' Rielly Re: Expanding Flexible Use of the 3.7 to 4.2 GHz Band," GN Docket No. 18-122, July 13, 2018, p. 2. https://ecfsapi.fcc.gov/file/07131575002139/FCC-18-91A3.pdf; Verizon "Ex Parte Re: Expanding Flexible Use of the 3.7 to 4.2 GHz Band," May 16, 2018, p. 1. https://ecfsapi.fcc.gov/file/10516106415285/2018%2005%2016%20Verizon%205G%20ex%20parte.pdf.

20. "Is There a Better Way to Maximize the Throughput of my Satellite Capacity?", Intelsat, 2018. http://www.intelsat.com/tools-resources/library/satellite-101/digital-compression.

There is also not necessarily a linear progression to the cost of clearing more frequencies. Satellite companies are limited by the characteristics of their hardware and beyond a certain point, they may have to, for example, launch new satellites. This process would result in a sharp jump in the cost of clearing spectrum, and even if that cost is willingly paid by carriers, it could significantly increase the time that clearing takes.

As a practical matter, therefore, there may be good reason to think that a smaller portion of the band will be cleared first with more coming to market as technology and network hardware evolve. In any case, both the FCC and interested private parties should seek to foster an ongoing market in this band rather than treating the current proceeding as a one-time affair.

Reforming the Full-band, Full-arc Policy

It is likely that the current full-band, full-arc arrangement is not conducive to maximally productive use in this band. Since satellite dishes are often only tuning in to a limited range of frequencies from one satellite at a time, the remaining frequencies and positions along the geostationary arc could be put to other uses without meaningfully disrupting current operations.

Incumbents claim that they need these expansive rights in order to have greater flexibility in their provision of service.[21] For example, they may wish to point their receiver at a different satellite or tune in to different frequencies in the future. However, these are rights that are not frequently used by the parties.[22] Most earth stations will persistently receive from only one satellite and use a consistent fraction of the 500 MHz in the band. It would, therefore, be advantageous to make these current uses explicit rather than to pretend that the entire width of the band is being used at every earth station that could point at a different satellite at any moment. Being clear about how this band is actually being used will allow for the utilization of unused frequencies in particular areas.

How to move away from the inefficiencies of full-band, full-arc coordination is, however, a delicate matter. It would be most efficient for the FCC to simply codify the existing frequency and directional uses of the band and open unused portions to the rest of the market. This route, however, may present political and legal obstacles that make it untenable. Incumbent users are not eager to have their expansive rights curtailed and they would likely resist such a change, perhaps as a regulatory taking. Whether or not such a case would have merit, the delays presented by prolonged litigation may end up being more costly to timely broadband deployment than attempting to reform the full-band, full-arc policy by an alternative means.

Such an alternative could take the form of simply increasing the flexibility of incumbents to sell unused capacity in the secondary market. If it is true that full-band, full-arc results in satellite incumbents maintaining rights to spectrum that goes persistently unused, then the incumbents ought to be willing to sell or lease that capacity. Satellite users could keep all their rights, but they would face opportunity costs for doing so. For example, the choice to maintain access to the full band and the full arc would mean turning down the revenue from offers to lease unused frequencies. If they do turn down such offers, that fact would demonstrate that maintaining access to the flexibility afforded by full-band, full-arc is more valuable than the alternative use.

This reform would accomplish a similar result as revoking the full-band, full-arc rights but without the delays and costs associated with litigation. This route would, of course, present its own delays and transaction costs associated with setting up and operating the secondary market. Evaluating the tradeoffs of each alternative will take serious study by the FCC.

Holding an Incentive Auction

Another way of repurposing the 3.7–4.2 GHz band would be to hold an incentive auction. This process was used in 2016 to clear parts of the 600 MHz TV band.[23] In an incentive auction, the FCC solicits bids from incumbents on how much money it would take for them to willingly clear a certain amount of spectrum. A second auction then solicits bids for the potentially cleared spectrum until a mutually agreeable price and quantity is reached. It is not clear, however, that this process would be superior to merely enhancing the flexibility of existing licenses and allowing private parties, including the proposed consortium, to make deals on their own.

21. American Cable Association, National Association of Broadcasters, National Public Radio Inc., NCTA - The Internet & Television Association, "Ex Parte Re: Expanding Flexible Use of the 3.7 to 4.2 GHz Band," GN Docket No. 18-122, June 15, 2018, pp. 4-5. https://ecfsapi.fcc.gov/file/10615344709012/061518%2017-183%2018-122%20ACA%20NAB%20NCTA%20NPR%20ex%20parte.pdf; Satellite Industry Association, "Comments In the Matter of Expanding Flexible Use in Mid-Band Spectrum Between 3.7-24 GHz," GN Docket No. 17-183, Oct. 2, 2017, pp. 25-31. https://ecfsapi.fcc.gov/file/10022703505533/SIA%20Comments%20on%20Mid-Band%20NOI%202%20Oct%202017.pdf.

22. Google LLC, "Comments in the Matter of Report on the Feasibility of Allowing Commercial Wireless Services, Licensed or Unlicensed, to Use or Share Use of the Frequencies Between 3.7-4.2 GHz," GN Docket No. 18-122, May 31, 2018, pp. 7-8. https://ecfsapi.fcc.gov/file/105312950814240/2018-05-31%20Google%20Comments%20(GN%2018-122).pdf; Broadband Access Coalition, "Comments in the Matter of Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz," GN Docket No. 17-183, Oct. 2, 2017, pp. 6-7. https://ecfsapi.fcc.gov/file/1002768614835/Mid-Band%20NOI%20--%20BAC%20Comments%20--%20FINAL2%20with%20Attachment%20--%2010.02.17.pdf.

23. Federal Communications Commission, "Broadcast Incentive Auction and Post-Auction Transition," May 9, 2017. https://www.fcc.gov/about-fcc/fcc-initiatives/incentive-auctions.

The choice between these approaches ought to be merely a matter of comparative transaction costs: the market mechanism that can maximize the ease of voluntary transactions will result in the most efficient outcome. Imposing the FCC as a middleman may delay the process more than a situation in which profit-driven parties deal with each other directly.

Auctioning Overlay Licenses

Another alternative is for the FCC to auction overlay licenses. These essentially give their buyers the right to use frequencies in a way that does not interfere with incumbents. The practical result would be that the overlay licensee negotiates with the incumbent to clear some or all of the licensed frequencies.

The full-band, full-arc characteristics of this band, however, make this option no better than a market for the whole band through something like a consortium model. Because current users can access the entire band, the overlay licensee would need to negotiate with all of them to be sure the desired frequency is actually cleared. The anticommons tragedy will befall such attempts to bargain for individual sections of the band. A solution to this problem, for example, through the consortium model, must be implemented before more efficient deals can be negotiated.

Effect on Downstream Services

Some parties have expressed concern about potential disruptions to downstream services that could result from repurposing portions of the band but those concerns can be incorporated into the economic models discussed above.[24] The current satellite incumbents are a content delivery service and they should be able to sell off some of their assets as dictated by market conditions. Certainly their consumers may prefer to maintain access to satellite service in this band, but the proper result in such a case would be for them to pay more for the delivery service, thereby changing the market conditions and signaling the relative value of satellite service compared to alternative uses.

Additionally, reconsideration of the 3.7–4.2 GHz band's allocation is an opportunity for downstream companies to weigh alternatives, such as fiber or other wireless service on other frequencies. These may be more expensive but again, the fact that certain factors of production become more expensive to certain companies is not, in itself, grounds for government intervention.

The opportunity for reconsidering services is important because there are consumers on both sides of the coin here. It is true that losing some satellite transmission capacity could increase prices or disrupt service for downstream consumers of TV or radio. But the new uses for mobile or fixed-wireless broadband will provide other, or perhaps the same, consumers with better broadband service. Given trends in consumption of media and communications services, it is likely that the overall effect will be a net positive. Changes in price driven by changes in supply and demand are signs of a healthy market, not problems in need of regulatory solutions.

CONCLUSION

We all want our TVs and radios to work, but we also want faster, more reliable Internet that works at home and on the move. The 3.7–4.2 GHz band is an ideal candidate to provide all these services but tradeoffs are omnipresent. The question before the FCC, then, is how to balance the changing demands for satellite downlink and wireless broadband. While past policy frameworks have complicated rights in this band, the agency should seek to rearrange rights in a way that minimizes transaction costs and allows markets to direct spectrum to productive uses.

ABOUT THE AUTHOR

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24. NCTA – The Internet & Television Association, pp. 2 and 11. https://ecfsapi.fcc.gov/file/10531818122999/053118%2018-122%20Comments.pdf; American Cable Association, "Comments in the Matter of Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz. GN Docket No. 17-183, pp. 4-16. https://ecfsapi.fcc.gov/file/10032114823976/ACA%20Mid-Band%20NOI%20Comments%20171002.pdf.