Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of:	)	
Use of Spectrum Bands Above 24 GHz	)	GN Docket No. 14-177
For Mobile Radio Services	)	

Comments of Petri Mähönen, Ljiljana Simić and Pierre de Vries

via electronic filing
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J. Pierre de Vries
Executive Fellow, Silicon Flatirons Center
University of Colorado Law School
Boulder, CO 80309
pierre.devries@colorado.edu

Petri Mähönen, Ljiljana Simić and Pierre de Vries respectfully comment on the Commission's Third Further Notice of Proposed Rulemaking (*FNPRM*) in the above-referenced docket.[1] The *FNPRM* seeks comment on a variety of topics related to the licensing of mm-wave services in a variety of bands, including:

- "[W]hether unlicensed services should be permitted in the [42–42.5 GHz] band under Part 30, or whether licensed services, unlicensed services, or other types of sharing besides unlicensed and licensed should be permitted under other rule parts as well";[2]
- "[A] proposed coordination mechanism and alternatives" and "whether offering three types of non-Federal licenses -- point-to-point licenses; base stations licenses; and site-cluster licenses -- would facilitate deployment in the Lower 37 GHz band," all "to facilitate shared use of the Lower 37 GHz band between Federal and non-Federal users, as well as among non-Federal users";[3]
- "On site-based licensing, as well as other licensing mechanisms" for the 26 GHz band.[4]

Prof. Petri Mähönen is currently a Full Professor and the Chair of Networked Systems with RWTH Aachen University. He is the Founding Head of the Institute for Networked Systems, RWTH Aachen University. He has been a Principal Investigator in several international research projects, including several large European Union initiatives that have studied wireless communications, including regulatory aspects. Dr. Ljiljana Simić is currently Principal Scientist at the Institute for Networked Systems at RWTH Aachen University. Her research interests are in mm-

[1] *Use of Spectrum Bands Above 24 GHz For Mobile Radio Services*, GN Docket No. 14-177, Third Report and Order, Memorandum Opinion and Order, and Third Further Notice of Proposed Rulemaking, FCC 18-73 (June 8, 2018), (*FNPRM*).

[2] *FNPRM* at 23, para. 52.

[3] *Id.* at 27–28, paras. 62, 64–65.

[4] *Id.* at 34–35, para. 89.

wave networking, efficient spectrum sharing paradigms, self-organizing and distributed networks, and telecommunications policy. She was Co-Chair of the IEEE INFOCOM 2018 Workshop on Millimeter-Wave Networked Systems. Dr. Pierre de Vries is Co-Director of the Spectrum Policy Initiative at the Silicon Flatirons Center of the University of Colorado, Boulder, and a Visiting Senior Scientist at the Institute for Networked Systems of RWTH Aachen University. He is currently a member of the FCC Technological Advisory Council.[5]

We welcome the Commission's willingness to consider operating regimes beyond exclusive area licensing and unlicensed. We believe that a debate in terms of these two extremes creates a false choice, especially in mm-wave where operating and propagation characteristics limit the potential for inter-system interference to levels well below that seen in microwave bands (below 6 GHz, say). We urge the Commission to consider recent academic contributions to the wireless system research literature that suggest to us that non-exclusive mm-wave licensing is a viable option.[6] We believe that non-exclusive licensing – meaning in this case, a limited number of large-area licenses assigned by auction – is an appropriate middle path between exclusive large-area licensing (which may lead to under-utilization) and unlicensed (which may not provide sufficient interference protection).

Below we provide excerpts from the current wireless research literature that link the viability of non-exclusive license operation to the small spatial interference footprint of inherently narrow mm-wave beams, large system bandwidths, and the blockage-prone nature of mm-wave propagation.[7] These same characteristics led the Commission to "the determination that the highly directional,

[5] This filing represents our independent judgment and is not to be understood as the opinion of our respective institutions.

[6] We were not involved in any of this research.

[7] It is well established that mm-wave systems will have to use high-gain, narrow-beamwidth antennas to offset the high attenuation at these frequencies; the practical engineering of such systems in turn relies on the feasibility, given the short wavelength, of packing a large number of antenna elements into a small form-factor electronically steerable antenna-array. Large system bandwidths are relevant as they increase the noise floor, and thus tend to make mm-wave cellular deployments noise-limited, rather than interference-limited (i.e. noise power dominates over the aggregate interference power).

'pencil-beam' signal characteristics permit systems in these [70/80/90 GHz] bands to be engineered so that many operations can co-exist in the same vicinity without causing interference to one another," leading it to adopt a flexible and innovative regulatory framework for the 71–76 GHz, 81-86 GHz, and 92–95 GHz bands.[8] We suspect these considerations also apply to mm-wave operation below 70 GHz, i.e., some or all of the bands at issue in the *FNPRM*.

Rebato et al., *The potential of resource sharing in 5G Millimeter-Wave bands* (2016)[9]

> The authors derive scaling laws for mm-wave cellular networks, i.e., how the network capacity scales with increasing density of base stations, with or without spectrum sharing. The authors note that mm-wave cellular networks "will likely reside in power and outage-limited regimes … [which] can result in super-linear scaling of capacity with density, suggesting a fundamentally better scaling with sharing," given that "links will have very wide bandwidths and are highly susceptible to blockage." This stands in contrast to the interference-limited nature of current cellular networks in the microwave bands. The authors conclude that "the massive bandwidth and spatial degrees of freedom are unlikely to be fully used by any one cellular operator." The authors note that "… our preliminary results reflect scenarios where resources follow a blind, uncoordinated allocation scheme … and show that this simplified approach actually performs very close to a fully-coordinated scheme."

[8] *Allocations and Service Rules for the 71-76 GHz, 81-86 GHz, and 92-95 GHz Bands*, WT Docket No. 02-146, Memorandum Opinion and Order, FCC 05-45, 3–4, para. 3 (Mar. 3, 2005).

[9] Mattia Rebato, Marco Mezzavilla, Sundeep Rangan & Michele Zorzi, *The Potential of Resource Sharing in 5G Millimeter-Wave Bands*, ArXiv, Feb. 24, 2016, at 1–2, https://arxiv.org/abs/1602.07732.

Gupta et al., *On the feasibility of sharing spectrum licenses in mmWave cellular systems* (2016)[10]

The authors study the feasibility of uncoordinated sharing of spectrum licenses among mm-wave cellular operators using an analytical model. Their results show that "license sharing among operators improves system performance by increasing per-user rate," and that "license sharing is more favorable as communication becomes more directional." The authors also show that the benefit of spectrum sharing for a two-operator system is comparable at 73 GHz and 28 GHz carrier frequencies (assuming a 1 GHz and 200 MHz total system bandwidth, respectively).

Boccardi et al., *Spectrum pooling in MmWave networks: Opportunities, challenges, and enablers* (2016)[11]

The authors present a simulation study of spectrum sharing among four operators, for a total system bandwidth of 1.2 GHz, at 32 GHz and 73 GHz. They conclude that "spectrum pooling at mmWave has the potential to use the resources more efficiently than traditional exclusive spectrum allocation to a single operator," but note that inter-operator coordination is "more critical at 32 GHz than at 73 GHz, due to the fact that the [lower gain] beamforming [assumed at 32 GHz] by itself is not sufficient to protect the weakest users from inter-network interference."

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[10] Abhishek K. Gupta, Jeffrey G. Andrews & Robert W. Heath, *On the Feasibility of Sharing Spectrum Licenses in mmWave Cellular Systems*, 64 IEEE Transactions on Communications 3981–95 (Sept. 2016), *available at* http://dx.doi.org/10.1109/tcomm.2016.2590467.

[11] Federico Boccardi et al., *Spectrum Pooling in MmWave Networks: Opportunities, Challenges, and Enablers*, 54 IEEE Communications Magazine 33–39 (Nov. 2016), *available at* http://dx.doi.org/10.1109/mcom.2016.1600191cm.

Fund et al., *Spectrum and infrastructure sharing in millimeter wave cellular networks: An economic perspective* (2016)[12]

> The premise of this work is that a "technological justification for resource sharing does not always translate to economic benefits." The authors confirm "the benefits of resource sharing from a purely technical view (without considering the effect on demand)," but argue that "economic analysis shows that resource sharing is not always the preferred strategy of service providers." This work also looks at asymmetric markets where one service provider is bigger than the other and finds that the leading service provider in a duopoly market prefers to share resources only under limited circumstances, i.e., "when sharing gains are small or the market is highly segmented."

We believe that recent wireless systems research literature thus points towards a licensing option that the Commission should consider seriously: a limited number of non-exclusive licenses for each band. The Commission would determine the geographical area they would cover. These licenses could be assigned, and their number chosen, by auction. While the approach used for 70/80/90 GHz band (a non-exclusive licensing scheme combined with the site-specific coordination and registration process) may be more generally applicable, we believe that the record and subsequent research such as that cited above would also support non-exclusive licensing limited to a small number of operators.

The Commission should consider the possibility of using a non-exclusive, limited-number licensing scheme for the mm-wave allocations in this proceeding as well as other mm-wave bands.

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[12] Fraida Fund, Shahram Shahsavari, Shivendra S. Panwar, Elza Erkip & Sundeep Rangan, *Spectrum and Infrastructure Sharing in Millimeter Wave Cellular Networks: An Economic Perspective*, ArXiv, May 15, 2016, at 1, 12, https://arxiv.org/abs/1605.04602.

We believe that the Commission should seek comment on this licensing option in future NPRMs. For example, it might seek input on:

- Whether non-exclusive licensing should be the default option above some frequency to be determined (say, 40 GHz);
- The number of licenses that might be issued in a non-exclusive band, and whether such a limit should be set ex ante by rulemaking or ex post through an auction mechanism; and
- Whether rules should require coordination among non-exclusive licensees or be left to their discretion.

Respectfully submitted,
/s/
Petri Mähönen
Ljiljana Simić
Pierre de Vries