IEEE ComSoc Technical sub-Committee on Backhaul/fronthaul Networking and Communications (TCBNC) Blog

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Contents

Chair's Message

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Dear TCBNC Members:

Millimeter wave (mmWave) technology and its application to the wireless backhaul for future network is considered as one of the most sought-after research topics today. I am very delighted to introduce you an inaugural issue of TCBNC Blog with special coverage on "MmWave Backhaul Networks: Opportunities and Challenges". This special issue includes virtual interviews with Dr. Amitava Ghosh from Nokia, Bell Labs and Prof. David J. Love form Purdue University. On behalf of the TCBNC executive committee members and our community members, I would like to extend our sincere appreciation to Dr. Amitava Ghosh and Prof. David J. Love for this opportunity to interpret their vision about feasibility of mmWave technology for enabling future wireless backhaul network.

I am very much sure that you will be excited to read through the interesting discussions on opportunities and challenges related to mmWave-enabled wireless backhaul networks and find the virtual interviews valuable to understand the rapidly changing research and development landscape in this domain; to learn future application use cases and associated challenges; and finally, to get leads on some recent work and open problems.

I would like to express my special thanks to Dr. Omid Semiari form Georgia Southern University and Dr. Syed Ali Raza Zaidi from University of Leeds, UK for serving as editors to this special issue and putting every effort to turn it into reality.

I would like to take this opportunity to welcome any suggestions from the community members to make TCBNC Blog more informative and interesting. You are welcome to either write to me at muhamamd.shakir@uws.ac.uk or approach any of the editors.

Best regards,
Muhammad Zeeshan Shakir
Chair IEEE ComSoc TCBNC

Muhammad Zeeshan Shakir is an Assistant Professor at the University of the West of Scotland (UWS), UK. Before joining UWS in Fall 2016, he has been working at Carleton University, Canada, Texas A&M University, Qatar and KAUST, Saudi Arabia on various national and international collaborative projects. Most of his research has been supported by industry partners such as Huawei, TELUS and sponsored by local funding agencies such as Natural Sciences and Engineering Research Council of Canada (NSERC), Qatar National Research Fund (QNRF) and KAUST Global Research Fund (GCR). His research interests include design, development and deployment of diverse wireless communication systems, including hyper-dense heterogeneous small cell networks, Green networks and 5G technologies such as D2D communications, Networked-flying platforms (NFPs) and IoT. He has published more than 75 technical journal and conference papers and has contributed to 7 books, all in reputable venues. He is an editor of 2 research monographs and an author of a book entitled Green Heterogeneous Wireless Networks published jointly by Wiley and IEEE Press. He has been/is serving as a Chair/Co-Chair/Member of several workshops/special sessions and technical program committee of different IEEE flagship conferences, including Globecom, ICC, VTC and WCNC. He is an Associate Technical Editor of IEEE Communications Magazine and has served as a lead Guest Editor/Guest Editor for IEEE Communications Magazine, IEEE Wireless Communications and IEEE Access. He is serving as a Chair of IEEE ComSoc emerging technical committee on backhaul/fronthaul networking and communications. He is a Senior Member of IEEE, an active member of IEEE ComSoc and IEEE Standard Association.

Feature Topic: Millimeter Wave Backhaul Networks: Opportunities and Challenges

Editors: Omid Semiari[1] and Syed Ali Raza Zaidi[2]

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The proliferation of emerging wireless services – including virtual reality (VR), intelligent transportation systems (ITS), among others – with stringent quality-of-service (QoS) requirements have strained the capacity of wireless networks. To address this challenge, many innovative ideas have been proposed in past decades, such as the dense deployment of small cells, multi-antenna communications, leveraging new frequency bands; to significantly increase the capacity and coverage at wireless access networks.

Despite the substantial effort to address the traffic management challenges at the wireless access, none of the new wireless services turn into reality without providing a fast, reliable, and cost-effective backhaul/fronthaul connectivity. In particular, for many applications with stringent latency and delay requirements (such as ITS), optimizing the end-to-end (E2E) performance – across wireless access and backhaul – is essential to meet the target QoS requirements (e.g., sub-milliseconds E2E latency). Such an E2E design mandates new backhaul solutions that: *first* provide large capacity to manage the substantial traffic requested by the end users; and *second*, support backhaul connectivity to large number of small cell base stations – as foreseen in the fifth generation (5G) wireless networks – while maintaining low capital expenditures (CAPEX) and operating expenditures (OPEX).

In this regard, operating at high-frequency bands (above 6 GHz), particularly at millimeter wave (mmWave) frequencies (30-300 GHz) is viewed by both academia and industry as an enabling solution to address the aforementioned challenges of 5G backhaul network. In fact, mmWave backhaul technology offers promising features, including: 1) High data rates and small over-the-air latency by exploiting the large available bandwidth at mmWave frequencies; 2) Relatively less implementation challenges compared with mmWave utilization at the access networks, due to the fixed location of base stations; 3) Higher capability for spectrum reuse, compared with sub-6 GHz microwave backhaul, due to highly directional backhaul links; 4) Small form-factor for transceivers that makes mmWave technology suitable for dense deployments at the street-level urban furniture such as lamp posts.

Nonetheless, mmWave backhaul faces several key challenges, such as short-range mmWave links (which can dictate mesh backhaul architecture with multi-hop backhaul connections), reliability (due to susceptibility to rain attenuation, blockage, among other factors), more complexity and overhead at the control plane for establishing directional links, dynamic resource management in self-backhauling architectures, and new deployment regulations (e.g., to control radiation impact on human body), among other challenges.

In this special issue, we focus on mmWave backhaul technology as the feature topic where we conduct interviews with two key researchers in this field. In particular, we discuss the opportunities, challenges, main solutions, and open problems pertaining the mmWave backhaul in 5G networks. We hope that this effort be useful for our readers, especially to those who are new in this field of research.

Omid Semiari is an Assistant Professor at the Electrical Engineering Department at Georgia Southern University. He received the BSc and MSc degrees in electrical engineering from the University of Tehran, in 2010 and 2012, respectively, and the PhD degree from Virginia Tech, in 2017. His research interests include wireless networks, millimeter wave communications, context-aware resource allocation, matching theory, and machine learning. In 2014, Dr. Semiari has worked as an intern at Bell Labs, in Stuttgart, on anticipatory, context-aware resource management in cellular networks. In 2016, he has joined Qualcomm CDMA Technologies for a summer internship, working on LTE-Advanced modem design. Dr. Semiari is the recipient of several research fellowship awards, including DAAD (German Academic Exchange Service) scholarship and NSF student travel grant. He has actively served as a reviewer for flagship IEEE Transactions and conferences and participated as the technical program committee (TPC) member for a variety of workshops at IEEE conferences, such as ICC and GLOBECOM.

Syed Ali Raza Zaidi is currently a University Academic Fellow (Assistant Professor) at the University of Leeds. He received his B.Eng degree in information and communication system engineering from the School of Electronics and Electrical Engineering, NUST, Pakistan in 2008. He was awarded the NUSTs most prestigious Rectors gold medal for his final year project. From September 2007 till August 2008, he served as a Research Assistant on a collaborative research project between NUST, Pakistan and Ajou University, South Korea. In 2008, he was awarded overseas research student scholarship along with Tetley Lupton and Excellence Scholarships to pursue his PhD at the School of Electronics and Electrical Engineering, University of Leeds, U.K. He was also awarded with COST IC0902, DAAD and Royal Academy of Engineering grants to promote his research. Dr. Zaidi was a visiting research scientist at Qatar Innovations and Mobility Centre from October to December 2013. He is also UK Liasion for the European Association for Signal Processing (EURASIP). He has been serving as co-chair of several special sessions/workshops and symposia in flagship conferences, such as ICC, VTC, CAMAD etc. Dr. Zaidi has served as Lead Guest Editor for IET Signal Processing SI on Recent Advances in Signal Processing for 5G Wireless Networks, Editor for IEEE Communication Letters. He is currently Associate Technical Editor for IEEE Communication magazine.

Interview with Dr. Amitava Ghosh

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1) Millimeter wave (mmWave) communication is seen as a cornerstone technology for next-generation wireless networks, especially to support wireless backhaul. Could you please elaborate why mmWave backhaul has attracted so much attention in recent years?

Nokia: mmWave has much more challenging propagation than traditional cellular bands with reduced intersite spacing of base stations and making signals more susceptible to blockage. Further, the availability of large chunks of bandwidth make mmWave spectrum suitable for backhaul communication having multi-Gbps transfer capacity to support both access and backhaul. Recently, 5G mmWave technology is being used for both access and backhaul and also for integrated access and backhaul (IAB).

2) Could you please explain typical use case scenarios of mmWave backhaul (urban vs. rural, indoor vs. outdoor)?

Nokia: Currently, mmWave backhaul links have been used mainly for outdoor scenarios. An example, will be fixed service wireless backhaul stations (WBSs) @ 70 GHz bands used for high frequency trading. WBSs are non-uniformly distributed over space, and specifically they tend to have higher density near city centers while they become very sparsely deployed in suburban areas. Another example would be the backhauling of lamp post deployed in smart city 5G small cell network. In the future, mmWave backhaul will be used to mitigate the limits of existing fiber networks connecting a high density mmWave access network through a select few egress points. mmWave backhaul will be used, in North America for example, at 28 GHz and 39 GHz in the short term and higher bands in the future. In addition to future 5G networks, mmWave backhaul can also be used to provide transport connectivity to the existing legacy mobile systems.

3) Could we expect to see a wide use of mmWave backhaul in near future? If applicable, please elaborate on the timeline that standardization bodies and operators have in mind to deploy the first generation of mmWave backhaul networks.

Nokia: mmWave outdoor deployment for applications like Last 200 meters to home and Hot Spot Deployment in urban micro scenarios require dense deployments right from the initial phases to get sufficient coverage. It is economically not feasible to provide fiber connectivity to each site until the new radio deployments become mature. Self-backhauling, using the same antenna arrays to dynamically switch between access and backhaul, with optimized scheduling and dynamic TDD enabling deployment cost reduction and improving system performance is needed for making mmWave a feasible technology for 5G. The 3GPP study item on Integrated Access and Backhaul (IAB) will start in January 2018 with standardization in Rel-16 timeframe. It is expected that the first generation 5G IAB technology will be deployed around 2021-2022 timeframe.

4) One of the key requirements of backhaul networks is reliability. Given that mmWave communication is both limited in range and susceptible to blockage, how mmWave technology can overcome these limitations and provide a reliable and seamless backhaul support?

Nokia: It is true that mmWave should overcome pathloss, blocking, high penetration and diffraction loss. This can be achieved with higher densification wherein shadowing is mitigated with base station diversity and rapidly rerouting around obstacles when user device is shadowed by an opaque obstacle in its path. The pathloss and blockage at mmWave are overcome by large number of antenna arrays and by meshed backhaul connections. Wireless mesh network (WMN) backhaul with built-in self-organizing network features like on-demand route re-selection and load balancing will provide fast recovery from link failures/blockages and from traffic congestion situations via the alternative path provided by the mesh topology. Another issue for mmWave backhaul links is to design beam steering algorithms which take into account imperfections like pole sway etc.

5) Beyond reliability, are there any other challenges for realizing the mmWave backhaul (e.g., coexistence with the wired or microwave backhaul)?

Nokia: The other challenge of 5G integrated access and backhaul systems is that they should co-exist with incumbents at various mmWave bands. As an example, 28GHz has Fixed Satellite Services (FSS) as an incumbent globally and is used for Earth-to-space gateway-type services in USA. At 70 GHz, there are primarily fixed service wireless backhaul stations (WBSs) and the 5G mmWave systems should co-exist with these WBS's. Nokia has done detailed co-existence studies @ 28 and 70 GHz bands with the incumbents and recommended to the regulators on how interference from incumbents to the 5G integrated access and backhaul systems can be addressed.

6) Could you please briefly introduce the most recent research project that you have done for addressing the challenges of mmWave backhaul?

Nokia: We have been involved in several projects related to mmWave. First and foremost Nokia is actively involved in shaping the 3GPP NR specification both for mmWave and sub 6 GHz spectrum. Nokia also developed a 70 GHz Proof-of-Concept system for both backhaul and access. Specifically, we have developed i) multi-hop meshed backhaul network to study effect of beam steering, pole sway etc. using lens antenna, ii) Access network which achieves a peak rate of 15 Gbps and includes features like low latency, dynamic TDD and rapid re-routing using lens antenna and phased arrays. Nokia has at the latest Mobile World Congress introduced a new compact 10Gbps E band radio as part of the Nokia Wavence Microwave portfolio, which will be soon commercially available for deployments. Finally, we are working on IAB which is a study item in 3GPP and will be standardized in Rel-16.

7) Beyond your own work, are there any resources that you would like to recommend, especially to those who are new in this field and want to learn more about the mmWave backhaul?

Nokia: There is a rich literature on mmWave backhauling some of which are listed below:

a. S. Singh, M. N. Kulkarni, A. Ghosh, and J. G. Andrews, “Tractable model for rate in self-backhauled millimeter wave cellular networks,” IEEE J. Sel. Areas Commun., vol. 33, no. 10, pp. 21962211, Oct. 2015.

b. S. Hur, T. Kim, D. J. Love, J. V. Krogmeier, T. Thomas, A. Ghosh et al., “Millimeter wave beamforming for wireless backhaul and access in small cell networks,” IEEE Trans. Commun., vol. 61, no. 10, pp. 43914403, Oct. 2013.

c. C. Dehos, J. L. Gonzlclez, A. D. Domenico, D. Ktlenas, and L. Dussopt, “Millimeter-wave access and backhauling: The solution to the exponential data traffic increase in 5G mobile communications”.

d. Z. Gao, L. Dai, D. Mi, Z. Wang, M. A. Imran, and M. Z. Shakir, “MmWave massive-MIMO-based wireless backhaul for the 5G ultradense network,” IEEE Wireless Commun., vol. 22, no. 5, pp. 1321, Oct. 2015.

e. S. Nie, G. R. MacCartney, S. Sun, and T. S. Rappaport, “28 GHz and 73 GHz signal outage study for millimeter wave cellular and backhaul communications,” in Proc. IEEE Int. Conf. Commun. (ICC), 2014, pp. 48564861.

f. M. Cudak, T. Kovarik, T. A. Thomas, A. Ghosh, Y. Kishiyama, and T. Nakamura, “Experimental mmWave 5G cellular system,” in Proc. IEEE Globecom Workshops, Dec. 2014, pp. 377381.

g. J.Salmelin, and E.Metsl. “LTE Backhaul”. Chichester, WS, UK: Wiley, 2016

h. M. Shariat, M. Dianati, K. Seppanen, T. Suihko, J. Putkonen, and V. Frascolla, “Enabling wireless backhauling for next generation mmWave networks,” in 2015 European Conference on Networks and Communications (EuCNC). IEEE, jun 2015, pp. 164168.

i. Z. Du, K. Aronkyto, J. Putkonen, J. Kapanen, E. Ohlmer, D. Swist, “5G E-band Backhaul System Measurements in Urban Street-Level Scenarios,” submitted to European Microwave Week, Germany, Nuremberg, 10-12 October 2017.

j. Z. Du, K. Aronkyto, J. Putkonen, J. Kapanen, E. Ohlmer, D. Swist, “5G Backhaul System Evaluations,” European Conference on Networks and Communications (EuCNC), Oulu, Finland, 12-15 June 2017.

k. P. Wainio and K. Seppanen, “Self-optimizing last-mile backhaul network for 5G small cells,” in 2016 IEEE International Conference on Communications Workshops (ICC). IEEE, may 2016, pp. 232239.

l. K. Seppanen, J. Kilpi, J. Paananen, T. Suihko, P. Wainio, and J. Kapanen, “Multipath routing for mmWave WMN backhaul,” in 2016 IEEE International Conference on Communications Workshops (ICC). IEEE, may 2016, pp. 246253.

m. J. Kilpi, K. Seppanen, T. Suihko, J. Paananen, D. T. Chen, and P. Wainio, “Link scheduling for mmWave WMN backhaul,” in 2017 IEEE International Conference on Communications (ICC). IEEE, may 2017, pp. 17.

n. R. Kalimulin, A. Artemenko, R. Maslennikov, J. Putkonen, and J. Salmelin, “Impact of mounting structures twists and sways on point-to-point millimeter-wave backhaul links,” in 2015 IEEE International Conference on Communication Workshop (ICCW). IEEE, jun 2015, pp. 1924.

o. Juha Ala-Laurinaho, Jouko Aurinsalo, Aki Karttunen, Member, IEEE, Mikko Kaunisto, Antti Lamminen, Juha Nurmiharju, Antti V. Risnen, Fellow, IEEE, Jussi Sily, Pekka Wainio "Two-Dimensional Beam-Steerable Integrated Lens Antenna System for 5G E-Band Access and Backhaul" IEEE Transactions on Microwave Theory and Techniques (Volume: 64, Issue: 7, July 2016)

p. J. Ala-Laurinaho, A. Karttunen, and A. Raisanen, "A mm-wave integrated lens antenna for E-band beam steering," in Antennas and Propagation (EuCAP), 2015 9th European Conference on, 2015, pp. 12.

8) What are the most important open problems and future research directions towards realizing the mmWave backhaul solution?

Nokia: The most important problems for mmWave backhaul are as follows:

a. How to overcome shadowing due to obstacles and foliage.

b. Physical layer solutions to support wireless backhaul links with high spectral efficiency

c. Self-organizing mesh for wireless backhaul and integrated access and backhaul

d. How to compensate for pole sway using novel beamforming algorithms/alignment techniques.

e. Light pole integrated mmWave backhaul solutions supporting smart city digital ecosystem including various sensors and other devices

f. Cost effective implementations including equipment size, ease of deployment and maintenance

g. For integrated access and backhaul

    a. Topology management for single-hop/multi-hop and redundant connectivity

    b. Route selection and optimization

    c. Dynamic resource allocation between the backhaul and access links

h. 5G ultra dense meshed mobile fronthauling and backhauling @ Ultra-high mmWave band (130-174GHz) for smart cities and enterprise connectivity.

Amitabha (Amitava) Ghosh is a Nokia Fellow and Head, Small Cell Research at Nokia Bell Labs. He joined Motorola in 1990 after receiving his Ph.D in Electrical Engineering from Southern Methodist University, Dallas. Since joining Motorola he worked on multiple wireless technologies starting from IS-95, cdma-2000, 1xEV- DV/1XTREME, 1xEV-DO, UMTS, HSPA, 802.16e/WiMAX and 3GPP LTE. Dr. Ghosh has 60 issued patents, has written multiple book chapters and has authored numerous external and internal technical papers. He is currently working on 3GPP LTE-Advanced and 5G technologies. His research interests are in the area of digital communications, signal processing and wireless communications. He is a Fellow of IEEE, recipient of 2016 IEEE Stephen O. Rice and 2017 Neal Shephard prize, member of IEEE Access editorial board and co-author of the book titled "Essentials of LTE and LTE-A".

Interview with Prof. David J. Love

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1) Millimeter wave (mmWave) communication is seen as a cornerstone technology for next-generation wireless networks, especially to support wireless backhaul. Could you please elaborate why mmWave backhaul has attracted so much attention in recent years?

With the exponential growth in wireless data demand, operators and original equipment manufacturers have begun to look beyond the customary sub-6 GHz bands, which are used by nearly all wireless broadband applications. The millimeter wave bands, roughly defined as the bands in 20-100 GHz, have been lightly used for commercial applications so far. These bands offer the potential to have multi-gigahertz of new spectrum available for 5G and beyond. This is an enormous bandwidth increase for commercial communications and could lead to newer and better ways to address the growth in data requirements. In comparison, most studies I have seen show that there is less than 1GHz of spectrum available for licensed broadband today. Of course, millimeter wave has been underutilized for a reason. There are a number of propagation challenges that must be overcome. Only recently have hardware advances made transceivers in these bands cost effective.

2) Could you please explain typical use case scenarios of mmWave backhaul (urban vs. rural, indoor vs. outdoor)?

Millimeter wave deployments would have the most impact in small cell (i.e., less than 100-500 meters) settings. This matches nicely with urban deployments. It could be used in either indoor or outdoor scenarios. If used indoor, the operator would likely have to be cognizant of propagation challenges within the building. Distances could increase in rural or semi-urban settings.

3) Could we expect to see a wide use of mmWave backhaul in near future? If applicable, please elaborate on the timeline that standardization bodies and operators have in mind to deploy the first generation of mmWave backhaul networks.

While much talk has focused on millimeter wave access, I believe backhaul may enable practical network deployments. A backhaul deployment would allow for a more closely controlled link, extremely high throughputs, and lower costs. Wireless backhaul could offer reliabilities that compare well with fiber. I believe the most widely used backhaul deployment will be self-backhauling, where an operator takes a portion of its spectrum and uses it for backhaul. This kind of architecture would allow flexible small cell deployments with cells connected in an ad hoc manner.

3GPP currently has a study item on Integrated Access and Backhaul, which is very exciting. Historically, access and backhaul designs have been strictly partitioned. 5G and beyond systems, however, might have access and backhaul links that are adaptive to each other and share many design features across the communication layers.

From what I understand, millimeter wave backhaul deployments might be seen around the same time as millimeter wave access deployments, as many manufacturers have already started designing for the emerging standard. There has been much discussion about possible 5G NR deployments in 2019.

4) One of the key requirements of backhaul networks is reliability. Given that mmWave communication is both limited in range and susceptible to blockage, how mmWave technology can overcome these limitations and provide a reliable and seamless backhaul support?

From what I understand, blockage is more of a serious problem in access deployments than in backhaul deployments. Nevertheless, millimeter wave can overcome these challenges at the physical layer by using larger numbers of antennas than have been used in previous sub-6 GHz deployments. These antennas will allow the transmitter to steer one or more narrow beams to maximize rate and reliability. At the higher layers, millimeter wave deployments will leverage deployment topologies that can adapt to link blockages or outages in some backhaul links.

5) Beyond reliability, are there any other challenges for realizing the mmWave backhaul (e.g., coexistence with the wired or microwave backhaul)?

I believe latency is the key challenge. If millimeter wave backhaul must achieve latencies lower than those found in LTE, a multi-hop backhauled small cell deployment will be challenging. There are also questions on what kind of distances operators will try to deploy. Wired backhauls clearly offer many benefits, but operators will have problems scaling wired backhaul deployments.

Another issue is electromagnetic exposure. The skin and the eye absorb millimeter wave signals quickly. I am not sure how regulatory bodies will handle millimeter wave access and backhaul connections. The standard specific absorption rate (SAR) regulations in their current form are likely not applicable to millimeter wave. More work is necessary to address this.

6) Could you please briefly introduce the most recent research project that you have done for addressing the challenges of mmWave backhaul?

We have done a substantial amount of work on beam design and beam alignment. The research addresses how a base station can correctly point its beam at a user equipment with one or more antennas. The beam design problem becomes important when the system is required to only use a finite number of possible beamformers or precoders.

Most recently, my students and I have been working on a National Science Foundation (NSF) project related to millimeter wave networks. The research team includes faculty at Purdue, Texas A&M, and the US Naval Academy. We are looking at physical layer, medium access layer, and network layer enhancements that could work together to support a highly adaptive (and programmable) millimeter wave system.

My students and I are also working on transmit architectures that can adapt to EM exposure constrained wireless systems. As I mentioned, if the EM exposure regulatory issues are severe, figuring out how to adapt the multiple antenna signal to these constraints will be critical. This research is funded by the NSF and jointly conducted by Purdue, Notre Dame, and the University of Illinois.

7) Beyond your own work, are there any resources that you would like to recommend, especially to those who are new in this field and want to learn more about the mmWave backhaul?

We published an early paper in this area:
S. Hur, T. Kim, D. J. Love, J. V. Krogmeier, T. Thomas, A. Ghosh, "Millimeter Wave Beamforming for Wireless Backhaul and Access in Small Cell Networks," IEEE Transactions on Communications, vol. 61, no. 10, pp. 4391-4403, Oct. 2013.

There are also multiple IEEE Communications Magazine articles available on millimeter wave, backhaul, and 5G NR.

8) What are the most important open problems and future research directions towards realizing the mmWave backhaul solution?

I personally believe that the largest open problem is understanding how millimeter wave systems should be regulated. Whatever regulations are enforced will have tremendous impact on system design and widespread acceptance of these devices.

There are also a large number of issues related to latency and multi-point deployments. Achieving low latencies will be challenging with self-backhauled networks.

David J. Love (S'98 - M'05 - SM'09 - F'15) received the B.S. (with highest honors), M.S.E., and Ph.D. degrees in electrical engineering from the University of Texas at Austin in 2000, 2002, and 2004, respectively. During the summers of 2000 and 2002, he was with Texas Instruments, Dallas, TX. Since August 2004, he has been with the School of Electrical and Computer Engineering at Purdue University, where he is now a Professor. He leads the College of Engineering Preeminent Team on Efficient Spectrum Usage. He has served as an Editor for the IEEE Transactions on Communications, an Associate Editor for the IEEE Transactions on Signal Processing, and a guest editor for special issues of the IEEE Journal on Selected Areas in Communications and the EURASIP Journal on Wireless Communications and Networking. His research interests are in the design and analysis of communication systems and MIMO array processing. Dr. Love is an inventor on approximately 30 U.S. patent filings, 27 of which have issued.

Dr. Love has been recognized as an IEEE Fellow and Thomson Reuters Highly Cited Researcher (2014,2015). He is a Fellow of the Royal Statistical Society and inducted into Tau Beta Pi and Eta Kappa Nu. Along with his co-authors, he won best paper awards from the IEEE Communications Society (2016 IEEE Communications Society Stephen O. Rice Prize), the IEEE Signal Processing Society (2015 IEEE Signal Processing Society Best Paper Award), and the IEEE Vehicular Technology Society (2009 IEEE Transactions on Vehicular Technology Jack Neubauer Memorial Award). He has received multiple IEEE Global Communications Conference (Globecom) best paper awards. He was the recipient of the Purdue HKN Outstanding Teacher Award in Fall 2010, Purdue ECE Graduate Student Association Outstanding Faculty Award in Fall 2013, and the Purdue HKN Outstanding Professor Award in Spring 2015 and Fall 2017. He was an invited participant to the 2011 NAE Frontiers of Engineering Education Symposium and 2016 EU-US NAE Frontiers of Engineering Symposium. In 2003, Dr. Love was awarded the IEEE Vehicular Technology Society Daniel Noble Fellowship.