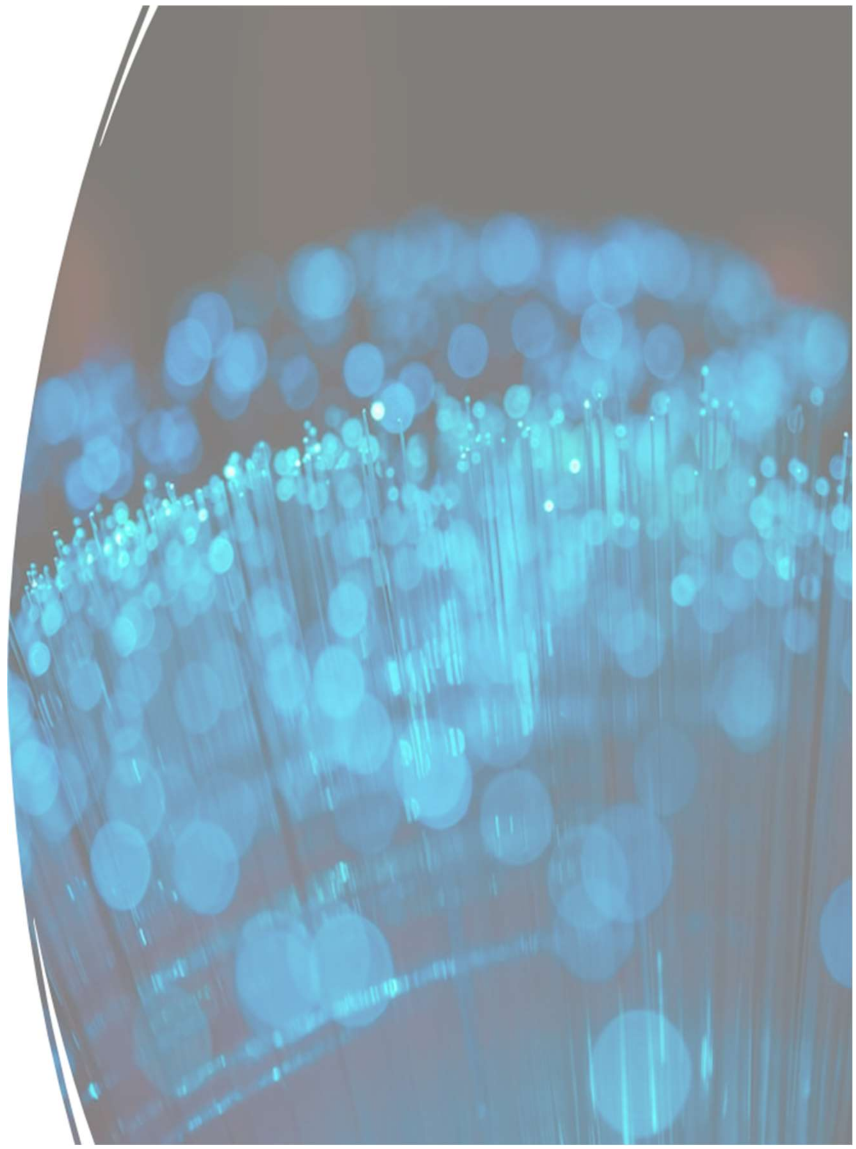
RINGS

Resilient and Intelligent NextG Systems



NSF RINGS PI Meeting Two Report

Event Date: 9-11 July 2024

IBM | Yorktown Heights, New York

Prepared by RINGS-VO

Report Date: November 2024

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About NSF RINGS

The National Science Foundation's Resilient & Intelligent NextG Systems (RINGS) program is dedicated to advancing research that could have a significant influence on the development of Next Generation (NextG) wireless, mobile communication, networking, sensing, and computing systems. The program aims to enhance the resilience of these networked systems. Modern communication devices and networks must support a wide array of critical services, and incorporate resilience through computation, coordination, and intelligent decision-making.

Resilience, which encompasses security, adaptability, and autonomy, ensures robust network and computing capabilities that can adapt quickly and degrade gracefully under extreme operating conditions. The RINGS program drives innovative approaches to improve both resilience and performance across various aspects of NextG communications, networking, and computing systems. The program aims to surpass the current research portfolio within the individual participating directorates by emphasizing improvements in resilience and performance across all layers of the networking protocol and computation stacks.

In this endeavor, the NSF is collaborating with the Office of the Under Secretary of Defense for Research and Engineering (OUSD R&E), the National Institute of Standards and Technology (NIST), and several industry partners. The program aims to fund collaborative team research that transcends traditional disciplinary boundaries to achieve its goals.

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1 Event Overview

The 2024 RINGS PI Meeting took place on July 9th thru the 11th at the IBM Thomas J. Watson Research Center in Yorktown Heights, New York. This two-and-a-half-day event aimed to nurture a community dedicated to advancing future networks and systems. It brought together researchers, industry partners, and experts from various fields to collaborate, exchange knowledge, and discuss the latest technology and research breakthroughs. The agenda featured interactive workshops, insightful presentations, informative poster sessions, brainstorming sessions, and engaging social events, all designed to foster in-person connections within the RINGS community and provide research updates.

Networking and a poster session offered valuable insights into innovation and the future of technology. Panel discussions facilitated the exchange of ideas and experiences among experts, while lightning talks provided quick summaries of key achievements and significant challenges in various research areas. Breakout group sessions allowed participants to engage in discussions on focused topic areas. The event included 100+ in-person attendees from academia, industry, and government, as well as representatives from all RINGS partners.

RINGS Community at the PI Event

Day 1

8:00 – Continental Breakfast / Check-in

9:00 – Welcome Opening Remarks & Theme Setting

9:30 – Project Presentations: Sharing Research Results (3 parallel tracks)

10:30 – Break

11:00 – Project Presentations: Sharing Research Results (3 parallel tracks)

12:30 – LUNCH

1:30 – Project Presentations: Sharing Research Results (3 parallel tracks)

2:30 – Poster Session /Break

3:15 – Synthesis Panel / People's Choice (single track)

4:00 – GROUP Photos!

4:15 – Poster Session

Day 2

8:00 – Continental Breakfast / Check-in

8:30 – Plenary: NSF Post RINGS Interest, Questions, Prompts

9:00 – Panel 1: Network Capabilities to Support Future Network Applications: Telesurgery/Medical, Ultra-Low Latency, AR/VR, etc.

10:00 – Break

10:15 – Panel 2: International, Inter-agency and Public-Private Partnerships in NextG

11:00 – Breakout instructions and time to move to other room

11:15 – Breakout Groups (4 parallel tracks)

12:15 – Lunch Break & Posters

1:15 – Panel 3: NextG Technology Frontiers

2:15 – Breakout Groups Continued (same groups and rooms as AM)

3:15 – Break

3:30 – Panel 4: Taming the Wireless Channel

4:30 – Poster Session

Day 3

8:00 – Continental Breakfast / Check-in

8:30 – Panel 5: Future Network Intelligence (AI)

9:30 – Connection & Collaboration – Exploring Collaboration Opportunities

10:00 – Break

10:45 – Breakout Outbriefs (8-10 min debrief from each Breakout group)

11:15 – Panel 6: NextG Academic Centers

12:00 – Closing Remarks and Conference Wrap-Up

12:30 – Box Lunches

Afternoon Optional Session / IBM Bonus Content:

1:30 – *AI Ethics Research*

2:00 – Security Research at IBM

2:30 – Hybrid Cloud Platform

3:00 – Coffee Break

3:15 – Panel: Generative AI for Communication Networks

4:15 – Antennas to AI platform for Integrated Communications and Sensing

2 Day 1 – Sharing Research Results

Note: Presentation recordings will be made available on the RINGS website.

2.1 Opening Remarks


Dan Ward (MITRE) *Hussein Abouzeid (NSF)*

The event was officially opened by Dan Ward (RINGS-VO), who emphasized the importance of sharing research results and networking opportunities over the next few days.

Hussein Abouzeid (NSF) also welcomed participants, highlighted the involvement of industry partners and agencies, and emphasized the event themes surrounding research results and future vision.

George Tulevski gave logistical information about the IBM facility, including security protocols and amenities. He encouraged attendees to explore the Thinklab, which showcases IBM's latest technologies.


Sudhir Gowda (IBM) *George Tulevski (IBM)*

Sudhir Gowda from IBM provided an overview of IBM and IBM Research, detailing their mission, global presence, and focus areas such as AI, hybrid cloud, quantum computing, and semiconductors. He emphasized IBM's commitment to open AI development and collaboration with academic and industry partners.

2.2 Session 1 – Auditorium. Facilitator: Pelle Karlsson-Ericsson

- I-RIM: Learning based Resilient Immersive Media-Compression, Delivery, and Interaction — **Shiwen Mao (Auburn University)**
- Bumblebee: A Neural Network Transformer Architecture for Summarization and Prediction in Interactive XR Applications — **Anthony Rowe (Carnegie Mellon University)**
- Deep Generative Models for Ultra High-Dimensional Next Generation Communication Systems — **Jeffrey Andrews (University of Texas at Austin)**
- Provably Robust Machine Learning for Next Generation Cellular Networks — **Deepak Vasisht (University of Illinois Urbana-Champaign)**

2.3 Session 1 - Think Lab. Facilitator: Kathy Ryall -RINGS-VO/MITRE

- Ensuring Reliability in mmWave Networks — **Christina Fragouli (University of California Los Angeles)**
- WISECOM – Wireless Integrated Sensing, Learning and Communication Networks — **Nuria Gonzalez Prelcic (North Carolina State University)**

- Mobility-driven Spectrum-Agile Resilient mmWave Communication Links for Unmanned Aerial Vehicle Traffic Management in the Sky **— Kamesh Namuduri (University of North Texas)**

2.4 Session 1 - Conference Room 14-101. Facilitator: Bodhisatwa Sadhu (IBM)

- Intelligent and Resilient Virtualization of Massive MIMO Physical Layer — **Lin Zhong (Yale University)**
- Wideband NextG Tb/s mm-Wave Communication and Networking — **Ali Niknejad (University of California Berkeley)**
- Resilient Wireless Systems for Future Uplink Traffic through Cell-Free, Loosely Coordinated Access — **Krishna Narayanan (Texas Engineering Experiment Station)**
- Bringing Post-Quantum Cryptography to Large-Scale NextG Systems — **Reza Azarderakhsh (Florida Atlantic University)**

2.5 Session 2 – Auditorium. Facilitator: Nageen Himayat (Intel Corporation)

- Collaborative Inference and Learning between Edge Swarms and the Cloud — **Sandeep Chinchali (University of Texas at Austin)**
- Learning-Enabled Ground and Air Integrated Networks (GAINs) — **Lingjia Liu (Virginia Polytechnic Institute)**
- Scalable and Resilient Networked Learning Systems — **Gustavo de Veciana (University of Texas at Austin)**
- Enabling Wireless Edge-cloud Services via Autonomous Resource Allocation and Robust Physical Layer Technologies — **Eytan Modiano (Massachusetts Institute of Technology)**
- A Deep Reinforcement Learning Enabled Large-scale UAV Network with Distributed Navigation, Mobility Control, and Resilience — **Yingbin Liang (The Ohio State University)**
- LARA: Layering for Active Resiliency and Awareness in Next-generation Wireless Networks — **Tara Javidi (University of California San Diego)**

2.6 Session 2 – Think Lab. Facilitator: Erich Nahum (IBM)

- Object-Oriented Video Analytics for Next-Generation Mobile Environments — **Ravi Netravali (Princeton University)**
- Accelerating the NextG Protocols Definition to Code Generation with an Automatic and Secure Verification-Compilation Tool-Chain — **Yan Chen (Northwestern University)**
- Power Resilient NextG Data Centers — **Simon Peter (University of Washington)**
- Reshaping the Last Mile for High Availability and Resilience — **Sylvia Ratnasy (University of California, Berkeley)**
- Deployable End-to-End Resilience for Critical Internet Applications via Modular Redundancy — **Dan Rubenstein (Columbia University)**
- Resilient Delivery of Real-Time Interactive Services Over NextG Compute-Dense Mobile Networks — **Andreas Molisch (University of Southern California)**

2.7 Session 2 – Conference Room 14-101. Facilitator: Rath Vannithamby (Intel)

- REALTIME: Resilient Edge-cloud Autonomous Learning with Timely Inferences — **Anand Sarwate (University of California, Berkeley)**

- Walk For Resiliency & Privacy: A Random Walk Framework for Learning at the Edge — **Salim El Rouayheb (University of California, Los Angeles)**
- Language-Agnostic Resilience Engineering at the Edge with WebAssembly — **Ben Titzer (University of California, San Diego)**
- Resilient Edge Networks with Data-driven Model-based Learning — **Yong Liu (University of California, Davis)**
- Enabling Joint Sensing, Communication, and Multi-tenant Edge AI for Cooperative Perception Systems — **Kaikai Liu (San Jose State University)**

2.8 Session 3 – Auditorium. Facilitator: Alberto Valdes-Garcia -IBM

- Internet of Things Resilience through Spectrum-Agile Circuits, Learning-Based Communications and Thermal Hardware Security — **Marvin Onabajo (Northeastern University)**
- Robust and Resilient Wireless Networks using Next Generation Spectrum — **Randall Berry (Northwestern University)**
- Enabling Data-Driven Innovation for Next-Generation Networks Via Synthetic Data **— Giulia Fanti (Carnegie Mellon University)**
- Harnessing the Complexity of Modern Electromagnetic Environments for Resilient Wireless Communications — **Steven Anlage (University of Maryland College Park)**

2.9 Session 3 - Think Lab. Facilitator: Dinesh Verma -IBM

- Resilient and Low-Latency Networks for Situation Awareness in the Factory of the Future — **Moe Win (Princeton University)**
- Resilient mmWave Networks via Distributed In-Surface Computing (mmRISC) — **Kaushik Sengupta (Princeton University)**
- Massive Extended-Array Transceivers for Robust Scaling of All-Digital mmWave MIMO — **Upanyu Madhow (University of California, Santa Barbara)**
- Just-in-Time Security: Adaptive Physical-Layer Security for NextG Low-Latency mmWave Wireless Networks — **Matthieu Bloch (Georgia Institute of Technology)**

2.10 Session 3 - Conference Room 14-101. Facilitator: Rick Boivie -IBM

- Resilience of NextG Communication Systems to Malicious Modification Attacks — **Aria Nosratinia (University of Texas at Dallas)**
- Building Next Generation Resilient Wireless Systems from Unsecure Hardware **— Sundeep Rangan (New York University)**
- Resilient Edge Ecosystem for Collaborative and Trustworthy Disaster Response (REsCue) — **Satyajayant Misra**
- NextSec: Zero-Trust, Programable and Verifiable Security Transformation for NextG — **Guofei Gu (Texas Engineering Experiment Station)**
- Coding over High-Frequency for Absolute Post-Quantum Security (CHAPS) — **Muriel Medard (Massachusetts Institute of Technology)**

2.11 Synthesis / People's Choice Panel

Synthesis Panel / People's Choice

The People's Choice Panel was co-moderated by Murat Torlak (NSF) and Rath Vannithamby (Intel). This panel showcased a subset of projects as voted by the audience.

- Gustavo de Veciana from the University of Texas at Austin discussed his project on Federated Learning and Network Resource Optimization, focusing on optimizing network resources to speed up convergence in machine learning through client sampling, lossy compression adaptation, and in-network aggregation.
- Giulia Fanti from Carnegie Mellon University presented her work on using synthetic data to reduce data sharing barriers in networking, with applications in reducing observability costs and storing long-term network traces, while also addressing privacy requirements.
- Deepak Vasisht from UIUC talked about the reliability of machine learning systems in wireless contexts, exploring adversarial attacks and vulnerabilities, and methods to improve training processes for more robust models, aiming to provide probabilistic guarantees for model performance.
- Upamanyu Madhow from UC Santa Barbara highlighted his project on millimeter wave communication and massive parallelization of DSP, addressing packaging difficulties through a tiled approach and developing power-efficient hardware for high-frequency bands.

Key discussions included combining projects for greater impact, addressing life or death consequences in machine learning systems, and the vision for transitioning projects beyond research. The panelists emphasized the importance of industry collaboration facilitated by RINGS, which had a positive impact on their research.

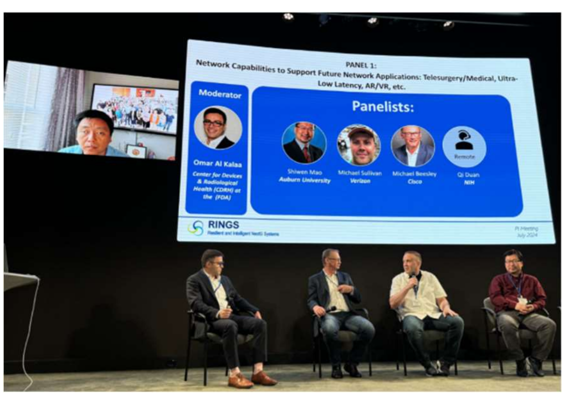
3 Day 2 - Roadmaps to the Future

3.1 Plenary: NSF Post RINGS

Hussein Abouzeid (NSF)

The plenary session focused on the future of research and development in next-generation networking, particularly beyond the RINGS program. The session began with an introduction emphasizing the importance of futuristic thinking, bold ideas, and addressing challenging questions. The National Science Foundation (NSF) is keen on understanding the community's research interests, priority areas, and effective research mechanisms. The session highlighted the importance of envisioning impactful technical advancements for the next 10-20 years and considering ideas that could change the world. The RINGS program, a significant public-private partnership, is nearing the end of its initial funding period, and there is a need to explore what's next. Key points discussed included the importance of international partnerships, particularly in the context of 6G and beyond, and the need for collaboration across countries. The session also touched on various technical challenges and research directions, such as AI and machine learning for networking, spectrum sharing, integrated sensing and communications, and security and privacy. NSF also emphasized the importance of industry partnerships and the need for continued collaboration to address these challenges. The session concluded with a call for input from the community to help shape the vision for future research programs, ensuring they are both focused and flexible enough to accommodate diverse and innovative ideas.

3.2 Panel 1: Network Capabilities to Support Future Network Applications



Panel 1

Moderator:

- Omar Al Kalaa (FDA)

Panelists:

- Shiwen Mao (Auburn)
- Michael Sullivan (Verizon)
- Michael Beesley (Cisco)
- Dan Fay (Microsoft Research)
- Qi Duan (NIH) REMOTE

The panel discussion focused on the requirements and challenges of future network applications, particularly in the context of telesurgery, medical applications, and ultra-low latency AR/VR. Mr. Beesley discussed the need to analyze use case requirements for mobile networks, highlighting mobility's benefits and costs. Mr. Sullivan noted the challenges of adopting 5G in hospitals due to existing infrastructure, while Mr. Mao emphasized understanding specific application requirements and device interoperability. Mr. Duan addressed reimbursement challenges for AR/VR in healthcare and the role of cloud infrastructure in extending reach. The panelists explored the feasibility of providing end-to-end QoS, with Mr. Beasley pointing out technological tools for RAN and packet core slicing, and challenges at peering points and cloud data centers. Business and ecosystem considerations were discussed, emphasizing the need for mutually agreeable commercial constructs. Audience engagement included questions about medical technology approval cycles and network scalability, with panelists stressing collaboration among stakeholders and research opportunities. The session concluded with a call for future research and collaboration to integrate network capabilities with vertical applications, particularly in healthcare. Key points discussed included:

Network Requirements and Gaps: The panelists emphasized the need to understand the specific requirements of each use case. They highlighted that not all applications, such as telesurgery, are best suited for mobile networks due to their need for stable, high-bandwidth connections, which are better served by fiber optics.

Technological and Business Challenges: The discussion covered the technological challenges in providing end-to-end quality of service (QoS) and the business challenges related to the deployment and operation of network infrastructure. The need for better interoperability and the importance of understanding the verticals' specific needs were stressed.

Regulatory and Reimbursement Issues: Dr. Duan highlighted the challenge of reimbursement for medical applications, which can hinder the adoption of new technologies. Dr. Al Kalaa from the FDA pointed out the importance of understanding the system's failure modes and mitigation strategies to ensure safety and effectiveness.

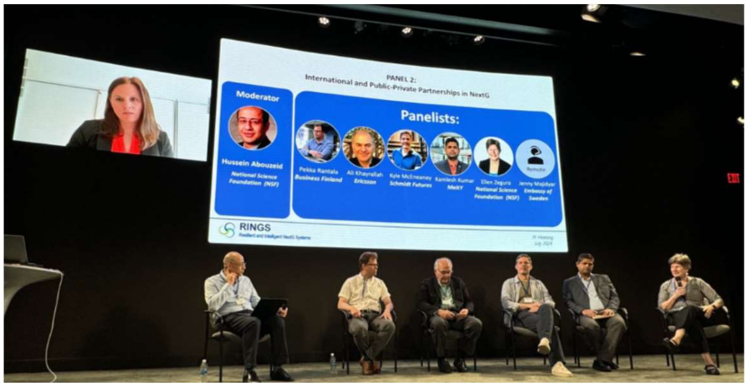
Future Directions and Collaboration: The panelists discussed the need for collaboration between the telecom industry and verticals to create mutually beneficial business models and technological solutions. They also mentioned the potential role of federal intervention to standardize and incentivize the development of these solutions.

Audience Engagement: The audience raised questions about the feasibility of end-to-end QoS, the role of AI in regulatory processes, and the integration of various stakeholders to address complex use cases like telesurgery and telehealth.

This panel discussion was prepared or accomplished by Dr. Qi Duan in his personal capacity. The opinions expressed in this article are the Dr. Duan's own and do not reflect the view of the National Institutes of Health, the Department of Health and Human Services, or the United States government.

This panel discussion was prepared or accomplished by Dr. Omar Al Kalaa in his personal capacity. The opinions expressed in this article are the Dr. Al Kalaa's own and do not reflect the view of the U.S. Food and Drug Administration, the Department of Health and Human Services, or the United States government.

3.3 Panel 2: International, Inter-agency and Public-Private Partnerships in NextG



Panel 2

Moderator:

- Hussein Abouzeid (NSF)

Panelists:

- Pekka Rantala (Finland)
- Ali Khayrallah (Ericsson)
- Kyle McEneaney (The Schmidt Family Foundation)
- Kamlesh Kumar (India)
- Ellen Zegura (NSF)
- Jenny Majidyar (Swedish embassy)

The panel discussed the importance and dynamics of collaborations in advancing NextG technologies. The panel included representatives from various sectors, including industry, government, and philanthropic organizations from the US, India, Sweden, and Finland. The panel explored international, inter-agency, and public-private partnerships in advancing NextG technologies. Participants discussed the significance of collaboration in developing 5G and 6G, emphasizing the role of industry, funding agencies, and international bodies. There was a focus on the importance of partnerships, with examples of countries like India and Sweden actively engaging in 6G development and international agreements. The conversation highlighted the philanthropic approach to connectivity and spectrum management, noting the challenges posed by geopolitical shifts and the need for global standards. Sustainability, affordability, and accessibility were identified as key priorities, with varying emphasis across different regions. The panelists agreed on leveraging existing collaboration frameworks and stressed the urgency of timely research to influence standards. Discussions also covered the role of government in fostering innovation and the potential for private sector-driven advancements in network infrastructure. The session concluded with reflections on the challenges and opportunities in creating effective partnerships for future communication technologies.

Discussion was focused several key topics:

Introductions and Perspectives: Panelists introduced themselves and shared their perspectives on the importance of partnerships in NextG research and development. They emphasized the need for collaboration across borders and sectors to drive innovation and address global challenges.

NSF's Role and Collaborations: NSF highlighted the agency's commitment to collaborations, both domestic and international, and the relatively new but growing emphasis on partnerships with industry and philanthropic organizations.

International Efforts: Representatives from India, Sweden, and Finland discussed their respective countries' efforts in promoting research and development in 5G and 6G technologies. They mentioned various funding initiatives, international agreements, and collaborative programs aimed at advancing NextG technologies.

Philanthropic Contributions: Schmidt Futures discussed the role of philanthropic organizations in filling gaps that other entities might not address. He emphasized the importance of being catalytic, consequential, and counter-cyclical in their efforts to support public benefit applications of technology.

Geopolitical and Security Considerations: Ericsson discussed the shifting global geopolitical landscape and its impact on network infrastructure and standards. He highlighted the importance of research and development in 5G and 6G, and the challenges posed by differing national standards.

Sustainability and Accessibility: The panel discussed the importance of sustainability, affordability, and accessibility in NextG technologies. They noted that different countries prioritize these aspects differently, but international collaborations could help address these challenges more effectively.

Government and Market Dynamics: The panel debated the role of government regulation versus market-driven solutions in advancing NextG technologies. They discussed the potential need for government mandates in areas like spectrum management and energy efficiency, while also recognizing the role of market incentives in driving innovation.

Audience Engagement: The panelists responded to audience questions about the effectiveness of government mandates, the role of industry in driving innovation, and the importance of learning from successful use cases of 5G. Overall, the panel underscored the critical role of international, inter-agency, and public-private partnerships in advancing NextG technologies, while also highlighting the challenges and opportunities in achieving global collaboration and innovation.

3.4 Breakout Group - Network Capabilities to Support future Network Applications & Future Network Intelligence. Facilitator: Dinesh Verma -IBM

This breakout session focused on the role of AI in the future of networks, particularly with the advent of Gen AI and its implications for network operations and security. The group discussed the evolving definition of networks, considering factors like edge computing and semantic networks. They debated the need for networks to adapt to various scenarios, including complete disconnection and power outages, and how AI could help manage these situations. Topics included:

Network Evolution: The definition of networks is changing with advancements like Gen AI and edge computing.

Security and AI: AI can both enhance network operations and pose security risks.

Future Applications: Identifying future applications that will drive network design, such as immersive 3D experiences and digital agriculture.

Interoperability and Accessibility: The need for networks to be interoperable and accessible, treating connectivity as a human right.

Technical and Economic Challenges: Balancing technical solutions with economic feasibility, and the role of AI in making networks more autonomous and cost-effective.

Environmental Considerations: The importance of designing networks with disposability and environmental impact in mind. The session concluded with a consensus on the importance of considering a wide range of applications and the need for networks to be intelligent, resilient, and environmentally sustainable.

During the second session on this topic, discussion centered on the evolving role of AI in network operations, highlighting both its potential to enhance efficiency and the security challenges it poses. Participants debated the future definition of networks, considering advancements like edge computing and semantic networks. The conversation also touched on the changing network ecosystem, questioning the roles of traditional providers and the impact of edge computing on cloud services. Expanding key performance indicators (KPIs) to include dependability, especially for mission-critical applications, was emphasized. The concept of "Network++" was introduced, focusing on resilience in disconnected scenarios. The potential of large language models (LLMs) to aid in network management was considered, alongside the role of edge processing in reducing data costs. There was a proposal to design networks with a focus on AI capabilities, leveraging AI for optimization. The need for affordable, energy-efficient solutions to provide ubiquitous connectivity, particularly in underserved regions, was stressed. Interoperability and accessibility were deemed crucial, with an emphasis on collaboration among stakeholders. The group expressed interest in intelligent networks that dynamically adjust to meet KPIs and inform users of capabilities. Emerging applications, such as immersive video experiences and digital agriculture, were identified as future drivers of network innovation. Additionally, the environmental impact and disposability of network devices were highlighted. The session concluded with a consensus on the complexity of solving network challenges, requiring a blend of technical, economic, and social solutions, with AI playing a key role in improving dependability and affordability.

3.5 Breakout Group - Joint Sensing and Communications. Facilitator: Eric Wang - Ericsson

The breakout session focused on the topic of integrated communication and sensing, particularly in the context of 6G technology. The morning session covered the background and growing interest in this area, discussing the potential for integrated communication sensing in 6G, operational bands, and various deployment scenarios. Key use cases mentioned included passive radar sensing, object detection, e.g. drone detection, positioning and localization, spectrum sharing, and enhancing communication through sensing. In the afternoon, the group aimed to identify important problems, research directions, and formulate recommendations. During the second session, discussion focused on integrated communication sensing, exploring its relevance in current and future technology landscapes. The conversation began with an overview of the 3GPP's release timelines, highlighting the inclusion of integrated communication and sensing and the anticipated 6G studies in future releases. Participants discussed the role of standard bodies in facilitating integrated communication sensing across various frequency bands, emphasizing the importance of spectrum sharing and coexistence with DoD applications. The discussion also touched on the challenges of implementing integrated sensing, such as the need for new radio technologies and the potential for utilizing existing infrastructure. Various sensing modalities, including passive radar and vehicular sensing, were considered, along with the potential for improving spectral efficiency and operational capabilities. The group explored potential use cases, such as enhancing security in stadiums and providing valuable data for infrastructure planning. The conversation concluded with considerations of the business implications, particularly the potential for generating new revenue streams for operators through enhanced services and applications.

Key recommendations included:

Benchmarks and Datasets: Establishing benchmarks and datasets for objective evaluation of algorithms, similar to what has been done in the machine learning community.

Quality of Service Framework: Developing a quality-of-service framework for sensing to ensure consistent and comparable results.

Proof of Concept and Test Beds: Encouraging the development of proof-of-concept setups and access to test beds to validate and compare algorithms in real-world scenarios.

Ground Truth Data: Emphasizing the importance of having ground truth data for validating sensing capabilities. Additional research topics discussed included channel modeling for sensing, making sensing systems resilient to spoofing, and the concept of network sensing. The session concluded with a consensus on the importance of these recommendations and the need for further research and development in these areas over the next 2-3 years to influence the initial releases of 6G technology.

3.6 Panel 3: NextG Technology Frontiers

Panel 3

- Keynote: Dr. Thomas Rondeau OUSD (R&E)

Moderator:

- Hussein Abouzeid (NSF)

Panelists:

- Nada Golmie (NIST)
- Sudharman Jayaweera (NSF)
- Jaydee Griffith (NTIA)
- Sridhar Kowdley (DHS)

The "NextG Technology Frontiers" panel, featured a keynote by Dr. Thomas Rondeau, Principal Director of FutureG at the Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)). Dr. Rondeau discussed the Department of Defense's (DoD) focus on 5G and 6G technologies, emphasizing the importance of collaboration with commercial industries to advance, adopt, adapt, and innovate these technologies for national security. He highlighted the need for ubiquitous secure and instant access secure, ubiquitous access the integration of non-terrestrial networking, and the potential of 6G technologies. Dr. Rondeau also touched on the DoD's efforts in various areas, including dual-use technologies, expeditionary and tactical communications, smart resilient logistics, and integrated sensing and communications (ISAC). He mentioned ongoing collaborations with NATO and the importance of workforce development in these technological areas. The most impactful future technology challenges, such as achieving ubiquitous service and integrating heterogeneous access to spectrum were also discussed. Panelists explored the need for a market-driven approach to incentivize investments in these technologies. The discussion highlighted the potential of software-driven advancements in 5G and 6G, the importance of developing integrated 5G modems in end-user devices, and the need for a more modular and interoperable approach to telecom infrastructure. The panelists also addressed workforce development challenges, emphasizing the need for increased funding, awareness, and collaboration between academia, industry, and government to build a robust pipeline of skilled professionals in the field of advanced communications.

3.7 Panel 4: Taming the Wireless Channel

Panel 4

Moderator:

- Huaiyu Dai, NSF

Panelists

- Brent Josefiak (L3 Harris)
- Puneet Sharma (Hewlett Packard Labs)
- Jim Baldo (George Mason University)

The panel featured discussions on various aspects of next-generation wireless communication, focusing on the challenges and opportunities in taming the wireless channel. Key points discussed included:

Millimeter Wave and Sub-Terahertz Channels: The panelists debated the potential and challenges of millimeter wave and sub-terahertz channels for next-generation networks. They noted the industry's mixed feelings about millimeter wave, emphasizing the need for spatial understanding and control information to facilitate highly directional communications.

Energy Consumption and Sustainability: The discussion highlighted the importance of optimizing energy consumption in next-generation networks. The panelists suggested using AI for network management, energy harvesting, and considering the carbon footprint of energy sources.

AI in Wireless Networks: The panel explored the integration of AI in wireless networks, discussing the need for edge computing, data pre-processing, and network slicing. They emphasized the importance of a holistic approach, combining compute and communication to achieve AI outcomes.

Data for AI: The panelists debated the merits of measurement campaigns versus AI-generated data for training AI models in wireless networks. They suggested a hybrid approach, combining real-world data with AI-generated data to develop robust models.

Resilience and Security: The panel discussed the need for enhanced physical layer security in next-generation networks, especially against adversaries equipped with AI capabilities. They highlighted the importance of protocol hardening, spatial techniques like beamforming, and using passive elements like meta-surfaces for security.

Sensing and Spectrum Management: The panelists addressed the role of sensing technologies in managing spectrum efficiently and detecting interference. They suggested integrating spectrum awareness into commercial and government devices and using AI for real-time spectrum management. The session concluded with a Q&A segment, where audience members raised additional points about spectrum interference, security, and the role of sensing technologies. The panelists emphasized the need for a comprehensive approach, combining various technologies and strategies to address the challenges of next-generation wireless communication.

4 Day 3 – Collaboration Opportunities

4.1 Panel 5: Future Network Intelligence

Panel 5

Moderator:

- Murat Torlak (NSF)

Speaker:

- Walter Willinger (NIKSUN)

Panelists:

- Nageen Himayat (Intel)
- Kuntal Chowdhury (NVIDIA)
- Junyi Li (Qualcomm)
- Emad Farag (Samsung)

The panel focused on the role of AI in enhancing network intelligence. The session began with Walter Willinger, Chief Scientist at NIKSUN, discussing the limitations of the current machine learning (ML) pipeline used in networking. He highlighted that while AI has been applied in networking for over a decade, the standard ML pipeline often results in models that are not generalizable, explainable, or trustworthy for network operators. Walter emphasized the need for a new pipeline that focuses on understanding causality and includes a closed-loop system for continuous improvement. The panelists, including experts from Intel Labs, NVIDIA, Qualcomm, and Samsung Research America, discussed various aspects of AI in networking. They acknowledged that current networks already have significant intelligence but identified gaps such as the lack of holistic evaluation methodologies, data harmonization, and the need for more integrated and explainable AI solutions. They also noted the importance of edge intelligence and the potential benefits of AI in areas like network energy saving, mobility optimization, and beam management. Audience questions touched on the challenges of data sharing and harmonization, the need for synthetic data generation, and the role of digital twins in simulating disaster scenarios. The panelists agreed that while there is a lot of research on decentralized networks and device-to-device communication, commercial adoption and standardization are lagging. They emphasized the importance of proactive planning and simulation to prepare for emergency situations. The session concluded with a call for higher standards in AI research and the need for models that are generalizable, explainable, and trustworthy. The panelists also highlighted the importance of keeping humans in the loop to ensure effective and efficient AI deployment in networking.

4.2 Partner & Sponsor Sidebar. Facilitator: Hussein Abouzeid (NSF)

The meeting discussed the RINGS program, focusing on collaboration with partners and sponsors. There was mention of ongoing discussions about future programs and the importance of resilience and intelligence in AI and ML research. Hussein highlighted the need for partnerships and the potential for follow-on programs like future of RINGS. The discussion covers the involvement of partners in the solicitation process, decision-making, and post-award engagement. Hussein noted that contributions from partners vary and that the program seeks both funding and active participation.

Also discussed is the importance of use cases and the interest from other agencies in driving research and demonstrating impact. The legal and logistical aspects of collaboration, including the need for Memorandums of Understanding (MOUs) was addressed. They emphasized the importance of having MOUs in place before finalizing the program and the role of partners in the review and evaluation process. The group acknowledged the urgency of aligning with industry timelines, particularly in the context of 6G standardization. They discussed the potential for the future to include different tracks within the same program to accommodate various interests and funding levels. The discussion also touched on the importance of data sharing and the challenges associated with accessing data for research. In addition, data sharing could be encouraged as a review criterion in the future NextG programs. Attendees were invited to share feedback and reminded of the importance of collaboration and timely input from stakeholders.

4.3 Breakout Group Out-Briefs

Mark Wegman-IBM

Facilitators from four breakout groups summarized their discussions, focusing on future network applications and intelligence over the next 5-10 years. Key points included the cyclical nature of network design (centralized vs. decentralized), the impact of various applications (both frivolous and serious), and the diversity of network KPIs. Despite known technical solutions, practical challenges persist due to legacy systems and ecosystem constraints.

The consensus was that future networks will integrate new technologies like AI and IoT, creating a different infrastructure. Recommendations included recognizing access to information as a human right and leveraging generic techniques to apply known solutions effectively.

4.4 Panel 6: NextG Academic Centers

Panel 6

Moderator:

- Eric Wang (Ericsson)

Panelists

- Shivendra Panwar (NYU)
- Gustavo De Veciana (UT Austin)
- Yasaman Ghasempour (Princeton University)
- Ismael Guvenc (NC State University)

The panel discussion on "NextG Academic Centers" featured four professors from various universities discussing their research focuses and goals related to 6G technology. Each professor introduced their respective 6G focused research centers and highlighted their unique research areas. The discussion also touched on the challenges of monetizing 5G and potential strategies for 6G, such as focusing on latency, energy efficiency, and new use cases like sensing. The panelists highlighted the importance of experimentation and test beds to transition academic research into practical applications. They also discussed the potential of differentiated services and the need for innovative business models to drive industry growth. The session concluded with questions from the audience, where the panelists shared successful technologies from their centers and discussed the balance between energy efficiency and innovation. The importance of industry-academia collaboration and the role of policy in shaping the future of 6G were also emphasized.

Shivendra Panwar (NYU): Focuses on terahertz propagation, RFIC devices, and applications like 360 video and edge networking.

Gustavo De Veciana (University of Texas at Austin): Covered AI in wireless systems, new spectrum topologies, pervasive sensing, and open networks.

Yasaman Ghasempour (Princeton University): Emphasized foundational topics from RF to terahertz circuits, intelligent compute, communication, and policy issues.

Ismail Guvenc (NC State University): Works on SDR experiments in sub-6 GHz and millimeter-wave bands, spectrum sharing, and the NSF AERPAW platform for experimentation with drones, advanced wireless systems, and autonomy

5 Appendix

5.1 Research Project List

Title	Organization	Principal Investigator
A Deep Reinforcement Learning Enabled Large-scale UAV Network with Distributed Navigation, Mobility Control, and Resilience	Ohio State University	Yingbin Liang
Accelerating the NextG Protocols Definition to Code Generation with an Automatic and Secure Verification-Compilation Tool-Chain	Northwestern University	Yan Chen
Bringing Post-Quantum Cryptography to Large-Scale NextG Systems	Florida Atlantic University	Reza Azarderakhsh
Building Next Generation Resilient Wireless Systems from Unsecure Hardware	New York University	Sundeep Rangan
Bumblebee: A Neural Network Transformer Architecture for Summarization and Prediction in Interactive XR Applications	Carnegie-Mellon University	Anthony Rowe
Coding over High-Frequency for Absolute Post-Quantum Security (CHAPS)	Massachusetts Institute of Technology	Muriel Medard
Collaborative Inference and Learning between Edge Swarms and the Cloud	University of Texas at Austin	Sandeep Chinchali
Deployable End-to-End Resilience for Critical Internet Applications via Modular Redundancy	Columbia University	Dan Rubenstein
Enabling Data-Driven Innovation for Next-	Carnegie-Mellon University	Giulia Fanti

Generation Networks Via Synthetic Data		
Enabling Joint Sensing, Communication, and Multi-tenant Edge AI for Cooperative Perception Systems	San Jose State University Foundation	Kaikai Liu
Enabling Wireless Edge-cloud Services via Autonomous Resource Allocation and Robust Physical Layer Technologies	Massachusetts Institute of Technology	Eytan Modiano
Ensuring Reliability in mmWave Networks	University of California-Los Angeles	Christina Fragouli
Harnessing the Complexity of Modern Electromagnetic Environments for Resilient Wireless Communications	University of Maryland, College Park	Steven Anlage
Intelligent and Resilient Virtualization of Massive MIMO Physical Layer	Yale University	Lin Zhong
Internet of Things Resilience through Spectrum-Agile Circuits, Learning-Based Communications and Thermal Hardware Security	Northeastern University	Marvin Onabajo
Just-in-Time Security: Adaptive Physical-Layer Security for NextG Low-Latency mmWave Wireless Networks	Georgia Tech Research Corporation	Matthieu Bloch
I-RIM: Learning based Resilient Immersive Media-Compression, Delivery, and Interaction	Auburn University	Shiwen Mao
Language-Agnostic Resilience Engineering at the Edge with WebAssembly	Carnegie-Mellon University	Heather Miller
LARA: Layering for Active Resiliency and Awareness in	University of California-San Diego	Tara Javidi

Next-generation Wireless Networks		
Learning-Enabled Ground and Air Integrated Networks (GAINs)	Virginia Polytechnic Institute and State University	Lingjia Liu
Massive Extended-Array Transceivers for Robust Scaling of All-Digital mmWave MIMO	University of California-Santa Barbara	Upamanyu Madhow
Mobility-driven Spectrum-Agile Resilient mmWave Communication Links for Unmanned Aerial Vehicle Traffic Management in the Sky	University of North Texas	Kamesh Namuduri
NextSec: Zero-Trust, Programmable and Verifiable Security Transformation for NextG	Texas A&M Engineering Experiment Station	Guofei Gu
Object-Oriented Video Analytics for Next-Generation Mobile Environments	Princeton University	Ravi Netravali
Power Resilient NextG Data Centers	University of Washington	Simon Peter
Provably Robust Machine Learning for Next Generation Cellular Networks	University of Illinois at Urbana-Champaign	Deepak Vasisht
REALTIME: Resilient Edge-cloud Autonomous Learning with Timely Inferences	Rutgers University New Brunswick	Anand Sarwate
Reshaping the Last Mile for High Availability and Resilience	University of California-Berkeley	Sylvia Ratnasamy
Resilience of NextG Communication Systems to Malicious Modification Attacks	University of Texas at Dallas	Aria Nosratinia

Resilient and Low-Latency Networks for Situation Awareness in the Factory of the Future	Massachusetts Institute of Technology	Moe Win
Resilient Delivery of Real-Time Interactive Services Over NextG Compute-Dense Mobile Networks	University of Southern California	Andreas Molisch
Resilient Edge Ecosystem for Collaborative and Trustworthy Disaster Response (REsCue)	New Mexico State University	Satyajayant Misra
Resilient Edge Networks with Data-driven Model-based Learning	New York University	Yong Liu
Resilient mmWave Networks via Distributed In-Surface Computing (mmRISC)	Princeton University	Kaushik Sengupta
Resilient Wireless Systems for Future Uplink Traffic through Cell-Free, Loosely Coordinated Access	Texas A&M Engineering Experiment Station	Krishna Narayanan
RINGS:Deep Generative Models for Ultra High-Dimensional Next Generation Communication Systems	University of Texas at Austin	Jeffrey Andrews
Robust and Resilient Wireless Networks using Next Generation Spectrum	Northwestern University	Randall Berry
Scalable and Resilient Networked Learning Systems	University of Texas at Austin	Gustavo de Veciana
Walk For Resiliency & Privacy: A Random Walk Framework for Learning at the Edge	Rutgers University New Brunswick	Salim El Rouayheb
Wideband NextG Tb/s mm-Wave Communication and Networking	University of California-Berkeley	Ali Niknejad
WISECOM – Wireless Integrated Sensing, Learning	North Carolina State University	Nuria Gonzalez Prelcic

and Communication
Networks

5.2 Research Project Quad Charts

Award #2146754 July 2024

Internet of Things Resilience through Spectrum-Agile Circuits, Learning-Based Communications and Thermal Hardware Security

Marvin Onabajo (monabajo@ece.neu.edu)

Objective

- Enabling of sub-6 GHz IoT networks in which resilience features are deeply embedded across layers from the circuit level to the wireless system level
- Spectrum sensing and adaptability on the circuit level and on the system level (edge device)
- On-chip temperature sensors to monitor power dissipation
- Machine learning algorithms for signal classification, anomaly detection, and RF fingerprinting

Challenges

- Creation of a simulation framework with behavioral models of circuits for DL algorithm development/testing:
  - Design of fast on-chip spectrum sensing circuits
  - Simulation together with learning-based spectrum analysis → Optimizations for spectrum agility
- Spectrum sensing: Reduction of computation overhead and latency without compromising classification performance → New DL-driven paradigm with semantic spectrum segmentation

Key Accomplishments

- Creation of an on-chip spectrum sensor design approach with tunable active resonators
- Deep Neural Network (DNN) classifier able to directly process I/Q samples for the generation of interference maps
- Demonstrated the first differential temperature sensor with a chopping technique and on-chip calibration → highest measured sensitivity
- Development of an autoencoder-based algorithm for the detection of Trojan circuits and their locations

Future Work

- Test board assembly for spectrum sensor prototype measurements
- Design of agile communication circuits adapted from the resonators in the spectrum sensors
- Wireless test platform development (custom chips/PCBs, SDR platform with XilinxZynq-7000 XC7Z045-2FFG900C SoC)
- Testing of the DL-based algorithm with experimental data collected in the field

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This content approved for public release.

Award # 2147196 July 2024

RINGS: Bringing Post-Quantum Cryptography to Large-Scale NextG Systems

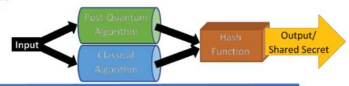
PI: Reza Azarderakhsh, Florida Atlantic University, FL, Co-PI: Kemal Akkaya, Florida International University, FL, Co-PI: Mumin Cebe, Marquette University, WI

Objective

- **Investigation of quantum-safe cryptography algorithms for IoT devices deployed in NextG system**
- **Efficient quantum-safe certificate management in NextG systems**
- **Developing an open-source and end-to-end 5G network testbed across cloud entities.**
- **Evaluating performance trade-offs in deploying PQ-based security schemes on the proposed testbed.**

Challenges

- **Physically secure HW implementations of PQC is not trivial**
- **The bandwidth of NB-IoT creates challenges to carry PQC Signature schemes over the network**
- **Current open-source implementations for 5G protocols are diverse and may not be interoperable**
- Hybrid Design



Key Accomplishments

- **Developed HW/SW primitives for for PQC deployment and implementation**
- **Developed a virtualized open-source 5G Stand Alone testbed at FIU campus.**
- **Integrated Post-quantum TLS into 5G Control Plane on this testbed**
- **Evaluated certificate revocation mechanisms on NB-IoT**

Future Work

- **More testing and evaluation with the current TLS tunnel-based approach**
- **Consideration of any other CP protocol that can integrate TLS**
- **Investigation of TLS certificate revocation overhead in 5G CP**

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Award # 2148104 July 2024

REALTIME: Resilient Edge-cloud Autonomous Learning with Timely Inferences

Anand D. Sarwate (anand.sarwate@rutgers.edu)

Objective

- **Optimize ML for offloading**
- **Manage latency in multi-agent systems**
- **Fully decentralized learning and opt.**

Challenges

- **Transition from point-to-point to multi-user.**
- **Need a canonical application**
- **Testbed integration**

Key Accomplishments

- **Using latency as part of the objective in ML training.**
- **Better understanding of AoI in new contexts.**
- **Comprehensive understanding for byzantine distributed optimization**

Future Work

- **Integrating project strands**
- **Building partnerships**
- **Testbed evaluations**

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Award # CNS-2148128

RINGS: Enabling Wireless Edge-cloud Services via Autonomous Resource Allocation and Robust Physical Layer Technologies

Eytan Modiano (MIT, PI) and Gil Zussman (Columbia)

Objective

Develop a resilient network architecture and control framework to support a broad range of critical applications including: smart cities, connected vehicles, AR/VR, and distributed/federated learning

Challenges

- Real world constraints are complex
- Required delay constraints
- Integration of theoretical framework with real systems

Key Accomplishments

- Physical layer Technology: Adaptive control of full duplex wireless, mmWave comms
- Network control: Network Utility Maximization (NUM) with unknown utilities, Minimum delay routing, Computational offloading
- System Demonstrations: Real time closed-loop application, Adaptive STreaming for Real-Time Video Analysis

Future Work

- Integration of the NUM/NC framework with streaming system
- Latency aware routing, scheduling, and offloading
- Joint communications and sensing – (with Nokia and with IBM PAAMs)

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November 2023

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Award # 2148141

July 2024

Deep Generative Models for Ultra High-Dimensional Next Generation Communication Systems CNS-2148141

Jeffrey G. Andrews, Alex Dimakis (jandrews@ece.utexas.edu)

Objective

•Develop a novel framework that generates user-specific wireless channels at precise locations using a conditional diffusion model to enhance spatial awareness and realism in synthetic datasets.

Challenges

•Extensive inference time of the diffusion model, which affects real-time application feasibility.

•Accurately capturing the sparse characteristics of mmWave channel matrices during data augmentation.

Key Accomplishments

•First method to generate user-specific channels at precise locations, providing detailed spatial awareness.

•The diffusion model enables sophisticated interpolations and extrapolations based on limited training data, outperforming other generative models.

Future Work

•Address the extensive inference time of the diffusion model to enable real-time applications, potentially through Progressive Distillation and Consistency Models.

•Explore Diffusion Posterior Sampling for inference from partial information and improve joint CSI acquisition and precoding methods.

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Award # 2148178 July 2024

RINGS: Mobility-driven Spectrum-Agile Resilient mmWave Communication Links for Unmanned Aerial Vehicle Traffic Management in the Sky

Kamesh Namuduri, Xiang Sun, and Ifana Mahbub
Kamesh.namuduri@unt.edu, sunxiang@unm.edu, Ifana.Mahbub@utdallas.edu
UNT · The University of New Mexico · UT Dallas

Objective

- Air corridor design and analysis
- Decentralized multi-UAV control for air corridors
- Federated learning-based control model fine-turning
- Software-defined networking (SDN) enabled UAV wireless mesh network
- Spectrum management in UAV networks for air corridors , and
- Phased-array antenna and beamforming using mmWave RF front-end system

Challenges

- The discrepancy between expected and measured velocities of a UAV when implementing HTransRL in the experimental testbed, thus increasing the probability of having collisions and boundary crossings
- Achieving an efficient and flexible in-band control to optimize a data path between the SDN controllers
- Achieving an efficient and flexible spectrum-sharing method for UAVs in air corridors
- Tracking and beamforming instantaneously while the UAV is moving

Key Accomplishments

- Developed concepts for digitized airspaces & V2V communication protocols.
- Developed air corridor models
- Proposed and demonstrated the hybrid transformer based multi-agent reinforcement learning (HTransRL) architecture for multi-UAV control
- Proposed and demonstrated the federated multi-agent reinforcement learning (FedMARL) framework to fine-tune HTransRL based on the transitions from the real-world environment
- Implemented SDN based wireless mesh network via B.A.T.M.A.N and OpenFlow
- Developed 3D frequency reuse planning model for UAV networks
- Demonstrated beamforming using 1 X 4 antenna array.

Future Work

- Analyzing the difference between expected and measured velocities of a UAV and incorporating this difference in the training process
- Optimizing the traditional link discovery process using prior information about UAVs, such as their destinations and trajectories
- Optimizing the 3D cell planning strategy
- Live demonstration of V2V communications and multi-UAV coordination in air corridors

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Award # 2148182 July 2024

RINGS: Walk For Resiliency & Privacy: A Random Walk Framework for Learning at the Edge

Salim El Rouayheb, sye8@scarletmail.rutgers.edu, Erdem Koyuncu, ekoyuncu@uic.edu, Hulya Seferoglu, hulya@uic.edu

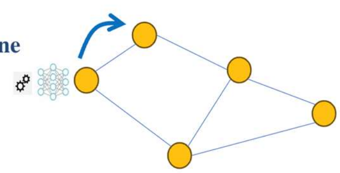
Objective

- Federated learning is vulnerable to a single point of failure! Communication bottleneck.
- Decentralized algorithms have been extensively studied in the literature. Gossip algorithms receiving the lion's share of research attention. → Too much communication overhead. → Convergence issues in async-gossip.
- **Solution:** Random walk learning.

Challenges

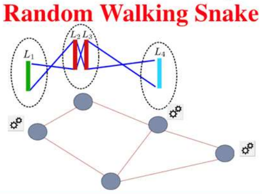
Random walk learning

- Model may not fit into one node.
- Multiple nodes can be used to speed-up.
- Convergence is slow.

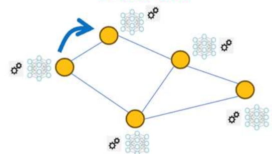


Key Accomplishments

Random Walking Snake



DIGEST



Future Work

- Multiple random walk.
- Split random walk learning.
- Random walk in adversarial settings.
- Differential privacy guarantees.

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Award # CNS- 2148183

RINGS: Robust and Resilient Wireless Networks using Next Generation Spectrum (CNS-2148183)

Randy Berry (Northwestern, PI) and Eytan Modiano (MIT, Co-PI)

Objective

Develop an architecture, associated resource provisioning mechanisms, and autonomous control algorithms to enable robust and resilient next-generation wireless networks based on infrastructure and spectrum sharing

Challenges

- How to design an architecture for sharing heterogeneous spectrum and infrastructure?
- How to design resilient network control algorithms for over-the-top providers utilizing shared infrastructure?

Key Accomplishments

- Spectrum pooling
- Relaxed incumbent protection
- Probabilistic service guarantees
- Learning-based channel selection
- Tracking control algorithms for unobservable underlay networks

Future Work

- Serving delay tolerant users using shared spectrum
- Providing "hard" delay guarantees over intermittent spectrum
- Probabilistic "drift-plus-penalty" framework

Northwestern | ENGINEERING

Award # 2148209

July 2024

Power Resilient NextG Data Centers

Simon Peter (simpeter@cs.washington.edu)

Objective

- **Power control plane**
  - **Power measurements**
  - **Power saving mechanisms**
  - **Power control hierarchy**
  - **Power controller**

Challenges

- **Power characteristics in edge data centers**
  - **Power usage/management characteristics**
- **Workloads characteristics**
  - **Shiftable workloads and their SLAs**

Key Accomplishments

- **Power instrumentation**
  - **CPU power estimation/attribution**
- **Power control**
  - **Prediction-based power control**

Future Work

- **Disaggregated power saving mechanisms**
- **Power-proportional disaggregated storage**

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Award # NSF/CNS-2148212 July 2024

RINGS: Learning-Enabled Ground and Air Integrated Networks (GAINs)

Lingjia Liu (VT), Robert Calderbank (Duke), and Yuejie Chi (CMU)

Objective

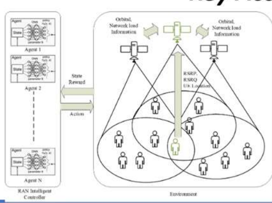
Communication and computing are unbalanced

1. How to design robust PHY waveforms across segments?
2. How to enable robust/resilient commun.?
3. How to design scheduling/resource allocation strategies considering comput. cap., commun. cost, and energy?
4. How to achieve resilient scheduling/resource allocation?

Challenges

- NTN evaluation using ns-3 requires substantial development in channel and mobility models.
- Fast and frequent handover due to high mobility of LEO satellites requires efficient handover algorithms in NTN.
- The network state information for network slicing in O-RAN framework gets outdated due to long propagation delay in NTN.

Key Accomplishments



- Zak-OTFS I-O Relation is *Predictable*
- Prediction is simple
- 2D-Reservoir Computing for OTFS symbol detection
- Multi-agent DRL for NTN handover
- ML-prediction assisted network slicing in O-RAN-empowered NTN

Future Work

- Adding additional features (e.g., propagation delay) to make a more robust ns-3 based integrated terrestrial-NTN simulator.
- Comprehensive testing and evaluation of the performance of the DRL handover algorithm on the ns-3 simulation platform.
- Complexity and convergence analysis of DRL based handover algorithm.
- Apply AI/ML-based solutions in other challenges (e.g., spectrum sharing, resource scheduling, etc.) associated with NTN

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Award # 2148224

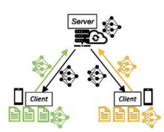
Scalable and Resilient Networked Learning Systems

Gustavo de Veciana and Haris Vikalo, Dept of ECE UT Austin

Objective

Next generation distributed and large-scale learning systems, e.g., based on federated learning (FL) , are increasingly experiencing:

1. heterogeneous wireless/wireline network variability and/or congestion
2. intermittency or churn in client availability to participate in the learning process.



This research project centers on developing engineering principles for the design of resilient and scalable networked learning systems.

Challenges

Challenge 1: Global models trained by a FL systems may be biased towards clients with higher availability and affected by limitations in the available communication resources.

Challenge 2: FL systems are exposed to, or indeed the cause of, congestion across a wide set of network resources. Further, they require frequent exchange of large files between the clients and server

Challenge 3: Clients may be driven by incentives to participate in the FL system.

Key Accomplishments

Addressing Intermittency & congestion

Developed client sampling strategies under intermittent client availability/churn which **minimize client sampling variability** and resulting impact on FL training convergence.

Developed FL algorithm which allows for time varying lossy compression and network adaptive client update compression policy which dynamically varies clients' lossy to **minimize expected wall clock training time**

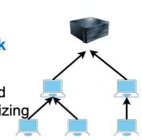
Addressing data & device heterogeneity

Developed a new approach to **clustered federated learning** which addresses the joint identification of clusters while training of multiple models.

Developed a **mixed-precision quantization** framework in support of federated learning on resource-constrained heterogeneous devices.

Future Work

Federated learning algorithms that exploit overlay network aggregation



Characterized optimal aggregation trees for synchronous setting and bounded delays for asynchronous schedules. Working on characterizing robustness to losses and tradeoffs when using redundancy and aggregation.

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Resilient and Intelligent NextG Systems
November 2023

Award # 2148253 July 2024

RINGS: A DEEP Reinforcement Learning Enabled Large-scale UAV Network with Distributed Navigation, Mobility Control, and Resilience

Yingbin Liang (OSU), Hai (Helen) Li (Duke U.), Qinru Qiu (Syracuse U.), Junshan Zhang (UC Davis)

Objective

Design a NextG resilient UAV navigation system, with high-performance communication, computation, automation and adaptivity

- Ambient sensing, real-time information processing, state tracking
- RL-based trajectory planning via augmented MDP
- Hardware-aware resource-efficient training for UAV networks
- Robustness and security design for UAV networks

Challenges

- Strong sensing capabilities to continuously monitor environment
- Excellent communication networks about sensing and control signals to function well
- Just-in-time mobility control with ultra-low latency
- Hardware-aware computation design of highly efficient algorithms
- Strong system resilience and defense functions

Key Accomplishments

- New reinforcement learning (RL) algorithms with acceleration, over time-varying environments, and provable sample efficiency
- Heterogenous architecture design on networks that handles multi-modality messages and with enhanced quality on runtime
- New neuro-symbolic belief map that accelerates RL training and improves learned policy
- Testing: Gazebo simulation environment for UAV controlled by external embedded GPU

Future Work

- New designs for partially observed Markov decision process (POMDP)
- Incorporating attention mechanism for more efficient message passing among UAVs
- Computationally efficient architecture search algorithms for UAV systems
- Simulation platforms for validating UAV message passing and control algorithms for UAV trajectory planning

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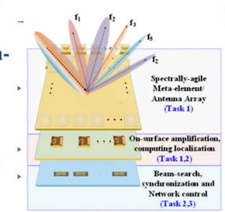
Award # 2148271 July 2024

Resilient mmWave Networks via Distributed In-Surface Computing (mmRISC)
Project Number: 2148271

Kaushik Sengupta, Princeton University (kaushiks@princeton.edu)
PRINCETON UNIVERSITY

Objective

- Incorporating intelligence in RIS with a new class of Silicon-chip Enabled Surfaces with On-surface Sensing.
- Physical Layer Security
- Enabling Multi-band Surfaces
- Comprehensive theoretical and experimental study of RIS-assisted mmWave wireless networks



Challenges

- Hardware Challenges: Creating scalable and low-power RIS/TIS with embedded sensing and packaging at mmWave is a challenge.
- Low power localization of multiple users in a mobile dynamic environment.
- Control Plane Challenges: Employing conventional channel sensing for RIS has key limitations in scalability and robustness (low-snr per element)
- Existing semi-exhaustive beam management protocols do not satisfy the latency requirements of next-gen networks.

Key Accomplishments

- First CMOS-enabled scalable programmable RS/TIS with gain and phase control.
- X-band RIS with embedded sensing
- *Wall-Street* enables simultaneous communication and handover sensing
- Near-field and hybrid near-far field channels in advanced sensing

Future Work

- Integrating CMOS-IC universal RIS/TIS at 60 GHz with gain/phase control.
- Localization capabilities of X-band RIS with embedded sensing
- Integrating the developed algorithm of on-surface sensing and AI-aided RIS adaptation with mmRISC transmit/reflectarrays
- Develop a software-defined testbed for real-time demonstration. Large-scale measurement in various dynamic environments demonstrating real-time link adaptation with reflectarrays

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Award # 2148293 July 2024

Building Next Generation Resilient Wireless Systems from Unsecure Hardware

S. Rangan, E. Erkip, R. Karri, F. Khorrami, M. Mezzavilla, P. Krishnamurthy (NYU)

Objective

- Build resilient networks from unsecure hardware?
- Capacity in adversarial channels
- Detection algorithms and performance
- Focus on disaggregated topologies

Challenges

- Need to extend Trojan detection for high data rates and analog / mix signals
- Need to extend adversarial capacity for multi-antennas and multiple users
- Leverage new methods for detection via localization

Key Accomplishments

- Adversarial capacity estimation
- O-RAN synchronization and attack
- Upper mid-band & satellites
- Open Trojan detection platform

Future Work

- More complex adversarial attack analysis
- FR3 robustness methods
- Satellites
- O-RAN platform development

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Award # 2148301 July 2024

RINGS: Language-Agnostic Resilience Engineering at the Edge with WebAssembly

Heather Miller (hmiller2@andrew.cmu.edu), Claire Le Goess, Ben L. Titzer

Objective

- Increase robustness of distributed applications running on Cloud/Edge using WebAssembly
- Apply fault-injection techniques to new domain

Challenges

- Distributed nature of faults
- Multi-language frameworks
- Lack of good instrumentation tools

Key Accomplishments

- Innovative WebAssembly implementation techniques for observability
- Fault-injection prototypes for two distributed platforms

Future Work

- Domain-specific language for instrumentation
- Program repair techniques for faults

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Award # 2148303 July 2024

Massive Extended-Array Transceivers for Robust Scaling of All-Digital mmWave MIMO

PIs: Upamanyu Madhow, Mark Rodwell
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UCSB

Objective

- Hardware/signal processing co-design for radical MU-MIMO scaling
  - Array scaling: tiling
  - Bandwidth scaling: reduce dynamic range
  - Computational scaling: channel sparsity

Challenges

- 6G focus moving from mmWave towards FR3 (7-15 GHz)
  - Limited success of mmWave in 5G
- How best to make an impact?
- Medium term: apply scaling concepts to lower frequencies
- Long term: Continue pushing technology for 100+ GHz
- Evangelize the potential of low-cost mmWave backhaul

Key Accomplishments

- Tiled beamspace DSP for digital tiles
  - Parallelize detection across users and tiles
  - Reduced complexity & overhead
- 75 and 140 GHz RFICs for RF beamforming tiles
  - Drastic reduction in per-element power

Future Work

- Tiled beamspace for scaling with digital tiles
  - Wideband regimes, lower freq bands
- 75 and 140 GHz RF beamforming tiles
  - Measurement & characterization of ICs
  - Scaling hybrid beamforming architectures
- Fundamental limits & performance evaluation with realistic channel models
  - Measured data and detailed ray tracing for typical urban environments

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This content approved for public release.

Award # 2148309 July 2024

Resilient Edge Networks with Data-Driven Model-Based Learning

Yong Liu (yongliu@nyu.edu)

Objective

- Edge Resilience in Two Loosely Classified Classes of Scenarios
  - Type A: expected demand and resource variations;
  - Type B: unexpected major shifts in demands and resource variations
- Data-Driven Model-Based Learning
  - Leverage models for domain knowledge, formal analysis, sample efficiency, and structured algorithms;
  - Leverage operational data for adaptive algorithms, data-driven exploration, model correction

Challenges

- Formal Analysis of Resilience?
- Robustness Guarantee with Dynamic Demands and Resources?
- Real Large Network, Traffic and Failure Data for Data-driven Approaches?

Key Accomplishments

- Structured Reinforcement Learning for Scheduling in Dense mmWave Networks
- Fast Restoration of Computation Flows
- Robust Lyapunov Optimization for LEO Constellation Network Routing Control

Future Work

- Learning-based Routing with In-Network Processing (RINP), joint routing and scheduling adaptation
- Progressive major failure recovery; inter-carrier collaboration
- Robust Lyapunov Optimization for Edge Networks.
- Deepen on-going industrial collaborations

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Award # 21482148315

Resilient Delivery of Real-Time Interactive Services over NextG Compute-Dense Mobile Networks

Andreas Molisch (USC, PI), Elza Erkip (NYU, Co-PI), Jaime Llorca (NYU, UNITN), Antonia Tulino (NYU, UNINA)

Objective

- **End-to-end RTI service optimization and control**
- Capturing:
  - Multi-tier **3C resource capabilities** of NextG networks
  - Multi-pipeline disaggregated nature, **3C resource consumption**, and strict latency constraints of RTI services
- Guaranteeing **reliable and resilient service delivery**

Challenges

- Efficiently training DRL & CDRL agents for network control
- Combining static opt, stochastic optimization (SO), and reinforcement learning (RL) policies
- Handling resilience challenges associated with user mobility, node failures, and link failures

Key Accomplishments

- **IDAGO**: centralized information-aware end-to-end service DAG orchestration
- **DI-DCNC**: distributed throughput-optimal control policy for multi-pipeline data-intensive applications
- **CDRL service control**: constrained DRL control policy minimizes total resource cost while guaranteeing reliable service delivery
- **CNF-OS**: global-local dual-timescale orchestration system

Future Work

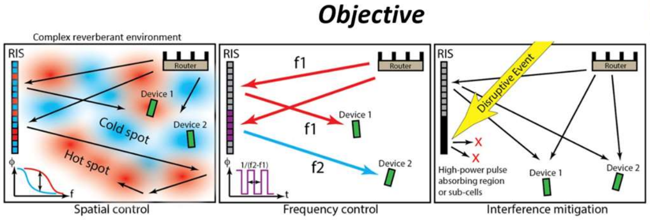
- Improve DRL training of network control agents by increasing relevant state exploration
- Leverage respective strengths of static optimization, SO, and RL, into overall orchestration system
- Explore centralized policies to proactively create redundancy, and distributed policies to reactively reroute packets and/or autoscale resources, in order assure resilient service delivery under high network dynamics

Award # ECCS2148318 July 2024

Harnessing the Complexity of Modern Electromagnetic Environments for Resilient Wireless Communications

Steven Anlage (anlage@umd.edu), Daniel Sievenpiper (dsievenpiper@eng.ucsd.edu), Tsampikos Kottos (tkottos@Wesleyan.edu)

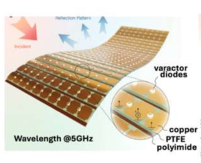
Objective

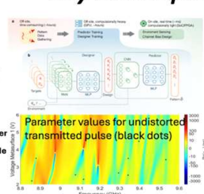


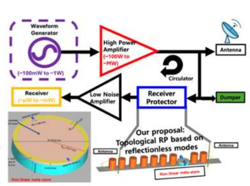
Challenges

- Identify the parameter subspace of RIS pixels for efficient wavefront shaping design associated with specific targets embedded in a reverberate environment
- Adapt ML based control algorithms from relatively simpler free-space environment to more complex reverberate environments
- Incorporate nonlinearities in wavefront shaping schemes

Key Accomplishments







Future Work

- Adapt ML control algorithms to tune RIS in reverberant environment
- Demonstrate (different frequency) radiation away/ towards (multiple) targets in reverberate cavities
- Develop a novel statistical scheme of wavefront design with superb targeting capabilities of multiple antennas embedded in a reverberate environment
- Identify pixels with greater impact – rapid adaptation to motion at human speed

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Award # 2148353 July 2024

RINGS: Enabling Joint Sensing, Communication, and Multi-tenant Edge AI for Cooperative Perception Systems

Kaikai Liu (kaikai.liu@sjsu.edu), Wencen Wu (wencen.wu@sjsu.edu)

Objective

- •Joint Sensing and Communication: Integrates multi-modal sensing and low-latency communication capabilities, utilizing the same fundamental hardware.
- •Distributed Cooperative Sensing: Facilitates distributed deep fusion for hybrid Radar/Camera/Lidar data and multi-station cooperative sensing.
- •Multi-Tenant Edge AI Platform: Features an edge cluster management framework and a cloud-based dashboard to enhance device accessibility, monitoring, and utilization, while enabling federated AI training and inference.

Challenges

- •Performance of radar sensing, antenna transmission crosstalk, and beamforming.
- •Enabling MIMO communication and interfacing our developed system with high-level network services and 5G DU devices.
- •Addressing data bottlenecks for pulling high-speed ADC data into FPGA and the software domain.
- •Tackling real-time AI processing bottlenecks in embedded devices. Resolving calibration and sensing data alignment issues in multi-modal raw sensor data fusion.
- •Overcoming synchronization and data collection problems in multi-station early fusion of sensor data and cooperative sensing and fusion.
- •Extending existing cluster management software to distributed edge AI devices.

Key Accomplishments

- •We developed two versions of Open Hardware Basestation Systems. The first is a Wideband Base Station Device that supports joint wideband OFDM communication (up to 200MHz) and radar detection (up to 400MHz). The second is a cost-effective Mobile Node featuring a 56MHz transceiver for OFDM communication bandwidth, while also achieving 500MHz wideband radar sensing with an external on-board frequency modulation device.
- •Custom deep learning frameworks and models for communication, radar sensing, and multi-modal data fusion based on PyTorch and Transformers.
- •V2X joint sensing with low-latency communication and multi-station LiDAR/camera raw data sharing; decentralized federated meta-learning for traffic flow prediction.
- •Multi-tenant edge computing framework offering automatic cluster management, orchestration, real-time device monitoring, and federated AI training and inference.

Future Work

- •Complete the prototype to demonstrate OFDM signal-based radar wide-band (400MHz) sensing and communication.
- •Continue developing the AI-based software framework for radar and communication. Enhance our AI-based framework for multi-modal data fusion (camera and LiDAR) and evaluate performance gains.
- •Demonstrate the edge-based framework for autonomous driving and intelligent traffic intersections.
- •Generalize our Decentralized Federated Meta-Learning (DFML) across diverse traffic conditions and dynamic environments.

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Award # 2148358 July 2024

RINGS: Resilient Edge Ecosystem for Collaborative and Trustworthy Disaster Response (REsCue)

Jay Misra, Reza Tourani, Abde Mtibaa, Roopa Vishwanathan, David Mitchell

Objective

Challenges

- System integration in face of diverse security and resiliency mechanisms
- Real-scenario evaluation at scale
- Cost and complexity of security, particularly for real-time services at the edge

Key Accomplishments

- Privacy-preserving and auditable resource discovery
- Distributed access control for using MABE
- Verifiable computation with redundancy and TEE MLaaS
- Privacy-preserving payment-channel network computation
- Joint learning and channel coding (tolerating channel error and reducing its overhead)

Future Work

- Reputation-based edge server choice
- Data-centric trusted computing for destination agnostic edge services
- Cryptographic construct for service verifiability
- Distributed identity management and reputation

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Award # 2148359

Enabling Data-driven Innovation for Next-Generation Networks via Synthetic Data

Giulia Fanti and Vyas Sekar

Objective

Goal: *"build foundations for flexible synthetic data sharing for data-driven design and management of NextG networks"*

- Use cases
- Foundations
- Implementation

Challenges

- High computational costs
- Fidelity and privacy notions are difficult to model due to complex correlations
- Usability needs improvement

Key Accomplishments

- Use cases:
  - Generative Compression
- Foundations:
  - Time series modeling
  - Observability distributed tracing modeling
  - New privacy framework
- Implementation:
  - NetShare library major refactor

Future Work

- Constrained generation
- Streaming generation
- Differentially-private generation

Award # CNS-2148382

July 2024

I-RIM: Learning based Resilient Immersive Media-Compression, Delivery, and Interaction

Shiwen Mao (smao@auburn.edu)

Objective

- To explore innovative technologies in NextG and Artificial intelligence (AI) to provide a unified media compression, communication, and computing framework to enable resilient wireless AR/VR

Challenges

- The sheer size of the visual data captured to represent 3D objects and scenes
- Extremely high data rates, stringent latency requirements, and heavy computation for viewpoint rendering
- End-to-end performance involves cross-layer design and optimization
- ML/AI models are heavily dependent on data

Key Accomplishments

- AI based dynamic point cloud geometry compression technique, in collaboration with Qualcomm's video team, was adopted in MPEG AI based PCC test model
- Top US team, IEEE CVPR Perception Beyond Visual Spectrum (PBVS) Workshop SAR and SAR+EO Image Recognition Challenge, June 2023
- Top US team and Top 2 among 100+ teams world-wide, IEEE CVPR PBVS Workshop Thermal Images Super-resolution challenge, June 2024
- Best demo award of INFOCOM 2024, May 2024
- Graduated two PhD students: Y. Sun (UMKC, 2023) and B. Kathariya (UMKC, 2024)

Future Work

- Application of Generative AI to enhance immersive user experience
- Investigate the recent new technique, Gaussian Splatting, for its application to deep learning-based compression and media streaming
- Recruit more graduate students
- Dissemination of research outcomes

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Award # 2148583 July 2024

NSF RINGS: Provably Robust Machine Learning for Next Generation Cellular Networks

Deepak Vasisht (deepakv@Illinois.edu)

Objective

Build machine learning-driven wireless systems to achieve

- *Better performance* compared to signal-processing approaches
- *Explainability* to better understand decisions
- *Provable reliability* to go beyond empirical testing and improve deployability

Challenges

- ML-driven wireless systems need to work with *complex-valued inputs*
- Wireless systems experience *hardware-induced imperfections* such as clock offsets
- Wireless signals are susceptible to a wide array of *adversarial and non-adversarial noise sources*

Key Accomplishments

- New ML-based sensing methods for RF-driven SLAM for robots (MobiCom'23, MobiSys'24)
- First real-world adversarial attack against ML-based wireless systems (NSDI'24, ICML'24)
- Novel theoretical and practical approaches for robust certified training (ICLR'23, PLDI'24)

Future Work

- Extending certified training to wireless systems for communication and sensing
- End-to-end demonstration of of certified training for wireless systems

Project URL: http://go.illinois.edu/nsfrings

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Award # 2433782 July 2024

RINGS WISECOM: Wireless Integrated Sensing, Learning and Communication Networks

Nuria Gonzalez Prelcic (ngprelcic@ucsd.edu)

Objective

- *Develop the fundamental hardware and algorithms for integrated communication and sensing*
- *Design algorithms and protocols that exploit sensing information to improve network adaptability and increase resilience*
- *Devise algorithms and protocols that exploit sensing information to improve network autonomy and increase resilience*

Challenges

- *Developing high accuracy and low complexity channel estimators at mmWave under non idealities*
- *Accurate modeling and simulation of self-interference in full duplex circuits*
- *Creation of datasets for sensor aided communication and joint sensing and communication*
- *Developing network architectures which do not depend on the number of users or size of the antenna arrays*
- *Rapid inference (few ms) to update the CSI-RS in response to SSB feedback*

Key Accomplishments

- *Designed all building blocks of a full-duplex 60 GHz phased arrays with sub-array interference cancellation*
- *Developed solution for high accuracy joint localization and communication at mmWave during initial access. Extended to the position and channel tracking scenario. Developed solution for RIS-aided localization under hardware impairments*
- *Designed a self interference aware analog beam codebook under communication and sensing metrics. Designed hybrid precoders and combiners for joint radar and communication exploiting a full duplex circuit*
- *Designed a system for radar aided communication*
- *Developed a network that designs the SSB codebook. Developed XBM, a neural network and beam selection strategy to design the initial access and refinement codebooks using end-to-end learning from beamspace representations*

Future Work

- ***Design and tape-out a complete beamforming front-end and interference cancellation circuit***
- ***Introducing orientation offset oscillation into the system model for position tracking***
- ***Introducing adaptation to the environment (distribution of users and targets) in the codebook design to reduce overhead and improve performance***
- ***Incorporate sensor-derived occupancy grids in the design of the SSB codebook***
- ***Introduce coordinated learning across multiple base stations for initial access and refinement codebook design***

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Award # UTAUS-SUB00000487 July 2024

Collaborative Inference and Learning Between Edge Swarms and the Cloud

Pete Warden, peteward@stanford.edu

Objective

- Protect users from unwanted audio and video recording
- Dramatically reduce amount of data sent by focusing on actionable information rather than raw streams of audio or image

Challenges

- Lack of motivation around privacy
- Technical difficulty
- Cross-disciplinary coordination

Key Accomplishments

- Machine Learning Sensors paper describing the systems approach
- Datasheets for Machine Learning Sensors paper

Future Work

- Local voice interfaces
- Information retrieval on the edge using LLMs

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Award # 2148021

RINGS: Wideband NextG Tb/s mm-Wave Communication and Networking

Prof. Ali Niknejad and Prof. Bora Nikolic

Objective

- Investigate extremely wideband communication in high mm-bands > 100 GHz
- Understand limits for CMOS, packaging, and antenna arrays
- Demonstrate MU-MIMO performance using 140 GHz testbed

Challenges

- Channel dispersion and other frequency-dependent non-idealities limits communication rate
- IC-package transition limits performance and requires expensive packaging
- CMOS performance > 100 GHz limited
- Beam squint in very large arrays limits bandwidth

Key Accomplishments

- Systematic study of chip-to-package transition and solution to allow low loss interface up to 300 GHz
- Spatial FFT proposed to solve beam squint
- High EIRP / datarate transmitter at 140 GHz

Future Work

- Demonstration of full MU-MIMO link at 140 GHz using custom hardware
- Focus on performance of active devices > 100 GHz to realize gain and bandwidth
- Investigate power efficient multi-tone architecture

RINGS
Resilient and Intelligent NextG Systems July 2024

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