NextG Alliance Academic Workshop: "An examination of three key issues: Smart Agriculture, Connected Vehicles & Spectrum Access"

NextG Alliance, an ATIS initiative

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Executive Summary

On December 6, 2022, the NextG Alliance held an Academic Workshop, gathering twenty-seven faculty from across various North American universities to engage in an interactive dialogue regarding anticipated technological advances and policy impacts within three key areas which are part of the 6G research roadmap. The workshop consisted of a three-hour session held virtually over Zoom, utilizing a collaborative whiteboard platform called “Mural.” Participants broke off into small groups centered around three key technology areas: Smart Agriculture, Connected Vehicles, and Spectrum Access. Below is an overall summary of the academic perspectives on these three key areas. A more detailed review of the discussions is contained within the subsequent section.

Smart Agriculture

Working Definition: *Leveraging advanced computing technologies (big data, the cloud, edge compute) and energy efficient wireless IoT sensors to improve sustainability, increase efficiency, and streamline logistic operations.*

Key Takeaways

Workshop participants ranked the following areas of research as the highest priority:

- Barriers to collaboration – Researchers and practitioner communities are physically separate and have distinct cultures; Agricultural tech and communications engineers do not easily interact.
- Automation of data is key; data flows are not autonomous, and this also requires interoperability beyond the connection technologies. There are assorted time scales of data in agriculture (milliseconds, minutes, hours, weeks & years).
- The mining of data requires fuller contextual metadata.
- Network connectivity does not need to be on all the time; connectivity needs to be transparent to the end user (opportunistic connections should be automatic)
- The connectivity can be network-agnostic; Ability to utilize 6G vs 4G vs Wi-Fi vs TVWS vs LoRa.
- Scalability of solutions: The current promising technology is all small scale (~1 acre). The newer technology needs to be able to operate in large working farms (100s -1000s of acres).
- Aggregation of sensing data and analysis is an important requirement.
- Study new radio technologies that can be applied to sensing.
- Adoption will be driven by impact on time and expense (ex. Corn); these impacts also have LCA aspects of sustainability, soil health, etc.

Expected Policy Impacts

- Need for "smart" policies and regulations that embody the real-world needs and consider variation in use cases, that understand sustainability varies over space and time (Ex. Water Policy)
- Innovation Barriers
- Create opportunities for stakeholder engagement
- Incentives for entrepreneurial investment - make agricultural industry more desirable to investors

- Consideration of academic research issues: IP Law, network accessibility, government funding, and academic collaboration

Connected Vehicles

Working Definition: *Enabling rich user experiences while also ensuring a trusted and secure environment through a convergence of innovation in Human Machine Interfaces (HMI) and broad services ecosystem.*

Key Takeaways

Workshop participants identified the following areas of research as a high priority:

- New network architectures should be developed which can create the efficiencies required to fully realize a connected vehicle environment
- Different network protocol approaches (beyond the current IP) could support the requirements associated with enabling connected vehicles
- Connectionless protocol architectures could provide the adaptability and flexibility required to meet the requirements for connected vehicles
- Additional efforts need to be taken towards identifying system-level exemplars and use-cases

Expected Policy Impacts

- Expanding stakeholders and relaxing policy restrictions
- Spectrum ownership and access oversight requires increased flexibility
- Democratize access to allow for a community-driven build out of connected vehicle capabilities
- New access mechanisms
- Data ownership and data collection requirements and/or legal ramifications
- Blackbox or digital twin to support improvements, investigations, etc.
- The development of use cases required to understand policy impacts

Spectrum Access

Working Definition: *Exploring new paradigms for spectrum access, management and sharing, including but not limited to licensed and unlicensed use.*

Key Takeaways

Workshop participants ranked the following areas of research as the highest priority:

- Spectrum Management
  - Need to research and identify alternatives and improvements to spectrum access systems and develop the tools to implement alternatives
  - Need to identify methods and mechanisms to predict spectrum use.
  - Need for spectrum usage data to support research.
  - Need to develop algorithmic-based AI spectrum resource management & control.
  - Need innovations on improving the efficiency and scalability of database-based access framework driving more efficient spectrum sharing. Improvements in spectrum enforcement, real-time monitoring, and real-time access.

  - Need to develop solutions to provide secure and zero latency network access.
  - Need to carefully investigate what spectrum is good for what scenario (e.g., access and backhaul/fronthaul/midhaul)
- Spectrum Sharing
  - 6G needs to be "sharing native".
    - Consider network sharing either in addition to or in combination with spectrum sharing.
  - New Federal radio systems need to be designed for sharing.
  - Open architectures/ORAN/virtual software services can enable spectrum sharing.
  - Need to understand, evaluate, and design spatial sharing/access solutions around the impact of beamforming & MIMO technology on spectrum sharing efficiency and privacy
  - AI/ML should be leveraged to anticipate need and changes to spectrum bands
  - Need to address privacy/operational security concerns for spectrum sharing solutions:
  - Need incentives/mechanisms to enable bidirectional spectrum sharing in licensed bands
  - Exploit propagation characteristics to reuse spectrum indoor (TN) and outdoor (NTN)
  - Spectrum sharing between terrestrial and non-terrestrial networks (NTNs)
  - Evaluate the potential for online cooperative spectrum leasing solutions for Device-to-Device communication
  - Secondary markets are needed at multiple time scales (including real time) and would differ at different bands since trading will depend on definition of rights
- Hardware
  - mmWave + hardware limitations: How we can achieve high performance compatible to existing technology
  - Spectrum utilization and interference identification is fundamentally different in networks with highly directional/MIMO beams; volumetric "beam space" is another space to be shared.
  - Need research to address spectrum management and sharing when Reconfigurable Intelligent Surfaces (RIS)/ Intelligent Reflecting Surface (IRS) are used in a radio network.
  - Relaxation of OOB (out of band) emission constraints (a policy item) can create freedom to develop lower complexity hardware
    - The concept of having "sunset clauses" on relaxed OOB performance limitations might provide a tool to temporarily leverage lower complexity hardware as better hardware solutions evolve over time
  - Receiver standards or other techniques may enable new technologies to coexist with legacy hardware.
  - Spectrum Sensing solution ideas and challenges discussed
- Other Spectrum Access Considerations
  - Large scale wireless testbeds are needed to evaluate spectrum management/sharing concepts and observe results in real world scenarios and in real time.
  - There needs to be a standard on what type of spectrum data is publicly sharable

Expected Policy Impacts

Sharing and Utilization Policy

- Find incentives/mechanisms to enable bidirectional spectrum sharing in licensed bands
- Include spectrum Sharing policy as a part of license rules.
- Identify spectrum policy impacts of Reconfigurable Intelligent Surfaces (RIS)/ Intelligent Reflecting Surface (IRS).
- Consider minimum utilization as a part of a license condition.
- Identify sharing policies for indoor vs. outdoor emissions.
- Perform spectrum access analysis using quantifiable metrics (Economy, spectrum usage etc.) to determine why one should have access to spectrum & identify the value proposition in spectrum sharing vs. exclusive licensing.

Data Policy

- Document & publish spectrum consumption & performance data (transmitter and receiver) to facilitate management
- Address policy and privacy / security issues for AI/ML training data; Ensure policies are advancing together with ML/AI for spectrum access?

Historical Transmitter Constraints

- Reconsider spectral efficiency as a primary criterion – less spectrally efficient solutions may have other benefits and enable solutions
- Relax (selectively) OOB emission constraints to create freedom to develop lower complexity hardware – consider having a sunset clause on relaxed performance as hardware improves

Test Places Policy

- National radio dynamic zones for use of testing spectrum (policy change)
- Create policy for testbeds

Specific Policy Ideas

- There is a need for dedicated bands for unmanned aerial systems spectrum -- current FCC policies do not allow even experimentation with UAVs at several bands that are otherwise possible to have experimental licenses (2.6 GHz, CBRS, 3.7 GHz...)
- Allow mobile operation in the TV White Space bands.

General Policy

- Suggestions for regulators:
  - Engage with researchers & understood new enablers for spectrum sharing
  - Need increased flexibility for FCC experimental licenses to test new spectrum sharing ideas
  - Stronger directive principles needed.
    - Federal and nonfederal/commercial
    - Need mandatory cross-agency process
  - Consider redefining the inter-working of civilian (FCC) and Federal (NTIA) spectrum regulatory approaches.
- Design for 6G and do not stay stuck on how it is done in 5G

Introduction

Launched in November 2020, NextG Alliance (NGA) is an initiative led by ATIS to advance North American leadership in wireless technology. As a member driven organization, NGA gathers thought leaders across both industry and academia to lay the foundation for 6G research and development over the next decade. The principal goals of the NGA are to build a national 6G roadmap, devise a strategic model for success, and establish global leadership for rapid commercialization of NextG technologies.

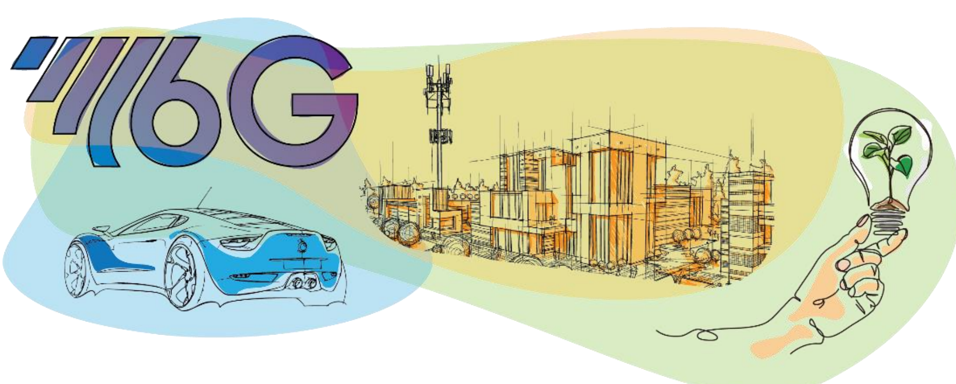
In serving the first of these goals, ATIS and Virginia Tech Applied Research Corporation, the Technical Program Office (TPO), partnered to host an academic workshop aimed at further building out the 6G roadmap. Focusing on three key technology areas selected by ATIS as areas needing further research and attention, Academics gathered for a virtual 3-hour workshop event to lend their expertise and perspective.

The workshop utilized a virtual whiteboard platform, allowing for synchronized inputs across three small breakout groups. Prior to the event day, participants provided survey input used to help formulate and shape the workshop discussion. During the event, academics had the opportunity for approximately 90 minutes (about 1 and a half hours) of debate and ideation within these breakout groups, ultimately synthesizing their ideas and presenting an out briefing to the full group with facilitation from the workshop rapporteurs.

Discussions in breakout groups were organized around three key technology areas surrounding 6G development:

- **Smart Agriculture** – Leveraging advanced computing technologies (big data, the cloud, edge compute) and energy-efficient wireless IoT sensors to improve sustainability, increase efficiency, and streamline logistic operations.
- **Connected Vehicles** – Enabling rich user experiences while also ensuring a trusted and secure environment through a convergence of innovation in Human Machine Interfaces (HMI) and broad services ecosystem.
- **Spectrum Access** – Exploring new paradigms for spectrum access, management and sharing, including but not limited to licensed and unlicensed use.

This report summarizes the ideas and takeaways from the workshop ideation and synthesis, presenting the academic participants' perspectives on the anticipated key technological advances on the horizon for 6G as well as the expected impacts on policy.



Smart Agriculture

While the NextG Alliance is working toward forecasting 6G technology, most of the agricultural sector is still focused on 4G technology. Identifying ideas and next steps we could take to make the agricultural sector adopt newer technologies is critical to realize and implement "smart agriculture." The following sections provide some thoughts on sensing, data, adoption, and connectivity that were raised by our workshop participants.

Sensing

One key aspect is adoption and integration of sensing technology. Installation of sensing devices is important, but the ability to control and improve their decision-making capabilities is going to drive the adoption. The driver for adoption is differences in how the system is implemented. The use of data for the decision using the sensing needs to consider the important goals for an agricultural industry – generating revenue and saving time. Another aspect to consider is leveraging sensing technology, UAVs, and autonomous tractors using the existing network infrastructure instead of deploying private network can help to integrate the new technologies faster in the agriculture sector. Current autonomous vehicles, UAVs, and drones' battery life is poor, so a mass deployment of sensors also needs to factor in the battery life associated with the host machines. With different network operators, making networks accessible, affordable, and ubiquitous is a critical step for sensing technology integration.

At the same time, we cannot ignore the environmental impact of these advancements. There needs to be some technology for sensory recovery. Littering IoT sensors will be a huge environmental challenge. The sensors can migrate into the ground and unintentionally live there for a long time creating a junkyard of abandoned sensors.

Important Questions

- Can we develop bio-degradable sensors?
- Can we create technologies to deploy hundreds of sensors such as specialized machines to plant them?
- How much capital investment is required in big agriculture and what are the enablers?

Key Takeaways

- Scalability of solutions: The current promising technology is all small scale (~1 acre). The newer technology needs to be able to operate in large working farms (100s -1000s of acres).
- Aggregation of sensing data and analysis is an important requirement.
- Study new radio technologies that can be applied to sensing.

Data

Participants identified the issue that data in the field of agriculture is still "broken," with disparate systems that do not connect well, despite innovation in cloud technology. There are multiple types of solutions available in the industry. With computation systems, cloud, OEMs differing among technology providers which create barriers to entry for new innovations. The technology providers assume good network connectivity, but many a times the network connections are unstable in rural areas. Industry providers prefer to manage their own cloud, which poses an obstacle for consumers ending up with products that are not interoperable. The contextual metadata is often missing with the higher resolution data that flows.

Innovative technologies need to enable farmers to make strategic decisions based on different pieces of data, such as during the growing season. Participants suggested that automation of data might be a key breakthrough for the field, allowing the data to move without monitoring or correction. Some of these sensors may not be as dependent on high data rate requirements, but some may require real-time high-resolution imaging process. Depending upon the application, timescale and feedback, the farmers can plan to grow crops season by season, monitor the yield, and then plan for the next monitoring period. For this to happen, the data may need to reside locally to enable farmers to control the applications.

Autonomous machines and devices may not always need high latency. For example, the latency requirements for irrigation systems can be measured in minutes; similarly, when a field is drying, the latency can be in the order of days. The soil moisture data can also be measured so tractors can be sent to irrigate the farms. The automation of data without manual intervention will free farmers to continue to perform logistics operations while operations such as seed planting and crop harvesting are done autonomously.

Important Questions

- What are some of the issues that are top priority for stakeholders?
- How important is latency in agricultural space?
- How can data flow autonomously in agricultural spaces?

Key Takeaways

- Automation of data is key. Data flows are not autonomous, and this also requires interoperability beyond the connection technologies. There are assorted time scales of data in agriculture (milliseconds, minutes, hours, weeks & years). The mining of data also requires more fuller contextual metadata.
- The connectivity between distinct parts and machinery is challenged due to different data sets. The data flow needs to be made seamless between the networks.

Adoption

Wireless companies aim to improve rural network services, but there is little progress in expanding rural access. Adoption comes from improved action – autonomous (or “control of”) sensing to help with decision making. There are a lot of innovations and new technologies, with some successes such as UAV spraying. However, there remains a need for major capital investment for more agricultural use. Agriculture automation must be a key application domain to drive advanced wireless research and development and application pilot. With different network operators, making networks accessible, affordable, and ubiquitous is a critical step for technology integration. Leveraging sensing technology, UAVs, autonomous tractors using the existing network infrastructure instead of deploying private networks can help to integrate the new technologies faster in the agriculture sector.

Important Questions

- How much capital investment is required in big agriculture and what are the enablers?
- How can we make the network affordable?

Key Takeaways

- Adoption will be driven by impact on time and expense: Corn can be used as an example, depicted in the figure below. These impacts also have life cycle assessment aspects of sustainability, soil health, etc.

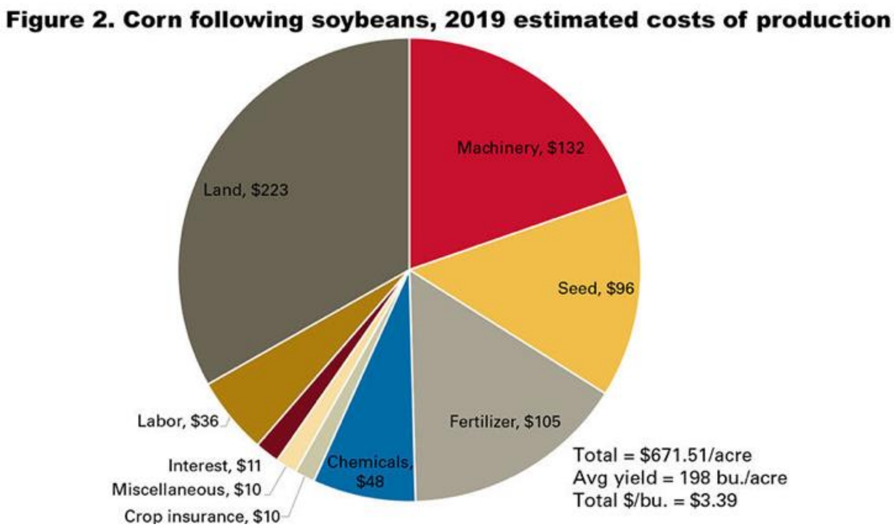


Figure 1: Corn following soybeans, 2019 estimated costs of production

Source: Iowa State University Cost of Production Worksheet

Connectivity

One key factor for rural connectivity is ensuring mobile networks can traverse long distances and consider the latency effects. With decision making at different timescales and at component level, the latency requirements would vary at distinct levels. The unused spectrum between TV stations called white spaces (TVWS) provides a valuable opportunity to improve rural broadband access. For example, the FarmBeats project by Microsoft aims to utilize the TV white space to enable data-driven farming. For users to know which spectrums are available to transmit, TVWS data systems are required to protect services for other uses. Companies such as Spectrum Bridge, Telcordia and Google have gained approval from FCC to manage TVWS databases.

In some use cases, the users may not need network 95% of the time. Network connectivity may be required only during farming and possibly only a few hours per year with machines. It is very expensive to build network infrastructure, and it may be difficult to justify these costs if it gets used very little. From a mobile operator perspective, it is challenging to prioritize services and devices only for farm use, so the next generation technology needs research on a mechanism to provision need-based services with right investment.

Important Questions

- Can network connectivity be available on a need-only basis? Could consumers look instead to fixed infrastructure, satellite uplink, and beamforming when in need of fast data transfer?
- Is it possible to tie networks to machines and bring the network to the farm on a temporary basis?

Key Takeaways

- Network connectivity doesn't need to be 'ON' all the time; connectivity needs to be transparent to the end user (opportunistic connections should be automatic)
- The connectivity can be network-agnostic; Ability to utilize 6G vs 4G vs Wi-Fi vs TVWS vs LoRa.

Policies to Drive Innovation

The below section summarizes academic participants' views on current water policy, barriers to innovation, investment challenges and academic research issues from the policy perspective.

Water Policy

Water is becoming a precious resource everywhere, but policy has not yet adapted to emerging climate realities. It is expensive to transport water unless it is flowing naturally. There is a need to innovate and sort technologies that can improve the availability of water and identify the minimum amount of water needed for crop irrigation. Geopolitically, some policies and judicial laws need to be revised for equitable and fair distribution of water rights between two states (example: longstanding litigation - *Kansas v. Colorado*)

Sensor-driven irrigation can help to reduce water consumption. However, based on the latest statistics on the sensor adoption rate, very few farms are using it. There needs to be preemptive regulation to encourage the use of sensing technologies, since currently, some of the policies and regulations come into practice only when we run out of water. With regards to sensor adoption, many African countries by law need to install soil moisture sensors. The cost of deployment in the US, however, is too high to pay off the investment, so somehow the perception needs to change to make it more attractive for technology developers to innovate cost effective solutions.

Innovation Barriers

There are many barriers in the agriculture industry in terms of policy. Regulations often fail to consider the spatial environment and the reality of interference. The fragmented nature of agriculture industries (OEMs, seed companies, crop protection, farmers, commodity consumers, etc.) are barriers to data flow. Implementing constraints on the use of hazardous fertilizer and protecting crops based on sustainability can force adoption of sensing and new technology in the sector.

Governmental organizations like USDA, FCC and NSF working groups can actively engage in the programs, work on the data standardization, and identify solutions to drive the adoption. A combination of data standards and automation can improve the use of technology in the sector.

The agricultural sector needs policies to enable Next Generation technology research and development, innovation community and capacity building in regions of excellence in Next G application domains. This means we need smart regulations – for example, a policy to give incentives for irrigation and water monitoring use. There needs to be more opportunities for stakeholder engagement.

Investment Challenges

Some of the divestment programs in the universities shrunk from important to low value programs and are relatively unknown within the community. Smart agriculture has had minimal impact and is not particularly popular among some top US colleges. Understanding the needs in this sector takes a long time. The perception of the agricultural sector to the outside world is that it is a stagnant field rather than an emerging or forthcoming one, and it is not readily thought of as embracing or needing the latest technologies. Simultaneously, the inward-looking aspect of the agriculture industry is hindering their interests instead of broadening them.

The lack of skilled workforce in the industry is another challenge. There is a need for innovative companies to get engaged in agriculture to attract further attention. For innovation and interest, agricultural companies need to hire and recruit students with technical background. At the same time, providing personnel working within the agricultural sector with training in computer/programing skills can also help.

Continued investment in the sector with advances in machinery, seed and fertilizer can reduce the costs and drive adoption.

Academic Research Issues

IP Law: The IP protections are limited for academia/industry partnerships. The IP law and policies can restrict research use. Promoting the idea of open source in sensing and agriculture requires a lot of effort.

Network Accessibility: The network connectivity needs to be ubiquitous and network agnostic for easy field installations. Exemptions on spectrum licensing requirements can encourage researchers to deploy proof of concept outside the research testbeds and perform field trials. Access to unlicensed ultra-wide band spectrum at low frequencies which can penetrate underground can immensely help with the adoption of sensing technology.

Government Funding: The current USDA grants may not be sufficient to perform research. The government needs to encourage capital investment. The industry needs sufficient funding programs to build sustainable innovation community and capacity in academia. (The funding levels for academic researchers are too low to keep the academia engaged).

Academic collaboration: From the academic perspective, agriculture schools are distantly located from university campuses, government offices, technology industry and other key institutions. This makes collaboration difficult for the stakeholders. The collaboration between agricultural scientists and technology innovators is missing. Improved interaction within and outside the universities and more incentives for entrepreneurial investment can improve collaboration and attract 'Agriculture.'

To summarize the policy views, we need smart policies and regulations that embody the real world needs and consider variation in use cases that understand sustainability varies over space and time. Smart regulations along with an enhanced level of engagement and collaboration among multiple stakeholders – Government institutions, academic researchers, agriculture scientists and technology experts can bridge this gap and drive the next generation technology adoption in agricultural sector.

Connected Vehicles

The Connected Vehicle workshop was attended by experts across academia who are involved in research related to the development of technologies which enable vehicles to become part of the larger Internet of Things (IoT) architecture. This includes technologies related to enabling large scale adoption of autonomous vehicles but extends beyond this function to include other enhancements to improve driver experience, vehicle efficiencies and safety. Participants of this session were asked to focus on addressing those areas which enable rich user experiences while also ensuring a trusted and secure environment through a convergence of innovation in Human Machine Interfaces (HMI) and broad services ecosystem. As part of this exercise, the group examined expected science and technology advances, important questions which need to be addressed and impacts on the various policy issues these capabilities may create.

Important Questions

There are several questions the group determined were particularly important to address in order to achieve the results of a connect vehicle environment.

- To what degree is 5G able to support Connected Vehicle use cases, and what is required within 6G to fully realize this goal?
- How are issues such as Dynamic Network Density addressed to ensure equal access for each vehicle within the architecture?
- Will 6G change the way we acquire and share data?
- Does satellite-based wireless connectivity (NTN), expand the use cases into otherwise denied geographical locations (i.e., rural environments with limited cellular coverage)?

Anticipated S&T Advances

During the collaboration, the group identified various advances within science and technology (S&T) which will be required if the desired Connected Vehicle capabilities are to become fully realized.

- The different relationships between Mobile Network Operators (MNOs), application providers, and end-users enable more opportunities for architecture improvements:
    - Increased use of open protocol stack for horizontal integration
    - Diverse modes of connectivity
    - Broader data throughput capacity
    - Increased flexibility in spectrum access
- Ability to advance beyond connection-oriented networking protocols
- Joint communication and sensing technologies enable efficiencies necessary to realize a robust Connect Vehicle architecture/environment
    - Autonomous vehicles utilize a series of different sensor types, to include LIDAR, but these sensing capabilities have limitations which need to be addressed
- Interoperability between legacy systems/sub-systems and new, advanced systems is necessary
- Development of a “black box” or digital twin of each vehicle (like an aircraft) would be a requirement for data driven vehicle operations, particularly for autonomous vehicles
- The establishment of benchmarks (datasets/reference models/workflows) is a key aspect of developing a Connected Vehicle architecture
- Development of dependency charts between "system-architecture" and "parameter-selection"

- Identifying & communicating benefits to end-users (low latency jitter-free, SDN)
- Requirements will drive network architectures, to include performance tradeoffs (between end-to-end system-, subsystem-, component-level)
- Enhancing wireless network coverage in rural areas to create ubiquitous coverage is a challenging, but critical aspect of fully realizing a Connected Vehicle environment
    - Non-terrestrial Networks (NTN) could provide increased coverage, particularly in rural environments, where cellular infrastructure is limited
- Network synchronization and optimization is a key component towards ensuring ubiquitous and seamless coverage
- Current architectures may result in intermittent connectivity for vehicles due to small cell area, fast mobility, etc. and this will have an overall impact on the performance of communication to the vehicle and access to algorithms which are being hosted within a cloud environment.
    - Ultra-low latency (ULL) protocols and/or new access mechanisms to minimize latency will be required;
    - High density protocols
- Research into determining new protocols beyond IP-based protocols could result in a more efficient network routing which improves on existing latency issues and network synchronization
- Research is required to determine the most efficient use of forward edge compute processing (onboard the vehicle) and cloud compute processing
    - Cloud-based compute requires assurance of connectivity

Impacts on Policy

- Blackbox or digital twin of vehicle will likely be required, particularly for autonomous vehicles or where driver decisions are based on data input from external sources
    - This creates a technical challenge associated with the volume of data which would be generated to support incident investigations
    - LIDAR and other sensing capabilities generate large volumes of data
- Security and billing restrictions require considerations to accommodate new network architecture
- Democratized participation in the design and deployment of denser wireless infrastructure
- Increased flexibility in spectrum ownership and access oversight is required
- Micro mobility in the city may generate ad-hoc requirements which need to be supported
- Spectrum efficiencies must be considered to allow sharing of bandwidth between different use cases
- Malicious actors will continue to seek opportunities to exploit, threaten and intimidate, requiring technologies to protect and policies to ensure public safety
- Vehicle sensing capabilities which allow for the sharing of data across the network, to include the ability for the data to be utilized in solving disputes, such as determining “fault” for car accidents

Key Takeaways

- New network architectures should be developed which can create the efficiencies required to fully realize a connected vehicle environment
- Different network protocol approaches (beyond the current IP) could support the requirements associated with enabling connected vehicles

- Connectionless protocol architectures could provide the adaptability and flexibility required to meet the requirements for connected vehicles
- Additional efforts need to be taken towards identifying system-level exemplars and use-cases
- Various policy areas must be addressed before Connected Vehicles is fully realized:
    - Expanding stakeholders and relaxing policy restrictions
    - Spectrum ownership and access oversight requires increased flexibility
    - Democratize access to allow for a community-driven build out of connect vehicle capabilities
    - New access mechanisms
    - Data ownership and data collection requirements and/or legal ramifications
    - Blackbox or digital twin to support improvements, investigations, etc.
    - The development of use cases required to understand policy impacts

Figure 2: Key Technology Area Definitions

Spectrum Access

Workshop participants were asked to assess the following topic: Spectrum Access: *Exploring new paradigms for spectrum access, management and sharing, including but not limited to licensed and unlicensed use.* Two separate breakout groups addressed the Spectrum Access question. The groups provided input on the question of wireless technology advancements related to spectrum access and provided responses that were grouped into three areas prior to the discussions with the addition of a fourth area to capture key ideas not fitting into the first three:

1. Spectrum Management
2. Spectrum Sharing
3. Hardware
4. Other Considerations

This section of the report addresses the results from both breakout groups, concluding with a summary of potential policy impacts from the discussion.

Spectrum Management

Spectrum Management is the art and science of managing the use of the radio spectrum in order to minimize interference and ensure radio spectrum is used to its most efficient extent and benefit for the public.

Important Questions

- How to maximize the use of licensed & unlicensed spectrum?
- How to enhance visibility of spectrum availability and reduce complexity for access and management of spectrum by diverse users and ownership?
- How to manage satellite and terrestrial spectrum needs? Can we develop SAS solutions for satellites?
- Can we use passive sensing technologies to detect, classify, localize jammers and interferers (e.g., RF sensor network relying on Keysight RF sensors)?
    - Technology gaps: signature database with different technologies, and characterization of nominal spectrum occupancy to distinguish interferers and jammers.
- Can we isolate or quarantine a malicious/ill-behavior radio? (Both technology and policy domains)

Key Takeaways

- Need to research and identify alternatives and improvements to spectrum access systems and develop the tools to implement alternatives
    - Enhance SAS with more flexibility - like supporting decision parameters, crowdsensing based measurements, etc.
    - SAS in a box.
    - A spectrum coordination system that allows dynamic sharing of licensed spectrum would be helpful in maximizing the use of licensed spectrum.
    - Need to develop a spectrum access system for secondary use
- Need to identify methods and mechanisms to predict spectrum use.

- Need for spectrum usage data to support research.
- Need to develop algorithmic-based AI spectrum resource management & control.
- Need innovations on improving the efficiency and scalability of database-based access framework driving more efficient spectrum sharing. Improvements in spectrum enforcement, real-time monitoring, and real-time access.
- Need to develop solutions to provide secure and zero latency network access.
- Need to carefully investigate what spectrum is good for what scenario (e.g., access and backhaul/fronthaul/midhaul)

Spectrum Sharing

Spectrum sharing is a way to optimize the use of the airwaves, or wireless communications channels, by enabling multiple categories of users to safely share the same frequency bands.

Spectrum sharing is necessary because growing demand is crowding the airwaves. Smartphones, the Internet of Things, military and public safety radios, wearable devices, smart vehicles, and countless other devices all depend on the same wireless bands of the electromagnetic spectrum to share data, voice, and images.

Participants noted that spectrum sharing can mean very different things. For example, mobile network operators can share the same spectrum between 4G (LTE) and 5G services. This is quite different than the Citizen Broadband Radio Service (CBRS) mechanism for sharing between federal radar operations and commercial 4G/5G International Mobile Telecommunications (IMT) services, and both are different than the type of dynamic frequency selection used for Wi-Fi with unlicensed spectrum (including Automated Frequency Coordination (AFC) in some bands. The group agreed that all these examples and more are forms of spectrum sharing.

Important Questions

- How should 6G standards address spectrum sharing?
- What are the impacts of Non-Terrestrial Networks (NTNs) on Spectrum Sharing?
- What is the resource we are sharing? (Need property rights abstraction.)
- What privacy/operational security concerns are raised by spectrum sharing solutions?

Key Takeaways

- 6G needs to be “sharing native”.
    - Consider network sharing either in addition to or in combination with spectrum sharing.
- New Federal radio systems need to be designed for sharing.
- Open architectures/ORAN/virtual software services can enable spectrum sharing.
- Need to understand, evaluate, and design spatial sharing/access solutions around the impact of beamforming & MIMO technology on spectrum sharing efficiency and privacy
- AI/ML should be leveraged to anticipate need and changes to spectrum bands
    - Dynamic and resilient spectrum sharing strategies - detect and predict unused spectrum
    - Better beamforming solutions for incumbent transmitters/receivers.
    - Fair spectrum scheduling and resource allocation w/ AI/ML

- Need to address privacy/operational security concerns for spectrum sharing solutions:
    - How to avoid data trafficking attacks and maintain user privacy (what to share and what not?)
    - Privacy-Preserving Techniques that can protect both incumbent user and secondary users
    - How to generate useful data and make the datasets publicly available to enable the integration of AI/ML techniques?
    - Data/Model poisoning related to AI/ML-based solutions (e.g., spectrum sensing models, and Adversarial Attacks)
    - To use any data that is shared for policy or comparison, we need to know provenance of data.
- Need incentives/mechanisms to enable bidirectional spectrum sharing in licensed bands
- Exploit propagation characteristics to reuse spectrum indoor (TN) and outdoor (NTN)
- Spectrum sharing between terrestrial and non-terrestrial networks (NTNs)
    - Need to develop handover mechanisms for enabling multi-tier spectrum sharing (non-terrestrial/terrestrial)
    - Spectrum is location and altitude dependent: how to interpolate across a geography and assess sharing opportunities?
- Evaluate the potential for online cooperative spectrum leasing solutions for Device-to-Device communication
- Adjacent multi-band spectrum sharing may improve network performance
- Evolution for CBRS in different bands
- Secondary markets are needed at multiple time scales (including real time) and would differ at different bands since trading will depend on definition of rights
    - Secondary markets require a lot of policy framework but also technical solutions like measurements and spectrum access/coordination systems.

Hardware

Key hardware technology development can impact spectrum access solutions.

Important Questions

- How does the evolution toward use of mmWave and higher spectrum affect spectrum access technology?
- Are receiver standards part of future spectrum access solutions?
- What are the hardware challenges of spectrum sensing?

Key Takeaways

- mmWave + hardware limitations:
    - How we can achieve high performance compatible to existing technology
    - Research on making power amplifies more efficient, especially at higher frequencies (tens of GHz and hundreds of GHs and THz)
    - How does hardware heterogeneity affect spectrum access?
    - Research and develop standardized APIs for mm Wave beam management
    - Scheduling to avoid adjacent channel interference/lower resolution on data converters

- Spectrum utilization and interference identification is fundamentally different in networks with highly directional/MIMO beams; volumetric “beam space” is another space to be shared.
  - Customize initial access/beam sweeping with AI/ML
  - Opportunity for Interference "shaping" in frequency domain and spatial/beam domain
- Need research to address spectrum management and sharing when Reconfigurable Intelligent Surfaces (RIS)/ Intelligent Reflecting Surface (IRS) are used in a radio network.
  - mm Wave (even high-end SDRs) hardware are not readily available, and if available, are quite expensive.
- Relaxation of OOB (out of band) emission constraints (a policy item) can create freedom to develop lower complexity hardware
  - The concept of having “sunset clauses” on relaxed OOB performance limitations might provide a tool to temporarily leverage lower complexity hardware as better hardware solutions evolve over time
- Receiver standards or other techniques may enable new technologies to coexist with legacy hardware.
  - Standardize and publish receiver performance figures
- Spectrum Sensing solution ideas and challenges:
  - Quantities to sense: demodulation versus power-only (greatly simplified architecture)
  - Sensitivity challenges for spectrum sensing (some passive receivers are more sensitive to interference) -- cost vs. performance trade-offs
  - Distributed and/or heterogeneous sensor networks? Use of network operator info (unlikely to be shared?)
  - Aerial or LEO (Low Earth Orbit) satellite sensing for large area sensing? Aerial systems can help evaluating spectrum occupancy sharing opportunities -- they will "see" significantly more opportunities and utilization at higher altitudes

Other Spectrum Access Considerations

Several key takeaways bridge these three sub-topic areas and are considered important outcomes of the collaboration session:

- Large scale wireless testbeds are needed to evaluate spectrum management/sharing concepts and observe results in real world scenarios and in real time. Important examples to be leveraged include:
  - NSF National Radio Dynamic Zone (NRDZ) is an important effort.
  - Platforms for Advanced Wireless Research (PAWR)
- There needs to be a standard on what type of spectrum data is publicly sharable. Existing data repositories include aggregate power in a given spectrum band. If I/Q samples can be collected, that may provide additional information about individual cells and can give more opportunities for sharing. That, however, has privacy concerns. https://www.fcc.gov/consumers/guides/interception-and-divulgence-radio-communications

Impacts on Policy

Policy refers to the rules and enforcement mechanisms that shape the strategy for spectrum access. Enforcement implies measurement and monitoring. What rules are and the expectation of enforcement actions affects behavior ex ante and ex post. Policy actions can subsidize, provide information, change rules, etc. to impact that.

Sharing and Utilization Policy

- Find incentives/mechanisms to enable bidirectional spectrum sharing in licensed bands
- Include spectrum Sharing policy as a part of license rules.
  - Develop policies that maximize the use of spectrum by allowing spectrum license owners to share their licensed spectrum with charges and without charges (e.g., tax incentives).
  - Enforcement needs to consider the likelihood of interference, whether intentional or accidental, etc. and the value it impacts.
  - Process needs to anticipate how trust of participants will evolve over time -- government sharing among agencies can be proven in easy case, and migrate further...
- Identify spectrum policy impacts of Reconfigurable Intelligent Surfaces (RIS)/ Intelligent Reflecting Surface (IRS).
- Consider minimum utilization as a part of a license condition.
- Identify sharing policies for indoor vs. outdoor emissions.
- Perform spectrum access analysis using quantifiable metrics (Economy, spectrum usage etc.) to determine why one should have access to spectrum & identify the value proposition in spectrum sharing vs. exclusive licensing.
  - Locking up spectrum with rights
    - Sharing = protected privacy. How do you compare the measurements?
    - What kind of measurements?
    - Simulated datasets that are the same across the sharing entities
    - Must know about nature of measurements to talk about economics of it
  - Need to identify an organization responsible for oversight
  - Secondary markets have hugely distinct characteristics
  - Realtime monitoring currently limited by database access required
  - Take advantage of propagation failure to take advantage of spectrum reuse

Data Policy

- Document & publish spectrum consumption & performance data (transmitter and receiver) to facilitate management
  - Large spectrum usage data sets
  - Standardize and publish Receiver performance figures
- Address policy and privacy / security issues for AI/ML training data; Ensure policies are advancing together with ML/AI for spectrum access?

Historical Transmitter Constraints

- Reconsider spectral efficiency as a primary criterion – less spectrally efficient solutions may have other benefits and enable solutions
- Relax (selectively) OOB emission constraints to create freedom to develop lower complexity hardware – consider having a sunset clause on relaxed performance as hardware improves
  - Current policy drives power hungry hardware/complex and systems at higher bands

    - New bands may help open new policies

Test Places Policy

- National radio dynamic zones for use of testing spectrum (policy change)
- Create policy for testbeds

Specific Policy Ideas

- There is a need for dedicated bands for unmanned aerial systems spectrum -- current FCC policies do not allow even experimentation with UAVs at several bands that are otherwise possible to have experimental licenses (2.6 GHz, CBRS, 3.7 GHz...)
- Allow mobile operation in the TV White Space bands.

General Policy

- Suggestions for regulators:
    - Engage with researchers & understood new enablers for spectrum sharing
    - Need increased flexibility for FCC experimental licenses to test new spectrum sharing ideas
    - Stronger directive principles needed.
        - Federal and nonfederal/commercial
        - Need mandatory cross-agency process
    - Consider redefining the inter-working of civilian (FCC) and Federal (NTIA) spectrum regulatory approaches.
- Design for 6G and do not stay stuck on how it is done in 5G

Conclusions

The three discussion areas comprising this workshop – Smart Agriculture, Connected Vehicles, and Spectrum Access – represent current gaps in the arena of 6G research and opportunities for further research. Each breakout group yielded valuable perspectives and takeaways, which can serve to help push forward the work being done within NGA related to each of these three technology areas. As a contribution-driven organization, NGA looks forward to expanding on the ideas captured during this workshop. In concluding the workshop, TPO encouraged workshop participants to seek out opportunities for input into current NGA White Papers or in the form of contributions or guest presentations expanding on these topics and offered to provide assistance with guiding faculty toward relevant areas to contribute. This report will be distributed to all workshop participants and made available for use by NGA working groups to further bolster their efforts. Workshop participants were enthusiastic about these topics and provided positive survey feedback regarding the overall experience. Future workshops would be beneficial towards shaping future verticals and goals of the NextG Alliance.

Appendix B: Agenda

Agenda- Tuesday, December 6, 2022

Virtual Sessions using Zoom and MURAL
All times listed are in Eastern Standard Time (EST)

Time	Title	Speaker
2:30 – 2:40	Welcome	Eric Burger/Kate Klemic
2:40 - 2:50	Framing Talk: Overview of NextG Alliance and 6G Roadmap	Eric Burger
2:50 – 3:10	Virtual Whiteboard Overview	Kate Klemic
3:10 – 4:15	Working Group I: Key 6G Technology Advances & Policy Impacts: Ideation *Small group discussions about the most exciting technology advances projected for key 6G technology areas and their likely impact on policy.* Group A – Connected Vehicles Group B – Smart Agriculture Group C – Spectrum Access I Group D – Spectrum Access II	
4:15 – 4:30	BREAK	
4:30 – 5:00	Working Group II: Key 6G Technology Advances & Policy Impacts: Synthesis *Small group discussion to synthesize and prioritize ideas for out briefing to whole group* Group A – Connected Vehicles Group B – Smart Agriculture Group C – Spectrum Access I Group D – Spectrum Access II	
5:00 – 5:20	Out briefing of Key Ideas & Whole Group Discussion *Small group out briefing to whole group*	Group Leads
5:20 – 5:30	Summary of Day & Next Steps	Eric Burger
5:30	SESSION 1 ADJOURNED	

Appendix C: Attendees

Mai Abdelmalek, *Virginia Tech*

Randall Berry, *Northwestern University*

Safdar Bouk, *Old Dominion University*

Dennis Buckmaster, *Purdue University*

Jonathan Chisum, *Notre Dame University*

Aloizio DaSilva, *Virginia Tech*

Thinh Doan, *Virginia Tech*

Monisha Ghosh, *Notre Dame University*

Ismail Guvenc, *NC State University*

Bo Ji, *Virginia Tech*

Colleen Josephson, *UC Santa Cruz*

James Krogmeier, *Purdue University*

Venkat Krovi, *Clemson University*

Murat Kuzlu, *Old Dominion University*

William Lehr, *MIT*

David Love, *Purdue University*

Vuk Marojevic, *Mississippi State University*

Jon Peha, *Carnegie Melon University*

Jeffrey Reed, *Virginia Tech*

Sumit Roy, *University of Washington*

Joao Santos, *Virginia Tech*

Vijay Shah, *George Mason University*

Cong Shen*, University of Virginia*

Nishith Tripathi, *Virginia Tech*

Kuang-Ching Wang, *Clemson University*

Kai Zeng, *George Mason University*

Hongwei Zhang, *Iowa State University*

Workshop Co-Chairs

Eric Burger, *Virginia Tech Applied Research Corporation, TPO Director*

Reza Arefi*, Intel Corporation*

Jonathan Borrill, *Anritsu*

Marc Grant, *AT&T*

Andrew Thiessen, *MITRE*

Kate Klemic, *Virginia Tech Applied Research Corporation*

NextG Alliance Observers

Susan Miller, *ATIS, President and CEO*

Mike Nawrocki, *ATIS, Vice President – Technology and Solutions*

Carroll Gray-Preston, *ATIS, Vice President – Innovation and Strategic Initiatives*

Lauren Layman, *ATIS, Vice President – Marketing and Public Relations*

Nicole Butler, *ATIS, Director – Strategic Initiatives*

Stephen Hayes, *Ericsson, Director of North American Standards*

Micaela Giuhat, *Microsoft, 5G Policy*

Ki-Dong Lee, *LG Electronics USA, Assistant Vice President*

Rapporteurs

Jordan Brown, *Virginia Tech Applied Research Corporation*

Matthew Bigman, *Virginia Tech Applied Research Corporation*

Cynthia Ramboyong, *Virginia Tech Applied Research Corporation*

Michael Miller, *Virginia Tech Applied Research Corporation*

Michael DiFrancisco, *Virginia Tech Applied Research Corporation*

Ankur Mistry, *Virginia Tech Applied Research Corporation*

Short Biosketches

Mai Abdelmalek, Postdoctoral Associate

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Currently a Postdoctoral Associate at Wireless@Virginia Tech. I got my Ph. D on April 2021 from Electrical and Computer Engineering department (ECE) at Florida International University (FIU). I received the B. Sc degree (Hons.) in 2013 from the Communications and Electronic Department at Faculty of Engineering, Alexandria University, Egypt, and M.S in Wireless Technology from Nile University (NU), Egypt, in 2016. Worked as a research assistant at Wireless Intelligent Networks Center (WINC), NU. Worked as a research assistant at Virginia Tech-Middle East and North Africa (VT-MENA) for one year between August 2015 and August 2016.

Fatemeh Afghah, Associate Professor

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Fatemeh Afghan is an Associate Professor with the Electrical and Computer Engineering Department at Clemson University. Prior to joining Clemson University, she was an Associate Professor (2020-2021) and an Assistant Professor (2015-2020) with the School of Informatics, Computing and Cyber Systems, Northern Arizona University, where she was the Director of Wireless Networking and Information Processing (WiNIP) Laboratory. Her research interests include wireless communication networks, decision making in multi-agent systems, radio spectrum management, UAV networks, security, and artificial intelligence in healthcare. Her recent project involves autonomous decision making in uncertain environments, using autonomous vehicles for disaster management and IoT security. NSF has continuously supported her research, AFRL, AFOSR, NIH, and Arizona Board of Regents, where she has served in the role of PI or the sole-PI for grants with a total of over $4.8M, and in the role of Co-PI for grants with a value of $5M. She is the recipient of several awards including the *Air Force Office of Scientific Research Young Investigator Award* in 2019, *NSF CAREER Award* in 2020, *NAU's Most Promising New Scholar Award* in 2020, *NSF CISE Research Initiation Initiative (CRII) Award* in 2017, AFRL *Visiting Research Faculty Award in 2016 and 2017*. and NC Space grant's New Investigator award in 2015.

Reza Arefi, Principal Engineer

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Reza Arefi leads Emerging Spectrum Strategies and planning at Intel's Next Generation & Standards group. In his role, he develops the market-driven spectrum and regulatory strategies that support Intel's existing and future wireless products. Reza has been actively contributing to standards and various industry and international regulatory groups since 1998, often in leadership roles. Reza is currently a Vice President of Global mobile Suppliers Association (GSA) and a Senior Member of IEEE. He is a Vice Chair of Spectrum Working Group at ATIS Next G Alliance. A Principal Engineer at Intel, he holds several patents in the areas of mm-wave technologies and spectrum sharing and is currently focused on identifying optimal spectral vehicles and regulatory developments that enable the next generation mobile use cases.

Randall Berry, Professor and Chair of ECE

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Prof. Berry's research covers resource allocation problems that arise in networked systems ranging from communication networks to social networks. This work uses mathematical models to gain insights into such systems and draws on tools from stochastic modeling, optimization, economics, and algorithms. Specific topics of current interest include developing distributed resource allocation techniques for wireless networks, dynamic spectrum sharing and wireless spectrum policy, understanding the role of incentives in network security and modeling learning and adoption in social networks.

Jonathan Borrill, Head of Global Market Technology

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Jonathan Borrill first became involved with Anritsu in 2001, after several years working with the UK government with what is now called Qinetiq – in those days it was a government research laboratory working on communications research. Borrill had previously graduated from Southampton University with a degree in electronics, specializing in communications and optics, in the late 1980s – just as the optics department at the university was entering a period of sustained growth.

Safdar Hussain Bouk, Research Assistant Professor

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Dr. Safdar H. Bouk did his bachelor's in Computer Systems Engineering from Mehran University of Engineering and Technology (MUET), Jamshoro in 2001. In 2005, He was awarded the Japanese Government's MONBUKAGAKUSHO (MEXT) scholarship for graduate studies. He completed his Master's and Ph.D. in Engineering from the Graduate School of Science and Technology, Keio University, Yokohama, Japan in 2007 and 2010, respectively. Dr. Bouk was a visiting scholar at UIUC, USA, during Summer 2001 and served as an Assistant Professor at COMSATS Institute of Information Technology, Islamabad, Pakistan from 2010 to 2016. In addition to that, he also served as a Research Professor at DGIST, Daegu, Korea from 2017 to 2021. Currently, he is serving as a research assistant professor at Virginia Modeling Analysis and Simulation Center (VMASC), Old Dominion University, VA, USA. His research interests include future Internet architectures, 5G and Next G networks, and security perspectives in future networks.

Dennis Buckmaster, Professor & Dean's Fellow for Digital Agriculture

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Dr. Dennis R. Buckmaster is a Professor of Agricultural and Biological Engineering and Dean's Fellow for Digital Agriculture at Purdue University. His three degrees in Agricultural Engineering are from Purdue University and Michigan State University. Dennis' past research includes forage systems and horticultural mechanization and with undergraduate and graduate teaching related to agricultural machinery design and systems management. Current focus is in the realm of Digital Agriculture. In this work with devices and data, he and collaborators collect, curate, communicate, and compute for improved agriculture and food systems. He is co-founder of the Purdue Open Ag Technology and Systems (OATS) Center with focus on bringing open source approaches to agriculture to speed innovation and improve the workforce. He is a co-PI on the IoT4Ag project – a partnership with 4 institutions under University of Pennsylvania leadership. Dennis is an award winning teacher who co-coordinates the Agricultural Systems Management program at Purdue.

Kuang Ching Wang, Professor

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Kuang-Ching "KC" Wang is a Professor of Electrical and Computer Engineering, the C. Tycho Howle Endowed Chair in Collaborative Computing, Associate Director of Research for the Watt Family Innovation Center, and Co-director for the Clemson AI Research Institute. KC received his PhD and MS degrees from University of Wisconsin, Madison. KC's research spans networking and computing systems and their applications across healthcare, cyber-physical systems, agriculture, and cybersecurity. For nearly two decades, KC has been leading national and institutional efforts in creating cutting edge testbeds for networking and computing systems in such projects as NSF GENI, NSF FABRIC, NSF Cloud, DoD VIPR-GS, and DARPA SensIT. KC has led efforts to broadly empower AI research and education, including the founding of Watt AI through partnership with IBM.

Jonathan Chisum, Associate Professor

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The focus of Professor Chisum's group is to develop circuit and antenna systems for millimeter-wave (MMW) wireless communications and sensing with dramatically improved performance over the state of the art, or which exhibit completely new functionality to enable new concepts. They do this by taking advantage of inherent characteristics in advanced materials and devices that fundamentally benefit the circuit/antenna system. Research includes MMW artificial materials and metamaterials for efficient and linear scanning GRIN lens antennas for satcom, MMW 5G and beyond; phase-change materials for programmable antennas and circuits; and nonlinear microwave and microwave/magnetic transceivers and sensors for low-power sensing.

Thinh Doan, Assistant Professor

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My research interests span the intersection of control theory, optimization, and applied probability theory, with the main focus on reinforcement learning, machine learning, and distributed optimization over multi-agent systems. I was born in Vietnam, where I got my bachelor's degree in ECE at Hanoi University of Science and Technology in 2008. I was very fortunate to study in the undergraduate talented program (majored in automatic control) and worked with Professor Hoang Minh Son for my dissertation. Then I obtained my master's in ECE at the University of Oklahoma in 2013, working with Professor Choon-Yik Tang. While at OU, I also worked as a GRA in Professor Younane N. Abousleiman's group. In 20218, I finished my Ph.D. in ECE at the University of Illinois at Urbana-Champaign, under the supervision of Professor Carolyn L. Beck. I was also fortunate to have Professor R. Srikant as my mentor. At Illinois, I was the recipient of the Harriett and Robert Perry Fellowship Award in two years, 2016 and 2017. Before joining VT, I was a TRIAD postdoctoral fellow at the Georgia Institute of Technology, working with Professors Siva Theja Maguluri and Justin Romberg.

Monisha Ghosh, Professor

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Monisha Ghosh completed a term as the Chief Technology Officer at the Federal Communications Commission (FCC) on June 14, 2021. In this role she reported to the Chairman of the FCC and was involved with setting national strategy and technology specifications related to the explosive growth of broadband wireless communications technologies. Prof. Ghosh previously served in the NSF as a rotating Program Director (IPA) within the Directorate of Computer & Information Science and Engineering (CISE) where she managed wireless networking research. At the NSF, she initiated one of the first large-scale programs that targets applications of machine learning to wireless networks. From 2015 to 2021, she also was a Research Professor at the University of Chicago, where she conducted research on wireless technologies for the 5G cellular, next-generation Wi-Fi systems, IoT, coexistence and spectrum sharing. She previously worked in industrial research and development at Interdigital, Philips Research, and Bell Laboratories on wireless systems such as the HDTV broadcast standard, cable standardization, and cognitive radio for the TV White Spaces. She is a Fellow of the IEEE.

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Dr. Ismail Guvenc (Fellow, IEEE) received his Ph.D. degree in electrical engineering from the University of South Florida in 2006. He was with Mitsubishi Electric Research Labs in 2005, with DOCOMO Innovations between 2006-2012, and with Florida International University between 2012-2016. Since 2016, he has been with the Department of Electrical and Computer Engineering at North Carolina State University, serving as a Full Professor since 2020. His recent research interests include 5G wireless systems, communications and networking with drones, and heterogeneous wireless networks. He has published more than 130 conference/journal papers and book chapters, and several standardization contributions. He co-authored/co-edited four books for Cambridge University Press and John Wiley & Sons, and served as an editor for IEEE Communications Letters (2010-2015), IEEE Wireless Communications Letters (2011-2016), IEEE Trans. Wireless Communications (2016-2021), Elsevier Physical Communications (2019-2020), and IEEE Trans. Communications (2020-Present), and as a guest editor for ten special issues for various journals. Dr. Guvenc is an inventor/coinventor of over 30 U.S. patents. He is the PI and the director for the NSF AERPAW project and the NC State site director for the NSF BWAC I/UCRC center. He is an IEEE Fellow, a senior member of the U.S. National Academy of Inventors, and a recipient of several awards, including the NC State University Faculty Scholar Award (2021), R. Ray Bennett Faculty Fellow Award (2019), FIU COE Faculty Research Award (2016), NSF CAREER Award (2015), Ralph E. Powe Junior Faculty Award (2014), and USF Outstanding Dissertation Award (2006).

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Bo Ji received his B.E. and M.E. degrees in Information Science and Electronic Engineering from Zhejiang University, Hangzhou, China, in 2004 and 2006, respectively, and his Ph.D. degree in Electrical and Computer Engineering from The Ohio State University, Columbus, OH, USA, in 2012. Dr. Ji is an Associate Professor in the Department of Computer Science at Virginia Tech. Prior to joining Virginia Tech, he was an Associate Professor in the Department of Computer and Information Sciences at Temple University where he was an Assistant Professor from July 2014 to June 2020. He was also a Senior Member of Technical Staff at AT&T Labs, San Ramon, CA, from January 2013 to June 2014. His research interests are in the modeling, analysis, control, optimization, and learning of computer and network systems, such as communication networks, information-update systems, cloud/datacenter networks, and cyber-physical systems. He has been the general co-chair of IEEE/IFIP WiOpt 2021 and the technical program co-chair of ITC 2021, and he has also served on the editorial boards of various IEEE/ACM journals (IEEE/ACM Transactions on Networking, IEEE Transactions on Network Science and Engineering, IEEE Internet of Things Journal, and IEEE Open Journal of the Communications Society). Dr. Ji is a senior member of the IEEE and the ACM. He was a recipient of the National Science Foundation (NSF) CAREER Award in 2017, the NSF CISE Research Initiation Initiative Award in 2017, the IEEE INFOCOM 2019 Best Paper Award, the IEEE/IFIP WiOpt 2022 Best Student Paper Award, and the IEEE TNSE Excellent Editor Award in 2021 and 2022.

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Colleen Josephson is a Senior Research Scientist VMware, and is chair and vice chair of the ATIS Next G Alliance Societal and Economic Needs and Green G working groups, respectively. Her research interests include wireless sensing and communications systems, with a focus on technology that furthers sustainable practices. Her work includes designing novel sensing paradigms for agriculture, inventing techniques for ultra-low power communication in indoor sensor networks, and exploiting non-traditional energy sources, such as microbes, for sustainable sensing. She received her PhD from Stanford University, and her MEng and SB degrees from MIT. In 2022 Dr. Josephson was recognized as a 2022 N2Women Rising Star in Networking and Communications. Dr. Josephson is also an Assistant Professor in the Electrical and Computer Engineering department at UC Santa Cruz.

James Krogmeier, Professor of ECE

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James V. Krogmeier received the BSEE degree from the University of Colorado at Boulder in 1981 and the MS and Ph.D. degrees from the University of Illinois at Urbana-Champaign in 1983 and 1990, respectively. From 1982 to 1984 he was a Member of Technical Staff at AT&T Bell Laboratories in Holmdel and Whippany, NJ. In this capacity he worked on development tools for digital signal processors and on ISDN interfaces for local loop applications. During 1990 he was an NSF-NATO Postdoctoral Fellow at the Ecole Nationale Superieure des Telecommunications in Paris, France. In August of 1990 he joined the faculty of Purdue University, West Lafayette, IN, where he is currently Professor of Electrical and

Computer Engineering. Professor Krogmeier's research interests include the application of signal processing in wireless communications, adaptive filtering, channel equalization, synchronization, precision agriculture, and intelligent transportation systems. He is also a co-founder of the Open Agricultural Technology and Systems (OATS) Center with a mission to research and promote open-source technologies for agriculture and food systems. Professor Krogmeier has served on a number of IEEE technical program committees and as an Associate Editor for the IEEE Transactions on Wireless Communications and the IEEE Transactions on Intelligent Transportation Systems.

Venkat Krovi, Michelin SmartState Professor

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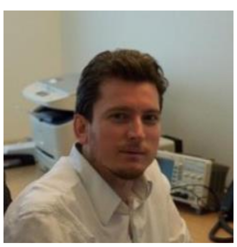
My research focuses on the complete lifecycle treatment (design, modeling, analysis, control, implementation and verification) of a new generation of smart, embedded mechanical, mechatronic and robotic systems. The recent explosion of communications capabilities, coupled with ongoing advances in computing effectiveness and revolutions in miniaturization of processors/ sensors/ actuators, has accelerated the pace of implementing truly distributed smart embedded systems with a variety of emergent applications in plant-automation systems, consumer electronics, automobile and defense applications. I focus both on theoretical formulation and experimental validation in the realization of such novel mechanical and mechatronic systems with the goal of realizing tangible enhancements in functionality, performance, and cost-effectiveness. Specific initiatives underway include multi-robot collaboration, mediated human-computer interfaces, haptic user-interface design and distributed real-time simulation and control of systems. My laboratory, the Automation Robotics and Mechatronics Laboratory (http://mechatronics.eng.buffalo.edu) is equipped with various high-speed computers for analysis, graphical animations and display to support our virtual prototyping efforts and a variety of sensors, actuators, computing platforms and tools for distributed embedded implementation and hardware-in-the-loop testing.



Murat Kuzlu, Professor

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Dr. Murat Kuzlu (Senior Member IEEE) joined Engineering Technology Department, Old Dominion University (ODU) as an Assistant Professor in 2018. He received his B.Sc., M.Sc., and Ph.D. degrees in Electronics and Telecommunications Engineering in 2001, 2004, and 2010, respectively. From 2005 to 2006, he worked as a Global Network Product Support Engineer at the Nortel Networks, Turkey. In 2006, he joined the Energy Institute of TUBITAK MAM (Scientific and Technological Research Council of Turkey the Marmara Research Center), where he worked as a senior researcher. Before joining ODU, he worked as a Research Assistant Professor at Virginia Tech's Advanced Research Institute. His research interests include smart grid, demand response, home and building energy management system, co-simulation, blockchain, explainable artificial intelligence, wireless communication and embedded systems.

William Lehr, Research Scientist, Economist, Industry Consultant

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Dr. William Lehr is a telecommunications and Internet industry economist and consultant with over twenty-five years of experience. He regularly advises senior industry executives and policymakers in the U.S. and abroad on the market, industry, and policy implications of events relevant to the Internet ecosystem. He is a research scientist in the Computer Science and Artificial Intelligence Laboratory (CSAIL) at the Massachusetts Institute of Technology, currently engaged several multidisciplinary research projects within the Advanced Networking Architecture Group in CSAIL (ANA). Dr. Lehr's research focuses on the economics and regulatory policy of Internet infrastructure industries. He teaches courses on economics, business strategy, and public policy issues facing telecommunications, Internet, and eCommerce companies, and is a frequent speaker at international industry and academic conferences. He is the author of numerous publications on such topics as the measurement of economic impacts of Information technologies, the economics of technical standard setting, the pricing of Internet services, and the implications of commercializing novel Internet and wireless technologies for industry structure and regulatory policy. Dr. Lehr holds a PhD in Economics from Stanford (1992), an MBA from the Wharton Graduate School (1985), and MSE (1984), BS (1979) and BA (1979) degrees from the University of Pennsylvania.

David Love, Nick Trbovich Professor of ECE

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David J. Love 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. Since August 2004, he has been with the School of Electrical and Computer Engineering, Purdue University, West Lafayette, IN, where he is now the Nick Trbovich Professor of Electrical and Computer Engineering. He currently serves as a Senior Editor for IEEE Signal Processing Magazine and previously 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. He also serves on the Executive Committee of the National Spectrum Consortium. His research interests are in the design and analysis of communication systems and MIMO array processing. His research has resulted in over 200 technical papers and 14000 citations. Dr. Love has been very involved in commercialization of his research with 31 issued U.S. patents. He is a frequent consultant on cellular and Wi-Fi systems, including patent licensing and litigation.

Vuk Marojevic, Associate Professor

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I gained wireless communications research and teaching experience during 10 years with the radio communications research group of the Universitat Politècnica de Catalunya. Over the past eight years I have actively participated in many research and educational projects with commitment to excellence. My research focuses on real-time computing resource management methods and algorithms for software-defined radio (SDR) transceivers. I currently investigate SDR clouds/Wireless Network Clouds, which enable on demand mapping and execution of the physical layer DSP chains on shared multiprocessor platforms.

Jon Peha, Professor and Center Director

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Jon Peha is a Professor and Center Director at Carnegie Mellon University (CMU). He has served at the Federal Communications Commission as the Chief Technologist, in the White House as Assistant Director of the Office of Science and Technology Policy, in industry as Chief Technical Officer of three high-tech companies, in the House Energy and Commerce Committee, and at USAID where he helped launch and then led a U.S. Government interagency program to assist developing countries with information infrastructure. At CMU, Dr. Peha is a Professor in the Dept. of Engineering & Public Policy and the Dept. of Electrical & Computer Engineering, Director of CMU's Center for Executive Education in Technology Policy, and former Associate Director of the Center for Wireless & Broadband Networking. Dr. Peha is an IEEE Fellow, an ALA Fellow, and an AAAS Fellow, and was selected by AAAS as one of 40 "Featured AAAS Science and Technology Policy Fellows" of the last 40 years ("40@40"). Dr. Peha has received the FCC's "Excellence in Engineering Award" for contributions to the U.S. National Broadband Plan, the IEEE Communications Society TCCN Publication Award for career contributions to spectrum management, and the Brown Engineering Medal.

Aloizio DaSilva, CCI xG Testbed Director

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Aloizio Da Silva is the CCI xG Testbed director, helping to speed up advancements in 5G and beyond by providing researchers, government, and industry a destination to try and validate new approaches. In addition, he is research faculty at the Bradley Department of Electrical and Computer Engineering at Virginia Tech. He also served as the technical project manager and researcher associate at US-IGNITE/NSF PAWR PPO where he managed and orchestrated PAWR testbeds, including AERPAW, POWDER, COSMOS, and ARA. PAWR is funded by the National Science Foundation (NSF) and a wireless industry consortium of 35 companies and associations. The $100 million public-private partnership aims to deploy and manage up to four city-scale research testbeds. He served as Research Fellow and 5G Portfolio Manager at the University of Bristol UK where he managed and conducted R&D in several European H2020 Projects on large-scale experimentation testbeds from physical to application layer. He worked on the Interplanetary Networking laboratory at JPL-NASA where he developed his Ph.D. dissertation developing a new congestion control mechanism based on reinforcement-learning for delay-and-disruption tolerant networks for deep-space communication and earth extreme environments.

Jeffrey Reed, Professor

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I am the cofounder of several commercial companies. Cognitive Radio Technologies (CRT) is a company that is commercializing cognitive radio technologies produced at Virginia Tech for commercial and military applications. Federated Wireless is a company that is commercializing 5G wireless systems and PFP Cybersecurity is a company that specializes in security for embedded systems, including Android platforms. I have also served as a consultant for approximately 30 organizations and more recently was engaged in consulting regarding the AT&T – T-Mobile merger and the band plan strategy for the 600 MHz auctions. I have served on the technical advisory boards for approximately six companies and as an informal advisor on national policy regarding wireless issues, most notably serving on the

President's Council of Advisors in Science and Technology (PCAST) Working Group on how to transition federal spectrum for commercial economic benefits. In 2014, I was selected to be a member of CSMAC, the advisory group on spectrum issues for the US Department of Commerce.

Sumit Roy, Professor
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Sumit Roy has been a faculty member in Electrical & Computer Engineering at the University of Washington since 1998, where he is presently CoE/ECE Integrated Systems Professor and directs Fundamentals of Networking lab. His research spans the gamut wireless communication and sensor network systems with a diverse emphasis: 4G and emerging 5G technologies, multi-standard wireless inter-networking and spectrum coexistence using cognitive radio platforms, terrestrial vehicular, aerial, and underwater networks. He spent 2001-03 on academic leave at Intel Wireless Technology Lab as a Senior Researcher/Standards Architect engaged in systems architecture and standards development for ultra-wideband systems (Wireless PANs) and next generation high-speed wireless LANs (802.11n). His activities for the IEEE Communications Society (ComSoc) include membership of several technical and conference program committees, notably the Technical Committee on Cognitive Networks. He was elevated to IEEE Fellow by ComSoc in 2007 for "contributions to multi-user communications theory and cross-layer design of wireless networking standards," served two stints as ComSoc Distinguished Lecturer (2014-15, 17-18) and is a frequent invited speaker @ various 5G forums such as IEEE 5G Summit.

Joao Santos, Postdoctoral Researcher
Virginia Tech

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Joao F. Santos is a 5G Testbed and AI Assurance Researcher with the Commonwealth Cyber Initiative (CCI) at Virginia Tech. His main research interests include radio resource management, radio virtualization, network slicing, network security, and end-to-end network orchestration. Dr. Santos research experience includes developing software-defined radio systems, implementing radio virtualization mechanisms, and bridging SDR with SDN in support of programmable end-to-end communication networks, which led to a number of articles published in international conferences and high-impact journals. Dr. Santos obtained his Ph.D. in Electronic & Electrical Engineering from Trinity College Dublin (TCD) (2021) and B.Sc. in Telecommunications Engineering from Universidade Federal Fluminense (UFF) (2016).

Vijay Shah, Assistant Professor
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Vijay K. Shah is an Assistant Professor in the Cybersecurity Engineering department at George Mason University starting July 2021. Before joining Mason, he was a Research Assistant Professor with the Bradley Department of Electrical and Computer Engineering at Virginia Tech and affiliated with Wireless@Virginia Tech Lab since 2019. His research interests include Resilient 5G/Next-G wireless systems, Secure Open Radio Access Networks (O-RAN), Trustworthy machine learning and wireless testbed development and prototyping.

Cong Shen, Assistant Professor
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Cong Shen received his B.S. and M.S. degrees from the Department of Electronic Engineering, Tsinghua University, China. He obtained a Ph.D. degree from the Electrical Engineering Department, University of California Los Angeles (UCLA). Prior to joining the Electrical and Computer Engineering Department at University of Virginia, Dr. Shen was a professor in the School of Information Science and Technology at University of Science and Technology of China (USTC). He also has extensive industry experience, having worked for Qualcomm Research, SpiderCloud Wireless, Silvus Technologies, and Xsense.ai, in various full-time and consulting roles. His general research interests are in the area of communication theory, wireless communications, and machine learning. He received the NSF CAREER award in 2022. He was the recipient of the Best Paper Award in 2021 IEEE International Conference on Communications (ICC), and the Excellent Paper Award in the 9th International Conference on Ubiquitous and Future Networks (ICUFN 2017). Currently, he serves as an associate editor for the IEEE Transactions on Communications, an editor for the IEEE Transactions on Green Communications and Networking, an editor for the IEEE Wireless Communications Letters, and an associate editor for IEEE Transactions on Machine Learning in Communications and Networking. He was the TPC co-chair of the Wireless Communications Symposium of IEEE Globecom 2021.

Andrew Thiessen, NGA Spectrum Working Group Chair
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Andrew Thiessen is the Head of 5G/xG at the MITRE Corporation, which is a non-profit that works in the public interest across Federal, state, and local governments, as well as industry and academia. Andrew is the MITRE representative to the NextG Alliance Steering Group and the Chair of the NextG Alliance Spectrum Working Group.

Nishith Tripathi, Research Associate Professor
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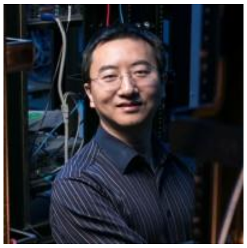
Nishith Tripathi is a research associate professor at Virginia Tech. Dr. Tripathi has 24 years of industry experience at Nortel Networks, Huawei Technologies, Samsung Research America, and Award Solutions. He led Samsung's NTN activities in 3GPP and made more than 30 contributions toward the development of the 3GPP NTN specifications. He is leading several research projects at Virginia Tech related to smart traffic intersections, smart ports, secure NTN, smart warehouses, UAV geofencing, indoor firefighter positioning, secure 5G, and 5G O-RAN testbeds. He has co-authored the cellular industry's first-ever multimedia book on 5G, a textbook on Cellular Communications, and a pioneering monograph on the applications of AI in cellular networks. He has hands-on experience and end-to-end expertise with various aspects of commercial wireless networks including the design, operations, testing, and optimization. As a wireless industry expert, Dr. Tripathi has contributed to organizations such as FCC, CTIA, GSMA, Scientific American, FTC, EE Times University, and CNN.



Kai Zeng, Associate Professor

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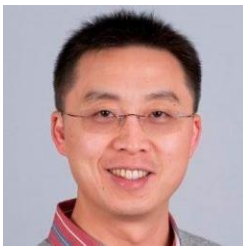
Kai Zeng is an Associate Professor in the Department of Electrical and Computer Engineering at the College of Engineering and Computing. He is also affiliated with the Department of Computer Science and Cyber Security Engineering. Prior to coming to Mason, he was a faculty member in the Department of Computer and Information Science at University of Michigan - Dearborn and a postdoctoral scholar in the Computer Science Department at University of California, Davis (UCD). His research interests include 5G wireless security, CPS/IoT security, spectrum sharing, machine learning, and physical layer security.



Hongwei Zhang, Professor

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Hongwei Zhang is a Professor of Electrical and Computer Engineering and the Director of the Center for Wireless, Communities and Innovation at Iowa State University. His research investigates modeling, algorithmic, and systems issues in wireless sensing and control networks (e.g., those in 5G and beyond) as well as their applications in connected and automated vehicles, XR, smart agriculture, and cyber-physical-human systems in general. He has led the development of open-innovation infrastructures for precision agriculture, connected and automated transportation, cellular networks, and IoT networks which have been used by researchers worldwide. For instance, he currently leads the $16M project ARA (www.arawireless.org) on rural broadband research. His research results and system software have served as foundational elements of the DARPA sensor network systems “A Line in the Sand” and “ExScal” which, with its 200-node wireless mesh network and 1,200-node sensor network, was the world’s largest wireless mesh network and wireless sensor network deployed at its time. He is a recipient of the National Science Foundation CAREER Award. He currently serves as an Editor for the IEEE Transactions on Wireless Communications, and he served as an editor for IEEE Internet of Things Journal in 2020 and 2021. He is the Co-Chair for the 2022 ACM Workshop on Wireless Network Testbeds, Experimental evaluation & CHaracterization (WiNTECH), and he was the Program Co-Chair of the 2019 IEEE Vehicular Networking Conference (VNC). He has also served on the program and/or organizing committees of conferences such as ICCPS, IPSN, INFOCOM, and ICC. More information about his work can be found from his website at http://www.ece.iastate.edu/~hongwei.

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Micaela Giuhat, Director

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Micaela brings along more than 20 years of industry experience, with previous executive positions in leading Unified Communications, Session Border Controller, and IP Networking companies in the U.S as well as abroad. Micaela Giuhat is a published and accomplished technical speaker and author, speaking at numerous conferences and events. Micaela Giuhat holds a Master of Science in Electrical Engineering from the University of Bucharest, Romania and a Master of Business Administration Degree from the University of Ottawa, Canada.

Carroll Gray-Preston, Innovation and Strategic Initiatives

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As Vice President – Innovation and Strategic Initiatives, Carroll Gray-Preston drives the development of initiatives that put emerging Innovation Agenda priorities, as set by the ATIS Board of Directors, into action. She also works to advance established ATIS initiatives, most recently in the areas of NFV, IoT and Distributed Ledger/Blockchain technologies. Her role encompasses identifying emerging ICT trends and how ATIS members can advance their business priorities in light of them. Gray-Preston honed her strengths as an R&D leader, systems architect and strategic planner most recently serving as Vice President of Strategic Operations and Customer Success at GENBAND (Nortel Networks) and Leader of Technology and Planning, Office of the CTO, where her expertise spanned Agile methodologies, platform and product strategy, cultural change and critical launch strategies. She is a patent holder in the area of Multimedia Services and IP Interconnect. Before joining ATIS as a Vice President, she led a standards task force that delivered a major report on the PSTN transition, which was used as input to evolve FCC services standards. Carroll holds a B.S. in Business Administration from the University of North Carolina at Chapel Hill as well as a Post-Baccalaureate Certificate in Computer Programming from the North Carolina State University.

Stephen Hayes, Director of North American Standards

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Stephen Hayes is the Director of Standards for Ericsson in North America. He has worked on various cellular issues over the last 20 years and been heavily involved in the evolution of the 3GPP family of technologies. His current focus includes the ATIS committees and 3GPP. He is also involved in several US advisory groups such as the FCC TAC (Technical Advisory Committee). Stephen is currently the Vice-Chair of 3GPP TSG-RAN. Stephen was chairman of the 3GPP systems group (3GPP-SA) from 2006- 2011. Before that, Stephen was the chair of the Core Network group in 3GPP. Stephen is also the chair of the 3GPP group on working procedures. Within ITU-T Stephen is chair of the Rapporteur group on Standardization Strategy.

Ki-Dong Lee, Assistant Vice President

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Dr. Ki-Dong Lee [Ph. D'01] has been actively involved for over 20 years in research and standardization of mobile/satellite communications systems in various organizations, including IEEE, NGMN Alliance, SAE (Society for Automotive Engineers) and 3GPP. He led Cellular-V2X Feasibility Study and Normative Work as the first V2X Rapporteur in 3GPP, which is the first-of its-kind vertical and application that 3GPP has accommodated into Rel-14 and 5G specifications. He extended his efforts to capture both the automotive industry's needs and communication standard's boundary in order to help identify functional and performance requirements that communication layers should be enhanced to meet.

Mike Nawrocki, Vice President of Technology

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As Vice President of Technology and Solutions, Mike Nawrocki focuses on strategic initiatives to advance ATIS members' business and technology priorities. Bringing extensive telecommunications strategy experience and a service provider perspective, Mike provides ATIS direction on emerging technology trends as well as next generation technologies and networks. Before ATIS, he served as Director – Standards for Verizon Technology, and previously, as principal technologist in Verizon's CTO organization. His extensive career with major service providers includes working in network planning and engineering positions at Verizon and AT&T Bell Labs. Mike has previously served on the MoCA Board of Directors and participated in FCC working groups, including the Technological Advisory Council, CSRIC and Network Reliability Council. At ATIS, he serves as a key policy interface with the FCC and other agencies. Mike holds a master's degree in Electrical Engineering – Communications from the George Washington University School of Engineering & Applied Science. He earned a bachelor's degree in Electrical Engineering from Johns Hopkins University.