VIRGINIA TECH

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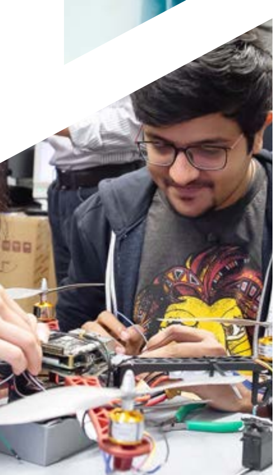
THE BRADLEY DEPARTMENT OF
ELECTRICAL & COMPUTER
ENGINEERING

FOCUS ON RESEARCH
2018

VIRGINIA TECH™



WHAT'S INSIDE

from the

ece

DEPARTMENT HEAD

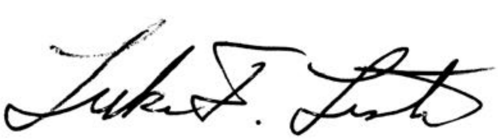
Greetings to our colleagues and alumni! As this document demonstrates, the Bradley Department of Electrical and Computer Engineering of Virginia Tech is conducting research in a growing variety of fields.

In the past two years, we have recruited 13 new faculty members in the areas of power systems, power electronics, operating systems, secure hardware/software systems, neuromorphic computing, wireless networks, remote sensing, and wide bandgap devices. Our faculty now stands at 81 tenured/tenure-track members, 38 research faculty, and 12 instructors/professors of practice/collegiate faculty.

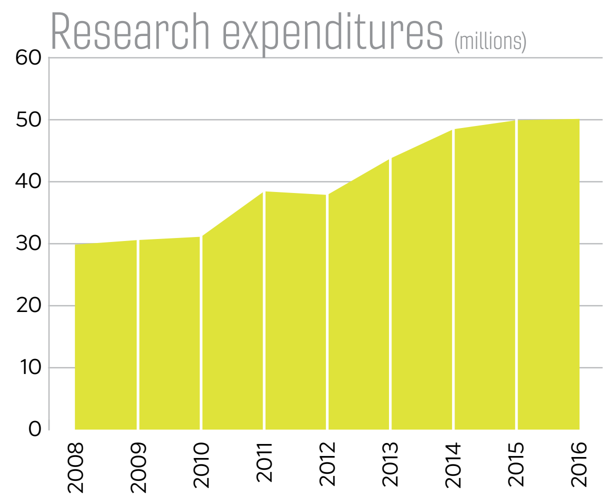
We are currently conducting searches in machine perception for autonomy, machine learning, power engineering, image processing, secure systems, the Honors College, and two MEng. degree program directorships. The search ads can be found on the department website ece.vt.edu.

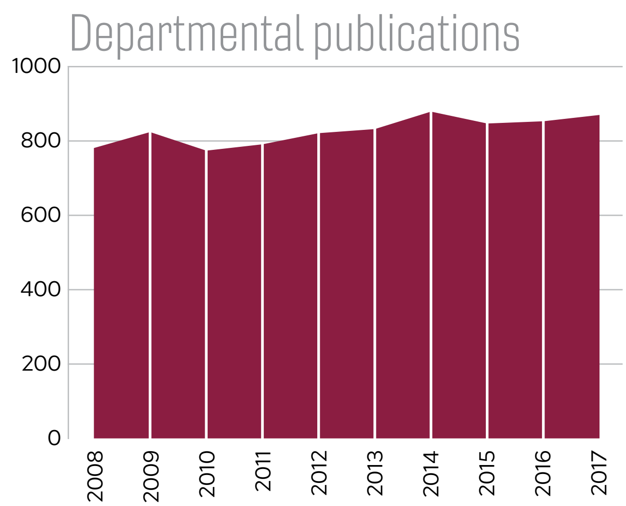
With more than 550 graduate students and 1,400 undergrads studying in the fields mentioned above and others such as computer vision, fiber-based sensing, cybersecurity, space science and engineering, nanophotonics, and computational biology, we have an extensive research portfolio that now realizes about $50 million annually. I can't realistically describe in this one document all of our research efforts. However, the following pages provide some highlights of the work that led to 58 Ph.D.s awarded in 2018.

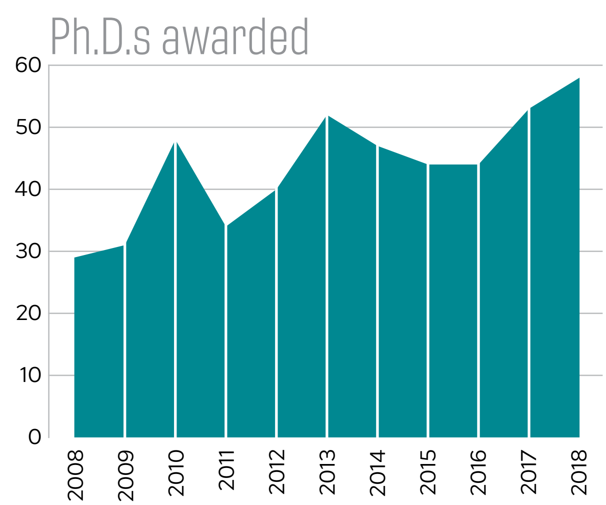
Please take a close look at the contents of this report, and if you have any questions about our research activities or want to get involved with the department, don't hesitate to contact me or another member of our faculty.



Luke Lester
Department Head







research distinctions

IEEE Fellows

Dushan Boroyevich (2006)
For advancement of control, modeling, and design of switching power converters.

Charles W. Bostian (1992)
For contributions to and leadership in the understanding of satellite path radio wave propagation.

Gary S. Brown (1986)
For contributions to the understanding and application of electromagnetic scattering from rough surfaces.

R. Michael Buehrer (2017)
For contributions to wideband signal processing in communications and geolocation.

David A. de Wolf (1988)
For contributions to wave propagation theory in random media and to the numerical simulation of wave and particle beams by phase-space methods.

Dong S. Ha (2008)
For leadership in VLSI design and testing.

Y. Thomas Hou (2014)
For contributions to modeling and optimization of wireless networks.

Michael S. Hsiao (2013)
For contributions to automatic test pattern generation of integrated circuits.

Jih-Sheng (Jason) Lai (2007)
For contributions to high performance high power inverters.

Fred C. Lee (1990)
For contributions to high-frequency quasi-resonant and multiresonant converters and for the development of a program of engineering education in power electronics.

Luke Lester (2013)
For contributions to quantum dot lasers.

Guo-Quan (G.Q.) Lu (2018)
For development of materials and packaging technologies for power electronics modules.

Theresa Mayer (2017)
For contributions to nanomaterials integration and directed assembly.

Lamine Mili (2016)
For contributions to robust state estimation for power systems.

Khai Ngo (2014)
For contributions to unified synthesis and modeling of switched mode converters.

Marius K. Orlowski (1997)
For contributions to modeling of MOSFET devices and technology.

Jung-Min (Jerry) Park (2017)
For contributions to dynamic spectrum sharing, cognitive radio networks, and security issues.

Arun G. Phadke (1980)
For contributions to the application of digital computers to power systems.

T.-C. Poon (2016)
For contributions to optical image processing and digital holography.

Saifur Rahman (1998)
For contributions to electric power engineering education.

Sanjay Raman (2013)
For leadership in adaptive microwave and millimeter-wave integrated circuits.

Krishnan Ramu (2001)
For contributions to the development of AC and switched reluctance motor drives.

Jeffrey H. Reed (2004)
For contributions to software defined radio.

Sedki M. Riad (1992)
For contributions to time-domain measurements through physical modeling of sampling devices.

Timothy D. Sands (2010)
For contributions to metal/semiconductor interfaces and heterogeneous integration.

Warren L. Stutzman (1989)
For contributions to wave propagation through the natural environment and antenna synthesis.

William H. Tranter (1985)
For contributions in communications and signal processing research, and for leadership in engineering education.

Yue (Joseph) Wang (2016)
For contributions to genomic signal analytics and image-based tissue characterization.

Amir I. Zaghloul (1992)
For contributions to the application of phased array antennas to communications satellite systems.

Other Fellows

National Academy of Inventors
Timothy D. Sands (2012)

American Institute for Medical and Biological Engineering Fellow
Yue (Joseph) Wang (2004)

Institute of Physics
Richard O. Claus (2001)
Ting-Chung (T.-C.) Poon (2014)

Optical Society of America
Ting-Chung (T.-C.) Poon (1998)

SPIE
Richard O. Claus (1992)
Luke Lester (2013)
Ting-Chung Poon (1999)
Anbo Wang (2010)

Materials Research Society
Timothy D. Sands (2009)

Applied Computational Electromagnetics Society Fellow
Amir I. Zaghloul

Presidential Early Career Award for Scientists and Engineers (PECASE)

Tom Martin (2006)
Sanjay Raman (2000)

National Academy of Inventors

Timothy D. Sands (2012)

National Academy of Engineering

Dushan Boroyevich (2014)
For advancements in control, modeling, and design of electronic power conversion for electric energy and transportation.

Fred C. Lee (2011)
For contributions to high-frequency power conversion and systems integration technologies, education, industry alliances, and technology transfer.

Arun G. Phadke (1993)
For contributions to the field of digital control, protection, and monitoring of power electrical systems.

NSF CAREER Awards

Masoud Agah (2008)
Paul K. Ampadu (2010)
Joseph B. Baker (2012)
Y. Thomas Hou (2004)
Michael S. Hsiao (2001)
Mark T. Jones (1997)
Vassilis Kekatos (2018)
Luke Lester (1995)
Qiang Li (2017)
G.Q. Lu (1995)
Allen B. MacKenzie (2005)
Tom Martin (2005)
Leyla Nazhandali (2008)
Jung-Min (Jerry) Park (2008)
Sanjay Raman (1999)
Walid Saad (2013)
Patrick Schaumont (2007)
Daniel J. Stilwell (2003)
Yong Xu (2007)
Yaling Yang (2011)
Yang (Cindy) Yi (2018)
Guoqiang Yu (2018)

top cited papers by ECE faculty

2009-2018*

1 **Modeling and analysis of K-tier downlink heterogeneous cellular networks**
1184 citations | HS Dhillon, RK Ganti, F Baccelli, JG Andrews, 2012

2 **Spectrum sensing for cognitive radio**
788 citations | S Haykin, DJ Thomson, JH Reed, 2009

3 **Coalitional game theory for communication networks**
777 citations | W Saad, Z Han, M Debbah, A Hjorungnes, T Basar, 2009

4 **Game theory in wireless and communication networks: theory, models, and applications**
752 citations | Z Han, D Niyato, W Saad, T Basar, A Hjørungnes, 2011

5 **Heterogeneous cellular networks: From theory to practice**
738 citations | Amitabha Ghosh, JG Andrews, N Mangalvedhe, R Ratasuk, B Mondal, M Cudak, E Visotsky, TA Thomas, Ping Xia, Han Shin Jo, Harpreet S Dhillon, Thomas D Novlan, 2012

6 **Synchronized phasor measurement applications in power systems**
733 citations | J De La Ree, V Centeno, JS Thorp, AG Phadke, 2010

7 **Multi-agent systems in a distributed smart grid: Design and implementation**
728 citations | M Pipattanasomporn, H Feroze, S Rahman, 2009

8 **Role of kinetic factors in chemical vapor deposition synthesis of uniform large area graphene using copper catalyst**
677 citations | S Bhaviripudi, X Jia, MS Dresselhaus, J Kong, 2010

9 **Synthesis of few-layer hexagonal boron nitride thin film by chemical vapor deposition**
658 citations | Yumeng Shi, Christoph Hamsen, Xiaoting Jia, Ki Kang Kim, Alfonso Reina, Mario Hofmann, Allen Long Hsu, Kai Zhang, Henan Li, Zhen-Yu Juang, Mildred S Dresselhaus, Lain-Jong Li, Jing Kong, 2010

10 **Synthesis of monolayer hexagonal boron nitride on Cu foil using chemical vapor deposition**
648 citations | Ki Kang Kim, Allen Hsu, Xiaoting Jia, Soo Min Kim, Yumeng Shi, Mario Hofmann, Daniel Nezich, Joaquin F Rodriguez-Nieva, Mildred Dresselhaus, Tomas Palacios, Jing Kong, 2011

*As of 10/1/2018

Powerhouse **past**

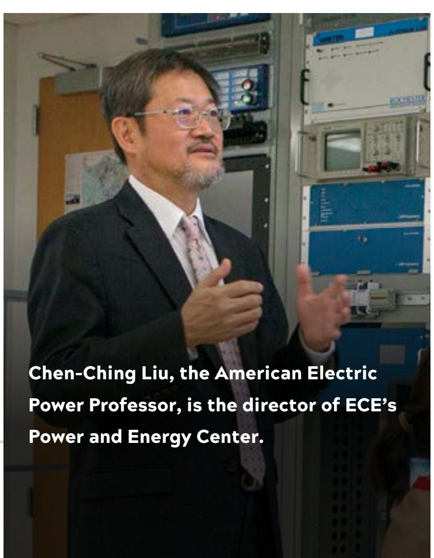
Electric power grid design is on the cusp of radical transformation, largely precipitated by renewable and distributed energy sources as well as the information age. As the power grid faces increasing automation, big data, new measurement techniques, and other complicating elements, there is a need for a new vision of the future power grid.

Already a national and international leader in power grid research and education, the field of power systems at Virginia Tech is positioning itself to continue the tradition of global leadership. In January, Chen-Ching Liu, the American Electric Power Professor, joined the department as the director of the Power and Energy Center (PEC). With his fellow researchers, Liu has been leading to strengthen industry collaborations and cross-disciplinary partnerships to support the new vision.

> "We have a vision that is grounded in the needs of both the power grid of today and the power grid of the future."
>
> **—Chen-Ching Liu**

"The Power and Energy Center has created a vision for the future power grid, or as we call it, the cyber-grid," said Liu.

The vision of cyber-grid is supported by four main components: measurement, power electronics, cybersecurity, and decentralization.



Chen-Ching Liu, the American Electric Power Professor, is the director of ECE's Power and Energy Center.

Measurements

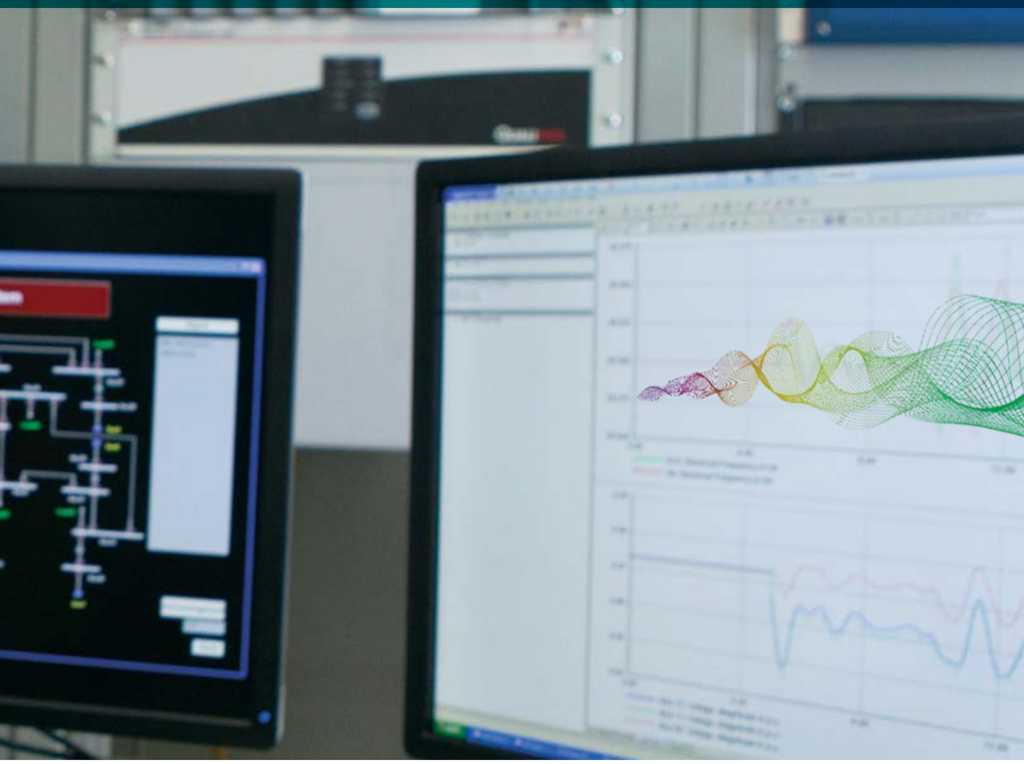
Thanks to decades of power systems innovation, led by ECE Professors Arun Phadke and the late James Thorp, "measurement is one of Virginia Tech's traditional strengths," said Liu.

Among Phadke and Thorp's many contributions to the electric power field, phasor measurement units (PMUs) have been recognized by electric utility industries around the world as the modern measurement system capable of providing data and information for advanced control, monitoring, and protection of power grids.

In addition to PMUs and other instrumentation deployed on the transmission grid, millions of smart meters have been installed at residential, commercial, and industrial locations in the distribution system.

"That's potentially a lot of data to deal with," said Liu, "and we will need to create a new set of analytical tools to extract information from the big data."

Powerhouse **future**



Graduate student Ruoxi Zhu navigates the Power and Energy Center testbed, which will integrate measurement, power electronics, cybersecurity, and decentralization for power grids of the future.

Power electronics

The future power grid is power electronics and power systems. At Virginia Tech, Liu's Power and Energy Center and the Center for Power Electronics Systems (CPES)—two world-renowned research centers in their respective fields—are only separated by two floors.

"This makes for a uniquely well-suited collaboration with a strong team that is unmatched by any university in the U.S.," said Liu.

Cybersecurity

Everything is computerized now, including the power grid. "The instrumentation, controls, and monitoring equipment—they're all computers, and they're all connected," said Liu. But this widely expanded connectivity also makes the power grid vulnerable to cyber intrusions.

Consequently, power grids should be treated as an integrated cyberphysical system and secured on both the cyber and physical fronts. This necessitates interdisciplinary innovation.

Decentralization

In the past, utility companies built, owned, operated, and maintained the grid, catering to "captive" customers.

But with an increase in renewable energy sources and electric vehicles, the monolithic grids have splintered into decentralized units, which are controlled by different groups and individuals. In this new paradigm, efficient grid operations are contingent upon collaborative decisions.

"This is a new challenge because we are used to doing things centrally," says Liu. "Now we have to develop control and operation planning methods to handle the new reality."

The testbed

Liu's group is building a testbed that integrates measurement, power electronics, cybersecurity, and decentralization along with their enabling technologies.

"It's going to look like the control center facility for the new power system environment that we have not seen before," said Liu. "The data and software will allow us to analyze how control methods will work within each micro power grid. Each of the components will have to work independently but also collaboratively with each other." As we figure out better control resources and strategies for them, we will be developing their capabilities to work with each other and bring the entire system together," explained Liu.

"These four components together represent cyber-grid challenges with enough work to keep all of us busy for many years," said Liu.

Attracting industry partners

One of Liu's main priorities is to develop relationships with industry partners and building teams to respond quickly to government calls for proposal.

"It takes time to build a relationship based on mutual trust and shared interests, but we're starting to see some success," said Liu.

In Liu's experience, the excitement that draws partners from different sectors of the industry are the same seeds that attract students to the program and propel faculty members to keep researching and innovating: The Power and Energy Center is committed to solving real-life problems and making a real-world impact.

"We have a vision that is grounded in the needs of both the power grid of today and the power grid of the future," said Liu.

Energy-harvested security

From left to right: Archanaa S. Krishnan (Ph.D. student), Daniel Dinu (postdoctoral student), and Patrick Schaumont demonstrate the secure intermittent computing protocol, which models how security protocols can be adapted to the minuscule and intermittent power regime of energy harvesters.

Consumers demand new smart gadgets, and they're getting them. Recent estimates report that by 2020, up to 50 billion devices will be connected to the internet—that's 6.6 devices for every person on Earth. Anticipating this explosion of connected devices, researchers are considering the energy price of our smarter world.

What if smaller devices could be powered by renewable energy? A solar cell, or a battery that runs on vibrations or heat? We would never have to charge our batteries again. Researchers and industry experts are increasingly looking to these instruments, called energy harvesters, to help shoulder the mounting demand for power.

Dong Ha is constructing a prototype energy-harvester to quantify the performance of cryptographic algorithms and the toll they would take on accumulated power.

But today's small-scale energy harvesters don't provide enough power to run complex cryptographic operations in real time. An energy harvester first has to accumulate enough energy to initiate the protocol, which hinders response times.

In short, sustainably powered miniature computers are either insecure or too slow to be useful.

"Neither of these is acceptable," says Patrick Schaumont, who, along with fellow ECE professor Dong Ha, received a $849,992 National Science Foundation grant to maintain information security in the energy-starved operating environment of embedded connected devices.

Cryptographic engineering

We are inundated with information from our devices; they update the amount in our bank accounts, monitor our heart rates, and ping us about appointments and anniversaries. And when it comes to our gadgets, especially the ones we strap around our wrists or slip into our pockets, we almost unfailingly believe them.

To protect the average consumer—and their unshakeable trust in personal devices—tightened security protocols need to be introduced at the manufacturing level, said Schaumont. He is focusing particularly on the next generation of connected devices that can be powered by energy harvesters.

Collecting renewable energy means dealing with an inconsistent or intermittent power source. The sun sets. The engine turns off and cools down. The person stops walking.

To optimize cryptographic algorithms and protocols in the face of unreliable power supplies, Schaumont and his team are developing techniques to generate and securely store "coupons"—tiny pre-computed packets that hold the results from cryptographic algorithms.

When the energy harvesters have a little extra energy at the end of a long car ride or a sunny day, that energy is funneled into the prep work of coupon generation, which speeds up online encryption and computation as new data comes in.

Energy-harvesting technologies

But, in order to do this efficiently, Schaumont and his team need to know how much energy is stored in an energy harvester at any given time.

Ha is studying the hardware side of this problem. He is constructing a prototype to quantify the performance of cryptographic algorithms on energy harvesters, and the toll they would take on accumulated power.

"By providing Schaumont's team with information on the level of energy we currently store, they can find ways to reduce latency and increase the data rate," said Ha.

In order to boost an energy harvester's efficiency, Ha and his team are seeking to reduce power dissipation of energy harvesting circuits, while extracting maximum power from transducers such as solar panels. They are also working on harvesting energy from multiple sources including solar, vibration, and thermal.

Verification and software synthesis

The researchers are also developing techniques to automate software code generation, verify the accuracy of these energy-aware cryptographic computations, and demonstrate that they're just as secure as the original cryptographic design.

Schaumont, Ha, and their teams are well on their way to establishing the cryptographic protocol and developing the energy-harvester prototype.

Dealing with delinquent drones

Drones roam among us. They monitor crops, survey traffic in real time, search for missing hikers, and even deliver burritos and popsicles.

Drones also go where they are far less welcome—the grounds of the White House, for instance. They also have interrupted firefighting and rescue operations in Colorado and California. So far, these incidents have been cases of over-curious spectators or operator error. But there have been exceptions where drones or other unmanned aerial systems have been weaponized or deployed for illegal purposes. They've been used to drop bombs in war zones and deliver contraband to prisons. In early August of this year, the Venezuelan president survived an assassination attempt via armed drone.

"Given that the number of drones will only increase, we expect there to be more of these incidents," said Ryan Gerdes, an assistant professor in ECE. "We believe that drones serve a social good, but we need to be sure our sensitive airspace, and to some extent our private airspace, is respected."

Gerdes and Jerry Park, an ECE professor, are collaborating with researchers from aerospace and ocean engineering, Georgia Tech, and the University of Arizona on a $957,712 National Science Foundation project to geographically limit and police drones. Called geofencing enforcement, their plans lay out the steps to identify, track, and safely decommission any trespassing drone—regardless of the sophistication or motives of their operators.

"Most commercial drones come equipped with a GPS and a database of places they can't go," explained Gerdes. But it doesn't require a very savvy user to bypass those checks and guards, he said.

"Virginia Tech sophomores or juniors would have no problem bypassing those guards," said Gerdes. "And you can even buy bypasses online."

Previous methods to bring down an errant drone have disrupted nearby wireless users or utterly destabilized the target, causing the drone to plummet violently to the ground, said Gerdes— "Not a good option for a crowded environment."

Gerdes, Park, and their collaborators are working to establish a series of protocols to 1) detect, identify, and track a rogue drone; 2) deploy "defender drones" to get as close to encroaching drone as possible; and 3) safely bring down an errant drone in a controlled manner.

Phase 1:
Detect and track encroaching drones

Drones can be considered flying wireless devices—many even use Wi-Fi signals to communicate with their ground operator or station.

Park, leveraging his background in wireless security, is leading investigations into commercially viable, cost-effective methods to distinguish drone-specific radio frequency (RF) signals from all the other wireless signals bouncing around.

They are investigating different identification methods for different threat types, ranging from a benign but negligent operator to a sophisticated, malicious operator.

For benign operators using off-the-shelf systems, Park's team is exploring the use of required, tamper-resistant signatures embedded at the waveform level in all transmissions.

"This is actually above and beyond detection," said Park. "We could uniquely identify or authenticate a drone by extracting the digital signature embedded in the RF signal they're emitting."

This approach, however, would incur some overhead: digital signatures consume computation power, said Park. "And then there's additional communication costs because you're periodically emitting these signatures, which requires extra power consumption and taxes the battery."

Park and his colleagues are also evaluating methods to authenticate transmissions from multiple, simultaneous UAS using the same channel.

Identifying unsophisticated, but malicious operators would require alternative techniques that prevent the operator from spoofing speed measurements of their drone. For this level threat, the team is developing secure doppler estimation techniques from moving antennas. Using a single, randomly moving antenna would ensure that the malicious operator could not effectively spoof the relative speed between the drone and the monitor.

To identify drones operated by sophisticated and malicious operators, the team is exploring passive radar methods. One promising approach taps ubiquitous "signals of opportunity," like LTE and Wi-Fi emitted for non-localization purposes, to detect and track drones.

Co-principal investigator Ming Li from the University of Arizona is working alongside Park on this phase, focusing on physical layer authentication and anti-jamming communications.

Phase 2:
Pursuit

Once a drone has been detected and tracked in an off-limits area, defender drones will take to the skies. At this point, the possible actions split off into evasive or engaging maneuvers. The researchers are developing plans (and backup plans) for different scenarios.

For example, they've designed two sets of plans to maneuver a defender drone close to the rogue drone and keep it there.

"The first one is based on machine learning and game theory and the second is based on robust control theory," said Gerdes. "We know there are limitations to each, but hopefully, when one approach doesn't work, the other one will."

Some unidentified drone operators will try to escape. To help defender drones keep up with threats, researchers are implementing machine learning techniques and reinforcement learning coupled with controls.

"This allows us to learn or infer a drone's intent and develop a control strategy that optimally counters what the drone is doing," said Gerdes.

Co-principal investigators Mazen Farhood from the aerospace and ocean engineering department and Kyriakos Vamvoudakis from Georgia Tech are focusing on this phase, validating the UAS flight control systems and employing reinforcement learning for intelligent control.

Phase 3:
Safely ground the drone

Once the defender is in position, it can bring the intruding drone to the ground with intentional electromagnetic interference (EMI). An attack on a drone's sensors essentially blinds it, preventing it from being able to sense the world or control itself. If the actuators are targeted, it will lose control of its motions—instead of receiving an "up" command and complying, for instance, it would move down instead.

"Our attacks are hard to defend against," said Gerdes, who is spearheading efforts for this phase due in part to his background in cyberphysical security. "The traditional way you would defend a drone from intentional EMI is through RF shielding, but for the particular type of the EMI we use, RF shielding is either prohibitively expensive and heavy, or it's simply not effective."

By navigating a defender drone into proximity with a rogue drone, enforcers won't have to interfere with other nearby (law-abiding) drones or issue blanket disruptions of wireless devices.

Cross-disciplinary collaboration and challenges

With experts in cyberphysical security, wireless communications, aerospace engineering, control systems, game theory, and machine learning and perception, this collaboration represents a cadre well-suited for a challenge as complex as geofencing drones.

"We will be able to simulate and model the individual components for each phase," said Park. "The next challenge involves connecting the pieces and implementing them in a realistic environment."

The group already is conducting experiments together, and they plan to demonstrate a defensive attack in a superficial environment by the spring.

Mahsa Foruhandeh (Ph.D. student and Pratham Oza (M.S. student) are working in Arlington, Va. with Ryan Gerdes (back left) and Jerry Park (back right) to implement defensive attack mechanisms on drones.

SECURING EVERYTHING

Next-generation security for the next generation

Your cellphone's identification information may not be as secure as you think it is. The Bluetooth connection in your new car can be exploited. Even the national power grid is a tempting target for hackers. Next generation wireless security isn't as strong as it could be, according to Jeffrey Reed, the Willis G. Worcester Professor of ECE.

5G—the fifth generation of cellular mobile communications—is supposed to overcome the weaknesses in the fourth-generation (LTE), said Reed. While 5G offers some improvements, researchers have already found issues.

Stakes are higher in 5G: "In 5G, we have what we call 'mission-critical situations, or life critical situations," said Reed. Autonomous vehicle control is expected to rely on 5G, as do public safety and national security systems.

"Wireless is the new battleground for warfare and terrorism," said Reed, citing recent detections of StingRay activity, controversial technology that allows for the surreptitious surveillance of our cellphones.

"Historically, there hasn't been as much emphasis on security," said Reed, because security doesn't make money at this stage of development.

ECE researchers are exploring a number of productive avenues, according to Reed.

"I think some of the best things come out of the smaller projects," he said. "If you're talking about $5 million, [funding agencies] don't want to take any risks. But they don't mind gambling with 50K, so it's the 50K projects that disproportionally provide big breakthroughs."

DarkNet

ECE contributors: Vuk Marojevic, Jeffrey Reed

DarkNet, an ongoing Oak Ridge National Laboratory project that includes ECE collaborators, refers to a highly secure, resilient, and redundant critical communications system that could support all elements of the grid and its supply chain.

"Too much of our critical infrastructure relies on the public internet," said Reed. "Recent developments in grid access and automation have created unintended, dangerous security vulnerabilities at all levels within the electricity subsector."

In its initial phase, DarkNet researchers are investigating how to get the power grid off the public internet; exploiting advanced communications like 5G and LTE for highly secure

As more of our critical infrastructure is connected, wireless security is increasingly important.

smart grid requirements; fielding advanced cyber and network security schemes like blockchain and quantum key distribution; exploring techniques to minimize attack surfaces in the internet and the internet of things (IoT); and enhancing grid state monitoring with advanced sensing, measurements, and escalating situational awareness.

Wireless security in the grid

ECE contributors: Vuk Marojevic, Jeffrey Reed

Efforts to modernize the power grid and make it "smarter" rely on wireless technology for collecting and communicating critical data. Today's communications technology will evolve into 5G technology or be replaced by new systems. Since wireless devices use the radio frequency (RF) spectrum, the smart grid is subject to RF interference.

Interference is often unintentional, but it can be used by adversaries to manipulate the system, make information unavailable, or cause information delays. Reed and his team are investigating the new 5G low-latency physical layer (PHY) security that will be needed by the power grid.

They are identifying key security threats for wireless IoT devices in the context of the smart grid, analyzing the vulnerability of 5G technology, quantifying the severity of threats based on experiments and simulation, and recommending the most effective threat mitigation.

Cyber resilience using bioinspired techniques

ECE contributors: Vuk Marojevic, Jeffrey Reed, Nistha Tandiya

In addition to preventive cyber security mechanisms, researchers are developing bioinspired resilience techniques to prepare for and mitigate a successful cyberattack—especially an attack on mission-critical infrastructure.

Bioinspired machine learning techniques, which include artificial immune system and swarm intelligence, can handle complex systems. ECE researchers are using them to analyze features from the physical layer of devices such as RF spectrum and transmitted waveforms.

"Bioinspired techniques can be implemented with limited knowledge about the problem structure, and they exhibit proactive learning, adaptability, and robustness," said Reed. "This makes them good candidates for cyber resilience problems."

Reed and his colleagues are exploring bioinspired methods to guarantee a minimum level of service, even while a system is under attack. In order to provide a system with this type of resilience, researchers have identified and are investigating four key tasks:

1. **Preparation for attacks**—understand the system and its environment
2. **Absorption phase**—guarantee a level of performance when an attack has already compromised the system
3. **Recovery phase**—restore normal functioning after an attack
4. **Evolution/Adaptation phase**—improve the system

Anomaly detection in a wireless network through RF spectrum processing

ECE contributors: Ahmad Jauhar, Vuk Marojevic, Nistha Tandiya

Although the critical applications that support the military and automated industries are designed with encryption, they are not sufficiently protected against increasingly sophisticated attacks.

In order to detect attacks in a wireless network, ECE researchers are designing a hybrid technique that combines misuse detection and the anomaly detection scheme. Misuse detection systems recognize and report the signature of certain attack patterns, but they can't identify a new kind of attack with an unknown signature. An anomaly detection scheme, which differentiates between self (normal) and non-self (abnormal) behavior of the system, overcomes the drawbacks of the misuse detection system—albeit with more false alarms and complexity.

By combining the two methods, researchers can achieve high detection accuracy for known attacks and identify unknown attacks while minimizing the false alarm rate.

> "Wireless is the new battleground for warfare and terrorism."
>
> —Jeffrey Reed

Privacy and security of geolocation database

ECE contributors: Behnam Bahrak, Sudeep Bhattarai, Jerry Park, Jeffery Reed, Abid Ullah

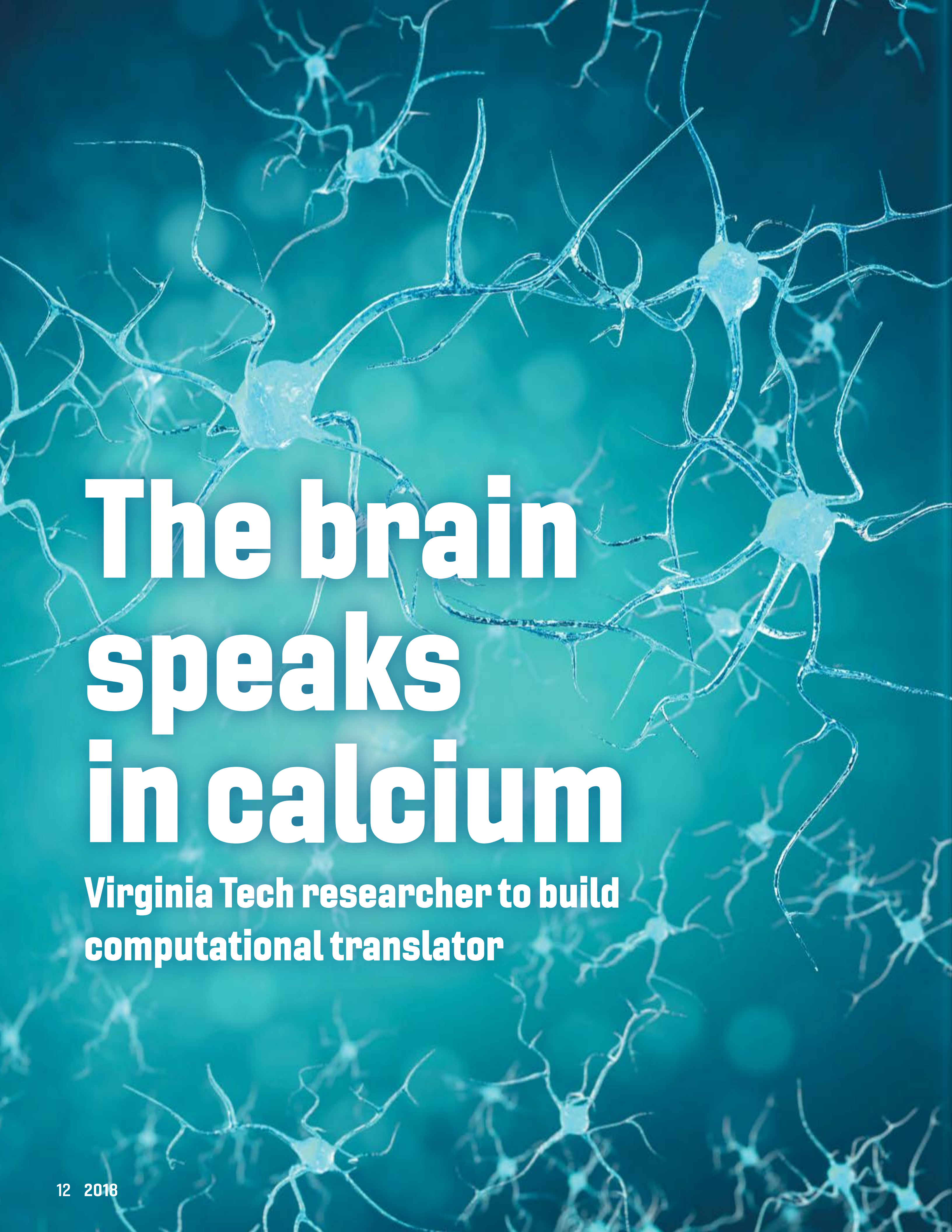
A 2012 FCC ruling proposed relying on a geolocation database of primary users' spectrum usage to allocate spectrum.

According to ECE researchers, although this method has advantages, it poses a potentially serious privacy problem: with a simple database query, secondary users may be able to determine the types and locations of primary (or incumbent) users operating in a region—violating operational privacy. Secondary users also might be able to dig deeper into the database using sophisticated inference techniques—which constitutes a database inference attack.

When the incumbents are federal government (including military) systems, then the information revealed by the databases can be serious, and possibly dangerous.

In collaboration with Motorola Solutions, ECE researchers proposed several techniques to preserve incumbent users' privacy, developed metrics to quantify the operational privacy of primary users, and the efficiency of secondary users' spectrum access.

They are also developing a proof-of-concept model to obfuscate the geolocation database content through a privacy reasoning engine and testing the system on the cognitive radio network (CORNET) testbed.



The brain speaks in calcium

Virginia Tech researcher to build computational translator

Behind every powerful neuron is a hard-working astrocyte—or rather, behind, in front of, over, under, and around every neuron is a network of brain cells called astrocytes.

While astrocytes are known to protect and support the brain, researchers are still puzzling over what role they play in brain diseases such as Alzheimer's, stroke, epilepsy, and schizophrenia.

Guoqiang Yu, an ECE assistant professor, was awarded the National Science Foundation (NSF) Faculty Early Career Development Award to develop new computational tools to interpret and analyze astrocyte activity data.

Decoding chemical communications

New research has shown that astrocytes are more actively engaged in brain processes than anyone knew, said Yu. They "listen to and proactively regulate neurons," explained Yu, and yet how they do this, and the impact they have on normal and pathological brains, is still unclear.

Unlike neurons, astrocytes do not generate electrical impulses. They communicate with each other and with neurons using chemical signals—specifically waves of calcium ions, which aid in the formation and function of synapses, the connections between neurons.

Although recent biotechnological advances have enabled scientists to monitor astrocyte interaction with unprecedented resolution, the immense scale and complexity of the data calls for rigorous computational modeling.

At present, researchers studying astrocyte activity must rely on a human studying time-lapse images and manually tracking regions of interest. According to Yu, this not only limits the scope of analysis, but also causes researchers to miss important information encoded in the mountains of complex, dynamic data.

A communication mystery

"There are no available models that can precisely characterize how astrocytes interact with each other and with neurons" and progress in astrocyte-based brain therapy has slowed as a result, said Yu.

Yu and his team have set out to correct this by developing the first data-driven model of astrocyte activity to automatically detect calcium signaling events, and then model and quantify them.

Real-life data

To meet the growing demand for analysis in action, Yu and his team will be applying the model to images of astrocyte activity in the brains of live mice.

"Any information researchers can glean about the processes taking place in a living organism will be richer and more complex than what we see in culture or brain-slice data," said Yu.

This data-based foundation will help researchers interpret astrocyte communication, and Yu hopes it will serve as a springboard for scientists pursuing new treatments for brain disorders.

Beyond the brain

Because the project will be grappling with computationally challenging problems, Yu can see broader potential applications and plans to package the computational tools he develops for use by other researchers.

"As we construct new statistical models and develop powerful generic machine learning theory and algorithms, what we generate may prove valuable for the community of computer science."

Yu's team has already published several algorithmic innovations developed during preliminary studies. All source code will be available through public open-source hosting websites, so that anyone can modify and tailor the code to their specific application and need.

Outreach and education

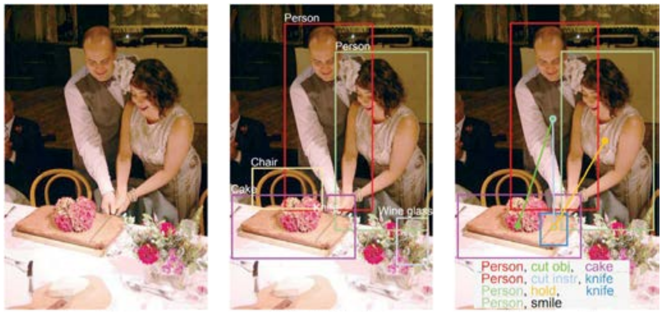
Yu's strategy will incorporate cutting-edge computational neuroscience problems into the engineering curriculum, improve the recruitment and retention of women and minority students, and create new opportunities for undergraduates to choose computational neuroscience as a career.

"Any information researchers can glean about the processes taking place in a living organism will be richer and more complex than what we see in culture or brain-slice data."

—Guoqiang Yu

Machine learning & cognition

While more applications and technologies are integrating machine learning, fundamental issues remain with how machines make decisions, adapt decision-making based on experience, and function more like a human brain.



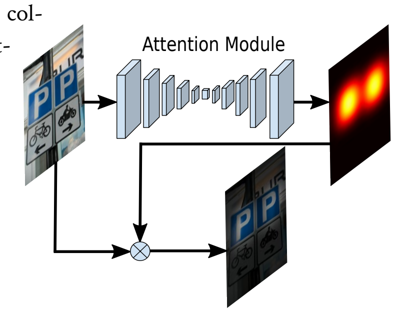
Input image Object detection HOI detection

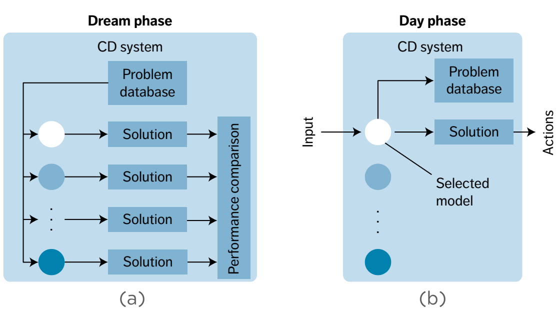
Detecting human-object interaction in images

For computers to understand what's happening in a visual scene or image, they need to recognize how humans interact with surrounding objects. We are tackling the challenge of detecting human-object interactions, which will take us a step closer to a fine-grained visual understanding of human activities.

Machine learning techniques to objectively detect ADHD

We are analyzing multi-channel electroencephalogram (EEG) data to discern the brain wave patterns associated with ADHD (attention deficit hyperactivity disorder). Using machine learning approaches on a small homogeneous dataset, we have been able to classify ADHD versus non-ADHD with very high accuracy. While this is a promising start, these approaches need to be applied to a much larger, non-homogeneous dataset in order to ascertain usability. Together with colleagues from the Department of Psychology, we are working toward establishing a large ADHD database so that our machine learning approaches can be refined and extended.





Depiction of the flow of information in (a) dream and (b) day phases. Input is presented only to the selected model in the day phase, which presents a solution and stores the problem for use while dreaming. The dream phase presents stored problems to all models to see which performs best.

Computational dreaming

Dreaming may be the key to understanding how the brain enables massively higher levels of parallelism than are found in computers, as well as how creative processes occur in the brain. We are focusing on the brain's ability to build and hypothesis-test potential strategies in nearly perfect parallelism, so that real-time (awake) usage models may be optimized. Computational dreaming (CD) is a meta-algorithm for cognition, and we have developed a maze-solving CD simulator that is about seven times superior to random model selection. Our work shows that CD tends to rediscover known maze-solving algorithms on its own, developing them from primitive moves to complete enumeration combined with a dream phase.

Bioinspired artificial systems design

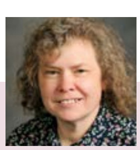
Biological systems usually perform well in the face of significant uncertainty, and ECE researchers are drawing on these systems, especially their control functions, to design artificial systems. We are investigating the theory of active inference, which seeks to explain a wide range of biological phenomena, as a means of controlling nonlinear systems in the presence of uncertainty and stochastic disturbances.

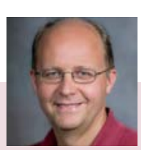
Active inference says that biological systems update a set of internal states that represent beliefs about the environment. The error between observations of the environment and predictions made from the internal states drives this process, updating beliefs about states and predictions, causing the system to act.


A. Lynn Abbott


A. A. (Louis) Beex


Jia-Bin Huang


JoAnn M. Paul

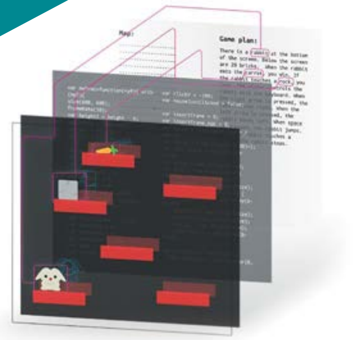

Christopher L. Wyatt

Systems software & design technology

Whether improving the speed, security, or capabilities of modern computer systems, our systems software and design researchers are leading the charge to manifest tomorrow's technologies.

Many of our research projects focus on the challenges of multicore operating systems. Because we are reaching the physical limits of semiconductors, multicore technologies are the only way to keep pace with the computing power needed by the exponential data growth we are experiencing today.

Both operating systems and software need to be able to take advantage of multiple cores, and especially multiple cores that aren't identical.



Cloud security

As we work more and more in the cloud instead of locally on personal computers, security issues are becoming increasingly obvious and dangerous. Deploying an entire desktop environment to the cloud is cost-effective, but can be risky. To mitigate those risks, we are isolating the applications into separate virtual machines, putting each application behind its own firewall while allowing them to share systems such as the filesystem for a seamless user environment.

Concurrency control abstractions, Byzantine failure model

In a project called Hyflow, we are working to understand what concurrency control abstractions can improve the programmability of multicore and distributed systems, without sacrificing performance, scalability, and dependability. A particular focus is the Byzantine failure model, which is an increasingly important security scenario for cloud infrastructures.

Heterogeneous computer architecture programmability

In the Popcorn Linux project, we are building a software stack—operating system, compiler, and run-time—that improves the programmability of heterogeneous computer architectures. The project is exploring an architecture design point that has multiple hardware cache-coherency domains, with each domain hosting cores of a different instruction-set-architecture, such as x86 or ARM.

Fast fabric networks

Borrowing technologies from networking researchers, we are exploring distributed operating system design that leverages fast fabric networks. Fast fabric networks are a network topology that spreads traffic across a mesh of tightly-woven nodes, and can open up opportunities to efficiently and tightly integrate multiple nodes into a single system.

A new way to program

Tomorrow's computer systems rely on tomorrow's computer programmers, and our researchers are working on that front as well. In a project called Game Changineer, our researchers are working on a new programming experience using natural language understanding. This method of programming still requires programmers to think logically, but allows the programming to flow like written paragraphs. Currently, the program is being piloted in K-12 classes at various schools, but the technology will ultimately be able to help programmers with anything from video games to autonomous vehicles—decreasing the opportunities for bugs and increasing their efficiency.

Concurrent data structures

When working with multiple architectures on a single processor, there are challenges at every level. One of these is a bottleneck from multiple systems trying to access key data structures concurrently, which in turn decreases the efficiency of coordinating hardware resources and applications. Our researchers are working on a new framework that will overcome this bottleneck.

Secure heterogeneous operating systems

Although making computers faster is an important research focus, we also make sure they are secure enough for critical applications. An offshoot of the Popcorn Linux project, Secure Popcorn Linux, combines a Linux kernel, application binary interface, and compiler technology to enable a running process to move between different binary architectures like x86, ARM, and MIPS. Using this combination, we can substantially mitigate or eliminate code reuse and hardware based side channel attacks. It also migrates the effects of information leak vulnerabilities.

Changwoo Min

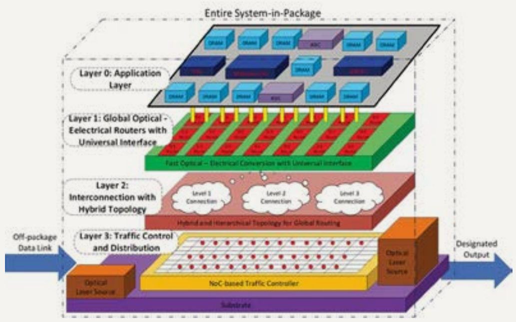
Michael S. Hsiao

Binoy Ravindran

Pierre Olivier

Secure embedded systems

As embedded systems take on larger roles in our lives, security is becoming a major concern–not only because the stored information is sensitive, but also because critical systems like vehicles and power plants have hefty consequences of failure. ECE researchers are tackling security of embedded systems on multiple levels.

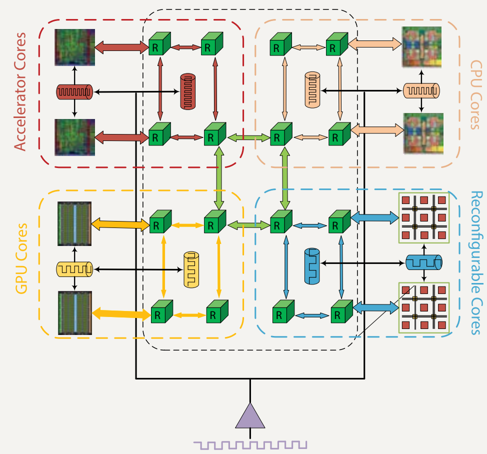


Semi-automation of emergency response systems

ECE researchers are designing a semi-automated, efficient, secure emergency response system that will provide guidance on the best action to take in an uncertain, potentially dangerous traffic situation. In some cases, the system will even take the appropriate action without human intervention. The system helps reduce the time needed for emergency vehicles to reach their destinations, while increasing the safety of non-emergency and emergency vehicles alike. We are also taking a real-time system approach to design efficient runtime algorithms to provide maneuver guidance to automated vehicles in both highway and urban settings.

Resource management of real-time embedded systems

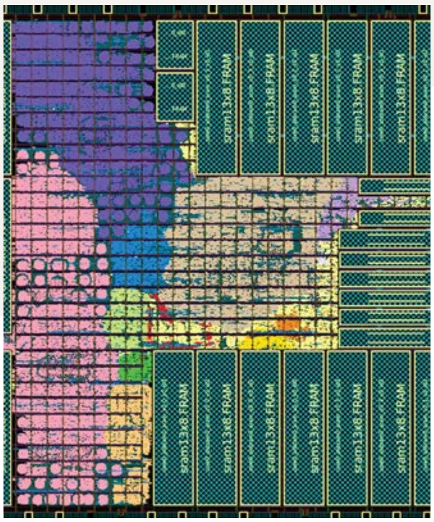
ECE researchers are deriving real-time task models that capture the dependencies between the physical environment state and timing parameters, and allow for tighter, less pessimistic timing guarantees. We have found that it is possible to make resource management decisions quickly without impacting accuracy, thus enabling the design of systems with size, weight, and power constraints.

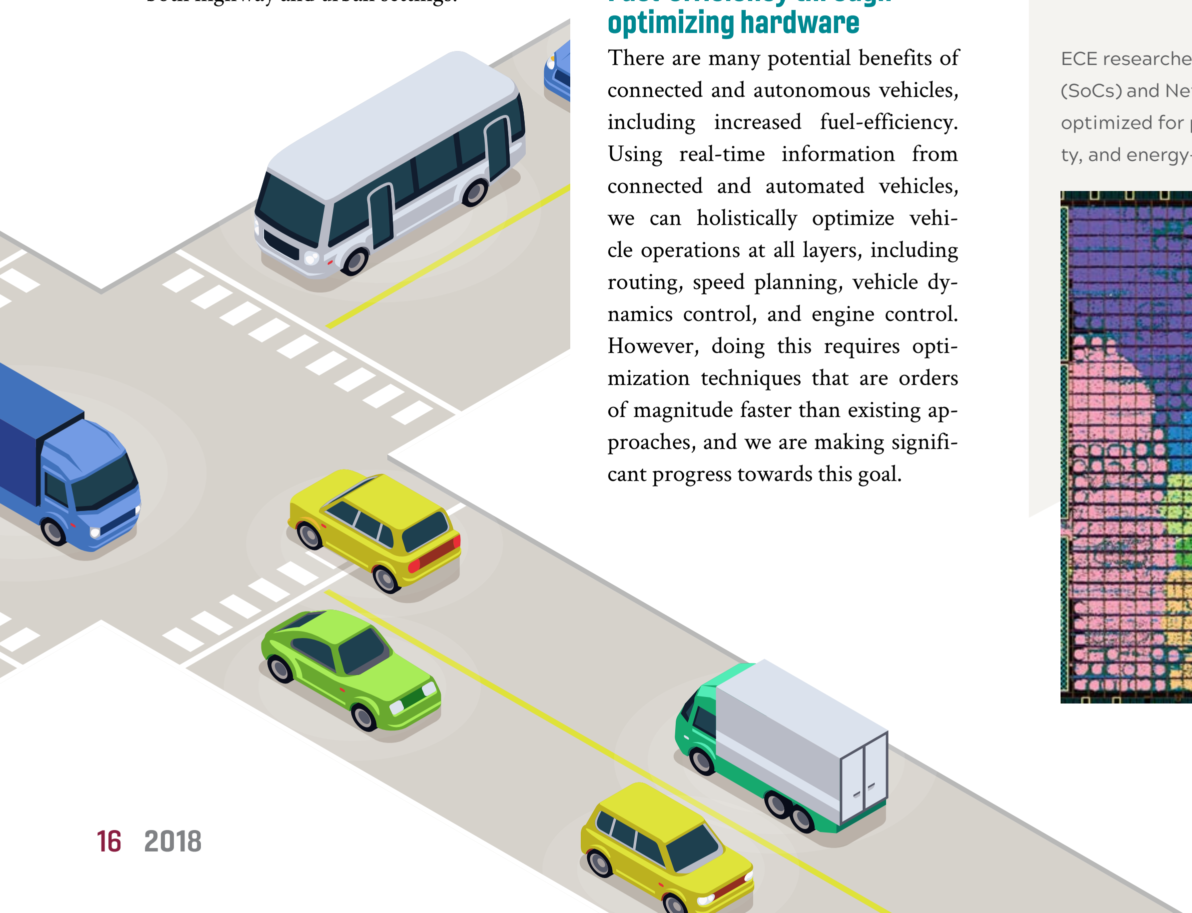


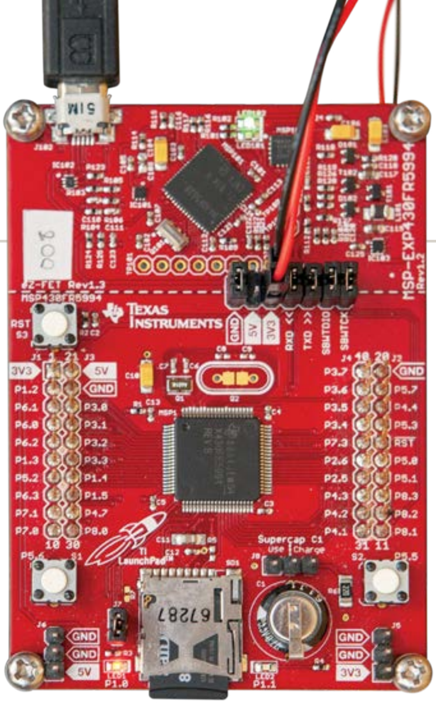
Fuel-efficiency through optimizing hardware

There are many potential benefits of connected and autonomous vehicles, including increased fuel-efficiency. Using real-time information from connected and automated vehicles, we can holistically optimize vehicle operations at all layers, including routing, speed planning, vehicle dynamics control, and engine control. However, doing this requires optimization techniques that are orders of magnitude faster than existing approaches, and we are making significant progress towards this goal.

ECE researchers are creating Systems-on-Chip (SoCs) and Networks-on-Chip (NoCs) that are optimized for performance, reliability, security, and energy-efficiency.







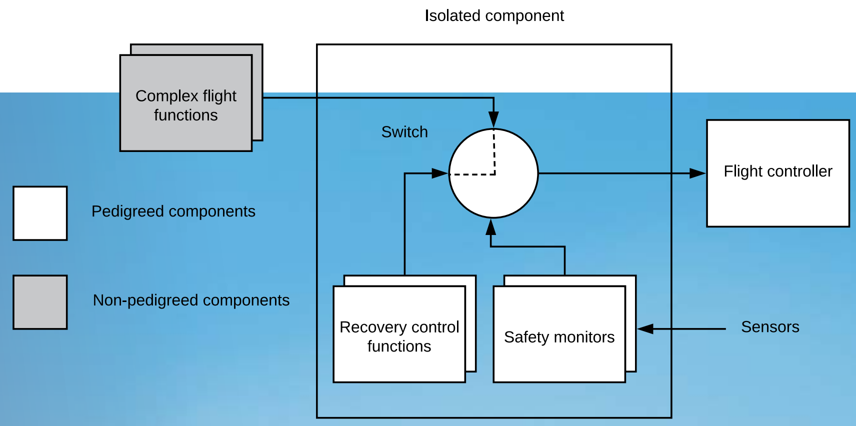
Low-cost security on reconfigurable platforms

With the rise of the Internet of Things, the need is growing for secure devices in small packages—which can be more vulnerable to certain kinds of attacks. One project investigates common hardware attacks, such as side-channel and fault injection attacks, on reconfigurable platforms like field programmable gate arrays (FPGAs), Systems-on-Chip (SoCs) and microcontrollers. We are then designing low-cost countermeasures to secure sensitive information.

Tamper-resistant hardware

Our researchers are developing a platform for tamper-resistant embedded software, focusing on two forms of hacking that target the processor hardware. Side-channel analysis exploits the physical effects of computing as a means to extract internal, secret details. Fault injections probe the processor hardware for similar internal details. Our technique creates multiple virtual processors in a single physical platform. The resulting software will be resistant to both attacks. The platform will also demonstrate novel logic minimization algorithms.

Another project involves a custom microprocessor chip that can detect hardware tampering. This chip is designed for embedded, portable devices that a hacker can physically manipulate, such as a chip-enabled credit card or mobile phone. This chip will detect tampering and can be programmed to actively respond to it.



Replacing human oversight

Our infrastructure is relying more and more on autonomous systems and machine learning. Machines, however, don't always react predictably to scenarios they've never encountered before. Before our systems can become fully autonomous, we need assurance that they won't fail. ECE researchers are working on multiple ways to provide this assurance at the hardware level for applications such as unmanned vehicles.

One project focuses on unmanned aerial vehicles (UAVs) where we use a system, independent of the control systems for the UAV, to monitor all communication between the flight controller and sensors to enforce a virtual cage.


Paul K. Ampadu


Thidapat (Tam) Chantem


William Diehl


Ryan M. Gerdes

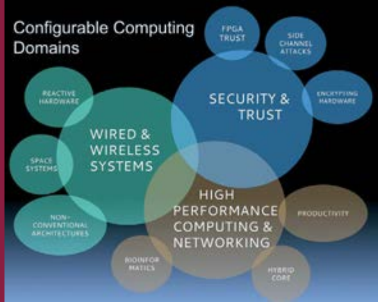

Leyla Nazhandali


Cameron D. Patterson


Patrick R. Schaumont


Haibo Zeng

Pervasive & configurable computing



With everything becoming "smart," we're continually asking computers to become more versatile. From making embedded devices that are able to do more with less real estate to embedding sensors and devices in unlikely places, ECE researchers are rising to the challenge.

Efficient, flexible software-defined networking

Configurable computing can enhance the agility and maintenance of software-defined networks, reducing the burden of computation and state maintenance on individual network nodes. This increases the number of useful acquired statistics in the network without disrupting normal network operation. We can improve productivity by automatically generating state sharing logic in the network and communicating new pieces of information to nodes where they are required. Software-defined networking makes computing systems more agile and flexible, and easier to analyze and debug.

Wearable technology

Using electronic textile technology, we are developing a wearable system for children with mobility impairments. The garment provides actuation technologies to directly assist movement and includes soft sensors that are directly integrated into the fabric. The sensors provide feedback and monitoring for the system, determining how well it functions and improves movement in everyday life.


Peter M. Athanas


Mark T. Jones


Thomas L. Martin


Paul E. Plassmann

Antennas & propagation

Whether designing antenna arrays for the next generation of wireless communication or studying phenomena in space with radio telescopes, ECE researchers are improving the methods and technology of signal propagation to transmit and receive information clearer, farther, and more accurately.

Array synthesis

Antenna arrays are capable of producing highly directive beams, a property which enables radars, communication systems, and high-resolution imaging. ECE researchers developed an array synthesis technique, which is particularly suitable for very large arrays for the 5G wireless communication systems. These arrays can meet design requirements such as half-power beamwidth (or directivity) and side lobe level without any limitation. The synthesis method provides a general approach to finding element currents.

Cognitive beamforming

Future millimeter-wave mobile communications networks will likely employ beamforming arrays, which contain hundreds to millions of elements at both the transmitting and receiving ends. A principal difficulty in such networks is initiating and maintaining beam alignment, a problem exacerbated by blockages along the line of sight. ECE researchers developed a technique to construct a map indicating the likely locations and geometry of blocking objects.


Steven W. Ellingson

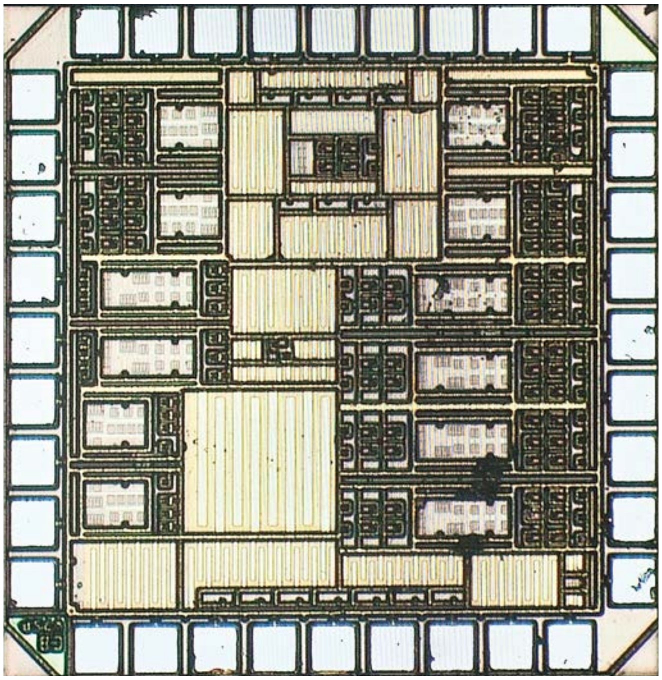

Majid Manteghi


Ahmad Safaai-Jazi


Amir I. Zaghloul

Multifunctional integrated circuits & systems

Research in multifunctional integrated circuits and systems has a tangible impact on our daily lives. Most high-performance electronic devices–computers, smart phones, multimedia, and entertainment devices–are constantly being updated to incorporate the newest technology. ECE researchers are pushing toward the next generation of high-performance computing, exploring microwave and millimeter-wave communications; delving into low-power devices like energy harvesters; and integrating complementary metal-oxide semiconductor (CMOS) technology, emerging nanoelectronic technology, and very-large-scale integrated circuits and systems.



A three-dimensional neuromorphic integrated circuit that mimics the human brain.

Very large-scale integrated circuits and systems

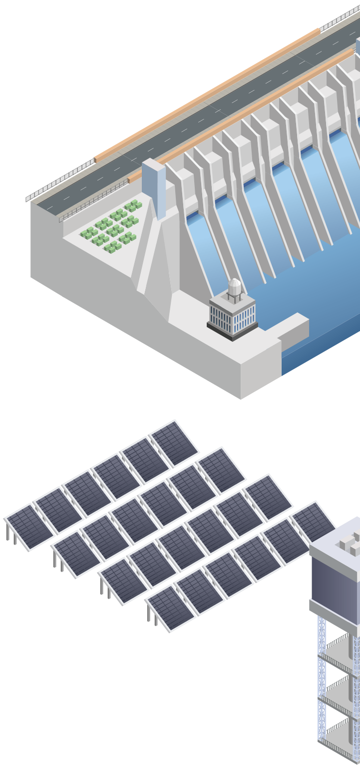
ECE research in very-large-scale integrated (VLSI) circuits and systems involves high-performance computing such as computer-aided design, artificial intelligence, and emerging nanodevices. We have been designing and fabricating analog neural chips for spiking recurrent neural networks, modeling and optimizing 3-D neuromorphic computing integrated circuits, designing and analyzing the energy-efficient circuits for green computing and renewable energy systems, and exploring the application of neuromorphic computing and deep learning to wireless communication and cybersecurity.

Terahertz RF ICs

Recent ECE research in radio frequency integrated circuits has been exploring terahertz integrated radio and radar systems as they apply to wireless communications, biological and chemical molecule sensing, and safety and security applications. We are also pursuing digitally-enhanced RF design techniques to improve performance, power efficiency, and multi-functionality.

Energy harvesting

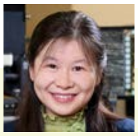
ECE researchers are investigating ways to prolong and source battery life with devices that gather and store the energy generated by everyday occurrences. These energy harvesters are integrated circuits powered by solar energy, thermal energy, vibrations, water flow, and hand cranks. We are also investigating methods to make them more efficient—reducing the power dissipation of energy harvesting circuits while extracting the maximum power from transducers.



Dong S. Ha

Luke F. Lester

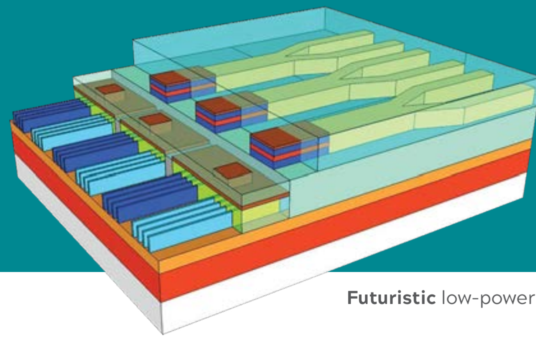
Sanjay Raman



Yang (Cindy) Yi

Microsystems, optoelectronics & devices

The small-scale matters, whether it's small devices to keep workers safe in the field or extending the physical limitations of silicon transistors. ECE researchers work with the materials that make up our technology–developing new devices to improve our world, then making them better, faster, and smaller.



Futuristic low-power chip on silicon

Additive manufacturing of power magnetics

Inductors and transformers are essential to switch-mode power converters. They are large, heavy, and difficult to integrate in a power converter. Traditional manufacturing often requires pressing, heating, shaping, and winding, which restricts design options. Novel designs that are more efficient (lower loss) and use less magnetic material, such as uniform or constant flux density inductors, are too expensive and take too long to make by traditional means. We have developed a series of magnetic paste materials—both powder-iron and ferrite systems—and used them successfully to make inductors and/or transformers by additive manufacturing. The materials we developed allow for rapid prototyping of novel designs of the magnetic components and ease their integration in power converters.

ECE researchers developed a nanosilver paste that bonds components to circuits with very high performance. The paste is serving as a springboard for developing magnetic material pastes for additive manufacturing (3-D printing) of components.

Packaging of wide bandgap power modules

An ongoing research project involves the design and fabrication of WBG power modules for better thermal dissipation, higher temperature capability, lower parasitics for fast switching, and improved thermo-mechanical reliability.

Heterogeneous integration of photonics and electronics on silicon

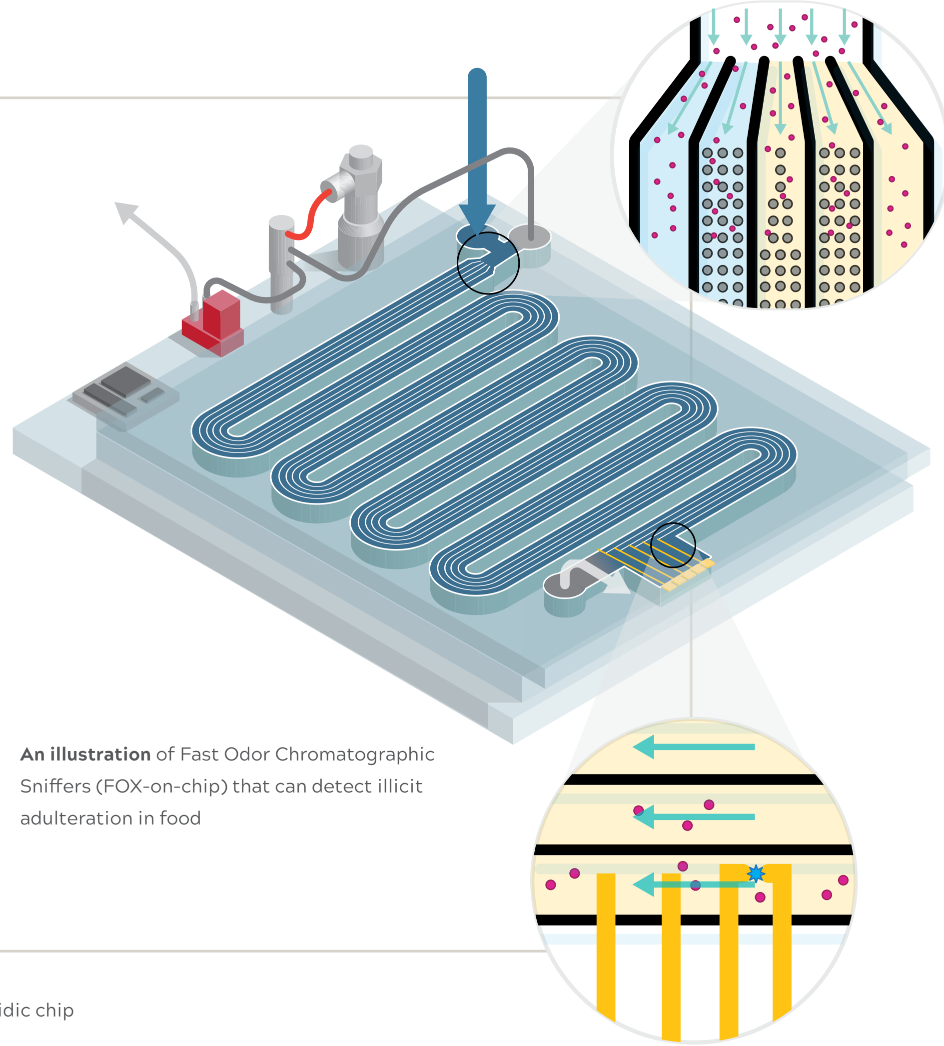
Current silicon-based CMOS technology is nearing the physical limits of its scaling potential, and increasing data rates pose a challenge to the transmission of electrical signals—while also maintaining low power consumption, low delay, and a high signal-to-noise ratio. Interconnect bottlenecks for inter- and intra-chip communication are projected to be major impediments to energy-efficient performance scaling, thus necessitating optical interconnects compatible with future CMOS process technologies. Co-integration of electronic and photonic materials and devices with Si manufacturing processes is considered one of the most promising ways to realize the potential of semiconductor compounds. ECE researchers are exploring applications of this integration in optical interconnects, chip-to-chip communication, and low-power and high-speed computing by using cheaper, larger Si wafers. Such monolithic chips will aid and enhance the everyday computing and communication experience for civilian and defense applications.

Resistive switching cell memory

Resistive switching cell memory, a non-volatile memory based on floating gate MOSFET technology, is a promising technology to supplant current non-volatile memory. In addition to having speed, scalability, density, endurance, and reliability advantages over the current floating gate (FLASH), they do not require silicon substrate. This means they can be stacked in multiple layers in the CMOS metallization, allowing for high densities. They can be placed directly above the logic area, solving the so-called latency problem. ECE researchers are manufacturing the resistive switching devices, and then electrically characterizing them in an effort to understand the basic mechanisms governing their behavior. We are exploring this technology as it applies to memory and neuromorphic applications.

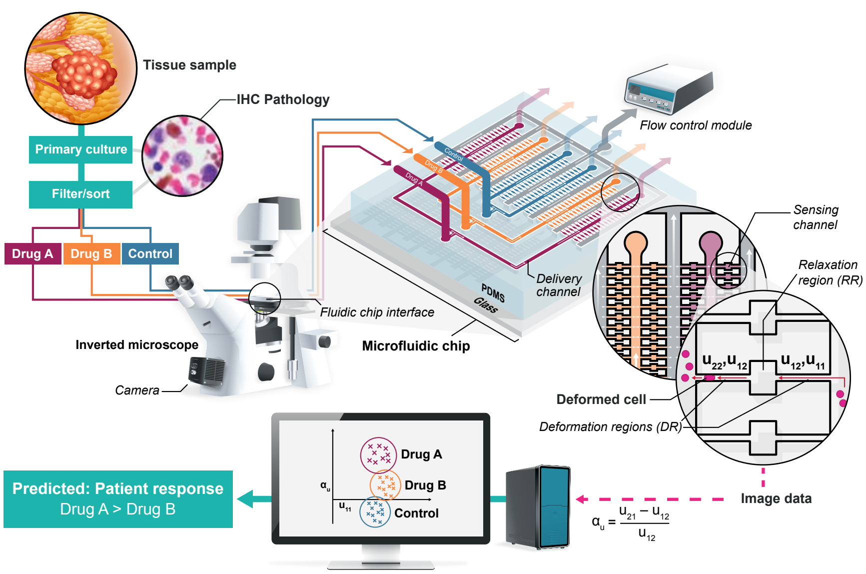
Micro-analytical chemistry

The Microelectromechanical Systems (MEMS) Laboratory at Virginia Tech has been at the forefront of research to develop a field-portable micro gas chromatography system comprising low-power MEMS components including preconcentrators, gas separation columns, and detectors. These systems for on-the-spot analysis of complex gaseous samples, like the air we breathe, can capture analytes even at very low concentrations and then separate and identify the presented compounds through a chromatographic mechanism. We are working on an NSF-funded project to develop Fast Odor Chromatographic Sniffers (FOX-on-chip) that can detect illicit adulteration in food by parallel analysis of the mixture through microfluidic channels and subsequent autonomous data. In line with this project, we are demonstrating the concept of digital chromatography or digital smell. The primary concept is to create electronics signatures (barcodes) for odors (smells) that can be synthesized in a distant location.



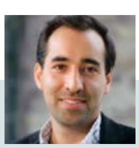
An illustration of Fast Odor Chromatographic Sniffers (FOX-on-chip) that can detect illicit adulteration in food

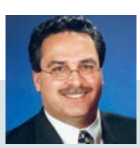
An illustration of a microfluidic chip



Microfluidics for cellular analysis

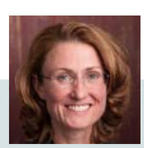
Through collaboration with hospitals and biomedical research communities, we are developing microfluidic channels that can decipher bioelectrical and biomechanical properties of living cells, looking for abnormal cells through alteration in their biophysical signatures. We are analyzing normal and cancerous breast cells, and we find biophysical cues that can be used for early cancer diagnosis or for assessing the efficacy of chemotherapeutic regimens. We are also investigating the sparsely concentrated circulating tumor cells in the blood of cancer patients through microfluidic constructs with on-chip electrical impedance outputs. Initial results using spiked cancer cells in mouse blood samples have shown the feasibility of our approach.

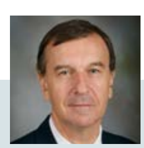

Masoud Agah

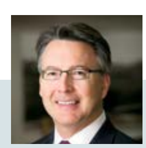

Louis J. Guido


Mantu K. Hudait


Guo-Quan (G.Q.) Lu

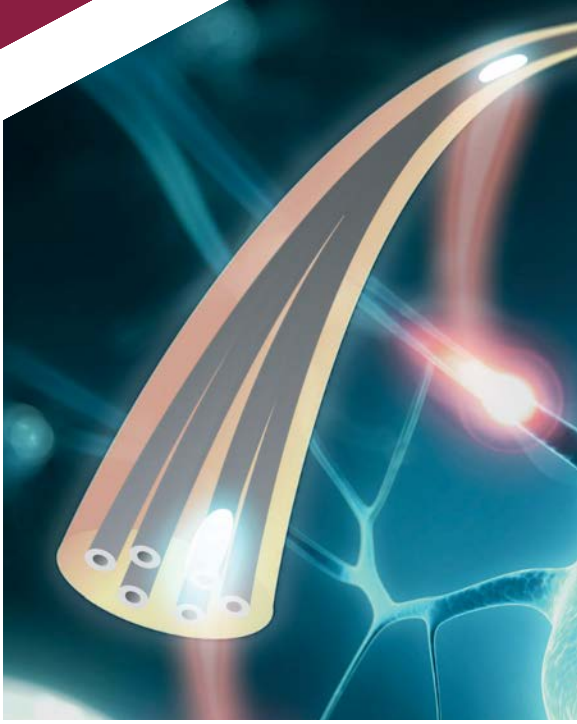

Theresa S. Mayer


Marius K. Orlowski


Timothy D. Sands

Optics & photonics

ECE research in optics and photonics seeks to better understand and exploit the physics of light to see (and interact with) conditions within biological tissue–including living cells and the human brain–and harsh conditions, like nuclear power plants.

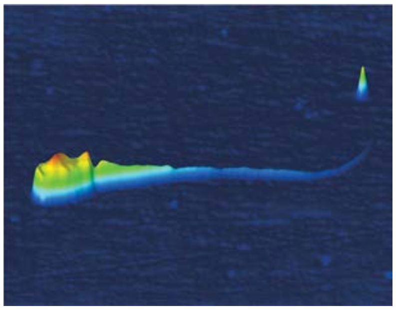


Carbon nanofiber-based electrodes for miniaturized, biocompatible in vivo neural interfacing.

Quantitative phase imaging

Conventional phase-contrast and differential interference contrast microscopy have long been indispensable in biology for examining unstained specimens. They are, however, inherently qualitative. Quantitative phase imaging (QPI) is a technique capable of providing the accurate cellular data used to develop effective metrics that permit accurate assessment of disease and treatment response. It has been applied to a variety of live cell imaging studies. ECE researchers are investigating QPI systems using novel spectral interferometry techniques.

A recently developed technique, spectral modulation interferometry (SMI), modulates sample information onto a spectrally oscillating carrier via optical interferometry. A single spectrum contains a continuous set of spatial, temporal, or spectroscopic information. SMI offers high-sensitivity, speckle-free phase images and presents a way to accurately quantify the dynamic behaviors of live cells.



A live sperm cell imaged by a quantitative phase microscope using spectral modulation interferometry. The sperm head, neck, midpiece and tail are clearly imaged with high sensitivity. Such quantitative information may be used to assess the health status of the sperm for screening purposes. The image is one frame of a dynamic video that captures the swimming motion of the cell at 200 frames per second.

Flexible, biocompatible fibers for brain implants

ECE researchers are developing flexible, multifunctional, biocompatible fibers for electrical, optical, and chemical communication with neural circuits in the brain. This technology will advance the fundamental understanding of neural circuits related to behavior by manipulating and monitoring single cell or small neuron group activities in the 3-D circuits. It can also lead to new therapeutic strategies for treating neurological disorders, including closed-loop treatment of epileptic seizures and brain tumors. We are developing flexible fibers and fabrics for distributed pressure sensing and interrogation of neural circuits in animal brains. We also have developed the first carbon nanofiber-based electrodes in fibers for miniaturized and biocompatible neural interface.

Nano-enabled photonics-electronics

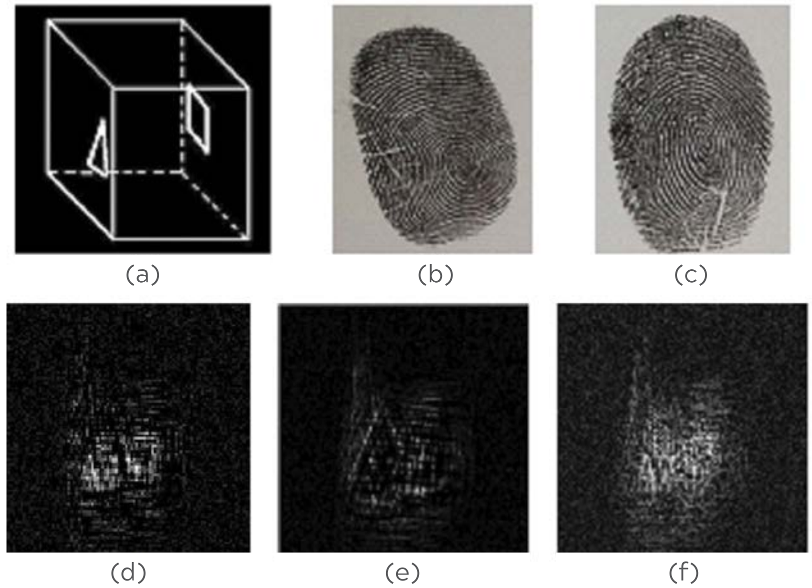
ECE researchers have been designing, manufacturing, and investigating nano-enabled photonics-electronics devices and systems (NePEDS). We are using this technology to target applications in health assessment, monitoring, and interventions; solar energy harvesting and conversion; and optoelectronics information technology.

Spectral interferometry techniques for microscopy

Converting today's microscopes, whose main goal is to offer visualization, into full quantification tools would allow new applications for scientists and commercial users. But in practice there are many challenges due to the multiple modes a microscope supports, including phase contrast, differential interference contrast, and polarized light. Special hardware is required to convert these modes into a quantitative tool, making integration difficult and expensive. ECE researchers are developing low-cost, highly integrable techniques via spectral interferometry that can be added to commercial microscopes via a compact accessory.

Ultrahigh temperature sensors

ECE researchers have been developing a sensor system based on a reduced-mode single crystal sapphire optical fiber and serial sapphire fiber Bragg gratings (FBGs). We have demonstrated the use of these FBGs for ultrahigh temperature sensing up to 1500° C, built and field-tested a prototype sensor system at the Virginia Tech Power Plant, and demonstrated the operation of acoustic FBGs in a single mode acoustic waveguide. This new technology holds significant promise for distributed sensing of strain, temperature, pressure, and corrosion in the extreme conditions present in nuclear power plants.



A figure showing (a) a 3-D object to be encrypted, (b) message sender's fingerprint (c) message receiver's fingerprint, (d) real part of encrypted complex hologram, (e) imaginary part of encrypted complex hologram, and (f) intensity distribution of the encrypted hologram.

Optical scanning holography

Standard digital holography employs a 2-D sensing array, such as a charge-coupled device (CCD), to capture holographic information. However, these methods are restricted by the finite size of the pixel elements in the 2-D array, leading to problems with image resolution, limited field of view, and remote sensing applications. We have been studying a single-pixel digital holographic technique (called optical scanning holography) in which 3-D (holographic) information is acquired by 2-D active laser scanning. Potential applications of the technique include holographic TV, 3-D coding and decoding, 3-D holographic microscopy and 3-D optical remote sensing. In computer-generated holography, intensive computation often causes bottlenecks, and we are also developing rapid algorithms for 3-D holographic display and holographic cryptography.

Wave theory of nanoparticle scattering

ECE researchers recently developed a rigorous wave theory of nanoparticle scattering that has been experimentally applied to nanoparticle sensing. Upon illumination, an individual nanoparticle scatters the incoming light in all directions. This slightly changes the arrival timing of the original light. By measuring this timing change and its spatial pattern, we may determine the size of the nanoparticle and its orientation. These measurements are only possible because of the high sensitivity imaging techniques developed by ECE researchers. Such a quantification tool promises to characterize nanoparticle dynamics in previously impossible ways. For example, it may provide high speed monitoring of nano-assembly processes at single particle level. It may also enable 3-D position and orientation tracking of single nanoparticles for studying intra-cellular processes.


Xiaoting Jia


Ting-Chung (T.-C.) Poon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Yong Xu


Wei Zhou


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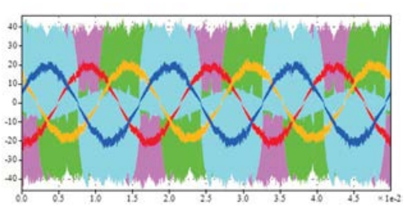
Yunhui Zhu

Power electronics

By applying novel designs and integrating new materials and topologies, researchers are making electricity conversion more efficient, more reliable, and less expensive. This, in turn, is enabling applications from electric vehicles to microprocessors to reduce the use of electricity and its impact on the environment. The Center for Power Electronics (CPES) is a former NSF Engineering Research Center and has 80 industry members. The Future Energy Electronics Center (FEEC) is noted for its work with the U.S. Department of Energy and inverters that achieve more than 99 percent efficiency.

Three-level neutral-point-clamped (NPC) topology prototype built using three interleaved power-channels attaining a power density of 120 W/in³.



Photovoltaic inverters

Power electronics advances are helping to improve the efficiency of photovoltaic (PV) systems. In a major effort, FEEC researchers are adopting wide bandgap semiconductor devices for a PV microinverter to fit into a panel junction box. The microinverter is slated to achieve ultrahigh efficiency, high reliability, low cost, and long life. Instead of the conventional kilohertz-range operation, the microinverter operates at the megahertz range. This reduces the size and potting materials of the passive components. Zero-voltage and zero-current operation will eliminate switching loss, and a two-stage design helps avoid the use of electrolytic capacitors. The size and cost reductions are important for continued commercialization of PV systems.

A CPES project recently developed an all SiC-MOSFET-based 40 kW commercial-scale PV inverter capable of operating in direct-to-line or transformerless mode. The inverter is capable of achieving 99 percent efficiency thanks to the use of triangular-conduction-mode (TCM) scheme, which ensures zero-voltage-switching (ZVS) at turn-on for all semiconductors.

ECE researchers are developing a SiC- and GaN-based high-frequency rectifier system, which is expected to cut back on data center energy consumption.

Improving data center efficiency

Due to the increasing use of cloud computing, data centers will represent 10 percent of the total worldwide electrical power consumption by 2020. The conventional AC data center power architecture has multiple stages, which cause excessive power loss in power distribution. CPES researchers are developing a SiC- and GaN-based high-frequency rectifier system that eliminates the use of a bulky 60 Hz transformer, plus several series connected power stages common in data center architecture. This will greatly reduce power conversion loss. Copper use will be reduced by 90 percent, and distribution-related conduction loss will be reduced by a factor of 10. The proposed system is expected to save more than 15 percent of data center energy consumption.

Electric vehicle chargers

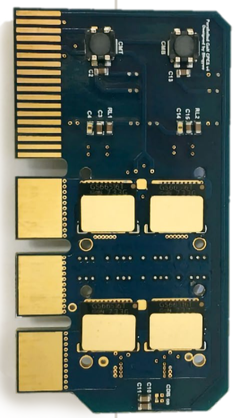
Onboard chargers for electric vehicles (EVs) typically operate at less that 94 percent efficiency and low power density using silicon devices with very low switching frequencies. ECE researchers are developing a high-voltage (11 kW) bi-directional onboard charger to achieve more than 96 percent efficiency. With the help of high frequency operation, the charger will be well-suited for manufacturing automation, reducing the overall cost.

In another project, a team is developing an extremely fast recharger for EVs. In order for recharging times to be similar to refueling times for gasoline-powered autos, the charger must be at least 400 kW. Conventional fast chargers are 50 kW, and the Tesla maximum is currently 120 kW. The CPES team is developing a novel, compact, scalable, solid state transformer-based 400 kW extremely fast charger. The project will also provide a user-friendly DC voltage interface to external renewable generation systems and an Energy Storage System.

ECE researchers are developing a high-voltage, bi-directional onboard electric vehicle charger to achieve more than 96 percent efficiency.

Exploring material boundaries

Exploring the boundaries that new GaN devices have in terms of power handling capability, CPES has developed an ultra-low-inductance 650 V 100 A switching cell using two paralleled 650 V 25 mΩ GaN e-HEMT devices with top-side thermal metallization from GaN Systems. This LLC converter demonstrated an efficiency exceeding 98 percent and a power density of 131 W/in^3 (8 kW/L).



Voltage regulators go mobile

Voltage regulators have been widely used in computing system to deliver power from energy sources, such as a battery, to microprocessors. Today's voltage regulator is usually constructed using discrete components and assembled on the motherboard. The discrete passive components, such as inductors and capacitors, are bulky and occupy a considerable footprint on the motherboard. An ECE team is developing a 20–50 MHz three-dimensional integrated voltage regulator for mobile devices. This will have a significant impact on power management solutions for smartphones and other mobile applications. It will help make the integrated voltage regulator a feasible approach to significantly reduce mobile devices power consumption, extending battery life and reducing electricity consumption.

Dushan Boroyevich

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Dong Dong

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Fred C. Lee

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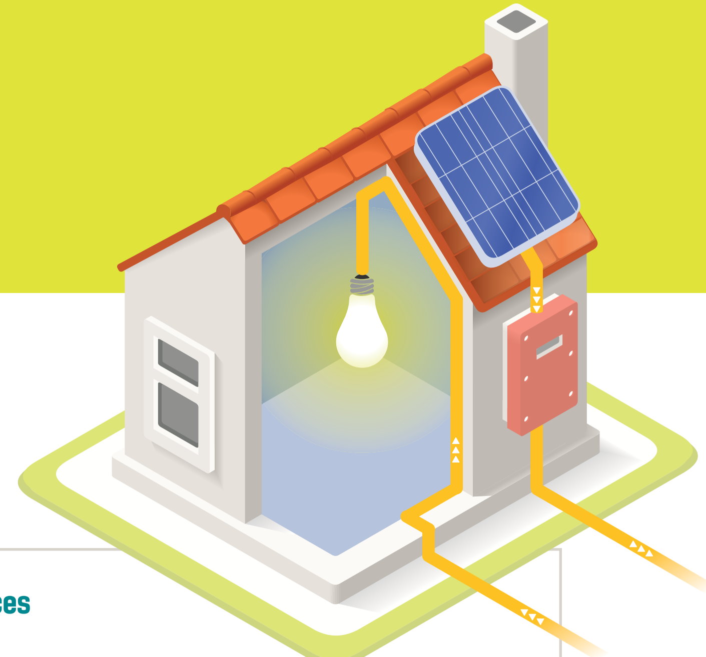
Khai D. T. Ngo

Yuhao Zhang

Energy systems

While engineers work to improve the resiliency, efficiency, and robustness of the world's electric power supplies, they are facing challenges with security, data acquisition and analysis, and integrating renewable, sometimes random, energy sources into a large, complex system. These challenges have opened new avenues of research in modeling, control, cybersecurity, machine learning, and communications.

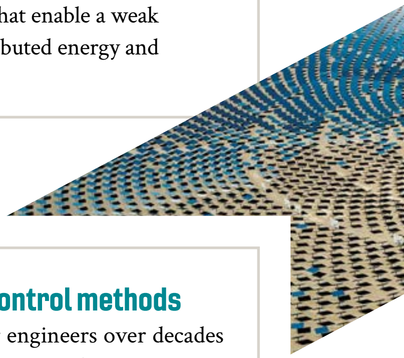


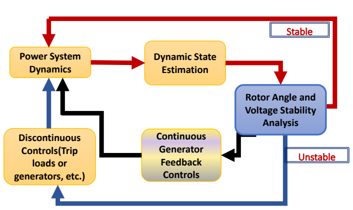
Grid probing

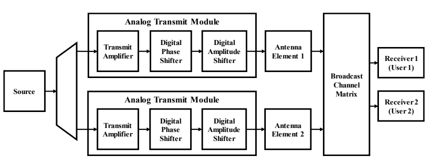
Upcoming energy technologies such as rooftop solar panels, batteries, and electric vehicles are interfaced to our AC electric power grids through AC/DC converters. These devices come with advanced sensing, communication, and control functionalities. We have shown through our grid probing project that if an electric utility can control these devices, we can determine non-metered consumption and the connectivity of the grid, which are often unknown.

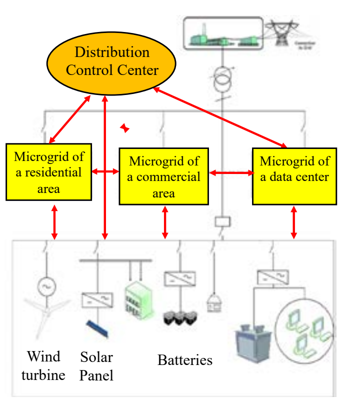
Restoring critical services with distributed energy

With funding from the U.S. Department of Energy and the Pacific Northwest National Laboratory, we are exploring the resiliency of distribution systems with respect to extreme events. The main focus is on restoring critical load/services after a catastrophic outage where the utility system is severely damaged and not available. In this situation, microgrids and distributed energy sources would be tapped to serve the critical load. We have proposed a new metric for resiliency based on the total MW-hour that the system is able to provide to critical services during system restoration. We also have developed new operation and control methodologies that enable a weak system to maintain a stable operating condition using only distributed energy and control resources.









New state estimation and control methods

The models that have aided power engineers over decades were not designed to accommodate today's massive data from new sensing devices or the random dynamics created by the growing numbers of intermittent, renewable energy sources. With funding from the NSF and the Pacific Northwest National Laboratory, we are developing new dynamic state estimation and control methods for today's grid. We have developed new dynamic estimators supported by a strong mathematical foundation that quantify the uncertainties involved with renewables and integrate them in a unified framework. We also have proposed a new voltage control scheme that minimizes the communication bandwidth requirement while exhibiting a system-wide situational awareness.

Detecting cyber intrusions of the power grid

Cyber intrusions have caused major power outages by disrupting the grid's operation and control systems. An ECE team has developed a cyberphysical system testbed to demonstrate how falsified control commands can be detected and stopped. In this project, anomalies are specified and identified for substation automation and supervisory control systems. Collaborative attacks are identified using relation-based models and algorithms. Ongoing work is to defend the supervisory control systems from attacks by falsified measurements through the communication systems of the power grid.

Machine learning for smart inverter control

We also have used tools from machine learning and big data analytics to train AC/DC inverters to behave harmoniously with each other, and improve the stability, reliability, and efficiency of our residential electric grids. Localized solutions, where each inverter operates in silo, have been ineffective. On the other hand, network-level coordination necessitates formidable cyber overhead—both in computation and communication. Leveraging advances in machine learning, we are hitting the sweet spot by using data to learn inverter control rules in an offline fashion, and later apply them in real-time with tunable cyber overhead.

Utilities are integrating solar and wind farms into their systems, which increases variability in their systems.

Taming energy variability

Solar and wind energy are highly variable. Sometimes there is a surplus of renewable energy, and we have to waste it. Other times, there is a sudden power deficit, and some electric loads have to shut down. As a possible solution, can we charge batteries during periods of surplus, and discharge batteries at deficit times? How can that be done in a smart way without knowing the upcoming surplus/deficit? What size should the battery be? Alternatively, during times of surplus, can we run pumps and push the water circulating in our city networks up to water towers in lieu of a battery? We are exploring these and other questions regarding energy variability in the grid.

Managing building energy

ECE researchers are continuing to hone the open-source software platform for building energy management systems to improve small and medium-sized building efficiency and help implement demand response.

Coupling natural gas networks with electric power systems

Decreasing natural gas prices and the capability of gas-fired electric power plants to rapidly respond to fluctuations from wind generation, both have resulted in a strong coupling between gas and electric power systems. To better capture this coupling and optimize the two energy systems in tandem, we are developing algorithmic solutions for improved modeling, optimization, and monitoring of natural gas networks.


Virgilio Centeno


Jaime De La Ree


Vassilis Kekatos

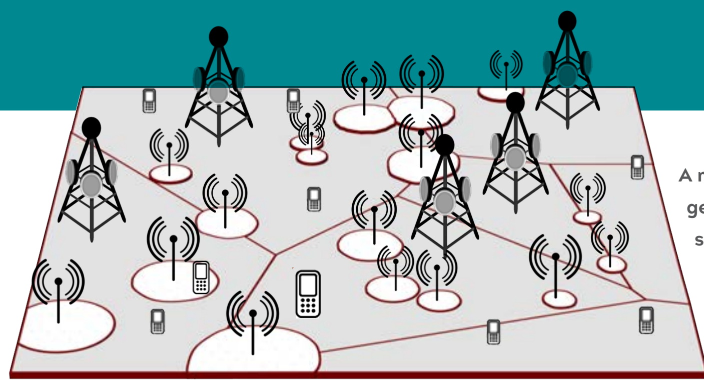

Chen-Ching Liu


Lamine M. Mili


Saifur Rahman

Networks & cybersecurity

ECE researchers in networks and cybersecurity are investigating fundamentally new techniques for the analysis, design, and optimization of large-scale communications systems; advancing performance limits of internet of things (IoT) systems through optimal coordination of algorithms across multiple layers; developing innovative solutions to complex science and engineering problems arising from wireless IoT; exploring brain-inspired computing; and enabling the vision of smart, connected, and secure cities of the future.

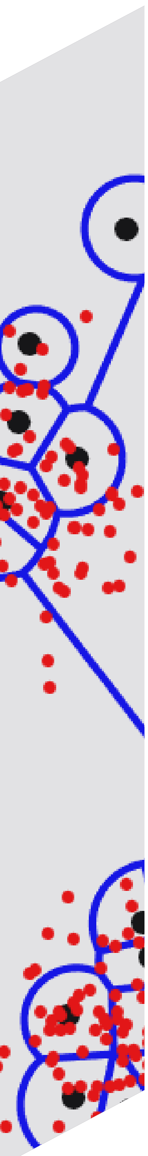


A new stochastic geometry-based spatial model for heterogeneous cellular networks.

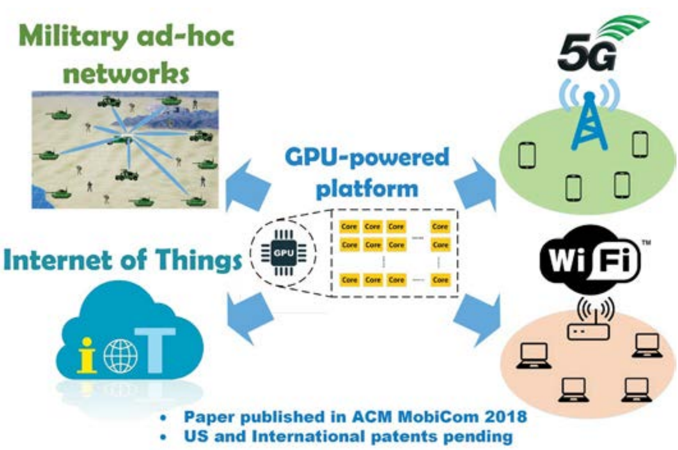
Stochastic geometry-based analysis and design of communications systems

ECE researchers are pioneering a fundamentally new analytical approach to the analysis and design of communications systems that not only captures the current deployment trends accurately, but also facilitates analysis leading to simple and easy-to-use expressions for key performance metrics.

This approach, based on random spatial models, has been applied to the design of different types of wireless communications systems, including heterogeneous cellular networks, vehicular networks, drone-assisted communications networks, energy harvesting communications, and device-to-device communications. Instead of considering network elements as deterministic, we endow them with a probability distribution. The added randomness allows us to use powerful tools from stochastic geometry for performance analysis. This approach has also been useful in areas outside communications, such as smart and connected communities and geolocation.



A new model for heterogeneous cellular networks using Poisson cluster processes.



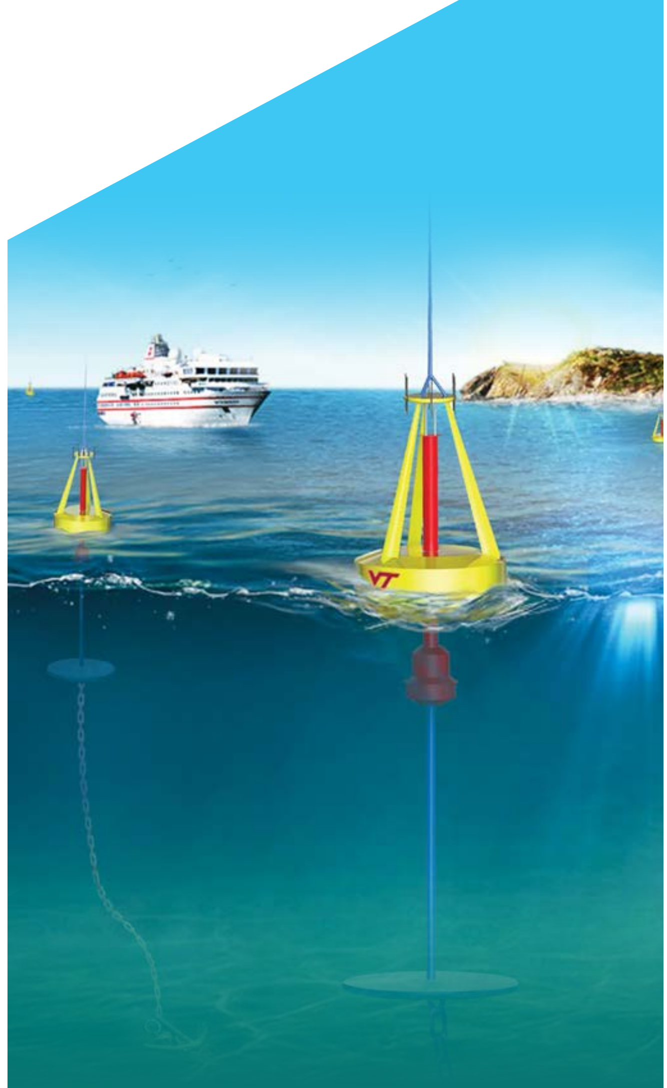
By employing intensification and random sampling techniques, ECE researchers are able to select a subset of sub-problems to match a given number of processing cores in a Graphical Processing Unit (GPU) for independent and parallel processing.

5G New Radio

As the next generation of cellular communication technology, 5G New Radio (NR) aims to cover a wide range of service cases, including broadband human-oriented communications, time-sensitive applications with ultra-low latency, and massive connectivity for the IoT.

NR is likely to operate on a higher frequency range than LTE, with much shorter coherence time. 5G NR is also expected to support applications with ultra-low latency. With such diverse service cases and channel conditions, the air interface design of NR must be much more flexible and scalable than that of LTE.

In our recent work, we invented an NR scheduler that can meet the stringent (~100 μs) time requirement that allows 5G NR to cope with the extremely short coherence times and support ultra-low latency applications (e.g., augmented/virtual reality, autonomous vehicles), many of which require sub-millisecond scale delay or response time.

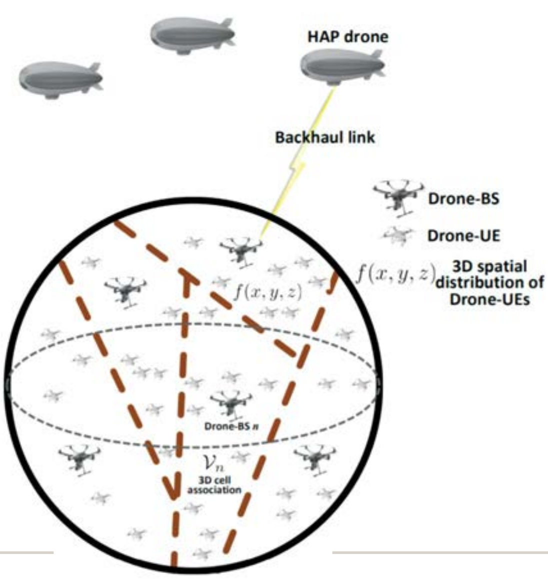


Communications, computing, and control design in smart cities

Joint design of communications, computing, and control is essential to autonomous (ground or air) vehicles in large-scale systems, such as a smart city. Our research provides the fundamental guidelines needed to equip existing communication systems for navigating and controlling autonomous vehicles. We have developed a broad range of machine learning and optimization algorithms that can be used to design fully autonomous wireless and vehicular systems, adapting their network operation to existing users, devices, and data sets.

Cellular network architecture will play a central role in providing connectivity to areas with little or no wireless connectivity, and we have designed a 3-D cellular network that can integrate drone-carried base stations and drone users and enable 5G cellular networks to support drone-based systems. We have also developed one of the first quality-of-experience (QoE) models for deploying virtual and augmented reality (VR/AR) services over wireless networks and designed a broad number of solutions for securing autonomous cyber-physical and IoT systems.

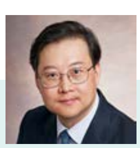
A 3-D cellular network with drone-based base stations, drone-based user equipment, and high-altitude platform drones that provide backhaul connectivity.

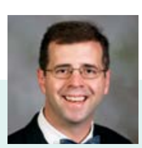


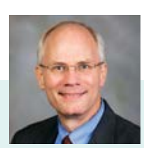
Energy harvesting for long-range maritime communications

Most existing marine communications technologies are limited and expensive. ECE researchers are working to fill the void of broadband wireless communications at sea by developing self-powered ocean mesh networks. A collection of floating base stations, or nodes, "talk" to each other to create a network connection across a large area. Once they've been dropped in the water, the base stations start to harvest energy from ocean waves and automatically form a mesh network. Users can then connect to the internet.

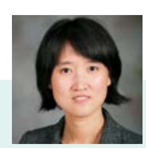

Harpreet S. Dhillon


Thomas Hou


Allen B. MacKenzie


Scott F. Midkiff


Walid Saad


Yaling Yang

Wireless & secure systems

ECE research in wireless and secure systems explores creative, efficient ways to meet the increasing demand for secure, efficient wireless access. These include dynamic methods for sharing the finite electromagnetic spectrum, authenticating cryptographic signatures, ensuring physical-layer resilience, harnessing new technology and artificial intelligence to improve wireless performance and protect wireless devices, and leveraging machine learning techniques to design the next generation of powerful wireless communication systems.

Deep learning for signal processing

ECE research is reimagining digital signal processing within the context of deep learning. By replacing signal processing logic with neural networks trained to perform the same task, we can eliminate the need for traditional serial processing, enabling significant latency and computational complexity reductions. Similarly, an entirely new world of cognitive radio is possible when the signal processing environment is built natively on top of a machine learning engine.

Vehicle-to-everything technologies

ECE researchers are studying the communications and networking requirements of V2X communication, which is the communication between a vehicle and anything that may interact with it—another vehicle, infrastructure, the cloud, or a passing pedestrian. V2X has applications in vehicular safety, efficient traffic management, and infotainment, but our research currently focuses on vehicular safety applications.

In the future, cars will be able to communicate with most aspects of their surroundings, including the roads, buildings, and other vehicles.

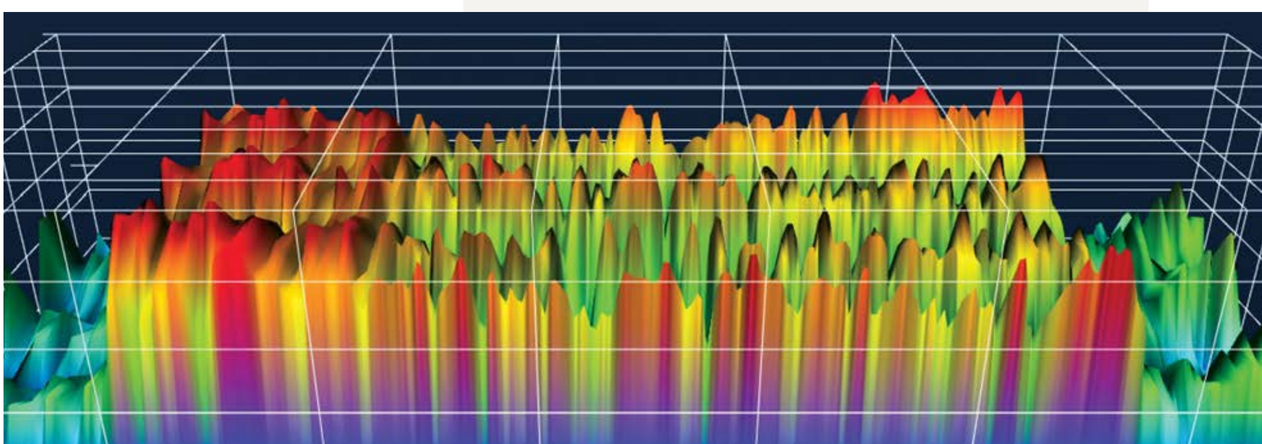
Coexistence of heterogeneous wireless access technologies in 5 GHz

As the demand for spectrum access skyrockets, 5 GHz bands have emerged as the most coveted bands for launching new wireless applications and services, and ECE researchers are devising ways that heterogeneous wireless technologies can coexist there.

CORNET expansion

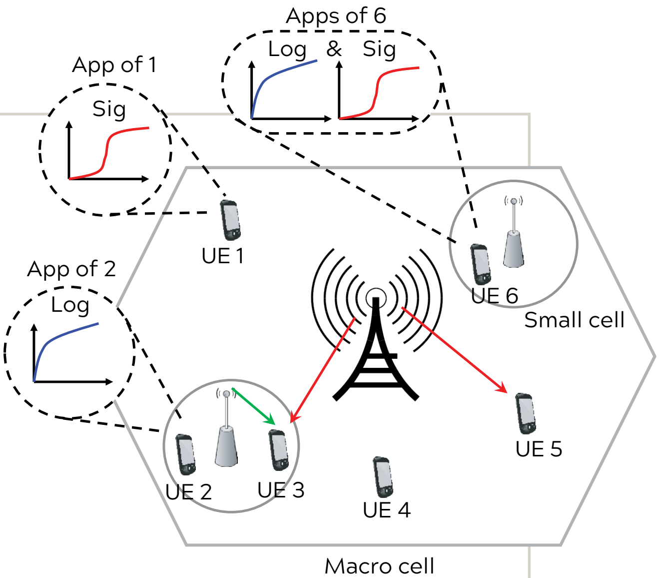
ECE investigators and colleagues will be deploying an instrumentation suite that will expand Virginia Tech's COgnitive Radio NETwork (CORNET) testbed to include airborne mobile radio frequency (RF) nodes to create an outdoor testbed for RF experimentation with unmanned aircraft systems (UAS).

Virginia Tech's COgnitive Radio NETwork (CORNET) testbed allows researchers to test sophisticated cognitive radio networks, generating the data they need to explore and optimize new technologies.

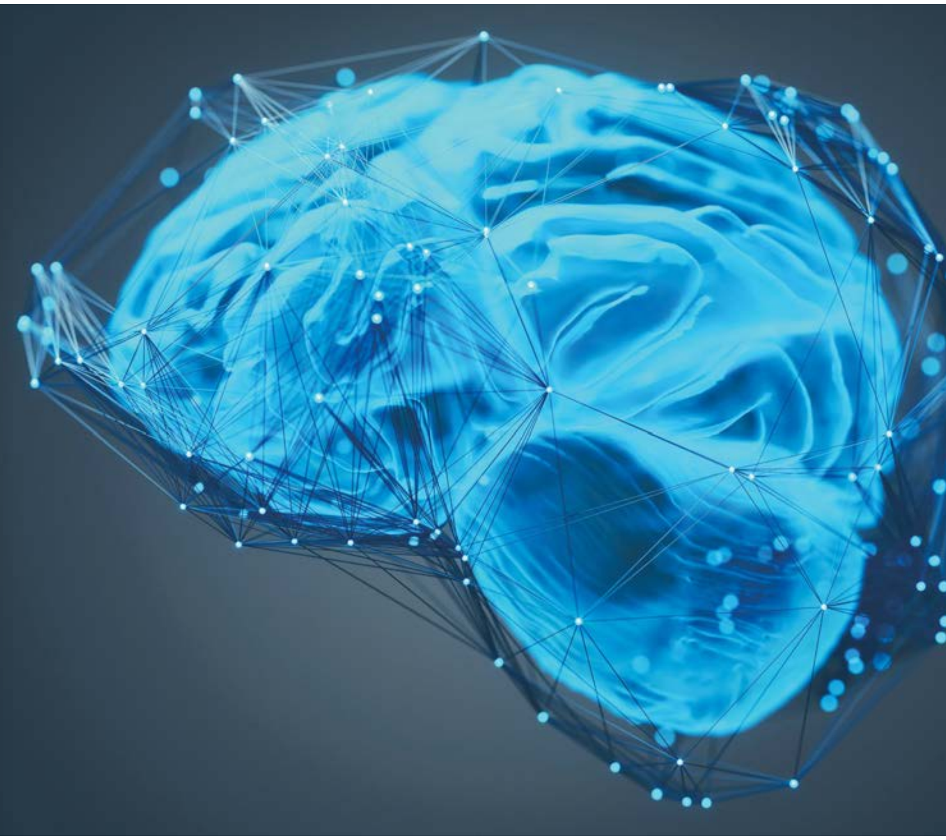


Resource allocation in wireless systems

In contested and congested environments, meeting quality of service requirements for wireless systems can be challenging. We are investigating distributed, optimal approaches to resource allocation in scenarios such as LTE carrier aggregation, radar spectrum sharing, and M2M communications for industrial control systems. Solutions range from straightforward utility maximization to secure auction techniques.



Resource allocation is challenging when considering the many users of a cellular network, like this system model with two groups of users.



Brain-inspired methods to improve wireless communications

ECE researchers are using brain-inspired machine learning techniques to increase the energy efficiency of wireless receivers by combining multiple-input multiple-output (MIMO) techniques with orthogonal frequency division multiplexing (OFDM). Using artificial neural networks, we are creating a completely new framework by detecting transmitted signals directly at the receiver, which minimize inefficiency.


Robert W. McGwier


Lingjia Liu


Jung-Min (Jerry) Park


R. Michael Buehrer


T. Charles Clancy


Carl B. Dietrich


Jeffrey H. Reed


Joseph G. Tront

Space and atmospheric science

Researchers at Space@VT study the geospace environment, including the effects of space-weather events on the structure and dynamics of the Earth's atmosphere and ionosphere. Using ground-based radar probes, sounding rockets, high-altitude balloons, and satellites, we investigate phenomena like the 2017 solar eclipse; effects of short and long duration solar variability on the Earth's upper atmosphere; upper atmospheric dynamics, chemistry and radiation; coupling phenomena between the solar wind and the Earth's magnetosphere; and polar mesospheric clouds.

To unlock mysteries of the geo-space environment, ECE researchers send experiments up on sounding rockets and develop payloads for satellites.

Radiative impacts of pollutants

ECE researchers are developing new instrumentation to observe the radiative impacts of pollutants. The new instruments are compact, robust, and suitable for implementation on constellations of satellites.

Impacts of space-weather events on the ionosphere

ECE researchers will be conducting atmospheric gravity wave studies via in-situ measurements of wave perturbations in the ionosphere and remote sensing of the middle atmosphere. These measurements can then be correlated with weather maps of the lower atmosphere, allowing for atmospheric coupling studies over a wide altitude range.

Exploring the upper atmosphere in the long polar night

A sounding rocket program is underway to explore the upper atmosphere of the Earth's polar night. This region is difficult to access and is relatively unobserved. We are particularly interested in the concentration of aurora-produced nitric oxide—which is a catalytic destroyer of ozone. The long polar winter nights are expected to contain large levels of nitric oxide, but with few observations, this is not well understood.

Aeronomy of ice

ECE researchers are engaged in further studies of middle atmosphere gravity waves in NASA's Aeronomy of Ice (AIM) mission. New algorithms to determine stratospheric gravity wave morphology will be applied to more than 10 years of AIM observations to form a unique dataset for studying the coupling of the Earth's upper and lower atmosphere.

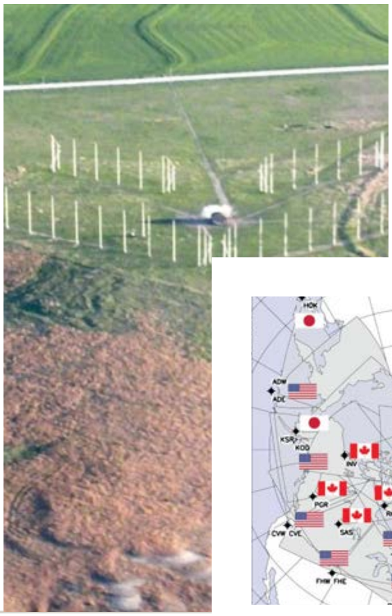
An ECE team installs space weather instrument station for the 40-degree magnetic meridian chain in the Antarctic.

Geospace upper-atmosphere investigations

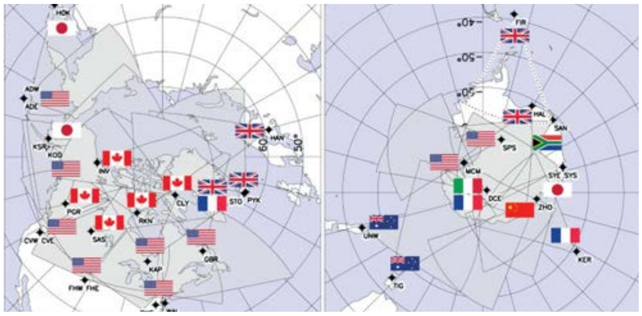
ECE researchers operate six autonomous, adaptive remote data collection platforms on the East Antarctic plateau. The platforms support fluxgate and induction magnetometers, dual frequency GPS receivers, and a high-frequency radio experiment to investigate high latitude space weather phenomena. Recent research has focused on magnetohydrodynamic wave events initiated by solar wind pressure pulses and seasonal interhemispheric differences in conductivity.

Mapping geospace phenomena

The Virginia Tech Super Dual Auroral Radar Network (SuperDARN) operates five high-frequency (HF) radars. We are investigating cause-and-effect influences in the solar wind-magnetosphere-ionosphere system using a variety of ground- and space-based datasets. Recent research examined the north-south inter-hemispheric symmetry of the Sub-Auroral Polarization Stream (SAPS).



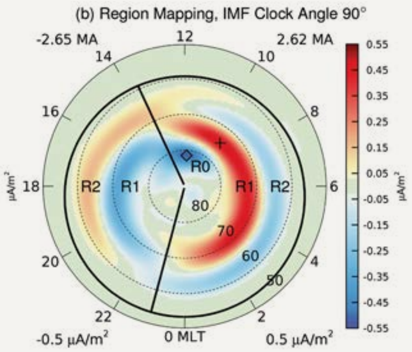
Right, above: The Virginia Tech SuperDARN HF radar facility located in western Kansas.



Far right: Map of the fields of view of radars that contribute to the SuperDARN collaboration with flags indicating their national affiliations.

Mapping polar ionospheric field-aligned currents

An ECE investigation examined how the currents flowing in and out of the ionosphere respond to the interplanetary electric field, the product of the solar wind velocity and Earth's magnetic field. We found that the magnetic field-aligned currents have a linear response to the level of solar wind driving, which was surprising since the electric fields in the ionosphere have been known to level off, or saturate, as the interplanetary electric increases.



Map of field-aligned currents where the Interplanetary Magnetic Field clock angle is 90 degrees, indicating the orientation angle of the magnetic field vector in a plane perpendicular to the Earth-Sun line.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Joseph B. Baker


C. Robert Clauer


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Autonomous systems

Imagine what could be accomplished by coordinated teams of autonomous robots in the air, on the ground, and underwater. ECE researchers are bringing this vision to life by developing efficient coordination algorithms and robust systems to explore autonomous collaboration and communication between heterogeneous robotic systems. They are building prototypes to map and monitor hazardous or inaccessible environments, aid search and rescue operations, enable interconnected infrastructure, and potentially transform environmental monitoring and management strategies.

Aerial and ground-based autonomous drones are being deployed to fulfill “dull, dirty, and dangerous” sensing tasks, like monitoring large, remote cattle farms.

Precision grazing

On large, remote cattle farms, ground and aerial robots can make all the difference for “precision grazing,” which increases livestock productivity by controlling cattle’s grazing patterns, noxious weeds, and plant diversity. We are developing multi-scale cyberphysical system-planning algorithms for autonomous monitoring and intervention, designing prototype systems, and building models to evaluate long-term grazing optimization.

Conducting a preliminary data collection test, ECE students and researchers sent an aerial drone into a mine in Kimballton, Virginia.

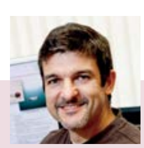
Search and rescue

Each year, thousands of people go missing in the United States. Challenging terrain and other constraints can slow human searches, but teams of robots can rapidly disperse and provide situational awareness for first responders. ECE researchers are investigating joint perception and planning in dynamic situations. They also are determining how to select and assign search tasks to complement human searchers in real-time.

Graduate students Stephen Krauss and Jack Webster are working with Dan Stilwell (right) to build autonomous vehicles that can rapidly map the mostly unknown ocean floor.

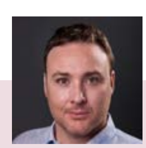
Marine autonomy and robotics: Collaborative subsea autonomy

We have more detailed maps of the Moon, Mars, and even Venus than we do of our own oceans. ECE researchers are developing and implementing new approaches to multi-vehicle coordination for applications that include subsea search and mapping, and collaborative autonomy for teams that include unmanned aerial vehicles (UAVs) and human-operated host platforms.



Daniel J. Stilwell

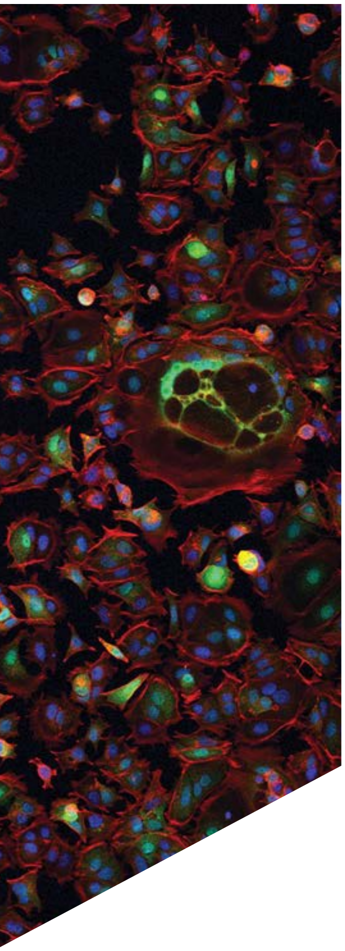
Pratap Tokekar



Ryan K. Williams

Computational systems biology

We are standing at a major inflection point for data and biomedical science–the way we view and practice scientific research is changing profoundly. These changes are being driven by computational systems biology, an interdisciplinary and data-driven approach to biomedicine, which will increasingly transform biomedicine from disease-driven and reactive to health-driven and predictive, yet preventative. ECE's systems biology researchers work with biologists, chemists, and clinical researchers to develop experiments and mathematical and computational models, along with underlying theory and software tools.



Targeted breast cancer therapy

Cancer treatments tend to work well for a period of time and then cease being beneficial once resistance develops. An ECE team is building mathematical models of breast cancer cells responding to different targeted therapies in an effort to figure out how to use combinations of drugs in a sequence that prevents the development of resistance. The model will be used to help doctors optimize therapies and provide clinical insight.

Microscope image of long-term estrogen deprived cells that are resistant to standard therapies.

Graphical time warping

Astrocytes are the most numerous glial cells and are estimated to outnumber neurons in the brain. They are deeply involved in normal brain development and in brain disease. Current methods of analyzing astrocyte activity data is essentially manual. ECE researchers have developed a suite of computational tools that automatically quantify the functional status of astrocytes. To understand astrocyte-calcium signal data, we invented a new mathematical theory for joint alignment of multiple curves, called graphical time warping. Our approach transforms the joint alignment problem into a network flow problem that can be exactly and efficiently solved.

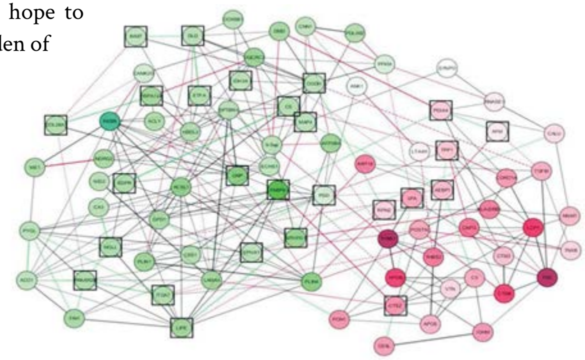
ECE researchers are developing computational tools to better understand the function of astrocytes, little-understood glial cells.

Cell communication in breast cancer

In this project, we seek to identify what drives breast cancer growth and determine how to stop it. We are applying computational modeling methods, using principles from machine learning and ecology, to study how therapy-resistant and sensitive cells cooperate to alter the response of cancer cells to treatment. This knowledge will be used to identify new interventions, or optimizations of existing regimens, to improve outcomes for patients.

Genomic and proteomic architecture of atherosclerosis

The disease process that causes heart attacks involves an abnormal collection of proteins in artery walls. An ECE team is working to identify these proteins and to discover why they accumulate and how to prevent them from doing so. We are applying multiple analysis methods to deconvolve complex proteomic signals to provide detailed descriptions of the arterial proteome and network re-wiring in atherosclerosis. We will use the knowledge gained to inform the design of an early disease detection assay and hope to help reduce the burden of atherosclerosis.



Plot depicting rewiring of the protein network between fibrous plaque and normal samples.

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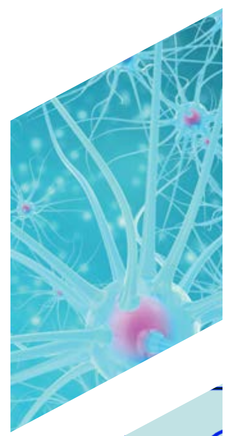

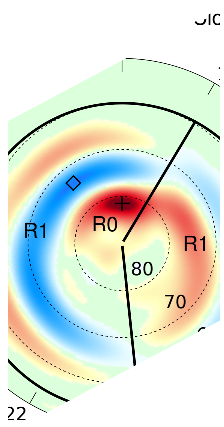

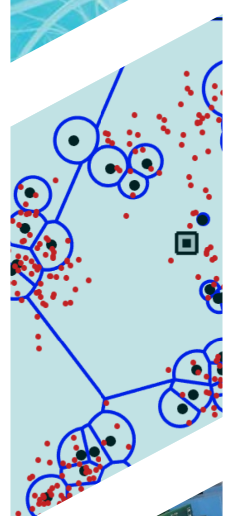




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