NYU WIRELESS

Pulse

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Featured Articles:

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Cover illustration by Marina Munn.

NYU WIRELESS is a vibrant academic research center pushing the boundaries of wireless communications, sensing, networking, and devices.

Centered at the NYU Tandon School of Engineering and involving leaders from industry, faculty, and students throughout the entire NYU community, NYU WIRELESS offers its Industrial Affiliate Members, students, and faculty members a world-class research environment that is creating fundamental knowledge, theories, and techniques for future mass-deployable wireless devices in a wide range of applications and markets.

Every January, NYU WIRELESS hosts an annual Open House for all of its students and Industrial Affiliate Members and hosts a major invitation-only wireless summit every April, in cooperation with Nokia Bell Laboratories, for the center's Industrial Affiliates and thought leaders throughout the global telecommunications industry.

NYU WIRELESS, info@nyuwireless.com

Leadership: Founding Director Ted Rappaport, Director Thomas L. Marzetta, and Associate Directors Sundeep Rangan, John-Ross Rizzo, and Dennis Shasha manage NYU WIRELESS across Brooklyn and Manhattan campuses of NYU. Prof. Rappaport has powered the 5G millimeter wave era and is a leading educator in the wireless arena, having authored many books and started three major academic wireless research centers. Prof. Rangan is an Electrical Engineering Professor at NYU Tandon and was a co-founder of Flarion Technologies, which developed Flash OFDM, one of the first cellular OFDM data systems. Prof. Marzetta originated the concept of Massive MIMO and continues to sustain contributions to the development and promotion of Massive MIMO. Prof. Rizzo is an Assistant Professor in the Departments of Rehabilitation Medicine and Neurology at NYU Langone Health. His research is focused on wearable technology and blindness and visual impairment. Prof. Shasha of Courant's Computer Science Department is widely known for his expertise in data-intensive algorithms and streaming data, and is a highly acclaimed inventor of mathematical puzzles.

The Industrial Affiliates Program: NYU WIRELESS invites corporate supporters to join our Industrial Affiliates program. The NYU WIRELESS Industrial Affiliates program offers a mutually beneficial relationship among NYU WIRELESS researchers, students, facilities, and leading industry partners, while fostering innovative research. NYU WIRELESS would like to thank our Industrial Affiliate Partners and NSF for their continued support. Learn more about our Industrial Affiliate program by visiting nyuwireless.com/industrial-affiliates.

NYU WIRELESS Newsletter

Download and read copies of our previous newsletters online
by visiting **nyuwireless.com/nyu-wireless-newsletter**

To every member of the NYU WIRELESS community,

let me begin by extending my best wishes for your continued health and well-being. As the world adjusts to a "new normal" in the wake of the tremendous health crisis we are experiencing, I am pleased to report that our labs at NYU WIRELESS have opened for critical research, and plans have been developed for a redesigned fall semester, with student safety paramount.

While it is difficult to be physically separated from colleagues and friends, the work of NYU WIRELESS continues remotely, and our mission has become more important than ever. For proof, consider the many telehealth tools now being employed to do everything from triaging possible COVID-19 patients to providing mental-health services. More specifically, two of our faculty members, Farokh Atashzar and Yao Wang, received a National Science Foundation grant to develop a smart wearable IOT COVID-19 BioTracker necklace designed to predict health anomalies (see page 12). Needless to say, such tools—so vital to minimizing the spread of the virus—would not be possible without reliable, high-speed wireless services.

In a similar vein, scientists are leveraging wireless technology to help track hotspots and infections; people around the world are becoming adept at doing their jobs via platforms like Zoom; and students, including, of course, those at NYU, are completing their coursework online. The importance of wireless networks has never been more apparent, and I'm proud that NYU WIRELESS is doing its part to keep people connected—in every sense of the word.

It's heartening to read about the ways in which our Industrial Affiliates have stepped up during this challenging time, with many carriers providing extra data at no cost and others offering a host of similar goodwill initiatives.

I'm especially proud of the work being done throughout the NYU Tandon School of Engineering, whose engineers—among other contributions—have designed face shields that can be made quickly and inexpensively; whose incubator companies have deployed their technologies for the greater good; and whose researchers have developed a platform to help the public access clear, scientist-led and evidence-based information and advice about the pandemic.

In line with our contributions to help with the pandemic, we also support the efforts of NYU to continue to foster a culture of inclusion and diversity.

I'm confident we will emerge from this period strong, focused, and future-minded, and for NYU WIRELESS that means continuing to be the academic leaders of 6G. Until a time when we can once again gather together, I hope you'll follow our progress as we move beyond 5G and that you'll continue to share your own news and success stories with us.

Thomas L. Marzetta
Director, NYU WIRELESS

Design by Milton Glaser. The creator of the popular I♥NY logo, Mr. Glaser was working on an image to indicate that "we have something in common" even during the pandemic. Mr. Glaser passed away in June 2020 while he was working on this image.

Why 5G is Safe

5G isn't spreading COVID-19, but it might transform society

Reprinted from Science Node.

What is 5G?

5G is the fifth generation of mobile technology. [Among other things,] it operates at a higher frequency than previous generations, enabling better bandwidth and faster data rates.

5G architecture pushes data closer to the end user, storing content at base stations around the world. Decentralization makes 5G even faster and more efficient.

There is no connection between COVID-19 infections and 5G. Anyone who tells you different either doesn't know what they're talking about or is trying to sell you on something.

But you don't have to take our word for it. We talked with Dr. Theodore Rappaport, founding director of NYU Wireless and 5G expert, about this claim. Not only does he state that there is "absolutely no factual basis" to a 5G-coronavirus connection, he's written an entire paper on the safety of this new mobile technology.

Despite the facts, at least 77 mobile towers were damaged recently in the UK by people concerned with catching this novel coronavirus via 5G. Rappaport took time out of his busy schedule to set the record straight about disinformation linking the rollout of 5G to the spread of the novel coronavirus. And just to make sure we didn't waste his day, we also talked about real concerns that might come with 5G deployment.

You should be more worried about putting on sunscreen

Rappaport is a professor of electrical engineering, computer science, and radiological medicine. His research led to the creation of the first Wi-Fi standard and the first US digital cellphone standards. He and his students engineered the world's first public Wi-Fi hotspots. So it's probably fair to say that he knows a lot more about wireless communication than Woody Harrelson.

If you're worried about dangerous radiation, tanning without sunscreen is a far bigger risk. More than 90% of skin cancers are caused by exposure to the sun's UV light.

"It boggles my mind why there's a fringe group that views this as an issue," says Rappaport. "The frequencies of cell phones and other radio devices are orders of magnitude below the energy level of ionizing radiation, which can lead to cancer."

Ionizing radiation, Rappaport explains, is strong enough to knock electrons out of a valence shell and force atoms to become unstable. These atoms are then called free radicals, which are linked to a host of health problems. Free radicals are a real risk—but cell phone signals aren't causing them.

"I tell people they should be more worried about putting on sunscreen or how often they fly above 10,000 feet and are exposed to galactic ionizing radiation," says Rappaport.

Overexposure to UV radiation suppresses your body's natural response to fighting infection. Specifically, too much sun can make conditions like the herpes simplex virus harder to control. So, if you're truly worried about harming your immune system, you'll be better off avoiding the beach this summer.

Benefits of 5G

Faster speeds
5G could reach 10 GB/second. Current 4G has a typical peak of only 0.1 GB/second. That's 100x faster.

Lower latency
Roundtrip data transmission clocks in at under 5 milliseconds.

Less congestion
5G can potentially support 1 million devices per square kilometer.

Bigger bandwidth
More data transmitted and smooth handling of usage spikes.

New tech
Paves the way for self-driving cars, robotic surgery, real-time gaming, and AR/VR.

In addition to this fear of decreased immune response, some conspiracy theorists say 5G towers are spreading the virus itself. While it's true that a virus can be transmitted by inanimate objects, this requires direct contact between a person and a surface contaminated by bodily fluids. In this case, elevator buttons and door handles are what you need to watch out for.

Throughout history, new technologies have prompted fear and suspicion in some members of society. But a focus on exaggerated fears can also obscure real concerns. 5G will have some problems that we'll need to address, but we can't do that if we're looking at the wrong things.

5G won't be perfect

Something we do need to consider when it comes to 5G is security. As Rappaport points out, 5G presents some new complications that will have to be confronted as the technology is more widely deployed.

One of 5G's greatest strengths is also one of its biggest weaknesses. More content will be stored at base stations. Information will be much more decentralized throughout the whole network. This allows for greater bandwidth and data rates, but it also makes protecting information harder.

"The security concerns are valid because there will be much more content out towards the edge of the network and closer to where people are," says Rappaport. "A lot of content will be replicated and stored in many places all at the same time. Access to data will become much easier if there's a security breach."

It's also important to consider the hardware necessary for 5G to function. For instance, Chinese tech giant Huawei's dominance in the production of 5G infrastructure equipment is an issue that concerns certain parts of the U.S. government. Whether that fear is based in reality or not remains to be seen, but it's something experts are interested in.

Fear of new technology is practically a human tradition. History provides plenty of examples in panicked rejections of everything from handwriting and the printing press to the telephone, radio, and television.

However, we cannot allow a small group of bad actors to define our steps into the future. Specifically, Rappaport reflects on how missing the 5G train could alter a country's economic prosperity.

"The countries with 5G will have faster, better data rates, access to new apps, and access to new products and services that exploit fiber optic-like speed going to every mobile device," says Rappaport.

"Think about Uber and YouTube—4G enabled Uber and YouTube and Netflix to become available to consumers on their phones. Countries that didn't have 4G weren't able to avail their citizens with those kinds of capabilities and the economic gain that came with it."

> There is no connection between COVID-19 infections and 5G. Anyone who tells you different either doesn't know what they're talking about or is trying to sell you on something.

Reprinted from Science Node™*, sciencenode.org; article by Kevin Steven Jackson.*

Tom Marzetta Honored

NYU WIRELSS Director Tom Marzetta was elected to the National Academy of Engineering (NAE) on February 6, 2020, a distinction that recognizes him as one of the world's top-tier engineers.

Tom was honored for his contributions to Massive Multiple-Input Multiple Output (MIMO) antenna arrays in wireless communications, a key enabler for 5G. One of the highest professional distinctions that can be accorded to an engineer, induction into the NAE honors those who have made exceptional contributions to engineering research and practice through pioneering advancements in new and developing fields of technology, traditional fields of engineering, or by developing and implementing innovative approaches to engineering education. The NAE has only 2,309 members in the United States and 281 international members.

Dr. Jim Breakall presented NYU WIRELESS director Tom Marzetta with RCA's Edwin Howard Armstrong Medal at the 110th Radio Club of America banquet and awards ceremony. The Armstrong Medal is presented when an individual has demonstrated excellence and made lasting contributions to radio arts and sciences.

Tom developed the concept of Massive MIMO during his twenty-two years at Bell Labs, where he directed the Communications and Statistical Sciences Department within the former Mathematical Sciences Research Center. His seminal paper, "Noncooperative cellular wireless with unlimited numbers of base station antennas," published in 2010 in IEEE Transactions on Wireless Communications, has been cited well over 4,000 times. He is the author or co-author of more than 220 published papers and is the lead author of the book Fundamentals of Massive MIMO, published in 2016.

"I am deeply honored to be in the company of such a transformative and talented group of engineers," Tom said. "While it is gratifying to receive this award for Massive MIMO, we must now look to the future, where even 5G won't be able to meet the communication requirements of augmented reality and holographic video. Our utmost research efforts are needed to create the technology that, eight or ten years from now, will enable 6G."

In addition to this most recent honor, on November 23, 2019 Tom received the Radio Club of America's (RCA) Armstrong Medal at its Awards Banquet in New York City. Tom was the second consecutive wireless researcher at the NYU Tandon School of Engineering to receive the award, following NYU WIRELESS Founding Director Ted Rappaport, who was honored by RCA in 2018. Tom was awarded this prestigious medal for his outstanding achievements and lasting contributions to radio arts and sciences. He joins a distinguished group of past recipients including Arthur Collins, Walter Cronkite, Harold Beverage, and Morgan O'Brien. Major Edwin H. Armstrong, for whom the medal is named, laid the foundations for much of modern radio, including circuitry and the FM radio system.

"Tom Marzetta is among the most respected researchers in the wireless field, and his presence on our faculty affirms the exceptional work being carried out here every day," said NYU Tandon School of Engineering Dean Jelena Kovačević. "That he and Ted Rappaport have both received the RCA Armstrong Medal, in consecutive years no less, cements NYU Tandon's status as a leader in wireless technology."

"Tom's groundbreaking research on Massive MIMO has enabled the spread of 5G, and his election to the National Academies of Engineering is a well-deserved honor," Dean Kovačević continued. "I am exceptionally proud to be able to call him my colleague at NYU Tandon and look forward to future NYU WIRELESS contributions to 6G under Tom's leadership."

Advance in Graphene Electronics

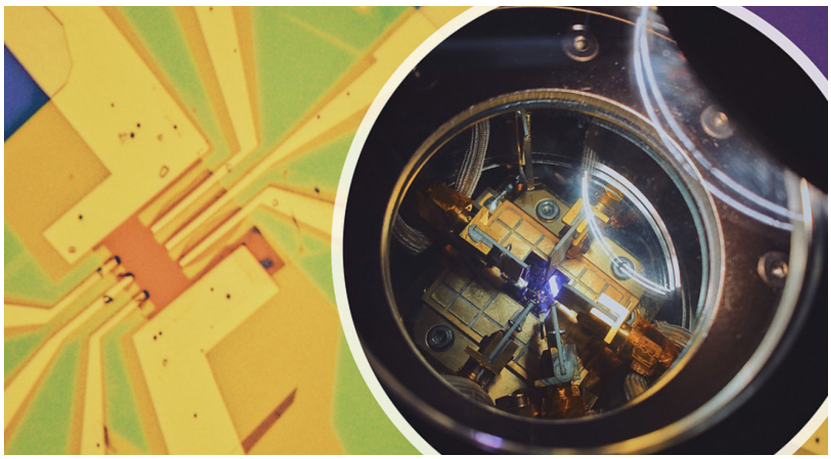
A team of researchers has discovered a versatile method for constructing high-quality van der Waals (vdW) graphene heterostructures, and their study was recently published online in *Nature Communications*.

The researchers are Davood Shahrjerdi, professor of Electrical and Computer Engineering at NYU Tandon School of Engineering and a faculty member of NYU WIRELESS; a group led by Javad Shabani of the Center for Quantum Phenomena, NYU; and Kenji Watanabe and Takashi Taniguchi of the National Institute for Materials Science, in Japan.

VdW heterostructures belong to a family of materials that possess many unique qualities, including the ability to be stacked on top of each other (much like Lego bricks) to create artificial electronic materials. In recent years, atomically thin layered materials have gained significant attention owing to their potential for building high-speed, low-power electronics. Best known among these materials is graphene, a single sheet of carbon atoms. However, while vdW heterostructures are critical to many scientific studies and technological applications of layered materials, efficient methods for building diverse vdW heterostructures had been lacking.

A crucial step for building vdW graphene heterostructures is the production of large monolayer graphene flakes on a substrate, a process called mechanical "exfoliation." The operation involves transferring the graphene flakes onto a target location for the assembly of the vdW heterostructure. An optimal substrate would therefore make it possible to efficiently and consistently exfoliate large flakes of monolayer graphene and subsequently release them on-demand for constructing a vdW heterostructure.

The research team applied a simple yet elegant solution to this challenge involving the use of a dual-function polymeric film with a thickness of below five nanometers (less than 1/10,000th the width of a human hair). This modification allows them to "tune" the film properties such that it promotes the exfoliation of monolayer graphene. Then, for the Lego-like assembly, they dissolve the polymeric film underneath the monolayer graphene using a drop of water, freeing graphene from the substrate.

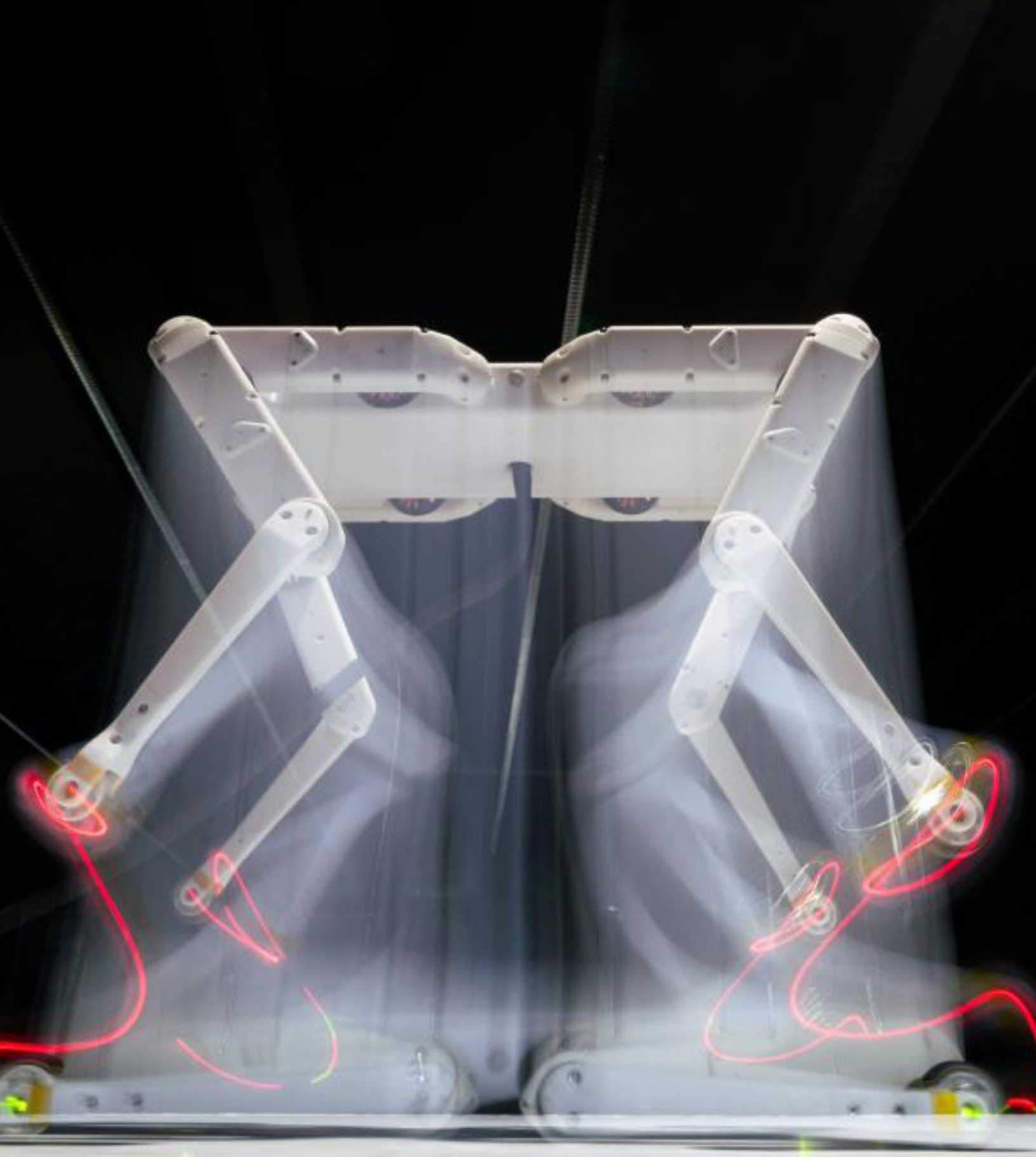


Depiction of a graphene-based field-effect transistor—one using an electric field to control the flow of electricity. Image courtesy of the Tandon School of Engineering.

"Our construction method is simple, high-yield, and generalizable to different layered materials," explained Davood. "It enabled us to optimize the exfoliation step independently of the layer transfer step and vice versa, resulting in two major outcomes: a consistent exfoliation method for producing large monolayer flakes and a high-yield layer transfer of exfoliated flakes. Also, by using graphene as a model material, we further established the remarkable material and electronic properties of the resulting heterostructures."

The team included investigators Zhujun Huang and Edoardo Cuniberto, Ph.D. students at NYU Tandon; Abdullah Alharbi of NYU Tandon and King Abdulaziz City for Science and Technology, Riyadh, Saudi Arabia; and William Mayer, postdoctoral researcher at NYU's Center for Quantum Phenomena. The research was supported by a grant from the National Science Foundation.

"Versatile construction of van der Waals heterostructures using a dual-function polymeric film" is available at www.nature.com.



Open-source, Low-cost Robot Makes Sophisticated Robotics Available to All

Robots capable of the sophisticated motions that define advanced physical actions like walking, jumping, and navigating terrain can cost $50,000 or more, making real-world experimentation prohibitively expensive for most.

Now, a collaborative team at NYU Tandon and the Max Planck Institute for Intelligent Systems (MPI-IS) in Tübingen and Stuttgart, Germany, has designed a relatively low-cost, easy- to-assemble quadruped robot called "Solo 8" that can be upgraded and modified, opening the door to sophisticated research and development for teams on limited budgets, including those at startups, smaller labs, and teaching institutions.

The researchers' work, "An Open Torque-Controlled Modular Robot Architecture for Legged Locomotion Research," was published in the April 2020 issue of IEEE Robotics and Automation Letters (https://arxiv.org/pdf/1910.00093.pdf). It was also presented this summer at ICRA, the virtual International Conference on Robotics and Automation, one of the world's leading robotic conferences. The team is led by NYU WIRELESS faculty member Ludovic Righetti, associate professor of electrical and computer engineering and mechanical and aerospace engineering at NYU Tandon School of Engineering, with collaborators at the Machines in Motion Laboratory at NYU Tandon and research groups at MPI-IS. Together they designed the device with an eye to making robot research and pedagogy more accessible to a broader range of institutions and labs. Through the use of the same open-source platform, researchers will also be able to compile comparative data, a critical step towards rapid progress in robotics.

Solo 8's functionality, including torque-controlled motors and actuated joints, allows it to move and behave similarly to far more expensive robots: It can, for example, perform jumping actions, walk in multiple configurations and directions, and recover orientation, posture, and stability after being overturned. Additionally, all the components of Solo 8 can be either 3D-printed or easily purchased in a shop, and the robot's construction files are freely available online under the BSD 3-clause license, enabling other scientists to leverage the modular set-up when prototyping and developing their own technology.

Developed under the aegis of the Open Dynamic Robot Initiative, the project was launched in 2016 by Ludovic and MPI-IS investigators Felix Grimminger, a mechatronics engineer, and Alexander Badri-Spröwitz, leader of the Dynamic Locomotion research group. It was initially funded by Ludovic's ERC starting grant and then by several MPI-IS' grassroots projects and a U.S. National Science Foundation grant.

Step by step, the four-legged robot is going places.

"Already many universities have approached us, wishing to make a copy of our robot and use it as a research platform," said Ludovic, who is also a research group leader at MPI-IS. He explained that the concept was recently used by the Empirical Inference Department at the MPI-IS to build robotic fingers that can manipulate objects.

"Our robot platform is a great base to quickly prototype and build high-performance

Videos of Solo 8 in action can be found on the Open Dynamic Robot Initiative YouTube Channel. The robot makes research possible in many areas, including:

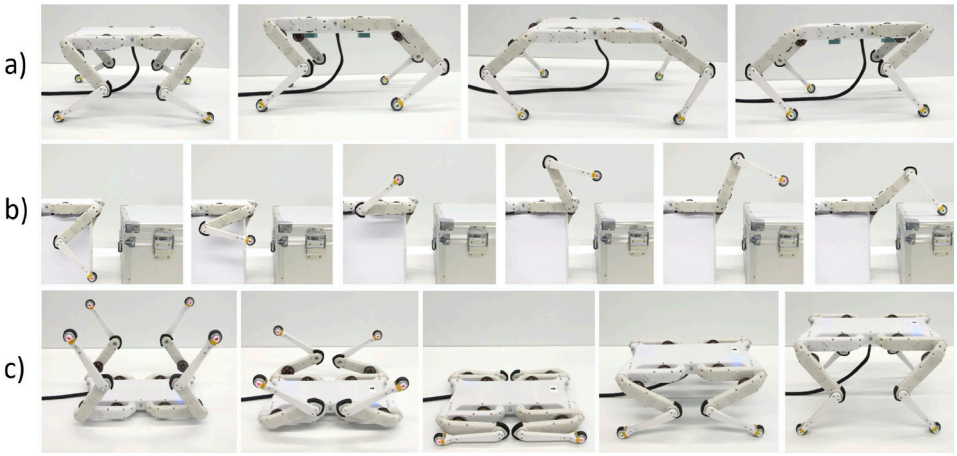
Exploration of animal-based limb movement and movement over laboratory surfaces, gravel, soil, sand, mud, and other rough terrains

Reinforcement learning for complex and dynamic behaviors, including those that push performance to stress limits that would be too risky to attempt with expensive platforms

Very dynamic locomotion (including parkour-style behaviors), which very few robots can perform

Manipulation of the environment, such as opening doors or pushing buttons

Integration of robots with advanced communications technology. Currently, the team is conducting NSF-funded research with NYU WIRELESS on control for Solo 8 through 5G wireless connectivity.



Example motion sequences: a) Legs can switch between all the four knee configurations, b) with more than 360° hip joint rotation capability, and little space to navigate, legs can be rotated first backwards, and then onto a step, c) in case the robot falls onto its back, it can re-orient its legs, and stand up without rotating the trunk.

hardware," he continued. "In return we benefit, because other researchers can contribute to the project; for example colleagues at the LAAS-CNRS in France have developed an electronic board to help communicate with the robot over WiFi. Also, complex control and learning algorithms can be rapidly tested on the platform, decreasing the time from idea to experimental validation. It greatly simplifies our research, and our open-source approach allows us to compare algorithms with other laboratories. In my lab in New York, we have developed very efficient motion optimization algorithms, but testing them on a complex, heavy robot can easily take half a year of work for several researchers; the same thing can be done more easily with Solo 8. That was a big time saver for us."

No need to reinvent the wheel!

"For a research group to develop such a robot themselves, it takes easily four years of work," said Alexander . "Additionally, you need a wide range of expertise. Our platform is the combined knowledge of several teams. Now any lab worldwide can go online, download the files and print the parts, and buy the remaining components from a catalog. And everybody can add extra features within a few extra weeks. Done! You've got yourself a world-class robot."

He added that with an estimated price of only a few thousand dollars, the robot—homemade and easy to tweak to meet individual research goals—is more accessible to a greater number of researchers and instructors than is a similar store-bought legged robot.

"Solo 8 has some novel capabilities that we are interested in exploring in the future," said Felix. "It has an extensive range of motion, for example. If the robot falls on its back, it can configure the legs the other way and just stand up. Or it can jump up to reach 65 cm from a standing height of 24 cm."

Thanks to torque-controlled motors, the robot achieves a spring-like behavior, which replicates the movement achieved by the muscles and elastic tendons in animal legs.

"The robot uses virtual springs, not mechanical springs. And as virtual springs, they can be programmed. You can, for instance, adjust the spring stiffness from soft to hard, which is interesting because we see variable stiffness in humans and animals. With adjusted stiffness, the robot achieves adaptive and robust locomotion behavior," Alexander added.

Solo 8 weighs just over two kilograms, providing a very high power-to-weight ratio. Most quadruped robots are significantly heavier and therefore more dangerous and harder to control in a research environment. With its low weight, the robot is easier and safer for students to handle; it can even be transported in a backpack, either home or to a conference.

The robot was dubbed Solo 8 in recognition of its eight actuated joints: each of its four robotic legs can change its angle and length. An updated version was recently completed, and preliminary tests have been conducted with twelve degrees of freedom, three per leg. The improved robot can now also step sideways.

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Robotic AI Functionality via 5G

Associate Professor Ludovic Righetti

A research team at NYU WIRELESS, with the support of the National Science Foundation's National Robotics Initiative 2.0, is laying the foundation for a wireless system that takes advantage of superfast 5G wireless communications to outsource a mobile robot's artificial intelligence functions to the edge cloud (the server in the cloud closest to the robot).

The collaborators—Ludovic Righetti (project lead), Siddharth Garg, Sundeep Rangan, and Elza Erkip—will design manipulation and locomotion algorithms that address some important technical hurdles to making 5G networks a viable bridge between robot and server.

Shifting AI capabilities from the robot to a remote server offers tantalizing operational benefits, such as allowing robots to perceive the environment, perform complex operations, and make decisions autonomously, all without incurring major energy and weight costs from onboard computational and power-generation equipment.

The team will focus on solving issues of reliability, safety of robotic operation under communication degradation, and scalability to multi-robot systems. The collaboration brings together expertise in several areas: robotics, computer architecture and computation, wireless networks, and information theory. "The goal is to design algorithms that optimally distribute computation between robots and the cloud for guaranteed safe robotic operation," said Elza.

Sundeep explained that while cloud robotics has long been seen as a way to offload power-consuming computation, it has remained elusive for real-time perception and control because of limited bandwidth and high latency of wireless communication systems. He described the problem as being exacerbated by the need to support the bandwidth-hungry video and LIDAR (light detection and ranging) systems commonly used on robots today.

"5G systems offer the potential for vastly higher data rates, but real-time cloud robotics remains challenging," he said. "A particular difficulty is that 5G communication using the millimeter wave (mmWave) bands are highly susceptible to blockage. As a result, links can have high-peak data rates, but may be only intermittently available."

The project considers various aspects of these challenges, including 5G channel modeling in robotics scenarios, dynamic partitioning of tasks between the cloud and robot, and the development of new control algorithms that can exploit high-rate links when available—but that also operate when links are blocked.

"The ultimate goal is to help the development of light-weight, autonomous, cloud-connected robotics," explained Ludovic, adding that outreach activities—including offering the team's algorithms for free—will be a major aspect of demonstrating the unique capabilities of 5G-enabled robotic systems. "We are lowering the barriers of entry for scientists and industries seeking to exploit 5G-enabled robotics by distributing the algorithms we develop through open-source and to industrial partners via NYU WIRELESS."

The group recently completed a paper in which they propose a novel approach that consists of a standard optimization-based controller on the network edge and a local linear, approximately optimal controller that significantly reduces on-board computational needs while increasing robustness to delay and possible loss of communication. The work will be presented at the IEEE Robotics and Automation Society's 2020 International Conference on Intelligent Robots and Systems (IROS), to be held in October.

NYU WIRELESS Annual Open House

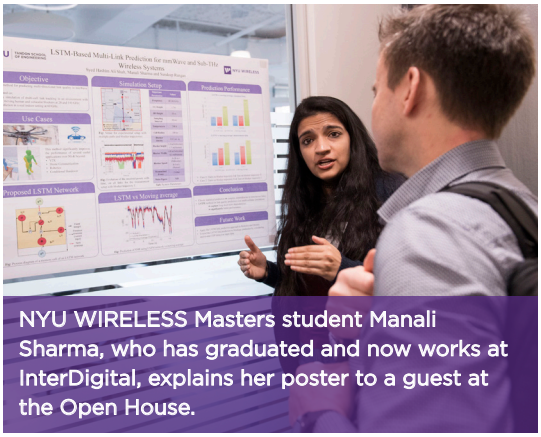
This year's annual NYU WIRELESS Open House/Recruiting Day was held on January 24, 2020. It was an extra special event, as Industrial Affiliate members were welcomed into our greatly expanded and improved space at 370 Jay Street in downtown Brooklyn. As described in our last issue of Pulse (available at NYUWIRELESS.com), NYU worked with the City of New York to renovate the long-unoccupied former MTA headquarters, transforming the building into an innovation hub for engineering, applied science, urban science, digital technology, and digital media arts. Open House visitors were excited to explore the newly renovated space, which features state-of-the-art labs, offices, meeting rooms, and seating areas for students to work and socialize.

Open House attendees also enjoyed a talk by Michael Marcus, formerly of the FCC and now a consultant on wireless technology and spectrum policy, who discussed opening spectrum above 100 GHz. Following this presentation, Professor Ramesh Karri of NYU Tandon School of Engineering provided a cybersecurity update, and NYU WIRELESS Industrial Affiliates reviewed their companies' latest developments and focus areas.

Afternoon activities included tours of various labs: Professor Giuseppe Loianno's Agile Robots & Perception Lab, Professor Ludovic Righetti's Machines in Motion Lab, and Professor Davood Shahrjerdi's Clean Room. Visitors also had the opportunity to learn from the twenty-five student research posters displayed throughout the floor, as well as seven lab demos. Malcolm Robertson, Strategic Planning Manager from NYU WIRELESS Industrial Affiliate Keysight Technologies, summed up the afternoon perfectly: "It was time well spent visiting the new lab and office space at NYU WIRELESS. I enjoyed speaking with the students about their demos, and it is always great to catch up with faculty members to learn about the latest project developments in wireless communications."

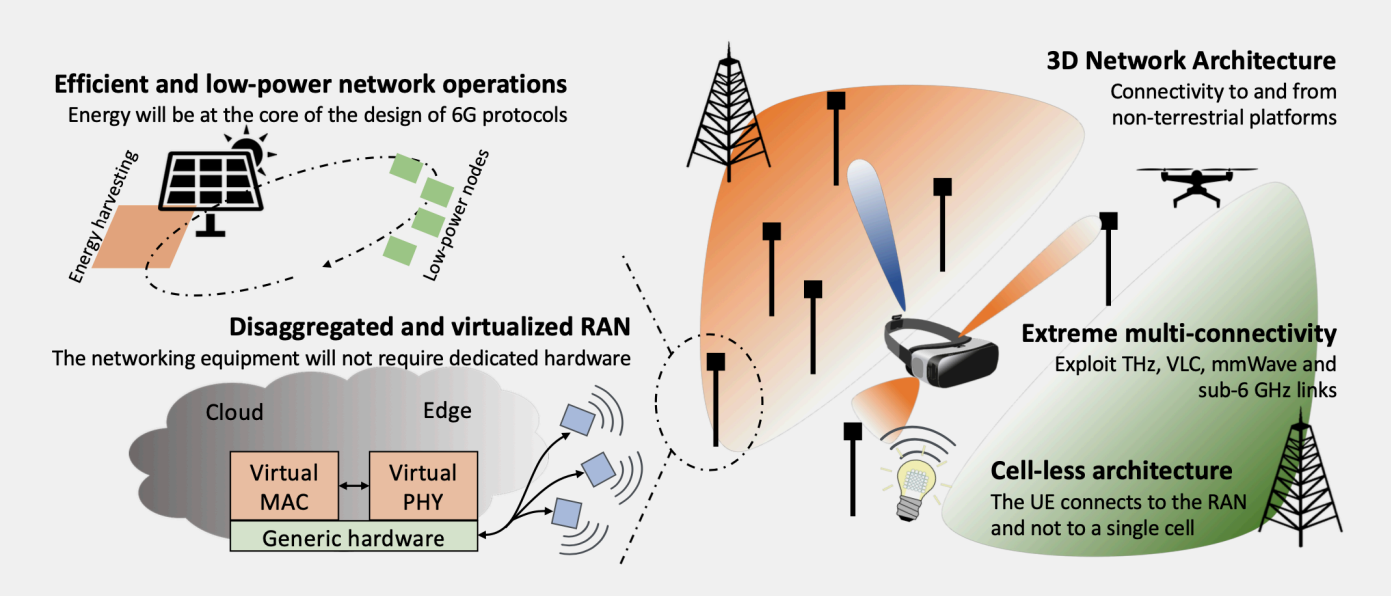
(l. to r.) Alexei Ashikhmin from Nokia Bell Labs and Andrea Pizzo, Postdoctoral Associate, NYU WIRELESS

(l. to r.) Professor Yao Wang, Dr. J.R. Rizzo and his demonstration, "Mapping/localization and obstacle negotiation meets advanced wearables for low vision," and Alain Boldini, PhD candidate, NYU Tandon.



NYU WIRELESS Masters student Manali Sharma, who has graduated and now works at InterDigital, explains her poster to a guest at the Open House.

(l. to r.) PhD student Dipankar Shakya; Malcolm Robertson from Keysight; PhD student Shihao Ju



6G Use Cases Discussion

The article *Toward 6G Networks: Use Cases and Technologies*, by authors Marco Giordani, Michele Polese, Marco Mezzavilla, Sundeep Rangan and Michele Zorzi, discusses use cases, requirements, and enabling technologies for 6G (6th generation) systems from an end-to-end and system-level perspective. Published earlier this year in *IEEE Communications Magazine*, the authors envision:

- novel communications technologies that leverage the spectrum above 100 GHz, including optical frequencies, in order to provide ultra-high-speed broadband access and enable new applications including holographic telepresence
- innovative network architectures aimed at providing 3D coverage to every connected device
- learning mechanisms to integrate intelligence in the network through inter-user, inter-operator knowledge sharing, which will ultimately reduce network management costs

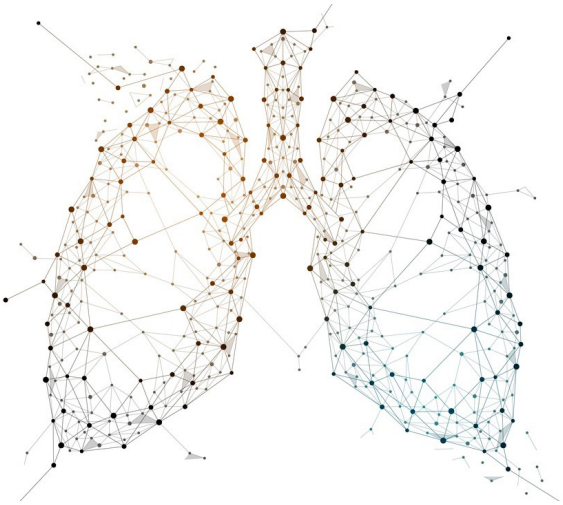
Based on these innovations, the article suggests the ways in which 6G will be developed to jointly meet stringent network demands in a holistic fashion, in view of the foreseen economic, social, technological, and environmental context of the 2030 era, thereby making the future a little bit closer.

M. Giordani, M. Polese, M. Mezzavilla, S. Rangan, and M. Zorzi, "Toward 6G Networks: Use Cases and Technologies," in IEEE Communications Magazine, vol. 58, no. 3, pp. 55-61, March 2020, doi: 10.1109/MCOM.001.1900411

Highly Cited Researchers

NYU WIRELESS Director Tom Marzetta and Founding Director Theodore Rappaport were recognized by the Web of Science Group, which named them among 2019's Highly Cited Researchers. The Group's annual list honors researchers from the global scientific community for their significant influence and achievements in their fields. The scientists and social scientists selected from around the world have published multiple papers that rank in the top one percent by citations in their field over the past decade (2008–18), according to Web of Science. The methodology that determines this "who's who" of influential researchers draws on the data and analysis compiled by bibliometric experts from the Institute for Scientific Information at the Web of Science Group, part of Clarivate Analytics. According to David Pendlebury, senior citation analyst at the Institute, "These researchers create gains for society, innovation, and knowledge that make the world healthier, richer, more sustainable, and more secure."

Wearable Technology Designed to Monitor Vital Signs



Farokh Atashzar

Yao Wang

COVID-19 has caused a severe shock to global healthcare systems. Unsettling spikes have been occurring throughout the world, accompanied by serious outbreaks of pneumonia associated with the infection. NYU WIRELESS Assistant Professor Farokh Atashzar and Professor Yao Wang saw the pressing need for smart and scalable wearable technologies that can be produced rapidly to assist in monitoring patients.

The researchers recently were awarded a National Science Foundation RAPID Response grant to support their development of a wireless smart IoMT (Internet of Medical Things) necklace capable of predicting the probability of COVID-related health anomalies through machine intelligence and data modeling. The necklace will contain sensors that can accurately, objectively, and continuously track a large spectrum of COVID-19 symptoms, including respiratory malfunction and infection.

The device—practical in both home and hospital settings—will record and tele-report the sound and vibrational dynamics of breathing and coughing, together with vital signs like blood oxygen saturation level, temperature, and heart rate. Using novel machine learning models, the information generated by the device will potentially aid practitioners in detecting early health anomalies and in predicting potential adverse events, reducing the burden on the healthcare system and the corresponding social and economic impacts.

Farokh and Yao expect their work to provide important data that will aid in fundamental research on the evolution of COVID-19 symptoms. They also anticipate that the device will be useful to patients with other respiratory conditions, including lung cancer, making it relevant well beyond the current pandemic.

NYU Spin-off Ensures Authenticity

NYU WIRELESS researcher Lakshmi Subramanian, together with Ashlesh Sharma, who received his PhD from NYU's Courant Institute of Mathematical Sciences in 2013, have co-founded an intriguing NYU spin-off: Entrupy, a company that combats product counterfeiting. Employing artificial intelligence, microscopy, and wireless capability, Entrupy is used by high-end retailers and second-hand re-sellers to scan a variety of products, comparing the scans with algorithms that have been trained with the company's database of existing microscopic images. The scan provides a result in seconds that verifies an item as authentic or counterfeit. Entrupy supports many luxury brands and was a 2019 Global AI Award Winner for AI Application/Product of the Year. Entrupy has offices in the US and Japan.

"We were pleased by how easy it was to transition to commercial development by working with NYU's Office of Industrial Liaison (OIL)," commented Lakshmi. "We are happy to be providing such a useful service to retailers and consumers."

Welcoming New NYU WIRELESS Members

NYU WIRELESS is proud to welcome four new members to our community, thus expanding the knowledge base we provide to our Industrial Affiliates. Each brings a wealth of experience to NYU Tandon, and we look forward to collaborating and sharing successes with them on future projects.

Farokh Atashzar is an Assistant Professor of both Electrical and Computer Engineering, and Mechanical and Aerospace Engineering at NYU Tandon School of Engineering. He also leads the Medical Robotics and Interactive Intelligent Technologies (MERIIT) Laboratory. He was previously a senior post-doctoral scientist in the Department of Bioengineering, Imperial College London, sponsored by the Natural Sciences and Engineering Research Council (NSERC) of Canada. His many awards include the highly competitive Ontario Graduate Scholarship (2013) and an NSERC Post-Doctoral Fellowship (2018). His research interests include medical robotics, neurorehabilitation robotics, surgical robotics, deep bio-signal processing, haptics, smart prosthetics, bio-feedback systems, telerobotics, physical human-robot interaction, advanced nonlinear control systems, passivity control theory, small-gain control theory, stability, adaptive filters, machine learning, and AI.

Jaime Llorca is a Research Professor with the Electrical and Computer Engineering Department. His research interests include network algorithms, modeling, optimization, and control, with applications to next-generation (5G/6G) communication networks, distributed cloud networking, mobile edge computing, and content distribution. He received a B.Sc. degree in Electrical Engineering from Universidad Politècnica de Catalunya, Barcelona, and M.S. and Ph.D. degrees in Electrical and Computer Engineering from the University of Maryland. He held a post-doctoral position with the Center for Networking of Infrastructure Sensors; a research scientist position with the End-to-End Networking Group at Alcatel-Lucent Bell Labs; and a senior research scientist position with the Network Algorithms Group at Nokia Bell Labs. He has authored more than ninety peer-reviewed publications and holds eighteen patents.

Kim Mahler is a post-doctoral researcher affiliated with both NYU WIRELESS and NYU CUSP (Center for Urban Science and Progress). His research interests involve the development of viable 5G applications, drone/vehicular communications, localization using 5G millimeter wave, and user-centric innovation. He received his M.Sc. degree with honors (2010) and his Doctorate of Engineering degree magna cum laude from the Technische Universität Berlin (2016). He also received an M.A. degree from the Universität der Künste Berlin/University of St. Gallen (2014). From 2010 to 2019, he was with the Wireless Communications and Networks Department at Fraunhofer Heinrich Hertz Institute, Berlin.

Antonia Tulino is a Research Professor in the Department of Electrical and Computer Engineering at NYU Tandon and a Professor with the Universit à degli Studi di Napoli Federico II. She received her Ph.D. in Electrical Engineering from Seconda Università degli Studi di Napoli and has held research positions with the Center for Wireless Communications, Princeton University; University of Oulu, Finland; and also with the Università degli Studi del Sannio, Benevento. Since 2002, Antonia has been collaborating with Bell Labs. Starting in September, she will be the Teaching Director of the 5G Academy, which is jointly organized by the Università degli Studi di Napoli Federico II and Capgemini, a leader in digital transformation. Her research interests are in the area of communication systems approached with the complementary tools provided by signal processing, information theory, and random matrix theory. From 2011 to 2013, she was a member of the editorial board of the IEEE Transactions on Information Theory and, in 2013, she was elevated to IEEE Fellow. Since 2019, she has served as Chair of the Information Theory Society Fellows Committee.

Assistant Professor Farokh Atashzar

Research Professor Jaime Llorca

Postdoctoral Researcher Kim Mahler

Research Professor Antonia Tulino

COSMOS Program Promotes STEM Outreach

The global economy is changing rapidly in response to technological advances, and in order to keep pace with the needs of industry, today's students must be proficient in science, technology, engineering, and math (STEM) skills. To better prepare students to face these challenges, the COSMOS educational project provides an innovative platform for teaching STEM in targeted K-12 classrooms.

The program was conceived to engage students from diverse racial, ethnic, and socioeconomic backgrounds and to increase their proficiency in STEM subjects. To date, the project has been successfully introduced in twenty middle schools and high schools throughout New York City.

PhD student Syed Hashim Ali Shah helps assemble COSMOS Toolkits.

Funded by the National Science Foundation, COSMOS (Cloud Enhanced Open Software-Defined Mobile Wireless Testbed for City-Scale Deployment) is focused on designing, developing, and deploying an advanced wireless testbed in New York City to support real-world experimentation in next-generation wireless technologies and applications. The COSMOS team, consisting of researchers from NYU Tandon School of Engineering, Rutgers, and Columbia, realized that the testbed-generated research could be transformed into an innovative learning platform for K-12 students.

The COSMOS education team, led by researchers at NYU Tandon, have designed and implemented novel K-12-related education activities. One component of these activities is the summer COSMOS RET (Research Experience for Teachers) Program, organized by NYU and Columbia. In this program, the COSMOS team works closely with teachers on the creation of K-12 STEM labs that are based on actual research experiments implemented in the same setup as the research experiments at COSMOS. Now in the third year of this program, the team has worked with more than twenty New York City teachers and has created more than 120 K-12 STEM labs. The labs run through an educational platform created with the COSMOS Educational Toolkit.

Using the tenets of inquiry-based teaching and learning, the COSMOS Educational Toolkit is a modified version of the COSMOS testbed that teachers can use in their classrooms. It consists of a hardware and software system designed to engage students in hands-on STEM experiments.

The major components of the kits are software-defined radios, processing units, IoT nodes, and a mobile node. According to NYU postdoctoral student Panagiotis Skrimponis, working under Research Assistant Professor Thanasis Korakis, "We are using Raspberry Pi kits to introduce mobility to experiments that students are performing in and outside the classroom. For example, they can use IoT sensors and Raspberry Pi as a gateway when they go on a field trip to collect environmental data. They then perform additional experiments where the effect of distance vs. signal strength measured, and use the Raspberry Pi as a mobile transmitter or receiver."

The second part of the COSMOS Educational Toolkit RET program is a professional development (PD) summer course that prepares and

Students exploring virtual reality with the COSMOS program on The Intrepid Sea, Air & Space Museum.

supports local teachers in using the toolkits in their classrooms. As a testament to the success of the PD program, teachers who have taken the summer course have presented the results of the RET program to COSMOS affiliate members. At an event held at the Columbia Data Science Institute in December 2019, the COSMOS Educational Toolkit was showcased to New York City teachers and their students by engineers from NYU WIRELESS Industrial Affiliate AT&T, researchers from NYU Tandon, and COSMOS partners from Columbia and Rutgers. The showcase introduced the teachers and students to the COSMOS Educational Toolkit and the ways in which it can be used in urban settings, as well as how it integrates technology into student curriculum. This summer seven New York City teachers are participating virtually in the COSMOS RET Summer Program, which will enable them to bring the theory and practice of wireless networking back to their classrooms in the fall.

The success of the COSMOS K-12 educational initiative has been widely recognized. Last year the work resulted in the COSMOS Educational Toolkit receiving a Best Presentation Award at the NE-ASTE (Northeast Association for Science Teacher Education) conference, and this year it was shortlisted for the Global Mobile Awards at the Mobile World Congress Barcelona 2020 under the Youth Mobile STEAM Activity for Young People category. A paper describing the development of the PD program and toolkit, "Evaluation: A Teacher Professional Development Program Using Wireless Communications and NGSS to Enhance STEM Teaching and Learning," was presented at the American Society for Educational Engineering (ASEE) virtual conference in June 2020 and can be found online at asee.org.

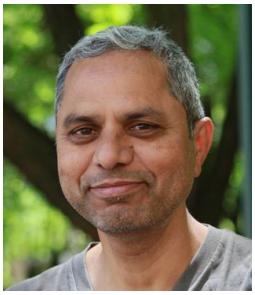
A parallel activity to the COSMOS educational program, originally developed by the COSMOS team, is 5G-COVET, a project that develops an educational suite that provides K-12 STEM labs based on virtual reality (VR) and 5G technologies. Each of the VR educational labs of the 5G-COVET platform form a virtual environment that the students visit together and use to solve riddles and puzzles, similar to an escape room experience. Using these technologies, particularly VR, seems to significantly enhance students' engagement with the curriculum. Additionally, students hone social skills through the collaborative nature of the program.

Using the tenets of inquiry-based teaching and learning, the COSMOS Educational Toolkit is a modified version of the COSMOS testbed that teachers can use in their classrooms. It consists of a hardware and software system designed to engage students in hands-on STEM experiments.

5G-COVET is one of the ten winning teams of Verizon's 5G EdTech Challenge Competition, which recognizes projects based on their "ability to solve for student engagement, teacher preparedness, and special needs support." Plans are underway for expansion of 5G-COVET, with a goal of bringing 5G and AR/VR educational applications to one hundred Title I middle schools across the U.S. by 2021.

News in Brief

Ramesh Karri Named IEEE Fellow



Ramesh Karri

Congratulations to Professor Ramesh Karri of NYU WIRELESS, who has been named a fellow of the Institute of Electrical and Electronics Engineers (IEEE), the world's largest technical professional association. Ramesh was honored for his contributions to and leadership in trustworthy electronic hardware.

Ramesh is a professor of electrical and computer engineering at NYU Tandon, co-founder and co-chair of the NYU Center for Cyber Security, and faculty leader for the world's most comprehensive student-led cybersecurity games, CSAW (Cyber Security Awareness Worldwide).

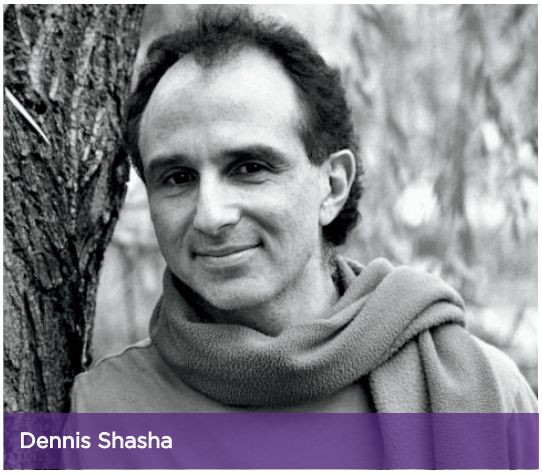
Ramesh, who has more than 250 journal and conference publications to his credit, was recognized for his seminal work in ensuring that the global hardware supply chain is as secure as possible. He is widely acknowledged within the industry for his advocacy and warnings about the need for strong hardware security. In 2002 he and his colleagues generated the first research on attack-resilient chip architecture, demonstrating before anyone else that integrated circuits' test and debug ports could be corrupted by hackers. Since then, he has pioneered the technique of microchip camouflaging, a tactic to prevent reverse engineering. His latest research involves developing safeguards for the growing additive manufacturing (3D-printing) industry, whose use of computer-aided design (CAD) files leaves it subject to threats including viruses and piracy.

Ramesh is also well known in the hardware security world for founding the Embedded Security Challenge, which, since 2008, has been held each year as part of CSAW. Research developed during the contest has propelled the entire field of hardware trust, and several students who have participated in the challenge have gone on to make important contributions to the field.

Dennis Shasha Receives SIGMOD Award

NYU WIRELESS Associate Director and Professor Dennis Shasha has received the 2020 Association for Computing Machinery's SIGMOD Contributions Award. The SIGMOD (Special Interest Group on Management of Data) award recognizes innovative work in the data management community to ensure reproducibility of publications. Reproducibility has influenced the ways in which the community approaches experimental assessments.

In addition to his work with NYU WIRELESS, Dennis is the Julius Silver Professor of Computer Science at the Courant Institute of NYU. He works on meta algorithms for machine learning to achieve guaranteed correctness rates; with biologists on pattern discovery for network inference; with computational chemists on algorithms for protein design; with physicists and financial experts on algorithms for time series; on clocked computation for DNA computing; and on computational reproducibility. He has written several books, co-authored more than eighty-five journal papers and eighty conference papers, and has twenty-five patents to his credit. He has written the puzzle column for publications including *Scientific American* and *Dr. Dobb's Journal*, and currently for the communications of the ACM. He is a fellow of the ACM and an INRIA International Chair.



Dennis Shasha

NYU WIRELESS Founding Director Ted Rappaport

6G & Beyond: Ted Rappaport Keynote Presentations

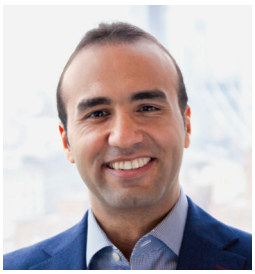
Professor Ted Rappaport had the honor of presenting a plenary keynote talk at IEEE's International Conference on Microwaves, Communications, Antennas & Electronic Systems (COMCAS) in Tel Aviv on November 4, 2019. COMCAS attracts a large global audience with broad and interdisciplinary topics. The scientific program included approximately 230 technical presentations.

Ted's presentation, "Wireless Beyond 100 GHz: Opportunities and Challenges for 6G and Beyond," explained how today's early experiences are laying the foundations for revolutionary products and services that will evolve over the next decade, which will eventually be part of 6G networks and beyond. He also chaired the conference session on Enhanced Communications Technologies for Future Networks and co-authored two papers that were presented (see Publications on page 20 for citations).

Ted also participated in the 6G Wireless Summit 2020. Originally intended to be held at the University of Oulu in Finland, the conference was instead produced as a virtual event in response to the COVID-19 pandemic. His talk on wireless communication and applications above 100 GHz can be accessed online at www.6gsummit.com/keynotes.

Kudos

Congratulations to NYU WIRELESS Professors Davood Shahrjerdi and Siddharth Garg, who both have been granted tenure in the Electrical and Computer Engineering Department at NYU Tandon School of Engineering.

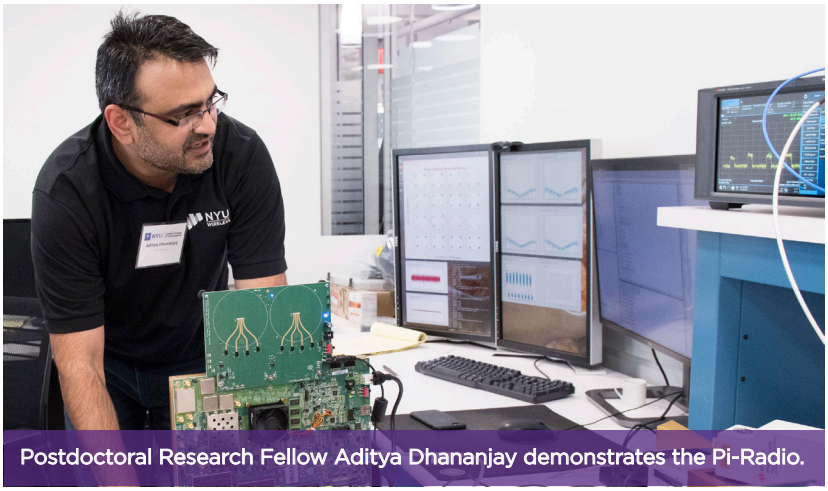

Davood Shahrjerdi


Siddharth Garg

Pi-Radio

Pi-Radio is a software-defined radio start-up designed to democratize experimental wireless research in the emergent millimeter wave (mmWave) frequency bands between 30 and 300 GHz. Founded by Aditya Dhananjay, Marco Mezzavilla, Sundeep Rangan, and Dennis Shasha from NYU WIRELESS, the start-up team hopes the system can be used by the academic wireless community to help graduating engineers develop real-world prototyping skills.

In a recent demo, the team was able to show the main benefits of a fully-digital beamformer, i.e., the ability to receive in multiple directions at the same time. In the experiment, the TX transmits four (the max allowed with 4 antennas) independent streams of data over an OFDM-based physical layer: one stream in each direction. The RX looks in all four directions simultaneously. For each RX angle, it attempts to synchronize and decode each of the four transmitted streams, as illustrated in the plot above/below. Faster synchronization results in an overall reduction of the system overhead and latency. More information can be found at pi-rad.io.


Postdoctoral Research Fellow Aditya Dhananjay demonstrates the Pi-Radio.

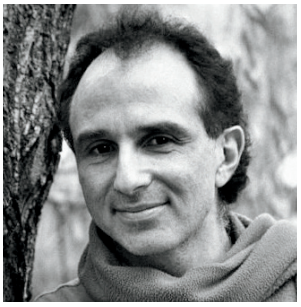
NYU WIRELESS Faculty, Post-Docs, and Research Engineers

Theodore Rappaport
Founding Director,
ECE, CS, Med.

Thomas L. Marzetta
Director, ECE

Sundeep Rangan
Associate Director, ECE

John-Ross Rizzo
Associate Director,
NYU Langone Health



Dennis Shasha
Associate Director, CS

Sundar Aditya
Post-Doctoral Associate

Farokh Atashzar
Assistant Professor

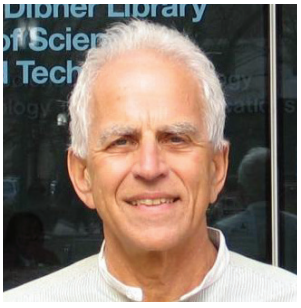
Henry Bertoni
Professor Emeritus, ECE

Aditya Dhananjay
Postdoctoral Associate, ECE

Elza Erkip
Institute Professor, ECE

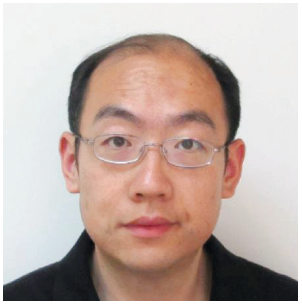
Fraida Fund
Postdoctoral Associate

Siddharth Garg
Associate Professor, ECE



David Goodman
Professor Emeritus, ECE

Michael Knox
Industry Professor, ECE



Pei Liu
Research Scientist, ECE

Yong Liu
Associate Professor, ECE

Jaime Llorca
Research Professor

Giuseppe Loianno
Assistant Professor

Kim Mahler
Post-Doctoral Researcher

Marco Mezzavilla
Research Scientist, ECE

Shivendra Panwar
Professor, ECE

Andrea Pizzo
Post-Doctoral Associate;

Ludovic Righetti
Associate Professor, ECE & MAE

Davood Shahrjerdi
Associate Professor, ECE

Farhad Shirani
Research Assistant Professor, ECE

Lakshminarayan Subramanian
Associate Professor, CS

Antonia Tulino
Research Professor

Yao Wang
Professor, ECE & BioMed

NYU WIRELESS Recent Publications

August 2019–June 2020

Terahertz (THz) Communications & Sensing

A. Pizzo, T. L. Marzetta and L. Sanguinetti, "Spatially-Stationary Model for Holographic MIMO Small-Scale Fading," in IEEE Journal on Selected Areas in Communications, June 2020

W. Xia, V. Semkin, M. Mezzavilla, G. Loianno, S. Rangan, "Multi-Array Designs for mmWave and Sub-THz Communication to UAVs," in 21st IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC), May 2020

P. Skrimponis, S. Dutta, M. Mezzavilla, S. Rangan, S. H. Mirfarshbafan, C. Studer, J. Buckwalter, and M. Rodwell, "Power Consumption Analysis for Mobile MmWave and Sub-THz Receivers," 2nd 6G Wireless Summit, March 2020

S. Ju, O. Kanhere, Y. Xing, T. S. Rappaport, "A Millimeter-Wave Channel Simulator NYUSIM with Spatial Consistency and Human Blockage" in Proc. IEEE 2019 Global Communications Conference, pp. 1–7, Dec. 2019

O. Kanhere, S. Ju, Y. Xing, T. S. Rappaport, "Map-Assisted Millimeter Wave Localization for Accurate Position Location," in Proc. IEEE 2019 Global Communications Conference, pp. 1–6, Dec. 2019

Y. Xing, O. Kanhere, S. Ju, T. S. Rappaport, "Indoor Wireless Channel Properties at Millimeter Wave and Sub-Terahertz Frequencies: Reflection, Scattering, and Path Loss," in Proc. IEEE 2019 Global Communications Conference, pp. 1–6, Dec. 2019

R. Kumar, A. Francini, S. Panwar, S. Sharma, "Design of an Enhanced Bearer Buffer for Latency Minimization in the Mobile RAN," in Proc. of IEEE GLOBECOM, Dec. 2019

T. S. Rappaport, "Wireless Beyond 100 GHz: Opportunities and Challenges for 6G and Beyond," IEEE COMCAS Conference Keynote, Tel Aviv, Israel, Nov. 2019

Mobile Edge & Low Latency Networking

D. Raychaudhuri, I. Seskar, G. Zussman, T. Korakis, D. Kilper, T. Chen, J. Kolodziejski, M. Sherman, Z. Kostic, X. Gu, H. Krishnaswamy, S. Maheshwari, P. Skrimponis, C. Gutterman, "Challenge: COSMOS: A city-scale programmable testbed for experimentation with advanced wireless," In Proceedings of the 26th Annual International Conference on Mobile Computing and Networking, April 2020

A. Koutsaftis, R. Kumar, P. Liu, S. Panwar, "Fast Inter-Base Station Ring (FIBR): A New Millimeter Wave Cellular Network Architecture" IEEE Journal on selected area of communication, Oct. 2019

Quantum Devices & Circuits

Y. Wang, Z. Jiao, Q. Yao, L.M. Balescu, Q. Liu, B. Tang, H.J.W. Zandvliet, "Structural and electronic properties of the α-GeSe surface," Surface science 686, 17-21, Aug. 2019

Huang, Z., Alharbi, A., Mayer, W. et al. Versatile construction of van der Waals heterostructures using a dual-function polymeric film. *Nat Commun* 11, 3029 (2020). https://doi.org/10.1038/s41467-020-16817-1

5G & 6G Applications

A. Srivastava, F. Fund, S. Panwar, "An experimental evaluation of low latency congestion control for mmwave links," in 2020 IEEE INFOCOM WKSHPS: CNERT 2020: Computer and Networking Experimental Research using Testbeds (INFOCOM 2020 WKSHPS CNERT 2020), July 2020.

Mohammad A. S., Kosta V., Bhargava M., "Enhancing Routing Protocol for Wireless Sensor Network to Advance Network Lifetime," Space Flight Center, USA, June 2020

P. Skrimponis, N. Makris, K. Cheng, J. Ostrometzky, Z. Kostic, G. Zussman, T. Korakis, and S. Borges Rajguru, "Evaluation: A Teacher Professional Development Program Using Wireless Communications and NGSS to Enhance STEM Teaching & Learning," 2020 ASEE Virtual Conference, June 2020

S. H. A. Shah et al., "Beamformed mmwave system propagation at 60GHz in an office environment" 2020 IEEE International Conference on Communications (ICC), pp. 1–7, June 2020

E. Rahimian, S. Zabihi, S.F. Atashzar, A. Asif, A. Mohammadi, "Surface EMG-Based Hand Gesture Recognition via Hybrid and Dilated Deep Neural Network Architectures for Neurorobotic Prostheses," Journal of Medical Robotics Research, Mar. 2020

M. Giordani, M., Polese, M. Mezzavilla, S. Rangan, and M. Zorzi, "Toward 6G Networks: Use Cases and Technologies," in IEEE Communications Magazine, vol. 58, no. 3, pp. 55-61, March 2020, doi: 10.1109/ MCOM.001.1900411

S. Shahtalebi, S.F. Atashzar, O. Samotus, R.V. Patelc, M.S. Jog, A. Mohammadi, "pHtnet: characterization and Deep Mining of involuntary pathological Hand tremor using Recurrent neural network Models," Scientific reports, Feb. 2020

M. Khosravi, S. F. Atashzar, G. Gilmore, M. S. Jog, R. V. Patel, "Intraoperative Localization of STN During DBS Surgery Using a Data-Driven Model," in IEEE Journal of Translational Engineering in Health and Medicine, vol. 8, pp. 1-9, Jan. 2020

T. Gathmann, S.F. Atashzar, P.G. Alva, D. Farina, "Wearable Dual-Frequency Vibrotactile System for Restoring Force and Stiffness Perception," IEEE Transactions on Haptics, Jan. 2020

M. Bernardinis, S.F. Atashzar, M.S. Jog, R.V. Patel, "Differential Temporal Perception Abilities in Parkinson's Disease Patients Based on Timing Magnitude," Scientific reports, Dec. 2019

C. Tunc, M. F. Ozkoc, S. Panwar, "Millimeter Wave Coverage and Blockage Duration Analysis for Vehicular Communications" 2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall), Honolulu, HI, USA, pp. 1-6., Sept. 2019

L.M. Optican, J.C. Rucker, J.R. Rizzo, T.E. Hudson, "Modeling gaze position-dependent opsoclonus," Progress in brain research 249, 35-61, Aug. 2019

J.R. Rizzoa, M. Beheshtia, A. Shafieesabeta, J. Funga, M. Hosseinia, "Mathematical Modelling in Motor Neuroscience: State of the Art and Translation to the Clinic, Gaze Orienting Mechanisms and Disease," Mathematical Modelling in Motor Neuroscience: State of the Art and Translation to the Clinic, Gaze Orienting Mechanisms and Disease, Aug. 2019

T. Baca, P. Stepan, V. Spurny, D. Hert, R. Penicka, M. Saska, J. Thomas, G. Loianno, V. Kumar, "Autonomous landing on a moving vehicle with an unmanned aerial vehicle," Journal of Field Robotics, Aug. 2019

Communication Foundations & Machine Learning

S. Dutta, A. Khalili, E. Erkip, S. Rangan, "Capacity Bounds for Communication Systems with Quantization and Spectral Constraints," IEEE International Symposium on Information Theory (ISIT), June 2020

A. Khalili, S. Shahsavari, M. A. Khojastpour, E. Erkip, "On Optimal Multi-user Beam Alignment in Millimeter Wave Wireless Systems," IEEE International Symposium on Information Theory (ISIT), June 2020

R. Lourenço, J. Freire, D. Shasha, "BugDoc: Algorithms to Debug Computational Processes" ACM SIGMOD, June 2020

S. Krishna, N. Patel, D. Shasha, T. Wies, "Verifying Concurrent Search Structure Templates" ACM SIGPLAN Conference on Programming Language Design and Implementation, June 2020

S. H. A. Shah, M. Sharma, S.Rangan, "LSTM-Based Multi-Link Prediction for mmWaveand Sub-THz Wireless Systems" accepted in 2020 IEEE International Conference on Communications (ICC), pp. 1–6, June 2020

M. Stachaczyk, S. F. Atashzar and D. Farina, "Adaptive Spatial Filtering of High-Density EMG for Reducing the Influence of Noise and Artefacts in Myoelectric Control," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, May 2020

J. Cirrone, M. D. Brooks, R. Bonneau, G. M. Coruzzi, D. Shasha, "OutPredict: multiple datasets can improve prediction of expression and inference of causality" Nature Scientific Reports, May 2020

A. Khalili, S. Shahsavari, F. Shirani, E. Erkip, and Y. C. Eldar, "On throughput of millimeter-wave MIMO systems with low-resolution ADCs," IEEE International Conference on Acoustics, Speech and signal Processing (ICASSP), April 2020

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