

Facilities, Equipment, and Other Resources

ACCESS will benefit from specific resources provided by the Core University Partners and our academic and other collaborators. Those resources and collaborations are listed here. The first four sections describe the Facilities, Equipment and Other Resources of the Core Universities and domestic academic partners. Section Five details the contributions of the unfunded collaborators, for example ACCESS' Senior Personnel, External Partners, and foreign universities.

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1. Key Research Facilities and Equipment

a. Testbeds

COSMOS Testbed in New York City

Background. The COSMOS project focuses on the design, development, and deployment of a city-scale advanced wireless testbed in order to support real-world experimentation on next-generation wireless technologies and applications. The project is part of the NSF Platforms for Advanced Wireless Research (PAWR) program and is supported by both the NSF and PAWR industry consortium. Rutgers University leads the project along with Columbia University and NYU. Other partners include New York City, City College of New York (CCNY), University of Arizona, Silicon Harlem, and IBM.



Figure 1: COSMOS Deployment Area and Node Types

The COSMOS architecture particularly focuses on ultra-high bandwidth and low latency wireless communication tightly coupled with edge cloud computing. The COSMOS testbed is being deployed in West Harlem between the Columbia Manhattanville and Morningside campuses and the City College Campus (see Figure 1 and Figure 2). This dense urban area encompasses 15 city blocks (between 120th St. and 135th St.). The testbed will consist of advanced software-defined radio nodes along with fiber-optic fronthaul and backhaul networks as well as edge and core cloud computing infrastructure integrated into an open programmable testbed architecture (see Figure 3). Unique mmWave radios (developed by IBM) will support the ultra-high bandwidth.

Figure 2 shows the project vision for full deployment (some locations are tentative and depend on availability of resources). It includes several Large nodes (beyond 5G base stations on rooftops with edge cloud capability, see Figure 6), Medium nodes (on lightpoles or on at building side), and over 100 Small nodes (static and mobile “users”).

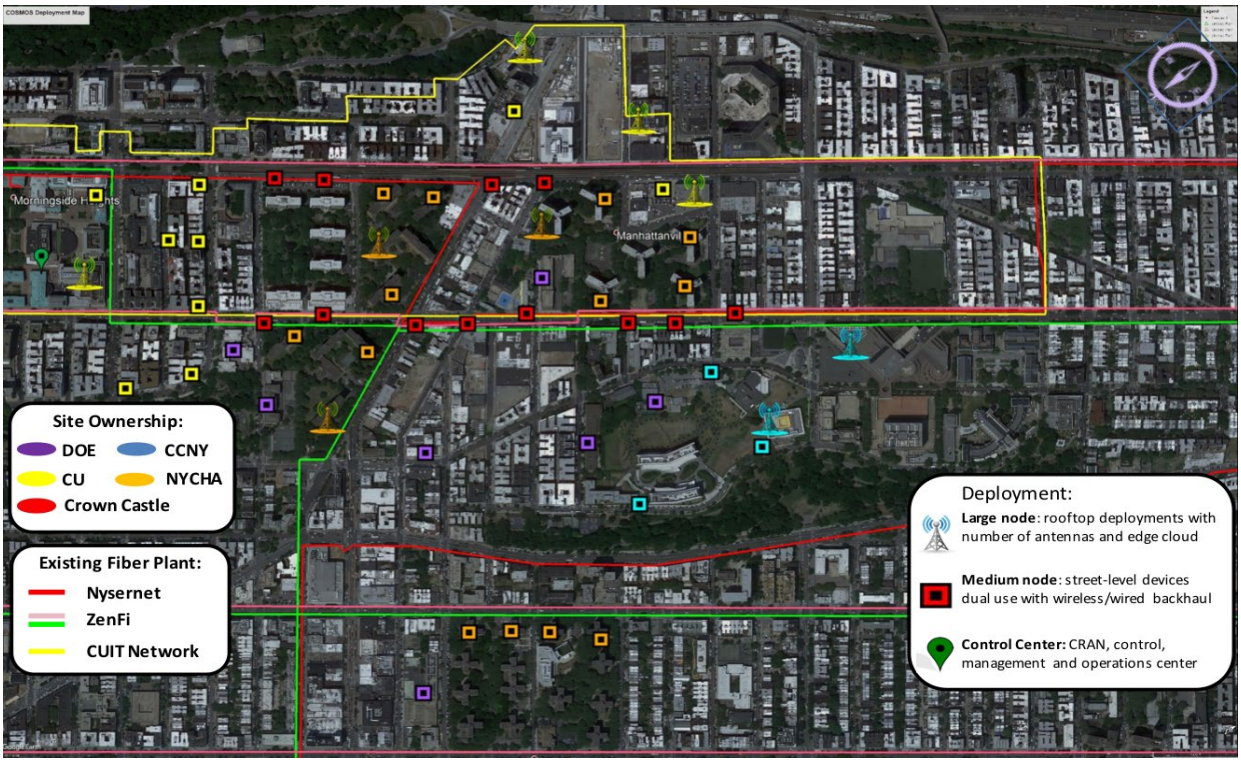


Figure 2: COSMOS Vision for Full Deployment in West Harlem (Node Locations are Tentative)

As Shown in Figure 4, the dark fiber runs shown in the Figure 2 will connect Large and many Medium sites so that the backhaul network topology can be configured over a range from full mesh to a ring or tree topology by using the multiple strands and switchable WDM routes (up to 96 wavelengths per fiber) within each fiber. ZenFi, Columbia, CCNY, and Crown Castle will provide fiber connectivity. It will be augmented by mmWave fixed wireless. Direct fiber connectivity will also be available to the main computing sites at Columbia, NYU, CCNY, and Silicon Harlem.

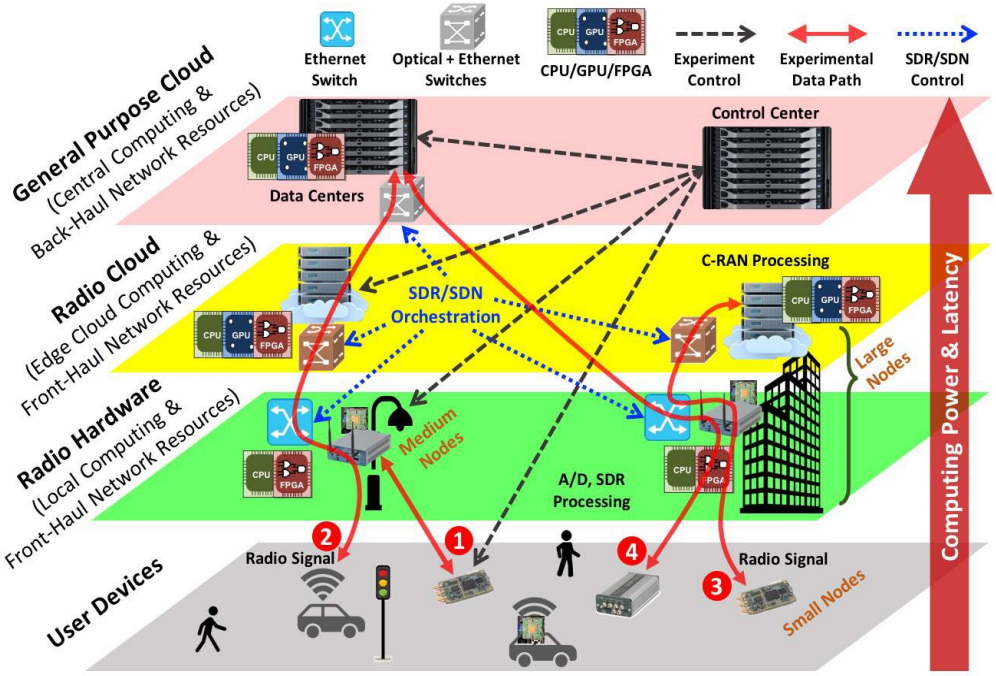


Figure 3: COSMOS System Architecture

Technology Building Blocks. The main technological building blocks of the testbed are detailed below.

SDR Node. The COSMOS radio node is an FPGA-assisted software defined radio similar to currently available platforms, but with significantly higher bandwidth capability and performance. Each node will have support for multiple RF front ends including <6 GHz and mmWave. This programmable node can be used to realize existing and future radio systems with wide bandwidths up to 1 GHz. See Figure 5 for more details.

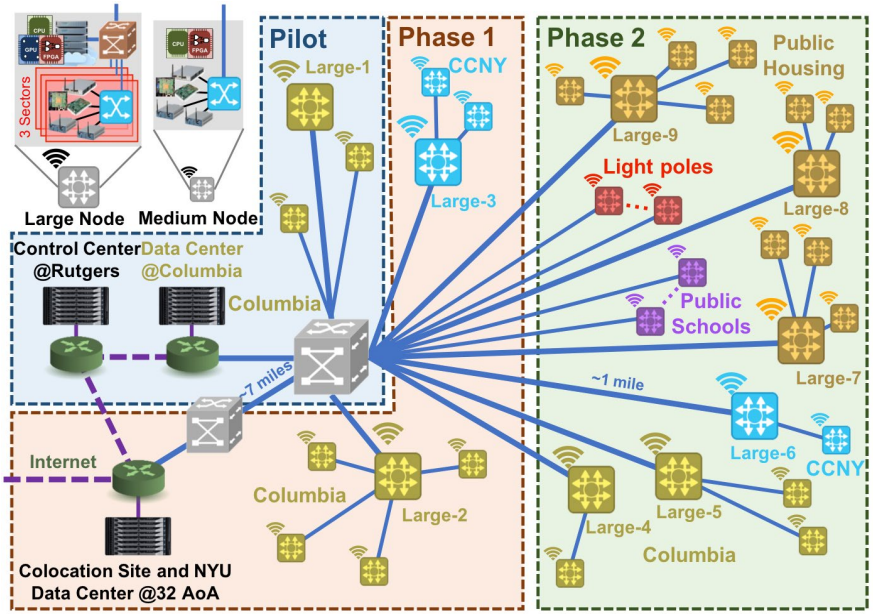


Figure 2: Planned Deployment Phases

mmWave Radio Platform. A key feature of the COSMOS platform is the integration of fully-programmable, high-performance SDR nodes with mmWave phased arrays. The 28GHz phased-array antenna module (PAAM), to be used for COSMOS features 4 tiled RFICs supporting 64 dual-polarized antennas, 8 beams enabling hybrid analog-digital beamforming and MIMO, ±50 degrees steerable beamwidth, +54 dBm saturated EIRP per beam/polarization, and up to 3 GHz IF.

Optical/SDN x-Haul Network. A unique, optical x-haul network is proposed to enable investigation of new high speed and low latency networking techniques to support emerging applications. The proposed x-

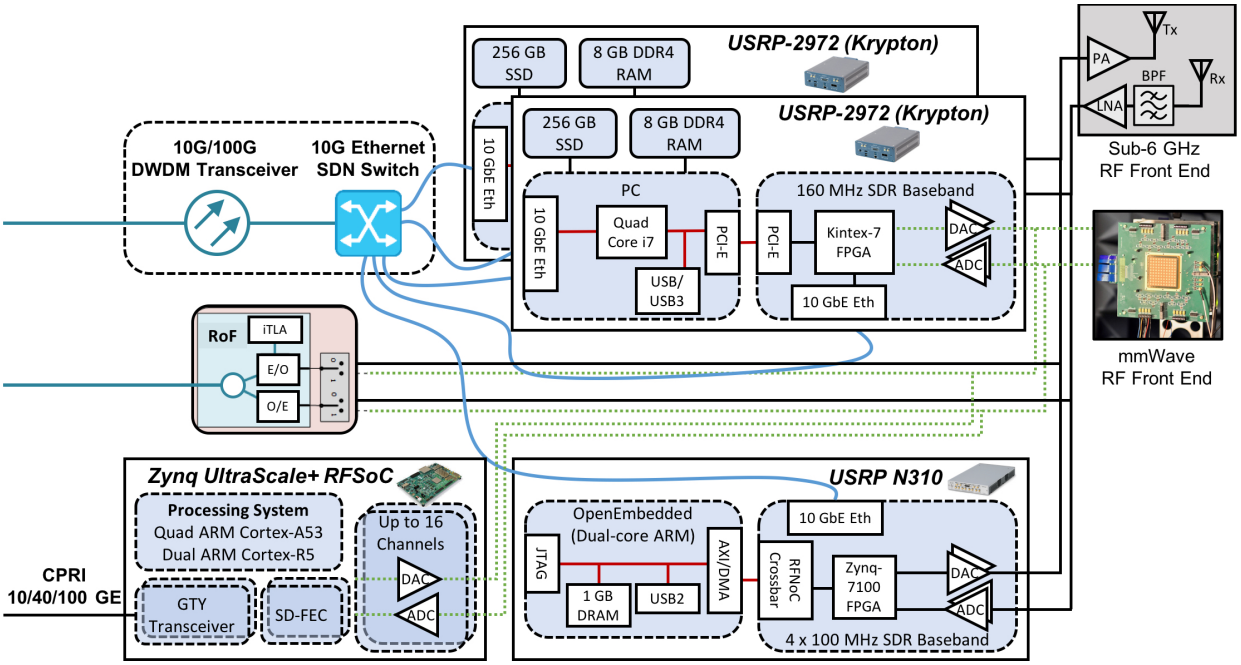


Figure 3: Architecture of an SDR Node

haul network uses wavelength division multiplexing (WDM) with wavelength switching in colorless, reconfigurable optical add-drop multiplexers (ROADM) to enable a wide range of topologies with different size

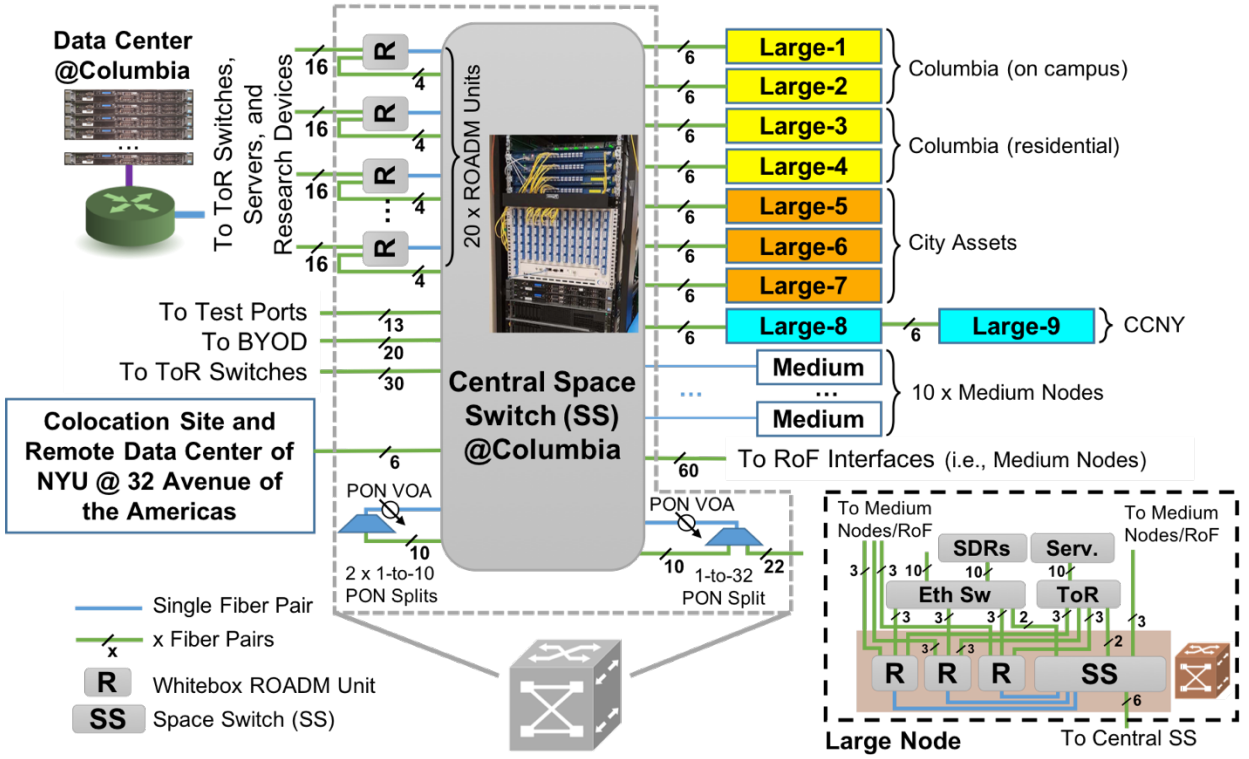


Figure 4: Optical X-Haul Architecture

front-haul, mid-haul, and back-haul networks. See Figure 6 for more details.

SDN Control. The SDN framework used in the COSMOS testbed integrates native and agent-based control of both wired and wireless resources, allowing SDN experiments to implement application driven control of the full set of optical and data networking technologies, as well as radio resource parameters such as power levels and frequency.

High-Performance Edge Cloud. The COSMOS architecture introduces a high-performance cloud as an integral part of the functionality of the SDR base station. Edge cloud processing sites will contain three kinds of computing resources, CPUs, GPU accelerators, and FPGAs in order to provide flexible and powerful signal processing capabilities, while also being able to handle general purpose computing tasks at the protocol layer and above. See Figure 7 for more details.

Testbed Control and Management Software. COSMOS control and management software is one of the critical technologies for successful operation of the testbed. The architecture is based on a central controller (similar in concept to SDN) which interfaces with experimenters, sets up resources for an experiment and manages experiment execution. The OMF testbed control

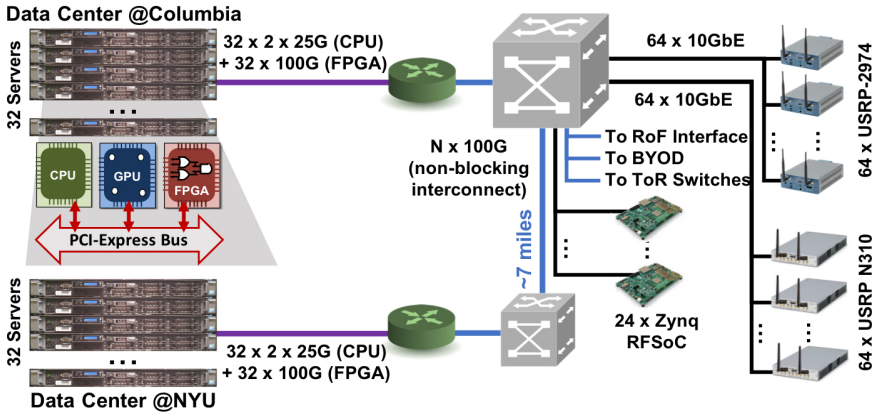


Figure 5: Edge Cloud Architecture

framework used in ORBIT (as described below, see Figure 12 and Figure 13) will be leveraged for this project.

RF Spectrum. COSMOS will support all key bands, with coverage in the 400 MHz to 6 GHz band, which also covers the new shared 3.5 GHz band that many have put forth as a key 5G band. A PAWS-compliant database will facilitate spectrum sharing with other COSMOS users and incumbents. The testbed will leverage the new program experimental licenses recently made available by the FCC.

End-User Devices. The testbed will incorporate a range of end-user devices including mobile data devices, AR/VR (augmented reality/virtual reality) equipment, high-resolution video cameras, connected cars and sensors/IoT devices. Devices requiring advanced wireless service will be attached to the small form-factor COSMOS radio nodes, while more mobile devices and IoT sensors with size/weight limitations will be supported by the base service layer provided by COTS radios.

Researchers will be able to run experiments remotely by logging into a web-based portal which will provide various facilities for experiment execution, measurements, and data collection. In addition to testbed design and deployment, the project's goals include the creation of an active user community with experimental researchers from both academia and industry, along with implementation of effective outreach programs aimed at education, the local community, and regional technology ventures.

While the testbed is designed to serve the research community, it will also serve as an important facility for the ERC given that 5 of the 7 universities participating in the ERC also take part in the testbed design, deployment, and operation.

COSMOS Testbed (City College of New York). CCNY is a testbed partner for **COSMOS** and will house Large nodes with directional antennae, Medium with omni-directional antennae, and Small nodes as well as optical switching and edge cloud infrastructure. COSMOS will be connected via dark fiber to the core optical switching at Columbia. In addition, CCNY has basic facilities for in-lab-scale experiments of wireless networking, security, and distributed processing: (a) a set of PCs, servers (Linux), switches and routers, and (b) a set of Wi-Fi access points and Ethernet ports.

Network Simulator/Emulator that are available include:

- Open Air Interface is to provide open source software and tools for 5G wireless research and product development that can run on general purpose computers.
- DETERNET which is a national testbed simulator for experimenting with networking and security issues. CCNY has an access to DETERNET and has been using it for research in networking and security issues.

The following test equipment for wireless communication systems are available:

Name	Specifications	Quantity	Use
RF spectrum analyzer	70004A	1	RF Spectrum Analysis
Network Analyzer	N5230A (20 Ghz)	1	RF Test
Signal Generator	E3630A	1	RF Test
Oscilloscope	Tektronix TDS 784C	1	Digital Signal Sampling
Analog Signal Generator	E8257D	1	Signal Sampling
Oscilloscope	HP 54503A	1	Digital Signal Sampling
Spectrum Analyzer	HP 8566A	1	Spectrum Analysis

Current Status. Initiated in April 2018, during the first year, major activities included (a) System design and technology development, (b) Pilot testbed deployment, and (c) Outreach.

Design and Development: The key technologies required to build the COSMOS system (for sub-6 Ghz operation) were designed and developed, including software defined radios for Small, Medium, and Large radio node sites (as illustrated in Figure 2), optical WDM switched network, cloud radio access network processing with FPGA and GPU assist, software-defined network infrastructure, and testbed management software.

Deployment: Following the completion of the development and prototyping of the technology components, the team effort moved to the development of an experiment sandbox and a pilot deployment. The pilot consists of three node sites (1 Large, and 2 Medium) on the Columbia University campus. The corresponding network infrastructure consisting of WDM optical switching for front-haul and back-haul with software-defined capabilities was set up within the campus. In addition, the city provided in-kind dark fiber connectivity to the NYU data center at 32 Avenue of the Americas. Pilot deployment has been completed with first demonstrations of capability conducted in May 2019 (see Figure 8).



Figure 6: Left: Large COSMOS Node Antennas Installed at Columbia; Center: Medium COSMOS Node; Right: Deployment of Fiber for COSMOS at the Intersection of 120th Street and Amsterdam Avenue

Future Work. Work in the upcoming year will include the completion of the mmWave technology components required to upgrade the radio nodes for 28 Ghz operation, continuing upgrades to each technology component (SDR, SDN, optical network, cloud and control software), release of the pilot system to early experimenters, and the deployment of Phase 1 system that includes nodes in Columbia University and CCNY along Amsterdam Avenue (see Figure 4). The project team will also conduct various test experiments on the COSMOS system (using the pilot and sandbox) until Phase 1 is released toward the end of 2020. The following phase will include extended deployment.

Integration with Local Community Efforts. Silicon Harlem, a COSMOS community partner, will take part in the ERC, is currently in the process of deploying three racks of 99 servers to set up a community edge cloud in Harlem. This effort is supported by Microsoft and is part of an ongoing NSF S&CC project in which Silicon Harlem and University of Arizona participate. This facility will connect to the COSMOS testbed and will provide resources in addition to the ones provided in Columbia, CCNY, and NYU.

Silicon Harlem is also currently initiating the 135 St Connect project which aims to enhance connectivity along the 135th St. corridor (135th St. is the northern border of the COSMOS testbed) and will provide an infrastructure to test wireless and community related applications in a corridor that includes numerous stakeholders (hospital, public housing, public library university, schools, police station, and the Schomburg Center for Research in Black Culture).

South Florida ACCESS Testbed in West Palm Beach, Florida

The South Florida ACCESS testbed will be located in the City of West Palm Beach. The city is one of three principal cities in the Miami Metropolitan Area, covering approximately 58 square miles, with approximately 110,000 residents, doubling in occupancy during weekdays. The testbed will build upon an existing infrastructure program led through Florida Atlantic University, with Dr. Hallstrom as PI, supported through the City of West Palm Beach, the Knight Foundation, and the Community Foundation of Palm Beach and Martin Counties. During the lifetime of the ERC, the testbed will reach each of the city's five districts. Initial installation and experimentation will focus on District Three, the hub of the city's bustling downtown.

The initial testbed serves two objectives: (1) The testbed will provide a foundation for understanding mobility patterns downtown and within other key areas. The focus will be on individual mobility patterns, at population scales. Mobility data will be fused with GIS content to annotate mobility origins, destinations, and routes (e.g., origin neighborhood, business type, degree of canopy cover). The resulting time-series data will enable the city to continuously monitor mobility impacts resulting from specific development initiatives, and to adapt those initiatives to optimize accessibility for residents. (2) The testbed will use the evolving dataset to learn the types of destinations (e.g., coffee shops, pharmacies, food banks) most frequently

visited by individuals. As residents move from one area of the city to another (or from another city altogether), the testbed will provide individualized recommendations on nearby destinations that are likely to be of interest. The concept is to learn the connections between people and place in the areas they most often frequent, and to use that knowledge to draw people to new places, and to establish new connections. The foundation of the platform is a Wi-EDGE-based monitoring fabric that captures human mobility patterns at the scale of an individual resident, with the capacity to aggregate across residents to establish population-wide patterns, and to monitor changes in those patterns over time. The initial implementation will rely on passive, anonymous monitoring of wireless signatures from cell phones and other smart devices, including Wi-Fi and Bluetooth signatures. Longer-term, elements of the NY testbed will be adopted (e.g., imaging devices, millimeter-wave radar).

The Wi-Edge monitoring will cover the heart of the downtown, with tendrils that stream out to reach other key destinations within the city, including the Tri-Rail station, and the city's historic Northwest. The former is a central mobility hub for commuters and visitors, and the latter is a culturally rich residential district undergoing redevelopment, with historically limited connectivity to the downtown area. Longer-term, the Wi-Edge installation will be mirrored at the Brickell Tri-Rail station in Miami, along Southwest First, with tendrils reaching out to key destinations in the surrounding area. The mirrored deployment strategy enables the transfer of person-to-place knowledge not only within the downtown area, but from Miami to West Palm Beach and vice-versa. Extending the Wi-Edge to the trains themselves is also a possibility, enabling even broader understanding of mobility patterns in South Florida.

The raw time-series data collected through Wi-Edge will be aggregated within a central store and enriched using GIS layers already available to the city. GIS enrichment will focus on individual paths and anonymous resident identifiers, tagging the physical attributes of each path (e.g., origin and destination type, canopy cover, sidewalk width), and the most common destinations of each individual (e.g., coffee shop, pharmacy, food bank). The resulting GIS-enriched dataset will serve as a powerful tool for monitoring and understanding mobility changes in the City of West Palm Beach resulting from infrastructure changes, business development initiatives, and other events, both planned and unforeseen.

The enriched dataset will also serve as a training reservoir for machine learning services that codify the connections among people and place by examining mobility sources, destinations, pathways, and dwell times. These connections make it possible to offer individualized recommendations to residents and visitors, drawing people to new areas within the city by offering recommendations consistent with the mobility patterns observed in other areas, including Miami. The technology implementation will initially rely on kiosks within the city, with messaging triggered via signature sensing, coupled to the main recommendation system. A visitor from Miami who occasionally visits a local pub might trigger a message recommending a stop at O'Shea's. A resident from the Northwest district observed to take long walks through her (hypothesized) neighborhood might be prompted to visit Centennial Square. Numerous other scenarios exist, from recommendations covering meals and entertainment, to recommendations covering public assistance and healthcare.

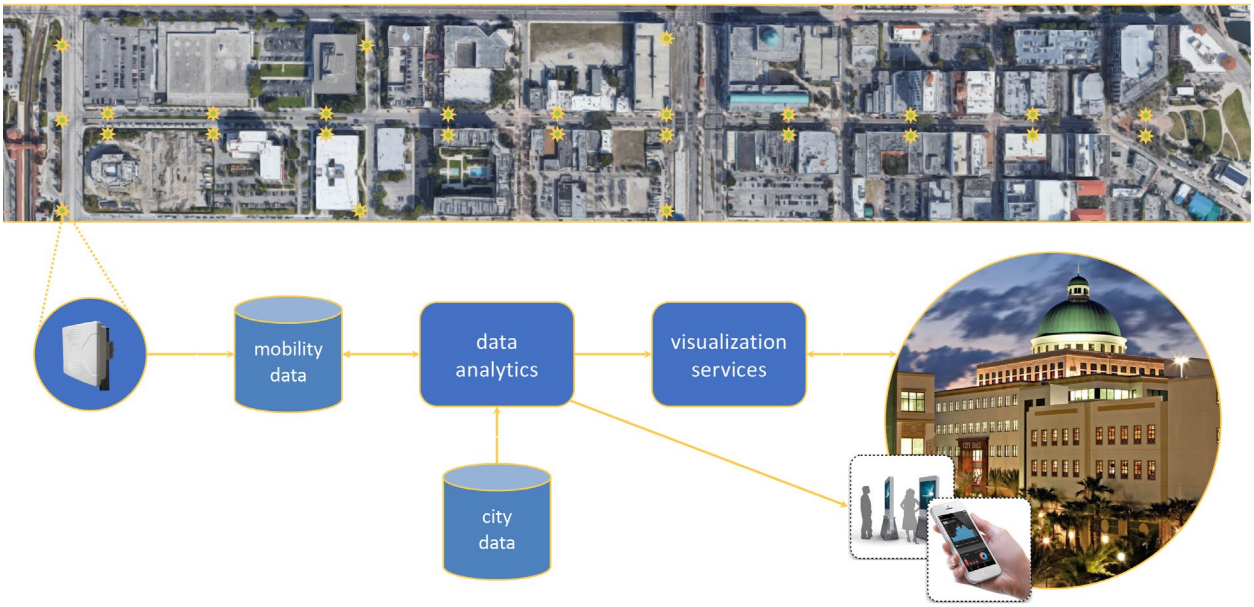


Figure 7: Overview of South Florida ACCESS Testbed

The preliminary installation plan for mobility sensing endpoints in District Three is illustrated in Figure 10. This plan is actively being revised in collaboration with the City of West Palm Beach, the Business Development Board of Palm Beach County, and other stakeholder groups.



Figure 8: Preliminary Installation Site for South Florida ACCESS Testbed

West Palm Beach Demographics. The population reflects the diversity of South Florida, with 58.9% of residents identifying as White, 34.3% of residents identifying as Black, 2.8% of residents identifying as Asian, and 23% of residents identifying as Hispanic or Latino. Approximately 27% of the city's residents identify as foreign born. A language other than English is spoken as the primary language in approximately 31.5% of homes. The median age of residents is higher than the national average, at approximately 40, with approximately 18.5% of residents over the age of 65. Approximately 6.6% of residents (>7,000 residents) under the age of 65 identify as having a disability.

West Palm Beach Emergency Response. For historic reasons, many dense urban areas are located on water, rendering examination of climate change impacts on StreetScapes important to study. Tropical storms, including hurricanes, pose one of the greatest threats to the City of West Palm Beach. Over the past four decades, these storms have increased both in frequency and intensity. Based on the most recent data available through NOAA, this trend is expected to continue, driven in large part by anthropogenic warming. Storm surge impacts are also expected to increase as sea levels continue to rise. As a point of reference, for the 2019 Atlantic season, NOAA forecasts 9-15 named storms, 4-8 hurricanes, 2-4 major hurricanes, and accumulated cyclone energy between 65%-140% of the median. Recovery costs to the federal government total, on average, $15.4B per year for Florida alone (more than half of total annual costs for the country). The Greater Miami Area, of which West Palm Beach is a part, is among the most vulnerable to tropical storm impacts.

Tropical storms pose an enormous, recurring threat to the City of West Palm Beach, with the potential to place significant strain on emergency response infrastructure and personnel. One of the most frequent impacts is damage to the electrical infrastructure, resulting in large-scale, potentially extended

blackouts. As a point of reference, in 2017, Hurricane Irma resulted in power loss to more than half of Florida's residents – with the most significant outages in the Greater Miami area, including West Palm Beach. In addition to the attendant infrastructure impacts (e.g., traffic signal outages, drawbridge outages, traffic monitoring outages, occupancy sensing outages), the loss of power affected cellular (and other wireless) communication infrastructure, with many residents unable to place or receive phone calls. This loss of communication poses an additional strain on responding emergency personnel. First responders and emergency managers would benefit from a hyper-local, infrastructure-lean communication network to support communication and situational awareness during emergency response efforts.

While hurricane force winds and flying debris pose a significant threat, the threat of flood damage is even greater. Perhaps surprisingly, flooding is responsible for the majority of hurricane-related deaths. In West Palm Beach, where sea level rise is already at the forefront of the city's planning efforts, storm-induced floods have the capacity to significantly hinder emergency response and evacuation efforts. With an average elevation of 13ft, the majority of the city is vulnerable to storm-induced flooding, including storm surge. These events have the capacity to rapidly alter the accessibility of structures and navigability of roadways – which tend to be narrow and one-way. Residents and first responders would benefit from a real-time route planning service, informed by hyper-local situational awareness (e.g., population clusters, debris presence, flood level, traffic volume).

b. Shared Laboratory Resources

Robert A.W. Carleton Laboratory (at Columbia University)

PI *Smyth* is the Faculty Director of Research of the Robert A. W. Carleton Laboratory, a 23,590 sq ft laboratory focused on the testing of civil engineering scale structures as well as the multiscale characterization of materials ranging from soft matter to metals with four full-time staff and several research scientists. Among its various facilities, ERC for ACCESS will make particular use of the Machine Shop and the Field Testing capabilities. Fortuitously, the facility's three floors with a high-bay renders it particularly useful for testing wireless equipment.



Figure 9: Robert A. W. Carleton Laboratory

The Machine Shop offers custom precision machining services. The shop specializes in ferrous and non-ferrous machining but is also capable of machining soft metals, polymers, and natural materials. A full assembly of heavy machine tools includes: Haas CNC Mill, Browne and Sharpe Reciprocating Precision Grinder, Cincinnati Horizontal/Vertical Mill with Acu-Rite DRO, Bridgeport Vertical Mill with Acu-Rite DRO, Clausing Colchester 15" Lathe with Acu-Rite DRO, various bandsaws, drill presses, and welding and grinding booths.

Field Testing Capabilities. The Carleton lab boasts extensive field instrumentation and analysis capabilities, both for dynamic applications. The lab's areas of expertise encompass the following instrumentation types for both a short and extended period of time:

- Dynamic strain instrumentation of large civil structures
- Multi-point autonomous GPS-synchronized triaxial acceleration instrumentation

- Multi-point differential GPS displacement instrumentation
- A large network of wireless accelerometers and battery powered NI data acquisition systems
- Low and high-amplitude vibration sensing, from DC to high frequency

The Carleton Laboratory has a rich history of supporting the New York engineering community with specialty testing services. It has served industry in a wide variety of problems, ranging from high-strength manhole cover to full-scale shoring system tests, as well as fatigue testing of suspension bridge wires and monotonic and cyclical concrete masonry block test courses.

The Wireless and Mobile Networking Laboratory (at Columbia University)

Professor Zussman's Wireless and Mobile Networking Laboratory is equipped with several NI USRPs, Android tablets, and various access points for wireless experimentation (mostly in the areas of wireless multicast and full duplex wireless, optical-wireless integration, and IoT). The lab currently houses a testbed of Energy Harvesting Active Networked Tags (EnHANTs) and a testbed composed of Texas Instruments energy harvesting nodes. Both testbeds include a light control system. The lab includes a testbed of a few generations of full-duplex software defined nodes developed within the Full Duplex wireless – from Integrated Circuits to Networking (FlexICoN) project. The lab houses optical switching equipment and has access to a dark fiber network (between Columbia and 32 Ave of Americas) facilitated by New York City as part as an ongoing EAGER project. This testbed is integrated with full-duplex nodes developed within the FlexICoN project and serves as a prototype for the optical-wireless infrastructure within the COSMOS testbed. The lab is connected via fiber to the COSMOS testbed optical switches and houses some of the COSMOS small nodes.

Intelligent and Connected Systems Lab (ICSL) (at Columbia University)

Directed by *Jiang*, this lab is dedicated to connected and embedded systems research and exploratory research, located inside the newly constructed Northwest Corner Building. In addition to general electronic lab instruments such as power supplies, multimeters, function generators, desktop computers, and oscilloscopes, ICSL has a number of maker equipment including a 3D printer, a modified high-resolution video drone, and a PCB printer with pickandplace and reflow capabilities. The ICSL maintains a collection of frequently used analog devices, sensors, actuators, wireless modules, and embedded platforms. Fume hoods and safety light curtains are also available.

Digital Video and Multimedia Lab (at Columbia University)

The Digital Video and Multimedia Lab (DVMM) directed by unfunded collaborator *Chang* is equipped with advanced facilities and tools for large-scale computer vision and machine learning research, including CPU/GPU clusters, storage servers (more than 130 TB), and large-scale video analysis tools. The DVMM has developed large video indexing and event detection systems, including NewsRover that has indexed more than 500,000 news video stories from live sources, and LarSDE that has analyzed video events from a network of more than 300 traffic cameras in NYC. The scalable indexing techniques developed by the lab have been used by law enforcement agencies to search more than 400M images in the area of human trafficking prevention. Recent research of the Lab also includes developing robust techniques for missing/corrupt data imputation across multiple sensory data streams from different times, locations, and devices.

Robotics Lab (at Cornell University, Cornell Tech Campus)

Professors *Ju* and *Lee* share a Robotics Lab with Professor Yoav Artzi in the Tata Innovation Center. The interactive Robotics Lab is a research environment for developing robotic technology and studying human-robot interaction. The robotics lab has 1089 sq ft of re-configurable space, flexible enough to allow researchers to set up different design experiments quickly and easily. It also allows researchers to investigate various aspects of design behavior in a detailed manner. The end results of the research carried out in the robotics laboratory are new patterns for interaction activity, data corpora for analysis and machine learning, new research methods and new design methods, behaviors or practices.

Human Computer Interaction Lab (at Cornell University, Cornell Tech Campus)

Professors *Azenkot*, *Nissenbaum* and *Ju* share a Human Computer Interaction Lab with Professors Nicola Dell, Mor Namaan and Tapan Parikh in the Tata Innovation Center. This space has over 1112 sq ft of space

dedicated to supporting community engagement activities, human participant studies, and design workshop activity. Specialized equipment is available for (1) developing and (2) analysis of interactive robots.

Virtual Reality equipment for use of simulation in development and testing of robot motion and interaction, PIs *Ju* and *Azkenkot*'s lab currently has 4 Oculus Rift VR Headsets augmented by Sterolabs ZED Mini Stereo cameras to prototype augmented and virtual reality applications for people with low vision, and also to enable simulation of interactions with robots and services intended for public use. We use Unity and Blender based simulation environments to preview and pre-test multi-robot multiperson interactions.

Video Capture and Analysis Equipment. The Future Automation Research Lab has video and teleoperation equipment specifically to enable in-the-field Wizard of Oz development and testing of human-robot interactions. The facilities enable rapid instrumentation and deployment of a wide array of robots in different human settings, for the purposes of encouraging iterative form and behavior experiments. We use iMotions video capture software to record and annotate participant video to enable analysis of patterns. Automatic recognition of facial expressions is made possible through the FACET module.

Instrumented Vehicle (at Cornell University, Cornell Tech Campus)

Professor *Ju* has an instrumented Toyota Prius V located in the garage of the Tata Innovation Center that is a research platform that makes possible on-road testing of sensing and networking, as well as in-vehicle driving studies with human participants.

Institute for Sensing and Embedded Network Systems Engineering (Florida Atlantic University)

The Institute for Sensing and Embedded Network Systems Engineering (I-SENSE) coordinates university-wide activities in Sensing and Smart Systems, one of four institutional emphasis areas identified in the university's 2015-2025 Strategic Plan for the Race to Excellence. I-SENSE is a technology clearinghouse for sensing, communication, data management, and data analytics technologies. The institute operates as an interdisciplinary hub, catalyzing research initiatives that crosscut disciplines, academia, government, and industry. An administrative core, a research core, and an engineering core support I-SENSE initiatives.

I-SENSE capabilities support two interconnected research areas. The first emphasizes *sensing*, ranging from the capture of environmental conditions in terrestrial and marine environments, to the capture of physiological and ambulatory signals in pedestrians and patients. The principal technical focus is on the development of embedded wireless sensor systems that enable transparent, real-time observation over long mission lifetimes. The second area emphasizes *smart systems*, leveraging networked sensors to provide real-time awareness of conditions, trends, and patterns, and to automate control of the sensed environment, vehicle, or object. This includes systems that support improved awareness of physical, social, and digital processes, among other complex information environments. Active areas of programmatic emphasis include *Infrastructure Systems*, *Marine and Environment*, and *Health and Behavior*.

I-SENSE includes 2 full-time administrative staff, 3 full-time engineering staff, 11 Faculty Fellows, approximately 40 affiliated faculty, approximately 30 graduate students, 3 postdocs, and approximately 15 undergraduate researchers. The team has access to approximately 4,000 sq ft of research laboratory space, state-of-the-art research equipment, and both college-level and centralized IT support. The team is supported through NSF, NIH, NIST, DOD, state, municipal, and industry partners.

I-SENSE capabilities include a strong operational component. The institute has a proven record of deploying and maintaining large-scale networked sensing installations distributed across challenging terrestrial and marine environments, over long mission timelines.

Mechanical Engineering Facilities. The Boca Raton, Harbor Branch, Jupiter, and Davie campuses provide robust support for mechanical engineering, machining, and fabrication. These facilities were designed to support world-class Ocean and Mechanical Engineering programs and are fully equipped with the tools and expertise necessary to machine and fabricate structures from a variety of materials, including wood, metal, polycarbonate, and other plastics.

SimSpace (New York University)

Torrens leads NYU's SimSpace, a 1,000 sq ft motion capture facility in the Media, Arts, and Technology (MTA) building in Downtown Brooklyn. SimSpace is equipped with 8 Vicon Vantage V5 infrared sensing cameras, 18 Vicon Vero V2.2 infrared sensing cameras, a Vicon Vue 1080i color camera, a Quanergy M8 LiDAR range-finding device, and a Pixy collision detection camera. The SimSpace is also equipped with a

HTC Vive Virtual Reality tracking system and headset, and a Microsoft HoloLens Augmented Reality headset for immersive visualization. The SimSpace is housed in NYU's Center for Urban Science + Progress with connections to NYU's Media and Games Network (MAGNET) in downtown Brooklyn, with broader access to addition motion capture facilities using Optitrak sensing systems.

Center for Urban Science and Progress (New York University)

New York University's Center for Urban Science + Progress (CUSP) occupies two full floors of 370 Jay St. located in Downtown Brooklyn, adjacent to the NYU Tandon School of Engineering. Within its 55,000 SF, CUSP houses seven labs: one with a 500-Gigapixel visualization wall; a lab for the Sounds of NYC project is equipped with a Genelec 8030.LSE PowerPak 5.1 Surround Monitoring System; the Quantified Community's lab; the Urban Observatory control room; a secure data access room; an 18-rack server room, and a shared electronics lab with optical benches.

CUSP specifically collaborates with more than 15 city agencies and divisions, including: Department of Transportation, Department of Buildings, Department of Sanitation, Department of Citywide Administrative Services, Department of Design and Construction, Department of City Planning, Department of Health and Mental Hygiene, Department of Environmental Protection, Department of Information Technology and Telecommunications, Department of Parks and Recreation, Police Department, and the Fire Department. Under this agreement, CUSP works with city agencies to develop specific agreements facilitate the exchange of data, documents, and records from the City to CUSP. CUSP utilizes aggregate data or de-identifies data containing personal information in accordance with current generally accepted principles and best practices.

Choromanska Lab (New York University)

The *Choromanska* Lab is located in Downtown Brooklyn. The Lab maintains 12 devboxes, each equipped with multicore CPU (6 to 32 cores), 128 GB RAM, and 4 GPUs (GTX1080 or GTX1080Ti). The Lab has access to the NYU HPC compute cluster. The Lab also maintains two robotic platforms based on one-sixth scale RC cars. The first one is equipped with 3 cameras and Jetson TX2 (embedded AI computing device). The second one is equipped with 3 high dynamic range cameras, LiDAR (Velodyne VLP-16), and Drive PX2 (autonomous vehicle computing platform). The Lab also has a collaboration with NVIDIA, with further conditional access to autonomous driving platforms in Holmdel, NJ.

Wireless Implementation Testbed Lab (New York University)

The Wireless Implementation Testbed Laboratory (WITest), directed by *Korakis*, is located at the NYU Tandon School of Engineering's main campus in the MetroTech Center area. The lab focuses on experimental inspired research based on implementation of new algorithms and mechanisms with open source software. The WITest facility consists of wireless and wired resources that are modular, reprogrammable and can be setup to implement new experimental scenarios. The control and management framework of the WITest infrastructure are based on open software frameworks (OMF/OML).

WiFi Open Source Drivers Testbed. The WiFi testbed of the lab consists of 30 wireless nodes. Each node consists of an Intel-based multi-core processors, 4 GB of RAM, 80GB of hard drive, several I/O ports (Ethernet, USB, etc), a Bluetooth interface, two commercial WiFi cards each and an LTE USB dongle. The WiFi cards are based on the Atheros chipset that is paired with the open source drivers MADWiFi, ATH5k, ATH9k, ATH10k. By modifying the open source drivers, researchers can build new MAC and network layer protocols. The testbed is remotely accessible and is managed and controlled by OMF (cOntrol and Management Framework).

Software Defined Radio (SDR) Testbed. This testbed consists of open source radio wireless platforms. More particular, it features 8 Open-Access Radio Platform (WARP) designed and build by Rice University and 10 Universal Software Radio Platform (USRP2) from Ettus Research operated using the widely adopted GNURadio software platform. Using the SDR testbed, researchers can implement new mechanisms in both the physical and MAC layer.

WITest has been a leading member for the GENI open 4G wireless campus network project which has led to deployment of open-API WiMAX/LTE Base Stations at ~13 campuses across the US. These open Base Stations enable large-scale mobile networking experiments covering a wide geographic area. WITest currently operates two WiMAX and one LTE Base Stations that are accessible to researchers through an online scheduling system. Up to 10 more LTE Base Stations can be instantiated through the

use of open source software (OpenAirInterface) that run on the SDR units. WITest Base Stations are also connected to the GENI/Internet 2 wideband backbone network, which can be used to set up and conduct wide-area network experiments.

WINLABs (Rutgers)

The Electrical and Computer Engineering Department and the Computer Science Department have extensive laboratory and equipment facilities to support research activities in the general areas of:

- Software defined radio (SDR) hardware and software
- Emulation, simulation, and analysis of large scale complex wireless systems
- Cross-layer wireless networks protocol design
- Next-generation Internet and software-defined networking (SDN)
- Securing wireless systems using physical-layer characteristics
- Security, privacy, and robustness of wireless sensor networks/IoT

Computer WINLAB has the capability of fabricating prototype devices and printed circuits with KandS wedge bonder, SMT rework equipment as well as various FPGA development platforms and programmable embedded platforms (APTIX, GNU radio USRP, etc.). The laboratories are also equipped with various network analyzers, RF spectrum analyzers, high-speed digitizing oscilloscopes, function generators, power meters and other general purpose laboratory equipment (shielded enclosures, antennas, etc.). WINLAB also maintains state-of-the-art computing facilities including 12 compute servers, 4 storage servers, a 20-processor HPC cluster and 12 high-performance workstations, and over 200 networked computers and laptops. The center maintains software licenses for a variety of simulation tools including Matlab, OPNET, all major hardware design tool chains including Cadence, Synopsys and Mentor Graphics, as well as specialized wireless communications tools like EEs of EDA, Wise, XFDTD and numerous other public domain simulation tools.

Office WINLAB's research and administrative operations are located at the Rutgers Technology Centre, at 671 US Route One, just south of the Rutgers Cook Campus. The Technology Centre provides meeting rooms and facilities for hosting workshop-oriented events and is capable of supporting roughly 70 attendees. Faculty advising offices and a satellite administrative office are also located on the 5th Floor of the CORE building in Busch Campus near the Electrical and Computer Engineering and Computer Science departments. Total floor space at these two locations is approximately 20,000 sq ft including about 7,000 sq ft of laboratories.

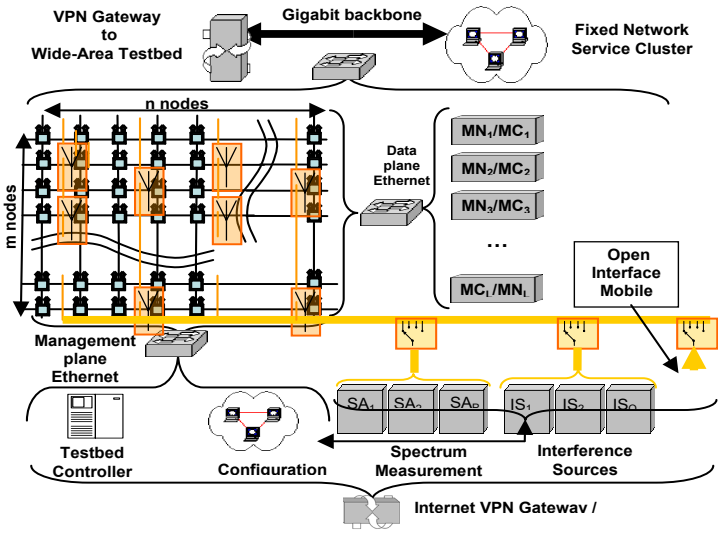


Figure 10: ORBIT radio grid Architecture

The ORBIT *open access testbed for next-generation wireless networking* at WINLAB provides a "real-world" experimentation means that is capable of capturing the complexity of the wireless channel and its impact on the protocol stack. ORBIT consists of a large-scale radio grid emulator (an array of 20x20 programmable nodes) as in Figure 12 and Figure 13 with *multiple* 802.11a/b/g and other interfaces. The ORBIT testbed has been extended to support additional wireless technologies beyond 802.11, and in particular the testbed includes several GNU Universal Software Radio Peripheral (USRP) software radio boards attached to ORBIT nodes via a USB2.0 interface. In addition to the basic grid, ORBIT provides radio mapping algorithms and a mobility emulation server that allows users to emulate real-world wireless scenarios in a controlled, reproducible experimental setting. ORBIT software allows experimenters to manipulate wireless interfaces (such as the

GnuRadio/USRP) to choreograph experiments, and to collect large volumes of performance data. Beyond the core testbed, ORBIT is augmented with additional experimental resources.

- RF instrumentation: The ORBIT grid includes equipment for measurement of radio signal levels and to create various types of artificial RF interference (white noise, colored noise, microwave oven like noise etc.) inside the grid. The interference generator is based on the RF Vector Signal Generator while the spectrum measurements are done using Vector Signal Analyzers.
- Network Monitoring**:** An independent WLAN monitoring system (using equipment donated by Aruba Networks) provides a MAC/network layer view of the radio grid's components using a number of WLAN "observers" spread across the system.
- Support Servers**:** The testbed's backend equipment includes several front-end servers for web services, experiment support and data storage. The database servers support multi-terabyte storage capacity. There is also an SDN-based Ethernet switching array with ~1400 ports necessary to switch traffic from 3 x 400 grid node interfaces and the servers. The ORBIT backend system includes a "GENI Rack" cluster for cloud computing experiments, and has been upgraded to "cloud RAN" capability under an NSF CRI project which started in 2015.



Figure 11: ORBIT Radio Grid at RU Tech Center Building



Figure 12: WiSER SDR Platform

WINLAB facilities also include several software defined radio platforms for cognitive radio and clean slate wireless system research. WINLAB's cognitive radio prototype's architecture is based on four major elements: (1) MEMS-based tri-band agile RF front-end, (2) FPGA-based software defined radio (SDR); (3) FPGA-based packet processing engine; and (4) embedded CPU core for control and management. These components are integrated into a single high-end prototype system (WINC2R) which leverages an SDR implementation from Lucent Bell Labs as the starting point. A second platform, the WiSER cognitive radio platform (depicted in Figure 14), is being developed at WINLAB as part of an NSF community research infrastructure project and is currently available for wideband SDR experimentation over ORBIT.

WINLAB is the host organization for the GENI WiMax/LTE wireless deployments, which provides WiMax and LTE basestations with open-APIs to about ten campus sites across the USA (with Rutgers-WINLAB serving as the lead. See figure 15). These cellular base stations enable large-scale mobile networking experiments covering a wide geographic area. The GENI campus deployment at Rutgers also includes programmable OpenFlow switched networking across various sites, a GENI "computing rack" used for cloud server experiments, and Gbps connectivity to the GENI/Internet2 backbone. WINLAB was selected as satellite NSF CloudLab site, and currently hosts a CloudLab computing cluster with connectivity to GENI and Internet2.

The WINLAB building is instrumented with active RFID tags throughout offices and lab areas in order to facilitate Internet-of-Things research. The active RFID tags are low power transmit-only devices that were developed at WINLAB and are connected to a set of sensor network gateways. The setup also includes the OWL middleware platform which enables context-aware sensor/IoT application development.

WINLAB is currently leading the COSMOS project which will deploy the testbed at Columbia, CCNY and the NYU Data Center, all in New York City. WINLAB@Rutgers University maintains close contact with the wireless industry, government, and other universities. The center disseminates research results to the aforementioned entities on a half-yearly basis. In support of this effort, WINLAB maintains a full-time administrative and engineering staff.



Figure 13: GENI SPIRAL-II WiMax deployment in North Brunswick, NJ

c. Data and Computational Resources

Columbia

Computing. Through its relationship with the Data Science Institute, the ERC has access to several High Performance Compute clusters housed in Columbia's centrally-managed Shared Research Computing Facility (SRCF). Terremoto is comprised of 110 servers (2640 cores) and eight Nvidia V100 GPU servers. All Terremoto servers are equipped with Dual Intel Skylake Gold 6126 processors. Habanero resources consist of 302 servers (7248 cores), Dual Intel E5-2650v4 Processors, and 27 Nvidia GPU servers with P100 and K80 GPUs.

Additionally, the Institute acquired from Yahoo! 40 HP compute servers to be used to support Institute research projects. These machines are configured with HP DL160 G5 2 x L5420 CPUs, 16GB of RAM and 1 x 1 TB 7.2K SATA Disk. Shared **storage** is available through a Network Appliance storage file server. Through the Computer Science department, the ERC has access to computing infrastructure consisting of a data center for computational, storage and VoIP services, one large student laboratory, featuring 18 Windows machines and 33 Linux towers each with 2 Nehalem processors, 8 cores and 24GB memory; a remote Linux cluster with 17 servers each with 2 Xeon processors and 4GB memory, and a number of computing facilities for individual research labs. The data center houses 14TB of Network Appliance file servers, a compute cluster consisting of a Linux cloud with 32 servers each with 2 Nehalem processors, 8 cores and 24GB memory.

This cloud can support approximately 5,000 of VMware instances. Additional computing facility includes 8 Intel Linux servers with 8 processors and 16GB memory each and 3 Sun Fire 280R servers, a 3Com VoIP system, and departmental load balanced web cluster with 6 servers and business process servers, an online backup server with 40TB capacity, along with supporting servers that provide print services, LDAP, DHCP, DNS, tapes backup and software distribution to the department. The data center is internally connected via Gigabit Ethernet and accesses the Internet and Internet2 via the campus fiber network. The University provides 802.11b coverage for most of the campus.

Network. Columbia University Information Technology maintains Columbia's commodity Internet connections that include 1 GB/s via Level 3, 5 GB/s via Cogent and 100 Mb/s via RCN (for RCN residential cable modem customers). Columbia's research and education network connections include a NYSERNet NYC and statewide regional optical network ("dark fiber"), a 1 GB/s connection to NYSERNet's IP network and from there to Internet2 and National Lambda Rail (NLR) packet net.

Cornell

Computing. Cornell Tech currently utilizes the facilities of the Computer and Information Sciences department on the main Ithaca campus to support general academic and research needs. This well staffed center includes:

- Over 1500 computer systems
- Red Hat Enterprise Linux compute servers
- Ubuntu Linux available for Robotics and other advanced needs
- A dozen Linux compute clusters of varying capacities and availability
- FRACTUS mini-cloud • Over 120 TB on-line storage (SMB/NFS)
- Three raised floor data center facilities, with a total of approximately 300 KV of 240 volt 3 phase power

Encrypted Data Storage. All videos streams and study data are encrypted and stored on network attached storage (NAS) drive residing in the Tata Innovation Center at the Cornell Tech campus. The data is backed up onto Network Attached Storage in a different building on the same campus. PI Ju has extensive experience with studies involving the capture of heterogeneous, multi-viewpoint data that needs to be synchronized to enable potential machine learning applications, and will be responsible for developing participant data workflows to synchronize, ingest, store and back up human participant study data.

Florida Atlantic University

Computing Laboratories. Faculty and students have access to state-of-the-art, open computing laboratories throughout campus. The College of Engineering and Computer Science provides additional access to five specialized computing laboratories for engineering students. Florida Atlantic's Office of Information Technology centrally supports these university facilities, with additional support through the college's Technical Services Group. Similarly access to modern computing laboratories supports coursework, after-school programs, and independent inquiry. All ACCESS personnel will have access to appropriate office space, modern desktop computers, and network connectivity.

Data Centers. As part of Florida Atlantic's comprehensive cyberinfrastructure plan, FAU has significantly expanded cloud and high-performance computing resources in recent years, with investments focused on the Boca Raton, Jupiter, and Harbor Branch data centers. **Boca Raton:** The 1,900 sq ft data center in Boca Raton hosts the university's private cloud, administrative, and compute servers. This includes 41 Hyper-V hosts running 347 virtual machines, and 39 VMware ESXi hosts running 304 virtual machines. Data storage is managed via a NetApp SAN providing 280TB of SAS storage, archived to dual tape libraries. Mission critical services are duplicated at the Northwest Regional Data Center in Tallahassee via the Florida Lambda Rail. **Jupiter:** The 400 sq ft data center on the Jupiter campus is similarly designed to support university-wide research and education. It serves as a dedicated high-performance computing center providing 4,560 compute cores, 18 Intel Xeon Phi accelerators, and 81 GPU accelerators to the university community. The Jupiter data center remains a focal point for future growth, with capacity for approximately 6,400 cores, and over 1PB of storage. **Harbor Branch:** The 288 sq ft data center on the Harbor Branch Oceanographic campus was established to support the growing computational demands of the 140 scientists and engineers who operate out of this world-renowned facility. This high-performance computing center provides local access to 512 cores, approximately 1TB of memory, and 48TB of storage.

Network Infrastructure. A recent NSF award (OAC-1541330) supported a major upgrade to Florida Atlantic University's networking infrastructure, establishing a new 10Gb science and engineering DMZ spanning the Boca Raton, Jupiter, and Harbor Branch campuses. Individual campuses rely on a hub-and-spoke design. The networking core on each campus operates at 10Gb, with 10Gb links from the core to buildings that house data-intensive research (e.g., electrical engineering, physics, computer science), and 1Gb links to other buildings. For access to computing and data storage resources made available through the Sunshine State Education and Research Computing Alliance, the Boca Raton core is connected to the Florida Lambda Rail via a 10Gb link. Wireless infrastructure on the Boca Raton campus relies on over 1,600 wireless access points, the majority of which offer 802.11N connectivity, with the remainder providing 802.11G connectivity. Both encrypted (WPA2 Enterprise) and unencrypted access are supported, with limitations on the computing resources that may be accessed through an unencrypted connection.

NYU CUSP Computing

CUSP's physical computing resources are housed in a dedicated server room in CUSP's Brooklyn office equipped with 20 HADOOP nodes each with 24TB of disk, 256GB of RAM, and 64 AMD cores; 1 management node; 2 (high memory) server nodes, each with 1GB of RAM and 32 Intel cores; 2 (utility) serve nodes, each with 32GB of RAM and 8 Intel cores; 10GB Ethernet networking for the cluster; and an IBM General Parallel File System supported by a two server configuration and approximately 1PB raw storage.

CUSP leverages a diverse range of existing, emerging, and new data flows, including data generated by and/or collected by the City of New York; sensor data, both from the City and from networks developed by CUSP for research; and novel data streams collected by CUSP researchers.

d. Headquarters

The ERC for ACCESS Headquarters will be located within a new space in Manhattanville which the Columbia Fu Foundation School of Engineering and Applied Science (SEAS) is creating to also house a Research and Education Center (REC) for FinTech, Business Analytics, and Artificial Intelligence. The leaders of the REC are very enthusiastic about the synergies the ERC for ACCESS would bring. Within the 10,000 sq ft space at 2276 12th Avenue adjacent to the new Manhattanville Campus, REC has identified three offices (100 sq ft each), approximately 800 sq ft of space for office cubicles (10 students/postdocs) as well as a 16 person dedicated (460 sq ft) conference room for the ERC for ACCESS. In addition to the dedicated spaces, the ERC can use three smaller meeting spaces as well as two large reconfigurable spaces which can be connected by rolling back a partition. These two spaces each accommodate over 50 occupants for a combined capacity of over 100 and will serve as the primary training and outreach facility, in addition to providing space for visiting FAU ACCESS faculty, post-docs and students.

The location of the Headquarters space in West Harlem makes it highly accessible to the community. The headquarters is located just next to the iconic Manhattanville viaduct and also directly across the street from the current incarnation of the famous Cotton Club jazz bar. Due to its location at an important intersection (125th Street and 12 Avenue), the headquarters offers the potential to install COSMOS nodes and run some wireless (and other sensor acquisition) experiments directly from the roof of the building.

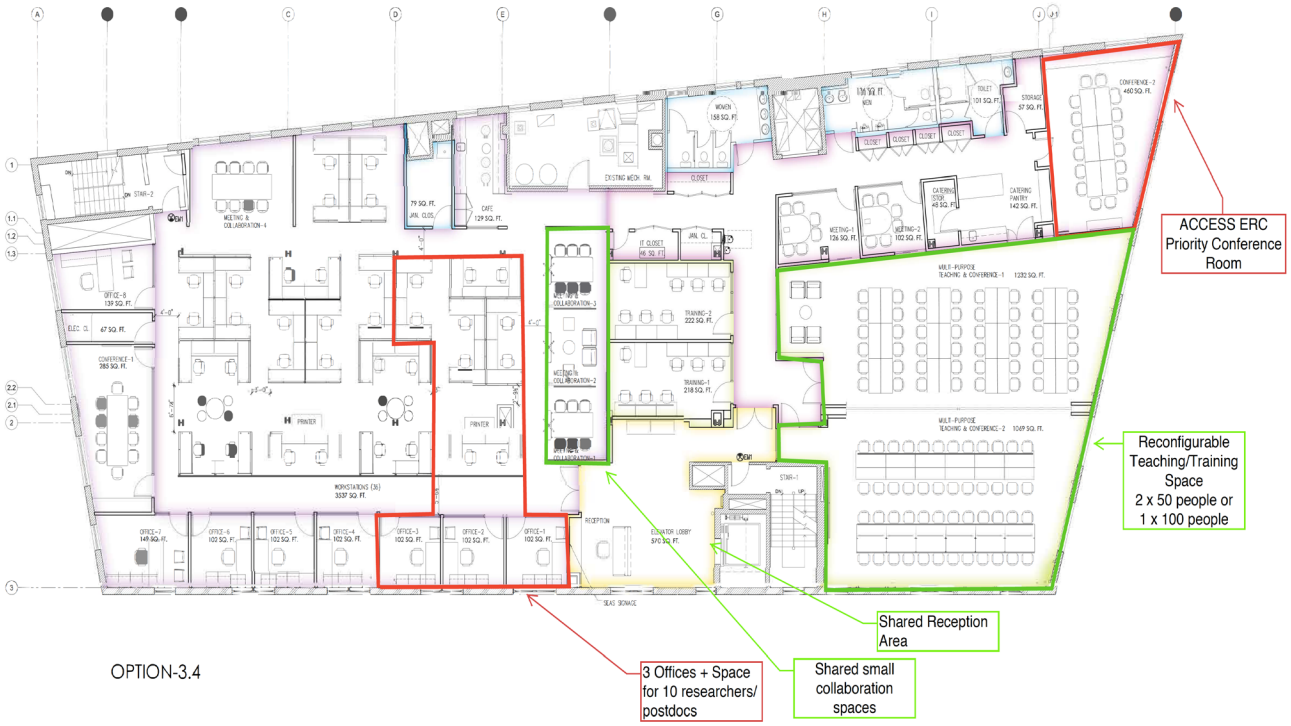


Figure 14: Planned Headquarters Space

ACCESS can also use the facilities of the Data Science Institute which is housed within 44,000 square feet of multifunctional space at Columbia University. This space includes faculty offices, 25-person and 15-person conference rooms, student work stations and collaborative meeting spaces, all designed to promote a collegial and interactive physical community around data science and to encourage interdisciplinary approaches to research training. The Institute's support staff assists with the financial management of the project, as well as ACCESS' educational and outreach activities.

NYU. In addition, NYU has pledged to provide space for the ERC team of faculty and students to work together in approximately 1,000 square feet of office and lab space in the newly-renovated hub for Media, Arts, and Technology in Brooklyn's MetroTech district, which is well-placed in a vibrant mixed-use streetscape of office, retail, transport, cultural, and civic activity in downtown Brooklyn. Along with access to NYU's CUSP facilities (including a double-height, 104-person seminar room; two study areas for Master's students; nineteen conference rooms and collaboration spaces, including one 28-person conference room, one 16-person conference room, three 12-person conference rooms, two 10-person conference rooms, four 5-person collaboration spaces, and eight 2-person collaboration spaces), this dedicated space will allow ACCESS to rotate meetings so as to facilitate attendance by undergraduates, graduates and post-docs from NYU and Cornell more easily.

e. Cyberinfrastructure

ERC for ACCESS will be headquartered in a new space that is being designed specifically to support both physical and virtual collaboration with conference rooms, training rooms, and advanced audiovisual equipment. In addition, the headquarters space will accommodate visitors from FAU. We are fortunate that the vast majority of the team members are local, facilitating easy exchange, and we have already discussed rotating various meetings among the various NYC universities to encourage participation of all students.

The planning grant and preparation of this proposal prompted the ERC Team to deploy various communications tools such as Slack, Google Drive etc., and Zoom for regularly scheduled meetings. We will continue to exploit these tools as well as others. ACCESS can leverage a contract that Columbia recently signed with **Redivis**, a company arising from the needs for reproducible data sharing. A web-based platform that is designed to host, vend, and query large datasets of diverse profiles, Redivis has developed a functionality

within a searchable and researcher friendly interface that promotes the sharing of data and code. The ACCESS team will utilize Redivis, with critical administrative and technical support from Columbia University Information Technology (CUIT). The partnership will develop standardized and accessible modalities for data sharing that are essential to further disseminate knowledge and facilitate education. Columbia, Cornell and NYU as well as CCNY all belong to **NYSERNet** (New York State Education and Research Network) which is a non-profit Internet Service Provider in New York State. It mainly provides Internet access to universities, colleges, museums, health care facilities, primary and secondary schools, and research institutions. NYSERNet was founded in 1986 as the first regional state-wide IP network in the United States. ERC for ACCESS will develop a web-site with sections for both external audiences and internal team members. The principles of Team Science shall guide the development and be supported by the experienced Data Science Institute Team.

2. University-based Facilities, Equipment, and Other Resources for Workforce Development

In addition to teaching its students and postdoctoral fellows how to perform fundamental, applied and translational research, ACCESS core universities have a variety of programs to provide critical complementary skills. This section focuses on developing ACCESS' students and postdocs. Other Resources to support our Workforce Development objectives outside of the Universities are addressed in Section 5 below.

a. Research Rigor and Reproducibility

Columbia has demonstrated leadership in developing a culture that values research quality and spearheaded a public forum. In 2016, and subsequently again in 2019, Columbia organized *A University Symposium: Promoting Credibility, Reproducibility and Integrity in Research*. In each case, Cornell, NYU and City University were among the six New York City research institutional co-hosts. This day-long symposium engaged the research community in a robust discussion of reproducibility and integrity with leading experts, high-profile journal editors, and funders. Over 300 attendees from 16 institutions in 2016 and 25 institutions in 2019 attended including Faculty/Researchers, Research Administrators, Students, Postdocs, and other. ACCESS will take advantage of the lead Institution's Research and Data Integrity (ReaDI) Program seeks to enhance research integrity, data management, and data quality across the institution. The ReaDI Program engages proactively with Columbia's research community in three ways:

It maintains a wide-ranging, web-based **repository of essential resources** and tools to support robust science across the research lifecycle, from experimental design through data collection and management, to analysis and publication. As Monya Baker points out in her 2016 *Nature* article, finding these types of resources challenges many researchers, but the ReaDI Program offers a one-stop-shop for authentication methods, information on statistical consulting services, discipline-specific literature on reproducibility, pre-publication checklists, and many other items.

It provides **outreach and training** on topics including data management, safeguarding research and data integrity, and rigor and reproducibility. The ReaDI Program proactively reaches Columbia's graduate students at resource fairs, orientation presentations, and department-specific seminars. New faculty orientations also highlight the Program.

It offers **individualized consultations** on data management and good laboratory practices. These consultations are available to principal investigators at all levels, and are customized to meet the principal investigator's needs and to maximize efficiency and research quality.

b. Teaching and Learning

ACCESS will tap each of the Core Universities' resources for Teaching and Learning to augment training of its students and postdocs.

Columbia

Columbia's Center for Teaching and Learning (CTL) employs over 40 full-time administrators with expertise in training faculty and graduate students – specifically those within engineering and the natural sciences – to continuously develop their pedagogical capacities.

Faculty and students can begin their semester by attending teaching orientation to learn evidence-based strategies they can implement on the first day of class. Fellows can participate in microteaching sessions to receive direct feedback and support from their peers; request Mid-Course Reviews with trained peer consultants who can help solicit feedback from students; request teaching observations to receive individualized feedback on their teaching; request in-person consultations to get support for their teaching and learning needs throughout the year; and seek advice, training, and support to experiment with a rich portfolio of online platforms and digital and media tools.

Cornell

Cornell's Center for the Integration of Research, Teaching and Learning (CIRTL) CIRTL at Cornell prepares graduate students and postdocs to excel as teachers, researchers, and as mentors. Through our CIRTL Network membership, graduate students and postdocs in all fields can prepare for academic careers in a wide range of settings. CIRTL programs are housed in the Cornell University Graduate School, and offer both local and online professional development opportunities.

Florida Atlantic University
The Program for Leadership and Professional Development provides resources and training to faculty, students and staff including how to: develop curriculum proposals, chair committees, teach classes that can range from small seminars to large lectures, mentor peers, resolve conflicts, and family-work balance. Building on the latest research in higher education administration and best practices at colleges and universities worldwide, the program offers opportunities to help current and prospective academic leaders become more effective at the tasks that make a university great.

NYU
NYU's Center for the Advancement of Teaching (CAT) promotes an ongoing, university-wide discussion about teaching and learning matters, striving both to facilitate that conversation and to contribute to it intellectually. We seek at once to provide practical resources and activities that foster the enhancement of teaching and learning and to develop greater commitment across schools and programs to supporting teaching in the diverse NYU campus community. NYU has a ToolKit for PhDs for teaching, writing and research.

c. Communicating Science

The critical nature of ACCESS' partnerships with non-academic entities underscores the need to communicate our research findings in language and forms beyond normal academic channels. Each of the core university partners has resources designed to foster such practices that ACCESS can leverage.

Columbia:
Columbia has developed a compendium of online resources to help scientist better connect with the press, the public, and policy makers. It offers Guides, Articles, Blogs, and links to Fellowships on its website. The Columbia University Postdoctoral Society created an Outreach and Communications Subcommittee in 2019 with the goal of connecting Columbia Postdocs with the broader NYC community and broadening local communications platforms and SciComm skills. It organizes workshops specifically to train postdocs in basic Scientific Communication skills, working with organizations such as The Alan Alda Center for Communicating Science.

ACCESS will also be advised by the Columbia Irving Institute's Community Engagement Core Resource (CECR) which promotes academic-community partnerships and public engagement in translational health research through outreach, education, informatics, training and funding programs. While a different research focus, CECR has valuable experience working in the same neighborhood and with many of the same community partners as the COSMOS testbed.

Cornell
Like Columbia, Cornell also offers a rich compendium of books, "how to" websites, blogs and commentary on its website.

FAU
Luiz Perez, Director of AU's Office of Research Communication will, on an as-needed basis, facilitate Communicating Science workshops based on similar training offered by the American Association for the Advancement of Science Communicating Science.

NYU
ACCESS can leverage the NYU Science Communication Workshops which seek to improve the communication skills of all participants, regardless of previous training in writing and speaking. Students learn to describe complicated, technical research in clear, jargon-free language; they learn to write persuasive opinion pieces about matters of broad societal concern emanating from the scientific and medical arenas; and they learn storytelling skills to convey the real feel of science and medicine on the move. They also learn how to communicate with scientific colleagues outside their immediate field, how to identify the audiences with whom they wish to communicate, and how to write for general interest publications. All writing assignments are workshopped in class and also critiqued in detail by the instructor.

While the workshops are focused on helping researchers communicate to the general public, workshop alumni often report that the training has also improved their grant writing, fellowship applications, institutional progress reports, and even preparation of scientific papers.

d. Postdoctoral Mentoring Resources

ACCESS will leverage the resources which each of the Core Universities has to mentor Postdocs as discussed in the Postdoctoral Mentoring Plan. ACCESS is fortunate that specific offices reside at each University and include such tools as an Individual Resource Plan.

3. University-based Facilities, Equipment, and Other Resources for Innovation Ecosystem

a. University Technology Transfer Offices

Each of the Core Universities will provide innovation and entrepreneurial support from their university technology transfer offices. All have already agreed to an intellectual property management plan and will provide additional guidance and administrative support for resulting intellectual property.

As the lead institution, ACCESS will lean on Columbia Technology Ventures (CTV) which is the technology transfer office for Columbia University and spearheads many of the technology development initiatives, entrepreneurial activities, external industry collaborations, and commercially-oriented multidisciplinary technology innovations across the university. CTV's core mission is to facilitate the transfer of inventions from academic research labs to the market for the benefit of society on a local, national, and global basis. Each year, CTV manages more than 350 invention disclosures, 100 license deals, and 20 new IP-backed start-ups, involving over 750 inventors across Columbia's campuses. CTV currently has over 1200 patent assets available for licensing, across research fields such as bio, IT, clean tech, devices, big data, nanotechnology, materials science, and more. 45 full time staff and an additional 30+ graduate student interns (CTV Fellows), provide broad support to the Columbia community and other stakeholders with marketing, legal (patents, contracts, etc.), business start-up help, and administrative tasks.

CTV has extensive experience founding and supporting technology initiatives to enable promising technologies to accelerate across the "valley of death" and reach the market as quickly and successfully as possible. Many of these initiatives are explicitly multi-institutional, requiring extensive collaboration with peer universities and their tech transfer offices. CTV has partnered with Cornell, NYU and CCNY numerous times, and looks forward to working with colleagues at FAU.

FAU

The FAU Office of Technology Development (OTD) manages intellectual property (IP) created by faculty and students at FAU. It provides impartial consultation on various legal protection and commercialization strategies, and collaborates with outside attorneys and consultants to offer additional resources. The office also works closely with the Office of Sponsored Programs to structure the IP and commercial provisions of sponsored research agreements. The office manages approximately 30-40 invention disclosers a year.

b. MakerSpaces and Shared Facilities for Entrepreneurial Activity

Each of the Core Universities will provide access to a MakerSpace for rapid prototype development and design testing.

Columbia

The Columbia MakerSpace (CMS) is a Columbia University affiliated workshop located in the S.W. Mudd Building on the Morningside campus. It provides a wide variety of tools and personnel support for students, scientists, and engineers to use and space in which they can a work, share ideas, and collaborate. The enthusiasm with which the Columbia community, including alumni, greeted the MakerSpace has prompted a major expansion which will be finished by Fall 2019. The MakerSpace offers 3D printers, laser and vinyl cutters, electronics tools and multiple other pieces of equipment.

Columbia Entrepreneurship Design Studio helps students, faculty, and alumni approach opportunities and challenges in a more entrepreneurial, collaborative, and creatively confident way. In particular, the Design Studio assists early stage entrepreneurs who want to understand more about their customers and drive towards a seamless product-market fit. In addition, the staff of the Design Studio works with students and alumni wanting to take an interdisciplinary approach to solving ambiguous problems. ERC for ACCESS will have opportunities to engage with the Design Studio to work through early product design concepts and working models.

Cornell

The Cornell Tech MakerLAB, in the Tata Innovation Center, features a wide variety of digital fabrication tools such as 3D printers, desktop CNC mills, and a large-bed laser cutter. These are used to rapidly prototype novel robots, devices and interfaces.

FAU

In May of 2019, FAU's College of Engineering and Computer Science received a $750,000 gift from the Gangals Nonprofit Foundation to establish a new 3,500 sq ft engineering maker space on the first floor of the Engineering East Building on Florida Atlantic's Boca Raton campus. The open, glass-walled space is located directly adjacent to the building's main entrance, providing excellent visibility to students, community partners and visitors. Renovation of the space and equipment acquisition will begin in the second half of 2019. The new maker space will primarily serve students at FAU, but dedicated access will also be granted to support community partners and local K-12 students, including Palm Beach State College, A.D. Henderson University School, and others. The space will provide equipment and personnel support for mechanical, electrical and computer engineering with an emphasis on rapid prototyping and testing. Existing assets include a large-volume laser cutter, a PCB mill, a PCB printer, an assisted pick-and-place machine, a PCB rework station, a reflow oven, numerous 3D printers, a CNC waterjet, a CNC mill, welding equipment, electronics inspection and test equipment and a wide assortment of power tools.

NYU

NYU has two makerspaces. Its original NYU MakerSpace in the MetroTech Center offers a range of tools from advanced software and milling machines, to 3D printers and integrated manufacturing facilities. The space is a local hub for hackathons, guest talks and other events that bring inventors and entrepreneurs together across disciplines to solve, learn and just hang out. NYU Tandon's newest facility, the MakerGarage, is located in the Clocktower Building, a 1920s cast-concrete edifice in Downtown Brooklyn. It is a much-welcome addition, particularly for participants in Tandon's Vertically Integrated Projects (VIP) program, which allows students to choose a hands-on project and work on it throughout much of their academic careers, and Tandon's student design and competition teams.

c. Incubators, Accelerators, Coworking Spaces and Mentorship Programs

ACCESS anticipates creating its own Lab-to-Market accelerator to translate its discoveries for societal benefit towards the latter half of the Center. Access will leverage the Columbia's **Lab-to-Market (L2M) Accelerator Network** which is a cross-discipline support system providing tactical and strategic guidance to the Columbia-affiliated accelerators in Life Sciences (Biomedical Accelerator or BioMedX, Accelerating Cancer Therapeutics or ACT, the Translational Therapeutics Accelerator or TRx), Clean Energy (PowerBridgeNY), Media and Tech (NYC Media Lab Combine), VR/AR (NYC RLabs), Blockchain (The Columbia | IBM Blockchain Accelerator), and Cybersecurity (CyberNYC). L2M plays a key role in facilitating the process of bringing the research from the lab to the marketplace. Collectively, the Columbia L2M accelerators have led to very impressive results that have grown exponentially over a very short number years: over 433 applications received, 247 teams run through educational bootcamps on product development and entrepreneurship, over 118 cash awards issued totally over $10M, 40+ commercial launches by accelerator teams, and over $116M in external follow-on funding raised by those teams. Where appropriate, ERC ACCESS innovators will be encouraged to participate in existing L2M accelerators. As the ERC's programs begin to grow, the landscape becomes better understood from a policy, privacy, and economic perspective, and we begin to produce more innovations a specific lab2market accelerator will be developed to ensure relevant regulatory, privacy, and market dynamics are understood and addressed to speed up the development, commercialization and adoption process.

ACCESS can also leverage the university's incubator. The **Columbia Startup Lab** (CSL) opened in June of 2014 and has become a living testimony to Columbia University's longstanding spirit of innovation, collaboration, and entrepreneurship. After 5 years, CSL has been headquarters to more than 250 Columbia-founded startups and over 350 members, in industries from FinTech to Fashion to Food and more! In total, these early-stage companies have raised more than $55M in venture funding and generated exit and acquisition value of $100M.

ERC for ACCESS will also be able to tap Columbia's Ignition Grants, Entrepreneurs-in-Residence, and Executives-in-Residence. **CTV's Executive in Residence (XIR) Program** aims to connect Columbia inventors and technologies with seasoned industry executives, venture capitalists, and serial entrepreneurs. By doing so, XIR leverages the deep domain expertise of these individuals to help accelerate the path of promising technologies towards market success. XIRs are encouraged to develop close ties with our inventors, entrepreneurs, and technology transfer team in order to help Columbia further develop these

technologies. The **CTV Executive Advisors Network (XAN)** is a new initiative designed to provide mentorship, networking, and marketing and investing advice to promising CTV startups, entrepreneurs and inventors. CTV's XANs come from backgrounds in entrepreneurship, venture capital, R&D, product design and business development, representing companies including Merck, Alcatel Lucent, Viacom, Amazon, Vimeo, Acorda Therapeutics, Medica Ventures, Shutterstock, IBM, Intel, Sanofi, Xerox, and Google.

The **Runway Startup Postdoc Program** is part business school, part research institution, part startup incubator. Based at the Jacobs Technion-Cornell Institute, Runway ushers recent PhDs in digital technology fields through a paradigm shift—from an academic mindset to an entrepreneurial outlook. Postdocs come to the Institute with ideas for unproven products and markets and receive significant support as well as mentorship from academic and business experts in connective media, health technology, security and privacy and computer vision, among a number of other fields.

FAU Tech Runway, a South Florida public-private partnership serves as a core entrepreneurship hub to accelerate technology development and incubate startup companies. This 28,000 sq ft collaborative working space provides entrepreneurs with a complete ecosystem that houses, educates, mentors and funds heir ventures from ideation phase through to the scaling stage. Since its inception in 2014 it has launched and served 72 startup companies, which have collectively raised more than $63.5m in capital, create more than 350 jobs and generated more than $64.7M in sales revenue. The annual Launch Competition selects 21 of the most promising companies for the year-long venture class program.

New York City Regional Innovation Node (NYCRIN): The New York City Regional Innovation Node (NYCRIN) is a network of over 25 leading universities in the New York, New Jersey, Connecticut, Delaware, and Pennsylvania area designed to support regional needs for innovation education, infrastructure and research by providing state-of-the-art training for academic researchers and technologists through the National Science Foundation I-Corps program. NYCRIN will work cooperatively to build, utilize and sustain a national innovation ecosystem that further enhances the development of technologies, products and processes that benefit society. I-Corps Nodes will foster understanding on how to identify, develop and support promising ideas that can generate value, create and implement tools and resources that enhance our nation's innovation capacity, gather, analyze, evaluate and utilize the data and insight resulting from the experiences of the I-Corps teams and share and leverage effective innovation practices on a national scale to improve the quality of life for the U.S. citizenry.

CUNY manages the New York City Regional Innovation Node (**NYCRIN**) designed to support regional needs for innovation education, infrastructure and research by providing state-of-the-art training for academic researchers and technologists through the National Science Foundation I-Corps program. NYCRIN will work cooperatively to build, utilize and sustain a national innovation ecosystem that further enhances the development of technologies, products and processes that benefit society. Columbia and Cornell are key partners of NYCRIN.

4. University- based Resources for Diversity and Inclusion

Each of the core universities provides Inclusive Training Support within the teaching and learning programs described under Workforce Development. Additional details regarding diversity and inclusion resources at each of the core institutions are below.

Columbia

Columbia has many formal and informal connections with the diverse and substantial economy of New York City. Diversity, inclusion, equity, and progressivism lie at the heart of the Columbia experience, as evidenced by multiple initiatives that will directly advance the quality of this ERC:

- Since 2005, Columbia has committed significant resources to its faculty diversity efforts. With the University's new commitment of $100M, the total investment in faculty diversity support stands at a total $185M. The current, University-wide iteration of the Faculty Diversity Initiative supports faculty recruitments, junior faculty career success, pipeline programs, and programming intended to enhance the climate of inclusiveness, among other initiatives.
- With the aim of serving the interests of Columbia's diverse community, The Kenneth A. Forde Diversity Alliance (KAFDA) was established in 2014 to bring together minority students, resident physicians, fellows, graduate students, faculty, research scientists, and allies. KAFDA seeks to develop networking opportunities, promote diversity awareness, foster mentoring relationships, and provide community service and leadership development opportunities.
- The University's Office of Disability Services offers a variety of services and will dispatch a staff liaison to aid the student throughout his or her educational activities.

Diversity and inclusion are not only central to the student experience: they are key components to learning and development. Columbia's Office of Multicultural Affairs recognizes that identity, social responsibility, allyship, and equity must be addressed at multiple, interconnected levels to best support students' various developmental stages. Fostering an inclusive on-campus environment in tandem with our roles within local and global contexts is crucial as the cultural and social identities of diversity continue to increase and shift. The Office of Multicultural Affairs responds to this necessity through Diversity Education and Training sessions. These include sessions on microaggressions, LGBTQIA @ Columbia, international student support, and communicating across cultures.

Cornell

Cornell leadership and community have collectively identified a number of initiatives and activities focused on creating a more inclusive and welcoming campus. Many were proposed by the Presidential Task Force on Campus Climate and the Provost's Task Force to Enhance Faculty Diversity, both of which did their work during the 2017-2018 academic year.

- Build a culture that values transparency, accountability, and communication around issues of diversity and inclusion.
- Develop visible institutional statements and symbols of our priorities, and policies that are well-aligned with them.
- Provide diversity education to all stakeholders.
- Increase faculty diversity and foster faculty commitment to diversity.
- Enhance the student experience to support social belonging and wellness Create more opportunities for intergroup interaction
- Recruit and retain a diverse staff workforce.

Cornell University maintains a public dashboard as a way of tracking progress on these initiatives. Numerous steps have been accomplished or remain a top priority to achieve the seven initiatives above.

In addition, Cornell Tech in particular is conscious as it says "although tech affects everyone, not everyone is represented when new products are launched and new companies are formed." Cornell Tech believes that increasing diversity and practicing inclusion is key to improving technology—and people's lives. Managing Entrepreneurial Officer at Cornell Tech and co-founder of early stage venture capital firm 645 Ventures Aaron Holiday has played a key role in helping launch Cornell Tech's Startup Studio program in addition to promoting social responsibility on campus. Denise Young Smith, formerly the Chief Human

Resources Officer and Vice President of Inclusion and Diversity at Apple, joined the Cornell Tech community as Executive-in-Residence in January 2018.

FAU

The Center for Inclusion, Diversity Education, and Advocacy (IDEAs) is led by *Guzman-Oliver*, who serves as the Diversity and Inclusion Lead for Florida Atlantic University in the ERC for ACCESS. She is a mentor in the Red Jacket Mentoring Project and chairs the university-wide Diversity Platform Council. *Guzman-Oliver* was awarded the "National Role Model Administrator Award" from Minority Access, Incorporated, and the "Patriotic Employer Award" from the Office of the Secretary of Defense in 2017. She was also showcased on the NENANI online periodical as a "Latina Woman in Leadership" and is the President of Advanced Leadership Strategies, LLC. The center comprises four offices:

- The **Office of Hispanic/Latinx Initiatives** and the **FUTUROS Success Program** aims to connect Hispanic/Latinx students to support services, resources, and programs that prepare them for academic success and future careers. The FUTUROS Success Program provides Hispanic/Latinx students with services and resources, such as advising, mentorship, financial assistance, and career services.
- The **Office of LGBTQ+ Initiatives** and **Allyship** seeks to create an affirming and equitable campus climate for Lesbian, Gay, Bisexual, Transgender, Queer, Questioning, and Ally (LGBTQ+) students. We provide training, educational, and social programing to Florida Atlantic University's students, faculty, and staff. The office aims to foster a visible network of support by coordinating inclusionary efforts across campus.
- The **Office of Diversity Education and Training** aims to foster an inclusive environment through diversity and inclusion training and educational programs. The office collaborates with units across the university to create an institutional climate of inclusive excellence that promotes awareness, social justice, and advocacy.
- The **Office of First-Generation Student Success** serves as a referral hub to the various services, to inspire and assist first-generation students at Florida Atlantic University, including academic support, advising, financial assistance and scholarships, mentorship, and the "First and Proud" registered student organization.

The Center highlights the experiences of traditionally marginalized groups through intentional interactions aimed at fostering awareness and cultivating new perspectives. By offering quality programs and educational opportunities to all students, Florida Atlantic University creates a campus climate that values differences and promotes equity.

NYU

NYU School of Engineering houses the **COSMOS education lab** that includes several educational toolkits which have been developed within Research Experience for Teachers (RET) programs in summers 2018 and 2019. The toolkit (see Figure17 implements a set of K-12 STEM education modules and consists of a hardware setup, a software framework, and supporting educational material. The hardware includes a small-scale testbed (mini-node) with basic COSMOS components as SDR nodes, IoT nodes, monitors, etc.

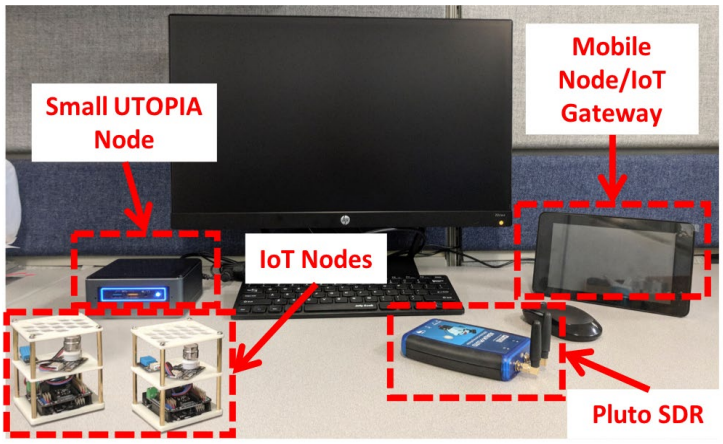


Figure 15: COSMOS Educational Toolkit

The software framework (see Figure 18) is a web-based interface that allows the user to select a particular module/lab and execute the experiment and collect the results automatically via a user-friendly GUI. With the help of the toolkit, the teachers can be introduced to concepts from wireless networking, computer science, physics, and robotics, through hands-on, real-world research experiments. They can later use similar toolkits to teach these concepts to their students.

Besides the COSMOS/ACCESS specific program, NYU has multiple programs addressing Diversity and Inclusion for its Faculty, Students and Staff. Of particular note for ERC ACCESS:

- The Provost's Mentoring Program for Diverse Faculty, a formal faculty mentoring program where full-time junior faculty are paired with senior faculty who have volunteered to offer mentorship and constructive support in navigating the university and addressing professional needs. Research and practice both support the importance of mentoring during the lifecycle of faculty. Faculty from historically underrepresented racial/ethnic groups and those traditionally underrepresented in their field benefit from this additional opportunity to find mentorship and guidance from senior colleagues.
- The Provost's Postdoctoral Fellowship Program supports promising scholars and educators from diverse backgrounds whose life experience and research experience will contribute significantly to academic excellence at NYU.
- Center for Multicultural Education and Programs enhances the NYU experience by fostering a more inclusive, aware and socially just community. CMEP accomplishes this by:
  - Fostering DIALOGUE that explores issues of identity, diversity and social justice.
  - Supporting the diverse NYU COMMUNITY in their personal, professional and academic lives.
  - Creating educational initiatives and campus-wide programming that ENGAGE the NYU community.
  - Cultivating allies and advocates to create and promote positive CHANGE.
- The New York University Lesbian, Gay, Bisexual, Transgender and Queer Student Center creates a welcoming environment for all University students, faculty, staff, and alumni interested in developing their understanding of LGBTQ communities. Support services, resources, programs, advocacy, training, education, and consultation are provided to members of the NYU community.
- Henry and Lucy Moses Center for Students with Disabilities: New York University is committed to providing equal educational opportunity and participation for students with disabilities. We work with NYU students to determine appropriate and reasonable accommodations that support equal access to a world-class education.

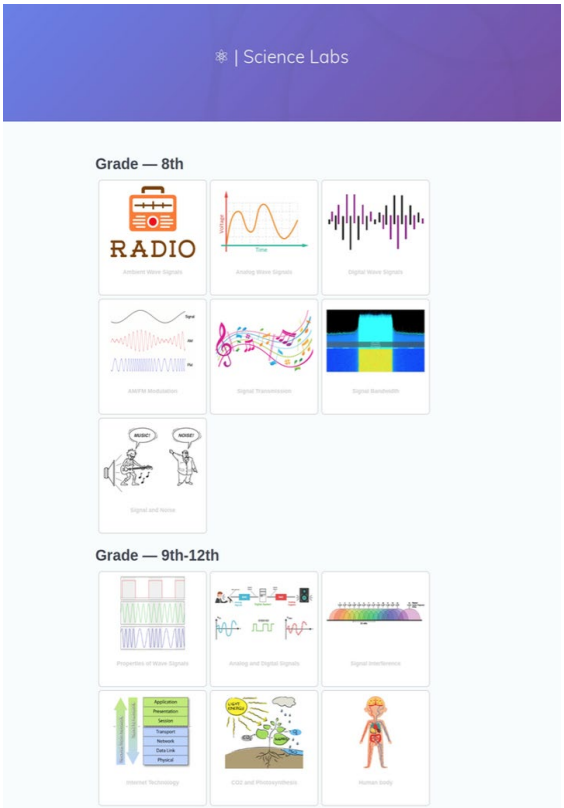


Figure 16: Toolkit Science Labs

5. Unfunded Collaborators

a. Senior Personnel Collaborators

Adrian *Brugger*, Associate Research Scientist in the Department of Civil Engineering and Engineering Mechanics at Columbia**,** directs the Robert A. W. Carleton Strength of Materials Laboratory described above under Key Research Facilities. Under Dr. *Brugger's* leadership over the past decade, the Laboratory now supports 150 concurrent academic users, up from approximately 25 in 2007. Specialty industry testing project activity has also increased by an order of magnitude. Dr. *Brugger* has extensive experience with field testing in a civil engineering context, having worked on numerous sensor network infrastructure monitoring projects in New York and beyond. In addition to his direct technical experience with field experimentation, his staff can support fabrication of test fixtures, configuration of sensors as well as the staging of wireless instrumentation in the large 3-story Carleton Laboratory. ACCESS anticipates frequent use of this critical laboratory, and the consultation of Dr. *Brugger*.

Agostino *Capponi*, Associate Professor of Industrial Engineering and Operations Research at Columbia, will contribute to the design of a framework that captures the decision making process arising in autonomous systems, including those for logistic operations, digital assistance, robotics, and self-driving systems. The framework be constructed around the value alignment principle: a machine can only provide a reliable service if its valuation of the costs and risks associated with each action are aligned with the human that it serves. This value alignment problem is critical to the successful completion of an operation.

As illustrative examples, consider the following application of the framework that will develop. Assume that a network of self-driving taxis tracks each time a user hails a ride. As a part of the service, the human is able to select one of the several routes or destinations that match a search query; for example, to local restaurants or retail stores. The network maintaining these cars would then keep track of each selection, marking when the human chose longer or shorter routes to higher or lower rated destinations. The framework is expected to generate a dynamic assessment of each user's preferences towards various destinations and on the user's sensitivity towards the risks involved in travel, such as the uncertainty of the arrival time to each destination. This assessment enables the taxicab to provide better service to the human, by presenting options that are customized for the user on the next ride. *Capponi* will also provide expertise in network traffic optimization in the presence of uncertainty.

Shih-Fu Chang, Senior Executive Vice Dean of Columbia's School for Applied Science and Engineering, and Richard Dicker Professor of Electrical Engineering and Computer Science directs the Digital Video and Multimedia Lab. The Lab is equipped with advanced facilities and tools for large-scale computer vision and machine learning research, including CPU/GPU clusters, storage servers (more than 130 TB), and large-scale video analysis tools. His group has developed large video indexing and event detection systems, including NewsRover that has indexed more than 500,000 news video stories from live sources, and LarSDE that has analyzed video events from a network of more than 300 traffic cameras in NYC. The scalable indexing techniques developed by the lab has been used by law enforcement agencies to search more than 400M images in the area of human trafficking prevention. Recent research of the Lab also includes developing robust techniques for missing/corrupt data imputation across multiple sensory data streams from different times, locations, and devices. Dr. *Chang's* lab will provide support to the Streetscape situational awareness research thrust 3 and in particular build on recent work in machine vision in the presence of occlusions. This is an extremely common situation in street scenes.

Ben Esner, Director of NYU's Center for K12 STEM Education which aims to increase access to high-quality learning experiences, STEM-focused higher education and related careers. The Center has numerous summer and academic year programs for students and teachers including the COSMOS RET program that ACCESS would amplify. Mr. *Esner* will bring the resources of the NYU Center to ensure the success of ACCESS's programs for students and teachers.

***Emily Ford*,** Director of Outreach Programs of Columbia's School for Applied Science and Engineering, develops and organizes outreach activities with faculty. She helps to further the mission of the University by connecting SEAS's faculty with the faculty and staff at K through 12 schools in New York City. Ms. *Ford* will work with Co-PI Culligan to help implement the pre-college and college activities such as RET, REU, and CURE.

Diane Levitt, the Senior Director of K-12 Education for Cornell Tech, drives Cornell Tech's engagement with the NYC computing education community, including the Department of Education's CS4All

initiative, and works with individual schools to catalyze K-12 computer science. She is responsible for Cornell Tech's annual conference: To Code and Beyond, convening educators, nonprofit and industry leaders, policymakers and funders to examine best practices and innovative solutions in K-12 computing education.

Eric Vieira**,** Director of Strategic Collaborations of Columbia's School for Applied Science and Engineering, will take an active role in supporting the development of the Center's corporate membership and the build-out of the Center's innovation ecosystem and alignment with existing entrepreneurial resources. Dr. Vieira has over 15 years of experience in academic-industry relations in both the public and private sector and has overseen the development of research collaborations (e.g. Mount Sinai + Pfizer CTI), workforce development programs (e.g. NYAS Science Alliance, CRA-CCC NYC ASCENT), and technology and business development bootcamps and accelerator programs (e.g. NYC's Entrepreneurship Lab for Bio and Health Tech – ELabNYC, NY ESD/CUNY START-UP NY).

David Yao, Piyasombatkul Family Professor of Industrial Engineering and Operations Research at Columbia University, will be developing simulation tools that can generate various scenarios to test out basic ideas and engineering designs, along with stochastic models to evaluate relevant performance measures and computational approaches to optimize them. *Yao* will support the network optimization research related to both street traffic as well as edge computing resources and data flows. In addition, he will consider dynamic pricing associated with dynamic congestion pricing, curb pricing etc. Assessing the network robustness is also of particular interest to *Yao*.

b. Corporate Collaborators

Amazon

Amazon research has some of the brightest minds focused across the ACCESS Streetscape applications, making Amazon an ideal industry partner. We look forward to our researchers collaborating with the ACCESS Program around students and research. Given Amazon's commitment to have a positive impact on customers, employees, small businesses, the economy, and communities our industry partnership will establish a strong ecosystem to help drive research, engineering workforce development, diversity and culture of inclusion, and the innovation ecosystem.

CARMERA

CARMERA operates an owned and professionally crowdsourced vehicular sensor network built from the ground up, which gathers continually updated 3D scene, change detection and analytics data. Our machine vision and geospatial data pipelines extract rich texture and insight for autonomous vehicles and built environment data customers, while helping make vehicles on city streets safer and adhering to privacy best practices. CARMERA's mission is to automate cities by maintaining the world's most robust real-time, street-level intelligence platform and to make it accessible to anyone. CARMERA looks forward to collaborating with the ACCESS team by providing them our rich data sets and our high definition maps both of which will help to advance the local intelligence of the streetscape.

Verizon

Verizon's goal is to deliver the promise of a digital world to give people the ability to do more, especially as we enter the Fourth Industrial Revolution with the introduction of 5G technology across the country.

Amazon believes strongly in the proposed Center's vision to improve every-day life at hyper-local scales of the streetscape, and as such look forward to collaborating with the ERC. Amazon looks forward to continuing to engage around the outreach education opportunities.

AIM Photonics

The American Institute for Manufacturing Integrated Photonics (AIM Photonics), is an industry driven public-private partnership that focuses the nation's premiere capabilities and expertise to capture critical global manufacturing leadership in a technology that is both essential to National security and positioned to provide a compelling return-on-investment to the U.S. economy. We are collaborating to share best practices and support the development of an industry eco-system in which companies can develop photonic chip based devices in AIM and then test them out in ACCESS and COSMOS.

Knight Foundation
Knight Foundation is a national foundation with strong local roots. Our goal is to foster informed and engaged communities, which we believe are essential for a healthy democracy. At Knight Foundation, we look to build successful cities and believe in the power to harness the growth of digital technology to improve how communities respond, connect and engage with residents. In Palm Beach County, Knight Foundation focuses on West Palm Beach and Lake Worth's goals for talent retention and economic opportunity and we look forward to collaborating with the ACCESS center on these goals.

Koffie Labs
Koffie Labs is an insurance company for commercial vehicles, using AI-driven predictive models, based out of the NYU Future Labs' office in Brooklyn. It maintains offices in the Media, Arts, and Technology (MTA) building in downtown Brooklyn, with co-working space. Koffie Labs also maintains an extensive data-set for insurance and risk assessment in the automotive and autonomous vehicle sectors, as well as risk assessment and pricing tools and services. We look forward to collaborating with the ACCESS center research especially in our shared goals around pushing technology forward for road safety.

c. Federal Government Collaborators

Army Research Laboratory (ARL) Computational and Informational Sciences Directorate
The U.S. Army Research Laboratory (ARL) of the U.S. Army Research Development and Engineering Command (RDECOM) is the Army's corporate, or central, laboratory. Its diverse assortment of unique facilities and dedicated workforce of government and private sector partners make up the largest source of world-class integrated research and analysis in the Army.

Of particular relevance to ACCESS is ARL's Collaborative Research Alliances (CRA) Internet of Battlefield Things (IOBT). The overall objective is to develop the fundamental understanding of dynamically-composable, adaptive, goal-driven Internet of Battlefield Things (IoBTs) to enable predictive analytics for intelligent command and control and battlefield services. Some research topics: 1) Theoretical foundations, models, and methods of autonomic complex systems that deliver adaptive cyber-physical capabilities and services necessary to enable effective command and control across military (blue), adversary (red), and civilian (gray) domains, 2) Distributed Asynchronous Processing and Analytics of Things: Scientific principles, theories, and methods and predictive processing, analytics, and anomaly detection of broadly heterogeneous and varied data that may be unknown combinations of sparse and voluminous; centralized and distributed; and trusted and suspect for the purposes of augmenting goal-driven decision-making and 3) Cyber-Physical Security.

The Battlefield Information Processing Branch looks forward to collaborating around research and experimentation with the ACCESS Center. Given the synergy of the convergence science being explored with the ACCESS center and the research topics of the Internet of Battlefield Things many common research objectives could be achieved. The ACCESS center test bed could also provide a valuable platform for outdoor experimentation of the Army's Internet of Battlefield Things. In addition, it is the intention to set up a Cooperative Research and Development Agreement (CRADA) to increase the overall research.

Draft CRADA Title and Purpose

Title: Experimentation for Basic and Applied Research involving the Internet of Things

Purpose of Collaboration: Conduct research and to develop experimentation capabilities for evaluating and validating theories, models, and algorithms for Internet of Things (IoT) to support command, control, and intelligence (C3I) and related analytical tasks. The goals include the design of a distributed hybrid testbed that can be both real and virtual as well as design and conduct experimentation to investigate questions regarding scalability, accessibility, timeliness, and allocation for IOT in information processing activities. This effort will help further the understanding and development of techniques for enabling accelerated decision making for complex tasks and environments. This work will support development of techniques, algorithms and testing to effectively, efficiently, and securely incorporate this technology. In addition, this work will explore methods to dynamically create networks of things that adapt as mission objectives evolve. This may include new techniques, theories, and practices that enable systems to analyze available resources and re-assemble components to best meet requirements. Also, the scope of this col-

laboration may investigate solutions to challenges of enriching resiliency against tampering, attacks or compromises along with modeling resources both cyber and physical that can be applied to smart places: campuses, cities, installations, intelligent buildings, smart manufacturing and utilities, and systems.

Air Force Research Laboratory (AFRL) Information Directorate

The Air Force Research Laboratory (AFRL), with headquarters at Wright-Patterson Air Force Base, Ohio, was created in October 1997. The laboratory was formed through the consolidation of four former Air Force laboratories and the Air Force Office of Scientific Research. AFRL's mission is leading the discovery, development and integration of affordable warfighting technologies for America's aerospace forces. It is a full-spectrum laboratory, responsible for planning and executing the Air Force' science and technology program. AFRL leads a worldwide government, industry, and academia partnership in the discovery, development, and delivery of a wide range of revolutionary technology. The laboratory provides leading-edge warfighting capabilities keeping our air, space, and cyberspace forces the world's best. The lab employs approximately 5,800 government people, including about 1,400 military and 4,400 civilian personnel. It is responsible for the Air Force's science and technology budget of nearly $2 billion, including: basic research, applied research, advanced technology development, and an additional $1.7 billion from AFRL customers. AFRL accomplishes its mission through nine technology directorates located throughout the United States, the Air Force Office of Scientific Research, and a central staff. Headquarters AFRL operates the Major Shared Resource Center at Wright-Patterson AFB, one of four high-performance computing centers in the Department of Defense. The center is tackling large-scale problems previously beyond the reach of processing platforms and providing a vast array of services in a collaborative environment which includes government, industry and academia.

AFRL's Information Directorate is pleased to serve as a collaborator on ACCESS, primarily in the area of next-generation wireless networking technologies, with an emphasis on software-defined radio technologies. The Information Directorate is the Air Force's and nation's premier research organization for Command, Control, Communications, Computers, and Intelligence (C4I) and Cyber technologies. The directorate explores, prototypes, and demonstrates high-impact, affordable and game-changing technologies. These technologies transform data into information and subsequently knowledge for decision makers to command and control forces. This knowledge gives our air, space and cyberspace forces the competitive advantage needed to protect and defend the nations.

Ours is to explore, prototype, and demonstrate high-impact, game changing technologies that enable the Air Force and Nation to maintain its superior technical advantage. We look forward to continued collaboration with the ACCESS team to realize this mission, leveraging ongoing collaborative work in software-defined radio technology.

d. State and Local Government Collaborators

The Mayor's Office of the Chief Technology Officer

The Mayor's Office of the Chief Technology Officer works to make broadband, smart city technologies, digital services, and the tech industry work for all New Yorkers. In our focus on smart cities technologies our team helps the City leverage these new technologies while also protecting the privacy and security of New Yorkers. This directly aligns with the ERC ACCESS Center. We already have numerous mechanisms in place for collaboration. Our office participates in the governance of the COSMOS research testbed. We conduct moonshot challenges for the private sector to address key problems identified by City agencies or by communities through our CoLabs program. These challenges have been consistent with the themes of the proposed ERC and we expect the program would be greatly enhanced through the Advancing Communications and Computing for Emerging Streetscapes (ACCESS) center. In particular, we have established the Cities Coalition for Digital Rights in partnership with dozens of cities; this coalition has "ethical security in public spaces" as a core principle, which means we have already mobilized a network of contributors and beneficiaries for that area of research.

The office serves as a coordinating entity for smart city initiatives across City agencies. We already have mechanisms to coordinate efforts across agencies and will serve to bring relevant agencies to support the ACCESS center on a variety of projects. As example here are a range of categories already under way. They map well to the ACCESS center four applied themes: road safety, ethical security in public spaces, last meter logistics and future outdoor work.

The City's smart city initiatives span a range of categories:

- Buildings and Infrastructure. Deploying solutions like automated indoor lighting and wireless water meters across New York City to help reduce energy expenses and greenhouse gas emissions.
- Transport and Mobility. Leveraging real-time transportation data to reduce congestion, improve the flow of traffic, and lower carbon emissions.
- Energy and environment. Using technology to monitor all areas of urban living, from garbage cans to reservoirs, to help the City adjust services to better meet New Yorkers' needs and reduce our carbon footprint.
- Public health and safety. Helping monitor and capture air quality data with environmental sensors, and helping police respond to emergencies more quickly using gunshot detection technology.
- Government and community. Leveraging smart technologies to better connect New Yorkers to their city. Services like online snow plow tracking use GPS to provide residents with real-time plow locations during the winter months, so they can plan accordingly.

It is clear the synergy to the Vision and Mission of the ACCESS Center that we are well positioned to collaborate around serving on advisory committees to provide the convergence NSF encourages to guide the transformation of streetscapes through Wi-EDGE engineering for public benefits. We have already had meetings with the PI, co-PI and other senior personnel on the proposal to discuss use-cases, student projects, and community engagement and we look forward to a continued strong collaboration.

New York City Economic Development Corporation (NYCEDC)

NYCEDC consists of teams of skilled and dedicated individuals with knowhow and expertise across many fields including community/neighborhood development, workforce development, real estate, industry and sector analysis, design, urban planning, marketing, engineering, financial analysis and more. But we all have one thing in common, a passion for New York City and its people.

Specifically, its focus on industry development aligns well with the ERC ACCESS Center's objectives of ecosystem and workforce development. For the last decade, the EDC has been at the center of supporting the growth of the tech sector in NYC. Through our public-private partnership, we can offer several benefits to the ERC ACCESS Center:

- Access to the startup ecosystem and integrating with our current programs and partnerships
    - Cleantech and Smart Cities: New Lab, Company, Urban Future Lab
    - VR/AR and Media: RLab, NYC Media Lab and Made in NY Media Center
    - Cybersecurity: CyberNYC
    - Blockchain: NYC Blockchain Center
    - AI and Ethics: NYC Center for Responsible AI
- Integration into workforce and talent development programs for the various industries we support
- Act as a convener of various ecosystem stakeholders and developer of potential partnerships

South Florida Regional Planning Council

The South Florida Regional Planning Council (Council) is one of Florida's ten regional planning councils. The Council serves three counties: Monroe, Miami-Dade, and Broward; 71 municipalities; and 4.3 million residents. Over the next 20 years, the Region is expected to grow to an increasingly diverse estimated population of more than 4.9 million residents. The Legislature has recognized the Councils as Florida's "only multipurpose regional entity that is in position to plan for and coordinate intergovernmental solutions to growth-related problems on greater-than local issues, provide technical assistance to local governments, and meet other needs of the communities in each region." Our collaboration with the ACCESS center will involve participating in economic development initiatives as well as providing important insights through our many programs. As example, our Transit Oriented Development (TOD) program focuses on creating vibrant, livable, sustainable communities. TOD involves the creation of compact, walkable, pedestrian-oriented, mixed-use communities centered around high-quality train systems. This program will feed community insights to the research efforts to align the research with societal needs.

New York City Department of Transportation (DOT)

DOT's mission is to provide for the safe, efficient, and environmentally responsible movement of people and goods in the City of New York and to maintain and enhance the transportation infrastructure crucial to

the economic vitality and quality of life of our primary customers, City residents. Department works to achieve the following goals:

- Provide safe, efficient, and environmentally responsible movement of pedestrians, goods, and vehicular traffic on the streets, highways, bridges, and waterways of the City's transportation network;
- Improve traffic mobility and reduce congestion throughout the City;
- Rehabilitate and maintain the City's infrastructure, including bridges, tunnels, streets, sidewalks, and highways;
- Encourage the use of mass transit and sustainable modes of transportation; and
- Conduct traffic safety educational programs.

Over 5,000 employees of the New York City Department of Transportation oversee one of the most complex urban transportation networks in the world. DOT's staff manage an annual operating budget of $900 million and a five-year $10.1 billion capital program, along with 6,000 miles of streets and highways, 12,000 miles of sidewalk, and 794 bridges and tunnels, including the iconic East River bridges. DOT's staff also installs and maintains over one million street signs, 12,700 signalized intersections, over 315,000 street lights, and over 200 million linear feet of markings.

NYC DOT can help the center to understand the challenges and use cases to improve the movement of people and goods to ensure the ACCESS center achieves its long-term goals. As an example of an area of interest and potential pilot is around programs to help make New York City's public space safer, more accessible and more vibrant. DOT initiatives for people with disabilities range from changing the timing of signals to allow additional crossing time for pedestrians to complete redesigns of major streets. The main goal of DOT's projects is always to improve safety for all New Yorkers, including those with low vision and limited mobility. The development of the Wi-EDGE system in an urban setting, successfully building an entwined system of networking, dynamic spectrum, and edge computing, and its subsequent use with a large heterogeneous fixed and mobile sensor layer to develop real-time situational awareness of the streetscape would be the ideal place to pilot new technologies around sensing and reacting to people with disabilities. City planners from DOT will look forward to collaborating in many ways, when possible data from many sources (cameras and sensors) can be made available for research purposes and have already been done so on a project with the PI of this center.

Florida Department of Transportation (FDOT)

The Florida Department of Transportation (FDOT or Department) is an executive agency, which means it reports directly to the Governor. FDOT's primary statutory responsibility is to coordinate the planning and development of a safe, viable, and balanced state transportation system serving all regions of the state, and to assure the compatibility of all components, including multimodal facilities. A multimodal transportation system combines two or more modes of movement of people or goods. Florida's transportation system includes roadway, air, rail, sea, spaceports, bus transit, and bicycle and pedestrian facilities.

Its mission is to provide a safe transportation system that ensures the mobility of people and goods, enhances economic prosperity, and preserves the quality of our environment and communities. ACCESS aligns to our mission and FDOT looks forward to collaborating with the ACCESS team to identify opportunities for leveraging the proposed Wi-Edge technology to improve the movement of people and goods throughout Florida and beyond.

Manhattan Borough President, Gale Brewer

Gale A. Brewer is the 27th Borough President of Manhattan, responsible for advising the Mayor and City Council on borough concerns, commenting on all land-use matters in the borough, advocating for the borough in the municipal budget process, and appointing members of Manhattan's 12 Community Boards. The Borough President also chairs the Borough Board, made up of City Council Members and Chairs from the Community Boards, and the Borough Services Cabinet, composed of senior officials from City agencies delivering services in the borough. In this capacity my collaboration will be to listen and provide my expertise pertaining to the policy implications of new research and in general center activities to ensure maximum overall impact and benefit to the community.

Council Member, 7th District, Mark D. Levine

New York City Councilmember Mark Levine represents the 7th District in Northern Manhattan. Serving as the Chair of Council Committee on Health and as a member of the Progressive Caucus, he is a leader on

many issues including housing, education, economic justice, transportation, environmentalism, and more. His collaboration will be around providing expertise on policy implications broadly across all of the Center activities.

Town+Gown @New York City Department of Design and Construction

Town+Gown is an applied research platform linking practitioner City agencies and organizations with academics on research projects, and if the proposal is selected for funding, Town+Gown agrees to provide coordination and facilitation services to align the NSF-funded project within the City, including:

- Work with the center to identify existing projects with New York City agencies that are in alignment with the center's mission.
- Disseminate best practices, webinars, learning opportunities for volunteer recruitment and training, project management, community engagement, and education developed by the proposed program.
- Participate in workshops as resources allow helping identify and invite city stakeholder
- Collaborate with members of the project team, who participate in Town+Gown's activities to disseminate results and shared resources produced by relevant city agent projects.
- Source projects aligned with the centers mission from New York City agencies, the lead PI and Co-PI Professor Patricia *Culligan* have existing collaborations with the City and participated in events organized by Town+Gown, which will continue to build connections in this area.

City of Coconut Creek, Florida

Coconut Creek is home to 61,000 residents and supports a diverse, growing business community. The City's Mainstreet Project, home to the Seminole Casino Coconut Creek and the Coconut Creek Promenade, a 23-acre, open-air, upscale shopping and restaurant center, has received the "Award of Excellence" for its Design Standards by the Florida Chapter of the American Planning Association (FAPA). When complete, the City's MainStreet area will be bustling with over 250 acres of LEED-certified businesses, upscale housing, and beautifully landscaped parks and greenways. This will provide a rich testing arena for incorporating new technologies for better living. We look forward to collaborating and providing access to data for sustaining our city.

City of West Palm Beach, Florida

West Palm Beach is one of three principal cities in the Miami Metropolitan Area, covering over 58 square miles, with approximately 110,000 residents and more than doubles during the workdays. City of West Palm Beach and Florida Atlantic University have established a dynamic partnership and the test bed is described in the facilities section. The City of West Balm Beach will be collaborating with access to data and participation in designing research projects for the shared mission of improving the quality of life.

Town of Davie, Florida

The Town of Davie is home to over 103,165 residents who live across a lush 35 square miles within central Broward. The Town of Davie is also the nexus of higher education in South Florida where several nationally known colleges, technical institutes, and universities make up the South Florida Educational Center. Davie's business climate ranges from your typical small proprietor to the headquarters of Fortune 500 firms such as Andrx Pharmaceuticals. We look forward to collaborating to support talent generation for our local industries and facilitate access to data for research.

City of Boca Raton, Florida

Boca Raton is the second largest city in the Palm Beaches, along five miles of Atlantic coastline. The city boasts a thriving business district that was pioneered from the development of the personal computer at the Boca Raton-based IBM campus in 1967. Today, over 30 corporate headquarters, from innovative startups to large corporations, call the City of Boca Raton home. The Boca Raton Airport offers a customs facility that welcomes travelers from all over the world, conveniently putting them minutes away from business centers, entertainment, and world-class dining. Boca Raton has three nationally ranked universities and an abundance of A-rated public and private K-12 schools that ingrain education, research, and innovation into the community. With a homegrown, educated workforce to build from, entrepreneurs and startups thrive in Boca Raton's climate. The City of Boca Raton is excited about the technology innovations,

educational programs, and technology transfer opportunities that will be created through the NSF ERC for ACCESS. The city looks forward to serving in an advisory capacity to help identify points of connection among ACCESS personnel, work products, city initiatives, and our growing business district. The city also looks forward to providing access to data with the center.

City of Port St. Lucie, Florida

Port St. Lucie is the 8th largest city in Florida with over 195,000 residents. Currently, it is the 3rd largest city in South Florida and the 8th largest city in Florida, surpassing Fort Lauderdale's population of 182,595. Adding a new level of transparency for the City organization, Project Tracker tool was created. Residents have an easy way to stay informed about projects happening in the City of Port St. Lucie – everything from road improvements to new development. This will enable a strong collaboration with the ACCESS center allowing researchers to understand projects like Riverwalk Boardwalk Project and Sidewalk Master Plan. It will give valuable insights for researchers to think through how technology could be used to advance the goals of the community.

City of Palm Beach Gardens, Florida

On March 20, 1959, John D. MacArthur, multimillionaire insurance magnate and landowner, announced plans to develop approximately 4,000 acres and provide homes for 55,000 people in a new community. The City of Palm Beach Gardens has grown steadily during its forty years in existence. In 1999, the John D. and Catherine T. MacArthur Foundation sold approximately 14,000 acres of land including approximately 5,000 acres in the City of Palm Beach Gardens. Mr. MacArthur envisioned the city streets lined with trees and flowers. Millions of dollars were wisely invested by MacArthur to create a Florida community with hundreds of waterways, rolling terrain, magnificent mature pine and shade trees, and rich foliage. Because Mr. MacArthur was a lover of trees and Mother Nature, he instructed that city streets and construction go around trees that had been growing there for many years, such as the Banyan trees. This made for an expensive proposition but he wanted to build a city that was entirely new and unblemished. As such the City of Palm Beach Gardens presents a unique topology for research collaboration around last meter logistics and other research areas.

City of Hollywood, Florida

The City of Hollywood is a beachfront community located in southeastern Broward County midway between Miami and Fort Lauderdale. Founded by Joseph Young in 1925, Hollywood is approximately 30 square miles in size and is Broward's third-largest municipality with a population of roughly 153,000 residents. Hollywood has an average annual high temperature of 83 degrees and low temperature of 68 degrees. We look forward to collaborating by providing access to data and providing insights into research topics that would benefit our citizens.

e. Community Collaborators

As appropriate the collaborators below will collaborate by:

- Participation in designing student projects
- Providing access to data
- Co-advise on student projects
- Participation in workshops, committees or task force
- Provide internships and other student experiences
- Providing insight to the research for community benefit

125th Street Business Improvement District

Property and Business Owners, community and government leaders, residents, and staff work closely together to improve the experiences of those who live, work, visit and invest in the Harlem community. We seek to:

- To catalyze economic development.
- To encourage the ongoing revitalization of 125th Street as a premier art, culture and entertainment destination.

- To celebrate and build upon existing cultural assets and secure future cultural presentation and production in Harlem.
- To facilitate active tourism.
- To increase pedestrian mobility and give the streetscape a cohesive modern appearance and reduce clutter,
- To develop additional public space.
- To include public art throughout the district.
- To create a high quality urban environment that contributes to an identity for the Harlem community.

Its collaboration will provide access to data it collects including:
- Street Conditions, including types of activity on the street with sub categories that list specifics related to the condition
- 311 Reports that BIDs reports annotated by when it is handled
- Commercial Audit of Types of Businesses on 125th Street, organized by those that are complimentary and used to prompt multiple experiences in a single trip
- Study of Street Vendors
- Demographic Trends including age, ethnicity and wealth
- Consumer demand via intercept surveys, telephone surveys and US Census, Claritas
- Consumer Expenditures for Retail from US Census and Claritas

National Federation of the Blind Assistive Technology Trainers Division

Throughout the design of assistive technologies in this proposal, we will engage with people with low vision and blindness professionals (e.g., Orientation and Mobility instructors). To recruit these participants, we will work closely with Ms. Chancey Fleet (see collaboration letter). Fleet coordinates technology education programs at the New York Public Library's Andrew Heiskell Braille and Talking Book Library. Her current library-based projects include group workshops highlighting mobile technologies for independent living and information literacy; programs introducing youth and adults to non-visual techniques for coding and making with Arduino; and the Dimensions projects, which equips community members with the training and tools they need to create accessible tactile maps, diagrams, graphics and objects. She is also the President of the National Federation of the Blind (a national advocacy organization) Assistive Technology Trainers Division. In this capacity, she has an extensive network and has been collaborating with Dr. Azenkot for the past five years on different assistive technology research projects.

Harlem Community Development Corporation (HCDC)

Harlem Community Development Corporation (HCDC is a successor to Harlem Urban Development Corporation aka HUDC), a New York State agency, was created in 1995 to serve the greater Harlem community, including East Harlem, Central Harlem, West Harlem and Washington Heights, through planning and facilitating the development of a range of community development projects and revitalization initiatives that will strengthen Upper Manhattan's economic stability and cultural vitality. I see HCDC's collaboration with ACCESS as important in helping us to achieve our goals.

Tech:NYC

Tech:NYC is an engaged network of tech leaders working to foster a dynamic, diverse, and creative New York. We bring together New Yorkers to support a successful technology ecosystem, attract and retain top-tier talent, and celebrate New York and the companies that call it home. Leveraging our network, Tech:NYC advocates for policies that support the growth of technology companies and technology talent in NYC; promote inclusion and diversity; and create access for all New Yorkers to connectivity, tools, and training.

Harlem Independent Living Center

Prior to May 1990, Harlem's disabled individuals were denied easy access to independent living services provided elsewhere in New York City. Based on a commitment to provide access to independent living services to these un-served and underserved individuals and to expand the system of independent living available to all New Yorkers, the Harlem Independent Living Center was incorporated on May 31, 1990. The Center's objective is to provide an array of independent living services to persons with disabilities to

increase their ability to function independently within their community. The Center is a community- based, non- residential, non- medical consumer- controlled organization which providing a “peer” approach to services: i.e. a place where people with disabilities frequently assist other disabled persons.

Upper Manhattan Empowerment Zone (UMEZ)
UMEZ, an independent not-for-profit corporation, began operations on February 14, 1995, and made its first round of grants and loans in October 1996. UMEZ focuses on workforce development programs aligned directly with employment opportunities, support for cultural programs and organizational development. Our mission is to sustain the economic revitalization of all communities in Upper Manhattan through job creation, corporate alliances, strategic investments, and small business assistance. UMEZ facilitates economic development in the neighborhoods of Central, West, and East Harlem; Washington Heights; and Inwood.

West Harlem Development Corporation
Since 2011 and through June 2017, WHDC has funded 159 nonprofits for $12.6 million to serve West Harlem/Manhattan Community District 9 (MCD9) residents with services in education, housing, workforce development, arts and culture, and more. At least 40,000 participants have been impacted. MCD9 is bounded (south to north) by 110th and 155th Streets and (east to west) by Manhattan, Morningside, St. Nicholas, Bradhurst, and Edgecombe Avenues to the Hudson River.

Harlem Children’s ZONE
Our goal is simple—to give our kids the individualized support they need to get to and through college and become productive, self-sustaining adults. Realizing this goal is difficult and complex, particularly since we are working with over 12,000 youth, many of them with tough challenges. Today, the Children’s Zone® serves more than 10,000 youth and nearly 10,000 adults and our organization as a whole serves over 12,509 youth and 12,498 adults. Due to the widely reported success of the Harlem Children’s Zone® Project, communities across the country and around the world have launched initiatives inspired by our model.

Mayo Clinic
Mayo Clinic is a nonprofit organization committed to clinical practice, education and research, providing expert, whole-person care to everyone who needs healing. William D. Freeman, MD, FAAN, FNCS Professor of Neurology and Neurosurgery serves as an expert in neurological and neurosurgical emergencies, acute stroke/cerebrovascular diseases, neurohospital medicine, and neurocritical care. Our ability to provide urgent care can be improved through the application of the streetscape. This is well aligned with my interests in advancing population and individualized medicine using robotic telemedicine and mobile health Apps. Currently my role involves teaching convergence in neuroscience to groups within the biomedical, life sciences, physical science, engineering and other fields to come together to solve unmet health needs. My collaboration with the ACCESS center will be around bringing my expertise in driving and teaching convergence.

Business Development Board of Palm Beach County
The mission of the Business Development Board (BDB) is to stimulate economic energy, promote business diversity and enrich the vitality of Palm Beach County through the relocation, retention and expansion of companies to or in Palm Beach County. In addition to the collaboration detailed above our collaboration will be focused around connecting students and faculty to opportunities from existing and emerging businesses in Palm Beach County

Community Foundation for Palm Beach and Martin Counties
We make charitable giving simple, effective and fulfilling by connecting donors with opportunities that are meaningful to them using charitable giving funds. Since inception, the Community Foundation has awarded more than $150 million in grants through the generosity of donors.

Manhattan Community Board 9
The purpose of Manhattan Community Board 9 (MCB9) is to ensure that City services are accessible and responsive to the needs of all residents, organizations, businesses, and institutions in West Harlem. The

New York City Charter mandates that all community boards advise and inform their respective constituencies on matters relevant to their immediate neighborhood. Toward this end, MCB9 convenes 9 committee meetings and Ad-Hoc Committee(s) each month: Arts and Culture; Economic Development; Health and Environment; Landmarks Preservation/Parks; Housing Land Use and Zoning; Uniformed Services, and Transportation; Senior Issues; Strategic Planning (Ad-Hoc); and Youth, Education, and Libraries.

Manhattan Community Board 10

Manhattan Community Board 10 is a local government agency of the City of New York encompassing the neighborhoods of Central Harlem in the Borough of Manhattan. Three of the District's four major boundaries are natural features: Harlem River to the north, Central Park to the south and the Fordham Cliffs to the west. The District's eastern border, Fifth Avenue, is its only boundary that is not a natural feature. Central Harlem has a population of approximately 120,000 people; occupies approximately 1.5 square miles of relatively flat land; and is often referred to as "the Valley" by long term residents.

Community Boards have an important advisory role in long-term community planning, Uniform Land Use Review Procedure (ULURP); reviewing applications for liquor licenses, sidewalk cafes, street fairs, street closings; assessing community needs in the City budget; ensuring the proper delivery of municipal services; and advocating for the welfare of the Community District and its residents. Like all other Community Boards, Community Board 10 is mandated by the City Charter of the City of New York.

Manhattan Community Board 11

Manhattan Community District 11 is bordered by 96th Street to the south, 142nd Street to the north, Fifth Avenue to the west, the East River and Harlem River to the east, and includes Randall’s Island, Ward’s Island and Marcus Garvey Park. As our neighborhood continues to grow, it is important to assess the needs of the people, schools, hospitals, museums, parks, community centers and all of the elements that are a part of our great community. Over 120,000 people call this neighborhood home, and it is the mission of this Community Board to ensure all constituent voices are adequately heard, equally represented, and armed with the information necessary to become effective advocates whom we stand side by side with to defend and shape our community’s future. It is incumbent upon all of us to participate in the civic processes taking place throughout our neighborhood.

f. Innovation Collaborators

New Lab

New Lab launched in the Brooklyn Navy Yard in 2016 with the aim of championing entrepreneurship and innovation. Our ecosystem includes over 130 member companies, partnerships with forward-thinking corporate and civic entities, investment from over 270 venture capitalists, and the support of domain experts – all working together to scale frontier technologies.

Our Urban Tech program, a partnership with the New York City Economic Development Corporation, supports a growing number of startups developing innovative solutions to the city's most pressing urban challenges. A focus for the program is enabling collaboration between entrepreneurs, civic stakeholders, government agencies, and enterprise companies through pilot projects and applied research. There is great alignment between the goals of this program and the ACCESS Center, and New Lab looks forward to a strong collaboration with the ACCESS Center as we support the growth of tech startups who are building products and services to improve the quality of life in cities.

Additionally, New Lab operates a robust STEM education program aimed at empowering the next generation by making frontier technologies accessible, immersive and inspiring. We’ve served over 1,500 local students to date and look forward to working with the ACCESS Center to make these resources available for more students.

Urban-X

The URBAN-X accelerator program provides 20 immersive weeks of customer development, product development, network-building and expert guidance for startups – all in preparation for fundraising. Our accelerator is unique in that our mentors are experts in urbantech challenges and deeply understand regulated industries and government procurement. Our acceptance rate for startups reimagining city life is roughly

2%, while 85% of our teams have gone on to receive their next round of capital. We've invested in some of the leading energy tech startups like Treau, Blueprint Power and Sapient Industries.

We look forward to serving as a Resource Partner for ACCESS. URBAN-X will work with ACCESS in the following ways:

- Serve as a "next step resource" for ACCESS teams. We believe that based on the rigorous selection process and resources provided by ACCESS, their teams are likely to be excellent candidates for URBAN-X. We can't guarantee spots for ACCESS teams, but we anticipate funding some great projects from the initiative.
- Collaborate with ACCESS on workshops and events to help build skills and increase the likelihood of venture funding for founders.

Lastly, having served since 2012 as a core national faculty for the NSF i-Corps program, I am pleased to see NSF funding new engineering research partnerships and encouraging the exploration of commercialization.

Media Lab

NYC Media Lab is a public-private partnership encompassing all the universities of NYC. NYC Media Lab is dedicated to driving innovation and ultimately job growth in media and technology by facilitating collaboration between the City's universities and its companies. Media Lab looks forward to collaborating by making its programs available. Of particular relevance is the NYC Media Lab's Combine program, a venture platform to advance entrepreneurship in emerging media technology. The Combine offers a lean startup accelerator for university startups, corporate intrapreneurship programs, and executive education. Its goal is to help entrepreneurs and innovative companies take advantage of NYC Media Lab's community and the City's thriving technology ecosystem.

RLab

A partnership between New York City and its universities, RLab is the nation's first city-funded center for research, education and entrepreneurship in virtual and augmented reality and related technologies. The RLab, maintains 16,500 sq ft of co-working labs, classrooms, and studios for research, entrepreneurship and education in virtual and augmented-reality, spatial computing and other emerging media technologies. RLab looks forward to collaborating by making their programs around education and entrepreneurship available to the ACCESS center student and faculty population.

g. Education Outreach and Workforce Development Collaborators

ACCESS center will collaborate with Workforce development organizations, Museums, School Administrators, School districts, Schools and Community colleges to ensure all of our current and future Research Experiences for Teachers and Students programs (RET, REU, CURE), WiTNY Summer Guild and programs of the future are robust and effective.

As appropriate the collaborators below will collaborate by:

- Encouraging Teachers and Schools to apply for research experiences and outreach programs.
- Referring its teachers to ACCESS's education program,
- Referring its students and alums to the variety of internships and education programs.
- Advise in the development and evaluation of workforce training curriculum
- Host student and teacher training events
- Participate in the development of new training programs
- Participate in the delivery of appropriate curriculum.
- Provide internships and other experiences to students

Collaborators include:

Women in Technology and Entrepreneurship in New York (WiTNY)

Women in Technology and Entrepreneurship in New York (WiTNY) Founder and Director Judith Spitz has agreed to collaborate with our ERC by expanding the Winternship program to include CUNY students to participate specifically on this ERC's projects. The Winternship program is a paid, three-week mini-internship.

Schomburg Center for Research in Black Culture, The New York City Public Library
The Schomburg Center for Research in Black Culture, a research library of The New York Public Library, is one of the world's leading research facilities devoted to the preservation of materials on the global African and African diasporan experiences. A focal point of cultural and intellectual life, the Center also functions as a research facility and cultural arts institution in the Harlem community providing public programs, exhibitions, fellowships and various initiatives that illuminate and illustrate the richness of black history and culture. The Schomberg Center enjoys high visibility across a wide range of audiences and supports forward thinking collaborations that educate our patrons, members, and Harlem Community. Columbia Universities proposed ACCESS Center receives our commitment in collaboration.

Museum of the City of New York
The Museum of the City of New York fosters understanding of the distinctive nature of urban life in the world's most influential metropolis. It engages visitors by celebrating, documenting, and interpreting the city's past, present, and future. Education is at the core of the Museum's mission. Explore and experience our learning opportunities for teachers, students, families and the community.

STRIVE
STRIVE is a nonprofit agency headquartered in East Harlem that provides skills training, certification, and job placement services to help New Yorkers get back to work. For more than 30 years, STRIVE has been providing career development services to more than 1,300 men and women annually. STRIVE offers a solution that benefits employers and participants alike: in-demand occupational skills training, reflective of local employer needs.

Superintendent for School District 5
Superintendents oversee schools in NYC. Some of their responsibilities include: Communicate Department of Education policy to both schools and the public, Supervise and evaluate school principals, appoint principals in district schools and Approve principal, assistant principals, and teacher tenure decisions.

School District of Palm Beach County, Florida
The School District of Palm Beach County is the tenth largest in the nation and the fifth largest in the State of Florida serving more than 193,000 students who speak 146 languages and dialects. As the largest employer in Palm Beach County, the school district has 22,340 employees, including more than 12,900 teachers. Our Vision: The School District of Palm Beach County envisions a dynamic collaborative multicultural community where education and lifelong learning are valued and supported, and all learners reach their highest potential and succeed in the global economy. Our Mission: The School District of Palm Beach County is committed to providing a world-class education with excellence and equity to empower each student to reach his or her highest potential with the most effective staff to foster the knowledge, skills, and ethics required for responsible citizenship and productive careers.

Broward School District, The School Board of Broward County, Florida
Broward County Public Schools is the 2nd largest school system in Florida and the 6th largest school system in the U.S. Broward County Public Schools (BCPS) continues to be spotlighted by the White House as a national model for expanding access to computer science in schools. Through the District's #BrowardCodes initiative, in 2017/18 more than 50,000 students are positively impacted by computer science offerings at 100 percent of BCPS K-12 schools. The Innovative Learning Department is an integral part of Broward County Public Schools' Learning Division within the Office of Academics, focusing on supporting and implementing innovations in teaching and learning to assist BCPS students, teachers, and administrators with transitioning to personalized learning environments. There are several units within the department: Instructional Technology, Instructional and Digital Materials, Library/Media, and Gifted and Talented.

The High School for Math, Science and Engineering at the City College of New York, New York
The High School for Math, Science and Engineering (HSMSE) at The City College of New York is a unique and unparalleled, collaborative, educational experience in which talented students are challenged to expand their intellect and to develop the habits of inquiry, expression, critical thinking, problem seeking as

well as problem solving, research and presentation. The academically rigorous learning environment focuses on math, science and engineering while emphasizing civic responsibility and the value of knowledge for its own intrinsic reward. The High School for Math, Science and Engineering (HSMSE) is one of eight highly selective specialized high schools established and run by the New York City Department of Education to serve the needs of academically gifted students. HSMSE students come from all five boroughs, from public and private middle schools, and from diverse ethnic backgrounds. When they graduate they are prepared for college and for life beyond by HSMSE's in-depth approach to learning. The school opened in 2002, graduating its first class in 2006. The demographics in 2017 for this 500 student, four-year institution were: 2% American Indian/Alaska Native; 37% Asian/Hawaiian/Pacific Islander; 9% Black; 17% Hispanic or Latino; 9% Multiracial; 26% White. HSMSE is conveniently located next door to CCNY's Engineering School which may house some of the COSMOS testbed equipment.

Columbia Secondary School for Math, Science and Engineering, New York, New York

The Columbia Secondary School for Math, Science, and Engineering is a public, sixth through twelfth grade school that opened in the fall of 2007, and is located in the COSMOS testbed. A partnership between the New York City Department of Education, the community, and Columbia University, CSS-MSE serves academically talented students who have an interest in a rigorous and demanding program focusing on math, science, and engineering. The school reached its full enrollment of close to 700 students during the 2013-2014 school year and graduated its first class of seniors in June, 2014.

Columbia Secondary's program of study provides a challenging academic experience that prepares its students for selective colleges; for careers in science, math, and engineering; and for a life of civic engagement and ethical responsibility. We train students to be socially and politically conscious, to be aware of their responsibility to their communities and the world, and to be dedicated to a life of creation and discovery in service of humanity.

A.D. Henderson University School, Boca Raton, Florida

The A.D. Henderson University School (ADHUS) is a national exemplary model for school systems and teacher preparation programs, improving education for diverse student populations through innovative, faculty-developed research and standards-based curriculum. The public Title I School is located on Florida Atlantic University's main campus in Boca Raton, within walking distance of I-SENSE facilities. As a demonstration site, the school is a partner in the teacher education process by providing an ideal setting for the observation and research of current instructional practices and strategies. The school serves as a location for practicum teaching experiences. Additional services to practitioners in the field are provided through professional visitation, conferences, workshops, demonstrations, and teaching videos.

ADHUS students complete their coursework on the Henderson campus from kindergarten through 9th grade. Beginning in the 10th grade, all coursework is completed via dual-enrollment in university courses on the Boca Raton campus. Students typically earn 3 years of college credits, and some earn their bachelor's degrees just prior to their high school diploma. Admission to the school is based on lottery for K-8, with merit criteria for 9-12. The school is designated as a Title I school. A major focus is a relatively new research program that matches students with faculty research mentors and supports these students through the research process. To support this transition, the research program provides a series of four one-credit-hour research methodology courses. These courses help students develop basic research skills, guide them in finding a faculty research mentor, and support them as they conduct research with that mentor.

With an enrollment of 1,151 students, world-class faculty push the limits of student development by fostering innovation, promoting early exposure to the hard sciences, and opening doors to research and hands-on discovery. U.S. News and World Report featured the school as *a national model for dual-enrollment*.

Donna Klein Jewish Academy

Donna Klein Jewish Academy is a diverse and close-knit community of families across the spectrum of Jewish denominations with a common commitment to Jewish identity, heritage and values. The school is located within the vibrant, 100-acre campus of the Jewish Federation of South Palm Beach County. Now in its 40th year, Donna Klein Jewish Academy continues to expand as a premier Jewish Community Day School. DKJA is recognized as the ONLY Jewish Community Day School in the world to have been honored

as a FranklinCovey Leader In Me Lighthouse School**,** demonstrating a leadership model of excellence emulated by schools locally, nationally and internationally. DKJA is a renowned educational institution, evident in the practices of *The 7 Habits of Highly Effective People*, which are infused in all aspects of daily life, curriculum and learning opportunities.

Palm Beach State College
Palm Beach State College has become the largest institution of higher education in Palm Beach County and the fourth largest (based on FTE) of the 28 colleges in the Florida College System. Palm Beach State College has been an integral player in the remarkable growth and prosperity of Palm Beach County. Our graduates - community and business leaders for generations - have impacted every industry and continue to do so today. Founded in 1933 as Florida's first public community college, Palm Beach State has grown from three classrooms and 41 local students to five campuses and 49,000 students from more than 158 countries. One of the top producers of associate degree graduates in the U.S., PBSC also offers baccalaureate degrees, professional certificates, career training, and corporate and continuing education.

h. Foreign Collaborators

University of L'Aquila, Department of Information Engineering
Our research and doctoral programme encompasses computer networking technologies, *wireless systems*, *networked multimedia applications*, quality of service, *mobile networking*, intelligent buildings, context driven information systems and *communication protocols*. Much of this research work is funded through research grants and supported by industry. Our project known as: Innovating City Planning through Information and Communication Technologies (INCIPICT) represents the context for testing advanced and pervasive wireless technologies, necessary to prepare the support layer for innovative applications and provides research on techniques solutions for reduction of energy consumption and increase of transmission speed (and bandwidth). ACCESS represents for us in itself an important confirmation of the work done to date in L'Aquila, and we look forward to this collaboration. Our University and our City are making significant efforts to develop a living laboratory model and the first feedbacks seem to be encouraging. We operate as a hub of a network of relationships that with this opportunity could be significantly enriched by enhancing this across the scientific areas in ACCESS.

Kyutech, Kyushu Institute of Technology
Kyushu Institute of Technology (Kyutech) was founded in 1907 in Japan, and currently consists of three faculties: Faculty of Engineering, Faculty of Computer Science and Systems Engineering, and Graduate School of Life Science and Systems Engineering, with more than 5500 students including over 300 foreign students.

Our Kyutech team would collaborate with the ACCESS Center in Wi-Edge vision by enhancing our on-going NSF-NICT joint-research project with CCNY. In particular, our collaboration will focus on sharing research around these topics (i) reliable and coverage-extendable wireless communication networking among end-devices and edge-cloud nodes by leveraging vehicles as mobile access point and mobile edge-cloud, and (ii) reliable and adaptable networking and distributed computing among edge-cloud nodes and central-cloud by realizing SDN-based data replication and process migration efficiently. We would also be happy to consider our graduate students visiting the ACCESS Center for potential collaborative projects for ACCESS.

Politecnico Milano, School of Engineering, Advanced Network Technology Laboratory
Politecnico Milano is a scientific-technological university which trains engineers, architects and industrial designers. The University has always focused on the quality and innovation of its teaching and research, developing a fruitful relationship with business and productive world by means of experimental research and technological transfer. The ANT Lab supports research projects in the area of communication networks. Given the main research areas are: Wireless Networks, Internet of Things, Internet of Energy/Smart Grid and Traffic Data Analysis we look forward to sharing our research findings and engaging in though visiting faculty, similar to our efforts already with FAU and workshops as deemed feasible.