Proposal Overview

Collaborative Research: NeTS: Medium: Resilient NextGen Wireless
Networks using Reconfigurable Integrated Access and Backhaul
Technologies with Edge Intelligence (NESTOR)

The promise of the emerging next generation (NextG) wireless networks and the Internet of Things (IoT) will not be fulfilled unless edge networks can be made secure and resilient, yet remain affordable for the service providers to deploy. With the advent of emerging technologies, such as Reconfigurable Intelligent Surfaces (RIS) that reduce the required number of expensive base stations while providing coverage, and low cost wireless Integrated Access and Backhaul (IAB) networks, the coverage of NextG networks can become truly ubiquitous. The emerging edge intelligence paradigm in the Internet of Things (IoT) will not

only help secure the IoT but also unlock its full potential. The NESTOR proposal calls for new robust network architectures, intelligent resource orchestration schemes, mobility management and handover models, dynamic spectrum access, and anomaly detection and trust models with the goal of securing NextG

networks from connectivity and service disruptions, as well as malicious actions or malfunction. NextG

wireless networks will be composed of a large number of highly mobile devices with intermittent, delay-sensitive, and personalized demand to be supported over resource-limited, unpredictable, and unreliable

wireless channels. To address these new NextG network challenges, the NESTOR project undertakes the task of injecting intelligence in the design of provably resilient and economics-aware resource orchestration, network trust and secure mechanisms for increasingly dynamic and disparate networks.
Keywords: Integrated Access and Backhaul, Resilient Resource Orchestration, Dynamic Spectrum Access,
Security and Trustworthiness, Next Generation Wireless Networks, IoT.

Facilities, Equipment and Other Resources

University of New Mexico

Dr. Eirini Eleni Tsiropoulou is an Assistant Professor with the Department of Electrical and Computer
Engineering (ECE) at the University of New Mexico (UNM). Part of the research activities of this project
will be conducted at the Performance and Resource OpTimizatiOn in Networks (PROTON) lab, led
by Dr. Tsiropoulou and located in the Department of Electrical and Computer Engineering (ECE) at the
University of New Mexico (UNM), main campus.
UNM School of Engineering
Part of the School of Engineering of UNM is the Center for Advanced Research Computing (CARC).
High-performance facilities include more than 3,000 cores and -1 PB of RAID5/RAID6 enterprise
storage. CARC's resources are available without charge to all faculty, student, and staff researchers at the
University, through support from the UNM Office of the Vice President for Research. CARC, located in
the Galles Building adjacent to the center of the main campus of the UNM, has 2700 square feet of
machine room space, and supports advanced hardware and software for a diverse community of
researchers at the University, spanning five Colleges and more than twenty departments. Systems include
dedicated machines, such as the Be the Xeon Phi/NVIDIA GTX Titan platform for experimental code
development in astrophysics and nanoscience, as well as an array of "community" clusters and parallel

machines. These include the poblano 256 GB, 64-core SMP system, a shared-memory server for memory-
intensive bioinformatics, computational biology, and multiphysics applications; the 200-node Galles

'green' Hadoop/high-throughput Beowulf cluster for bioinformatics and "big data" applications; and five
production parallel machines: nano, Gibbs, pequena, Metropolis, and Ulam. The Center's newest
supercomputer, Xena, designed for high-throughput, memory-intensive GPU-based MATLAB and hybrid

parallel applications, and supported by an NSF MRI award, is the recent addition. The CARC facilities
support custom parallel C/C++/Fortran code with MPI (message-passing interface); most of these systems
have OpenMP, as well licenses for MATLAB. The CARC maintains a 15-foot diameter Sky-Skan Dome

Theater display system with six projectors and five-channel audio, switchable between an 8-node dual-
CPU Windows-based rendering farm (with 10 TB of dedicated RAID storage) and a 16-core 32 GB RAM

Mac Pro real-time rendering engine with advanced Nvidia graphics capabilities.
PROTON Lab

Figure 1 Performance and Resource Optimization in Networks Lab – PROTON Lab, University of New

Mexico

Space - The PROTON Lab led by Dr. Tsiropoulou has sufficient office and lab/group space (665 sq. ft.)

in ECE Building, UNM to accommodate a group of 12 graduate students, undergraduate students, high-
school students, postdocs, and visitors.

Major computing equipment in the Performance and Resource OpTimization in Networks (PROTON) -
Lab, led by Dr. Tsiropoulou, includes: (i) twelve Dell OptiPlex 790 workstation with 16GB 1333MHz
DDR3 SDRAM, Intel (R) Core (TM): 7-2600 CPU @ 3.40GHz and 1GB AMD RADEON HD 6450
graphics card, (ii) a Dell Inspiron 7537 Laptop with 16 GB 1600MHz DDR3 SDRAM, Intel (R) Core
(TM): i7-4500U CPU @ 1.80GHz and 2GB GDDR5 nVidia GeForce GT 750M graphics card, (iii) a Dell

Inspiron 15 Gaming Laptop with 16 GB 2400MHz, DDR4 SDRAM, Intel (R) Core (TM): i7-7700HQ
CPU @ 3.8 GHz and 4GB GDDR5 nVidia GeForce GTX 1050 graphics card, and (iv) three MacBook
Pro Laptop with 16GB 2133MHz LPDDR3 memory, and Intel (R) Core (TM): i7 Kaby Lake CPU @ 2.5
GHz. Also, the PROTON lab is equipped with four Intel i7-8700 6 core CPU, 32GB RAM, 256GB SSD,
four NETGEAR AC5300 WiFi routers, five Cora-Z7-07S, five Zybo-Z7, and one USRP 2900. Besides
that, the PROTON lab also houses low-end mobile computing equipment for Master students and senior
project design students, which includes one Lenovo IdeaPad S400 laptop computer, equipped with Intel
I3 and three Toshiba Satellite C55D laptop computers, equipped with AMD Quad Core A6 and 8G RAM.
Sensors and microcomputers include a number of Raspberry Pi 3 Model B single-board computers and
a number of Dialog Semiconductor DA14583 IoT Sensors.
Software - A rich software environment of commercial state-of-the-art software tools is available. This
includes, but is not limited to: Mathworks Simulink, MATLAB, CST Microwave Studio, Solid Works 3D
CAD design software, Cadence, Xilinx ISE, Tanner EDA, Mentor Graphics, CST Microwave Studio,
HFSS, Microsoft Office and Visual Studio Packages and Labview 2017.
Other equipment includes an installed Sonitor Ultrasound Real Time Location System (RTLS). In
addition, the PROTON lab also houses two Impinj xArray gateways as a fixed infrastructure passive
RFID reader.
The PROTON lab is supported by dedicated engineering staff with expertise in networking and
communications tools, software development and simulation.

Facilities, Equipment, and Other Resources

1 Facilities at New York University

The Electrical Engineering and Computer Science Department at the at New York University Tandon School of Engineering is located on the ninth floor of the 370 Jay Street building on the Brooklyn campus. The PI serves as the director of the Center for Advanced Technologies in Telecommunications (CATT), which is sponsored by New York State and houses many specialized laboratories and a modern office setting which accommodates over 40 students and 8 faculty. Among its research facilities, most of the implementation work proposed will be conducted in the following labs.

1.1 COSMOS

New York University is a participant in the recently funded Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment (COSMOS) project, which is part of the NSF Platforms for Advanced Wireless Research (PAWR) program. PI Shivendra Panwar also serves as a co-PI in the COSMOS.

The COSMOS testbed will be deployed in upper Manhattan and will consist of 40-50 advanced software-defined radio nodes along with fiber-optic front-haul and back-haul networks and edge and core cloud computing infrastructure. We plan to utilize this testbed starting from Year 2 of this project.

1.2 Wireless Implementation Testbed Laboratory

The Wireless Implementation Testbed Laboratory at NYU focuses on the design, study and implementation of wireless protocols and their performance in a real environment. Most of the equipment in the lab was acquired with the help of an NSF MRI grant (Acquisition of an Experimental Platform for Wireless Multimedia Networking, MRI-0722868). Witest Lab is equipped with two wireless testbeds: An Open Source Wireless Drivers Testbed and an All Software Radio Wireless Testbed.

The goal of the Open Source Wireless Drivers Testbed is to provide a platform that can be used to build realistic wireless MAC protocols, similar to those on the WiFi commercial products. The wireless interfaces of the nodes are commercial wireless cards based on the IEEE 802.11 standard (Intersil, Atheros, Intel). The cards communicate with the operating system though open source drivers (HostAP, MadWiFi and Intel). The testbed consists of 30 nodes. Each node consists of a

motherboard with a 1 GHz Pentium processor, 1GB RAM, 40 GB of local disc and the appropriate
input-output interfaces. It has two mini PCI slots. The nodes are connected through Ethernet interfaces and they are managed by a server.
The goal of the All Software Radio Testbed is to provide a radio platform that can be used to build from scratch new protocols and mechanisms in the PHY and MAC layer by defining their functionality using software. It is a flexible platform to explore the potential of new features that can not be implemented in the open source drivers due to the fact that the lower layer of the MAC
implementation is controlled by the hardware and the firmware of the wireless card. This testbed consists of 12 nodes that are based on two different platforms: 6 Universal Software Radio Platform
(USRP) from Ettus Research and 6 Wireless Access Radio Platform (WARP) from Rice University.
The Witest lab has installed two NEC WiMAX base stations, funded by the GENI project.
This testbed enables us to leverage a state-of-the-art IEEE 802.16e WiMAX base station product

from NEC to prototype an open, programmable and virtualizable cellular base station for GENI.
The labs have also acquired 12 WiMAX USB adapters and over 10 Intel MINI PCI-E cards for wireless clients.

1.3 Wireless Information Systems Laboratory

The Wireless Information Systems Laboratory at NYU was initially developed as a basic teaching
and research facility for undergraduate and graduate students. Equipment for the lab was originally

acquired in 1994 with the help of a NSF Instrumentation and Laboratory improvement grant (National Science Foundation Instrument and Laboratory Improvement grant USE-9250315) including

matching funds from Hewlett-Packard, Cellular One, and John Fluke Manufacturing Company, and the MRI grant mentioned above. More recently, the lab has benefit from equipment donations
from Qualcomm and National Instruments. The major research platforms in this lab are:

• HPC real-time network emulation: A high performance computing (HPC) cluster is being developed for real-time emulation of medium size cellular networks. The physical layer is modeled in computer simulation using standard industry models, while the MAC and upper layers run “as is.” The networks are simulated in real-time using a ns3 network simulator modifed for multithreading across multiple cores, which is implemented on generic Linux machines connected via an Infiniband switch. Real application can natively “plug into” the simulation to test actual application and transport layer protocols.

• National Instruments LabView Testbed: Smaller, more detailed simulations can be performed on testbed supplied by National Instruments. National Instruments has supplied WISL two PXI chassis with modules for RF, baseband and real-time network layer processing. National Instruments is providing LabView-based modules to emulate an 3GPP LTE physical layer so that we can test our algorithms on industry standard cellular systems. The LabView modules are based partially on FPGA IP cores licensed to NYU by donation from Xilinx. The system has sufficient capabilities to simulate two base stations and two mobiles, each with 10 MHz and 2x2 antennas.

In addition to the research platforms, the lab is equipped with six test stations configured for operation by two students. Each station is equipped with a 1.5GHz spectrum analyzer, digital storage oscilloscope, 1.0 GHz Radio Frequency (RF) signal generator, noise generator, true Root Mean Square (RMS) voltmeter, dc power supplies, function generators, printer, desktop computer, frequency/event counters, double balanced mixers, power splitters and associated test components.

The lab is also equipped with the following standard RF and digital test equipment including Agilent vector signal generator, signal analyzer, network analyzer, 500 MHz 4+16 channel scope, InfniVision FPGA Probe, Continental Resources Handheld Spectrum Analyzer and a Tektronix 600MS/s, 2 Channel, 14bits Arbitrary Waveform Generator.

The other platform we recently acquired is the InterDigital Edgelink research prototype, which allows us to build a carrier-grade mesh backhaul providing multi-gigabit throughput over a commercial 802.11ad (WiGig) solution. Each Edgelink node is equipped with a 32-element phased array antenna that supports four 2 GHz wide channels at the 60GHz unlicensed band. We aim to use emerging SDN frameworks including OpenDaylight and OpenvSwitch to develop research prototypes. A specific focus will be adopting these open source solutions to support wireless networking protocols where link characteristics are more dynamic than the wireline networking software built on this SDN framework.

Facilities, Equipment, and Other Resources at Missouri S&T, USA

1) Facilities in Creative Research in Wireless Mobility and Networking (CReWMaN) Lab
The CReWMaN Lab (directed by PI Sajal Das) has 15 workstations, 3 high end servers, 9 laptops, Gigabit
routers, switches and networking infrastructures, wireless LAN access points, Bluetooth kits, 60 wireless
sensors (MicaZ, iMote, TelosB), 8 smartphones (Galaxy, iPhone), health sensors (Shimmer), smart
watches, multifunction laser printer, network attached storage and 4 servers. The lab has a dedicated section
for testbed development. CReWMaN has storage and computational facilities to implement and validate
the proposed architectures, algorithms and solutions in the PsychSense project; conduct simulation and real
experiments; develop prototypes; and disseminate research outcomes.
Heterogeneous Sensing Testbed: CReWMaN has a heterogeneous and multimedia Wireless Sensor
Network testbed composed of 60 sensor nodes interfacing with standalone sensing platforms (Arduino)
along with Bluetooth communication, smartphones and wearables. It also has Software Defined
Networking kits with USRP board and daughter boards for wireless experiments. Specific equipment
include 6 Nokia N900 mobile Internet devices, 6 Nexus One smartphones; 5 Digikey Beagleboards (each
based on the Texas Instruments OMAP36x platform); 3 Crossbow iMote.Builder kits (each with 3 sensors);
4 Crossbow IMB400 sensor cameras (up to 640x480 resolution); 3 Sentilla Perk kits with 3 sensor nodes
each; 15 SunSpot development kits with 3 sensor nodes each; 50 MEMSIC TelosB sensor nodes (with
temperature, light, humidity sensors); Shimmer health sensor kit; 10 Arduino sensor boards; 9 Raspberry
Pi small single board computer; 4 KW EZ Electricity Usage Monitor; 2 Mastech MS3302 AC Current
Clamp Transducer; 40 Crossbow MICAz sensors; 10 Crossbow Cricket sensors (with ultrasound range).

Figure 1: Smart Environment Setup – (a) Sensor Layout in the Lab, (b) Technology Infrastructure,
(c) Off-the-shelf IoT devices, Sensors and Actuators available for prototype development,

(c) Programmable Micro-controllers

2) University-wide Resources:
Missouri S&T's Office of Information Technology (OIT) provides advanced campus-wide computing resources with high-speed backbone infrastructure in support of teaching and research. These resources include a campus wide telecommunication infrastructure (including wireless access), numerous distributed computer clusters, and a large number of I/O peripherals (e.g., smart terminals, printers). There are several general-purpose computing labs with numerous networked Linux and Windows PCs and printers.
The OIT manages Missouri S&T's two high performance computing (HPC) facility.
(a) The Forge HPC cluster with 1958 x86 Processor Cores on 165 nodes, where nodes range from Dell C6220 II to Dell 1950 servers, interconnected with FDR Infiniband and memory ranges up to 256G/Node. The HPC contains a lustre appliance with 48TB of high-speed scratch interconnected with FDR Infiniband. There are 12 nodes with two NVidia Tesla C2075 GPUS and 4 nodes with 7 NVidia Tesla C2075 GPUs.
(b) The Foundry HPS cluster (acquired recently through an MRI grant) has the following configurations.
Compute nodes: There are 143 compute (Dell C6525) nodes in the Foundry configured as: 4 node chassis, each containing dual 32 core AMD EPYC 7502 CPUs with 256 GB DDR4 ram and 6 480GB SSD drives in raid 0. These processors have a base clock of 2.5 Ghz and can do 16 double precision floating point operations per clock cycle. There are total 64 of these cores in each compute node, which means that there

is a theoretical 2.5 TFlops per compute node. Other details about compute nodes – BogoMIPS: 4990.27;
L1d cache: 32K; L1i cache: 32K; L2 cache: 512K; L3 cache: 16384K.
GPU nodes: There are 6 GPU nodes in the Foundry. Each node has 4 Tesla V100 GPUs interconnected
with each other via NVlink inside a C4140 chassis. The nodes are interconnected via HDR Infiniband for
direct memory access from node to node. Each of the 24 GPUs has 32GB memory. Each GPU can deliver
around 8 TFlops of double precision calculations. That puts the total for a GPU node at around 32TFlops.

Each node is interconnected with 100Gbps HDR100 Infiniband. This interconnection however is 5:1 over-
subscribed from one rack to another, meaning that if the network is fully busy the max bandwidth from a

node in rack A to a node in rack B should be around 20Gb/s. However, from node to node in the same rack
it should maintain the full 100Gbps bandwidth.
Storage: The Foundry home directory storage is available from an NFS share backed by our enterprise
SAN. This storage will provide 10 TB of raw storage, limited to 50GB per user.
Each user gets a scratch directory created for them at /lustre/scratch/$USER also for temporary storage.
Additionally, Missouri S&T has 41 Computer Learning Centers, consisting of 553 PCs, 122 Mac's, 112
workstations, and a variety of printers, scanners, and other peripheral devices. Extensive software
development tools and applications, such as Visual C++, JAVA, MATHEMATICA, MATLAB, ORACLE,
and MYSQL, are available from these computers. All computers are networked with high-speed Internet
connections. The OIT has an application software development and support structure with about 65
professional software developers, IT managers, and IT support professionals dedicated to developing
application software and providing support for all of PCs, Macs, and Unix/Linux computers.
3) Other Resources:
The Department of Computer Science at Missouri S&T has a Cloud infrastructure and several other
computer laboratories for developing advanced software systems. The Intelligent Systems Center (ISC),

where PIs are research investigators, has a technical specialist to support the center’s research activities.