WINLAB Overview

June 4th, 2017

WINLAB

Rutgers, The State University of New Jersey
www.winlab.rutgers.edu
Contact: Ivan Seskar, Associate Director
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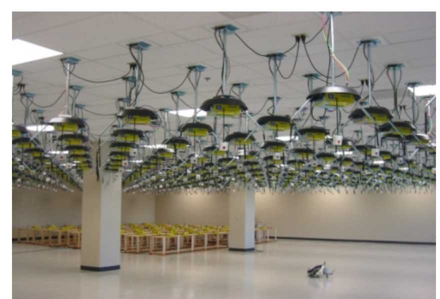
WINLAB Summary: Mission & Resources

- WINLAB founded in 1989 as a collaborative industry-university research center with specialized focus on wireless networking
  - Mission is to advance both research and education in the area of wireless technology (… a topic of fast growing importance across the entire information technology field!)
  - Research scope includes information theory, radio technology, wireless networks, mobile computing and pervasive systems
  - Participation in several major federal research initiatives in the wireless and networking fields - cognitive radio/spectrum, future Internet architecture (FIA), GENI
  - Unique SOE resource with local, national and international recognition and impact
- WINLAB resources in brief:
  - ~25 faculty/staff, most from the ECE and CS departments at Rutgers
  - ~40-50 grad students (80% PhD, 20% MS) – ~50 PhD's graduated since 2005; ~30 UG internship
  - ~$5-6 M/yr research funding (80% federal, 20% industry); ~10 sponsors from all over the world
  - ~20,000 sq-ft facility, mostly at the Rt 1 Technology Center building (see photo)
  - Unique experimental capabilities including ORBIT testbed (see photo) and WiNC2R cognitive radio

WINLAB Tech Center Facility



ORBIT Radio Grid Testbed

Status Update: Research Topics 12/16

Mobile Computing & Pervasive cluster

Crowdsourcing of Physical World Tasks

Mobile User Privacy

Guardian Angel Safety Systems

Mobile Edge Cloud

Privacy in IoT

Automotive Inforverse

Resilient Smart Cities

IoT Networking & Software Platform

Content Delivery Networks

Location Privacy via De-Idenfication

Cloud Enabled Green Communication

JUNO Mobile Cloud CPS

Networking cluster

MobilityFirst Future Internet Architecture

EIR

GNRS

Router design

5G Mobile

MF-VN

V2V

MCDN

M-homing.

ID Arch

NICE/MF

S-CDN

GENI Project

Wireless Network Virtualization

Wireless Network Security

Prospect Theory for Data Network Pricing

DSRC V2V Simulator

Advanced Wireless & City-Scale Testbeds

Distributed Spectrum Assignment (SMART)

Updating Systems & Networks

Wireless SDN

Open Base Station/ Software LTE

5G System

Radio/PHY & Spectrum

White Space Backhaul

SDN Spectrum Management

Low Latency 5G Design

LTE/WiFi Coexistence

ORBIT Cloud & CloudLab Ext

Machine Learning & social protocols for spectrum

Network Coding

Radar Spectrum Sharing

Massive MIMO

Visual MIMO

Spectrum Sensing & Radar Comm

Software Defined Radio Platforms (WISER)

Directional Networking Waveform

Optical/Wireless Integration

Status Update: Major Research Themes for Current & Future Projects

- Next-gen mobile core network – 5G/NGP/IETF
- Decentralized spectrum architecture (SMART)
- Software defined wireless networks (SDWN)
- "Big Data" architecture/privacy/applications for mobile
- Internet-of-Things architecture & key technologies
- "Edge cloud" for mobile and real-time CPS services
- Advanced wireless (B5G/PAWR) & city-scale testbeds
- Resilient smart city architecture
- Ultra-resilient wireless networks for disaster recovery

- …other

Status Update: Industry Research Topics

- Ongoing topics/collaborations with companies
  - InterDigital: ICN architecture
  - Toyota: vehicular networking
  - SES: satellite CDN network
  - Ericsson: 5G architecture (EC METIS-II), dynamic spectrum, open LTE virtualization
  - Huawei: internet-of-things (IoT) architecture, low-latency 5G network, identifier-based mobile core network
  - US Army: Directional networking waveform for tactical networks
  - Cisco: Mobile edge cloud architecture and modeling
  - Merck: IoT system for healthcare monitoring
  - Major DoD contractor: MobilityFirst for tactical

Status Update: Industry Sponsors (Current & Recent)

verizon wireless

ERICSSON

HUAWEI

US Army CECOM

InterDigital

NTT docomo

SES

Cisco Systems

NEC

Qualcomm

NICT National Institute of Information and Communications Technology *

Toyota InfoTechnology Center *

Nokia *

Aruba Networks *

InPoint *
Semandex
Zipreel

****Research Partners***

WINLAB Summary: People


Dipankar Raychaudhuri


Roy Yates


Narayan Mandayam

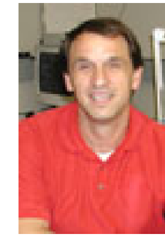

Janne Lindqvist


Wade Trappe

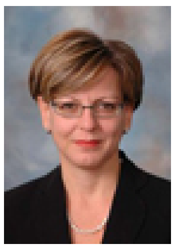

Predrag Spasojevic


Yanyong Zhang


Marco Gruteser

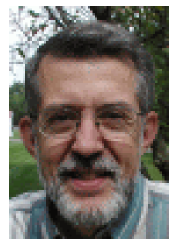

Ivan Seskar


Yicheng Lu


Athina Petropulu


Larry Greenstein


Dick Frenkiel

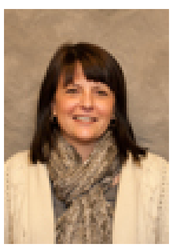

Rich Howard

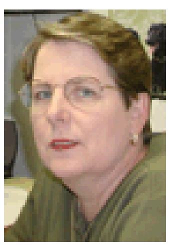

Richard Martin

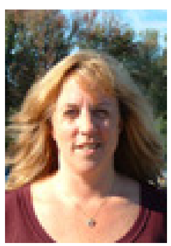

Anand Sarwate


Hui Xiong

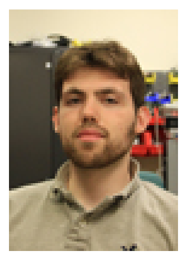

Thu Nguyen

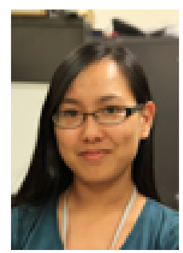

Lisa Musso


Noreen DeCarlo


Janice Campanella


Elaine Connors


Michael Sherman


Elisa Servito

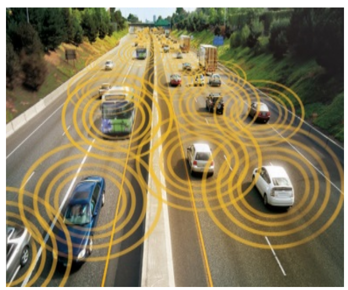

~40-PhD & MS Students as of 2016 (see www.winlab.rutgers.edu for photos)


Prashanthi Madala


Vivek Singh

MobilityFirst Project Background

- Started in 2010 under NSF FIA, continuing under FIA-NP
- Project team: Rutgers, UMass, Michigan, Wisconsin, Duke, MIT, Nebraska
- Clean-slate architecture motivated by fundamental shift of Internet services to mobile platforms → ~10B in 2020!
- Use cases:



Vehicular Networks

Content Delivery

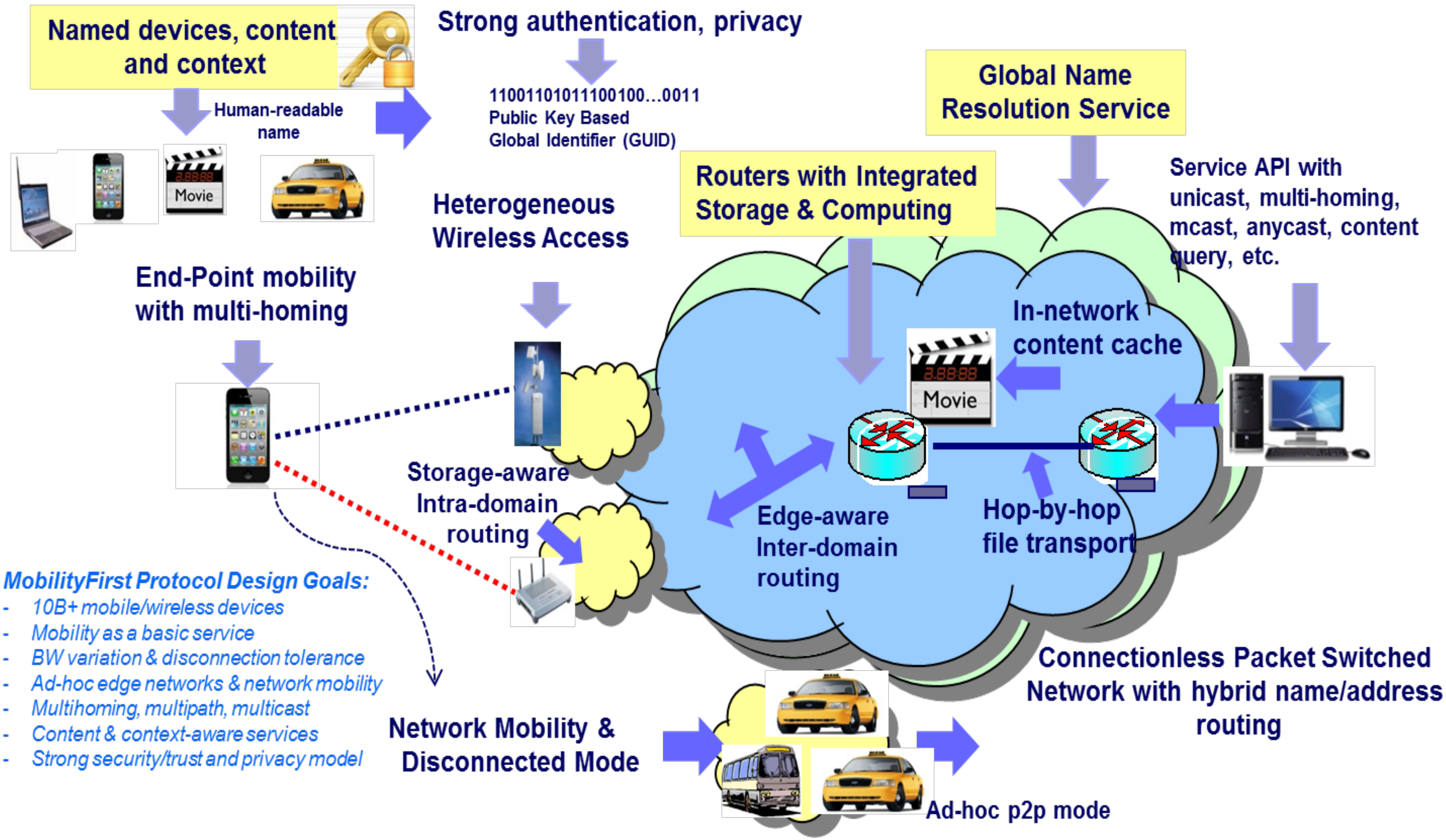
Cloud Services

Mobile Data
("5G", WiFi First, ...)

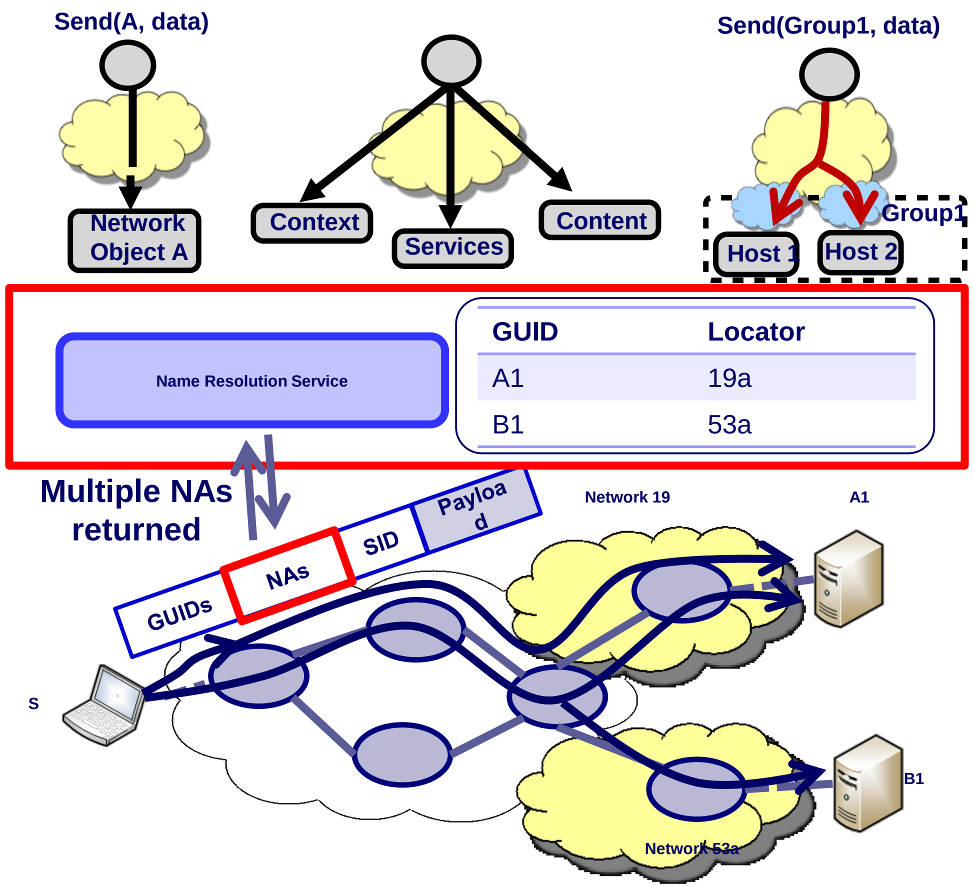
Emergency Networks

Internet-of-Things

MobilityFirst Architecture Summary



A Named-Object Architecture



GUID	Locator
A1	19a
B1	53a

Name Based Service Layer

- Flat globally unique identifiers (GUIDs) for network attached objects.
- Global Name Resolution Service.

Hybrid Routing

- Hybrid name/address based routing scheme is used for scalability.
- Block transport protocol

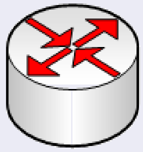
Name Based Services

- Name-based networking abstractions
- GUID-centric service API (send, recv, get, exec, etc)

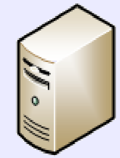
Computing/Service Layer

- Virtualized compute layer that enables novel programmable network services.
- Packet cloud services in the DP

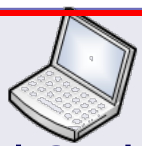
MF Prototype: Key Components



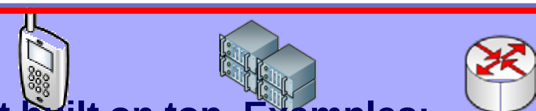
Router:
- Click modular router based implementation.
- Dynamic-binding using GNRS, hop-by-hop transport, and storage-aware routing.
- Provides access connectivity to clients through multiple technologies.
- Rate monitoring service at edge access.



GNRS:
- DMAP based implementation (DHT based distributed service).
- Java based, hardware and OS independent.
- Interchangeable network access layer/technology.



Network Stack:
- C++ software implementation that uses the pcap library to intercept and inject packets.
- GUID based Network API available for C/C++ and JAVA programs.
- Implements manager with support for simple migration policies (e.g. “use wifi”).

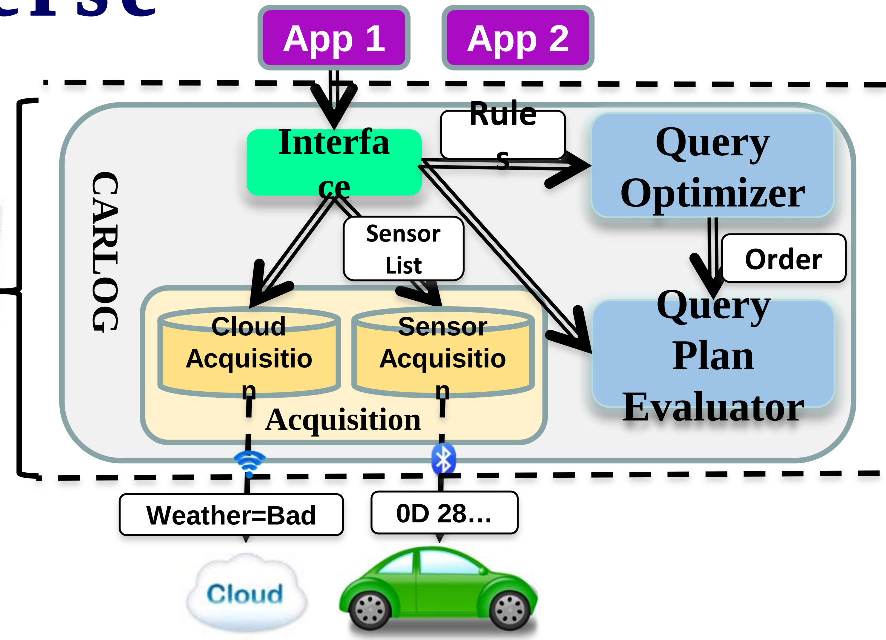


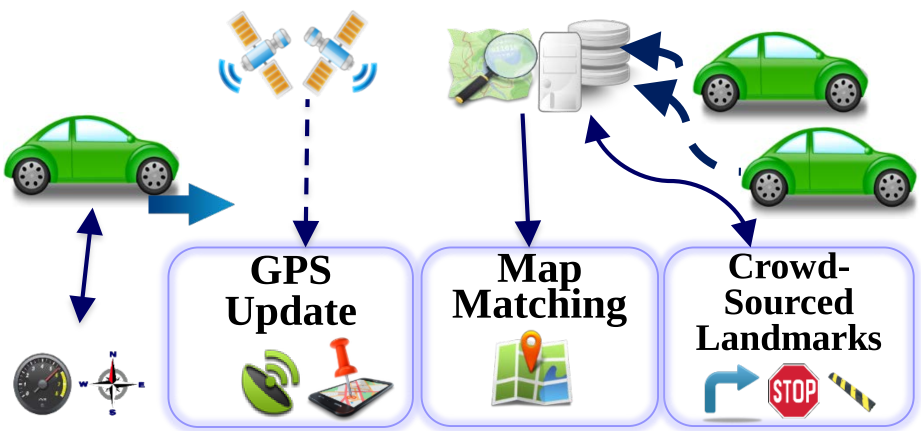
Rest built on top. Examples:
- Contextual applications and services.
- In-Network Services (cloudlet).
- Virtual Network Support.

Common Framework:
- OML based results collection and display.
- OMF based experiment control.

The Automotive Infoverse

- Design software that permits the rapid development of apps using the infoverse.
- Processing the infoverse to explore how to derive important factors that affect PERCS goals.
- Exploring methods to generate feedback that characterize how these factors affect the specific PERCS goal.
- Develop methods for assuring the quality of data in the automotive infoverse





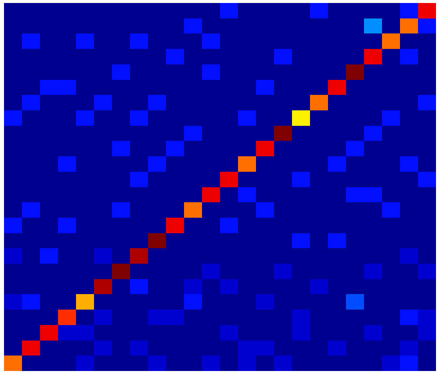
Aggregating traces of in-built sensor data to create an Information Universe

- Vehicular Context Sensing
- Infrastructure Sensing
- Localization

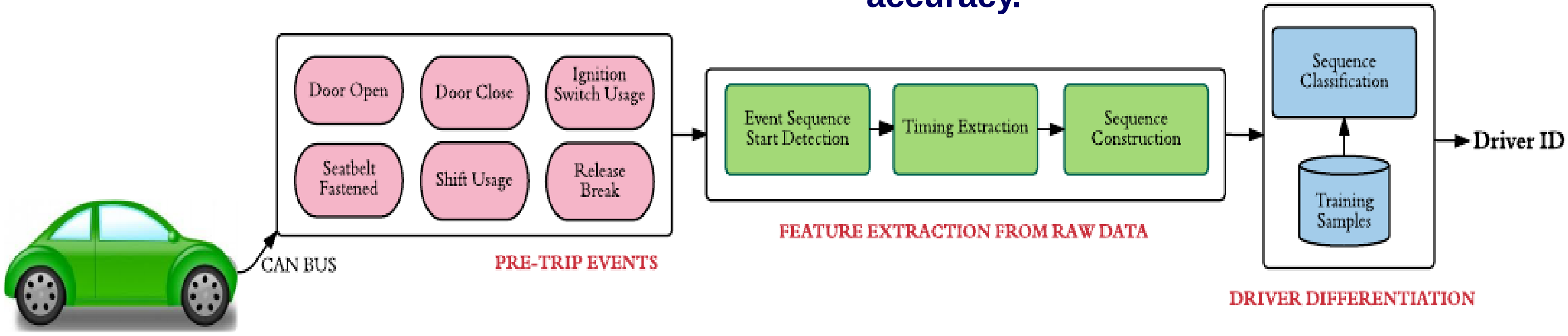
Driver Differentiation from In-Vehicle Data

Prof. Marco Gruteser

- Distinguish different drivers based on their behavior as observed through in-car sensors
- Identify a minimal set of in–vehicle data for driver distinction
- CARLOG framework on the smartphone used to log data from the CAN bus
- A learning algorithm on the remote server extracts features
- The incoming sequence is matched to a driver in the database



Up to 16 drivers can be distinguished 90% accuracy.

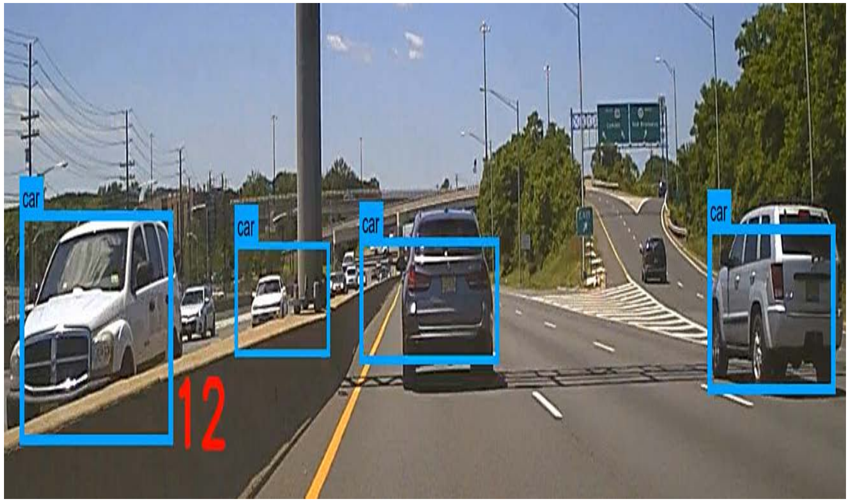


Collaborative Sensing: A Traffic Density Estimation Case Study

Prof. Marco Gruteser

- Develop count/speed estimation techniques based on in-car camera video
- Use collaboration to compute overall congestion levels from collected estimates

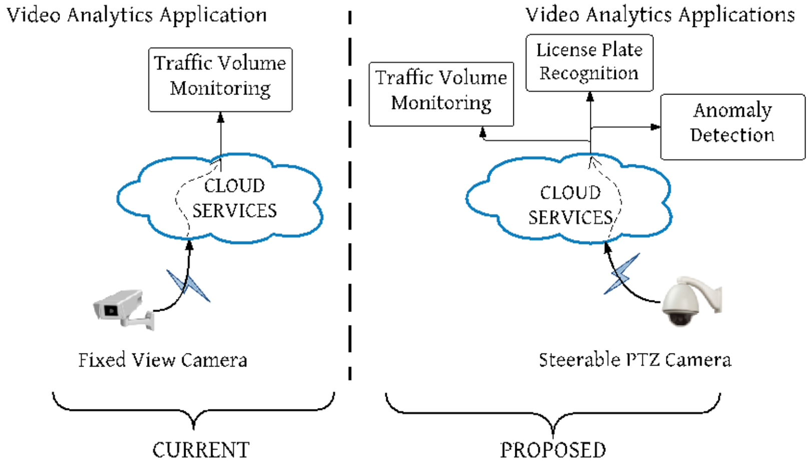
- Developed a vehicle-based camera sensing platform with deep-learning system (YOLO*) for image detection.
- Preliminary single vehicle count/speed accuracy ~ 80%

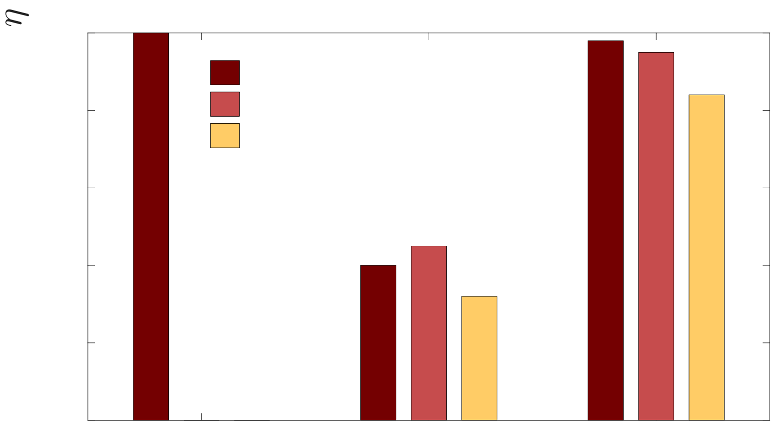


Panoptes: Multiple Application Support on Steerable Infrastructure Cameras

Prof. Marco Gruteser

- Breaks the one-to-one binding between application and camera view
- Virtualizes camera view and presents different view to different applications
- Mobility-aware scheduler steers the camera providing the expected view for each application
- Minimal compromise in performance, compared to commonplace fixed view cameras.





Towards Resilient Smart Cities

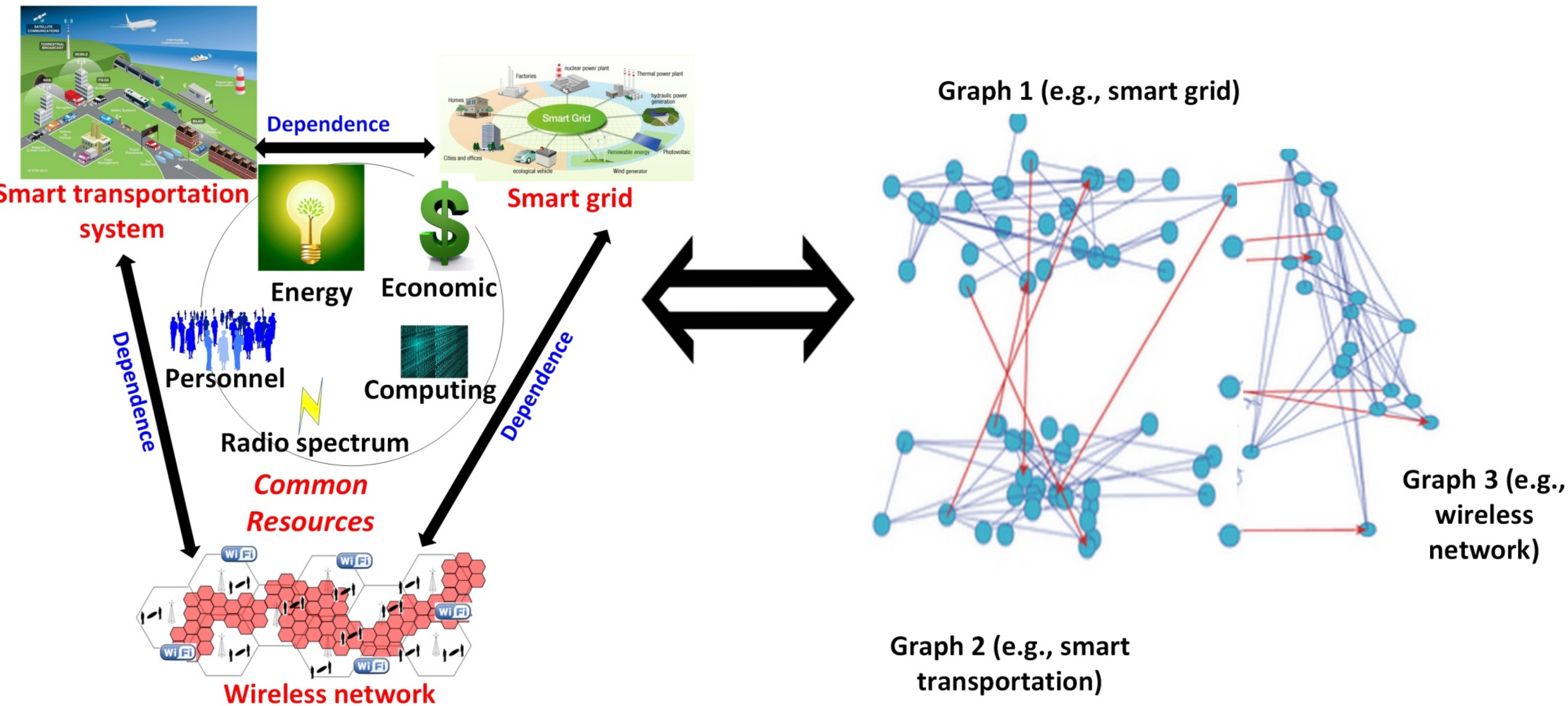
Prof. Narayan Mandayam

- Collaborative Project with Virginia Tech (PI: Walid Saad) and Florida International University (PI: Arif Sarwat)
- Vision of Smart City requires synergistic integration of cyber-physical critical infrastructures (CIs) such as
  - transportation, wireless systems, water networks, power grids
- Shared Resources
  - energy, computation, wireless spectrum, users and personnel, and economic investments
- Correlated failures
  - day-to-day operations, natural disasters, or malicious attacks
- Team of engineers, economists, psychologists
  - Analytical models and algorithms for resource sharing, simulators, emulators and testbeds

Towards Resilient Smart Cities (cont.)

Prof. Narayan Mandayam

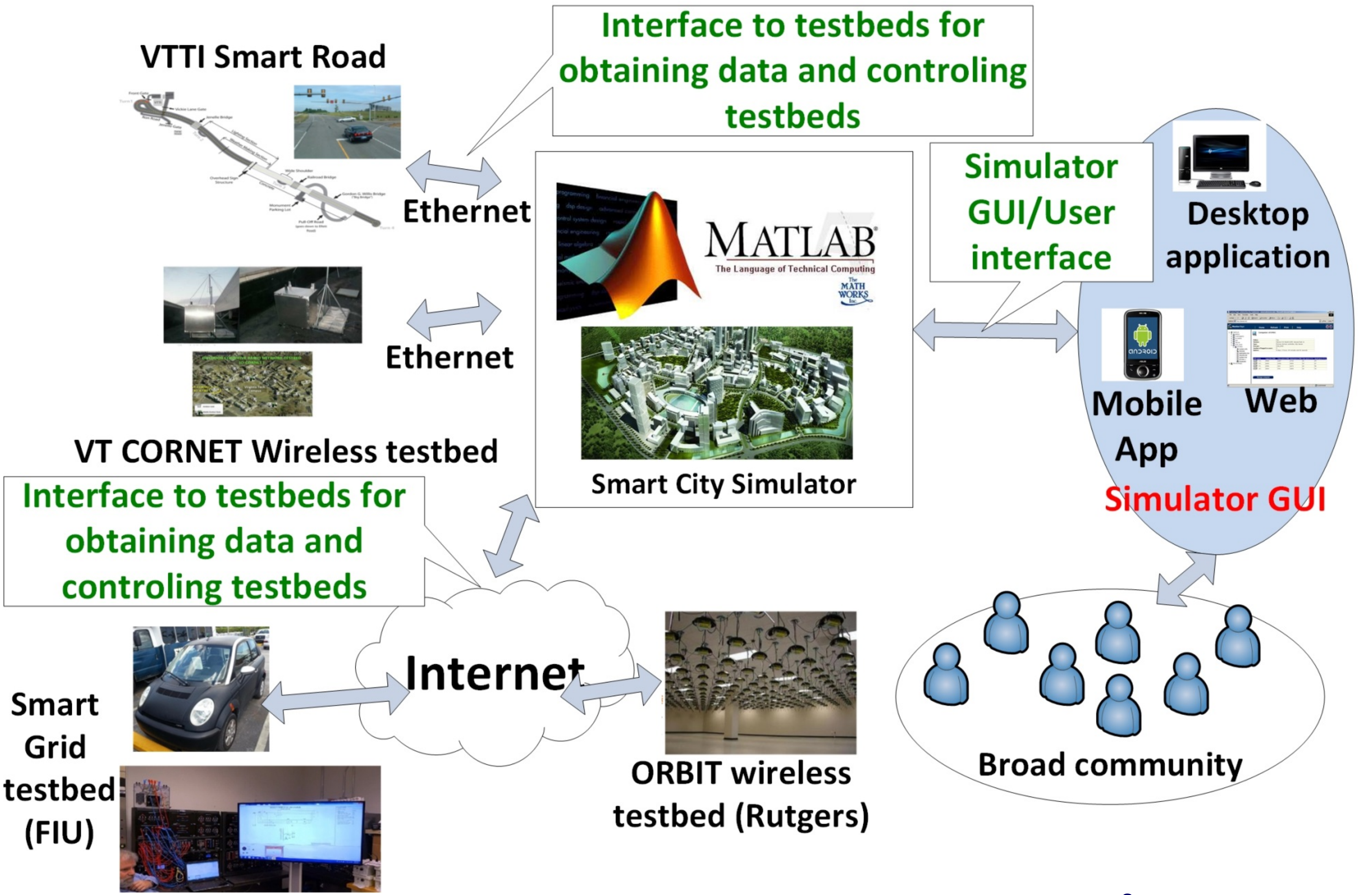
- Communication/Grid Models
- Economic Models
- Behavioral Models
- Graph Theory
- Game Theory
- Machine Learning



Towards Resilient Smart Cities (cont.)

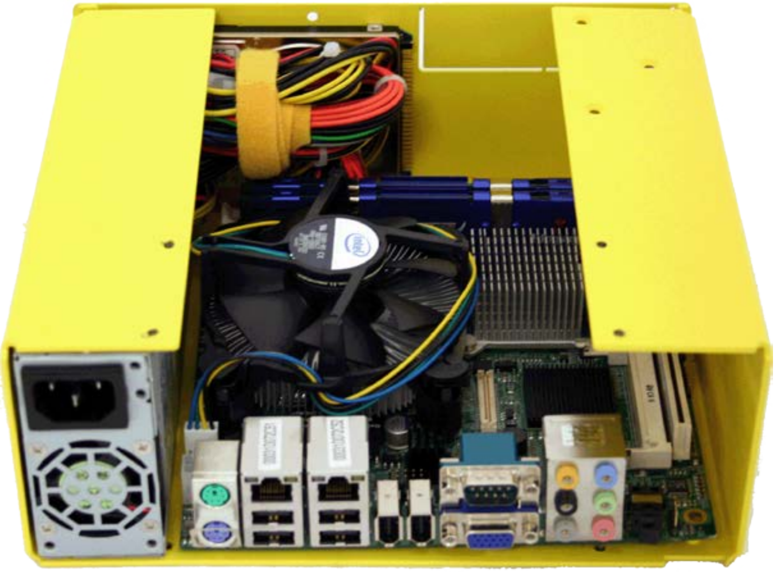
Integration of Testbeds

Prof. Narayan Mandayam



ORBIT (Testbed)

ORBIT Radio Node (Version 4)

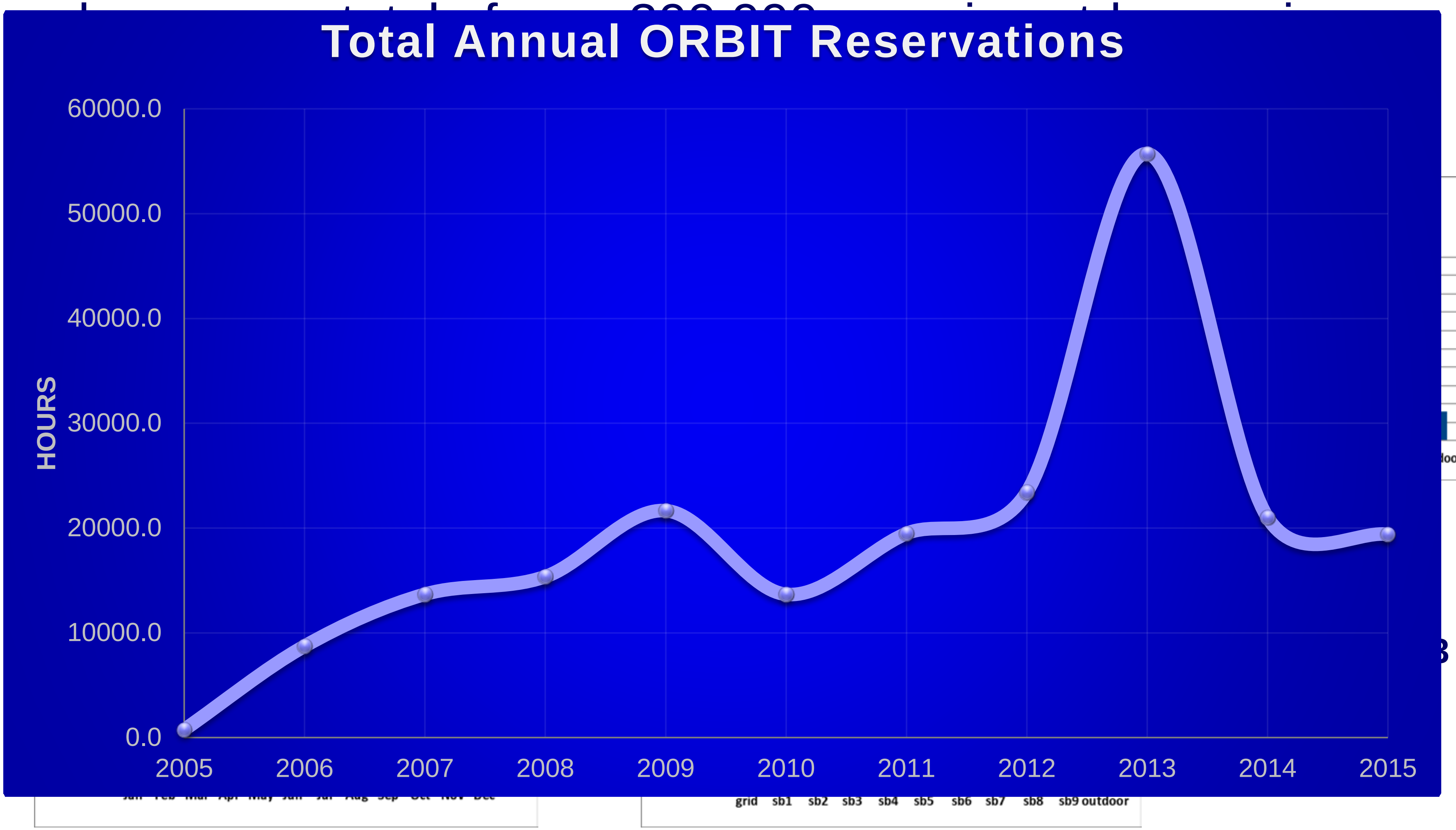


- I7-4770 3.4 GHz Q87T Express chipset
- 16 GB DDR3
- 2 x Gigabit Ethernet ports
- PCI-Express 2.0 X16
- 2 x Mini-PCIexpress socket
- 8 x USB 3.0
- OOB Mgmgt.

- Xeon E5-2600v3 with 18 cores
- 64 GB DDR4
- 2 x 10G Ethernet ports
- 2 x Gigabit Ethernet ports
- PCI-Express 3.0 X16
- 8 x USB 3.0
- OOB Mgmgt.

Usage Statistics

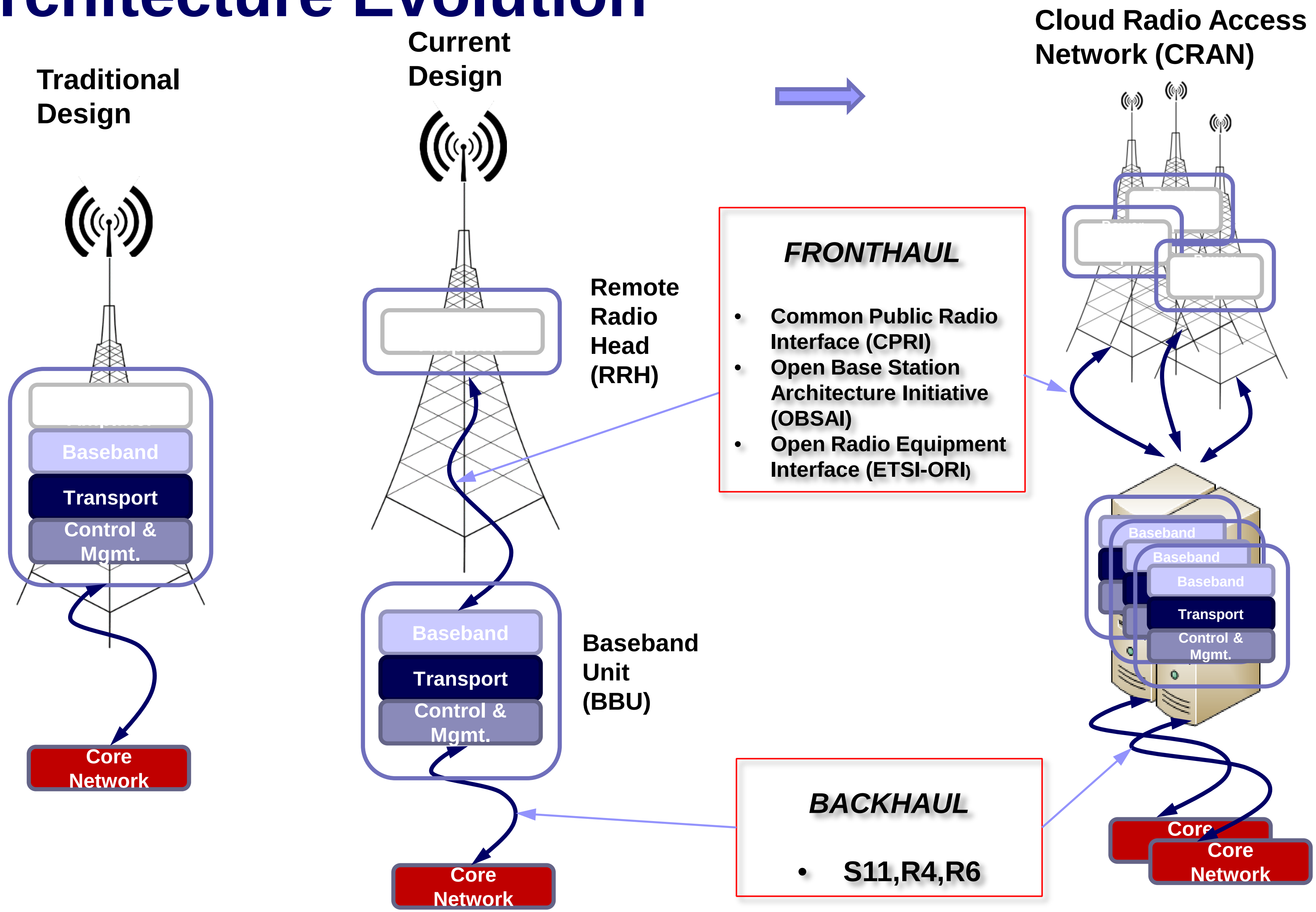
- ORBIT has 1300+ registered users in 400+ groups who



ORBIT Grid

ORBIT Grid (this morning)

ORBIT Today: Support For Basestation Architecture Evolution



ORBIT Today: Massive-MIMO

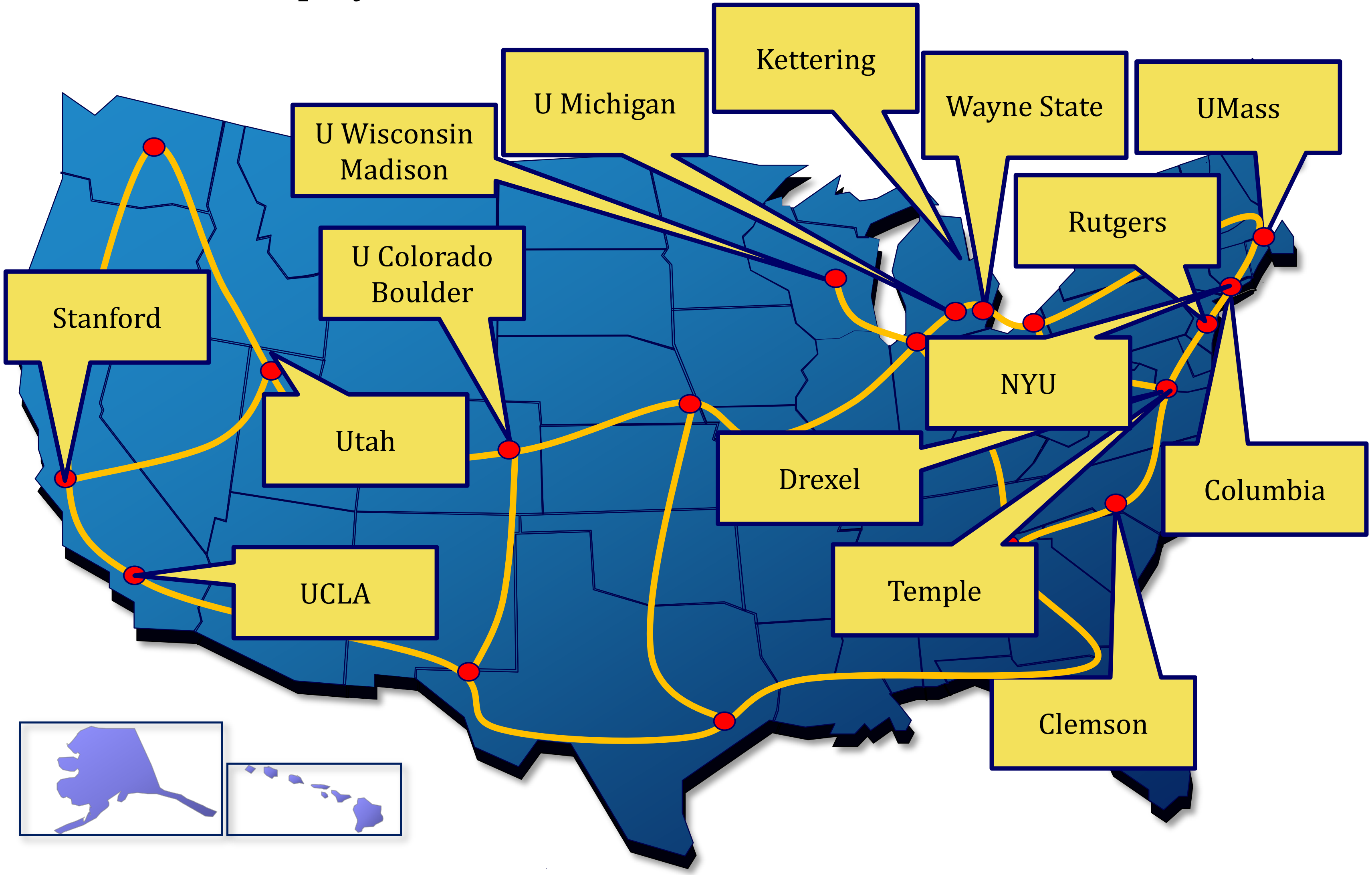
- 40 USRP X310s
  - Available FPGA resources:

Resource Type	Number
DSP48 Blocks	58K
Block Rams (18 kB)	14K
Logic Cells	7.2M
Slices (LUTs)	1.5M

  - RF 2 x UBX-160 (10 MHz - 6 GHz RF, 160 MHz BB BW)
  - 2 x 10G Ethernet for fronthaul/interconnect
  - Four corner movable mini-racks (4 x 20 x 20 -> 1 x 80 x 80)
- > 500+ GPP Cores/CloudLab Rack
- Number of GPU platforms
- 32x40G SDN aggregation switch

GENI Wireless Deployment

- 32 WiMAX and LTE BS on 14 campuses
- SDN (Click and OVS based) datapath/backbone
- 10 mini-ORBIT deployments some with SDRs



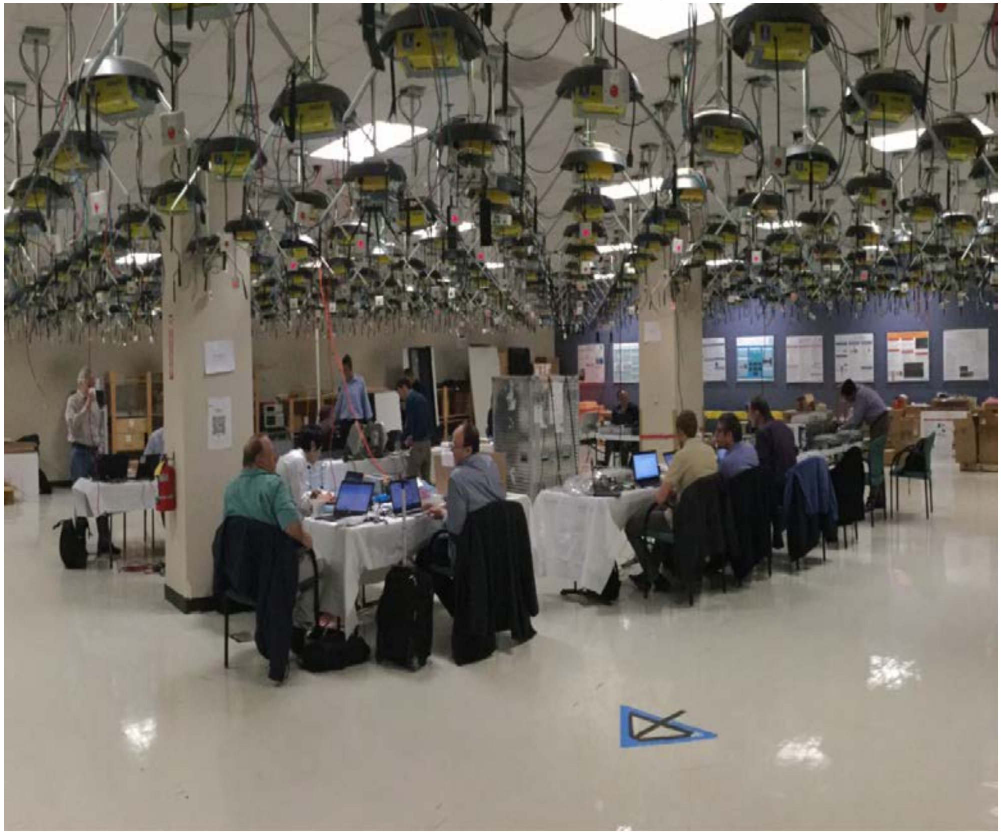
ONF Wireless Transport Third Proof Of Concept (PoC)

Ivan Seskar,

Scope of the PoC:

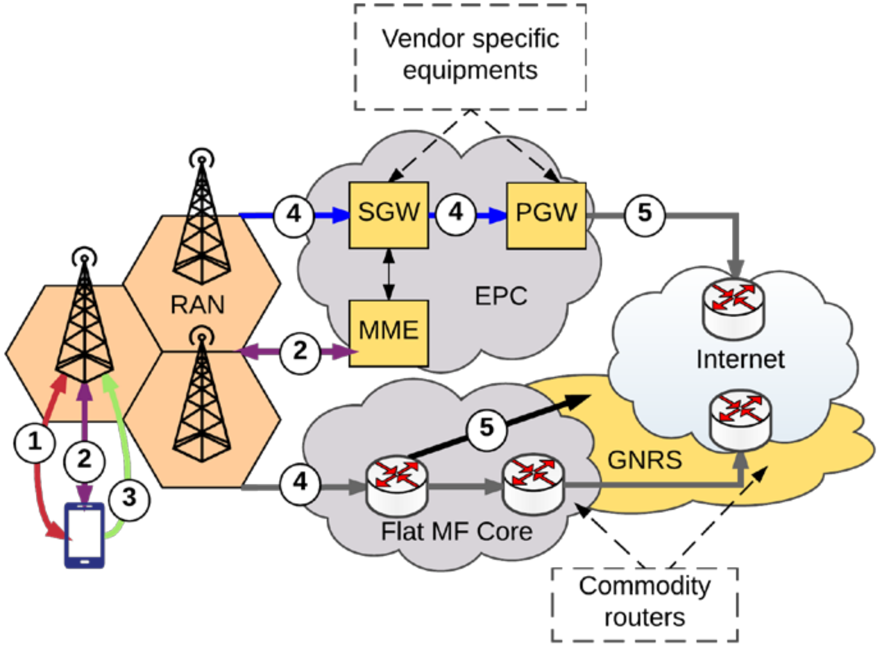
- **Extend the standardized µWave/mmWave model in a multivendor microwave network to cover all parameters modeled by TR-532**
- **Verify/validate the extensibility of the model to mmWave equipment (both indoor and outdoor)**
- **Demontrate new use cases: ‘closed Loop automation’, ‘frequency spectrum management’, ‘Test Automation’.**

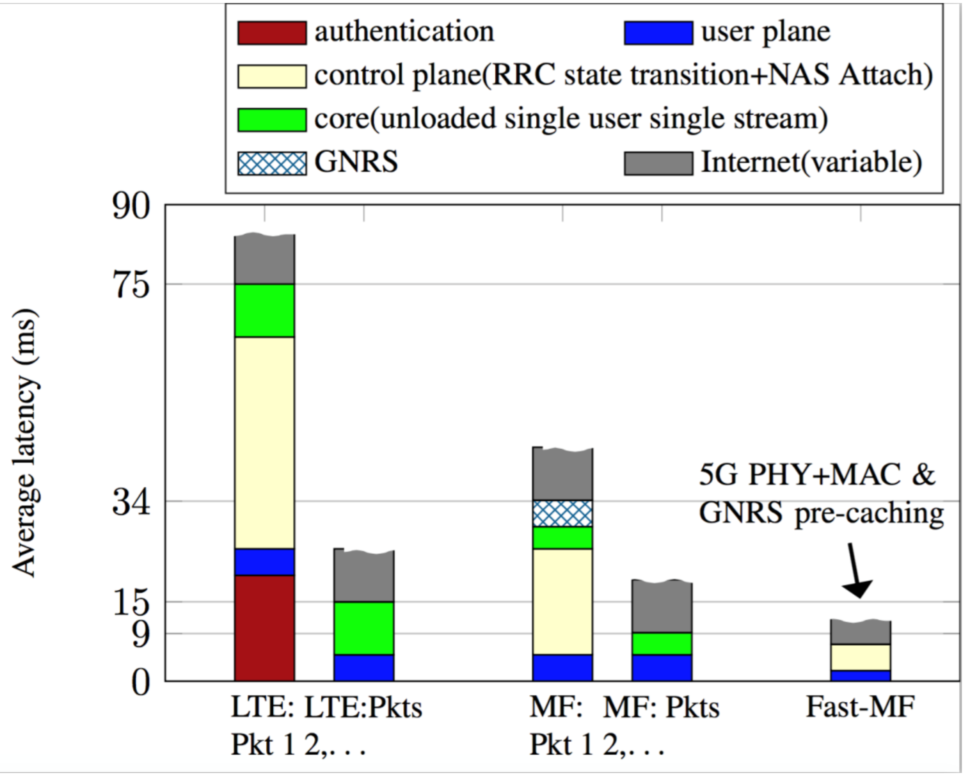
Hosted by AT&T in WINLAB, 24-28 October 2016



Next-Generation Mobile Network "Flat" LTE Core

Prof. D. Raychaudhuri



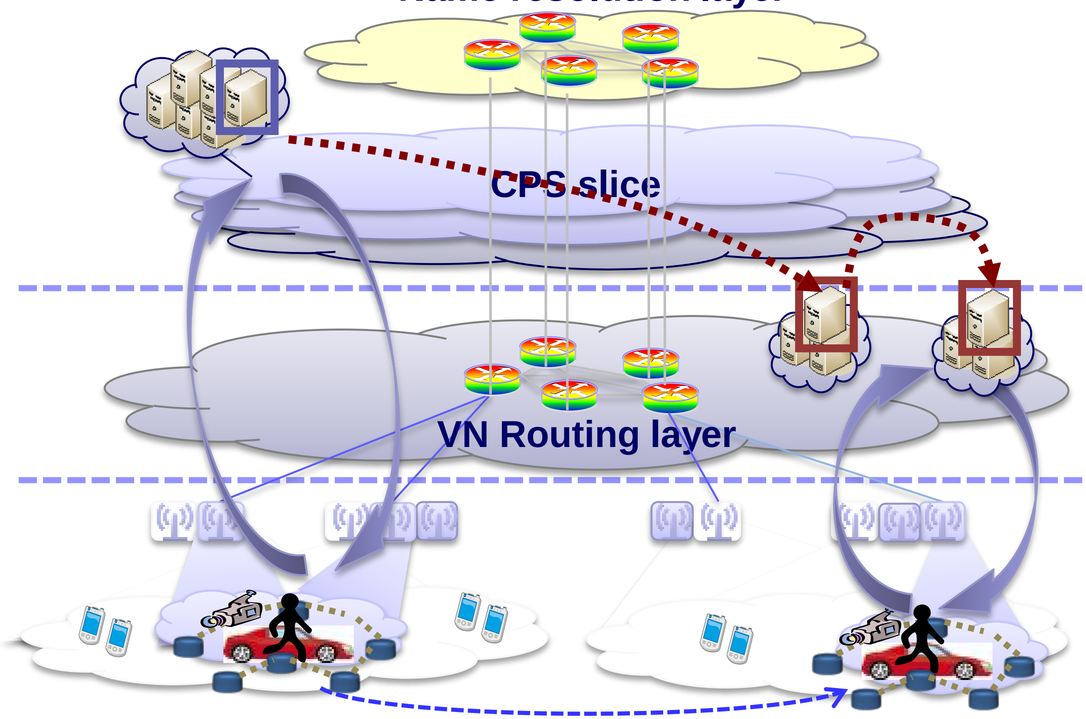


Latency comparisons between LTE/3GPP and a flat MF Core Network

Prof. D. Raychaudhuri

Virtual Mobile Cloud Network (vMCN) – JUNO project

Joint work with NICT, Japan



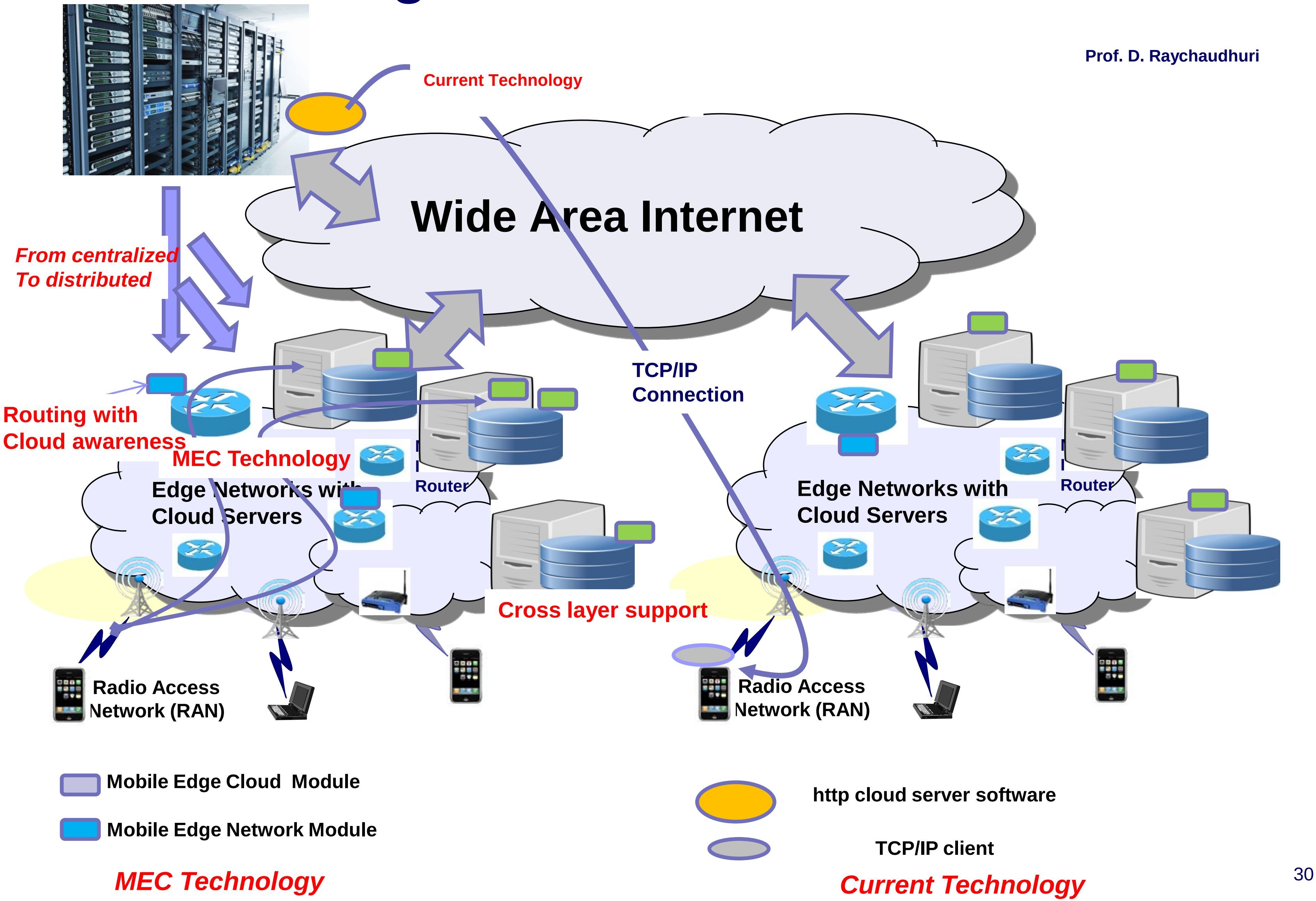
Service Anycast & Dynamic Migration of Cloud Service:
- **Application requirements support**

Name-based virtual network:
- **Provides NFV services**

vBS on the move
- **Virtualization of WIFI AP**
- **SDN based backend**

- ***Goal*: development and validation of advanced virtual networking techniques for scalable support of real-time/mobile CPS applications.**
- ***Challenge*: Low latency support requires fast access from mobile device to cloud service with bounded delay.**
- ***Challenge*: Optimal placement and dynamic migration of cloud services.**

Mobile Edge Cloud Architecture

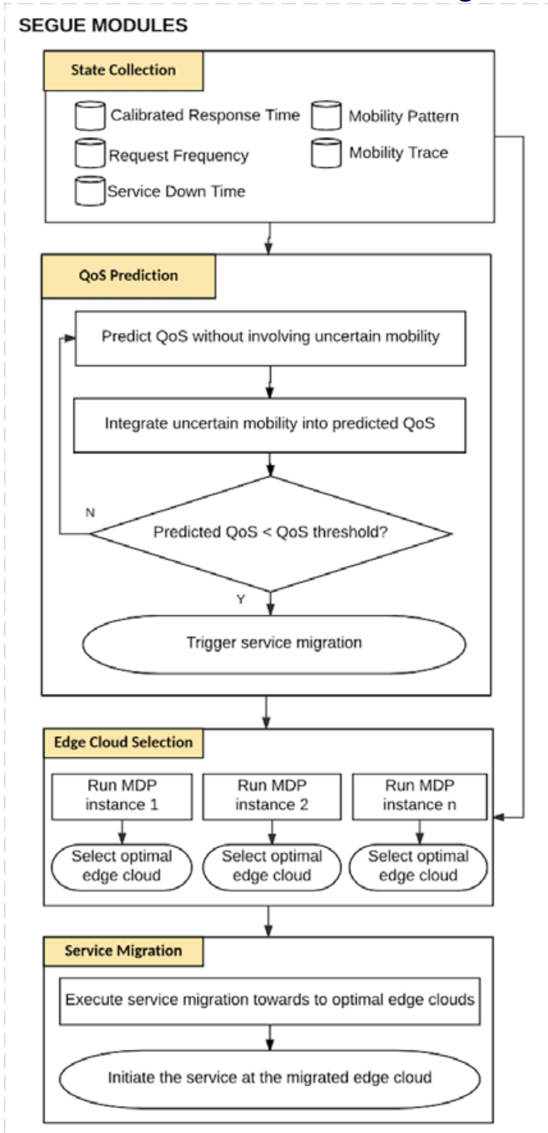


SEGUE: Edge Cloud Optimization Model

- Primary objective: *consistent meeting of reliable QoS* in the presence of *dynamic network and edge cloud server states*

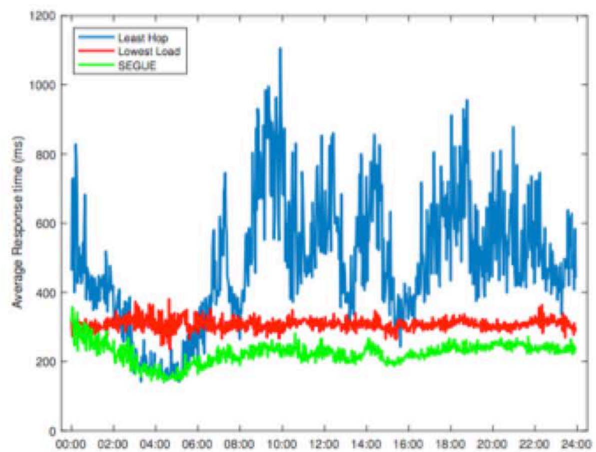
Prof. D. Raychaudhuri

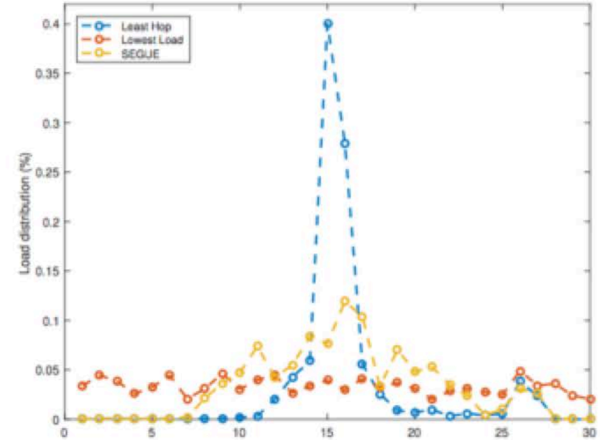
- Answers the two migration questions: *when* and *where*.



Performance Evaluation

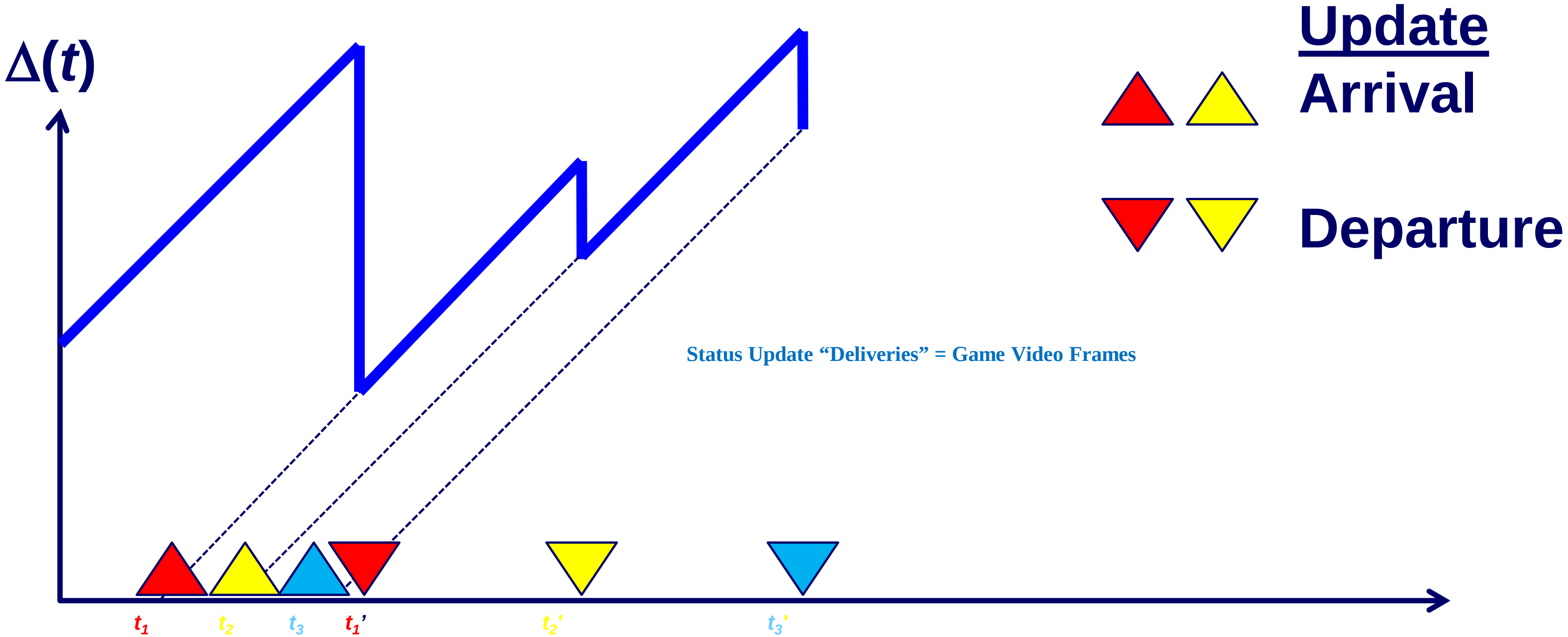
- Evaluate SEGUE's performance using an augmented reality application with the real mobility trace of 320 taxis in Rome.
- Analyze the average response time of all mobile users in every 2 minutes and workload distribution among 30 edge cloud servers in a whole day
- Compare the performance of SEGUE with the lowest workload migration and the least hop migration





Cloud gaming as an status updating system

Prof. Roy Yates



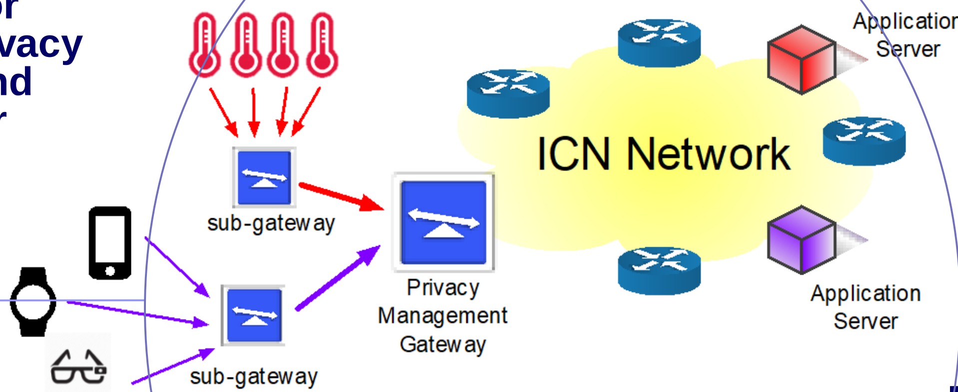
- High Update Rate ⇒ Queueing Delay
- Low Update Rate ⇒ Not enough fresh information

PERMIT: Privacy-Enabled Resource Management for IoT Networks

PI: Anand D. Sarwate,
Co-PI: Narayan B. Mandayam

Challenge:

- Develop techniques for managing privacy risk, utility, and bandwidth for future IoT systems



Different IoT systems are accessed by services through privacy-managing gateways

Scientific Impact:

- Show how to use differential privacy in IoT systems
- Suggests that “baking in” privacy at sensors/gateway may be feasible

Solution:

- Use quantization rate to trade off distortion and privacy.
- New privacy allocation strategies for quantizers.
- Ongoing: behavioral econ. perspectives

Broader Impact:

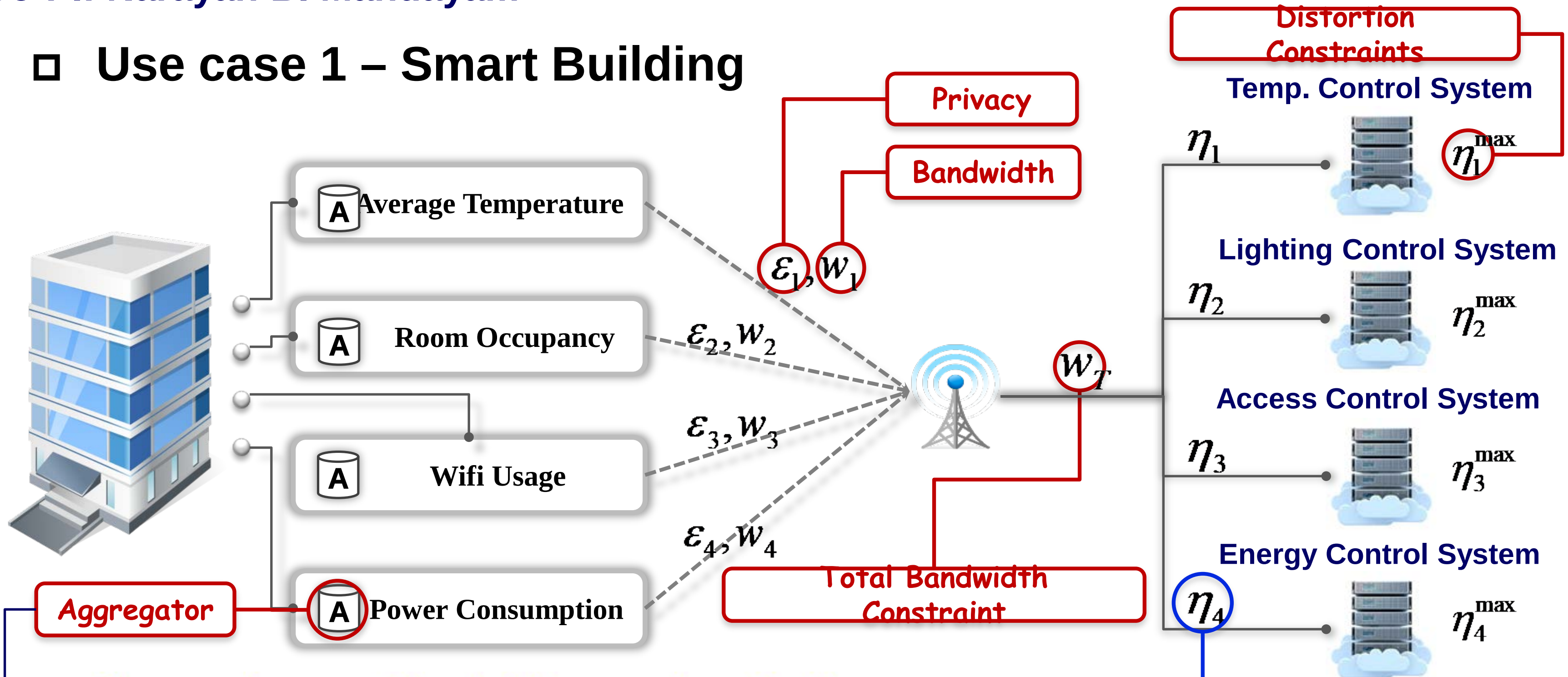
- Demonstrate ways to make privacy-centric sensing systems.
- Plans for testing at WINLAB ORBIT testbed.
- Student researcher: Sijie Xiong

Award # 1617849
Rutgers, The State University of New Jersey
Contact: Anand D. Sarwate (anand.sarwate@rutgers.edu)

Privacy-centric bandwidth allocation

PI: Anand D. Sarwate,
Co-PI: Narayan B. Mandayam

- Use case 1 – Smart Building



Given a privacy and bandwidth control mechanism, the distortion η_i is a function of ϵ_i and w_i. → $\eta_i = l(\varepsilon_i, w_i)$

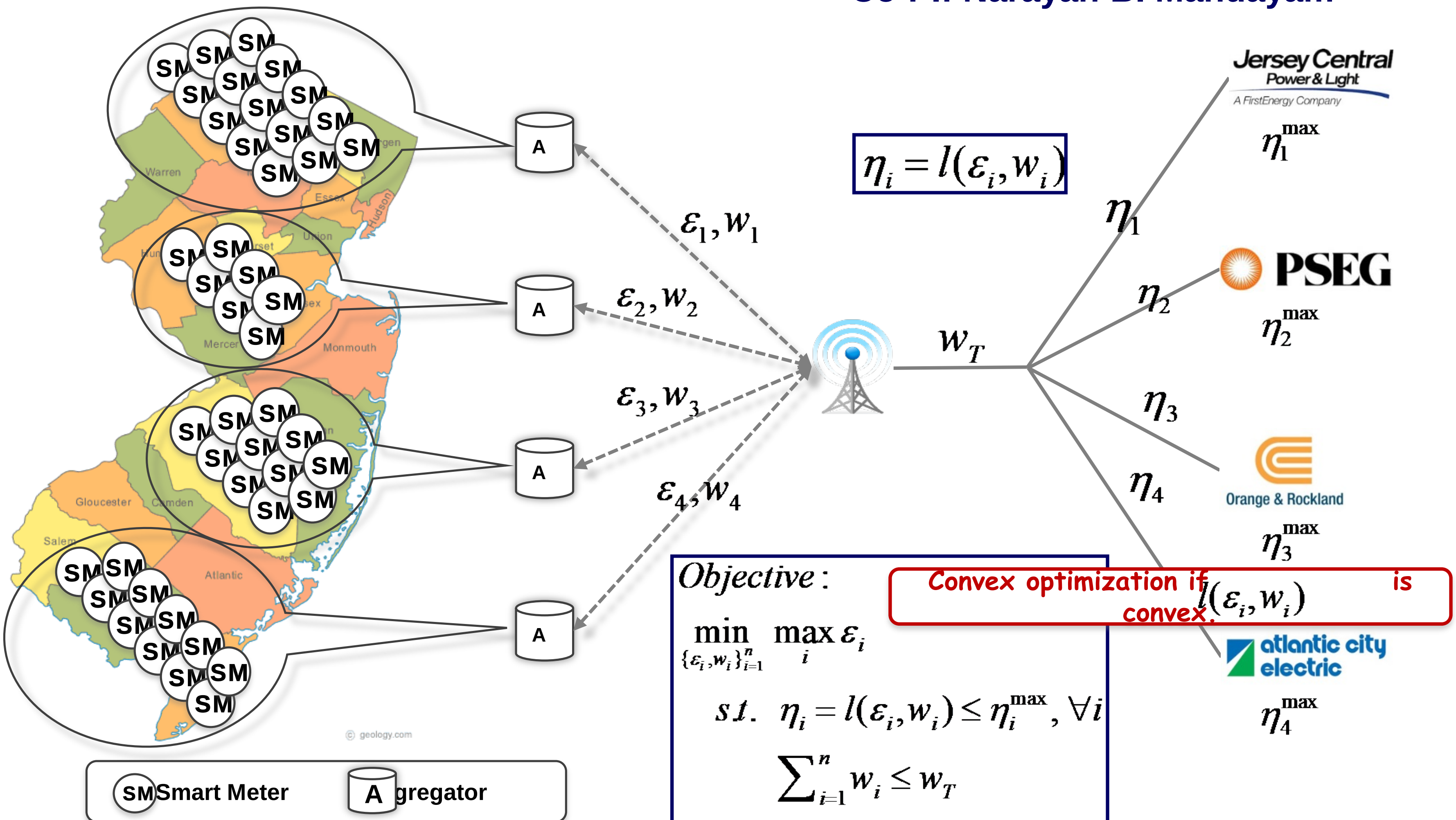
Definition. *(Differential Privacy) A randomized mechanism $\mathcal{M} : \mathcal{X}^n \to \mathcal{Y}$ that maps data to an arbitrary output space $\mathcal{Y}$ gives ϵ-differential privacy if for all data sets $x^n, \tilde{x}^n \in \mathcal{X}^n$ differing in at most one element, $d_H(x^n, \tilde{x}^n) \leq 1$, and for all measurable $\mathcal{S} \subseteq \mathcal{Y}$,* **The larger the ϵ is, the higher the privacy risk.**

$$\mathbb{P}(\mathcal{M}(x^n) \in \mathcal{S}) \leq e^{\epsilon}\mathbb{P}(\mathcal{M}(\tilde{x}^n) \in \mathcal{S}) \;\Leftrightarrow\; |\log \mathbb{P}(\mathcal{M}(x^n) \in \mathcal{S}) - \log \mathbb{P}(\mathcal{M}(\tilde{x}^n) \in \mathcal{S})| \leq \epsilon.$$

Privacy-centric bandwidth allocation

- Use case 2 – Smart Grid

PI: Anand D. Sarwate,
Co-PI: Narayan B. Mandayam



Objective :

$$\min_{\{\varepsilon_i, w_i\}_{i=1}^{n}} \ \max_i \varepsilon_i$$

$$s.t. \ \ \eta_i = l(\varepsilon_i, w_i) \le \eta_i^{\max}, \ \forall i$$

$$\sum_{i=1}^{n} w_i \le w_T$$

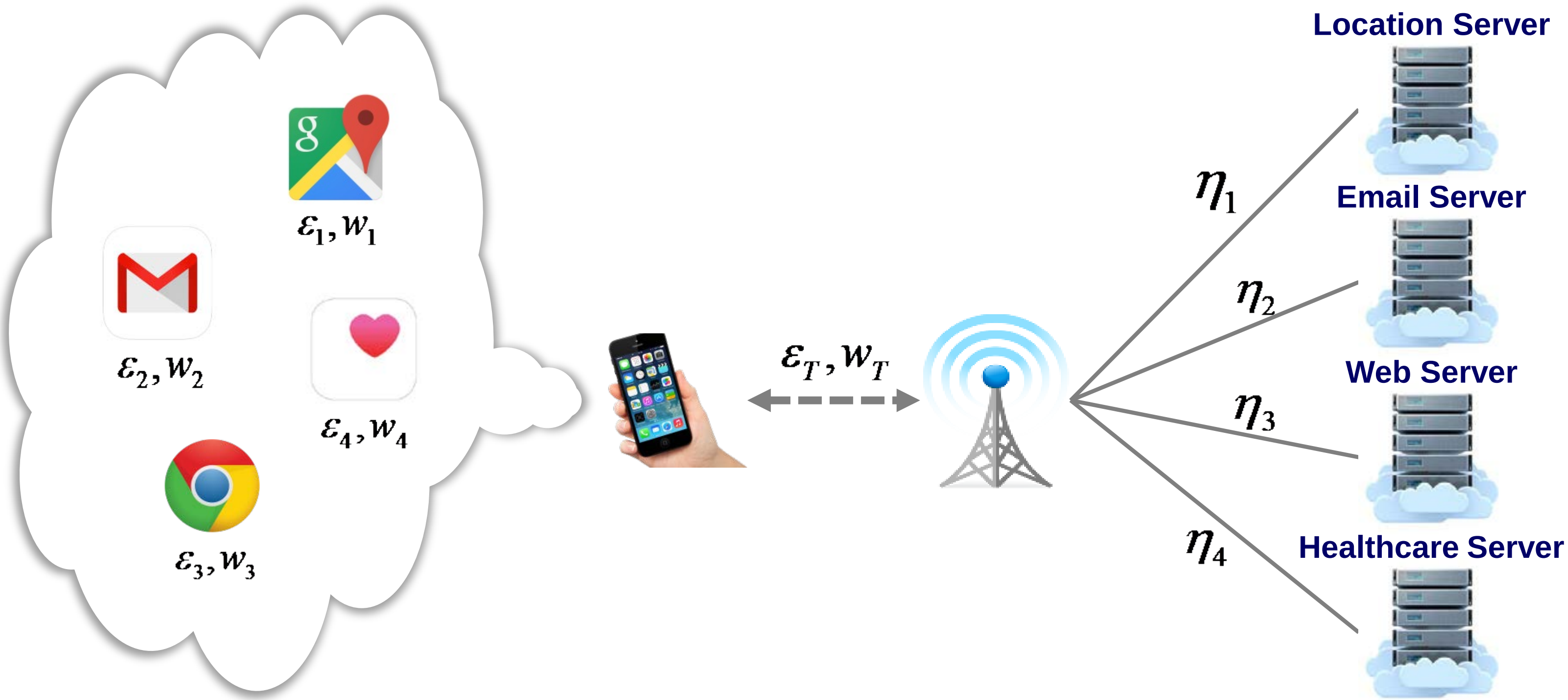
$$\varepsilon_i, w_i \ge 0, \ \forall i$$

Convex optimization if $l(\varepsilon_i, w_i)$ is convex.

Other directions

PI: Anand D. Sarwate,
Co-PI: Narayan B. Mandayam

- Optimizing other metrics related to privacy
- Integrating Access Control with diverse privacy guarantees
- Pricing privacy – are people willing to pay for privacy?
- Use case 3 – Smartphone (local differential privacy [1])



[1] Xiong, Sijie, Anand D. Sarwate, and Narayan B. Mandayam. "Randomized requantization with local differential privacy." *2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. IEEE, 2016.

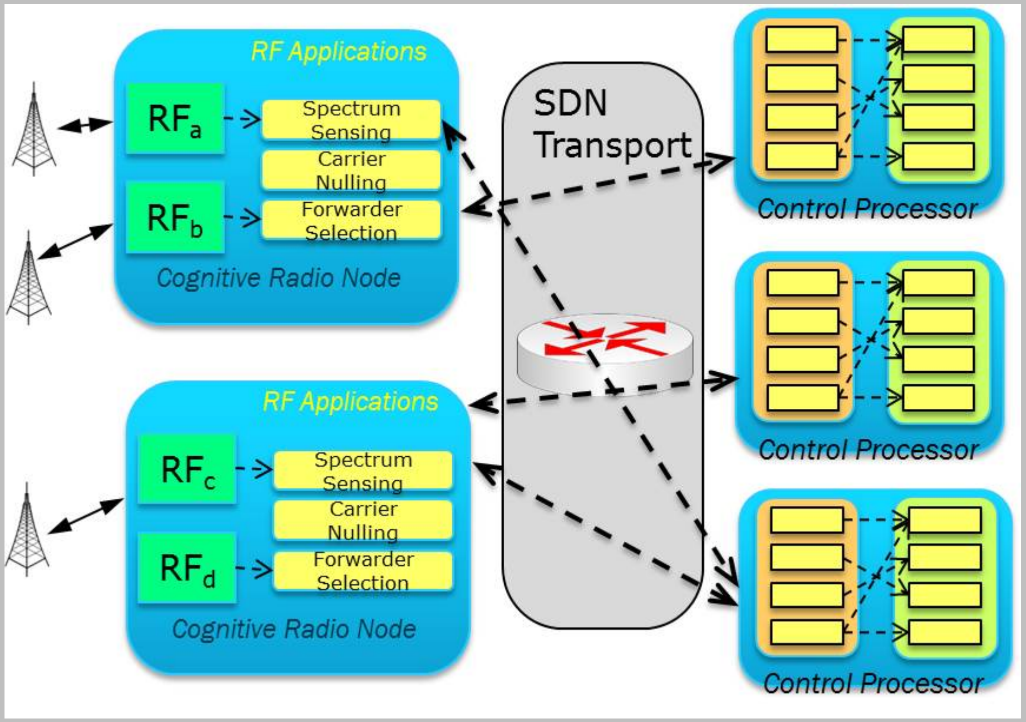
Software Defined Framework (SDR/SDN) for Spectrum Sharing

Narayan Mandayam & Ivan Seskar

SDN enables a logically centralized controller to manage distributed collection of network elements: user devices, switches, wireless APs

System 1
DoD

System 2
Commercial

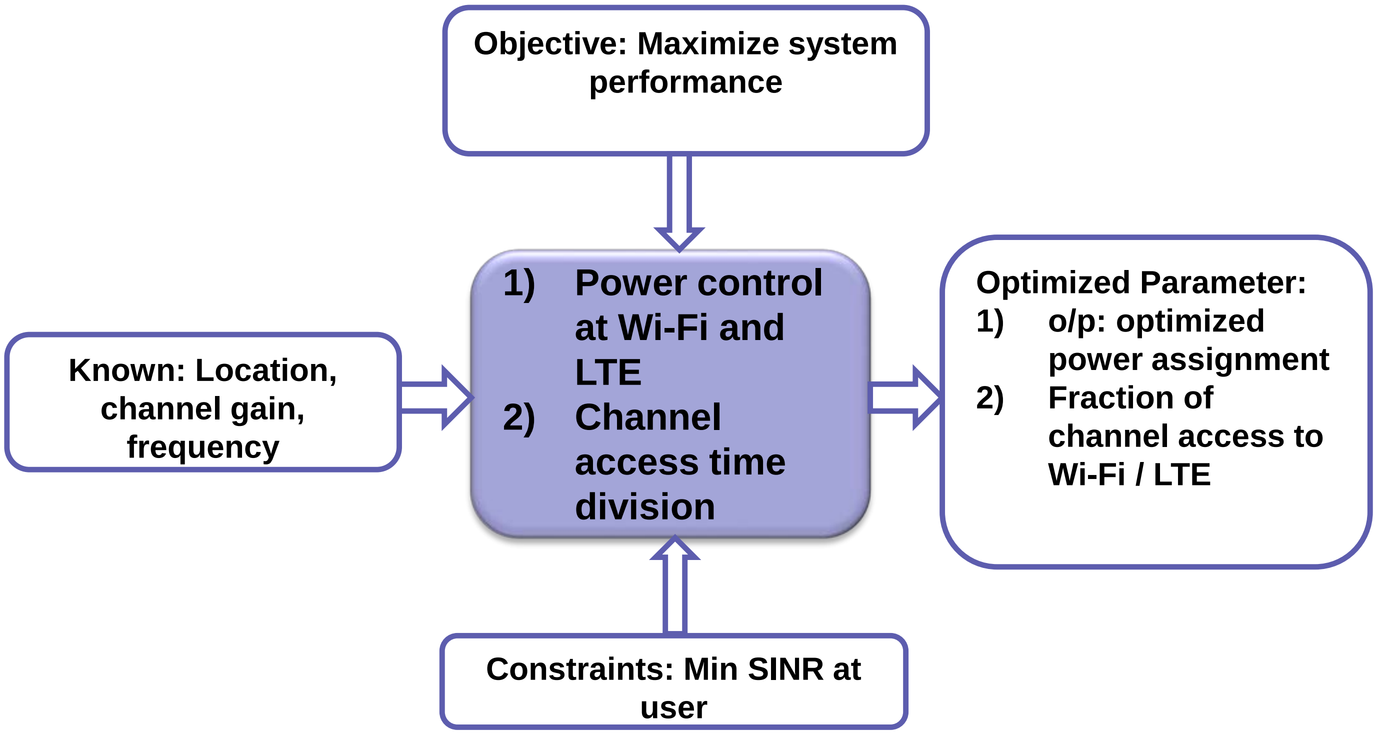


NC-OFDMA is a key enabler in spectrum sharing between DoD and commercial wireless systems

Decentralized Spectrum Architecture (SMART)

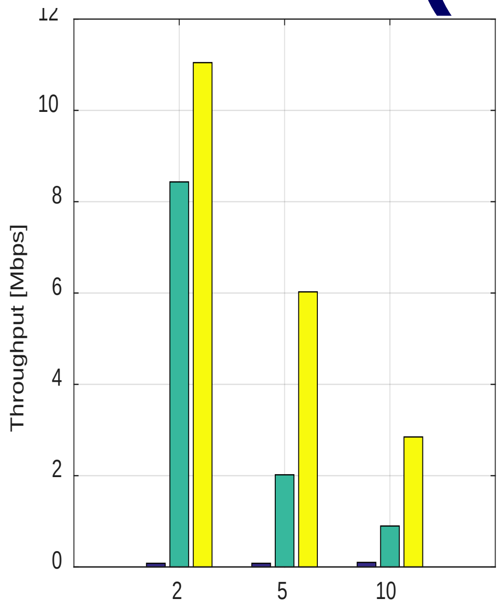
Prof. D. Raychaudhuri
(joint work with Prof. Rexford, Prineton U)

- Earlier work – Wi-Fi and LTE spectrum coordination via centralized optimization



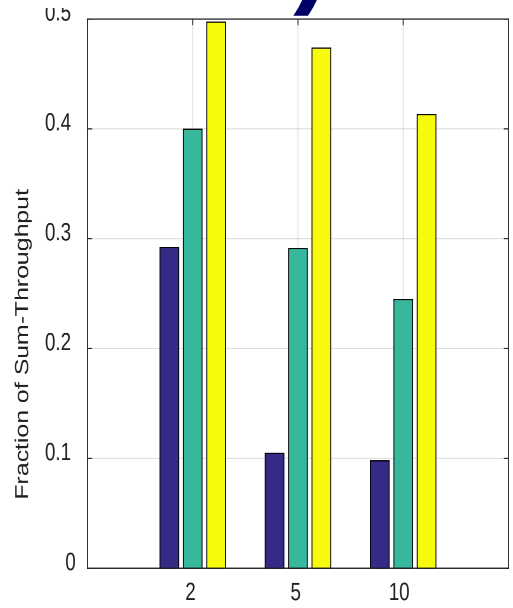
Decentralized Spectrum Architecture (SMART)

Prof. D. Raychaudhuri



N

10 percentile throughput across Wi-Fi / LTE



N

Fraction of Wi-Fi throughput in Wi-Fi + LTE throughput

No Coordination
Pwr Control
TimeDivCh Access

***N* = No. of Wi-Fi links = No. of LTE links**

Spectrum coordination improves system performance but limited by large-scale deployment, logical extension – Distributed Spectrum Management

Low-Latency LTE

Prof. Dola Saha
(SUNY-Albany & WINLAB)

- LTE primarily was designed to support human-originated traffic (audio/video).
- Most of the IoTs transmit short and sporadic messages.
- An idle User Equipment takes about 50-60 ms to reconnect to the network. (~ 480 bytes of overhead)
- Overwhelming surge in control plane -> resource utilization inefficiencies.
- Need for a design with no or less control plane signaling.
- Aim was to transmit data without waiting for access.

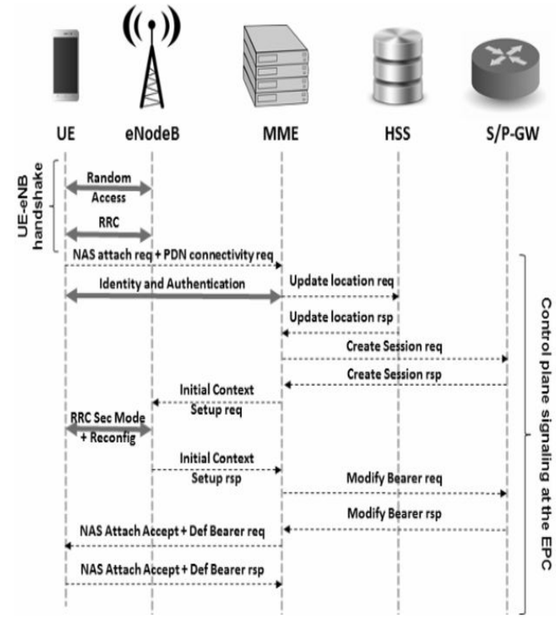


Fig 1: Control Plane signaling for UE attach

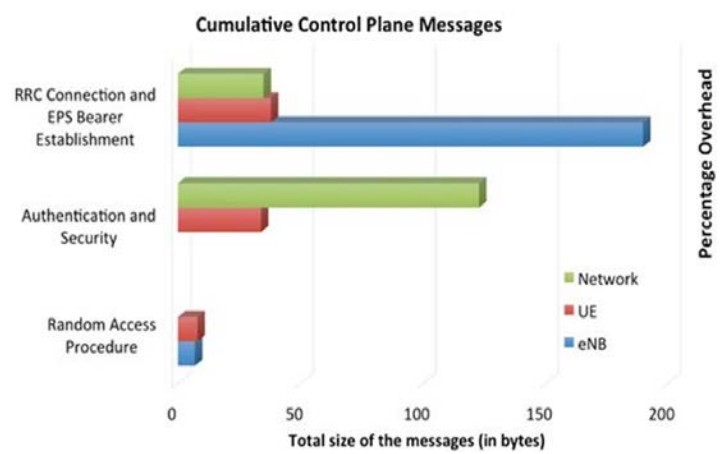
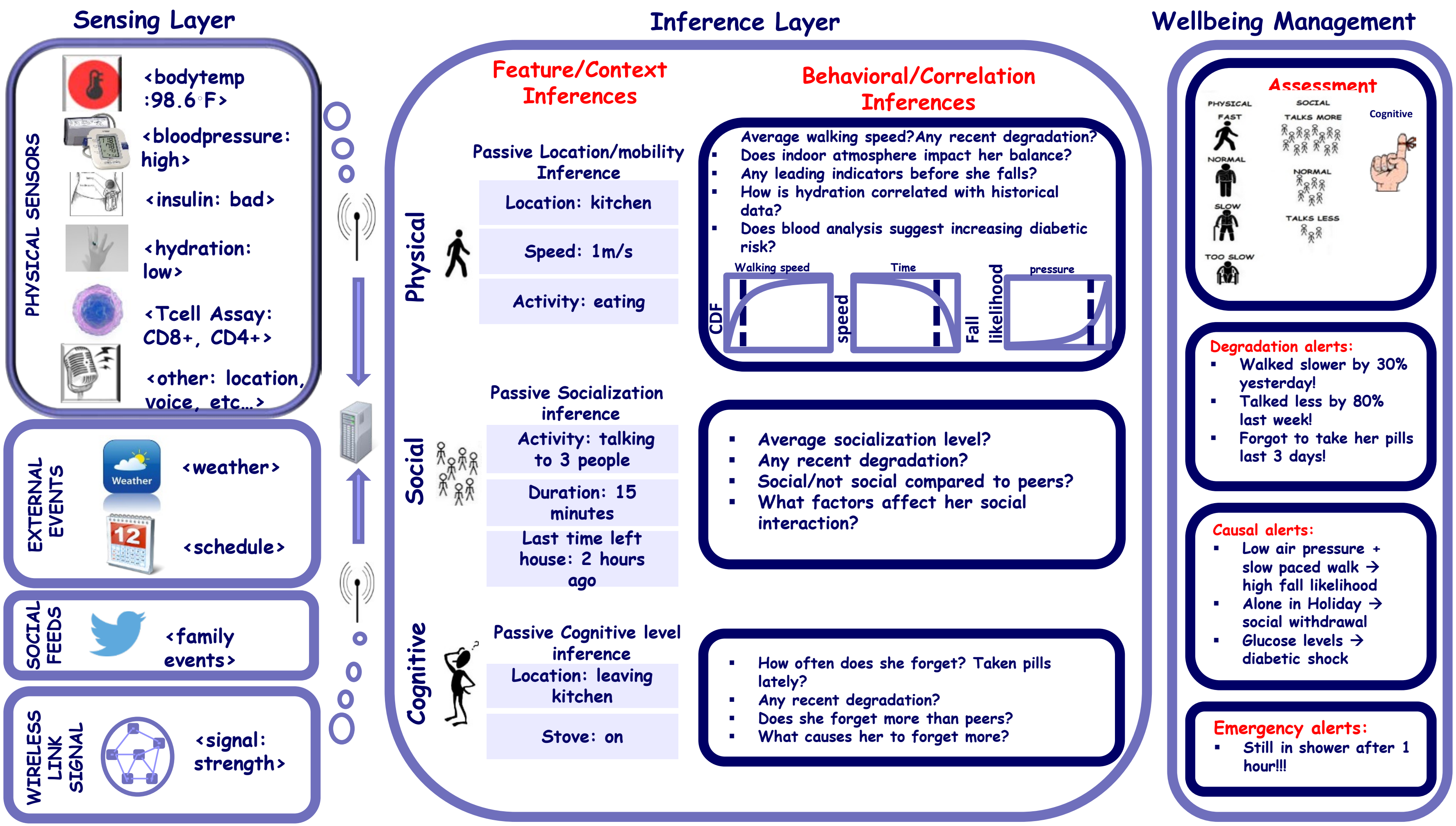


Fig 2: Cumulative Overhead in Control Plane

WINLAB is collaborating with Merck to develop medical sensing, inference, and active monitoring by healthcare professionals



Wade Trappe & Rich Howard

International Collaboration Projects

GENI

(Global Environment for Network Innovation)

ORCA

(Open Radio Control Architecture)

JUNO

(Virtual Mobile Cloud Network for Realizing Scalable, Real-Time Cyber Physical Systems)

FLEX

(**F**IRE **L**TE testbeds for open **EX**perimentation)

WiSHFUL

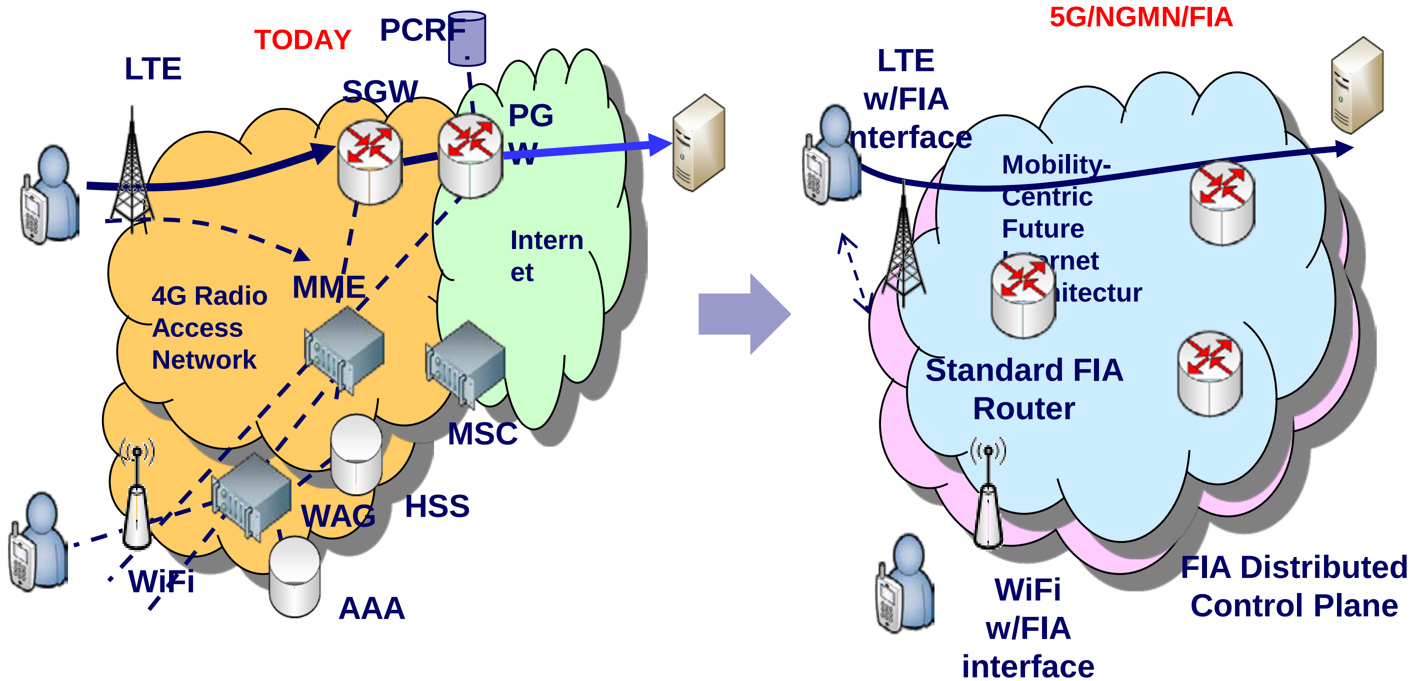
(Wireless Software and Hardware platforms for Flexible and Unified radio and network controL)

METIS-II

(Mobile and wireless communications Enablers for the Twenty-twenty Information Society)

METiS-II: Definition of 5G Mobile Network Architecture

Ivan Seskar, PI

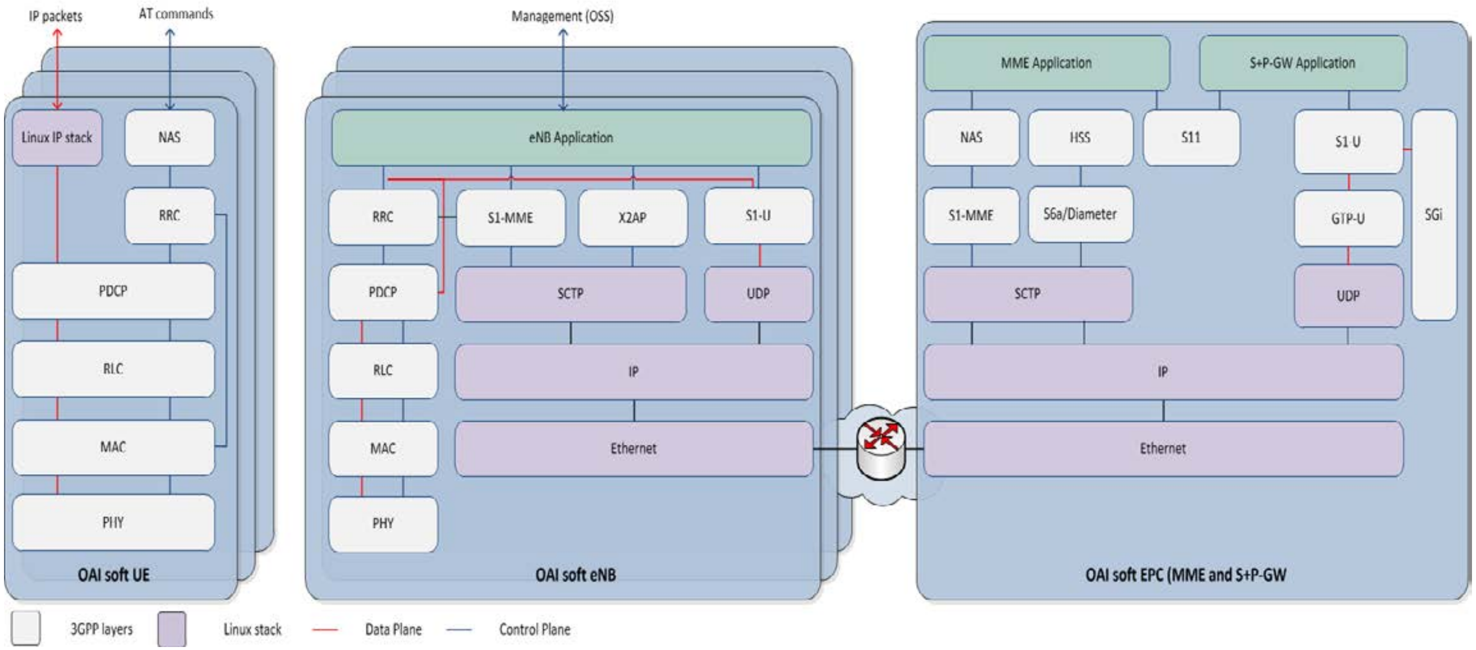


- Hybrid 3GPP & IP arch
- Complex control interfaces!
- Technology specific
- IP tunneling in data path
- Gateways (..bottlenecks, sub-optimum routing,..)

- **Unified Internet/Mobile Net arch with integrated support for naming, authentication, mobility, etc.**
- **Simplified distributed control!**
- **Technology neutral –BS or AP plug-in**
- **Flat! No gateways or tunnels!**
- **Mobile devices as “first class” citizens**

OpenAirInterface

Ivan Seskar, PI

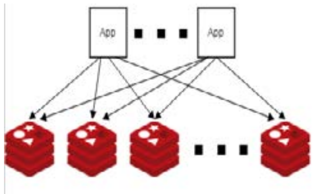


- Commercial UE ↔ OAI eNB + Commercial EPC *
- Commercial UE ↔ OAI eNB + OAI EPC *
- Commercial UE ↔ Commercial eNB + OAI EPC *
- OAI UE ↔ Commercial eNB + OAI EPC *
- OAI UE ↔ Commercial eNB + Commercial EPC *
- OAI UE ↔ OAI eNB + Commercial EPC
- OAI UE ↔ OAI eNB + OAI EPC

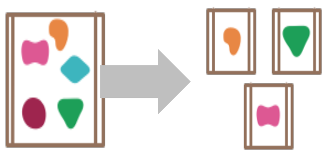
Courtesy: Navid Nikaein, Eurecom/Open Air Interface

OAI Roadmap: Toward Software-defined 5G Network

Ivan Seskar, PI



- **Cloud-native 5G networks**
  - Phase 1: Stateless through distributed shared memory, multite
  - Phase 2: Mircoservice Architecture and NFV
  - Supported projects: FP7 MCN, FUI ELASTIC

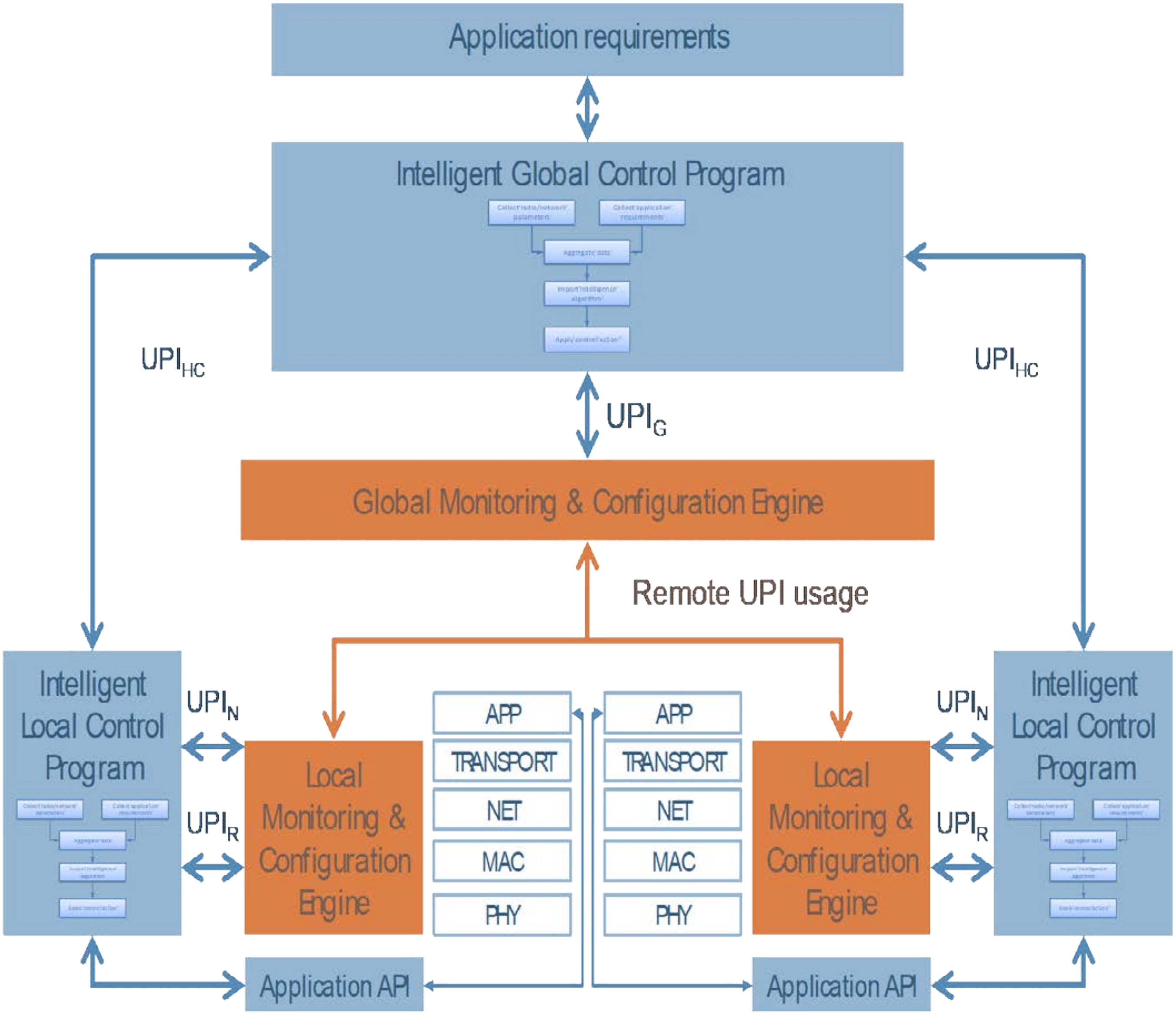


- **Network Orchestration**
  - Approach 1) Openstack and heatstack orchestrator
  - Approach 2) Juju modeling for service-oriented deployment (https://jujucharms.com/q/oai)
  - Supported project: FP7 MCN, FP7 FLEX, Canonical partnership program
- **Network Programmability → network slicing**
  - Agent-controller protocol and southband API in support of SDN+MEC
    - agents: in charge of network function monitoring and programmability
    - Network controller: network abstraction (network state graphs), network application
      - realtime, standalone mode or as a plugin
  - Supported projects: H2020 Coherent, H2020 Q4Health, ETSI MEC PoC

Courtesy: Raymond Knopp, Euricomm

WiSHFUL: Integrating intelligence to the general architecture

Ivan Seskar, PI



FLEX Project: Controlling and Managing the LTE components

Ivan Seskar, PI

- Challenges:
  - Managing and Controlling different:
    - base station components;
    - EPC networks;
    - datapath configurations;
    - types of UEs.
  - Unified control through a common tool.
  - Completely isolated slices with guaranteed bit rate and allocation and retention policy.
  - Enabling SDN configuration on the backend of the LTE network.
  - Standardized API for interconnecting the LTE testbeds.
  - Measurement collection from distributed resources.