Using the COSMOS testbed for measurement-based wireless, optical, edge-cloud, and smart cities research

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The COSMOS testbed design and deployment is joint work with the COSMOS team (www.cosmos-lab.org)
COSMOS: Project Vision

Cloud enhanced Open Software-defined Mobile wireless testbed for city-Scale deployment

- **Latency** and **compute power** are two important dimensions and metrics
- **Edge computing** can enable real-time applications
- **Objective**: Real-world investigation of urban environments with
  - Ultra-high bandwidth (~Gbps)
  - Low latency (<5 ms)
  - Powerful edge computing
- **Enablers**:
  - 10s of 64-element millimeter-wave arrays
  - 10s of miles of Manhattan dark fiber
  - B5G edge cloud base stations
  - Cameras and Lidars
  - Remote-access
  - Programmability

The infrastructure can enable data collection and evaluation of algorithms for real-time applications in domains such as AR/VR, connected cars, and smart city

COSMOS: Deployment

- **To NJ Edge**
- **To COSM-IC**
- **32 Avenue of the Americas (32 AoA)**
- **Silicon Harlem**
- **City College**
- **Columbia**
- **Deployed**
- **Ongoing/Planned**
- **Deployed**
- **To be deployed**

- ** Deployed:**
  - Medium Node (md)
  - Large Node (lg)

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  - Large Node (lg)

- **Locations:**
  - Columbia
  - CCNY
  - FCC Innovation Zone
  - CS3 ERC HQ

- **Networks:**
  - To COSM-IC
  - To NJ Edge
COSMOS: Design and Architecture

- **Key design challenge:** Gbps+ performance and full programmability from the radio level to the central/edge cloud
  - Fully programmable multi-layered computing architecture for flexible experimentation

- **Key technologies:**
  - Software-define radios (SDRs)
  - Millimeter-wave (mmWave) radios
  - Optical x-haul networks
  - Edge cloud
  - Control and management software

- **Experiment examples:**
  - Open-access full-duplex wireless
  - Optical-wireless x-haul networking
  - Smart intersections
Example Experiment: Smart Intersection (with Kentyou)

- Edge cloud computing and inference for support of cloud assisted vehicles
- Sensor data acquisition: low latency & high bandwidth wireless links
- **Real-time** (latency) – useful for traffic interaction/management
  - Vehicle speed: 10 km/h → ~3 m/s → \(~0.1\) m in 1 frame of a video (@30 fps)
  - Useful to prevent accidents, target round-trip latency = 1/30 second

120th St and Amsterdam

Videos fed into the COSMOS edge node for vehicles/pedestrians detection and classification

Visualization on Kentyou User Interface

Only obtained information (the raw video will not be sent to preserve privacy) is sent to Kentyou UI.

mmWave Measurements

- 28 GHz channel measurements in the COSMOS testbed area in a **dense urban canyon** environment
  - Representative (potential) deployment sites of mmWave BSs (building rooftops, street lightpoles, etc.)
  - Extensive measurements on **long sidewalks** (up to 1,100 m) with **fine-grained link step size** (1.5/3 m)
- **41+ million** measurements were collected from **2,600+ links** on **22 sidewalks** in **4 different sites**
  - Characterizations of path gain, effective beamforming gain, SNR coverage, and achievable data rates

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**4-way city intersection**

**Building rooftop**

**Cross-avenue bridge**

**An open-space park**

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**mmWave Measurements**

- Extensive outdoor-to-indoor measurements within different buildings: **29+ million** measurements were collected from over **2,200 links** in **7 different sites**

  ![Outdoor-to-outdoor measurements](image1)
  ![Outdoor-to-indoor measurements](image2)

Case Study at a Middle School

- Hamilton Grange Middle School in West Harlem, NYC
- Measurements taken from transmitter locations in school parking lot and basketball courts to five different classrooms
- Classroom measurements show the feasibility of coverage from an outdoors mmWave transmitter
  - Worst-case Shannon capacity of 1.3 Gbps
- Dataset publicly available
Key Technology: mmWave

Programmable mmWave radios and end-to-end mmWave systems in Sandbox 1 @Rutgers


Remote control of the X-Y Table

COSM-IC: COSMOS
Interconnecting Continents
Tutorials and Datasets

COSMOS Cameras Data-set

- 1st-floor videos (anonymized): https://drive.google.com/drive/u/0/folders/1QxKf6XEQty2/tg/27A0Z10e5
- 2nd-floor videos (anonymized): https://drive.google.com/drive/u/0/folders/1R17J69eRazZz2_u1HvCQfGw6QmKbWBF
- 12th-floor videos (120th St.): https://drive.google.com/drive/u/0/folders/1SEoxAAYReps4kKvY74kqum/7BU
- 12th-floor videos (Amsterdam Ave.): https://drive.google.com/drive/u/0/folders/1qG-62oH1Tg-0dyzo78tWzGDv1GleEK

The 12th-floor cameras capture images of cars and pedestrians such that neither faces nor license plates can be recognized. Therefore there is no need for post-processing for privacy protection.

Anonymization Workflow for 1st and 2nd-floor Cameras

The anonymization workflow is described in the following paper and also described briefly below. We would app datasets above.

A. Angue, Z. Duan, G. Zussman, and Z. Kostic, "Real-Time Video Anonymization in Smart City Intersections," [Paper Title], [Conference], [Year].

Videos from the 1st and 2nd floor, saved in this directory, are the outputs of the COSMOS YOLOv4 blurring scripts. Faces and license plates are anonymized with Gaussian blurred areas defined by bounding box detection coordinates.

1. Frames are read individually from a video file.
2. Each frame is:

Datasets

- This wiki page includes information about the datasets collected using the COSMOS testbed.

Wireless Datasets

- COSMOS large and medium node coverage measurements
- Outdoor-to-indoor 28GHz wireless measurements in Manhattan

Optical Datasets

- COSMOS ROADM EDFA gain spectrum measurement dataset

Smart City Datasets

- COSMOS camera dataset

IBM 28GHz PAAM Basics

Description

In this tutorial, we demonstrate the basic use of the IBM 28 GHz phased array antenna modules (PAAMs) with USRP N310 software-defined radios (SDRs) in the COSMOS Sandboxes (sb1, sb2).

The following paper describes the integration of the IBM 28 GHz PAAMs (beta-version) with USRP SDRs in the COSMOS testbed. We would appreciate it if you cite this paper when publishing results obtained using the PAAMs deployed in COSMOS.


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More details can be found on https://wiki.cosmos-lab.org
Summary

• COSMOS – A city-scale programmable advanced wireless testbed in West Harlem
  • Enables ongoing research on wireless/optical networks and smart cities
  • Deployed within an FCC innovation Zone

• Supported experimentation:
  • Full Duplex, mmWave, Optical-wireless x-haul networking, ORAN, Dynamic spectrum access, International experiments (COSM-IC), Smart intersections and edge cloud

• Offers various unique capabilities both in term of data collection and experimentation/deployment

• “Learning for networks” is being studied for smart intersections and edge cloud, full duplex, optics, dynamic spectrum access
Thank You!

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Key Technology: Software-Define Radios

- Software-defined radio (SDR) nodes at various performance levels and form factors:
  - (i) 0.4–6 GHz bands, (ii) 28/60 GHz bands (with up to ~500 MHz bandwidth), Gbps
- Signal processing can be spread between radio node & edge cloud RAN
COSM-IC - Federation of Testbeds

• To scale up
• To use/combine special resources (e.g. mmWave, wireless robots, high-performance computing, etc.)
• To re-use experiments (class exercises, scientifically, …)
• Redundancy (e.g., testbed in maintenance)