PSCR 2022 The Digital Experience

A Platform for Experimental Research in Critical Voice Communications

Jan Janak, Artiom Baloian, Kahlil Dozier,
Dan Rubenstein, Henning Schulzrinne - Columbia University
Lauren Berny, Charles Jennings - John Jay College

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This work was performed under the following financial assistance award 70NANB19H003 from U.S. Department of Commerce, National Institute of Standards and Technology.

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Outline

1. Project Objectives
2. Testbed Design
3. Remote Listening Experiments
4. Interactive Game Experiments
5. Summary & Next Steps

Project Objectives

How does the quality of the communication channel affect first responder communications?

- Four phase approach:
  a. **Build a communication testbed**
     i. Emulate real mission critical voice (MCV) systems
     ii. Configurable audio & network impairments
  b. **Experiment with trained first responders**
     i. Communicate using the testbed in a controlled environment
  c. **Measure communication performance**
     i. Analyze data collected during experiments
  d. **Build mathematical models**
     i. Channel conditions -> performance measures

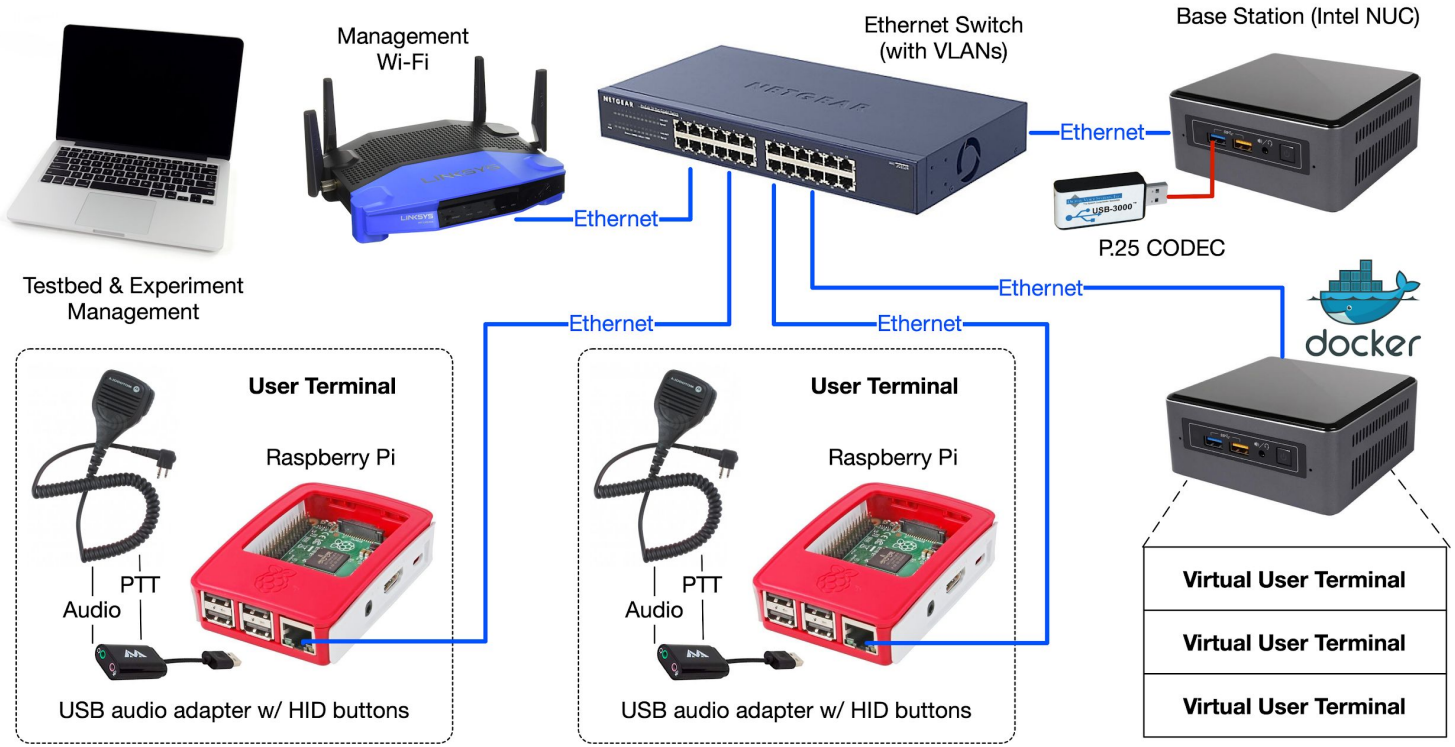
Quality of Experience (QoE) Measures

- Comprehension errors
  - repeat transmitted messages
- Task errors
  - wrong information recorded
- Usage errors
  - pressing push-to-talk (PTT) button too early or too late
- Length and latency of responses
  - pauses between requests and start of transmission
- Subjective ratings of user experience
  - rated frustration with radios

Testbed Design

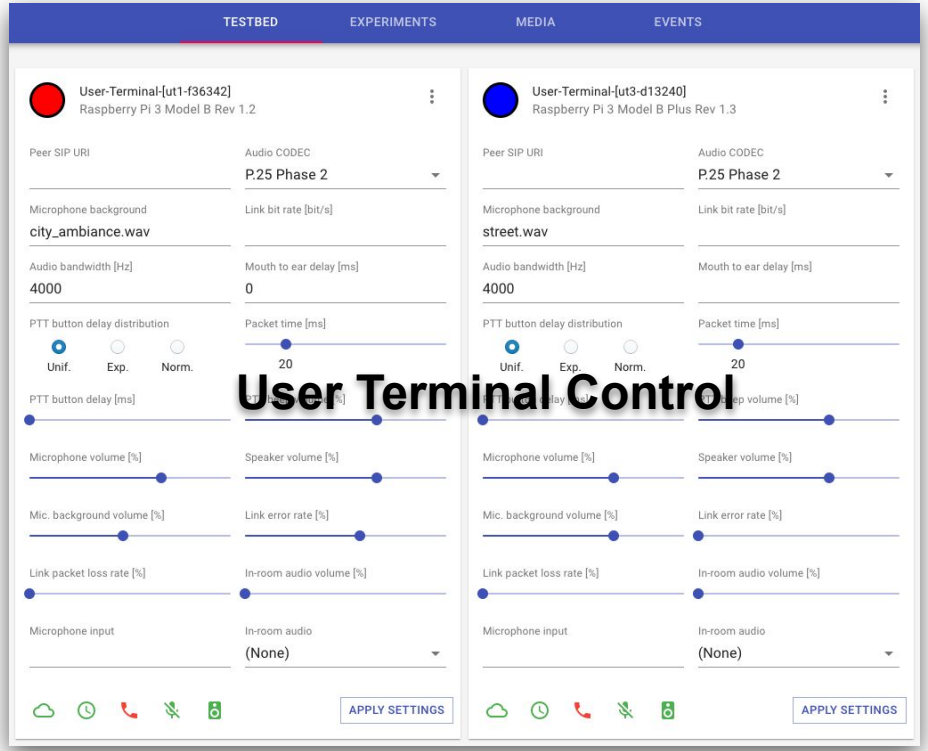
- Open hardware & software
- Affordable off-the-shelf components (Raspberry Pi for user terminals)
- Emulates analog & digital MCV systems (including P.25 Phase 1 & 2)
- Programmable audio & network impairments
- Support for interactive and listening (at-home) experiments
- Testbed and experiment management from the browser
- Python environment for experiment evaluation and analysis

Testbed Hardware Architecture

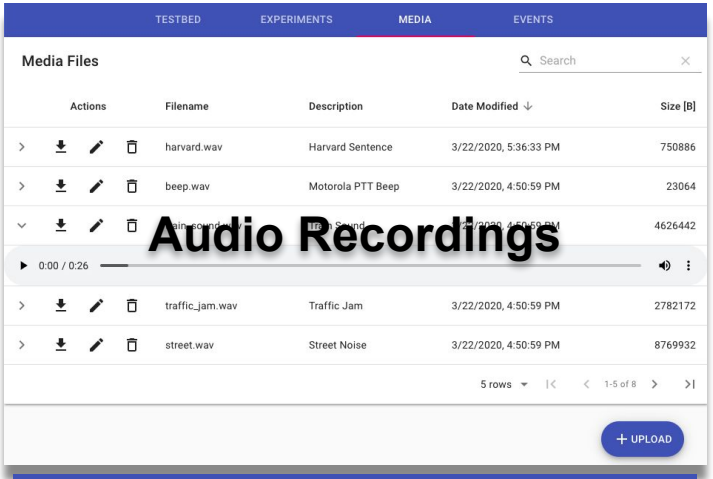


Testbed Prototype at Columbia University

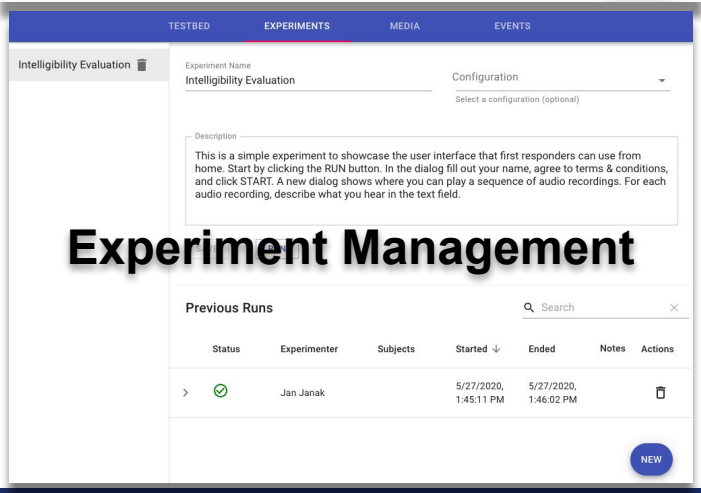
Testbed User Interface



User Terminal Control



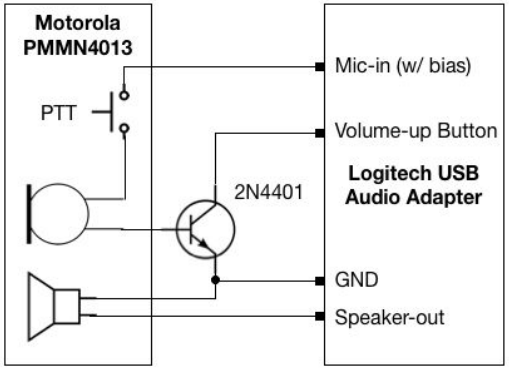
Audio Recordings

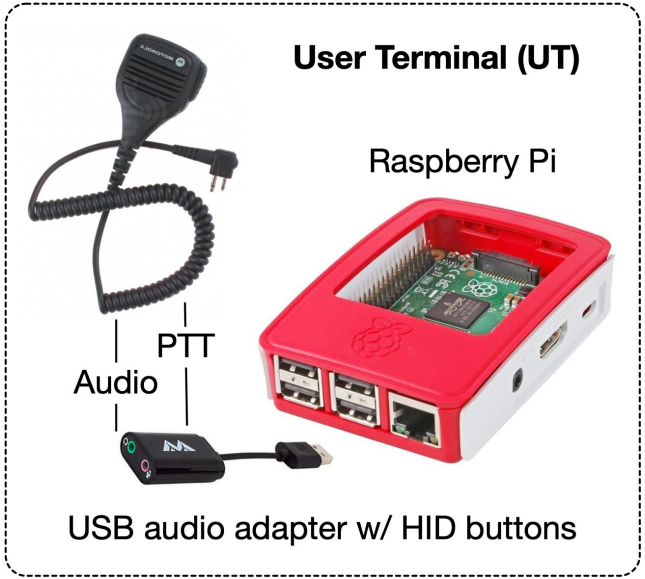


Experiment Management

User Terminal Hardware Architecture

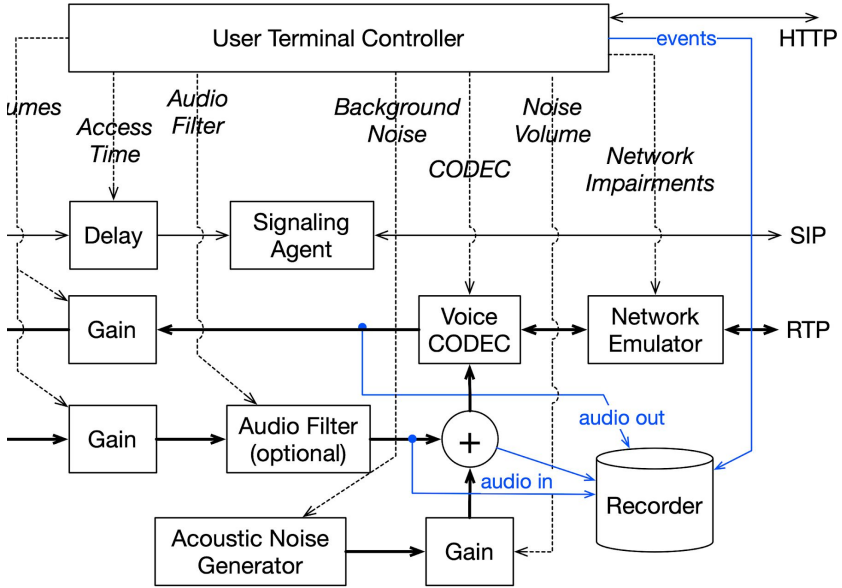
- Connect Motorola speaker to Raspberry Pi
- Emulates PTT communication device
- The device applies audio impairments





User Terminal Software Architecture

- Custom controller application
- PulseAudio for audio processing
- Baresip SIP user agent (P.25 codec)
- Linux kernel network emulator
- Custom event & audio recorder



Supported Impairments

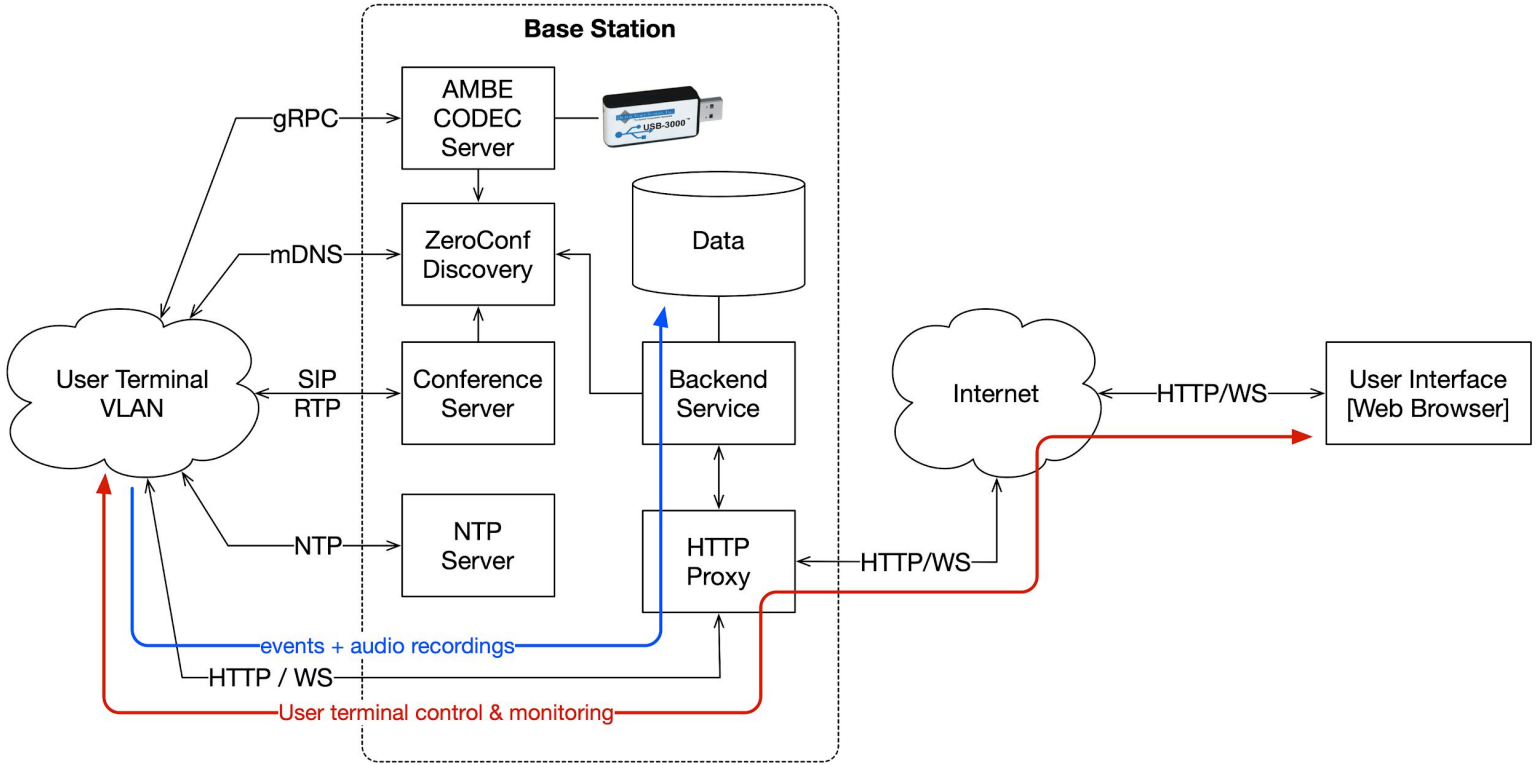
Audio

- Background noise injection
- Fine-grained volume control
- Audio filtering (bandwidth, low-pass)
- Variable PTT delay (mic audio cut-off)
- Voice compression (codec selection)

Network

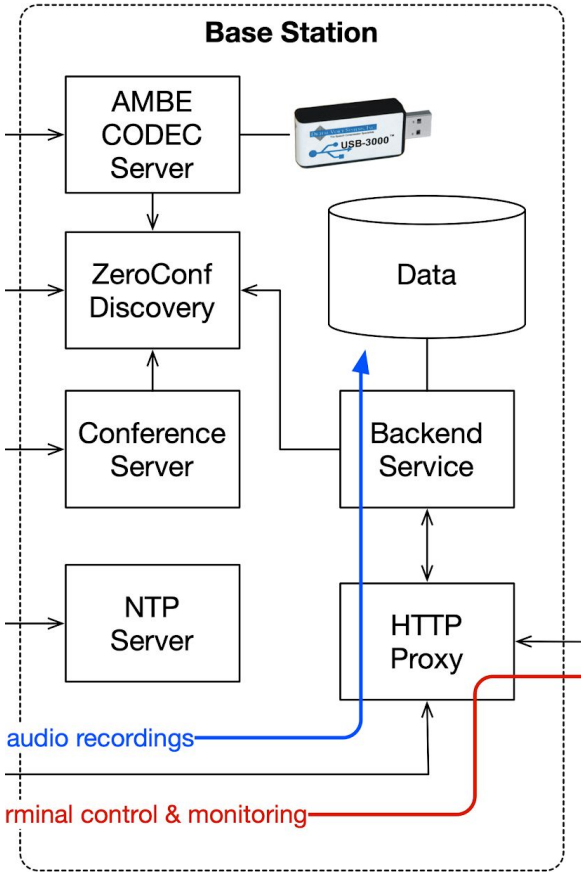
- Configurable mouth-to-ear delay
- Maximum bandwidth limitation
- Modulation rate (baud rate)
- Packet loss
- Bit error injection

Base Station Software Architecture



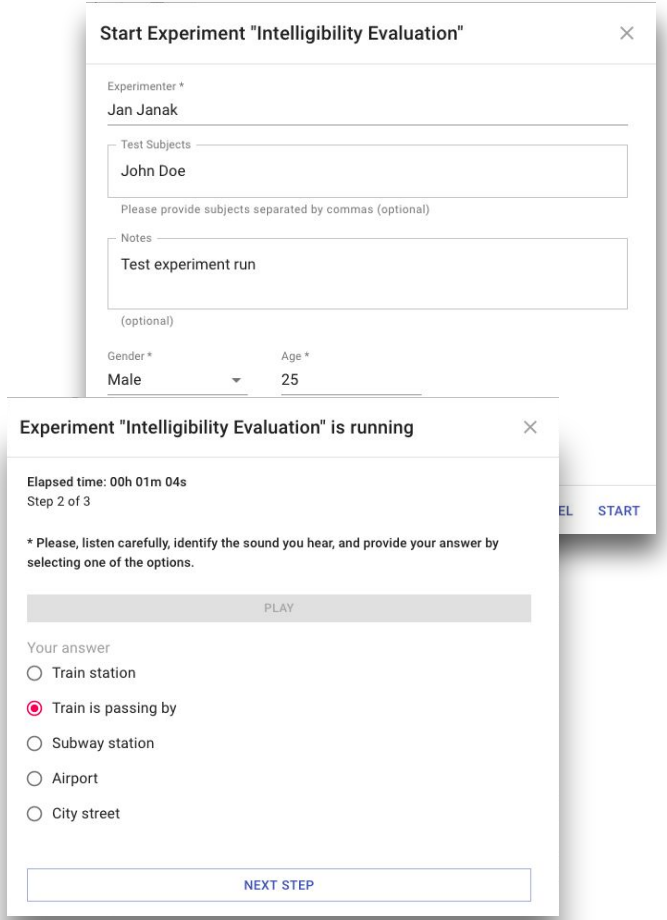
Base Station Services

- Custom Advanced Multi-Band Excitation (AMBE) codec server
- ZeroConf for service discovery
- SIP conference server emulates RF channels
- NTP for user terminal time synchronization
- MongoDB for data storage



Remote Listening Experiments

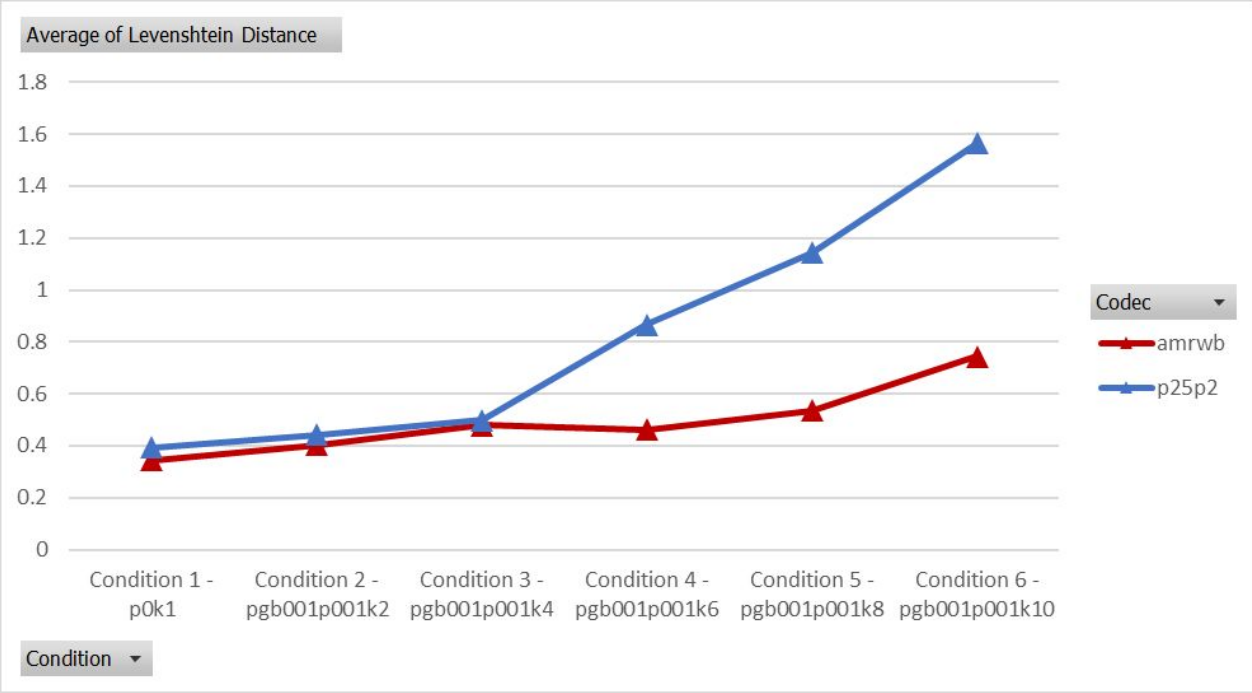
- A series of impaired audio recordings
- Browser UI for playback & data collection
- Anti-cheat design (play once only, no pause)
- Accessible from first responders' homes



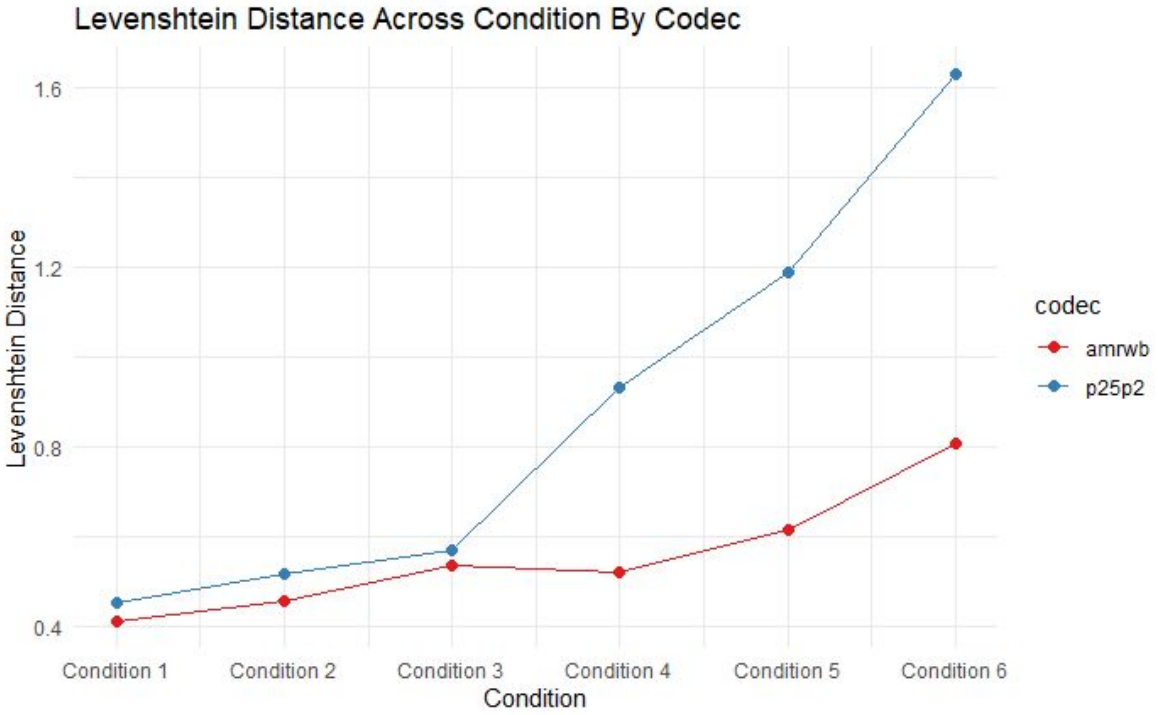
License Plate Listening Experiment

- New Jersey license plates using NATO alphabet
- 48 participants x 72 trials = 3,456 total trials
- Correlated (Gilbert-Elliot model) frame loss and bit errors
- Compare codec performance: P.25 Phase 2 versus AMR

Listening Experiment Results



Listening Experiment Results (continued)



Differences Between Codecs:
Condition 1, p0k1 (reference group)
Condition 2, pgb001p001k2 (p = .847)
Condition 3, pgb001p001k4 (p = .933)
Condition 4, pgb001p001k6 (p <.001)
Condition 5, pgb001p001k8 (p <.001)
Condition 6, pgb001p001k10 (p <.001)

Note: Graph is predicted values

Interactive Experiment in EDGE* Environment

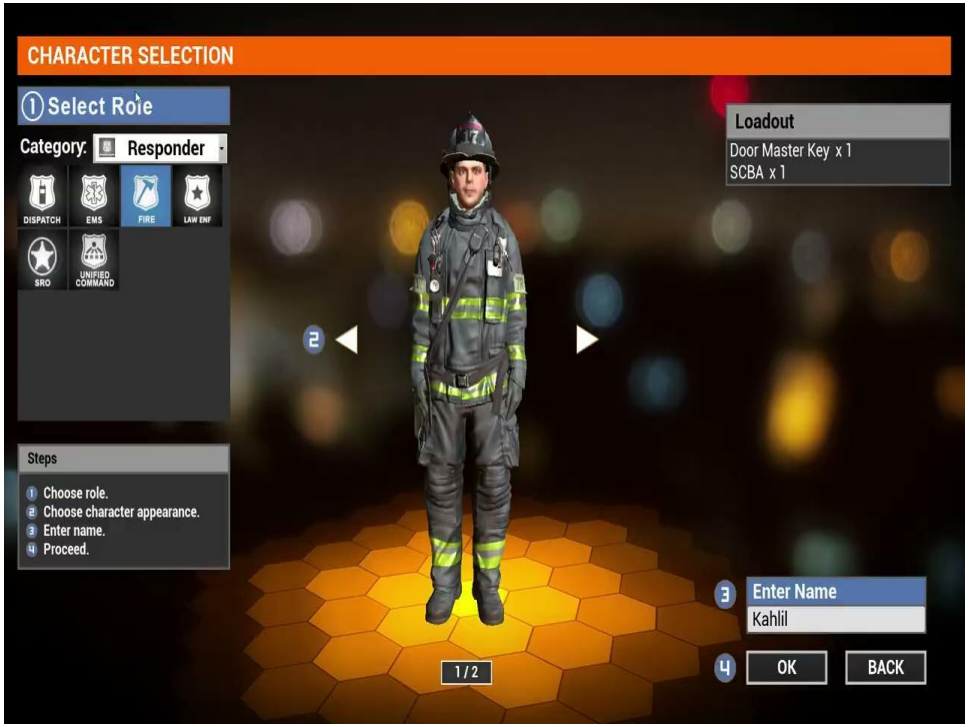
- Virtual training platform for first responders
- Coordinated response to critical incidents
- Developed by the U.S. Department of Homeland Security (DHS)
- Built on the Unreal game engine
- Two training environments: hotel and school

* Enhanced Dynamic Geo-Social Environment (EDGE)

Source: https://www.dhs.gov/science-and-technology/EDGE

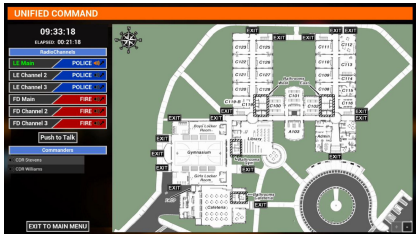
EDGE Gameplay

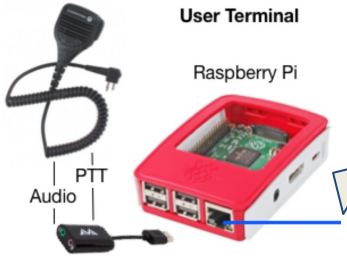
https://www.youtube.com/watch?v=nFoLQ4M2CRc



EDGE+MCV Testbed @ Columbia

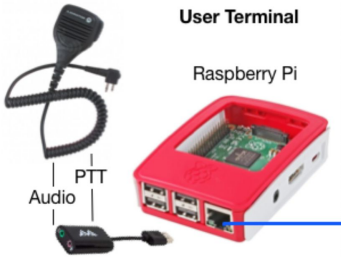
Dispatcher





USB audio adapter w/ HID buttons

First responder (test subject)



USB audio adapter w/ HID buttons

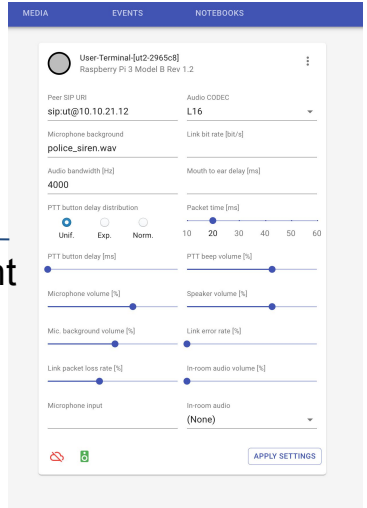
voice

voice

Testbed base station

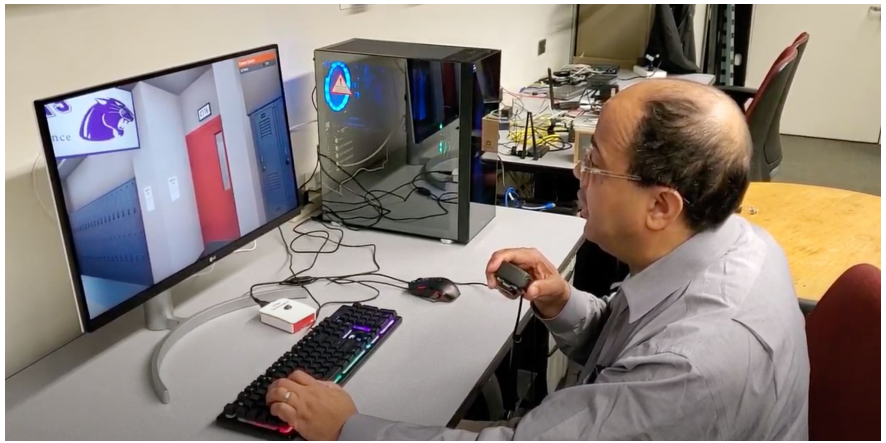
Impairment control

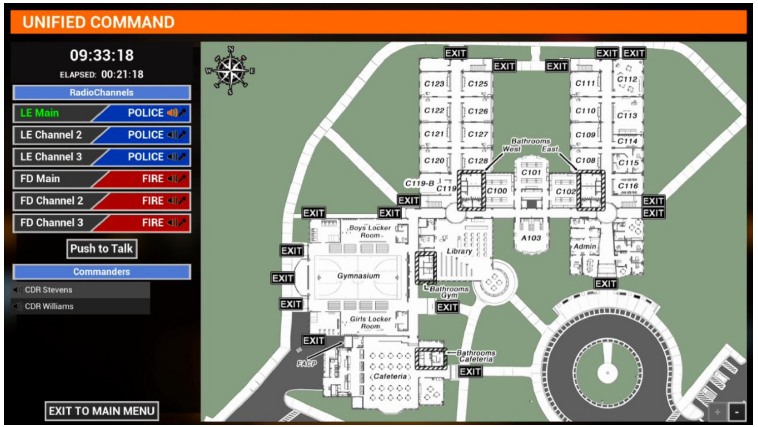
Experimenter

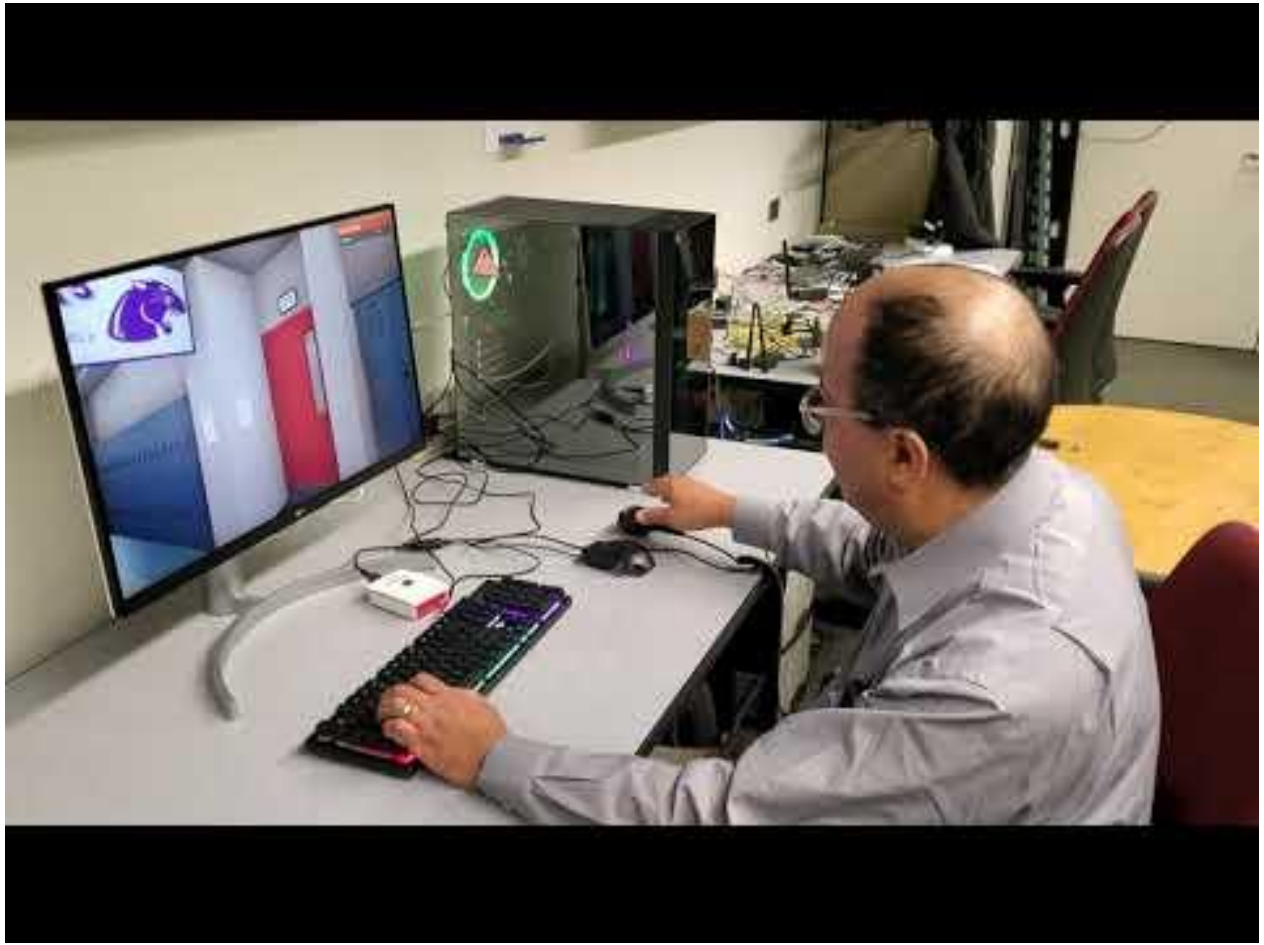


EDGE First Responder Experiment

- Human test subject in EDGE
- Two-way communication with dispatcher via MCV testbed
  - Variables: MtE delay, PTT delay, access time



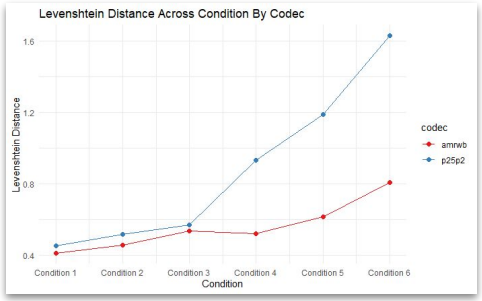


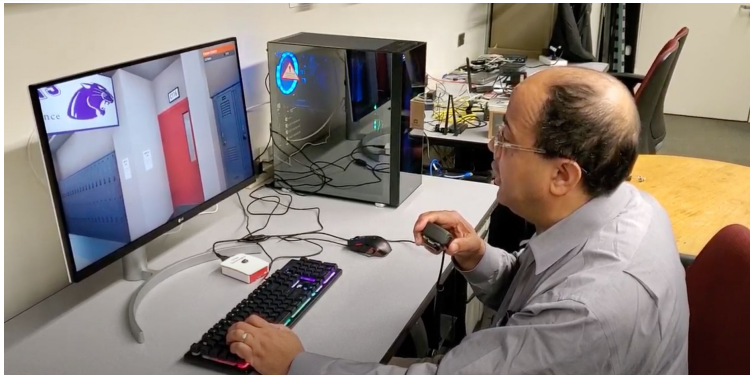


Platform for Experimental Research in Critical Voice Communications

Summary

- Open testbed for experiments with MCV
  - Remote listening experiments
  - Interactive delay-based experiments
- Ongoing human subject experiments
  - Listening experiment performed & evaluated
  - Interactive (EDGE) experiment underway





https://irtlab.gitlab.io/mcv-testbed

Next Steps

1. Run experiments with first responders on Columbia University campus
2. Measure true Mouth-to-Ear (MtE) delay of the testbed
3. Develop mathematical models to estimate performance measures from channel condition (impairment levels)

Additional Resources

- Project website is online
- Testbed source code available under the MIT license
- Free software developed for the project:
  - PulseAudio client for NodeJS: https://github.com/janakj/pulseaudio.js
  - Client library for DVSI AMBE vocoder chips: https://github.com/janakj/ambe

Project Website

https://irtlab.gitlab.io/mcv-testbed