LOG-a-TEC testbed applications

CREW Training days 2nd edition - January 14-15, 2014 Ghent

Matevž Vučnik - Jožef Stefan Institute (JSI)

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Outline

- **What is LOG-a-TEC?**
  - Setup & Building blocks
- **What can LOG-a-TEC offer to Experimenters?**
  - Testbed capabilities with focus on TVWS experimenting
  - Long-term measurements
  - Dynamic composition of networking protocols
  - Photovoltaics system monitoring
  - Air quality monitoring
- **What types of TVWS experiments can be carried out at LOG-a-TEC?**
- **Game theoretic interference mitigation – demo**
- **Wireless microphone emulation with VESNA - demo**

What (and where) is LOG-a-TEC?

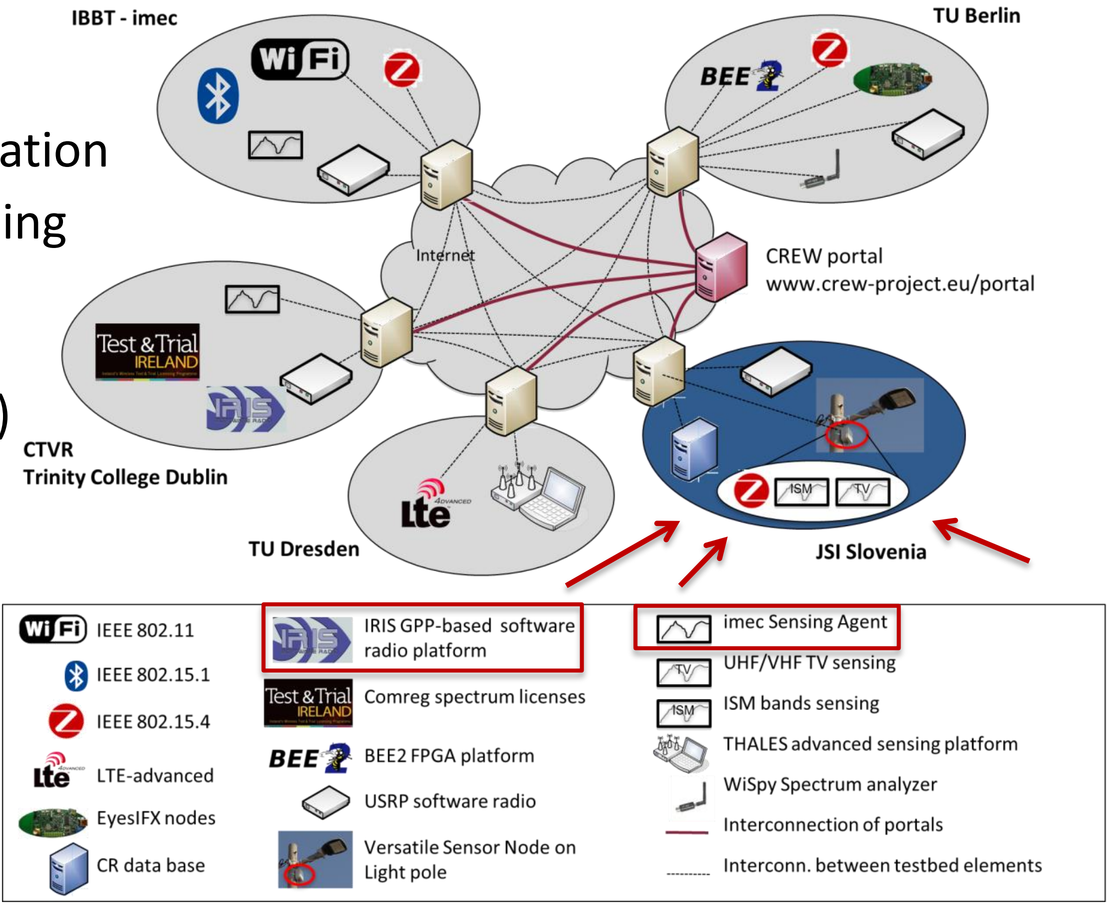
JSI testbed as part of CREW federation

JSI campus, Ljubljana

- Combined indoor and outdoor installation
- Used for cognitive networking experimentation
- Used for spectrum sensing and cognitive radio experimentation (test site for LOG-a-TEC)

LOG-a-TEC, Logatec

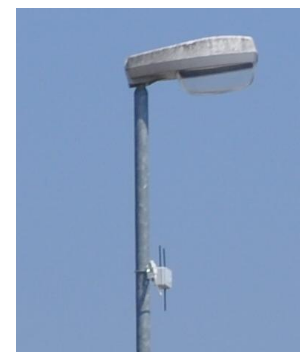
- Outdoor installation
- Used for spectrum sensing and cognitive radio



LOG-a-TEC testbed

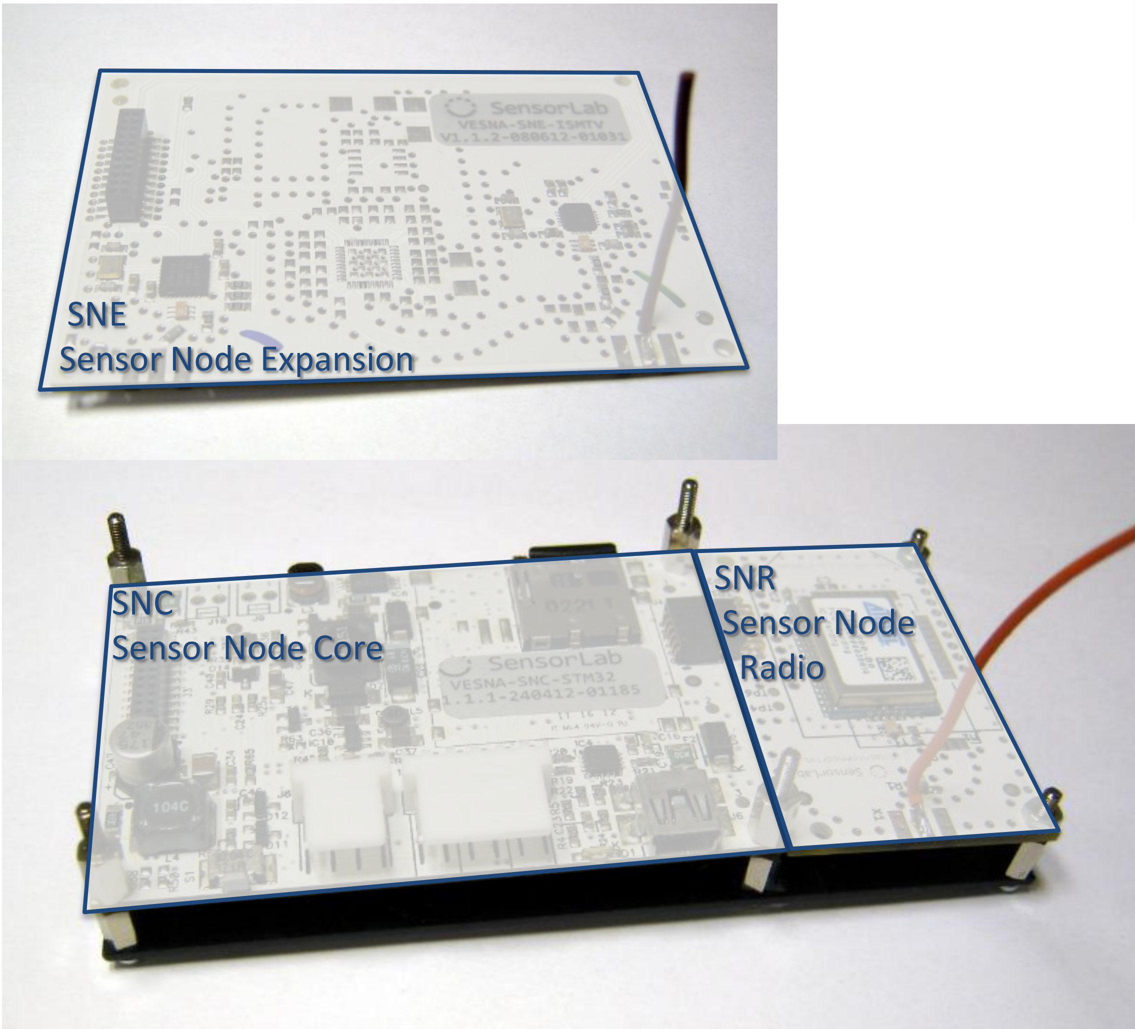
- Deployed in the city of Logatec, Slovenia

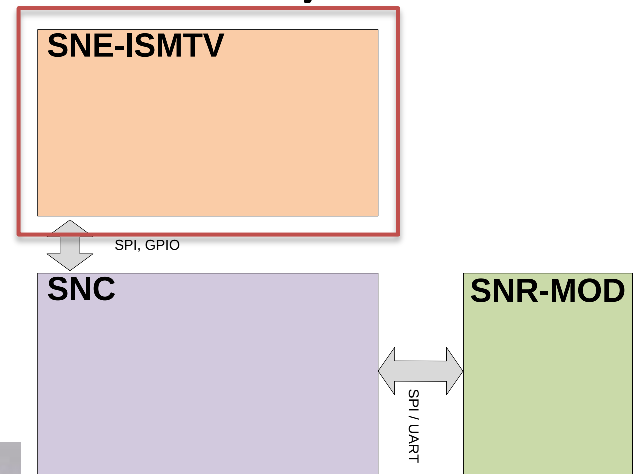
- Based on wireless sensor network
- Sensor nodes are (mostly) installed on public light poles
- Infrastructure rewiring ensures 24/7 power supply
- Can be used for spectrum sensing and cognitive radio experimentally-driven research



VESNA

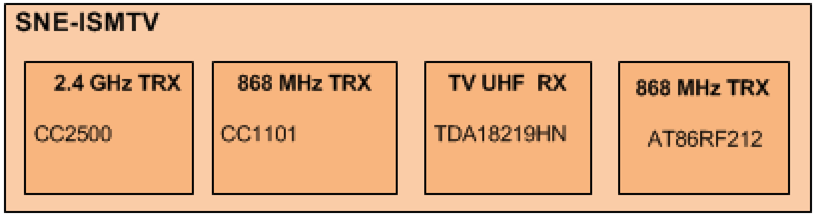
- VESNA = VErsatile platform for Sensor Network Applications
- Modular platform for WSN (VESNA = SNC + SNR + SNE)





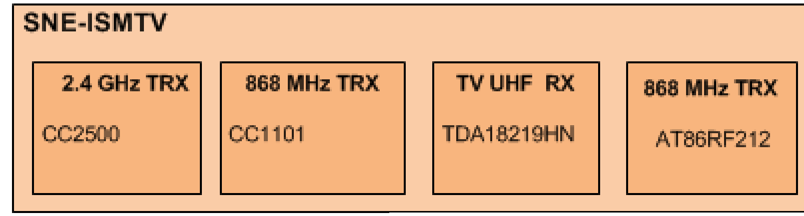
VESNA SNE-ISMTV

- **One PCB with several placement options**



- **Spectrum sensing**
  - ISM 868 MHz RF transceiver
    - Based on CC1101 (sub-GHz @ 315, 433, 783, 868, 915 MHz)
    - Receiver sensitivity of -112 dBm @ 868 Mhz
    - Programmable output power up to 12 dBm
  - ISM 2.4 GHz RF transceiver
    - Based on CC2500 (2.4 GHz)
    - Receiver sensitivity of -104 dBm
    - Programmable output power up to 1 dBm

VESNA SNE-ISMTV



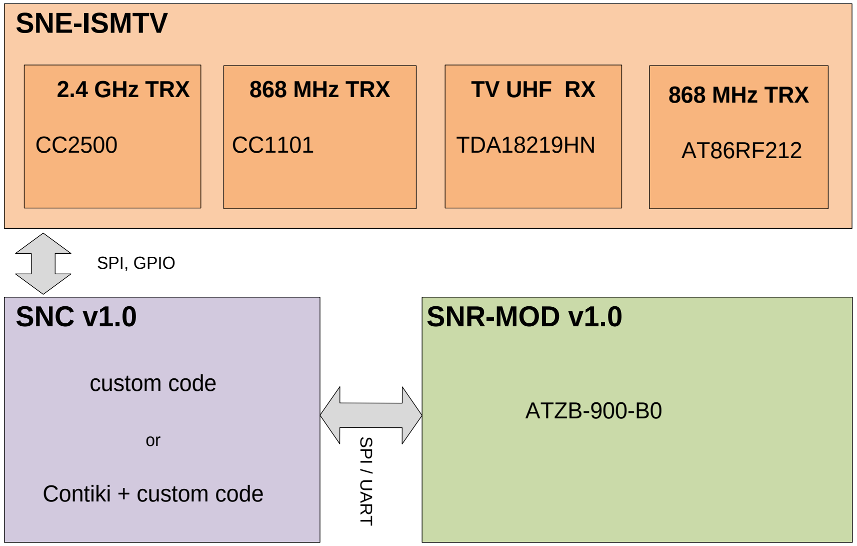
Spectrum sensing

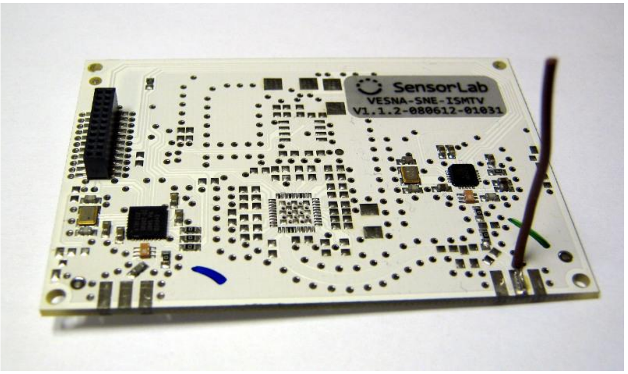
- VHF/UHF (TVWS)
  - NXP TDA18219HN silicon tuner
  - Analog device: AD8307 logarithmic amplifier
  - RF input range: 420 – 870 MHz
  - Bandwidth: 1.7 MHz, 8 MHz
  - ±1 dB linearity
  - 60 dB dynamic range

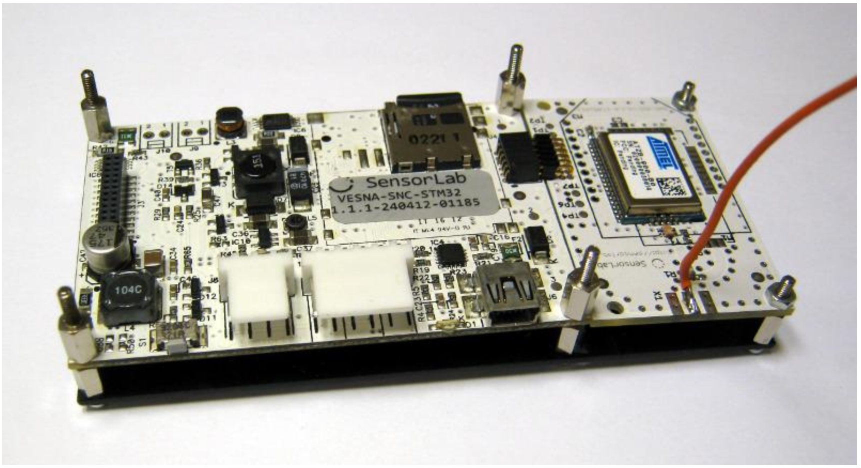
IEEE 802.15.4 transceiver

- ISM 868 MHz
  - Based on Atmel AT86RF212

VESNA assembling for LOG-a-TEC



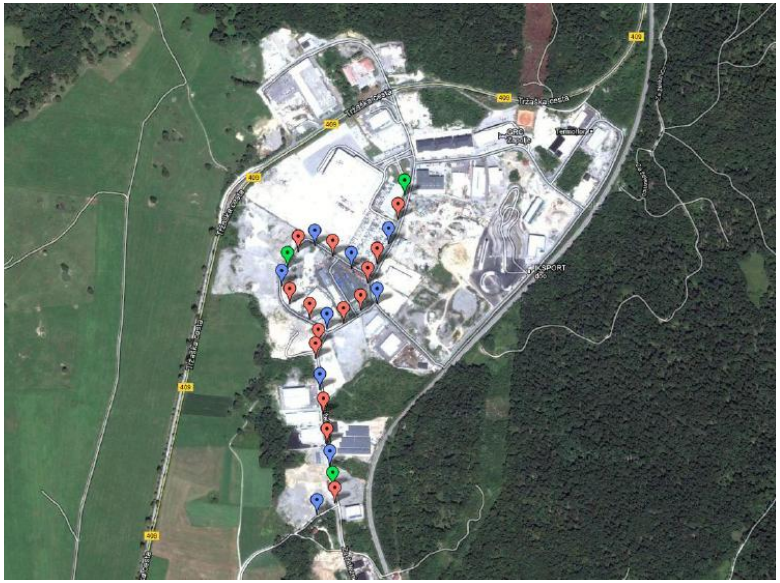




LOG-a-TEC deployment

LOG-a-TEC testbed

- **50 (CREW) sensor nodes are deployed in 2 clusters**
  - City center
  - Industrial zone
- **Management network ZigBee @ 868 MHz, Ethernet gateway**

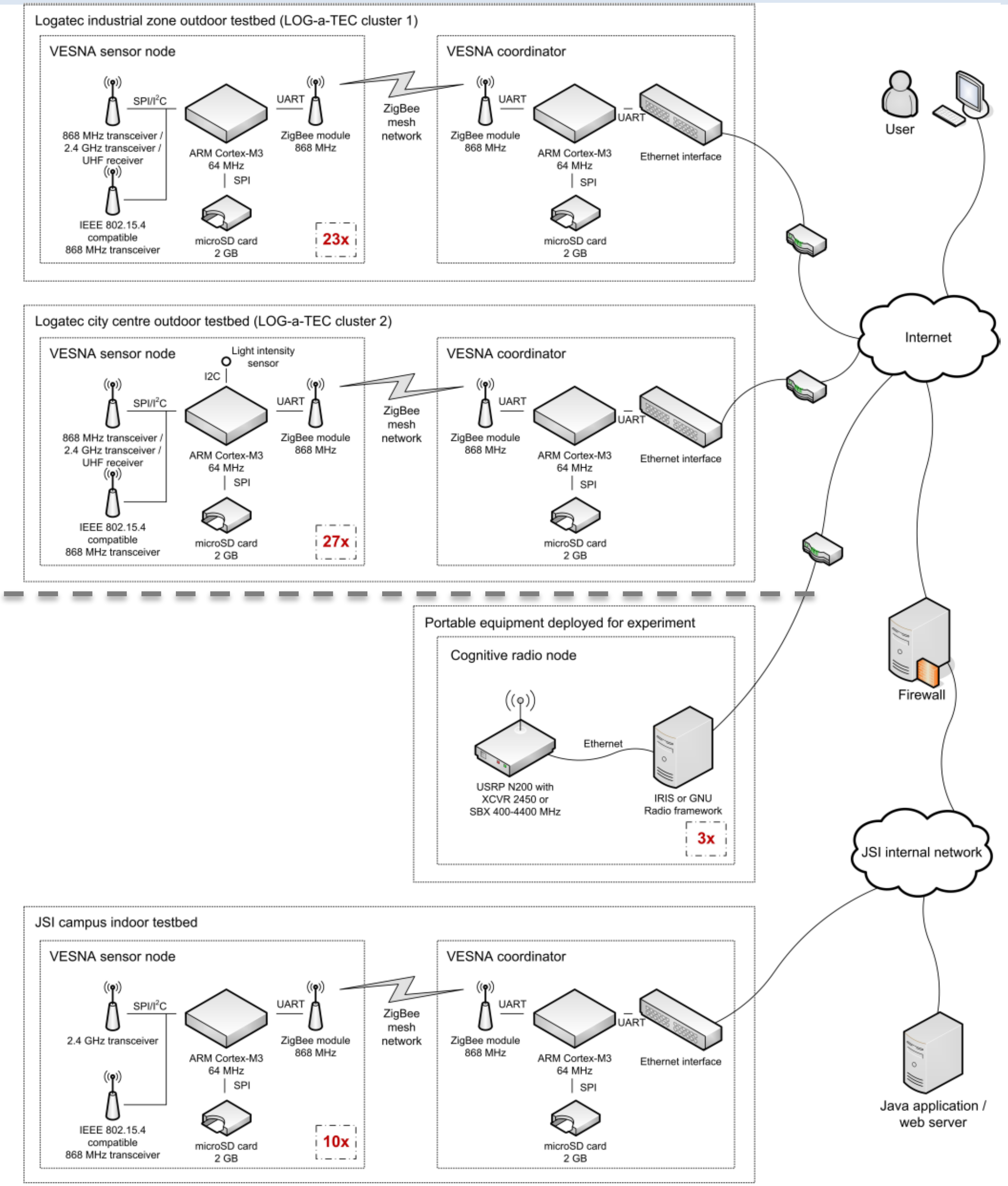


green – UHF, blue - ISM 868 MHz, red - ISM 2400 MHz, yellow - reserve locations

LOG-a-TEC hardware components

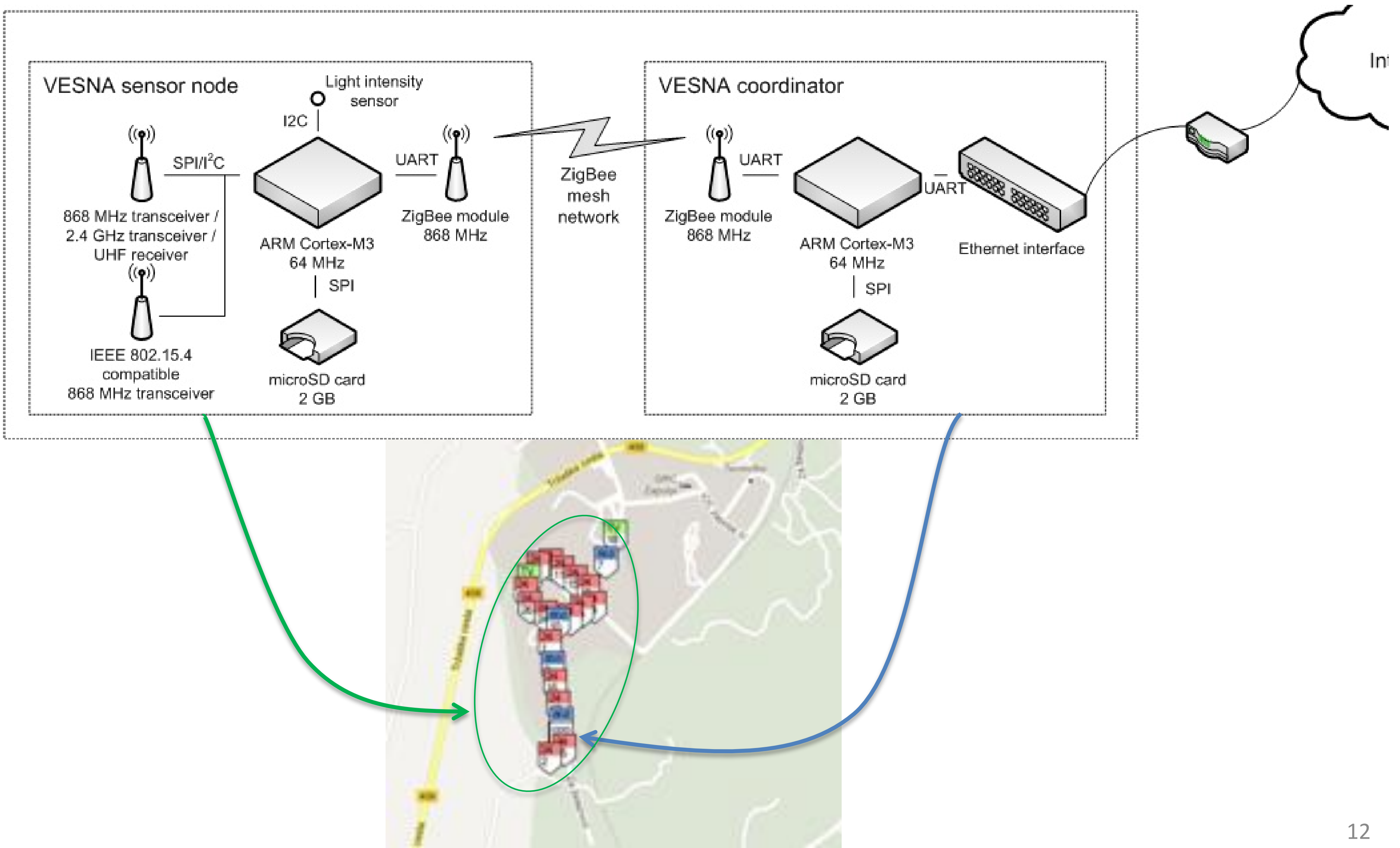
City of Logatec

JSI Campus / Ljubljana

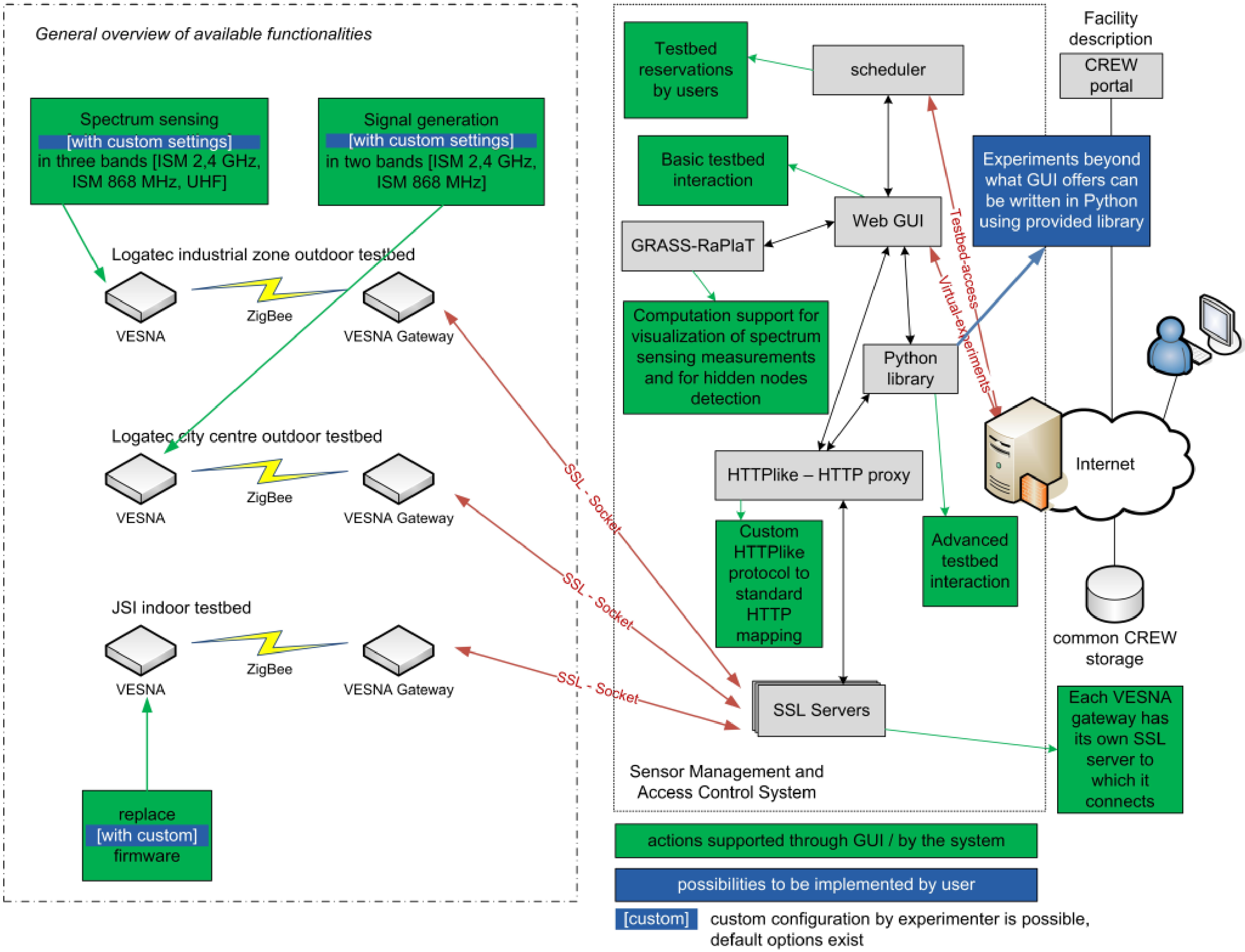


LOG-a-TEC hardware components

VESNA-based testbed HW components



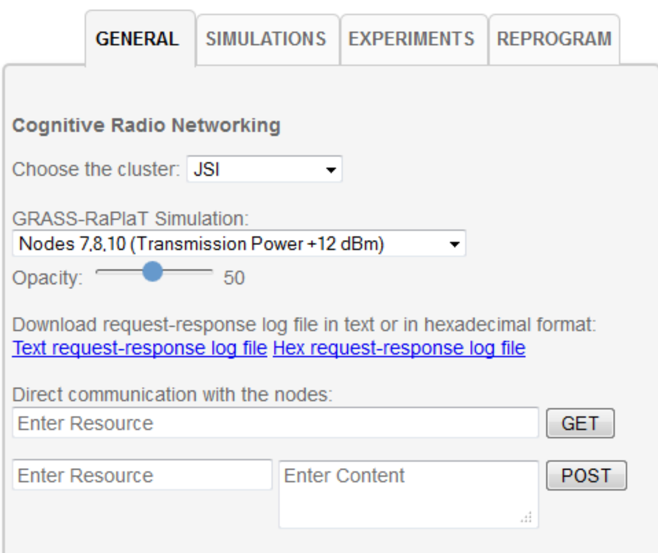
LOG-a-TEC testbed functionalities

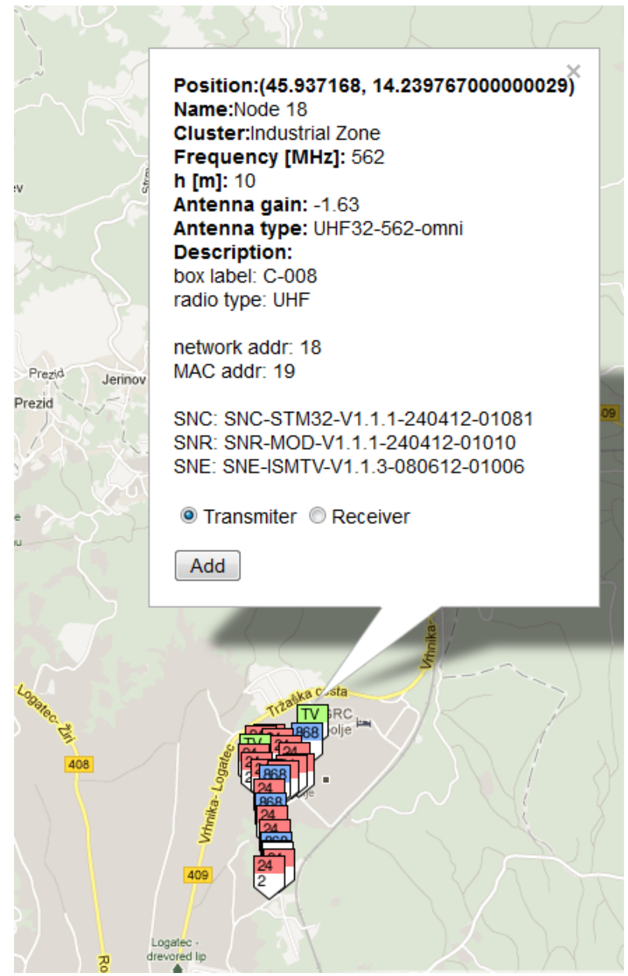


LOG-a-TEC testbed remote access portal

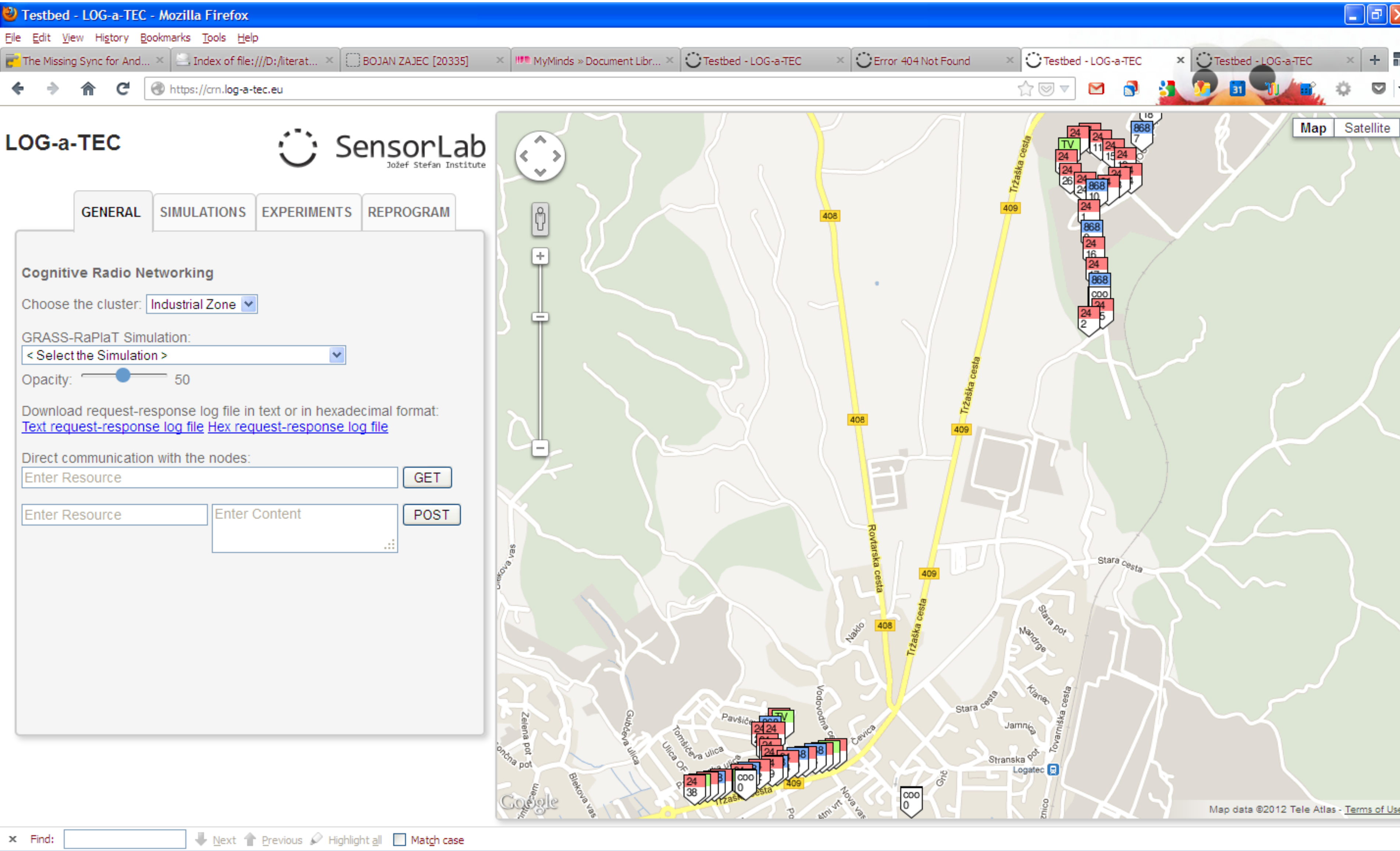
Testbed access portal at www.log-a-tec.eu allows to

- Show node status
- Choose particular cluster
- Perform an experiment
  - described as a sequence of GET and POST requests
- Remotely (over-the-air) reprogram resources

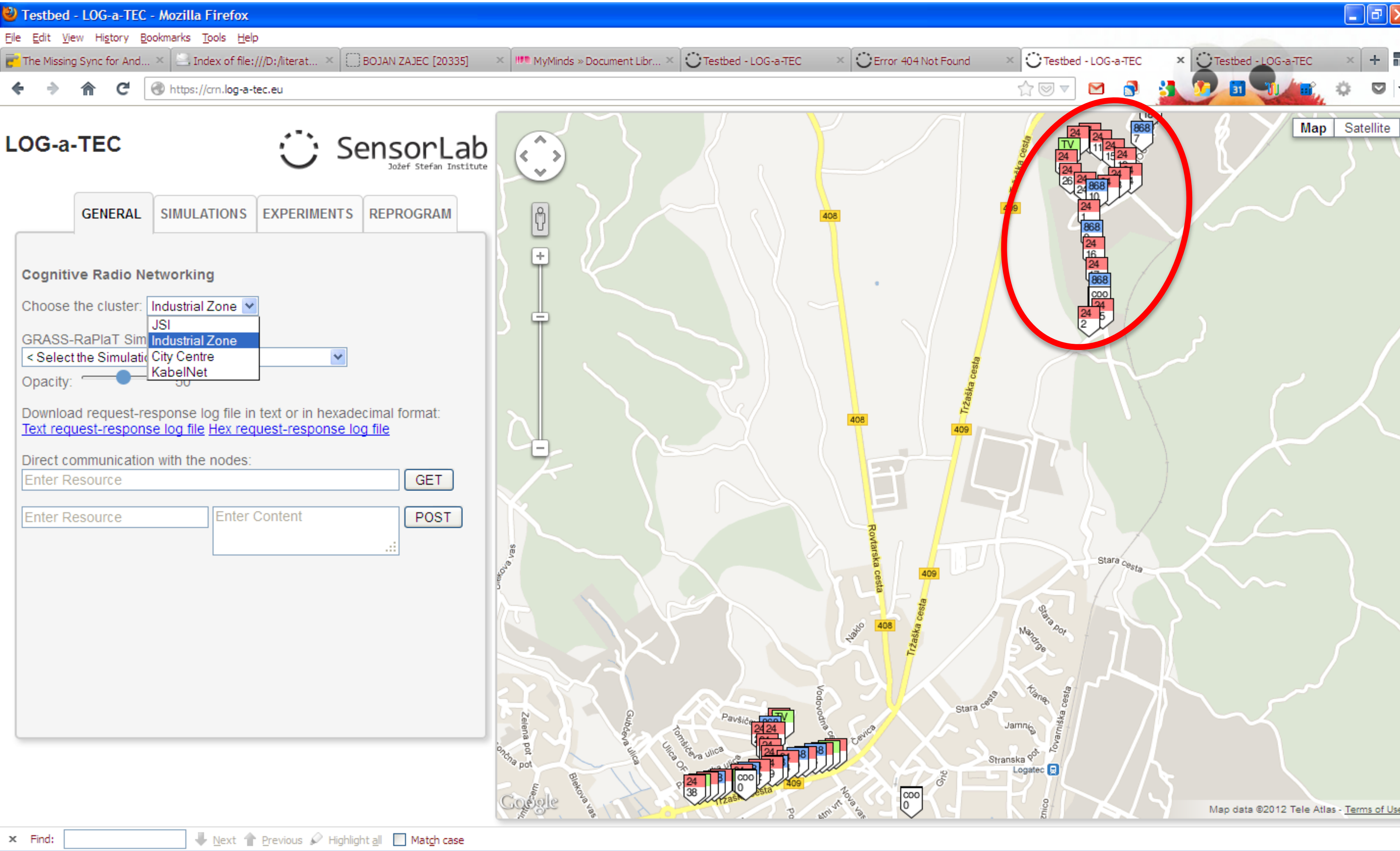




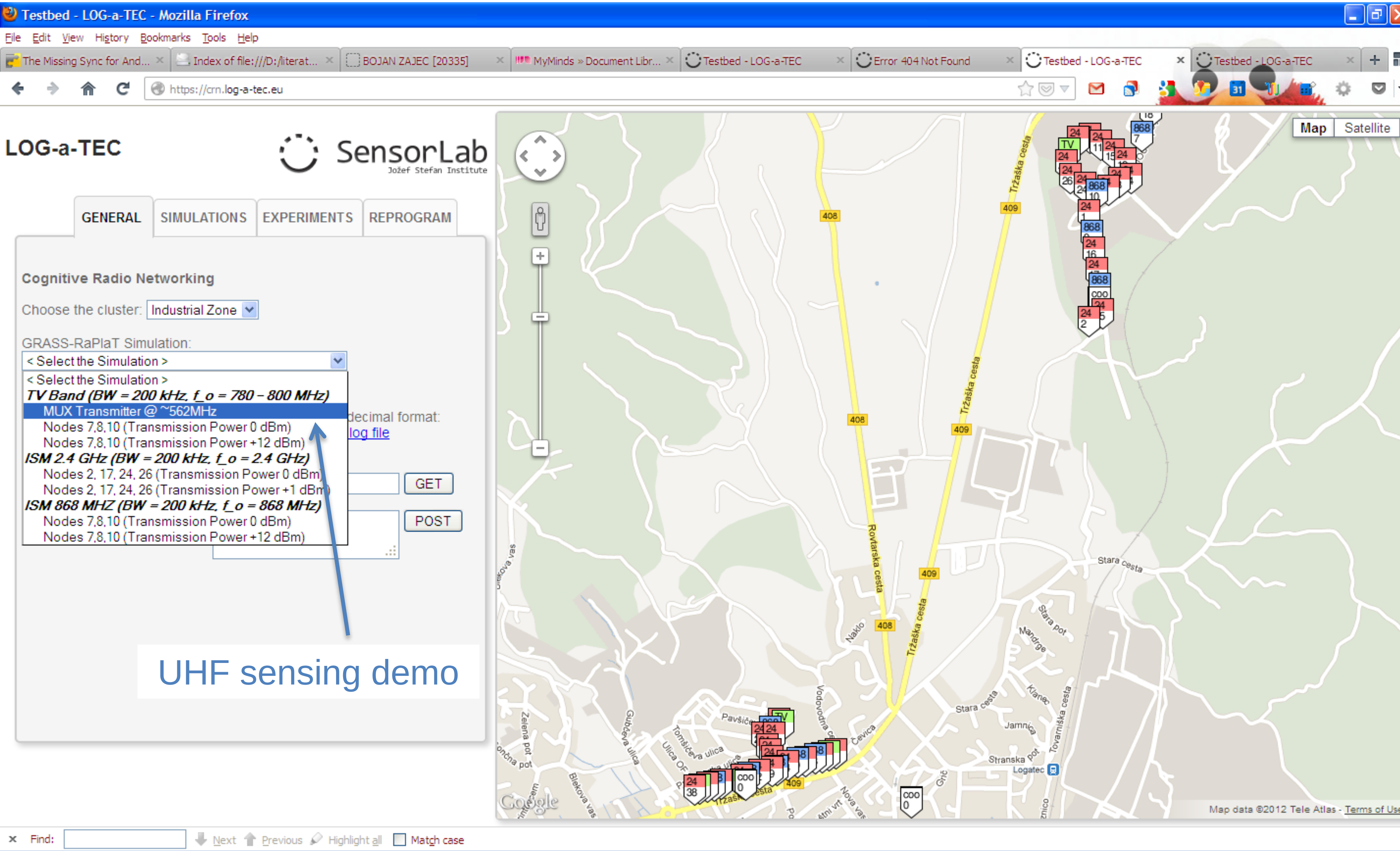
LOG-a-TEC testbed remote access portal



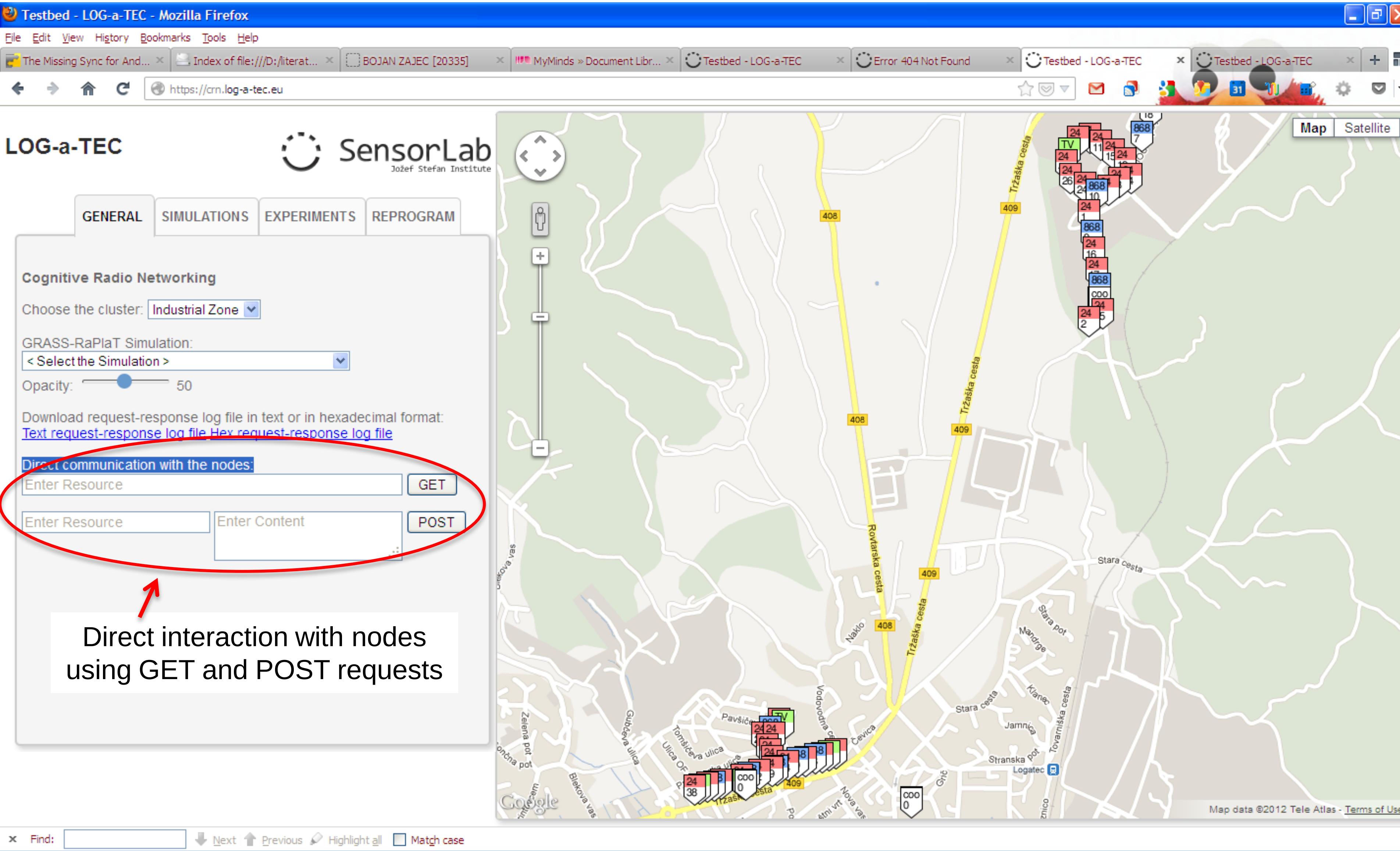
LOG-a-TEC testbed remote access portal



LOG-a-TEC testbed remote access portal

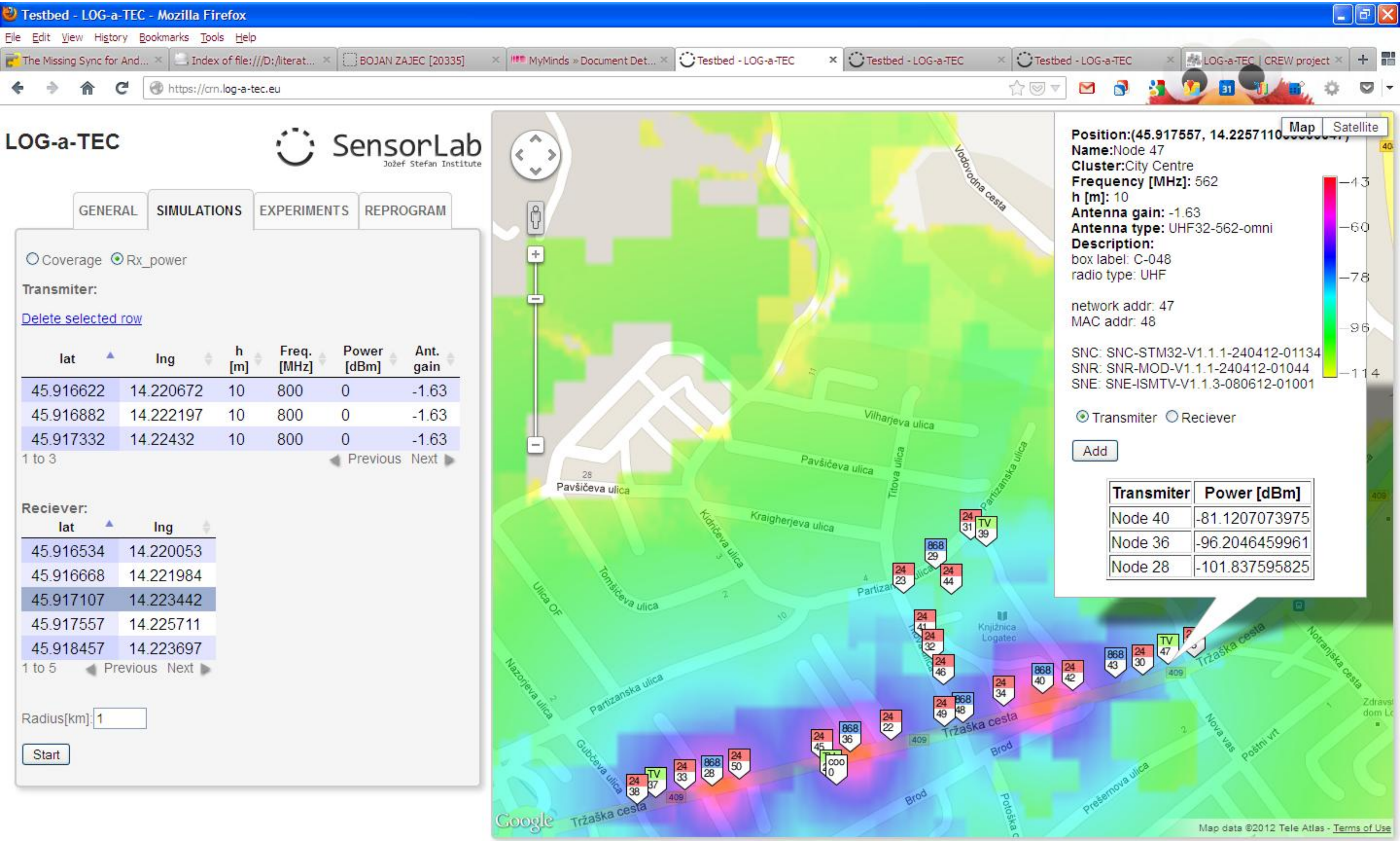


LOG-a-TEC testbed remote access portal

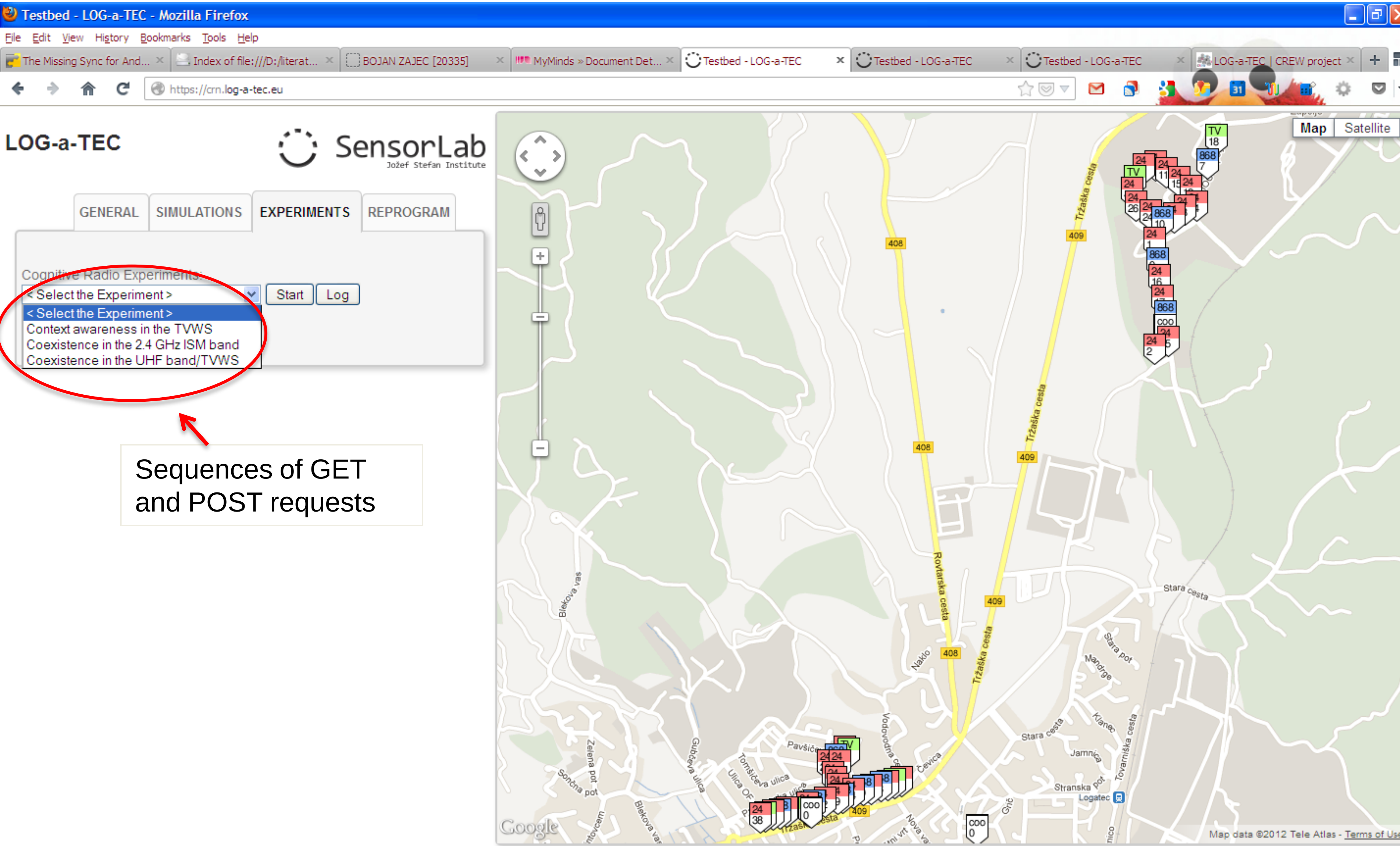


Direct interaction with nodes using GET and POST requests

LOG-a-TEC testbed remote access portal



LOG-a-TEC testbed remote access portal



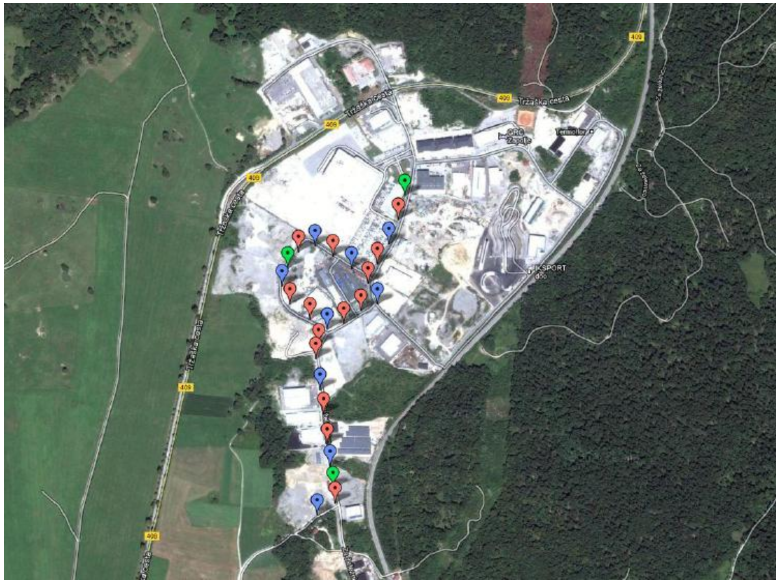
Sequences of GET and POST requests

What can LOG-a-TEC offer to Experimenters?

What LOG-a-TEC offers to experimenters

Placing experiments in realistic outdoor environments

- sub-urban industrial zone, city center

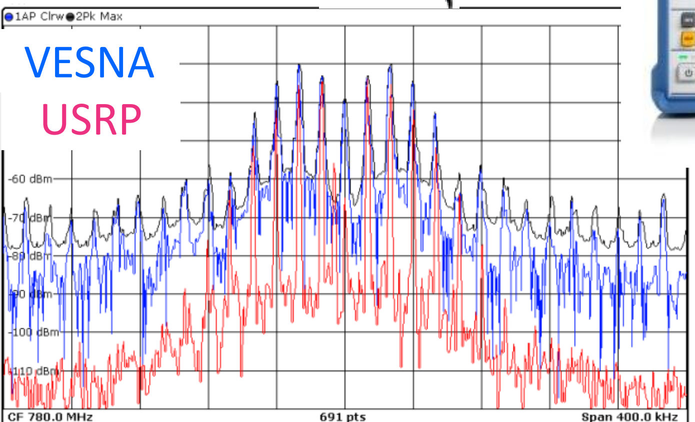


What LOG-a-TEC offers to experimenters

Signal transmitting equipment

- 11 remotely reprogrammable nodes on street lights
  - narrow-band TX in the upper part of UHF band (780-800 MHz)
  - emulation of wireless microphones
- R&S SMBV100A vector signal generator
- USRP N210
- (local DVB-T multiplex transmitter, not under testbed control)

mic



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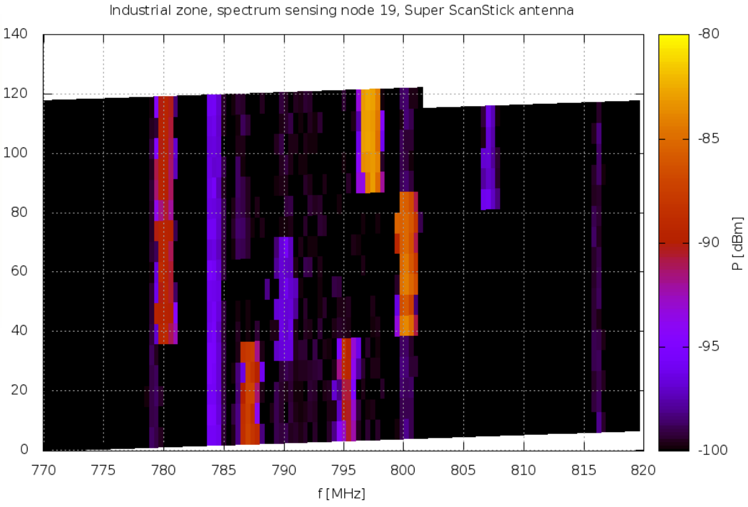


What LOG-a-TEC offers to experimenters

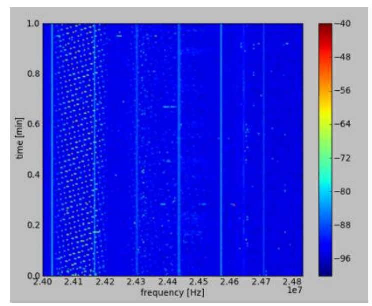
Spectrum sensing equipment

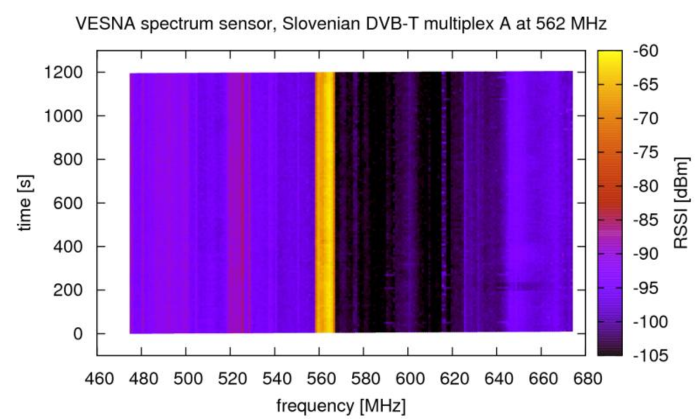
- 19 remotely reprogrammable nodes on street lights
  - 8 wide-band energy detectors
  - 11 narrow-band receivers
- R&S FSV spectrum analyzer
- USRP N210

What LOG-a-TEC offers to experimenters

- VESNA Spectrum sensing software
- A batch of pre-prepared spectrum sensing profiles is available
- Once profile is selected VESNA sensor node is accordingly configured
- Experiment is run according to spectrum sensing specifications
- Results are saved locally on the SD card and sent in batches to the server

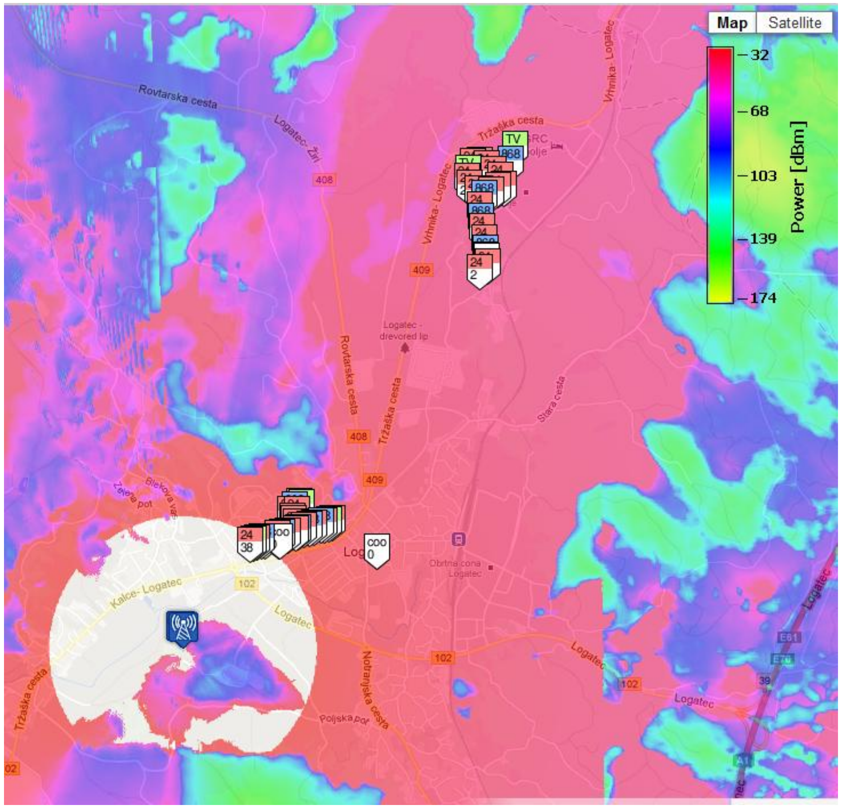
Sensing profile
- Frequency band
- Channel bandwidth
- Averaging
- …





What LOG-a-TEC offers to experimenters

- **Integrated Radio Planning Tool (RaPlaT) based on open-source GIS system GRASS**
  - Experiment planning
  - Tx radio coverage calculation
  - Visualisation
  - Supporting REM estimation



- **Incorporating**
  - Digital Elevation Model
  - Clutter file
  - Six path loss prediction models
  - Ray-tracing approach for rural and urban environments

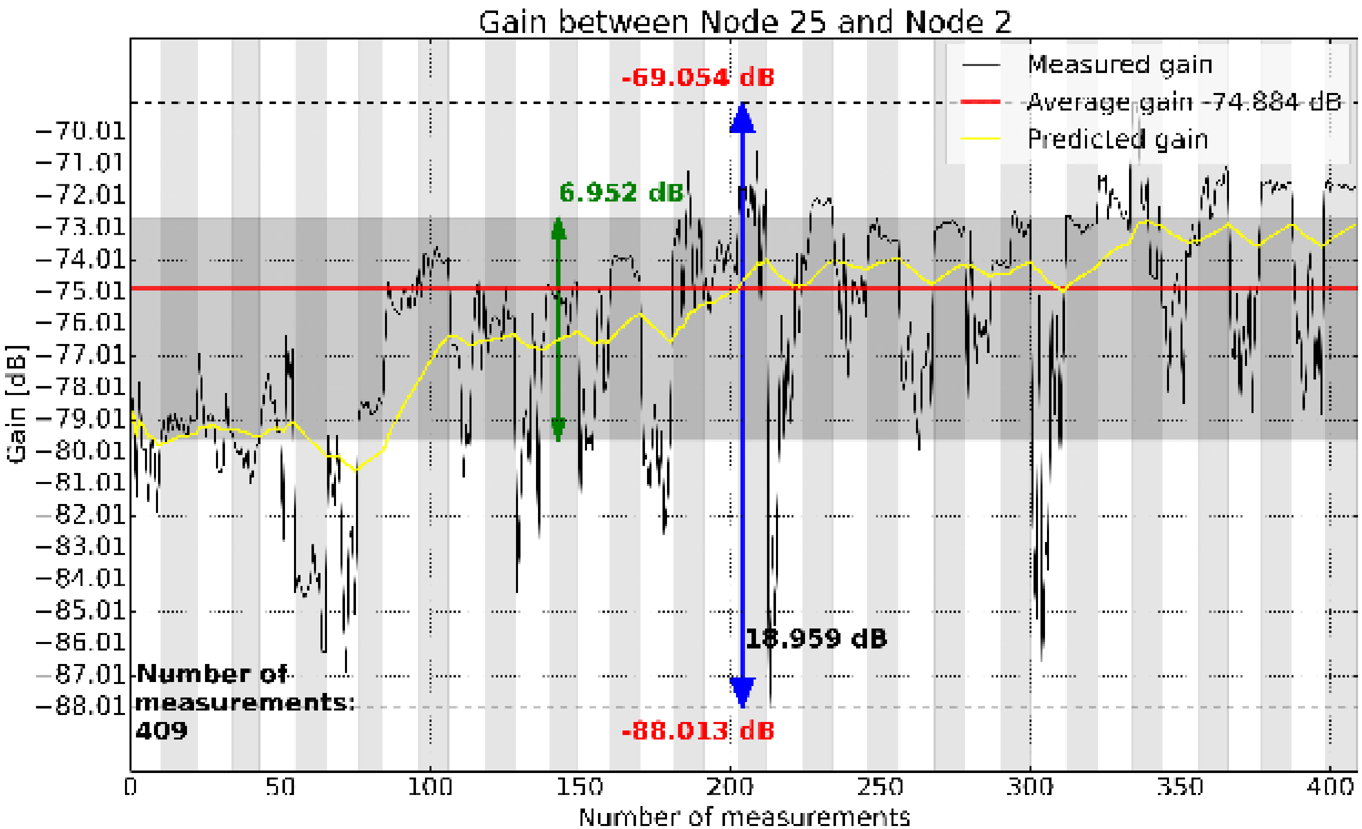
Available also as stand alone tool for download from http://www-e6.ijs.si/en/software/grass-raplat

Long-term measurements

- **Few long-term spectrum occupancy studies**
  - what are seasonal variations in band utilization?
  - long-term trends in spectrum usage?
  - effects of weather on spectrum sensing accuracy
- **Larger data sets would also help research into**
  - channel opportunity prediction algorithms
  - can serve as a training set for machine learning
  - participatory sensing algorithms
- **LOG-a-TEC enables collection of such data**
  - spectrum sensing devices deployed in two sub-urban environments
  - low-cost sensing devices developed for LOG-a-TEC can be deployed in other environments

Long term measurements (1)

■ **Channel gain between pairs of nodes**

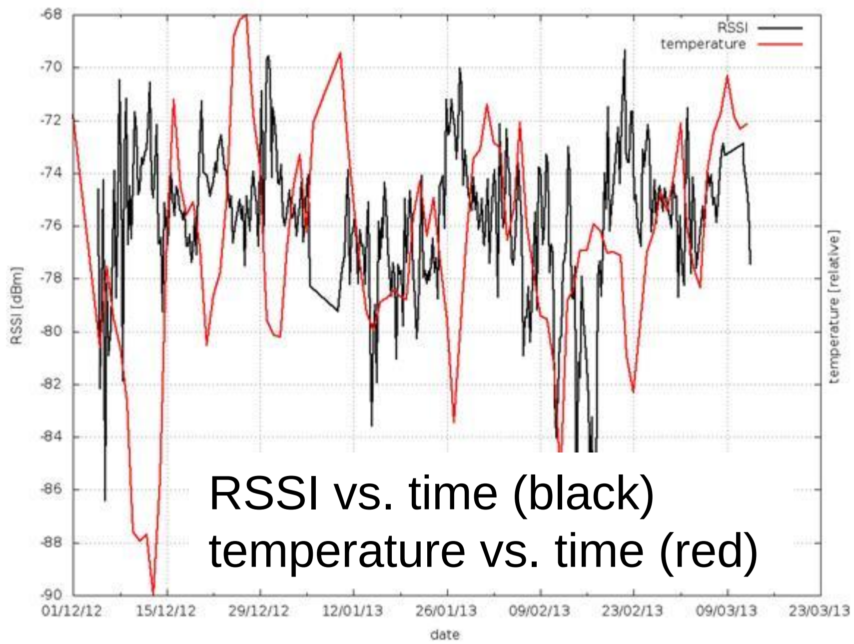


** 24 days, twice a day 1h (12.30-13-30, 21-22)*

Long term measurements (2)

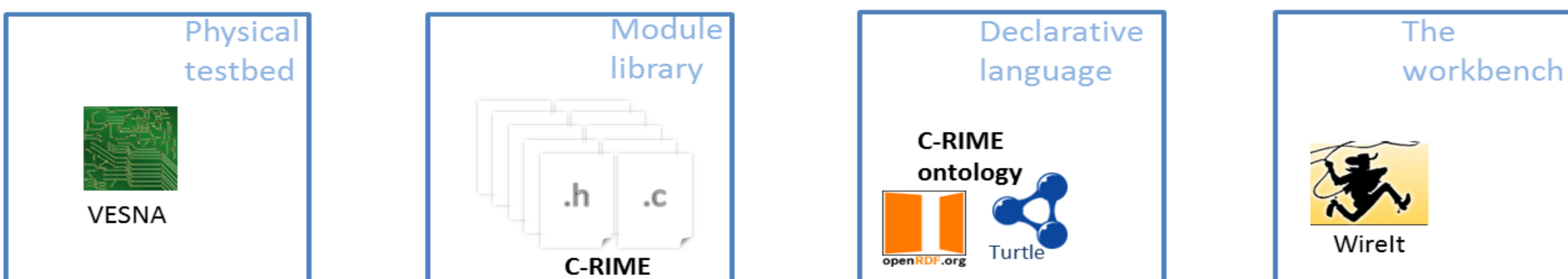
Effects of environment on accuracy of spectrum sensing

- Explore effects of aging, temperatue, humitity, precipitation on out-door spectrum sensing hardware and propagation environment.
- 12 radio links in LOG-a-TEC industrial zone testbed,
  4 RSSI measurements/day, November 2012 – April 2013



Dynamic composition of services

- **VESNA based testbed at JSI campus supporting quick prototyping, deployment and testing of modular protocol stacks as a composition of communication services**
- **Based on ProtoStack tool**
  - HW platforms hosting Contiki OS
  - Composeable Rime (CRime) Module library of basic communication primitives (based on Contiki Rime stack)
  - Declarative language based on RDF (Resource Description Framework) enabling machine supported composing and automatic validation of protocol stacks
  - Web based workbench



How to Experiment in LOG-a-TEC?

1. **Remote experiments (RE)**
   1. Define your experiments
   2. Ask for an account to LOG-a-TEC
   3. Use the Python scripts https://github.com/sensorlab/vesna-alh-tools to develop your own experiment / Use the web portal to run pre-defined experiments and simulations https://crn.log-a-tec.eu/

2. **On site experiments (OE)**
   1. If the experiments requires mobile equipment or a particular type of equipment to be brought on site

3. **A mix of remote and on-site experiments (ME)**
   1. A combination of the above

What types of TVWS experiments can be carried out at LOG-a-TEC?

LOG-a-TEC testbed applications in TVWS

1. **Experiments related to geolocation databases for TVWS access**
   - Determining location of transmitters
   - Verification of propagation models
   - Monitoring and verification of occupancy databases
   - Adding dynamic content

2. **Long-term statistical data gathering**

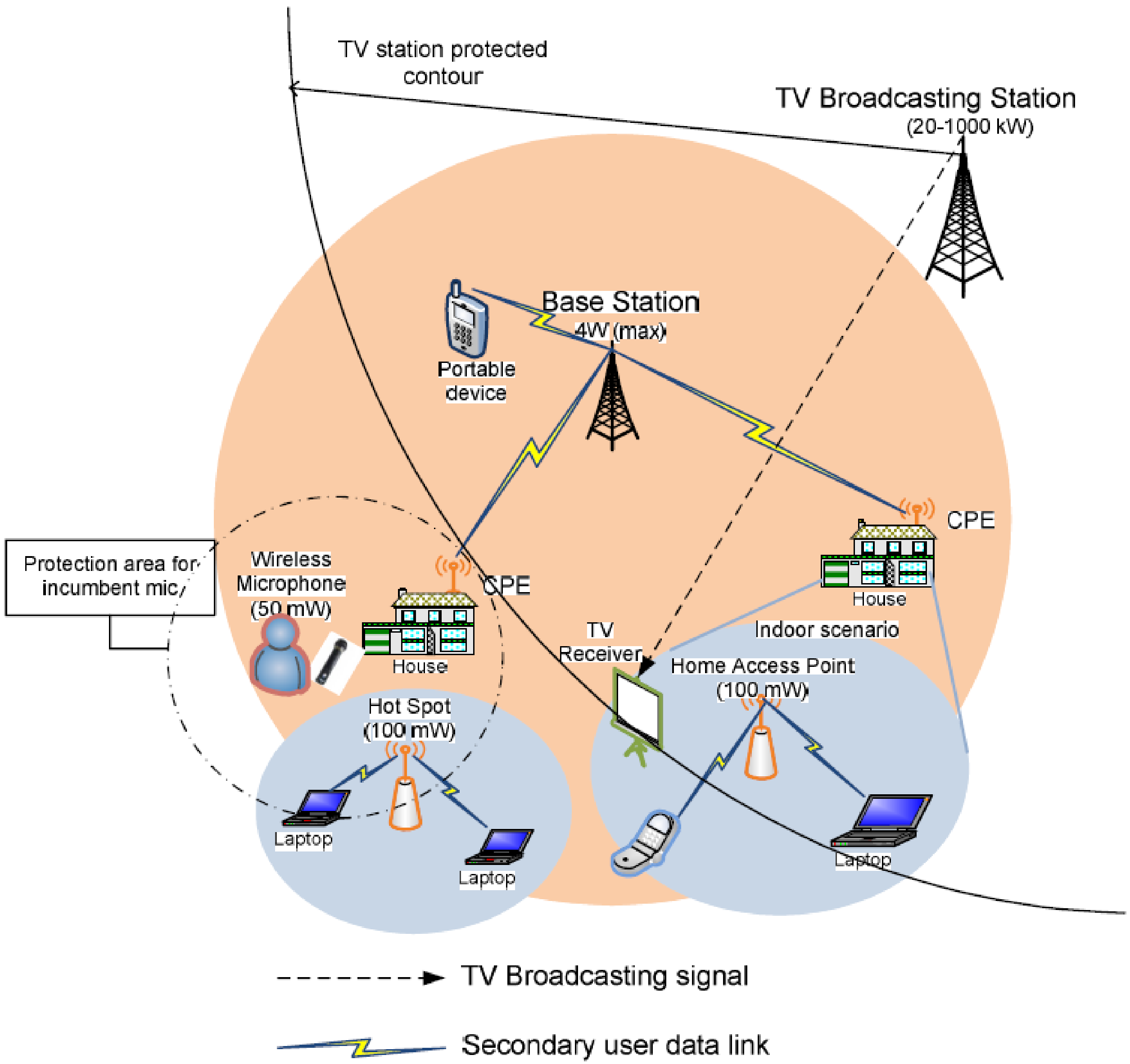
3. **Implementing spectrum sensing on low-cost devices**

Determining location of transmitters

Determining the location of mobile transmitters

- Primary (wireless microphones) and or secondary users
- Calculated using triangulation from detected signal strength from multiple receivers in the testbed
- Knowing transmitter location appropriate exclusion zone can be added to the geolocation database

Typical heterogeneous coexistence scenario

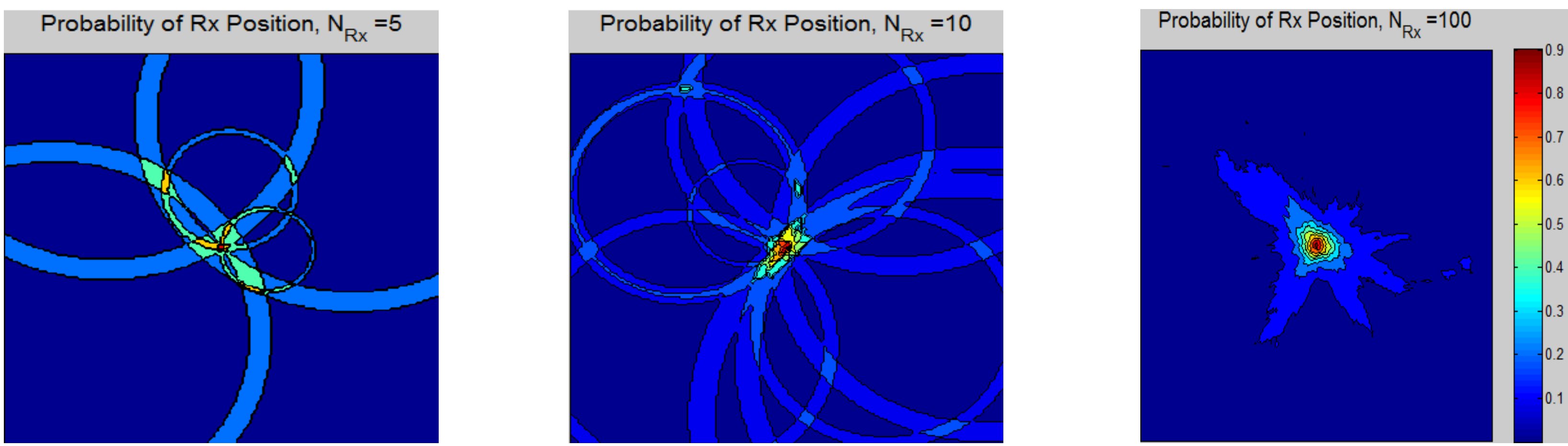


Triangulation from detected signal strength

Questions addressed

- How accurately can the location be determined?
- How does the location uncertainty depend on the number and location of sensing nodes?
- What kind of infrastructure is needed for sufficient detection?

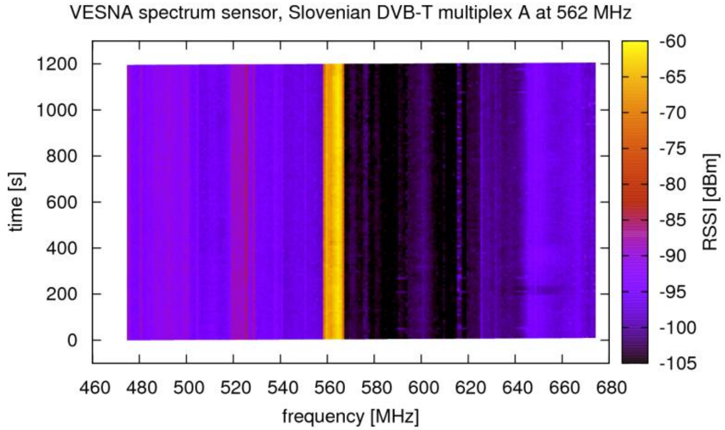
Estimation of Tx location



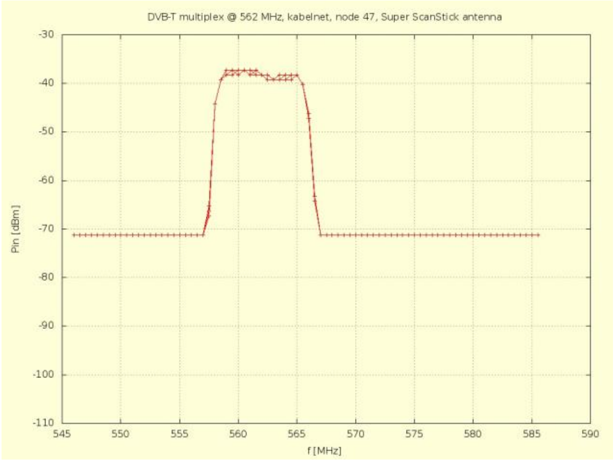
- Assuming free space loss and omnidirectional antenna
- Exclusion zone can be calculated and added to geol. database

Distributed spectrum sensing in UHF

- Using multiple VESNA sensing nodes in Log-a-tec outdoor testbed to build a **radio environment map**
- Avoiding the **hidden node problem**, minimizing primary user interference
- **Context-awareness** experiments in licensed bands
- The central Slovenian DVB-T multiplex can be clearly seen at 562 MHz



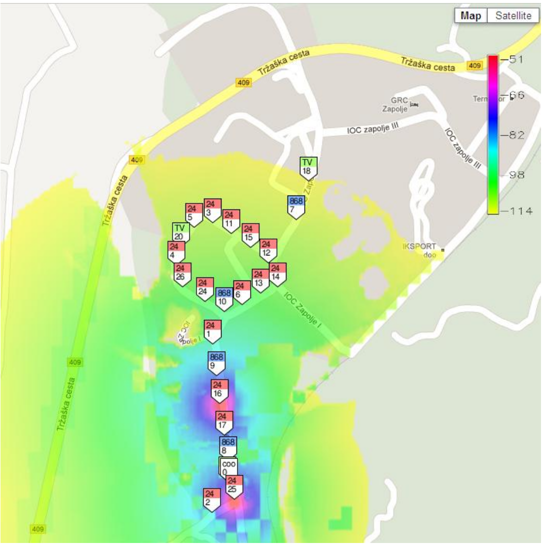
Node 47 – Super ScanStick Antenna

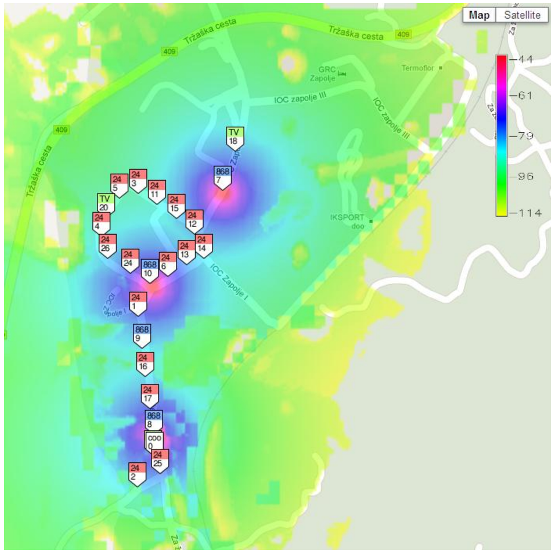


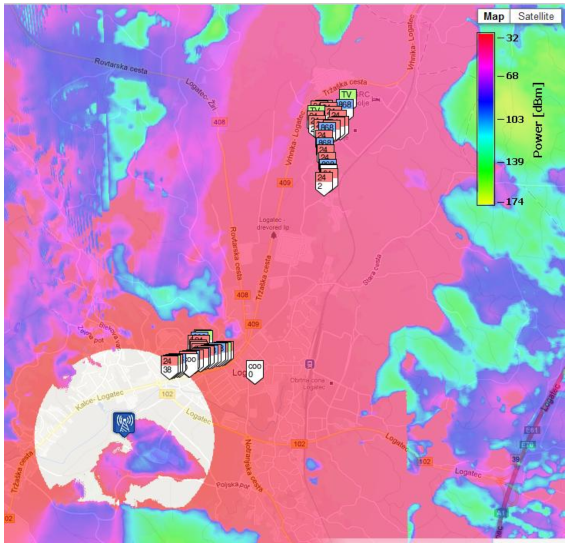
Verification of propagation models

Models are used to populate geolocation databases

- For stationary transmitters coverage can be calculated from location, power and terrain data





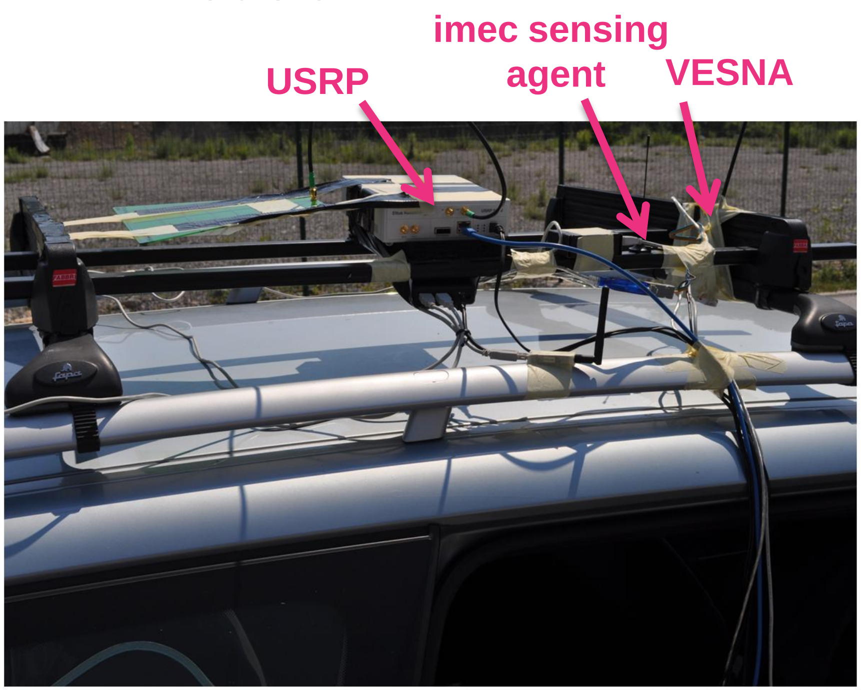


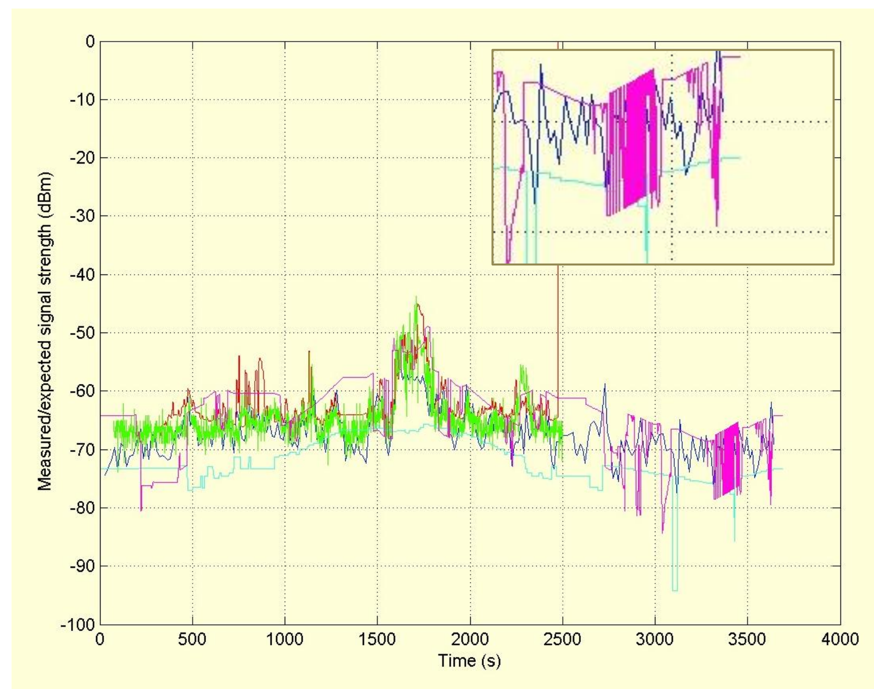
LOG-a-TEC testbed can be used to validate models

- known environment
- compare measurements to calculations
- experiment performed at CREW meeting in June 2012

Heterogeneous spectrum sensing in UHF band

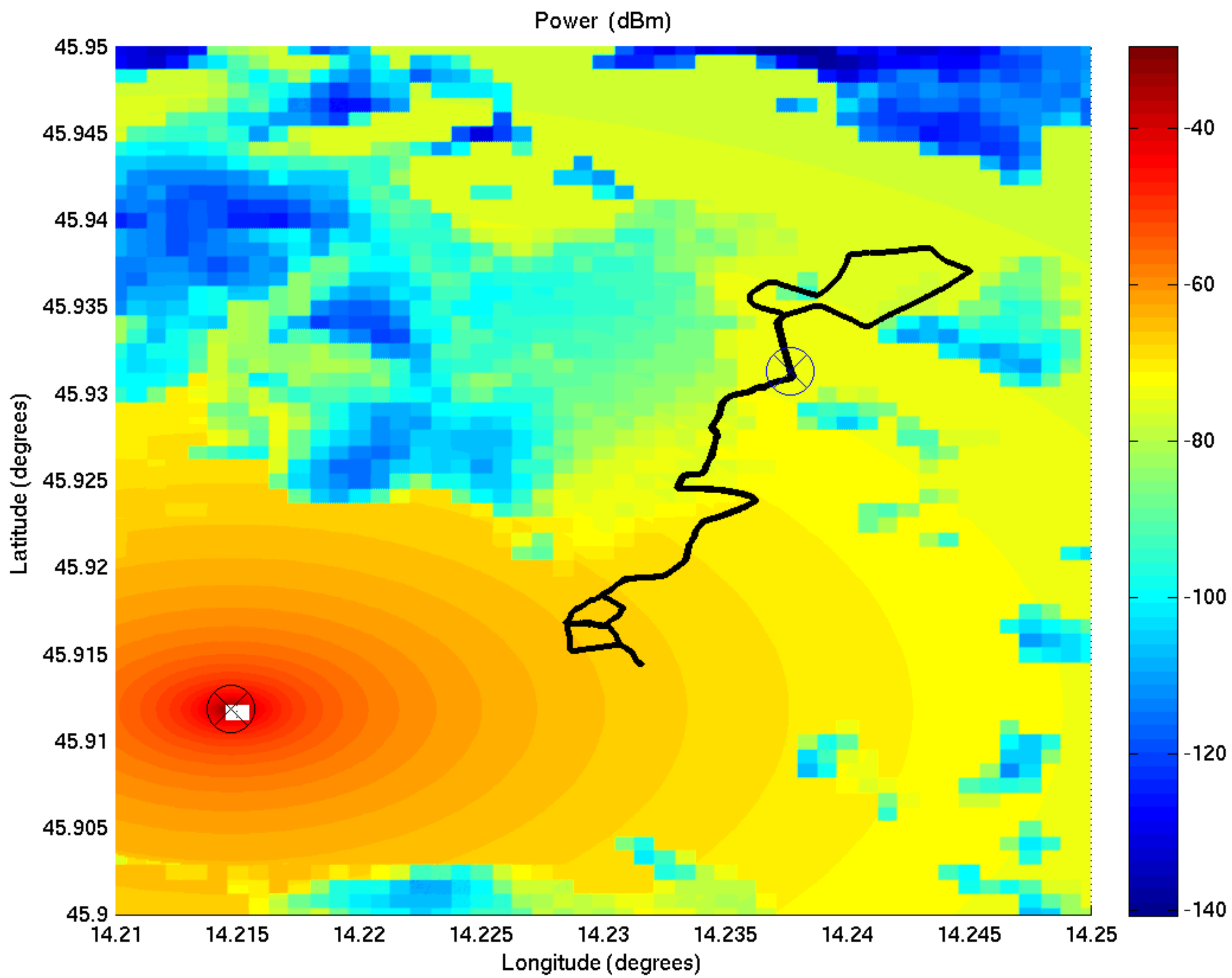
- Outdoor experiment with **relocation** of equipment
- Using **common data format** for easy processing and reporting
- Estimation of signal strength using **Longley-Rice channel model** and **GRASS-RaPlaT radio planning** tool
- **Comparison** of sensing devices to estimations from channel models



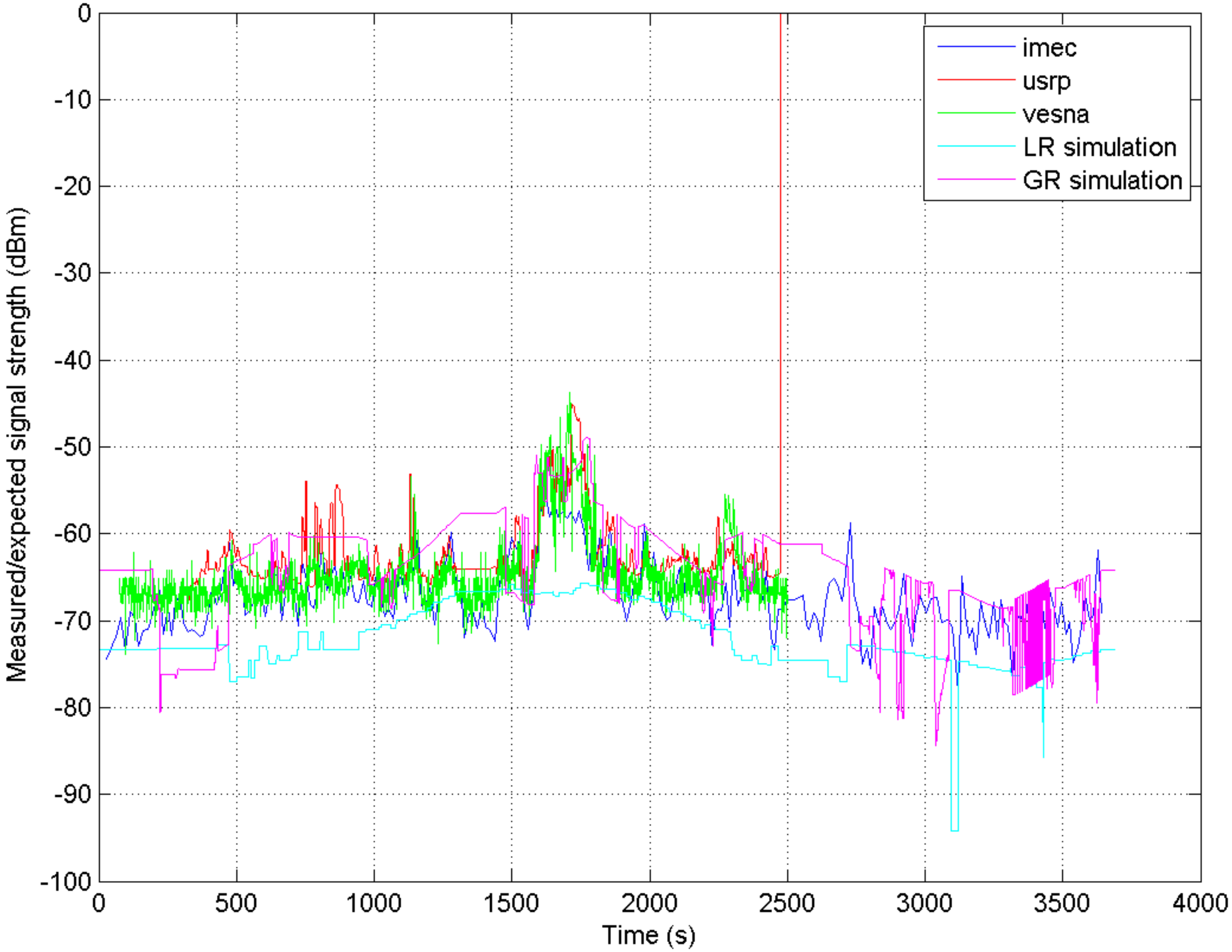


Measurement route

Route and LR-calculated power levels



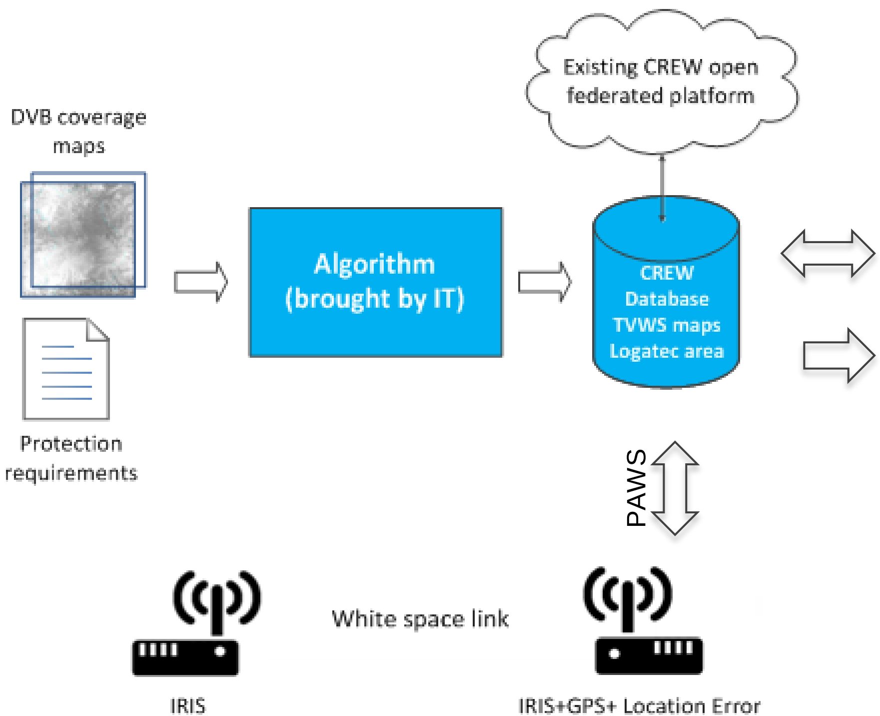
Measured vs. calculated signal strength



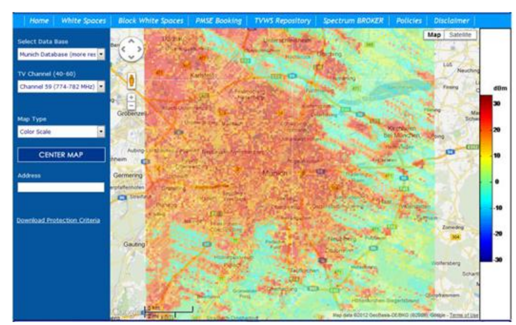
Adding dynamic content

Experiment by Instituto de Telecomunicações and CMSF-Sistemas de Informação (CREW Open Call 2)

- geolocation database assisted by a low-cost densely deployed spectrum monitoring network
- to protect dynamic primary systems, such as wireless microphones that are not registered in the database



LOG-a-TEC testbed



Logatec TVWS maps

DEMO: Coexistence in licensed and unlicensed bands in an outdoor environment:

- Game theoretic interference mitigation
- Wireless microphone emulation with VESNA

Game theoretic interference mitigation

Interference mitigation is a fundamental problem

- Individual users of spectrum want to increase their own bandwidth, minimize power consumption.
- Higher bandwidth → higher power
  → more interference to other users.

Game theoretic approach

- Users of spectrum modeled as players in a game.
- In each turn users adjust their own TX power, observing others
- What are the stable states of such a game (if any?)
- Can selfish behavior lead to fair sharing of spectrum for all?

Implementing a simple power allocation game

- A lot of power allocation games have been investigated in literature using theory and simulations.
- Missing practical experience.

Problem definition

Adopting ProActive Power Update (PAPU) algorithm[#]

- set of N players, N = {1, 2,.., N}   (a player being a Tx-Rx pair)
- and their corresponding power allocation profile
  P = {p_1, p_2, … p_N},
- the utility function of a player $u_i = log\left(1 + \frac{h_{ii}p_i}{n_0 + \sum_{j\neq i} h_{ji}p_j}\right)$

- maximize the global utility function, while minimizing the globally allocated power

$$max \sum_i u_i$$

$$min \sum_i p_i$$

[#] G. Fang et al., "Distributed Inter-Network Interference Coordination for Wireless Body Area Networks", IEEE Globecom 2010.

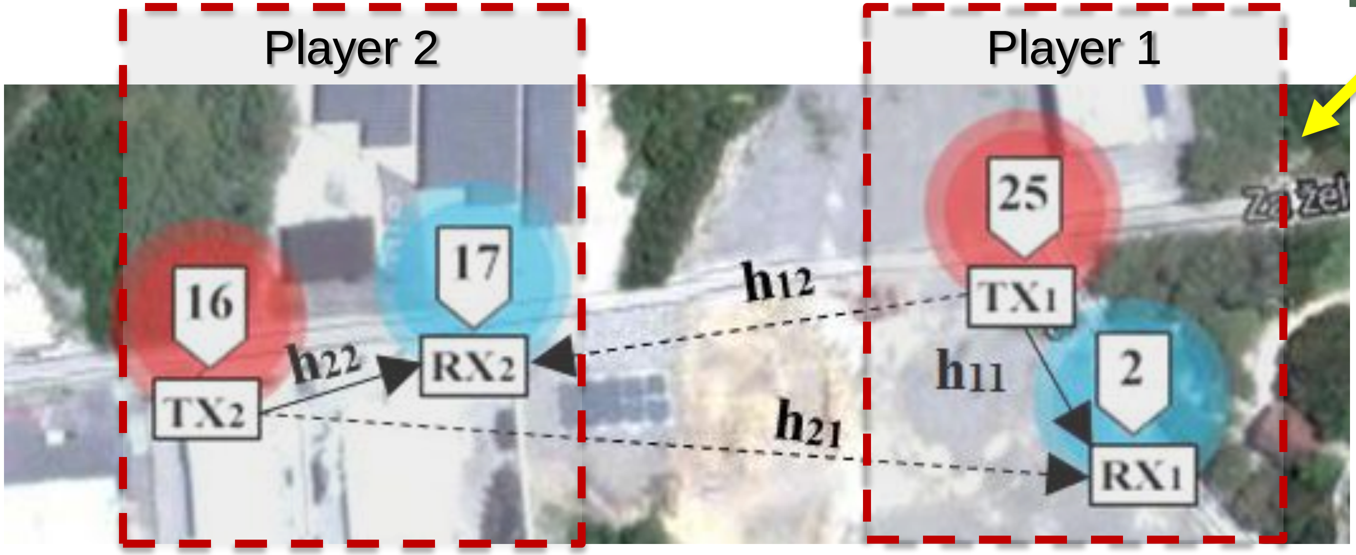
Methodology

- **Identification of experimental set-up and constraints.**
  - Theory requires that certain criteria must be met in order for the game to reach an equilibrium.
  - This limits the choice of sensor nodes that are capable of playing the game
- **Adaptation of the theoretical framework for the use in a testbed rather than in a simulation scenario.**
  - Channel gains h_{ij} are not known before-hand.
  - Only discrete TX power settings available.
- **Implementation and experimental evaluation.**

Experimental set-up

Demo set-up

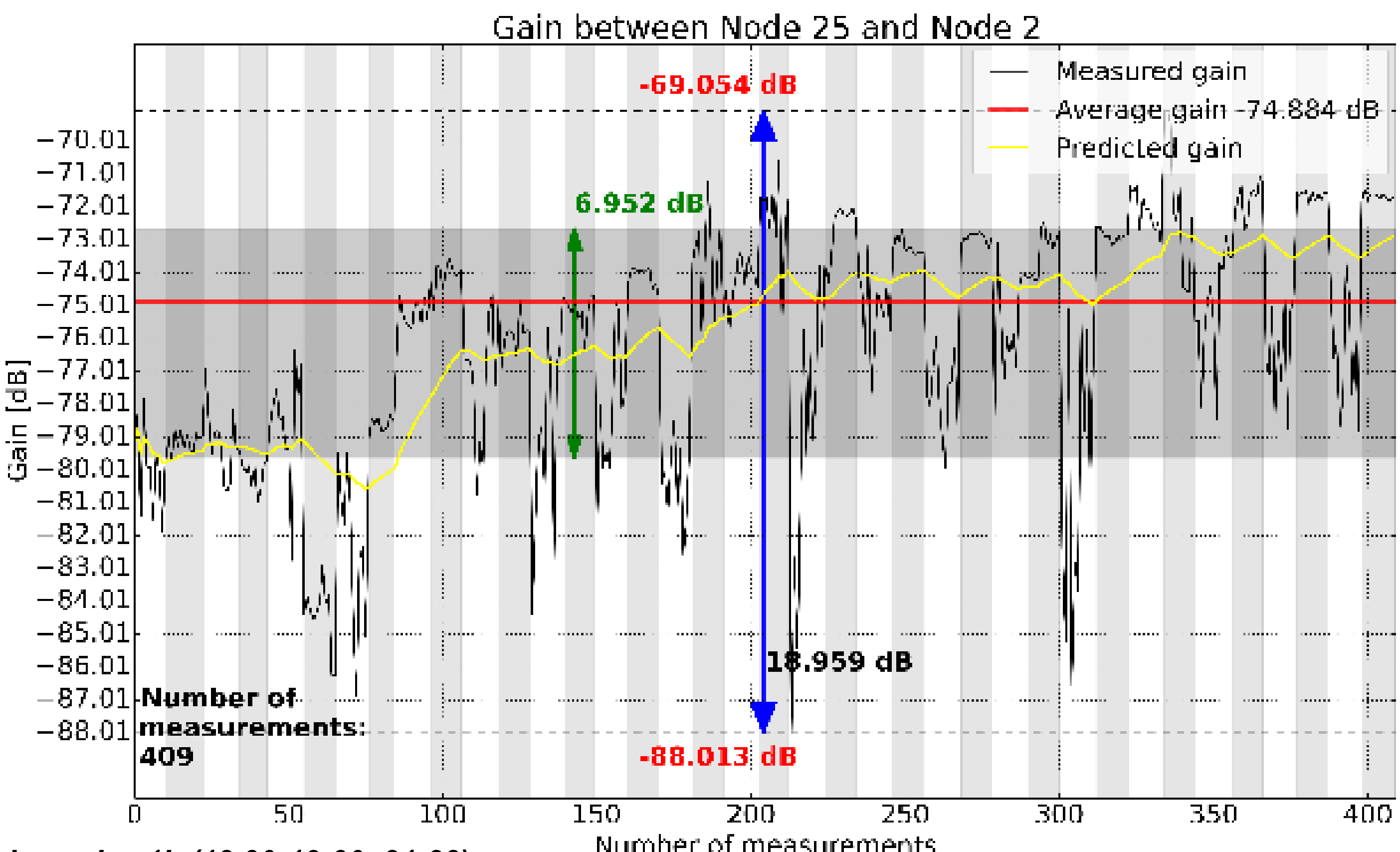
- Players are pairs of sensor nodes (TX, RX) in LOG-a-TEC testbed
- Nodes implement ProActive Power Allocation Update (PAPU) algorithm



Parameter estimation

Channel gain between pairs of nodes

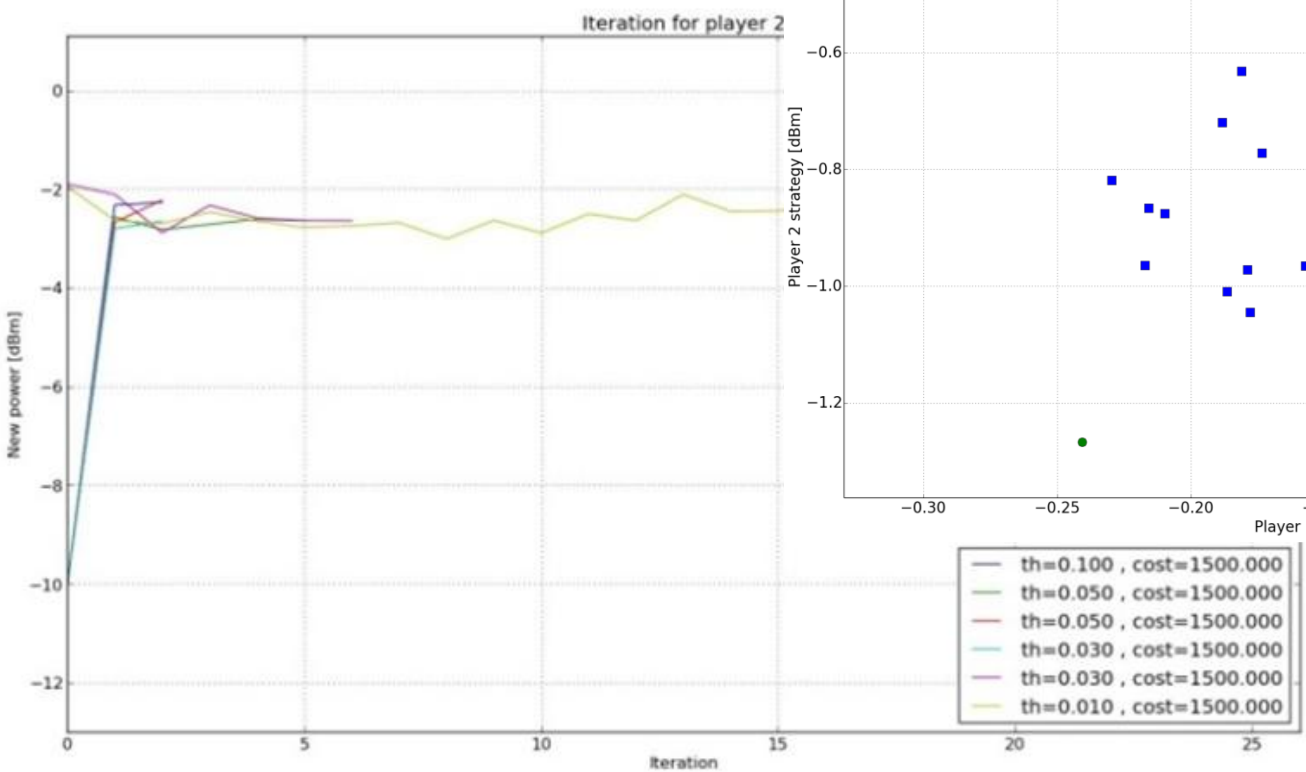
- Instantaneous → first part of demonstration
- Average *
- Estimated using the Kalman predictor * (used for final implementation)

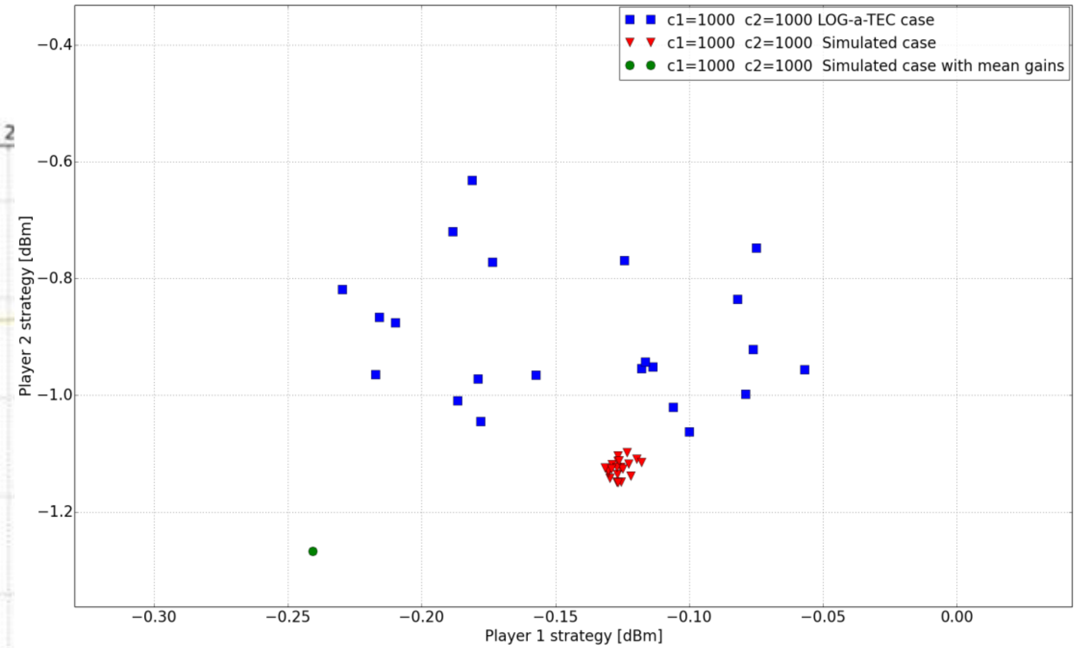


* 24 days, twice a day 1h (12.30-13-30, 21-22)

Main results of experiment

- We have shown that a game theoretic interference mitigation is feasible to evaluate on an experimental infrastructure.
- Results show that the game converges to Nash equilibria.

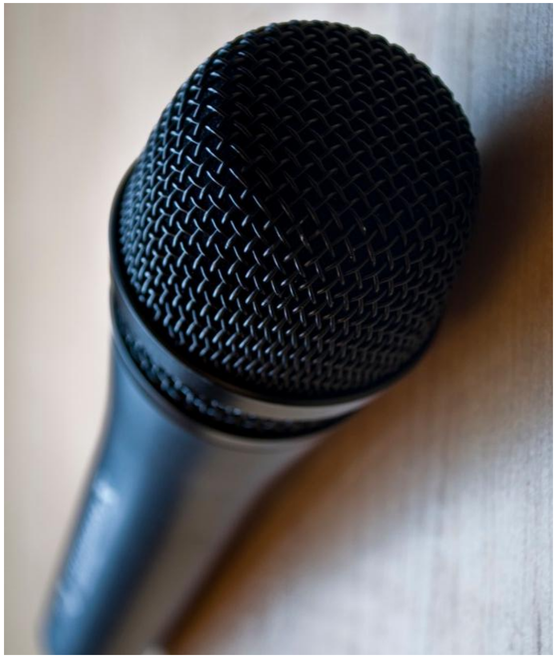




Wireless microphone emulation with VESNA

PMSE are an important spectrum sensing target

- Wireless microphones are a primary user.
- Secondary users need spectrum sensing to determine exclusion zones.
- Ability to reproduce wireless microphone transmissions on VESNA simplifies remote experiments



Context of the experiment

IEEE wireless microphone simulation method

- Three reference signals approximating typical use cases
- Carrier modulated with a sinusoidal signal

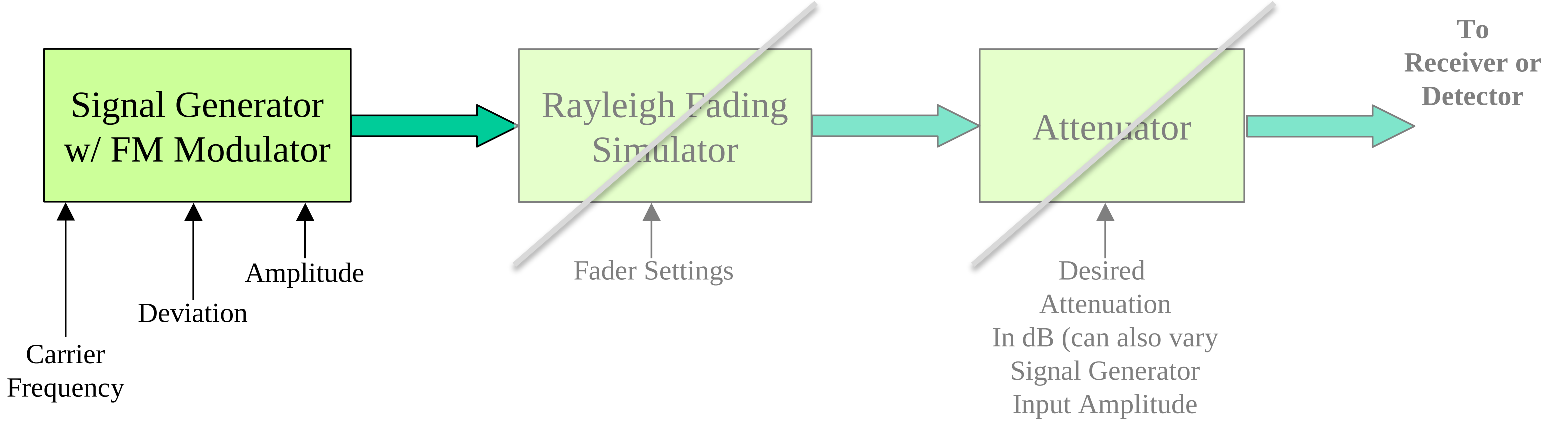
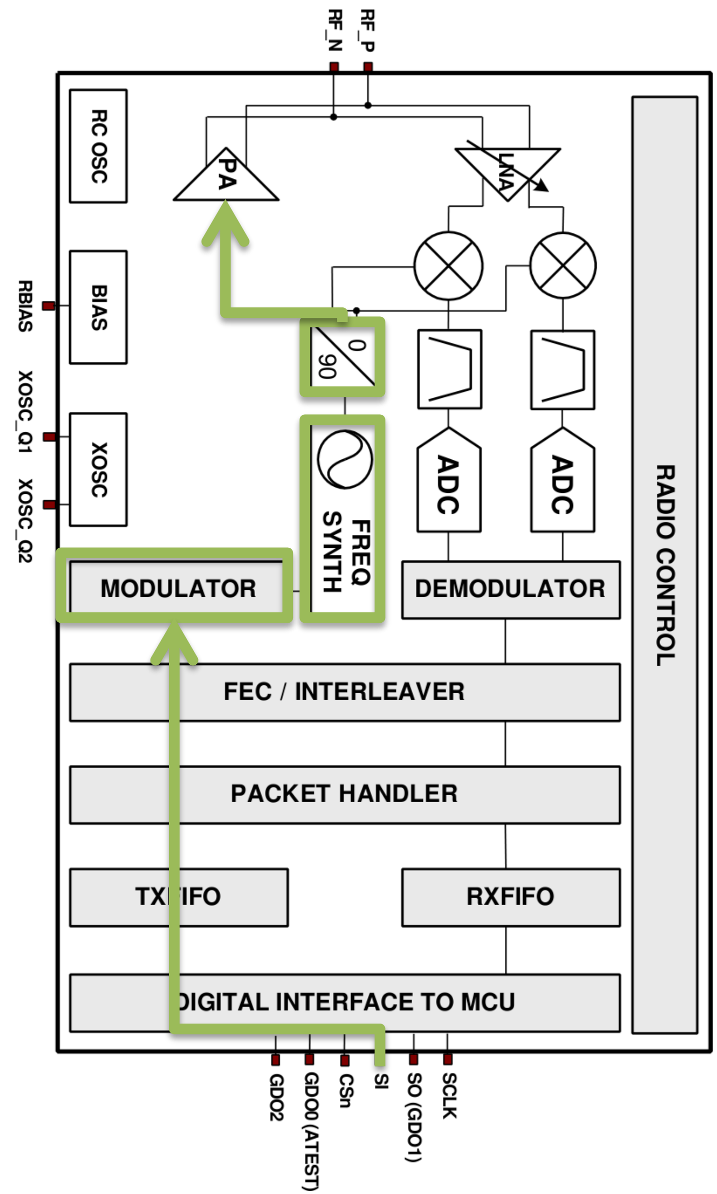


Table 1. FM parameters and bandwidth for each operating situation

Operating mode	A_m (a.u.)	f_m (kHz)	Δf (kHz)	β	$B_{90\%}$ (kHz)
Silent	1	32	5	0.16	37
Soft speaker	1	3.9	15	3.85	19
Loud speaker	1	13.4	32.6	2.43	46

Context of the experiment

- **Emulating PMSE on VESNA nodes in LOG-a-TEC**
  - Low-power sub-1 GHz transceivers on VESNA do not implement an analog FM modulator.
  - Solution is to generate a baseband signal in software
  - Use hardware FSK block for frequency modulation



Storyline of demo

Demo set-up

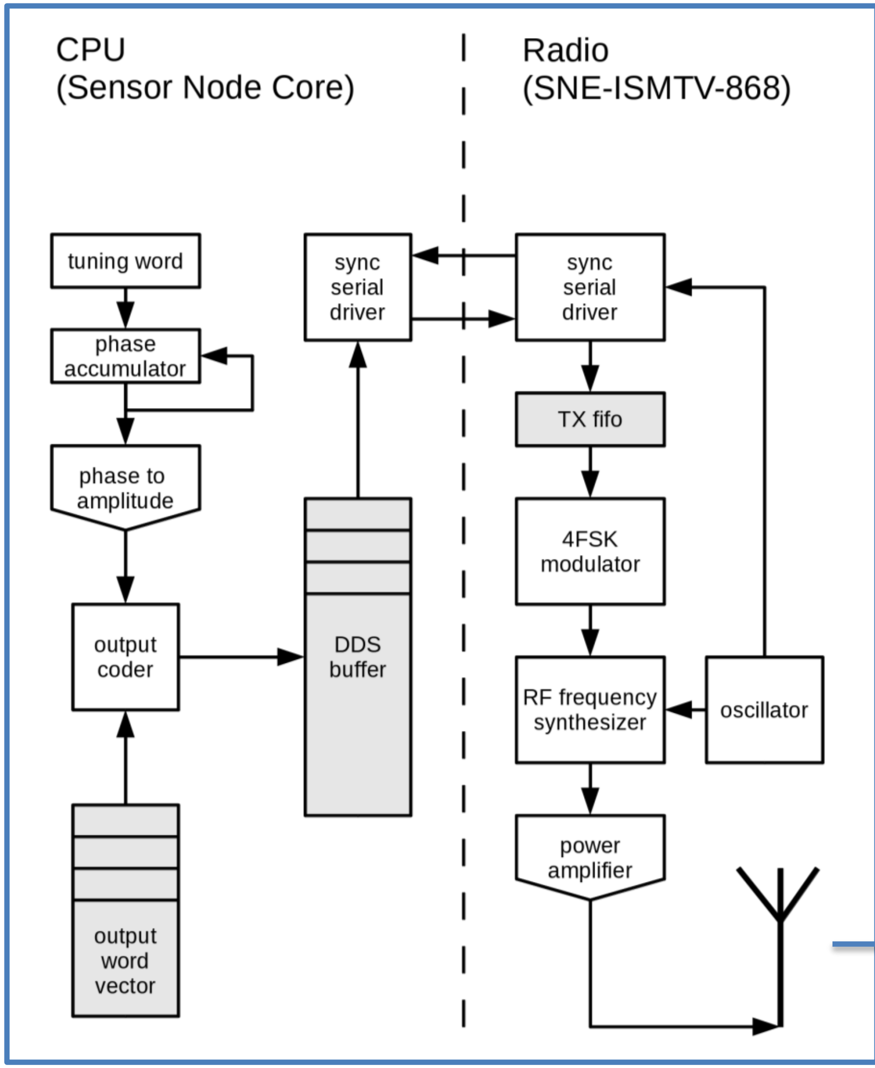
- A VESNA node with SNE-ISMTV radio is emulating a wireless microphone transmission with the „loud speaker“ profile.
- The signal is received through a coaxial cable by an USRP.
- A spectrum similar to the ideal IEEE microphone simulation profile can be seen on the screen.

IEEE PROFILE
„LOUD SPEAKER“

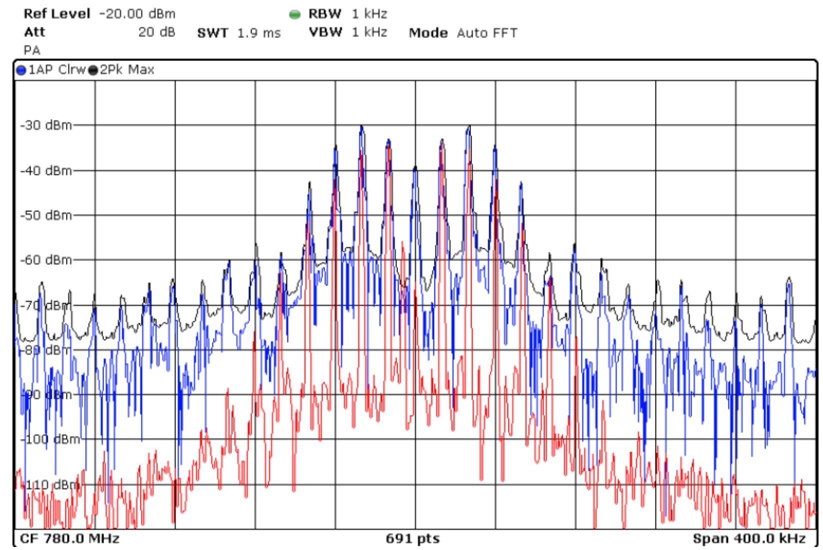
- VESNA node can also be programmed to synthesize an arbitrary waveform.
- USRP is set up to simulate an FM receiver.
- Music is heard from laptop speakers.

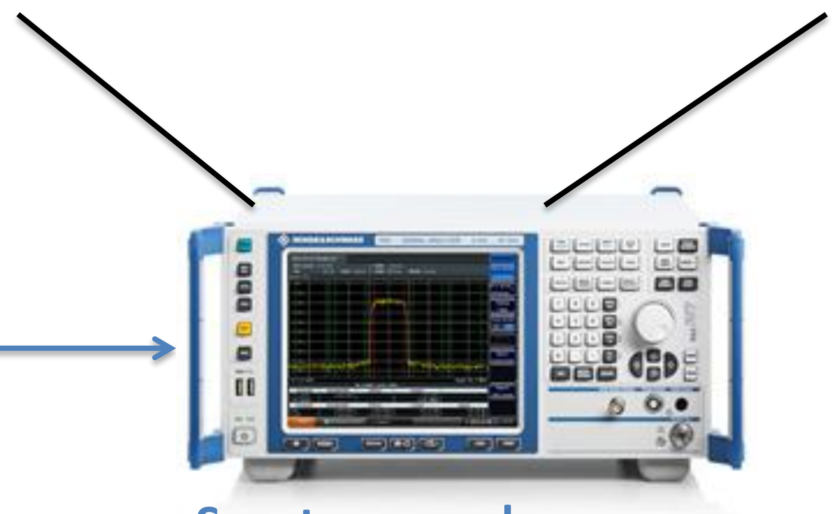
SYNTHESIZED
AUDIO WAVEFORM

Storyline of demo



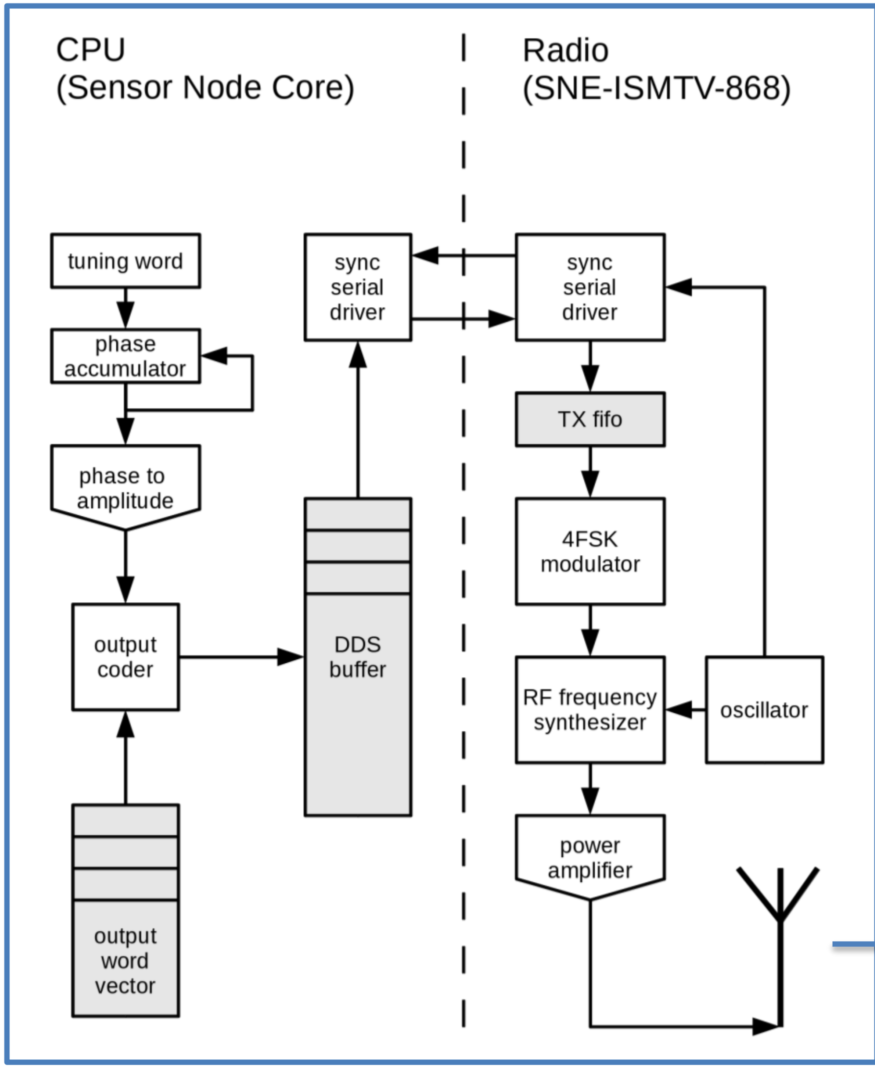
VESNA sensor node





Spectrum analyzer

Storyline of demo

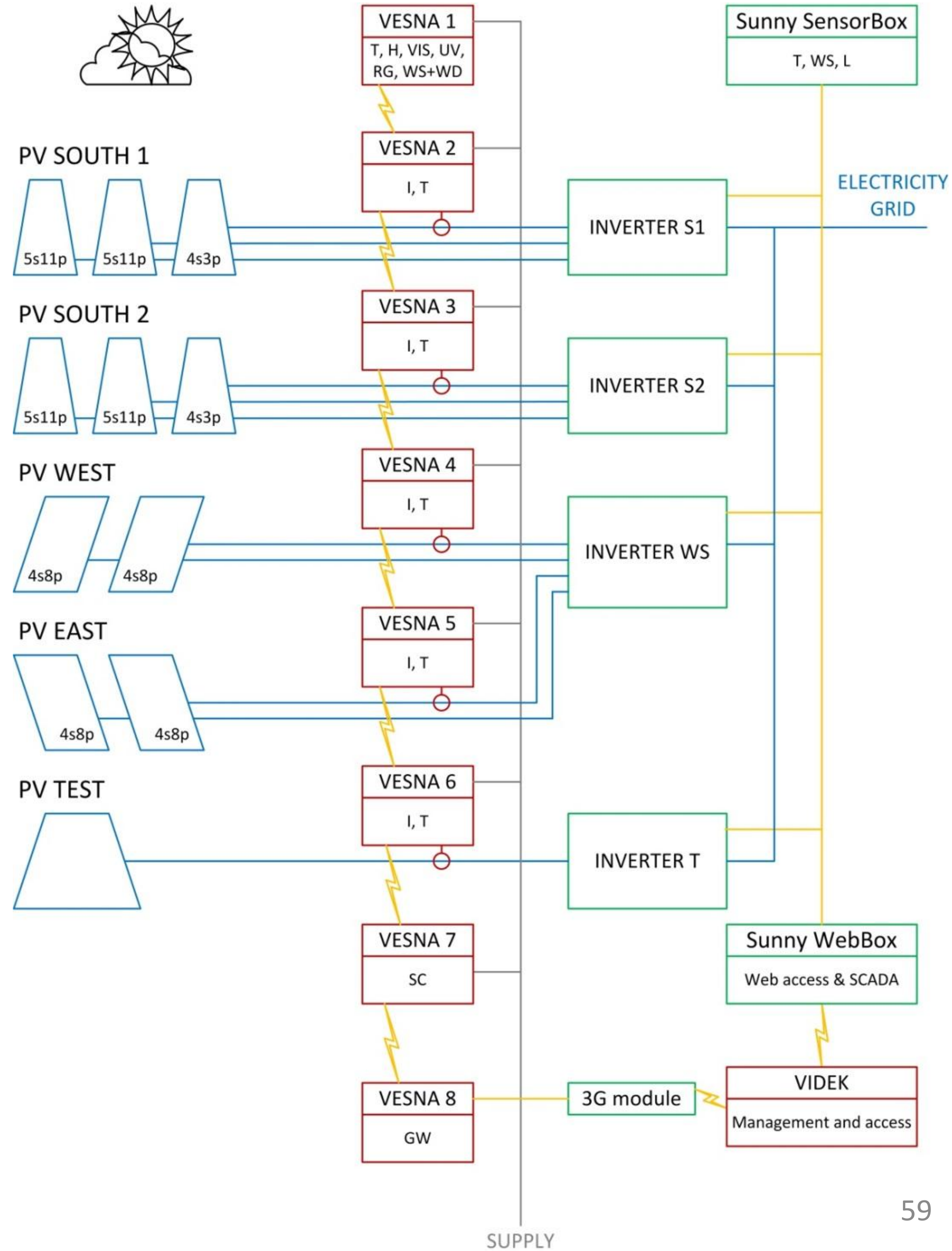


VESNA sensor node

Wireless microphone receiver

Photovoltaics system monitoring

- **5 sets of PV panels**
  - S, E, W orientation
  - Amorphous & crystalline silicon
- **7 VESNA sensor nodes**
  - Weather
  - Temp. + current
  - Reference solar cell
- **1 VESNA GW**
  - 3G radio module
- **ZigBee sensor network @ 868 MHz**



Air quality monitoring

- **FP7 CITI-SENSE- Development of sensor-based Citizens' Observatory Community for improving quality of life in cities**
  - Urban quality
  - Public spaces
  - Schools indor

  Indoor/outdoor air quality, weather, radiation, noise level …

- **VESNA**
  - Gas sensors - CO_2, CO, Nox, VOC
  - Environmental sensors – air pressure, temperature, humidity, luminence, weather
  - Noise sensor
- **LOG-a-TEC testbed**
  - Trial and validation of VESNA based prototype system
  - Final pilot system deployed in Ljubljana (+ 8 EU cities)

CREW

SEVENTH FRAMEWORK PROGRAMME

Thanks for attention!

matevz.vucnik@ijs.si

http://sensorlab.ijs.si/

SensorLab
Jožef Stefan Institute