Local and Low-Cost White Space Detection

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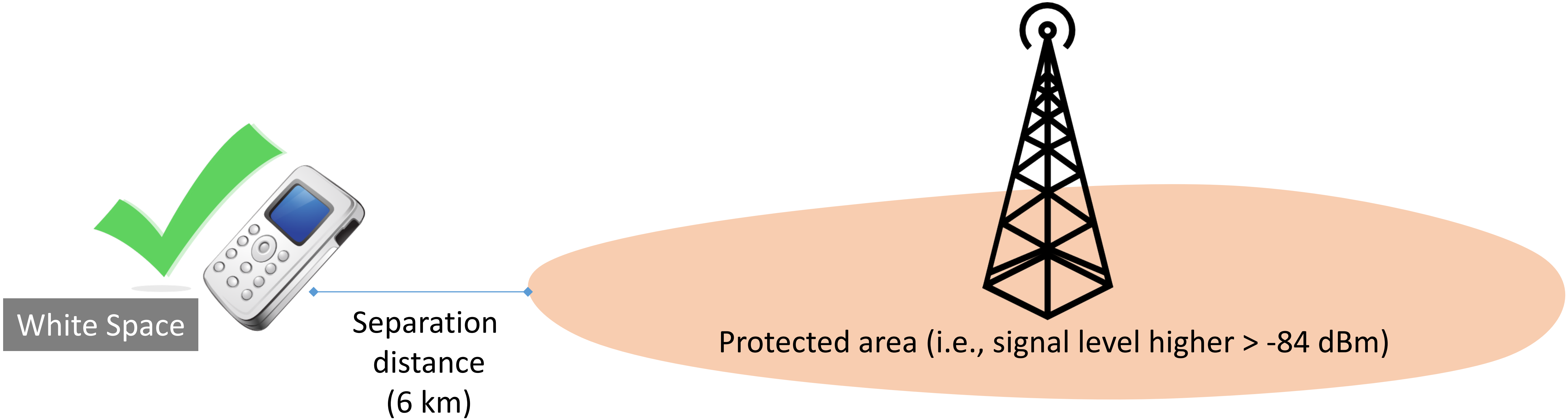
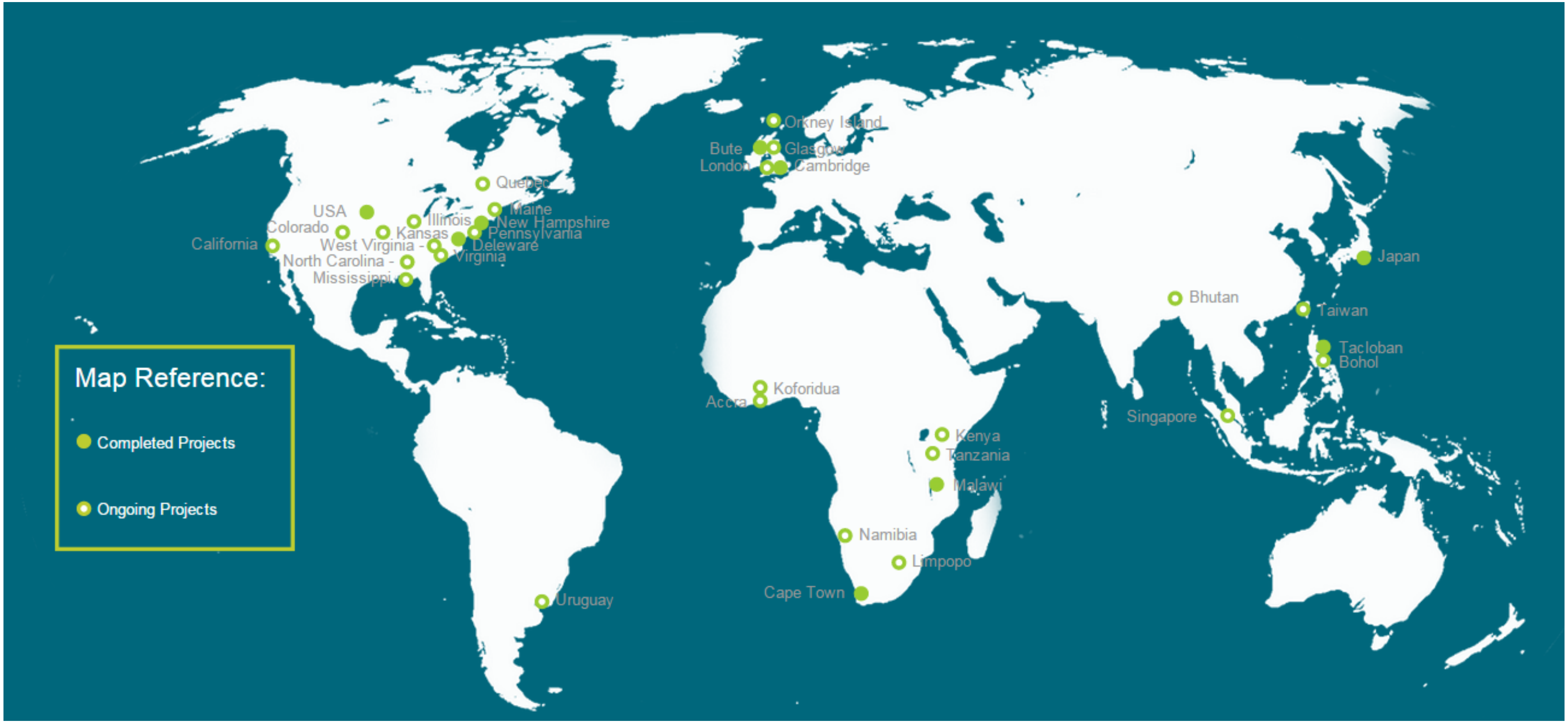
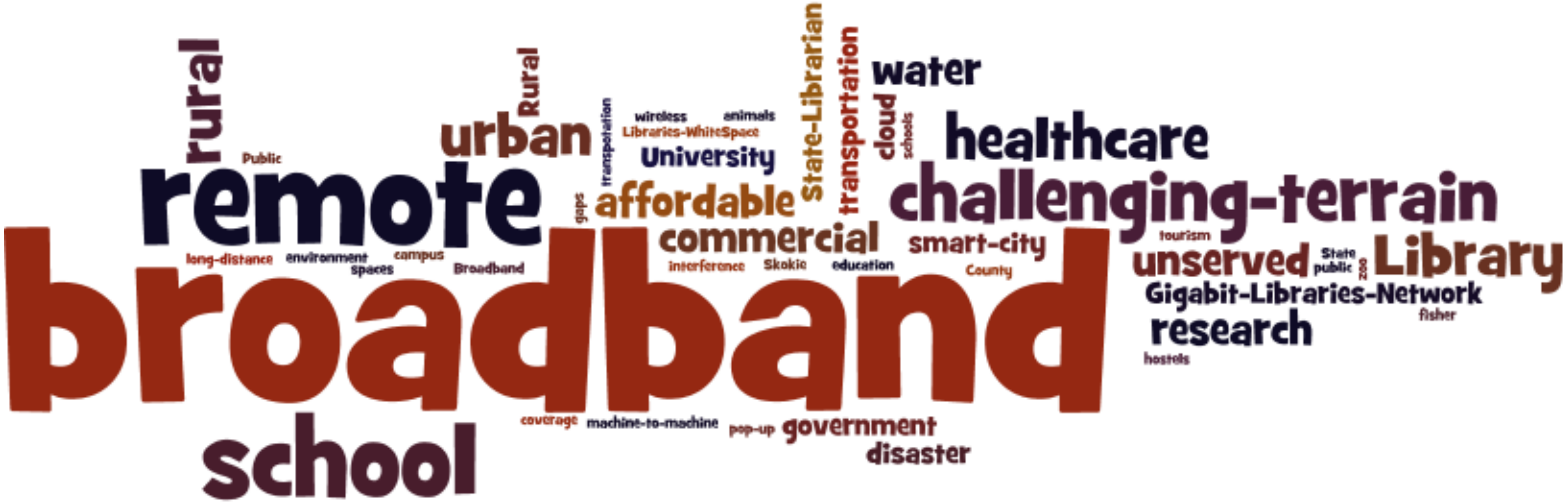
White Space Definition

- A vacant UHF and VHF channel, determined by two factors
  - Outside the **protected area** of a TV station where the TV signal is higher than -84 dBm
  - With an additional ***separation distance*** of 6 kilometers





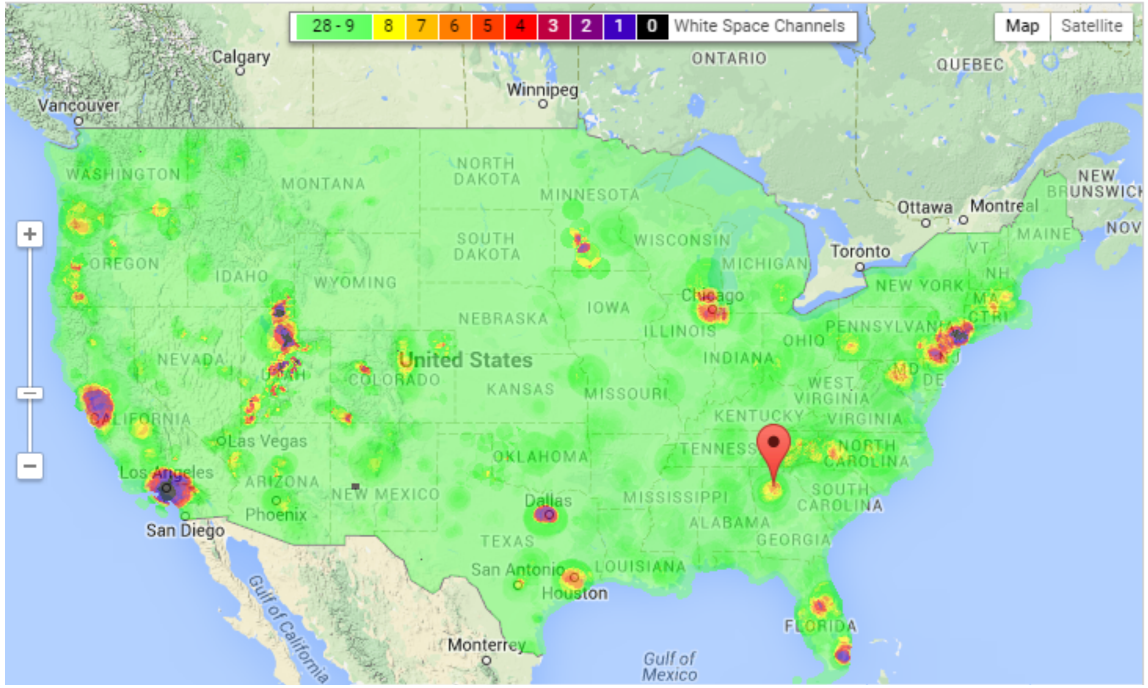
Commercial deployments, pilots, and trials deployments of White Space Networks all over the world according to Dynamic Spectrum Alliance



Applications tested on current deployments of White Space Networks worldwide

White Space Detection

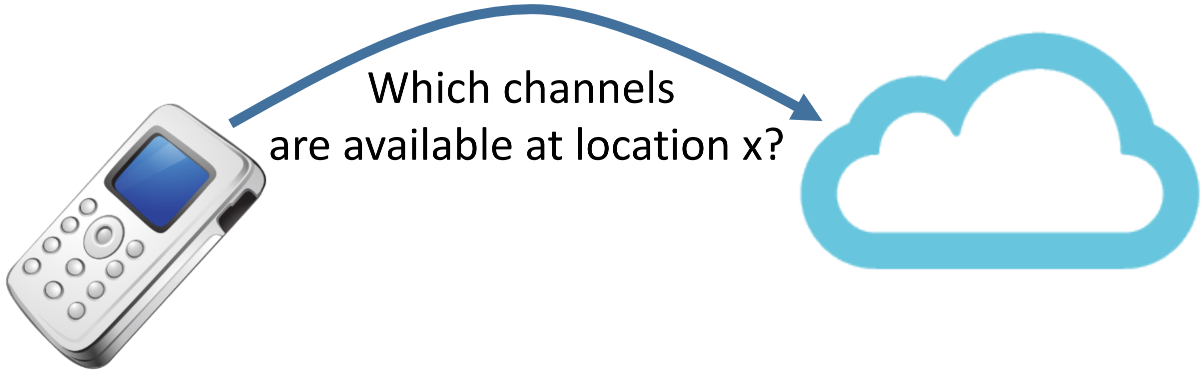
- Detection is one of the most challenging tasks in white space operation
    1. Spatial variability
    2. Temporal variability
    3. Strict requirement of spectrum incumbents protection
    4. Lack of white spaces in urban scenarios



Visualization from Google Spectrum Database of White Space Availability in the US

White Space Detection Approaches
#1 Spectrum Databases

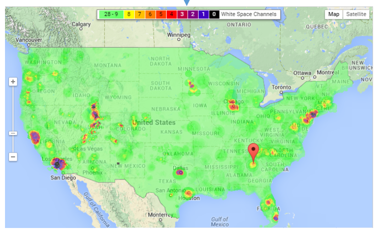
- Query a central spectrum database (e.g., Google spectrum database)



White Space Detection Approaches
#1 Spectrum Databases

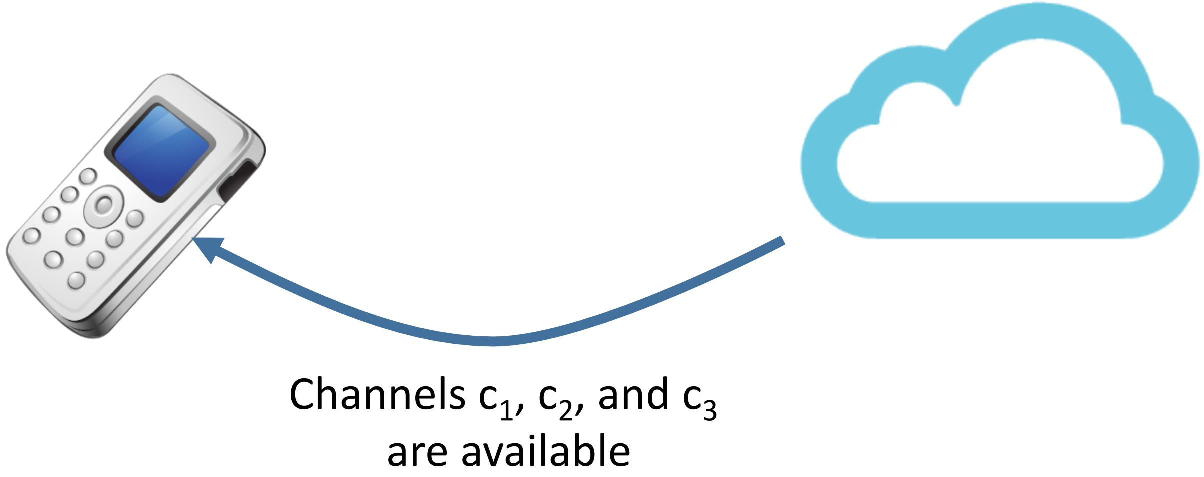
- Query a central spectrum database (e.g., Google spectrum database)
  - Database rely on propagation models to determine coverage areas of all TV towers

Look up propagation model results for that specific location



White Space Detection Approaches
#1 Spectrum Databases

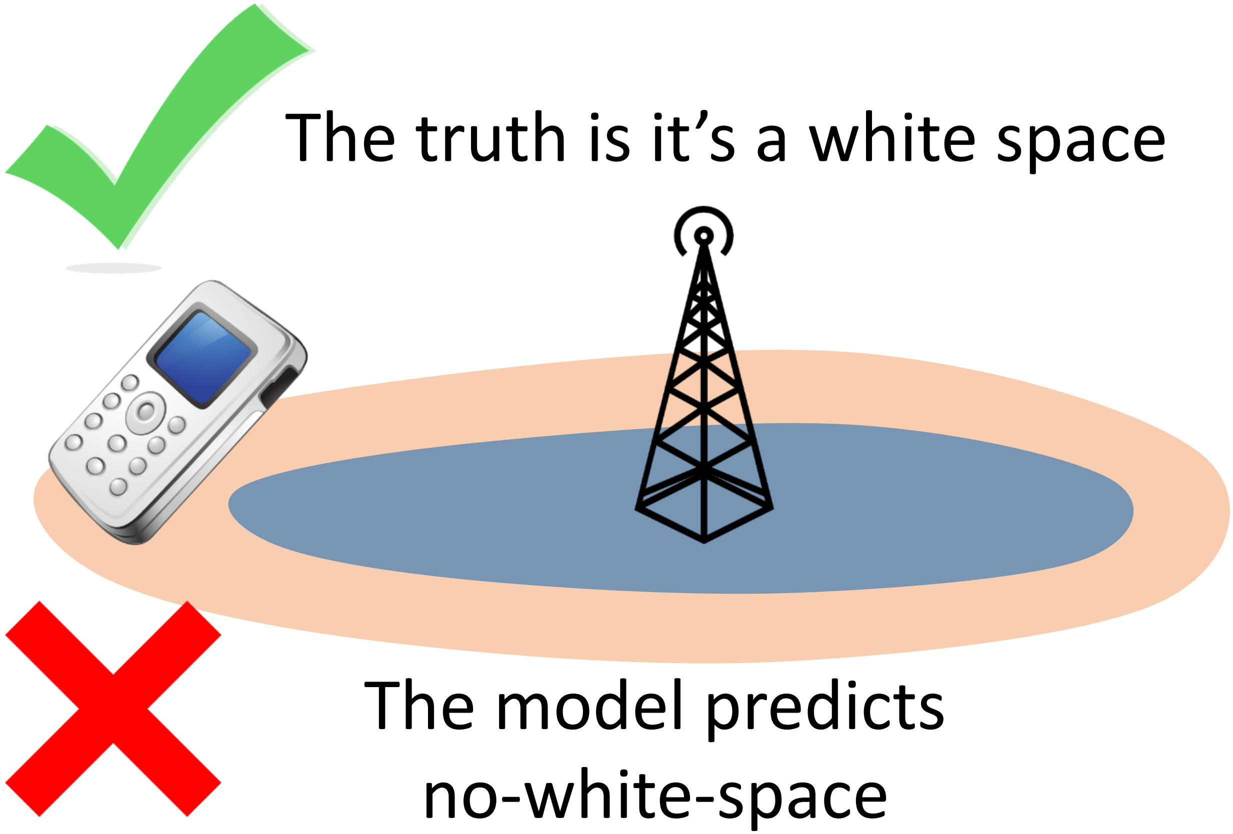
- Query a central spectrum database (e.g., Google spectrum database)
  - Database rely on propagation models to determine coverage areas of all TV towers
  - Database replies with available channels for only location x



White Space Detection Approaches

#1 Spectrum Databases - Drawbacks

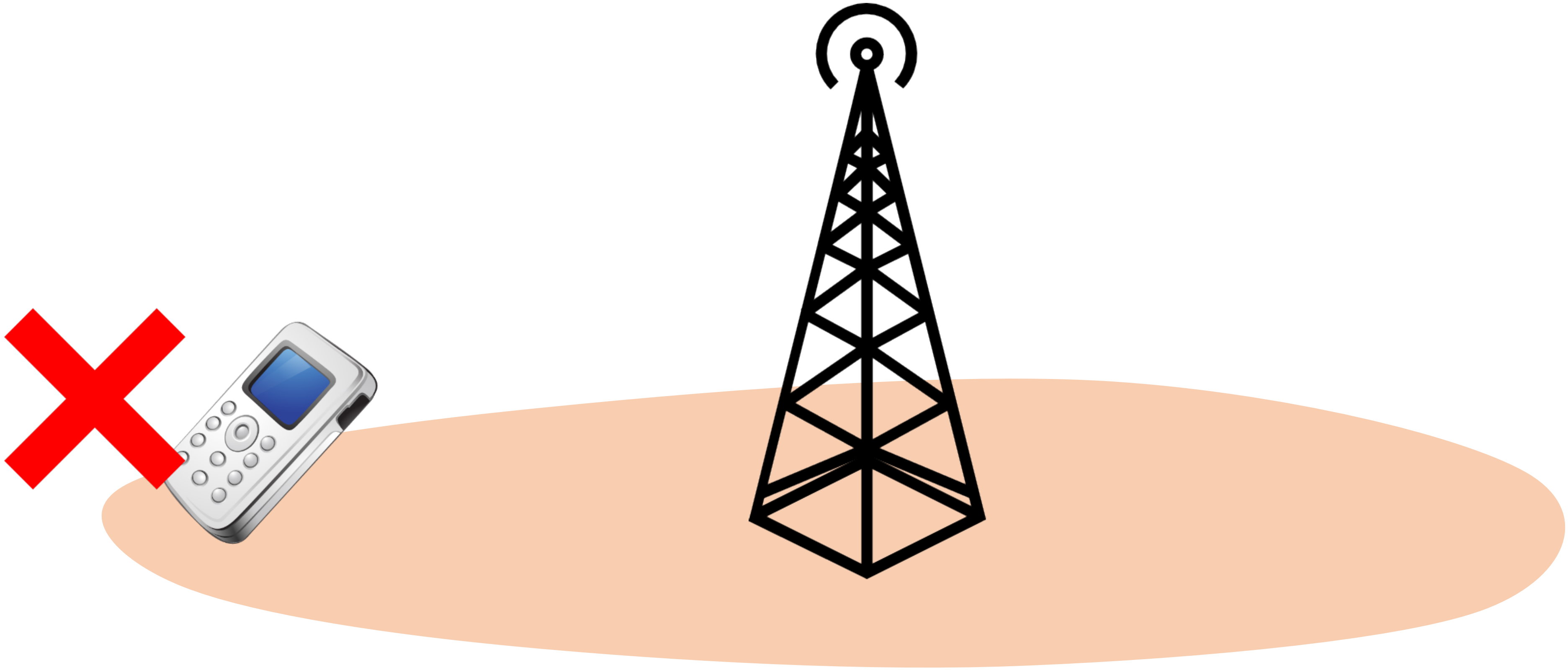
- Propagation models are generic and do not account for characteristics of different areas
  - Models tend to overestimate coverage area of TV towers
  - Relying on models tend to be over protective of TV towers resulting fewer available white spaces



White Space Detection Approaches

#2 Spectrum Sensing

- Scan TV frequencies for TV channels



White Space Detection Approaches
#2 Spectrum Sensing

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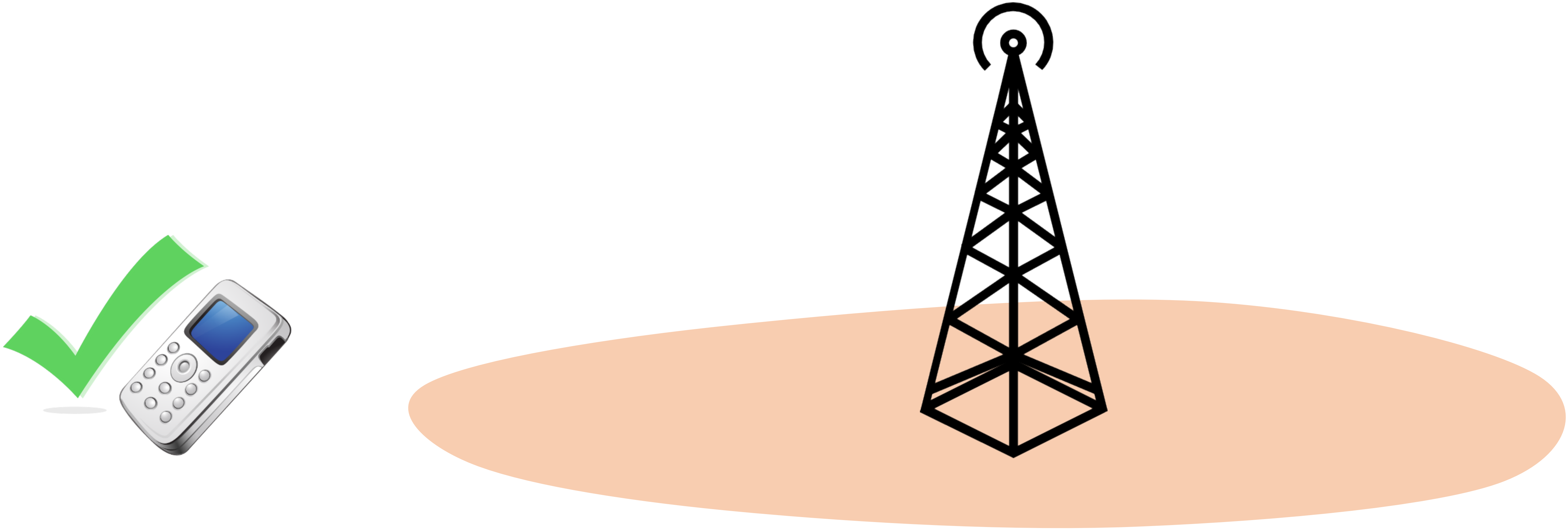
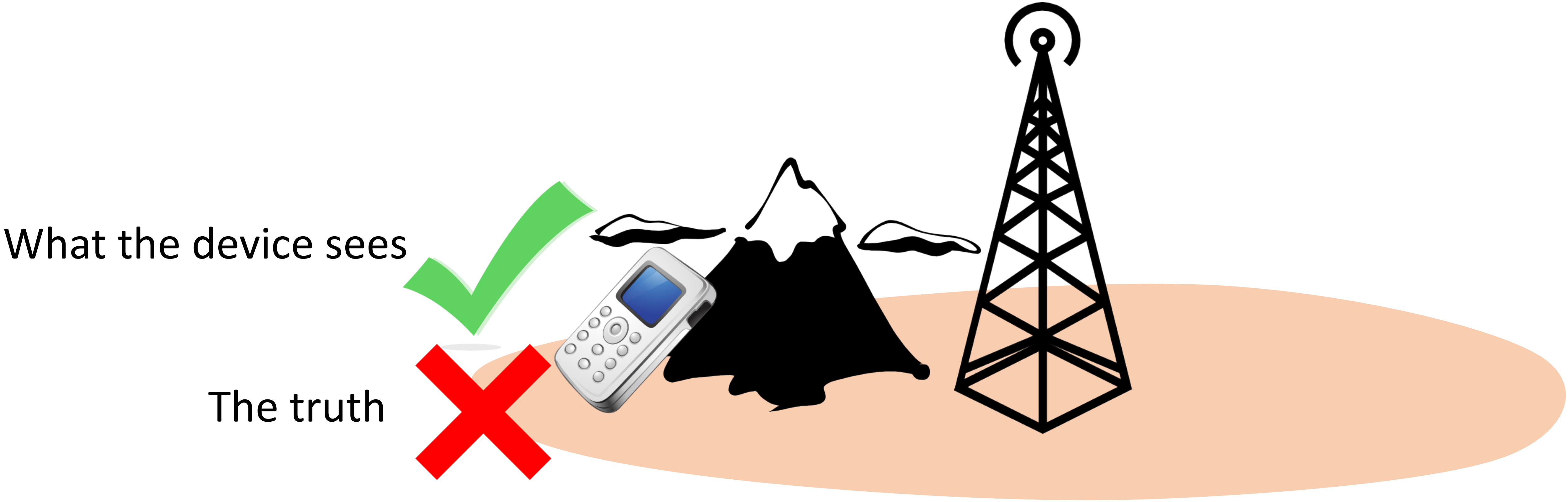


White Space Detection Approaches

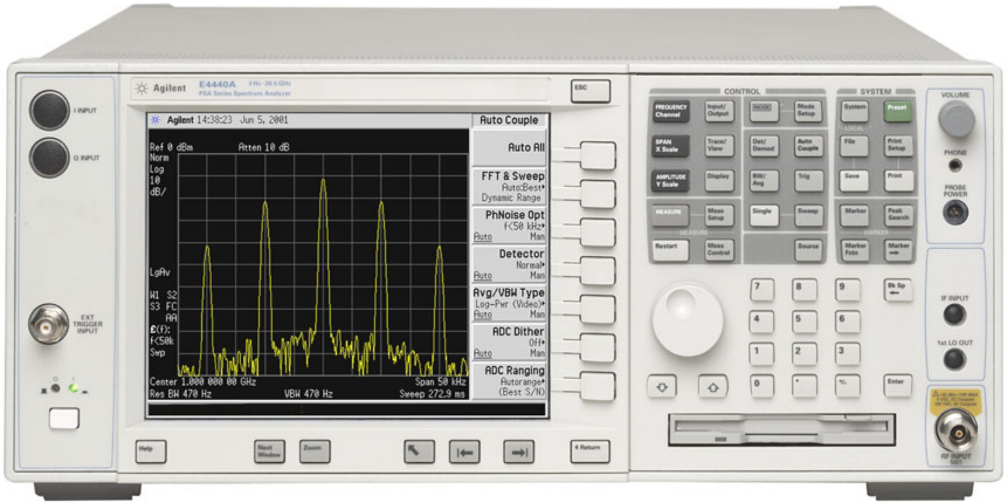
#2 Spectrum Sensing - Drawbacks

- Hidden node cases can lead to false predictions



White Space Detection Approaches
#2 Spectrum Sensing - Drawbacks

- Hidden node cases can lead to false predictions
- Spectrum sensing is required to be done with very high sensitivity that can only be detected using a ***Spectrum Analyzer***
  - *Heavy*
  - *Expensive*
  - *Requires an expert to operate it*



Our Goal

Allow this setup to detect white spaces locally and accurately

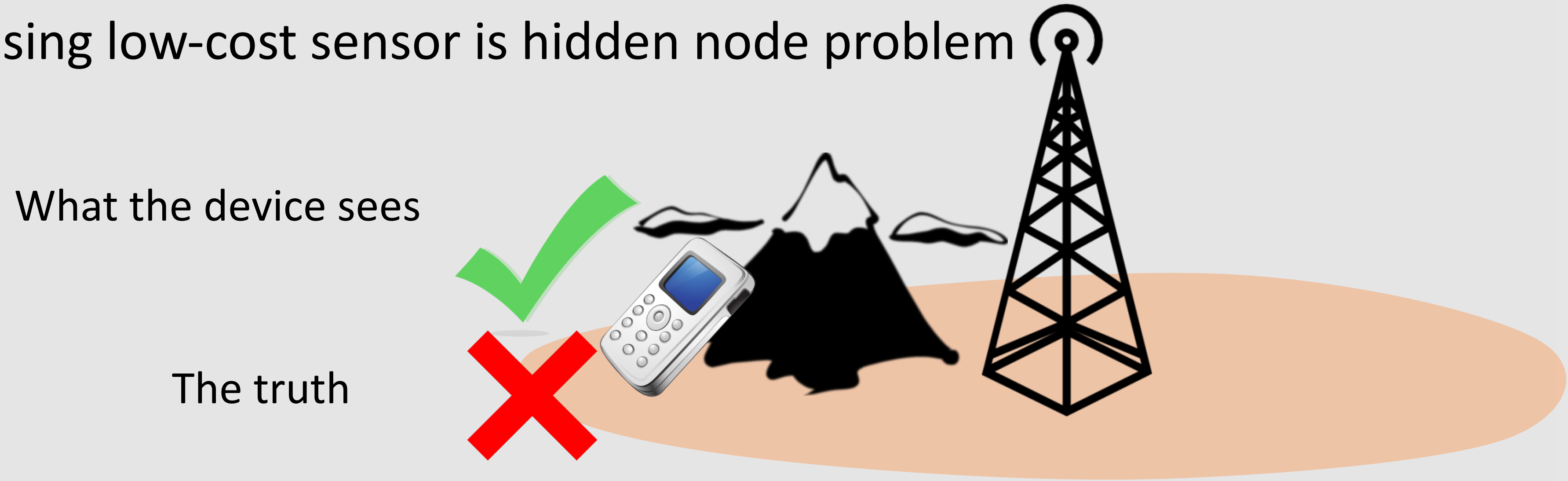
A phone connected to a TV dongle

Outline

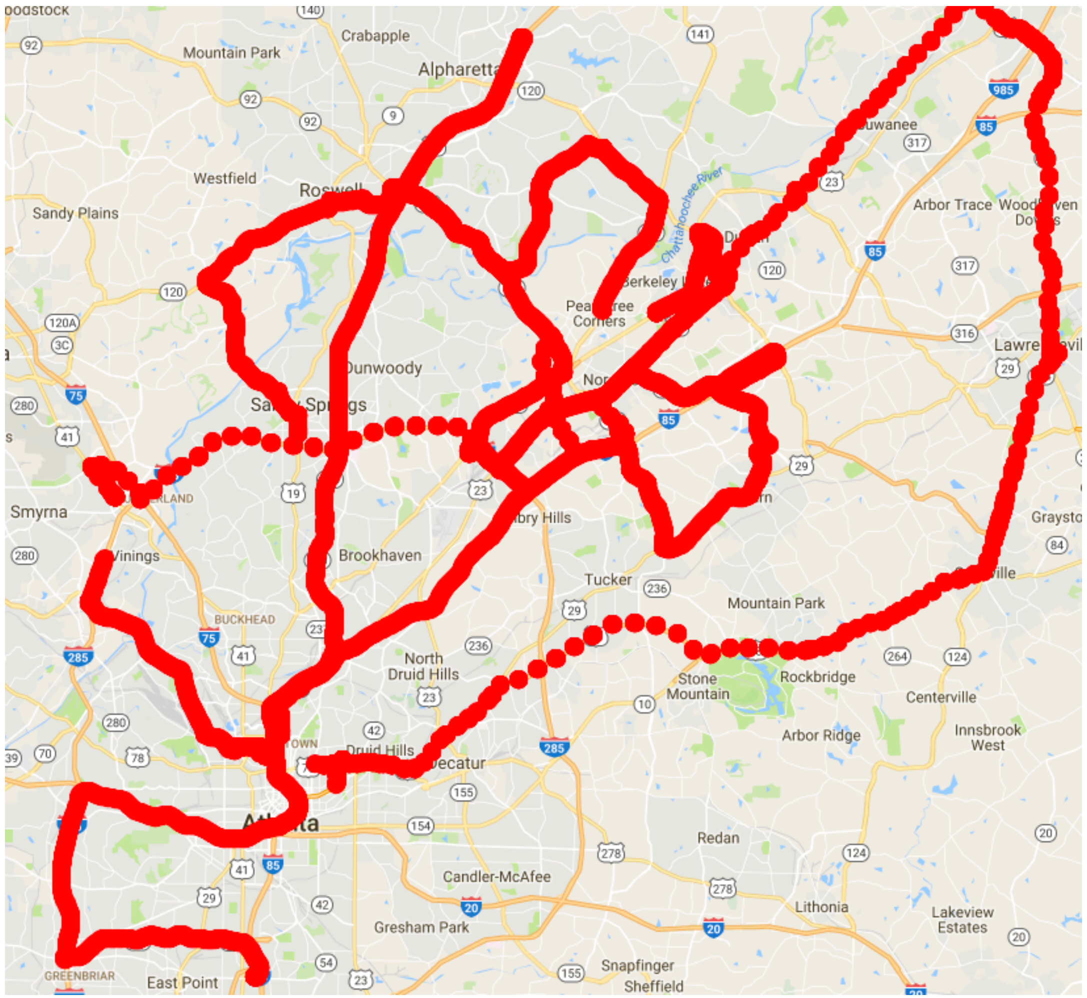
- How viable are low-cost sensors for white space detection?
  - Measurement study methodology
  - Measurement study findings
- White space Adaptive Local DetectOr (WALDO)
  - Intuition
  - Model Construction
  - Architecture
- Evaluation
- Conclusion

How viable are low-cost sensors for white space detection?

- Main challenge of using low-cost sensor is hidden node problem



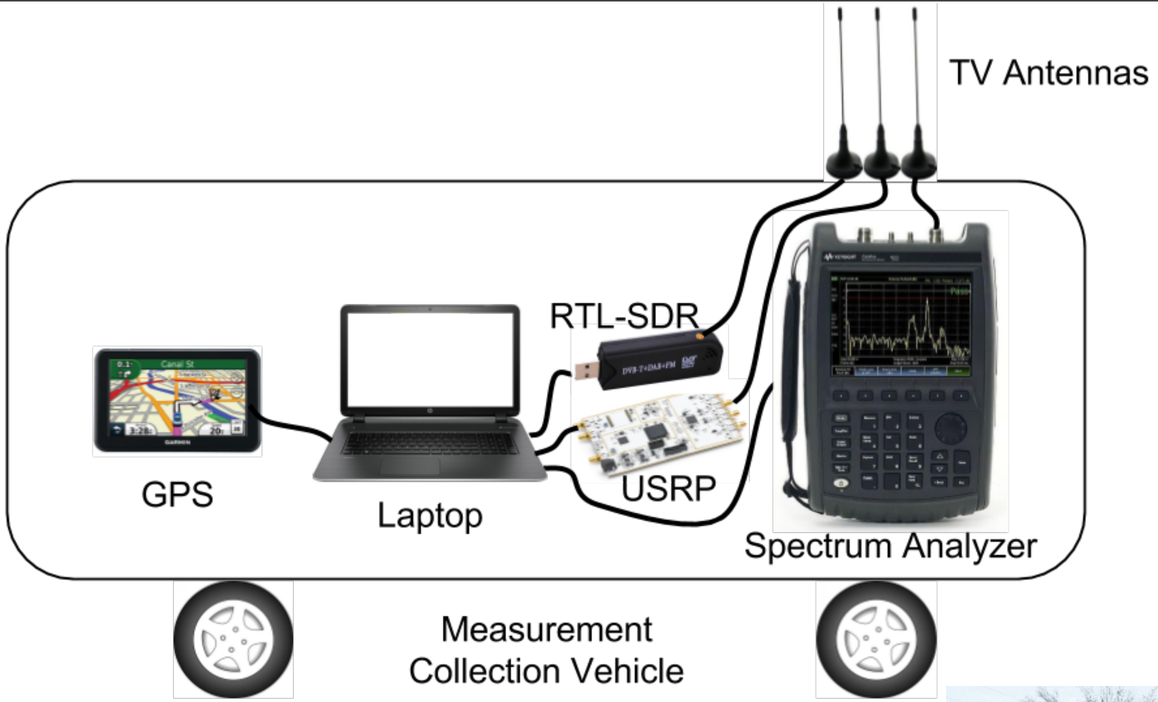
- Assume that each node knows the signal readings from all nodes around it
  - Can we use low-cost sensors to accurately detect white spaces?

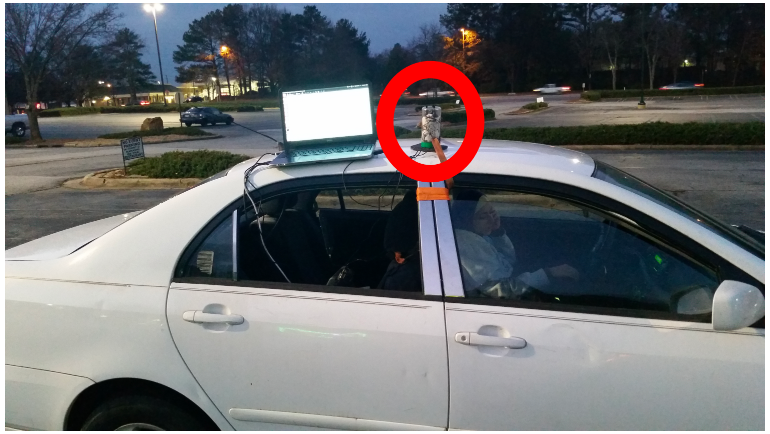


Measurement Study Methodology

- Readings of 7 channels collected over a continuous driving path
- Readings collected from a **USRP**, an **RTL-SDR dongle,** and a **Spectrum Analyzer** simultaneously and each reading tagged with current location
- Readings collected over an area of 700 km^2 in Metro Atlanta
- Each point labeled as safe/not safe for white space operation for each channel based on global knowledge

Measurement Study Setup

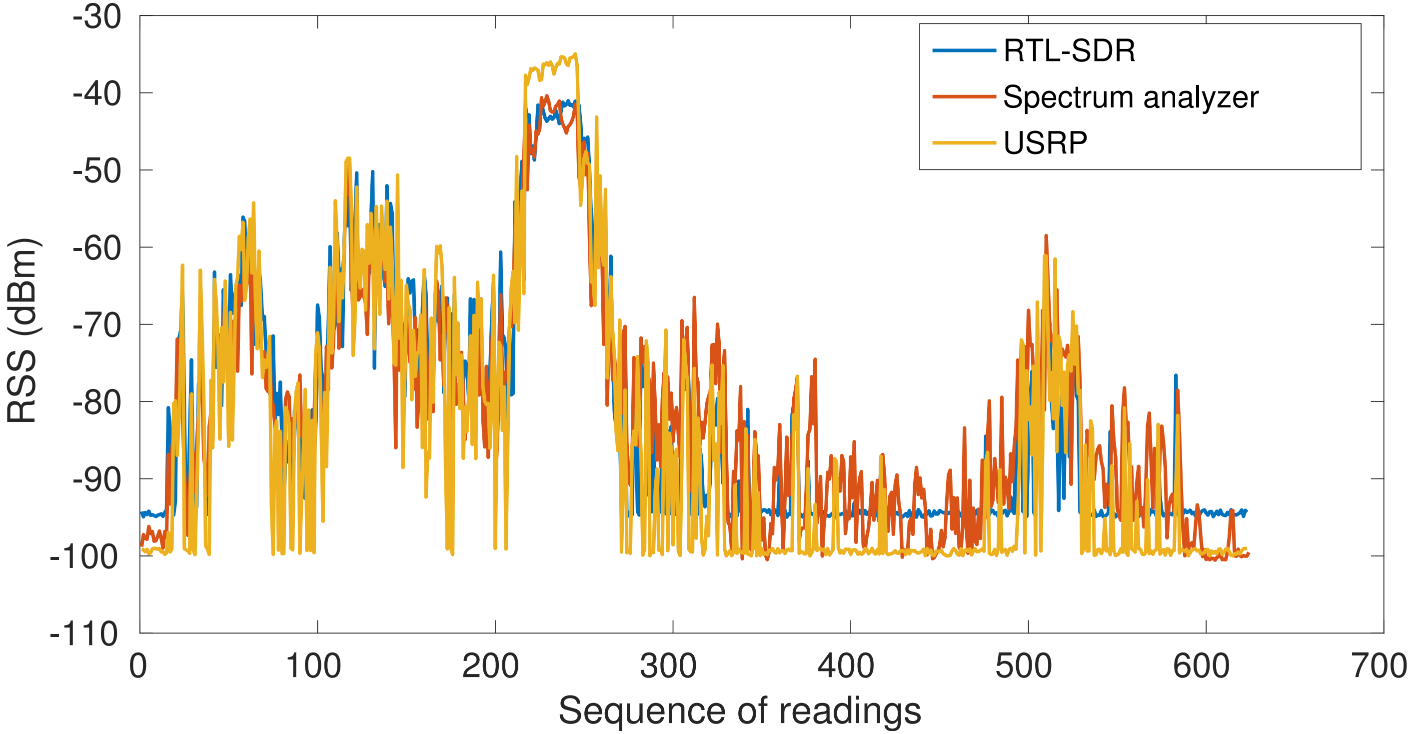




procedure LABELDATASET ()
  for all Node n in Dataset **do**
    if $Power(n) > -84$ dBm **then**
      $SetNotSafe(n)$
      for all Node n' in Dataset **do**
        if $Dist(n, n') \leq 6$ km **then**
          $SetNotSafe(n')$

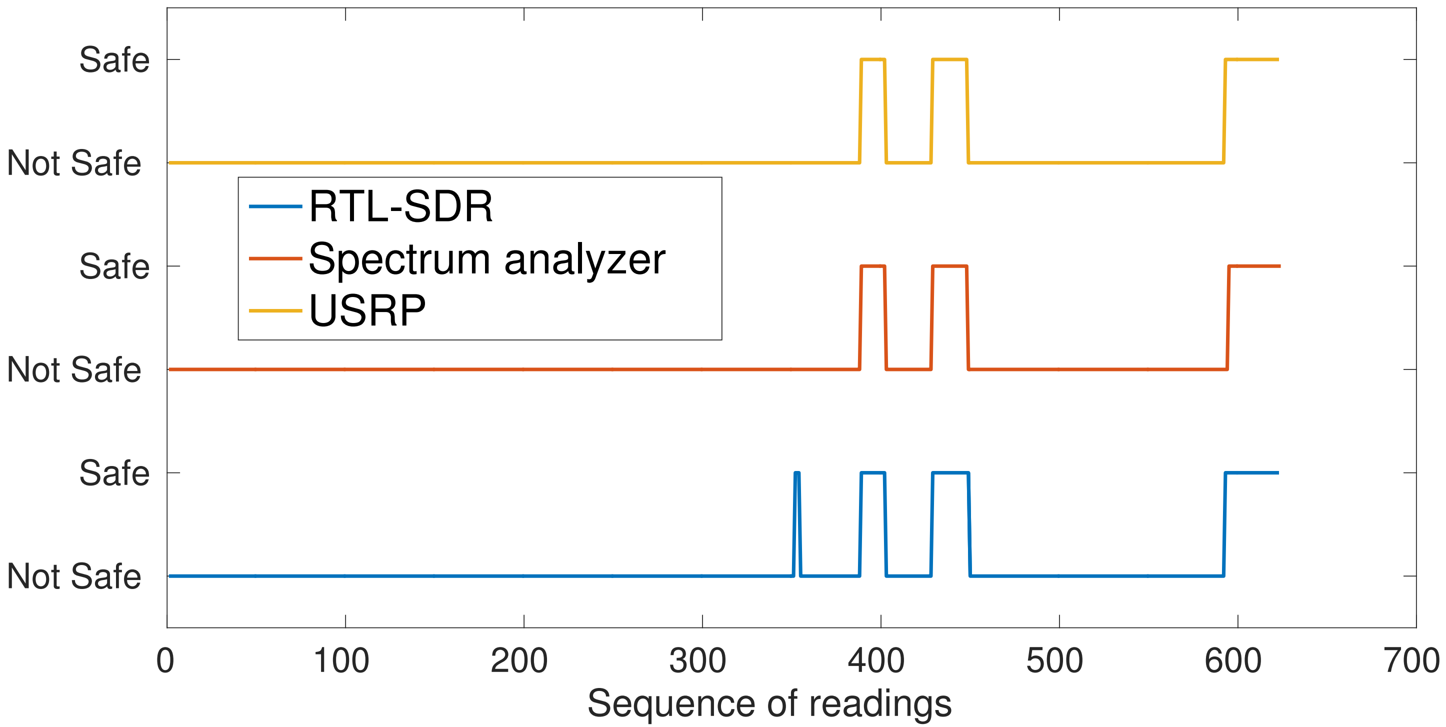
Measurement Study Methodology
Data Labeling

Low-cost Sensors vs. Spectrum Analyzer



Signal Strength Measurements for Channel 30

Low-cost Sensors vs. Spectrum Analyzer



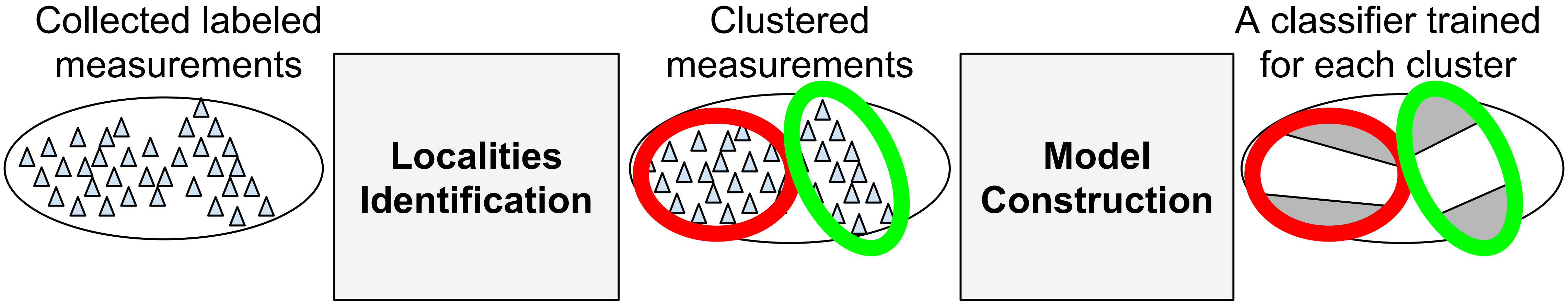
White Space Operation Decision for channel 30

WALDO Intuition

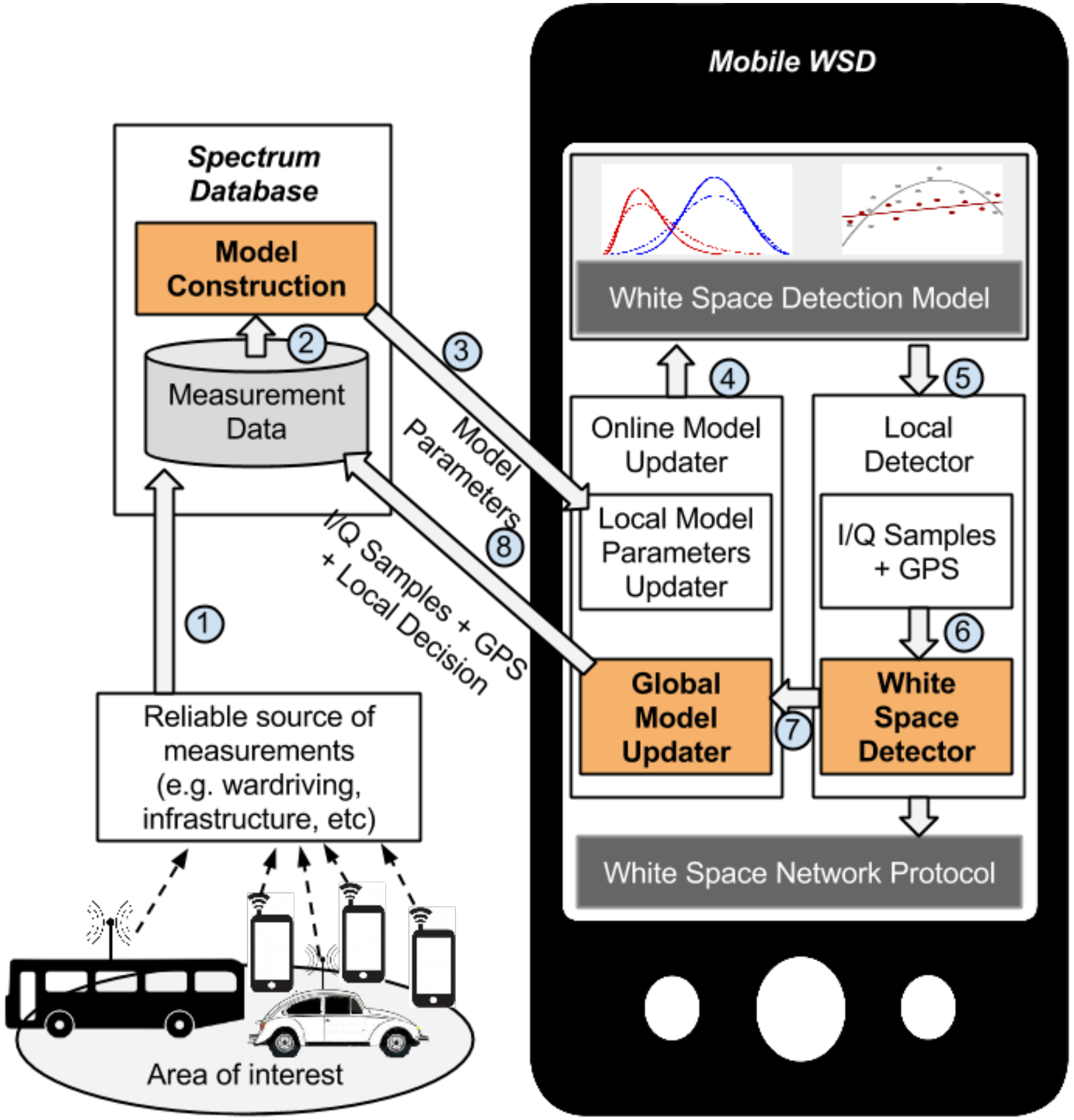
Given that perfect, with perfect knowledge, low-cost sensors have high accuracy

- Can we construct a model that captures global knowledge and allows for high accuracy local decision making?
  - A model should be able to represent **large areas** while being **compact** to avoid repetitive communication with the models repository
  - A model should capture the relationship between both **location** and **local signal features** with the global decision instead of only location used by databases

Constructing a WALDO Model



A light weight model is needed to make exchanges between the database and the mobile device are rare and short



WALDO Architecture

1. Collect readings from trusted sources
2. Construct a classification model from readings

3, 4. Update local model of the mobile device

5, 6. Device uses updated model, its location, and spectrum sensing information to detect white spaces

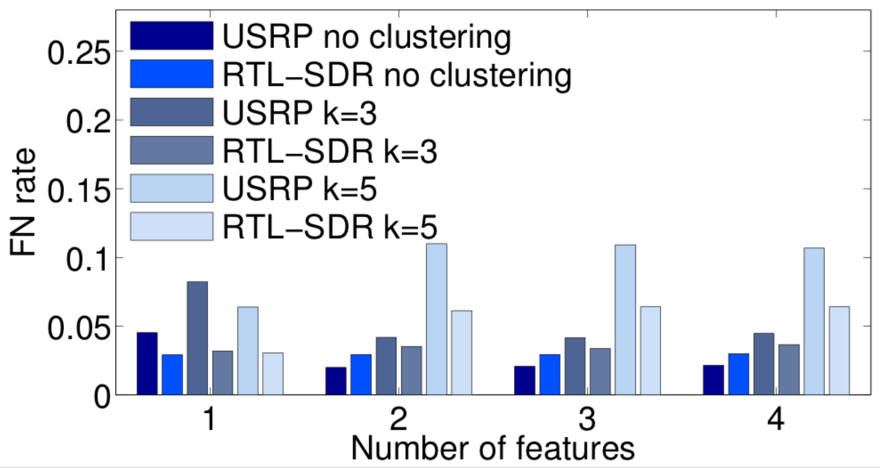
7,8. New collected readings used to update model

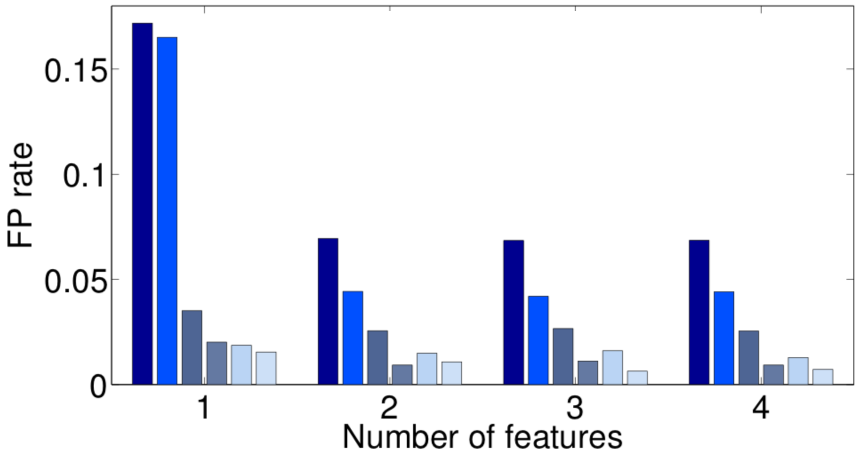
Evaluation Approach

- We use the data from the measurement study
- We compare two basic machine learning algorithms and use 10-fold cross validation to verify our findings
- For all 7 channels, we study
  - Effect of the clustering step on detection accuracy
  - Effect of number of features on detection accuracy
  - Effect of dataset size on detection accuracy
- We compare WALDO with V-Scope [Zhang et. al MobiCom’14]

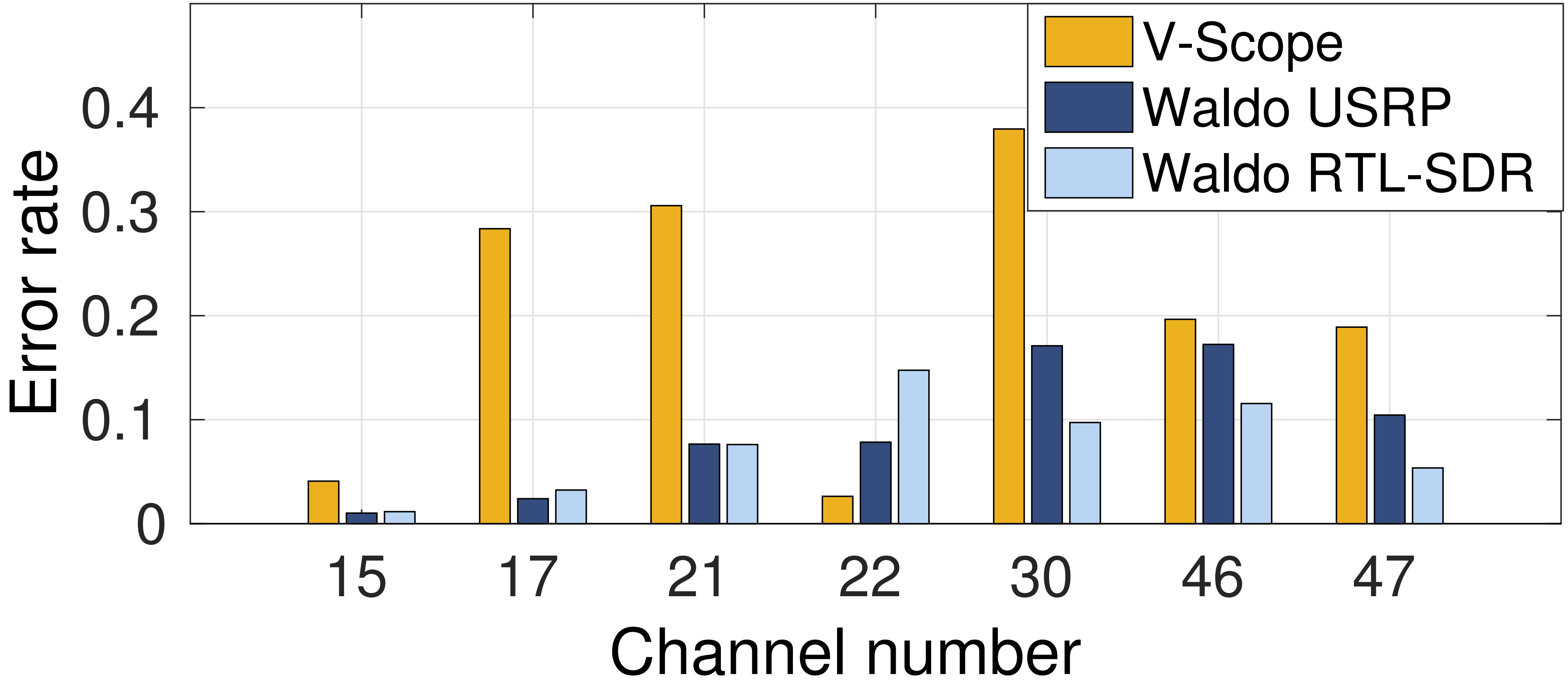
Evaluation Summary

- Increasing number of clusters significantly improves accuracy
  - It also reduces the area the model represents
- Adding signal features improves performance but improvement saturates
- False positive rate which is what determines protection of incumbents is always lower than 5% and can read around 1%
  - 1% FP rate is the equivalent of getting only one reading wrong





Comparison with V-Scope



Conclusion

- Low-cost sensors are a viable option for highly accurate white space detection
- WALDO relies on low-cost sensors to perform white space detection decision locally using globally constructed models
- WALDO outperforms the state of the art spectrum databases by better capturing the propagation of TV signals

Questions?

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