Measurement-Augmented Spectrum Databases for White Spaces

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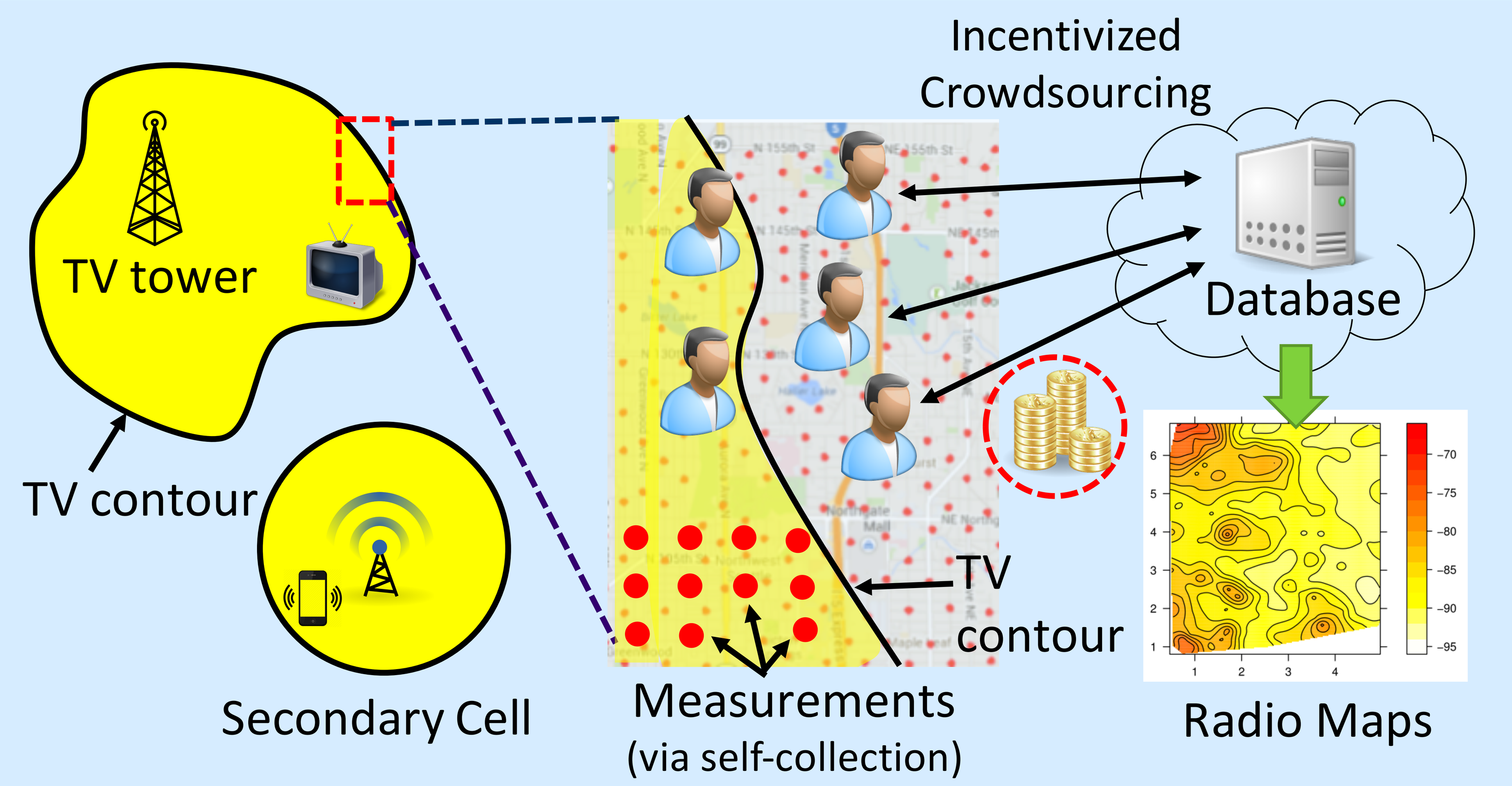
INTRODUCTION

- Increasing demand for more wireless spectrum to sustain skyrocketing growth in wireless services;
- **Reclaiming White Spaces** (WS), i.e., idle channels, requires accurate estimation of RSSI in both space and time;
- Current databases (DBs) based on empirically-driven radio propagation modeling provide notoriously poor estimates;
- **Measurement-augmented spectrum DBs** powered by **statistical interpolation techniques** (e.g., Kriging) may come to rescue;
- To reduce the cost for large-scale spectrum sensing, **incentivized crowdsourcing** is a promising and practical alternative to single-party measurement collection (e.g., drive tests).

OVERVIEW



OBJECTIVES

- **Reclaim lost WS opportunities** by improving RSSI estimation via data-driven statistical interpolation techniques (e.g., Kriging);
- **Develop an incentivized crowdsourcing framework** for collecting distributed, large-scale spectrum measurements;
- **Motivate FCC to re-consider and re-orient current TVWS rules** in this direction, so as to kindle a new competitive marketplace in WS.

CHALLENGES

- Large-scale, dense spectrum measurements must be collected for constructing radio maps or augmenting propagation models;
- Sensing data must be properly integrated into spectrum DBs for efficient processing and extraction of information;
- Users must be properly incentivized to sustain crowdsourcing.

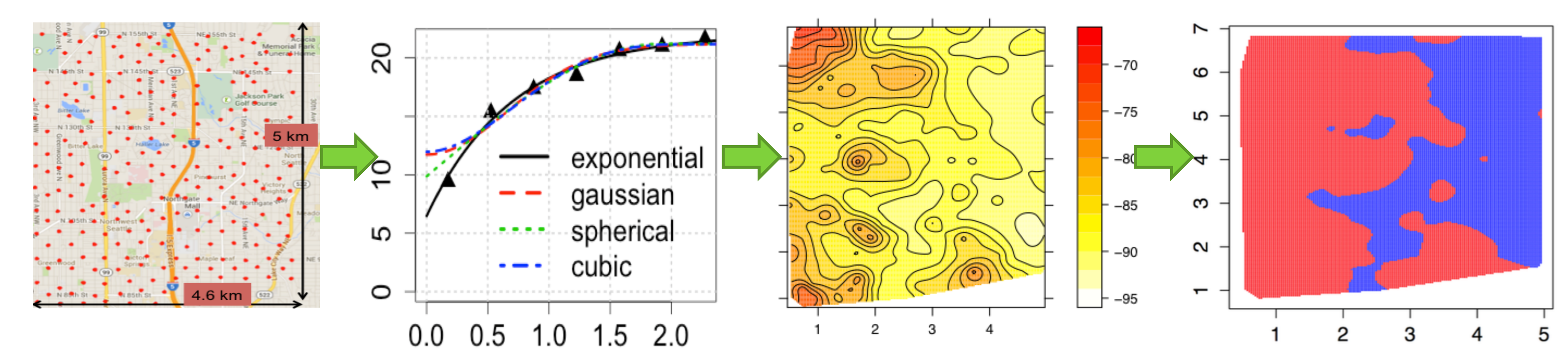
TOPIC 1: TV COVERAGE ESTIMATION VIA SPATIAL INTERPOLATION

Problem

How to **apply statistical interpolation** (Kriging) for radio mapping and **improve TV coverage estimation**?

Ordinary Kriging (OK)

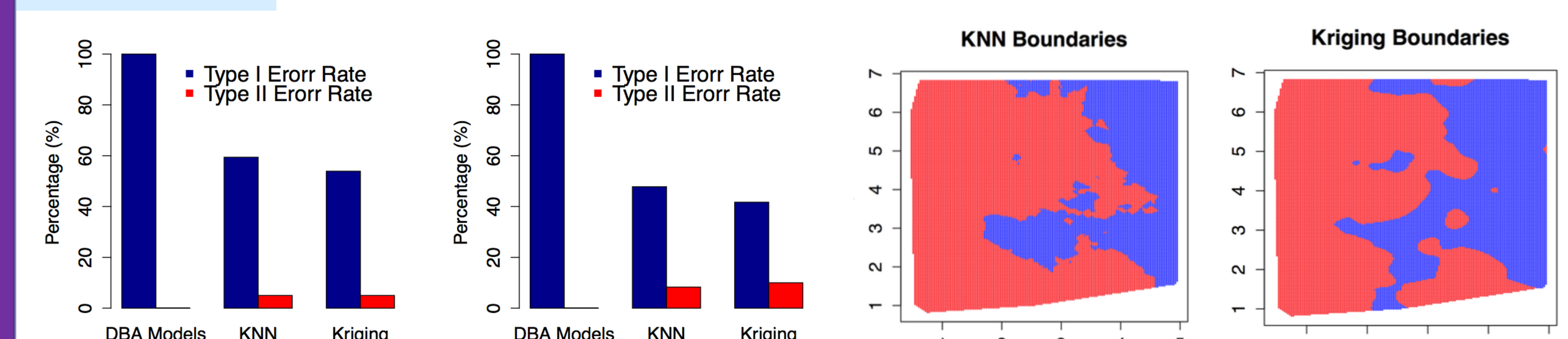
- OK models RSS at a location $\boldsymbol{x}$ as $Z(\boldsymbol{x}) = \boldsymbol{\mu}(\boldsymbol{x}) + \delta(\boldsymbol{x})$
- **Stationary**: $\mathbb{E}[Z(\boldsymbol{x})] = \mu$, $\mathbb{E}\left[\left(Z(\boldsymbol{x}) - Z(\boldsymbol{x}+\boldsymbol{h})\right)^2\right] = 2\gamma(\boldsymbol{h})$
- **Interpolation**: $\hat{Z}(\boldsymbol{x_0}) = \sum_{i=1}^{n} \omega_i Z(\boldsymbol{x_i})$, where $\sum_{i=1}^{n} \omega_i = 1$.
- **Minimizing MSE** $\mathbb{E}[\left(\hat{Z}(\boldsymbol{x_0}) - Z(\boldsymbol{x_0})\right)^2]$ gives $\{\omega_i^*\}$.
- MMSE is **Kriging variance** (i.e. prediction-error variance.)



(a) Measurements (b) Estimate $\gamma(h)$ (c) Radio Map (d) Boundary map

Boundary Estimation

- **Type 1 error** (ϵ_1): a channel is predicted to be occupied (0), when it is actually available (1).
- **Type 2 error** (ϵ_2): a channel is predicted to be available (1), when it is actually occupied (0).
- Goal: **reduce ϵ_1 (i.e., missing WS opportunities),** while **keeping ϵ_2 (i.e., possible interference) below a limit**.



(a) $\epsilon_2 \le 5\%$ (b) $\epsilon_2 \le 10\%$

Conclusion

- Kriging outperforms empirical DBA models in RSS prediction by exploiting local measurements;
- Kriging boundaries achieve better performance than DBA and *k*-Nearest Neighbor (kNN) boundaries.

TOPIC 2: INCENTIVIZED CROWDSOURCING FOR RADIO MAPPING

Problem

How to **incentivize users (mechanism design)** and **achieve good interpolation performance (sampling design)**?

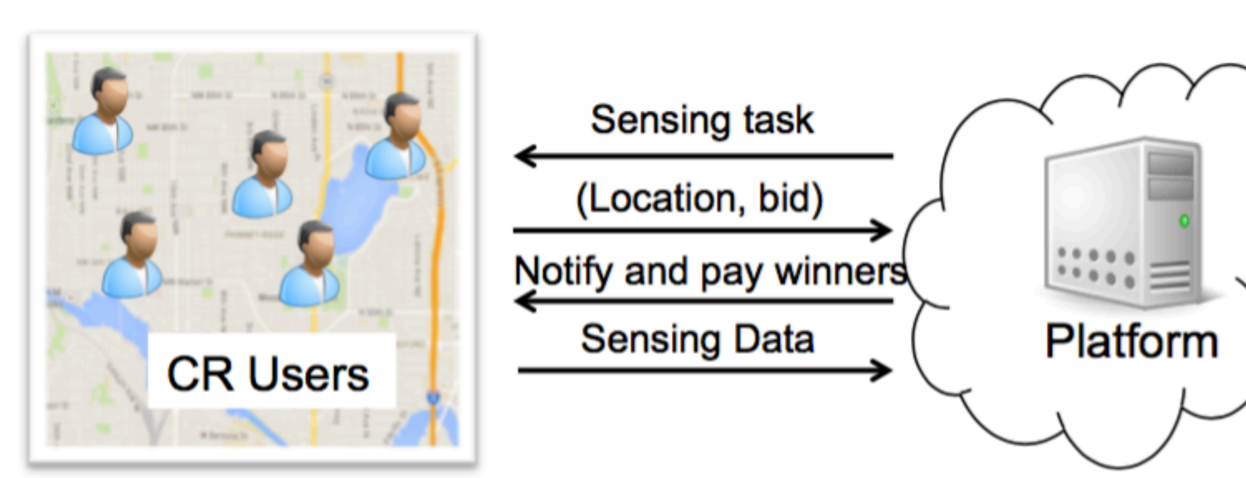


Fig. Proposed incentivized crowdsourcing system.

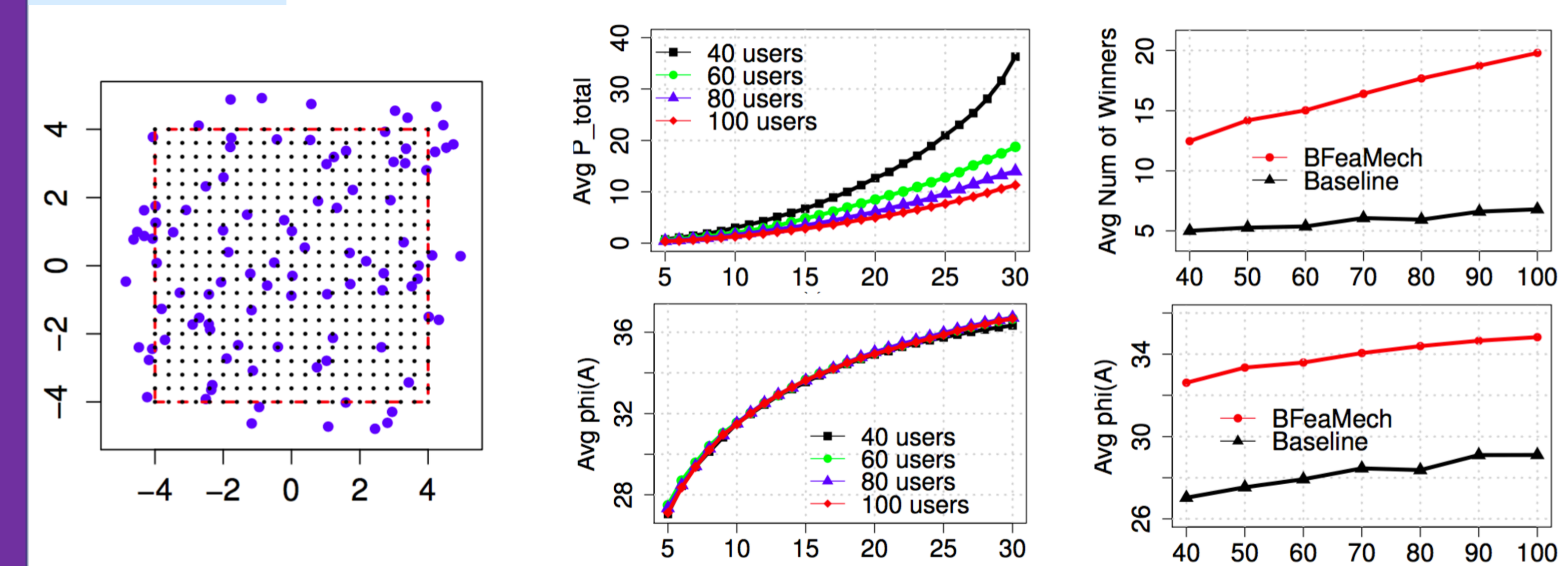
System Model

- Each user i incurs a **private cost** $c_i > 0$ for sensing;
- User i submits its current **location** x_i and a **bid** b_i;
- Properties: **budget-feasible (BF)**, **truthfulness (TF)**, **individual rationality (IR)**, **computational efficiency (CE)**.
- The platform's objective:

$$\max_{\mathcal{A}\subseteq\Omega} \phi(\mathcal{A})$$

$$\text{Subject to } \sum_{i\in\mathcal{A}} p_i \le B \text{ (BF), TF, IR, CE}$$

where $\phi(\mathcal{A})$ is the **average Kriging-variance reduction**.



(a) Sample topology of 100 randomly distributed users (b) **Budget-Free Mechanism** with a cardinality constraint (c) **Budget-Feasible Mech.** versus a baseline mech.

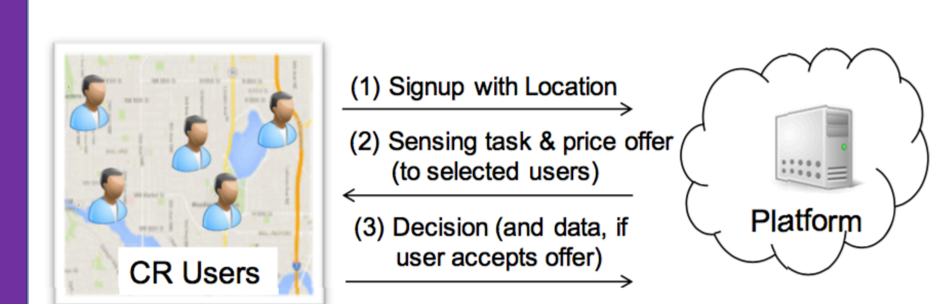
Conclusion

- We proposed an incentivized crowdsourcing system that is BF, TF, IR and CE.
- The proposed mechanism achieves significantly better performance over the state-of-art baseline mechanism.

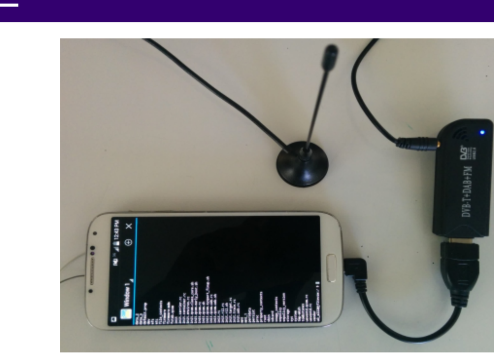
CONCLUSION

- The measurement-augmented databases powered by spatial statistics can improve RSSI prediction and reclaim lost WS opportunities.
- The incentivized crowdsourcing is a feasible and promising approach for distributed, large-scale spectrum measurement.

FUTURE WORK



(a) Pricing mechanism



(b) A crowdsourcing prototype with smartphone-based spectrum sensors

REFERENCES

[1] X. Ying, C. W. Kim, and S. Roy, "Revisiting TV coverage estimation with measurement-based statistical interpolation," in *Communication Systems and Networks (COMSNETS), 2015 7th International Conference on*, 2015, pp. 1–8.

[2] X. Ying, S. Roy, and R. Poovendran, "Incentivizing crowdsourcing for radio environment mapping with statistical interpolation," in *Dynamic Spectrum Access Networks (DySPAN), 2015 IEEE International Symposium on*, 2015, pp. 365–374.

[3] X. Ying, S. Roy, and R. Poovendran, "Pricing Mechanism for Quality-Based Radio Mapping via Crowdsourcing" (in preparation)