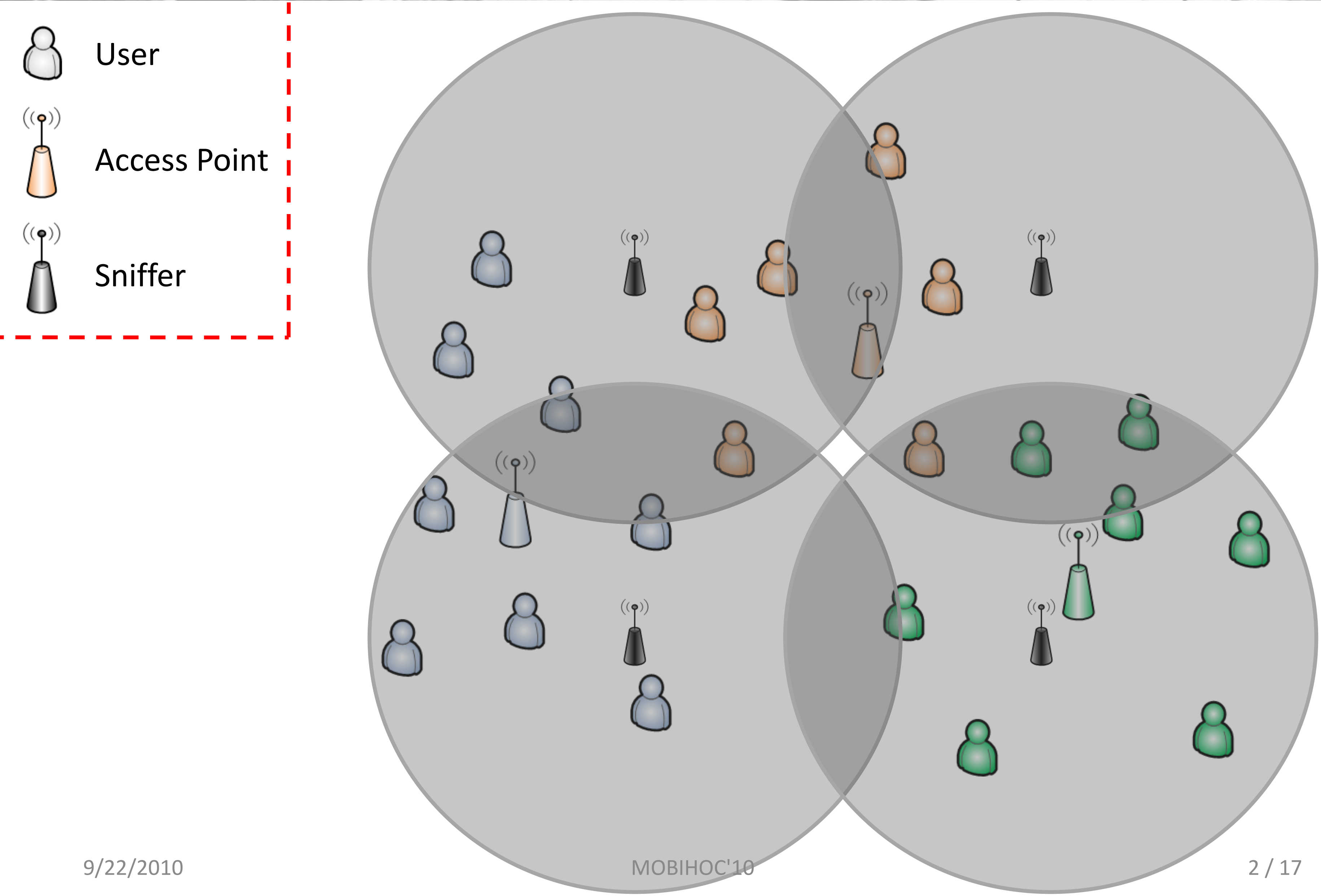
On Quality of Monitoring for Multi-channel Wireless Infrastructure Networks

Arun Chhetri, **Huy Nguyen**, Gabriel Scalosub*, and Rong Zheng

Department of Computer Science
University of Houston, TX, USA

*Department of Communication Systems Engineering
Ben-Gurion University, Beer-Sheva, Israel


User
Access Point
Sniffer

Outline

1. Introduction
2. Problem Formulation
3. QoM under User-centric Model
4. QoM under Sniffer-centric Model
5. Simulation and Experiments
6. Conclusion and Future Work

Wireless Network Monitoring

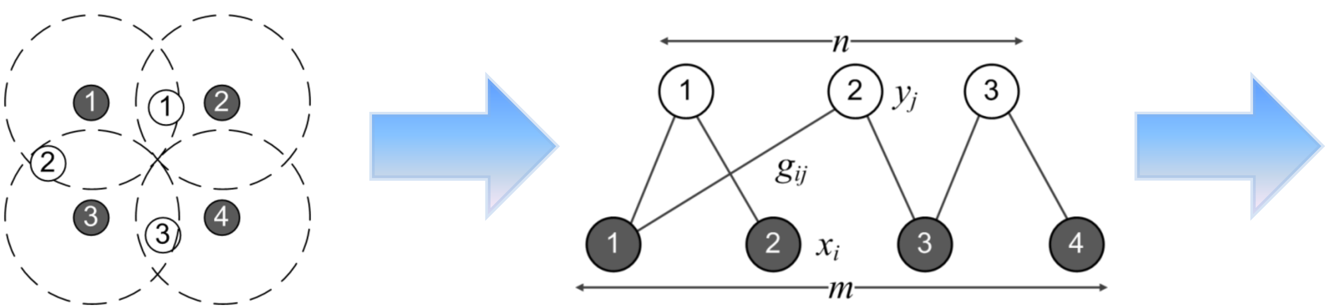
- Active vs. Passive monitoring
- Passive monitoring: using a dedicated set of sniffers
- Different sniffer capturing capability
  – User-centric model: frame-level information
  – Sniffer-centric model: binary channel activity
- Quality of Monitoring (QoM)
  – total expected number of active users captured

Our Contributions

- Formulate the problem of QoM maximization
  - NP-hard
- Study interaction between two models: user-centric and sniffer-centric
- Propose a comprehensive scheme for QoM problem in both models
- Derive approximation algorithms to maximize QoM with proven lower bounds

Problem Formulation

- Assumption: user activities are independent
- User-centric model
  - Consider a system of m sniffers, n users and k channels
  - A sniffer can only monitor a single channel at any time
  - Each user has a transmission probability p_u
  - $\boldsymbol{G}$: binary relationship matrix between sniffers and users
  - $\boldsymbol{G}$ and p_u are given



$$\boldsymbol{G} = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix}$$

Problem Formulation

- Sniffer-centric model
  - User activity ($\mathbf{y}$, p_u) and mixing matrix $\mathbf{G}$ are not available
  - Observation from m sniffers: $\mathbf{x} = [x_1, x_2, \ldots, x_m]$
  - Problem overview: $x_i = \bigvee_{j=1}^{n} g_{ij} \wedge y_j$
    - g_{ij} (unknown), y_j (unknown)
- Versus User-centric model
  - Not as expressive as User-centric model
  - Aggregated statistics with less fluctuant tendency
  - Less hardware requirement and storage complexity

MEC (Max Effort Coverage)

- With a set of sniffers, find the largest weighted set of users that can be monitored

$$
\begin{array}{lll}
\text{max.} & \sum_{u \in U} p_u y_u & \\
\text{s.t.} & \sum_{k=1}^{K} z_{s,k} \le 1 & \forall s \in S \\
 & y_u \le \sum_{s \in N(u)} z_{s,c(u)} & \forall u \in U \\
 & y_u \le 1 & \forall u \in U \\
 & y_u, z_{s,k} \in \{0,1\} & \forall u, s, k.
\end{array}
$$

$z_{s,k} = 1$ if a sniffer is assigned to chan. k

$y_u = 1$ if the user u is monitored

p_u is the weight associated with user u

- Different from the problem in [Bagchi 09]
- Using a reduction from the problem of MON3SAT, we proved that
  - The unweighted MEC problem is NP-hard, even for k = 2.
  - The MEC problem is NP-hard to approximate to within a factor of $7/8 + \varepsilon$ for every $\varepsilon > 0$

Algorithms for MEC

- Random: sniffers are assigned randomly to a channel
- Max: sniffers are assigned to its busiest channel
- Greedy: sniffers are assigned to the channel that minimize the number of unmonitored users.

  Approximation factor: 1/2
- LP-Round: solving the LP-relaxation of MEC, then round the fractional result into a integral solution (with e.g., probabilistic rounding technique in [Srinivasan 01]).

  Approximation factor: $(1 – 1/e) \approx 0.632$

QoM under Sniffer-centric Model

- Convert Sniffer-centric to User-centric model
- Inferring $\boldsymbol{G}$:
  - Classic Independent Component Analysis (ICA): $\mathbf{x} = \boldsymbol{G}\,\mathbf{y}$
  - ICA assumes continuous variables → not directly applicable
  - Two steps process:
    1. Apply ICA to get an estimation of linear mixing matrix $\hat{G}_L$
       - Non-negative fractional values in $\hat{G}_L$
    2. Quantize $\hat{G}_L$ to have the binary mixing matrix $\hat{G}$
       - Normalizing and thresholding

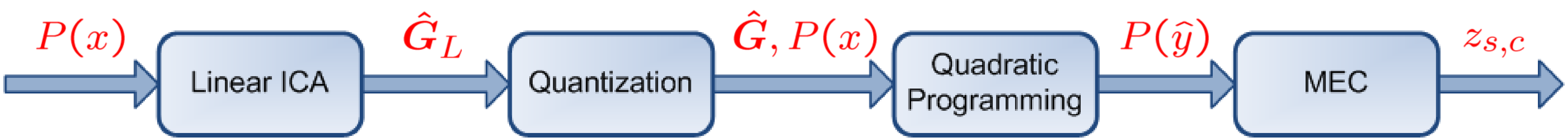
QoM under Sniffer-centric Model

- Inferring p_u given $\boldsymbol{G}$:
  - Assuming all users are independent

$$p(x_i = 0) = \prod_{\hat{g}_{ij}=1} p(y_j = 0)$$

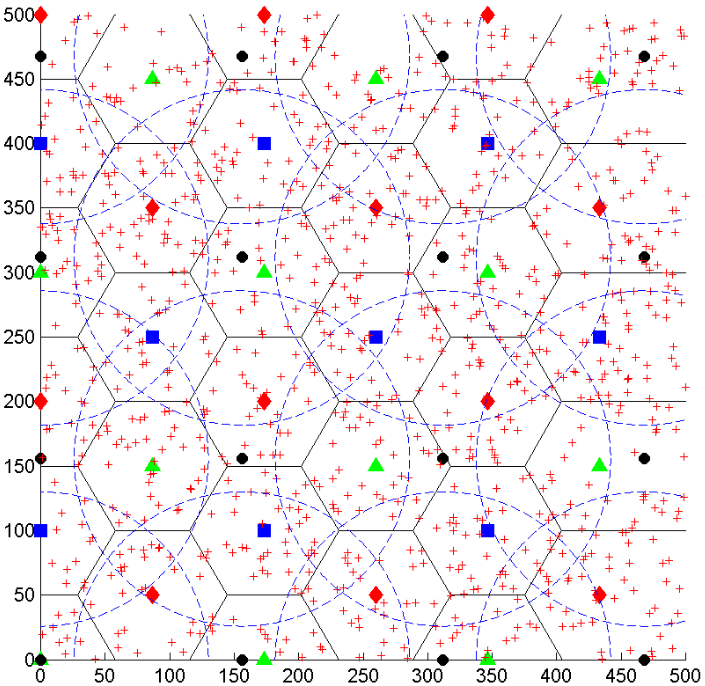
  - Let $\alpha_i = \log(p(x_i = 0)), \beta_i = \log(p(y_j = 0))$
  - Define $\alpha = [\alpha_1, \alpha_2, \ldots, \alpha_m]^T, \beta = [\beta_1, \beta_2, \ldots, \beta_n]^T$
  - We have the quadratic programming problem

$$\begin{aligned} \text{min.} \quad & \| \alpha - \hat{G}\beta \|^2 \\ \text{s.t.} \quad & \beta < 0, \end{aligned}$$

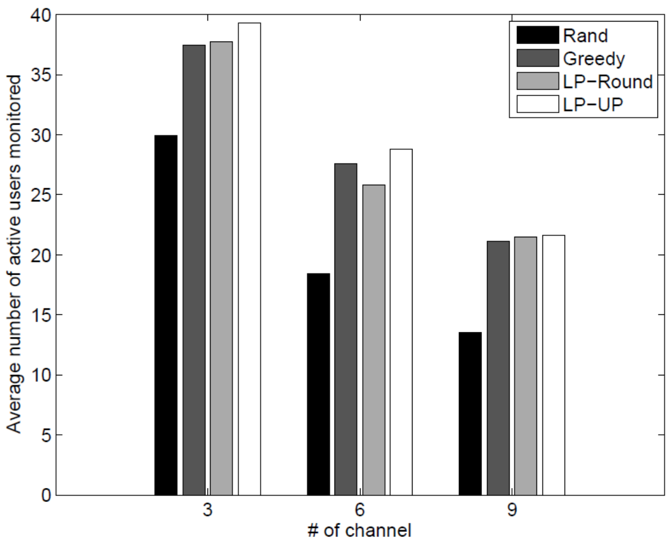


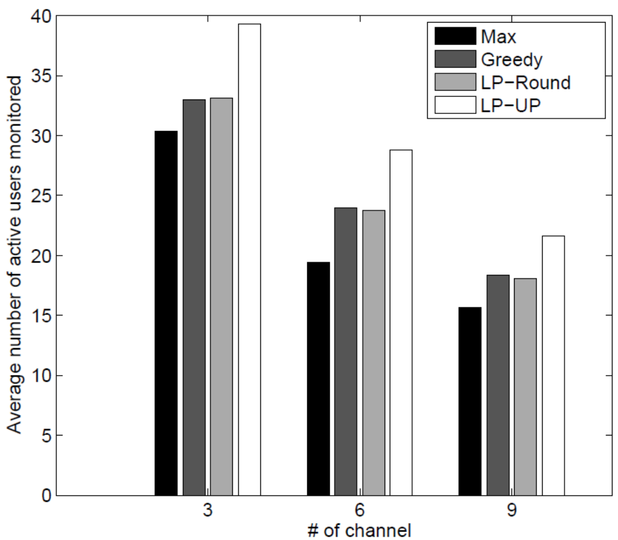
Synthetic Traces

- 1000 wireless users are randomly placed on a 500x500 square meter area.
- 25 sniffers are deployed in a grid formation
- Distance = 100 meters
- Coverage radius = 120 meters
- $p_u \in (0, 0.06]$
- Average busy p on each cell ≈ 0.3
- Orthogonal channels = {3, 6, 9}
- Observations T = 10,000



Synthetic Traces

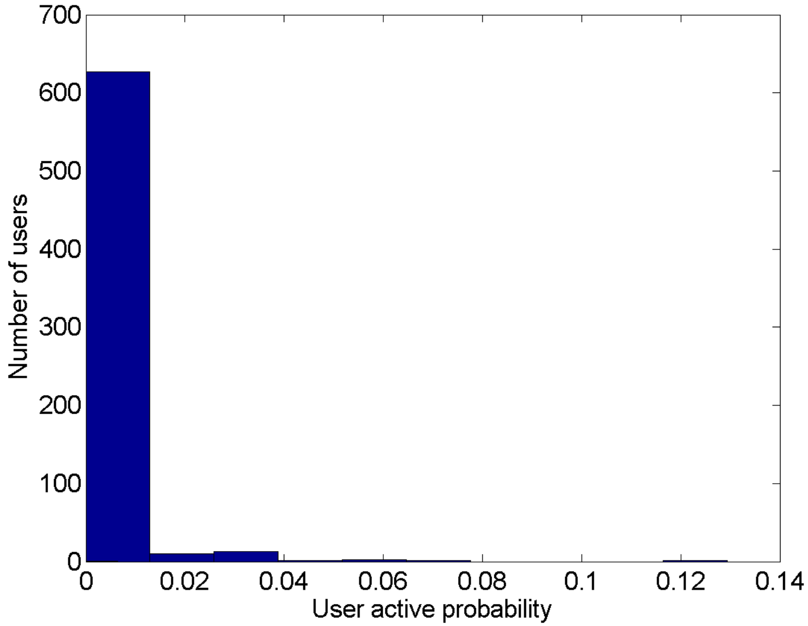




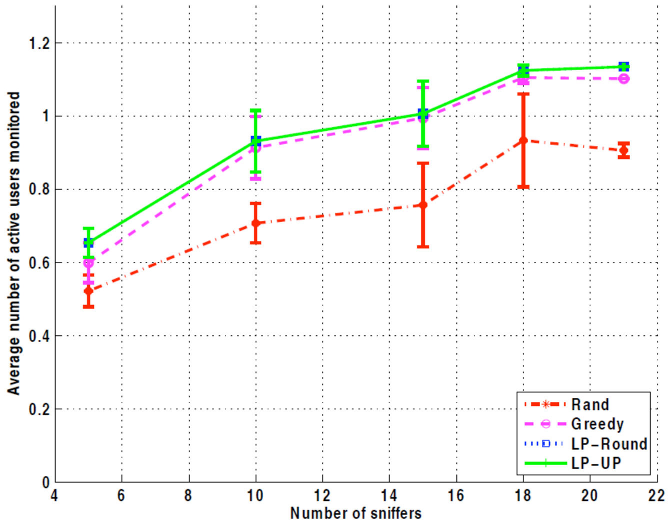
User-centric Model	**Sniffer-centric Model**
• Greedy and LP-Round are close to LP-UP • Rand gets worst as no. of channels increases	• Greedy and LP-Round outperform Max • Degradations comparing to User-centric Model

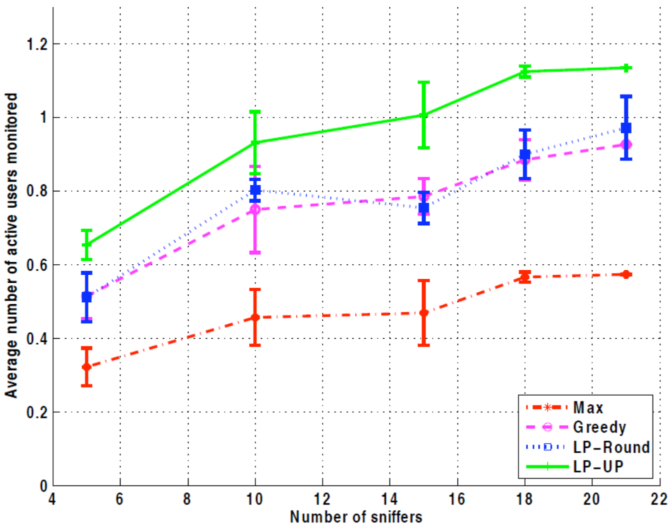
Real Traces

- 21 WiFi sniffers deployed at M.D. Anderson Library, U. of Houston
- Number of observations $T = 300{,}000$
- 655 unique users identified on 3 WiFi channels (1, 6, 11)
- Average $p_u = 0.0014$
- Varies number of selected sniffers from 5 – 21



Real Traces





User-centric Model	Sniffer-centric Model
• Greedy and LP-Round are close to LP-UP • QoM and sniffer no. are monotonically increasing	• Greedy and LP-Round outperform Max • Degradations comparing to User-centric Model

Conclusion and Future Work

- Derive and address the problem of maximizing QoM (MEC) in multi-channel wireless networks
- Recover user-level info from sniffer observation
- Solve the MEC problem with proposed algorithms on synthetic and real systems
- Ongoing researches
  - Binary Independent Component Analysis with OR Mixtures
    http://arxiv.org/abs/1007.0528
  - Various network applications
    E.g.: PU separation in cognitive radio system, Link loss analysis in multicast network …

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THANK YOU FOR YOUR ATTENTION

nahuy@cs.uh.edu
http://wireless.cs.uh.edu