Femto-Matching: Efficient Traffic Offloading in Heterogeneous Cellular Networks

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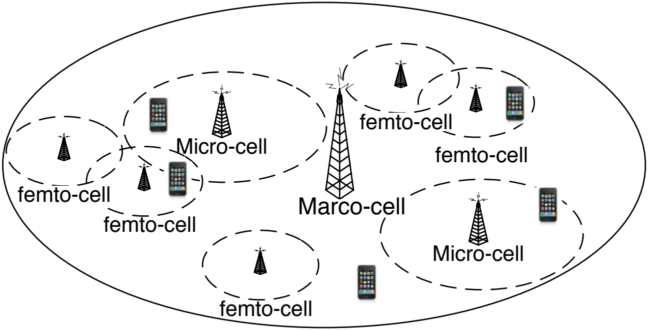
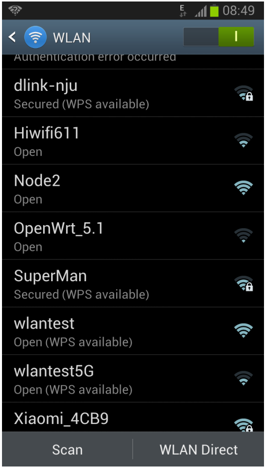
Heterogeneous Cellular Networks



- Cellular networks use multiple layers of basestations to improve spatial utility
- Small cells such as femtocell or WiFi APs help offloading the traffic form the macro-cell

User Association Problem

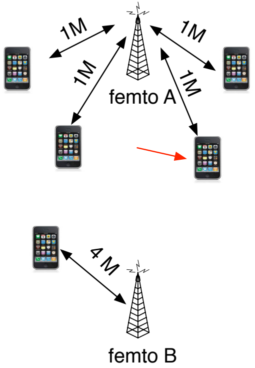
- Mobile devices can connect to multiple basestations
- Basestations provide different service qualities
- Traditional approach
  - strongest signal
  - lowest price
  - highest transmission rate



Problems for Existing Approaches

Scenarios of suboptimal solutions

- For the user
  - overly crowded basestations
- For the carrier
  - low utilization of femto-cells
  - overload of marco-cells



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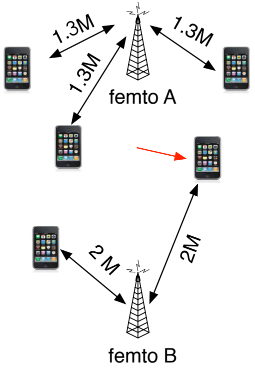

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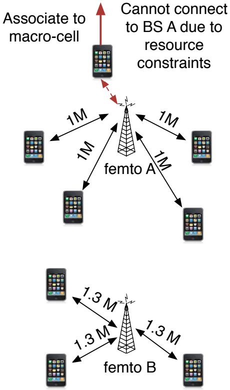

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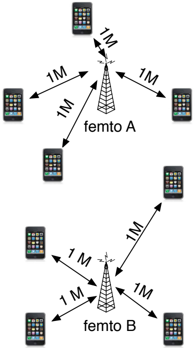
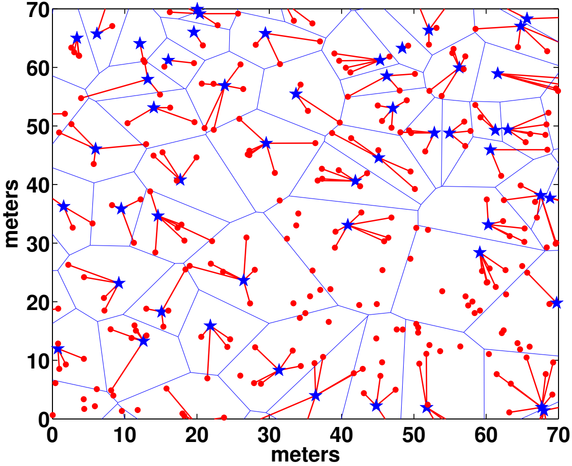
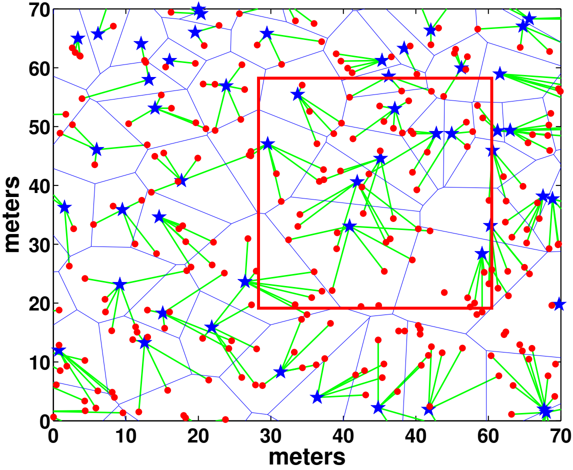


Randomly Deployed Network



An example for randomly deployed network

Randomly Deployed Network



“orphan nodes” 20% → 5%

Key Challenges

- Misaligned objectives for users and network operators
  - Users want better throughput
  - Operators want better resource utilization
- Both the femto-cells and the users are randomly distributed
- Require a global view to fully optimize the system
- Mobile devices move all the time
- One device usually only associates with one basestation

Problem Formulation

- Objective: maximize the overall utility
  - Proportional Fairness

$$\max \quad \sum_i \log\Big(\sum_j c_{ij} r_{ij} a_{ij}\Big)$$

- Constraints:
  - Basestations split their resources to associated users
  - Users only associate to one basestation

$$\begin{aligned} \textstyle\sum_i c_{ij} \le 1 \quad & \forall j \in \mathcal{B}, \\ \textstyle\sum_j a_{ij} \le 1 \quad & \forall i \in \mathcal{U}, \\ a_{ij} \in \{0,1\},\ c_{ij} \ge 0 \quad & \forall i \in \mathcal{U}, j \in \mathcal{B}. \end{aligned}$$

Problem Transformation

- Mixed integer programming problem, but can be solved optimally
- Key observations
  - Within a single cell, the resources will be divided evenly in the proportional fairness case:

    e.g., $k-1$ users in BS j, with rate $r_{1j}, r_{2j}, \ldots$

    Each user takes $\frac{1}{k-1}$ of resources (time slots, RB,..), throughput $\frac{r_{1j}}{k-1}, \frac{r_{2j}}{k-1}, \ldots$

    Overall utility:

$$\sum_{i=1}^{k-1} \log \frac{r_{ij}}{k-1} = \sum_{i=1}^{k-1} \log r_{ij} - (k-1)\log(k-1)$$

Problem Transformation

- A new user k with rate r_{kj} joins
- Rate of existing users reduces to $\frac{r_{ij}}{k}$
- Overall utility:

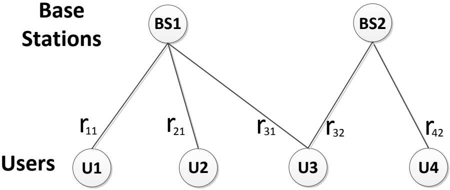
$$\sum_{i=1}^{k-1} \log \frac{r_{ij}}{k} + \log \frac{r_{kj}}{k} = \sum_{i=1}^{k-1} \log r_{ij} + \log r_{kj} - k \log k$$

- Marginal utility of user k:

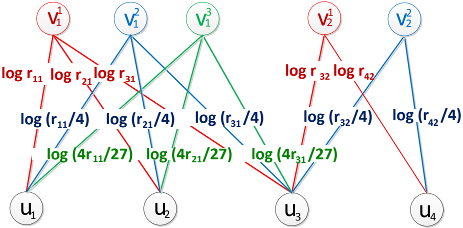
$$\log r_{kj} + (k-1)\log(k-1) - k \log k$$

Converting the problem to an equivalent maximum weighted matching problem

Original network



- Splitting BS to virtual BSs
- Weights are marginal utilities



Distributed Solution

- Exploit the special structure of the problem to design a distributed matching algorithm
- Basic idea
  - Divide the edge weight to two parts, maintained separately by the BS and user
  - Use the price to characterize the importance of the resource
- Auction process
  - **Initialization**: BSs set the initial prices for all virtual BSs; Users estimate transmission rates
  - **Iterative auction**
    - BSs announce the lowest price among virtual BSs
    - Users submit bids to the BS with highest gain
    - BSs select the user with highest bid and adjusts prices
  - **Finalize the association**

Handling Mobility

- Incremental adjustment
- Node join
  - New node bids for the available resources in femtocells
  - Considering the cascading re-association
- Node leave
  - BS reduces the prices of the vacancy
  - Restart auction only when necessary

Performance Analysis

- Performance metrics
  - Offloading efficiency η:
    ratio of users served by femtocells, reflects the efficiency of femtocells
- Both the femtocells and users are distributed as Poisson Point Process, system parameters:
  - l: Load factor $l = \lambda_u / \lambda_f$
  - κ: Number of users can be served by one femtocell
- Consider the efficiency of different schemes:
  - Associate to nearest BS
  - Matching schemes

Performance Comparation

- Associate to nearest BS

  Offloading efficiency around 74% due to randomness in deployment

l	$\kappa = 1$	$\kappa = 2$	$\kappa = 3$	$\kappa = 4$	$\kappa = 5$	$\kappa = 6$
1	**0.5851**	0.8474	0.9483	0.9835	0.9950	0.9985
2		**0.6636**	0.8230	0.9110	0.9568	0.9796
3			**0.6980**	0.8132	0.8877	0.9341
4				**0.7176**	0.8080	0.8721
5					**0.7303**	0.8048
6						**0.7393**

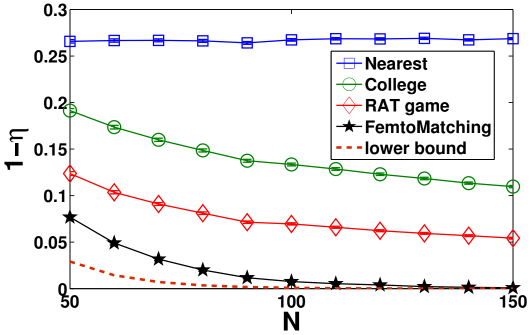
- Matching scheme

  Offloading efficiency approaching 1, under higher network density.

Experiment Setup

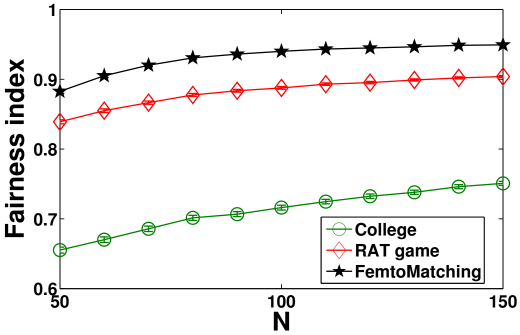
- Experiments setups
  - Simulations with randomly generated networks
  - Trace-driven simulations on UIUC UIM trace
- Algorithms
  - Associate to nearest
  - RAT selection game
  - College admission algorithm
  - Femto-Matching

Experimental Results I



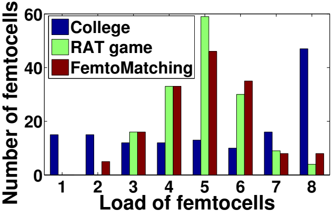
Femto-matching has lowest ratio of not offloaded users

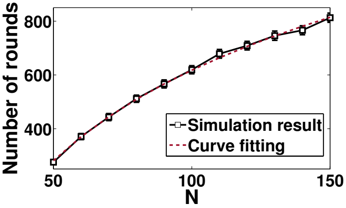
Experimental Results II



Femto-matching provides better fairness

Experimental Results III





Femto-matching provides better load balancing among femtocells and has low computational cost

Conclusion and Future Works

- Matching provides a good way to smooth out the randomness in deployment
- It is possible to distributively calculate the optimal proportional fairness allocation
- Future researches
  - Detailed performance evaluation for mobility
  - Truthfulness in auction

Q & A

Thanks!