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ICASSP

Traffic-Aware Association in HetNet

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Problem Statement

☐ Conventional User Association in HetNet:

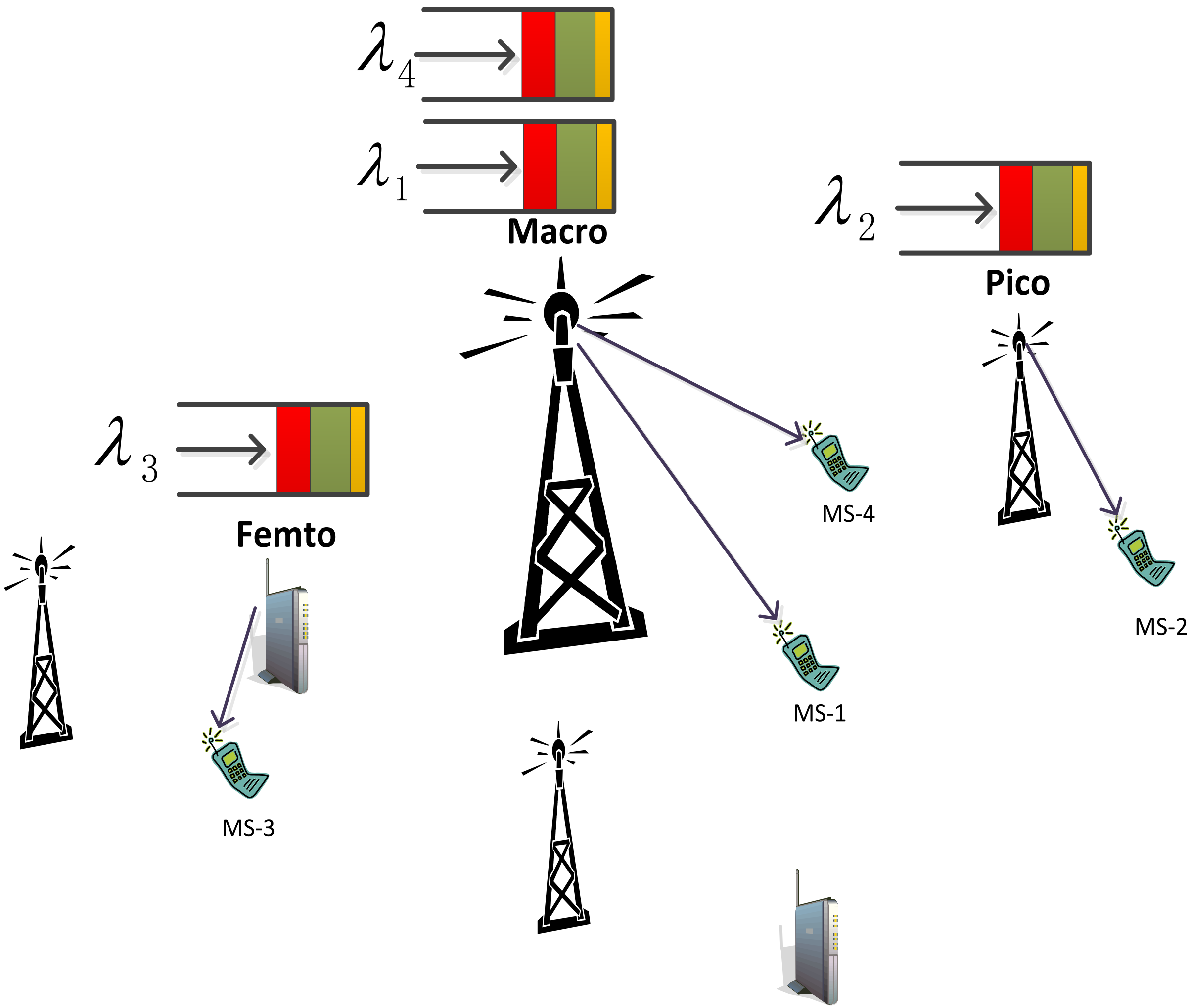
- Max-DL-SINR association as in 2G/3G/4G networks
- Cell Range Expansion [Sesia et al'11, Andrews et al'14]
- Joint optimization of association and resource allocation
  - Assuming Best-Effort (BE) traffic
  - Performance metrics
    - the sum of log-rate [Fooladivanda et al'13, Ye et al'13, Deb et al'14]
    - number of admitted users [Li et al'12]
    - sum of the inverse of the per-user throughput [Chen'11]

☐ Our proposed association rule:

✓ Model the DL QoS traffic explicitly

✓ Optimize the network-wide packet delay performance

HetNet with QoS Traffic



Definitions:

B : system BW in Hz
P_n: txmn pwr of BS-n
λ_k: pkt arrival rate of MS-k
L_k: avg pkt length in bits of MS-k
$h_{k,n}$: channel btw MS-k and BS-n
$x_{k,n}$: assoc indx of MS-k to BS-n
$y_{k,n}$: resource alloc

Assumptions:

i.i.d. exp inter-arrival times
i.i.d. exp packet lengths
BS always ON
full freq. reuse

Problem Formulation

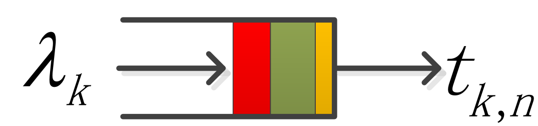
- Avg rate of MS-k associated with BS-n occupying all resources:

$$R_{k,n} = B \log \left(1 + \frac{P_n |h_{k,n}|^2}{\sum_{l=1, l \neq n}^{N} P_l |h_{k,l}|^2 + \sigma^2} \right)$$

- Service time for the traffic towards MS-k is i.i.d. exp with mean:

$$t_{k,n} = \frac{L_k}{y_{k,n} R_{k,n}} = \frac{1}{y_{k,n} r_{k,n}}$$

- Avg delay for a packet in the M/M/1 queue:



$$\tau_{k,n} = \frac{1}{1/t_{k,n} - \lambda_k} = \frac{1}{y_{k,n} r_{k,n} - \lambda_k}$$

Problem Formulation

- **Optimal association rule to minimize the average pkt delay across the whole network:**

$$
\begin{aligned}
\underset{x_{k,n},y_{k,n}}{\text{minimize}} \quad & \frac{1}{\sum_{k=1}^{K}\lambda_k}\sum_{n=1}^{N}\sum_{k=1}^{K}\frac{x_{k,n}\lambda_k}{y_{k,n}r_{k,n}-x_{k,n}\lambda_k} \\
\text{subject to} \quad & \sum_{n=1}^{N} x_{k,n} = 1.0, \forall k = 1,...,K \\
& \sum_{k=1}^{K} y_{k,n} \le 1.0, \forall n = 1,...,N \\
& x_{k,n} \in \{0,1\}, \forall k = 1,...,K, n = 1,...,N \\
& y_{k,n} > \frac{x_{k,n}\lambda_k}{r_{k,n}}, \forall k = 1,...,K, n = 1,...,N.
\end{aligned}
$$

P1

- A classic knapsack problem is NP-hard [Bertsekas'99]
- **We try to find low-complexity approx. solutions!**

Step 1: Opt Resource Alloc

☐ Proposition 1:

At BS-n, given user association, when the following feasibility condition is met:

$$\sum_{k=1}^{K} \frac{x_{k,n}\lambda_k}{r_{k,n}} < 1.0,$$

the optimal resource allocation minimizing the average pkt delay is as follows:

$$y_{k,n} = \frac{x_{k,n}\lambda_k}{r_{k,n}} + \frac{1 - \sum_{u=1}^{K} \frac{x_{u,n}\lambda_u}{r_{u,n}}}{\sum_{u=1}^{K} \sqrt{\frac{x_{u,n}\lambda_u}{r_{u,n}}}} \sqrt{\frac{x_{k,n}\lambda_k}{r_{k,n}}}.$$

$$y_{k,n} = \frac{1}{\sum_{u=1}^{K} \frac{x_{u,n}\lambda_u}{r_{u,n}}} \frac{x_{k,n}\lambda_k}{r_{k,n}}$$

linear approx

Simplified Problem

Optimal Association:

$$\begin{aligned}
\underset{x_{k,n}}{\text{minimize}} \quad & \sum_{k=1}^{K}\sum_{n=1}^{N} \frac{x_{k,n}\lambda_k}{r_{k,n}} \frac{1}{1-\sum_{u=1}^{K}\frac{x_{u,n}\lambda_u}{r_{u,n}}} \\
\text{subject to} \quad & \sum_{n=1}^{N} x_{k,n} = 1, \forall k = 1, ..., K \\
& x_{k,n} \in \{0,1\}, \forall k = 1, ..., K, n = 1, ..., N \\
& \sum_{k=1}^{K} \frac{x_{k,n}\lambda_k}{r_{k,n}} < 1, \forall n = 1, ..., N
\end{aligned}$$

P2

convex relaxation

$$\begin{aligned}
\underset{x_{k,n}}{\text{minimize}} \quad & f(\{x_{u,n}\}) = \sum_{k=1}^{K} f_k(\{x_{u,n}\}) \\
\text{subject to} \quad & \sum_{n=1}^{N} x_{k,n} = 1, \forall k = 1, ..., K \\
& x_{k,n} \in [0,1], \forall k = 1, ..., K, n = 1, ..., N \\
& \sum_{k=1}^{K} \frac{x_{k,n}\lambda_k}{r_{k,n}} < 1, \forall n = 1, ..., N
\end{aligned}$$

P3

$$f_k(\{x_{u,n}\}) = \sum_{n=1}^{N} \frac{x_{k,n}\lambda_k}{r_{k,n}} \frac{1}{1-\sum_{u=1}^{K}\frac{x_{u,n}\lambda_u}{r_{u,n}}}$$

Step 2: Opt Association

☐ Proposition 2

For MS-k, given others' association, the optimal association of MS-k minimizing the objective function in problem P3 is as follows:

$$x_{k,n} = \max\left\{0, \frac{r_{k,n}\delta_{k,n}}{\lambda_k} - \alpha\sqrt{\frac{r_{k,n}}{\lambda_k}}\right\}$$

chosen such that $\sum x_{k,n} = 1$

$$\delta_{k,n} := 1 - \sum_{u=1,u\neq k}^{K} \frac{x_{u,n}\lambda_u}{r_{u,n}}$$

available load in BS-n for MS-k

Traffic-Aware Assoc Algorithm

1. Feasible start: (LP)

$$\begin{aligned} \underset{x_{k,n},s}{\text{minimize}} \quad & s \\ \text{subject to} \quad & \textstyle\sum_{n=1}^{N} x_{k,n} = 1, \forall k \\ & x_{k,n} \in [0,1], \forall k, n \\ & \textstyle\sum_{k=1}^{K} x_{k,n} \frac{\lambda_k}{r_{k,n}} - 1 \leq s, \forall n. \end{aligned}$$

2. Iterations:

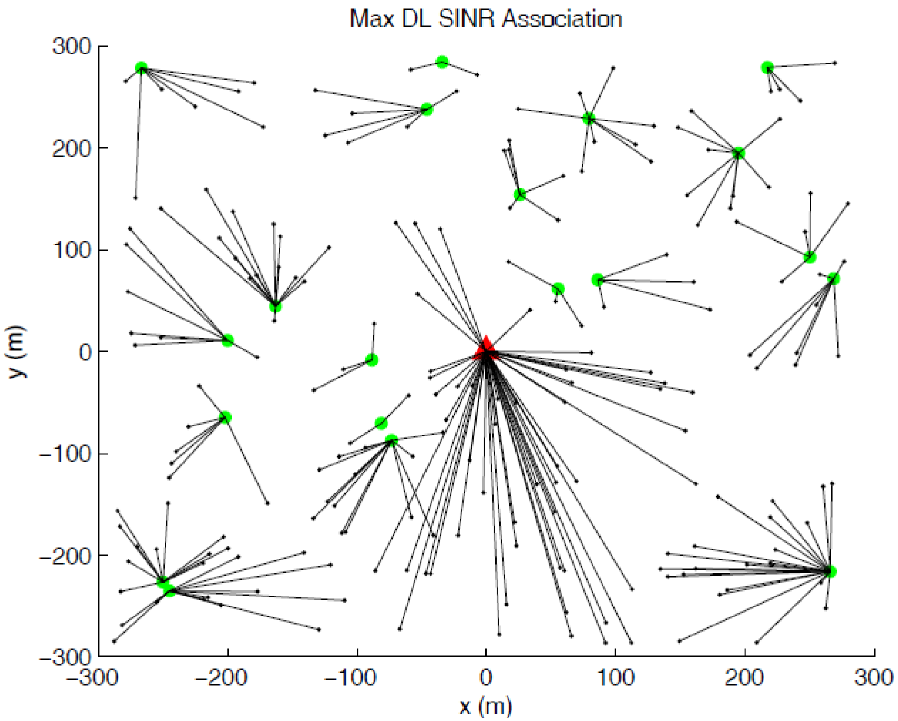
Update the association pattern of each MS 1-by-1 with the rule in Proposition 2.

3. Finalizing:

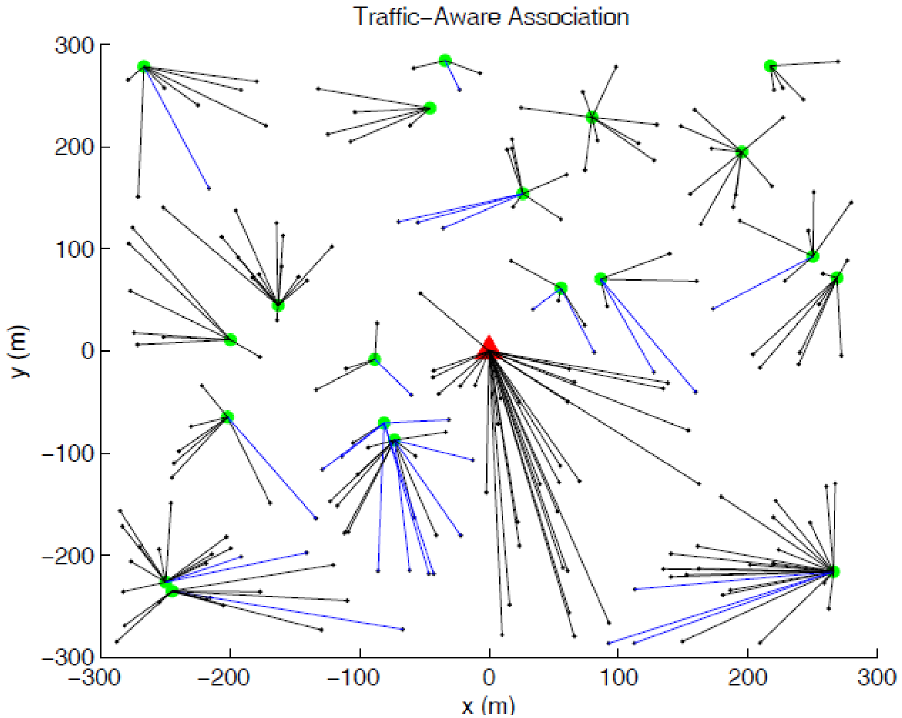
Make the converging association pattern a practical one:

$$x_{k,n}^{(f)} = 1\{x_{k,n} > x_{k,l}, \forall l \neq n\}$$

Simulations

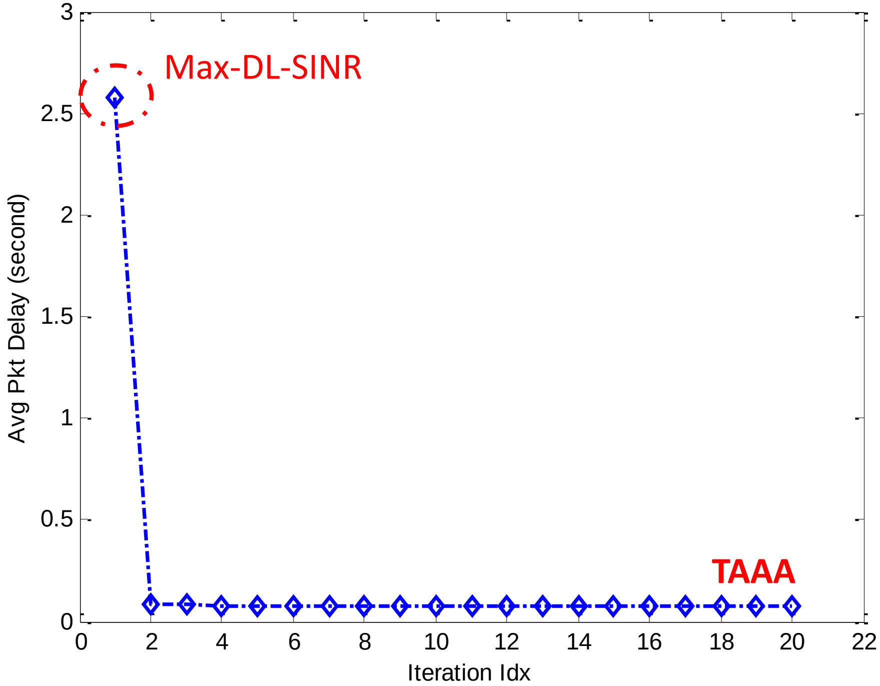


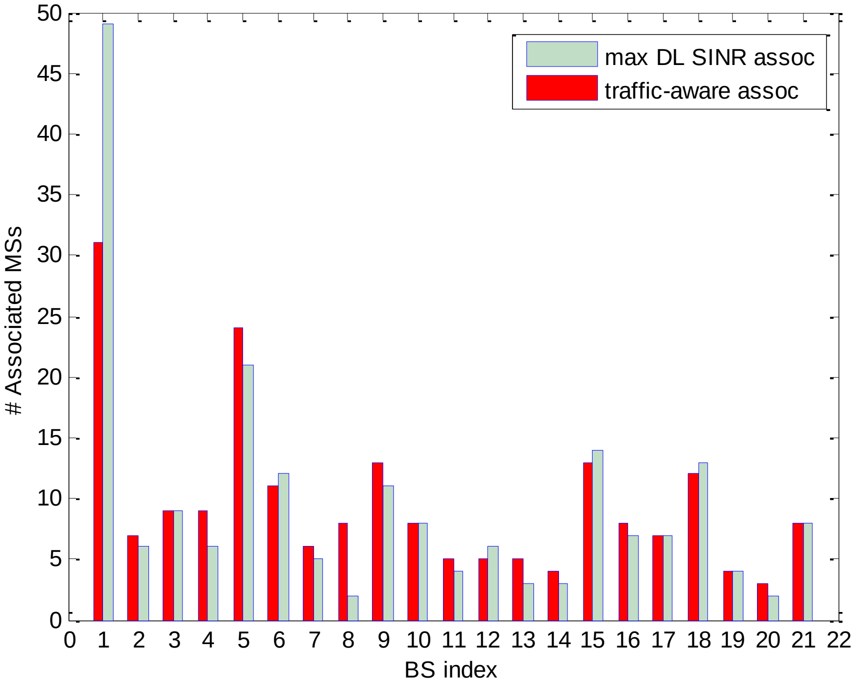
Maximum DL SINR association (Red Triangle: Macro-BS; Green Circle: Pico-BS; Black Dot: MS).



Traffic-aware association (Blue links indicate the association changes w.r.t. the Max-DL-SINR rule).

Simulations





Average packet delay and load of each BS

Conclusion

- **In heterogeneous networks with QoS traffic:**
  - ✓ Closed-form optimal resource allocation when users' association pattern is fixed
  - ✓ Closed-form optimal association scheme for one MS when given others' association
  - ✓ Our proposed low-complexity association algorithm: TAAA enjoys fast convergence and provides significant performance gain