Efficient mmWave Wireless Backhauling for Dense Small-Cell Deployments

Ming Hsieh Department of Electrical Engineering

USC Viterbi School of Engineering

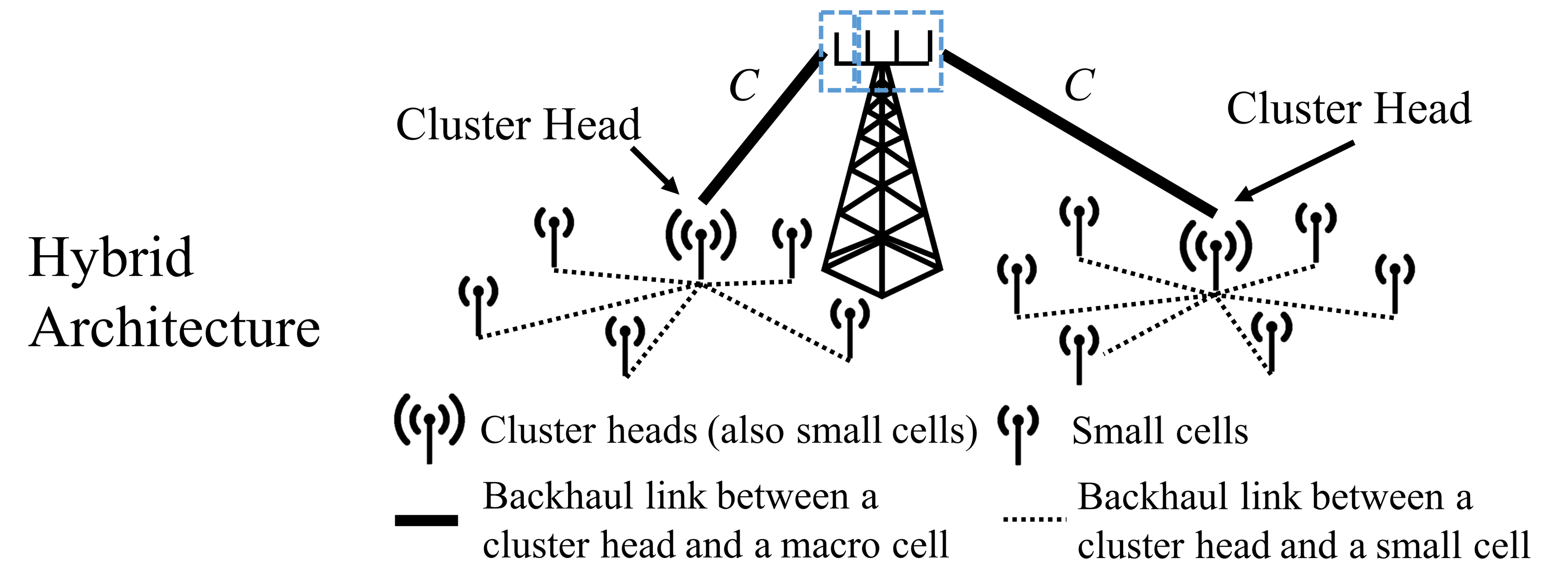
Po-Han Huang and Konstantinos Psounis

Motivation

- High demand for 5G cellular networks → Dense small-cell deployments → Wireless backhauling via mmWave and hybrid beamforming for these small cells
- Model mmWave backhaul links by dedicated macro-cell antennas as pseudo-wires with limited interference
- New algorithms for wireless backhauling required
  - ✓ To optimally select cluster heads among the small cells
  - ✓ To optimally select the link capacity of the backhaul links between the macro cell and the cluster cells
    - ➢ how many antennas of the macro cell to dedicate at each backhaul link
  - ✓ To maximize the achieved system throughput

Notation	Description
x_i	Decision variable specifying which small cell i is a cluster head
$y_{i,j}$	Decision variable specifying to which cluster head i a small cell j is connected
$\mathcal{S}$	The set of small cells
d_i	Distance between macro cell and cluster head i
P_t	Transmission power of macro cell
W	Bandwidth of a frequency slot
N_0	Noise power spectral density
α	Path loss exponent
C	Backhaul capacity for every cluster head
$N_i(C, d_i)$	Number of antennas for backhauling of cluster head i
N_{MAX}	Maximum number of available antennas in macro cell
$\mathcal{A}: a_{i,j}$	Adjacency matrix and its elements

System Architecture



- Consider the saturation throughput regime
- Assume each link between a cluster head and the macro cell has the same capacity for load balancing
- Use hybrid beamforming: $N_i(C, d_i) = \left\lceil \frac{(2^{\frac{C}{W}} - 1) N_0 W d_i^{\alpha}}{P_t} \right\rceil$

Mixed Integer Nonlinear Programming (MINLP)

$$\max_{x_i, y_{i,j}, C} \sum_{\forall i \in \mathcal{S}} C \cdot x_i$$ } Maximize the total throughput

subject to

$$y_{i,j} \le x_i \cdot a_{i,j}, \ \forall i, j \in \mathcal{S}$$
$$\sum_{\forall i \in \mathcal{S}} y_{i,j} = 1, \ \forall j \in \mathcal{S}$$
} Coverage constraints

$$\sum_{\forall i \in \mathcal{S}} N_i(C, d_i) \cdot x_i \le N_{MAX},$$ } Antenna constraint

$$x_i = \{0, 1\}, \ \forall i \in \mathcal{S}$$
$$y_{i,j} = \{0, 1\}, \ \forall i, j \in \mathcal{S}$$
$$C \in \mathbb{R}+$$

Tradeoff $C \leftrightarrow \sum_{\forall i \in \mathcal{S}} x_i$

Alternate Convex Search Heuristic (ACSH)

Fix $x_i, \forall i \in \mathcal{S}$

Initialization

Randomly picking up a set of $x_i, \forall i \in \mathcal{S}$, e.g., (1,…,1). $O = 0$ & $O^* = 0$

Check Improvement

If $O \ge O^*$, $O^* = O$, and continue the algorithm

Else, stop the algorithm

(x_i)

Rounding Version

Solve the following eq.

$$\sum_{\forall i \in \mathcal{S} \& x_i = 1} \tilde{N}_i(C, d_i) = N_{MAX}$$

$$\tilde{N}_i(C, d_i) = \frac{(2^{\frac{C}{W}} - 1) N_0 W d_i^{\alpha}}{P_t}$$

Time Complexity:

$O(c|\mathcal{S}|^2 \log|\mathcal{S}| + |\mathcal{S}| \log|\mathcal{S}|)$

Fix C

Knapsack Problem

Input: $x_i', N_i, \forall i \in \mathcal{S}$, C, and N_{MAX}.
Output: $x_i, \forall i \in \mathcal{S}$.

```
Initialize x_i, ∀i ∈ S = x'_i, ∀i ∈ S
Sort ∀i ∈ S and x_i = 0 by R_i = C / N_i
    in ascending order with new index ĩ.
for ∀ĩ ∈ S do
    if N_MAX − N_ĩ ≥ 0 then
        x_ĩ = 1
        N_MAX = N_MAX − N_ĩ
    end if
end for
```

Using $x_i, \forall i \in \mathcal{S}$ to obtain O

(x_i, O, x'_i, C)

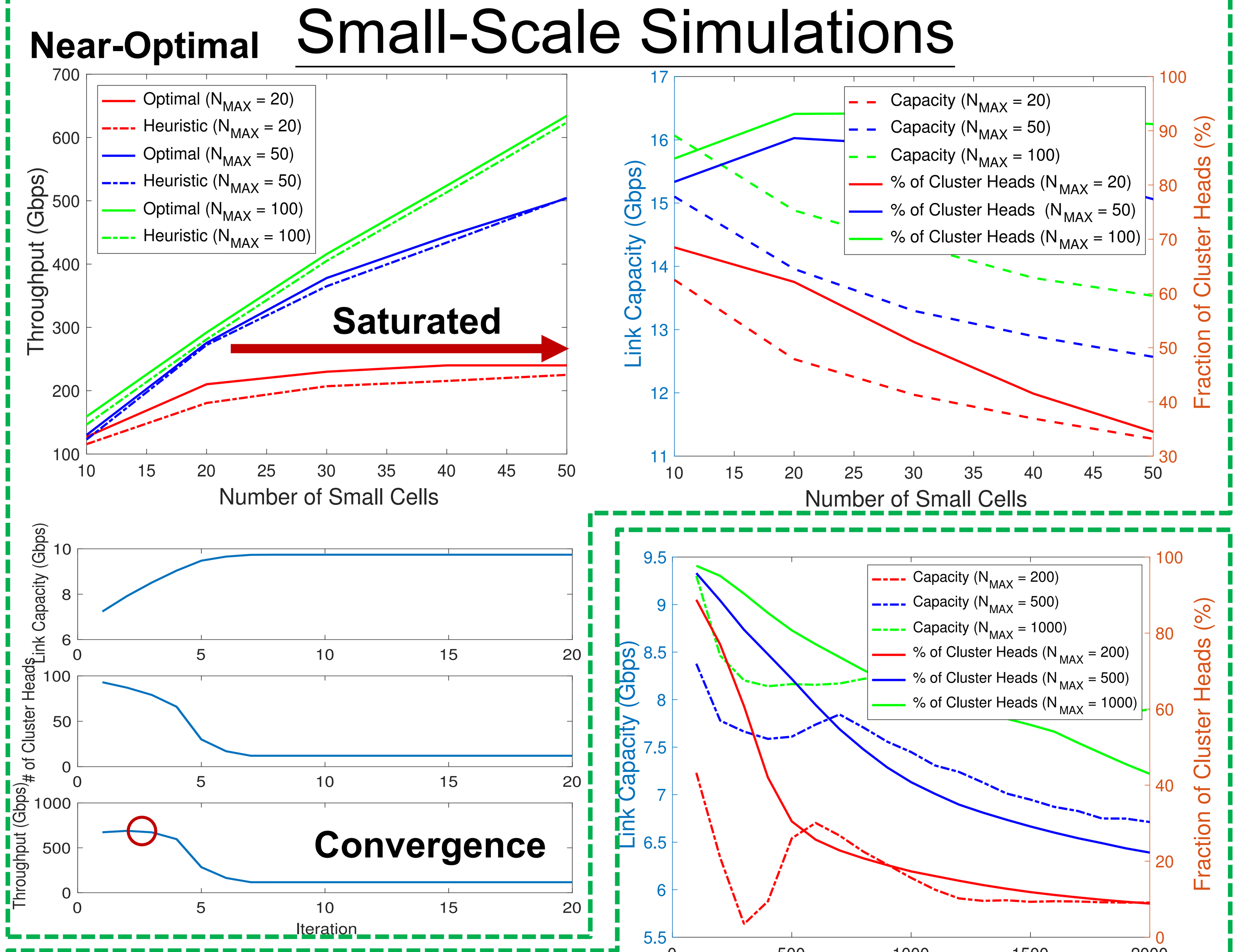
Set-Cover Problem

Input: $N_i, \forall i \in \mathcal{S}$.
Output: $x_i, \forall i \in \mathcal{S}$.

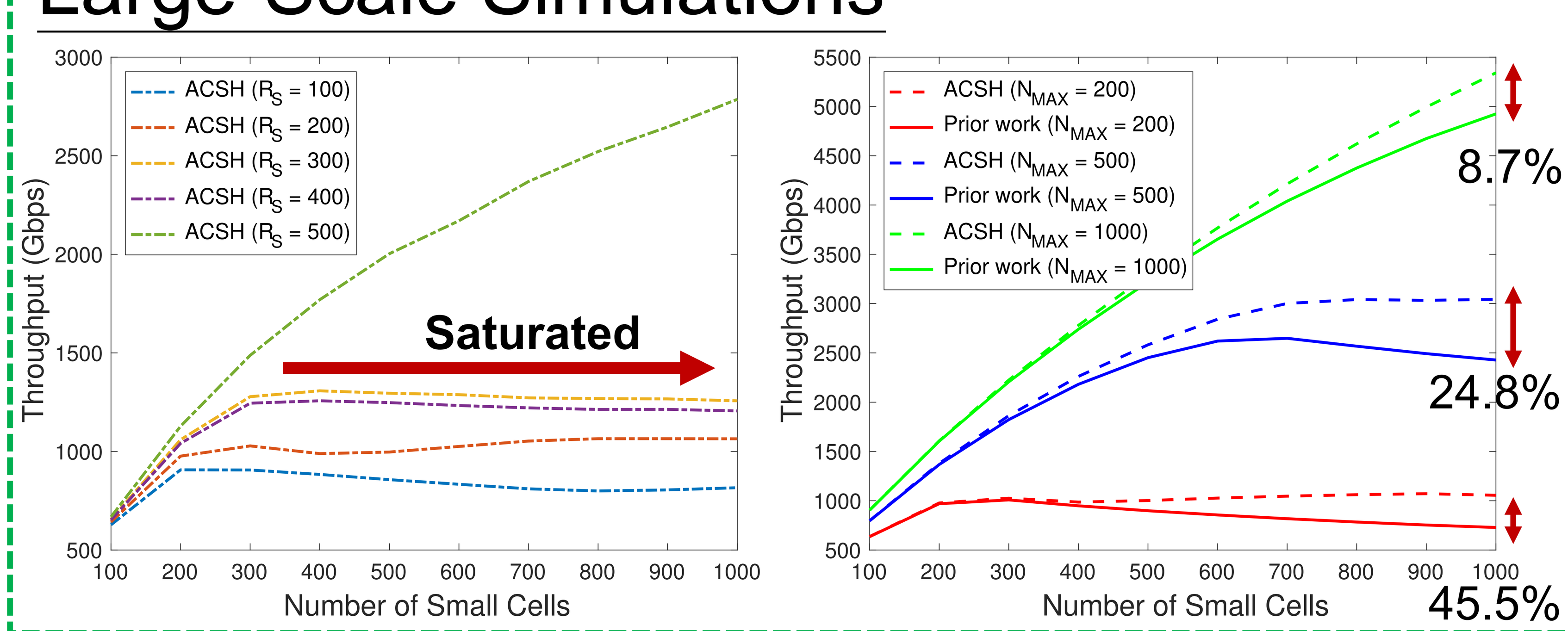
```
Initialize x_i, ∀i ∈ S = {0, ..., 0}.
Calculate |S_i|, ∀i ∈ S.
while |S|! = 0 do
    ĩ = arg max_{∀i∈S} K_i = N_i / |S_i|
    x_ĩ = 1
    S ← S − ĩ
    Update |S_i|, ∀i ∈ S.
end while
```

Simulation Results of ACSH

Small-Scale Simulations



Large-Scale Simulations



pohanh@usc.edu

Ming Hsieh Institute
Ming Hsieh Department of Electrical Engineering