# Metropolitan-Scale Radio Resource Management

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in collaboration with Zhiyi Zhou, Binnan Zhuang, Ermin Wei, Michael L. Honig

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Northwestern University

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May 11, 2017

# New spectrum and technologies for 5G and IoT

- ▶ Heterogeneous frequency resources, including lower frequencies and millimeter wave bands (e.g., 700 MHz, 28 GHz, 37 GHz, 39 GHz, 64-71 GHz, ...);
- ▶ Many small cells;
- ▶ Many antennas (massive MIMO);
- ▶ Full duplex;
- ▶ Massive/grant-free access for IoT;
- ▶ Non-orthogonal multiple access for IoT;
- ▶ Traffic and interference will vary significantly from cell to cell.

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# Metropolitan-scale deployment
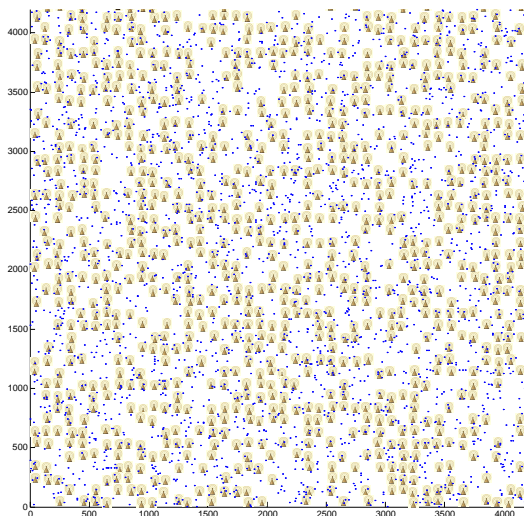
## Radio resource management (RRM)

At any time, which access points (APs) should serve a given user equipment (UE)?

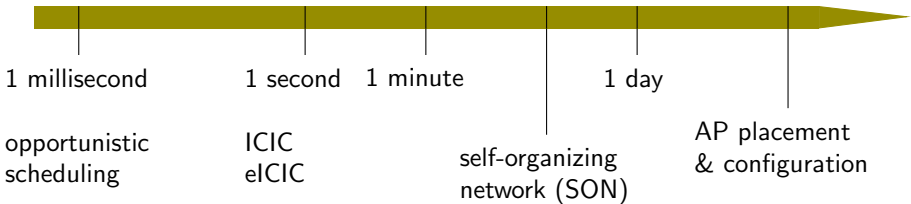What frequencies and powers should each AP-UE link use?
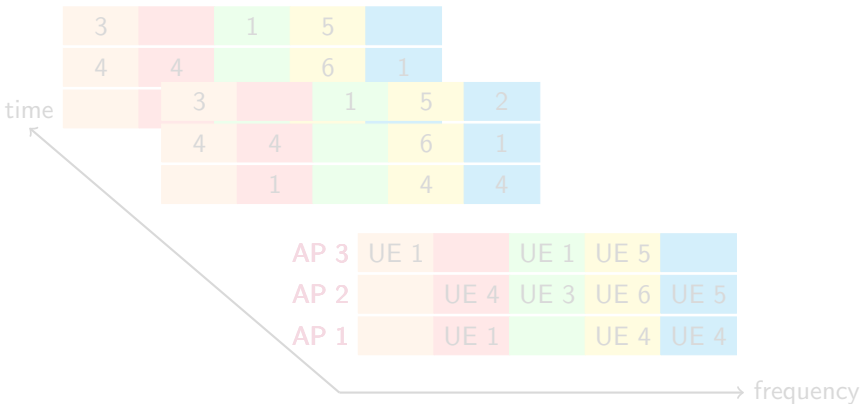
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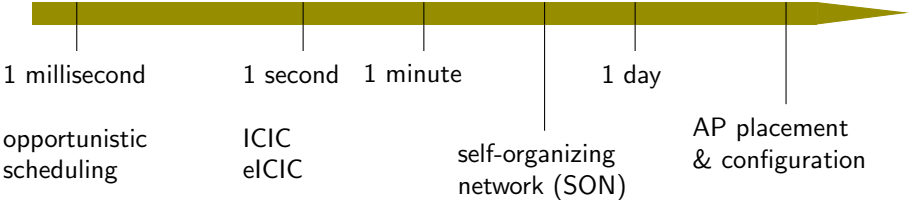What frequencies and powers should each AP-UE link use?

## Timescales



1 millisecond            1 second    1 minute              1 day

opportunistic            ICIC                                        AP placement
scheduling               eICIC                                       & configuration
                                     self-organizing
                                     network (SON)

▶ Scheduling is likely to be distributed, cooperation is local;

▶ The aggregate traffic demand and large-scale fading vary slowly;

▶ Coarse resource allocation can be carried out over a metropolitan area.

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# Cloud radio access network (C-RAN)
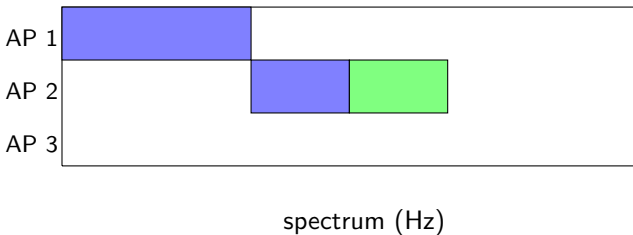


(NEC labs)
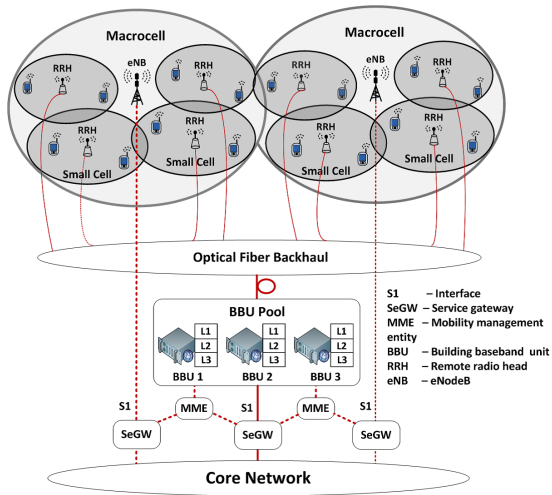
## Our vision: C-RAN + Metropolitan-area RRM

Metropolitan-area
radio resource
management
(Ma-RRM)

C-RAN scheduler

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(average) traffic conditions



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(average) channel state information

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(average) traffic conditions



Metropolitan-area radio resource management (Ma-RRM)

queue states

C-RAN scheduler

(average) channel state information

# Our vision: C-RAN + Metropolitan-area RRM



(average) traffic conditions

Metropolitan-area radio resource management (Ma-RRM)

queue states

C-RAN scheduler

UE-AP associations
carrier assignments
subcarrier assignments

(average) channel state information

# Our vision: C-RAN + Metropolitan-area RRM

Background
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Spectrum management
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Optimized allocation
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Performance
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conclusion
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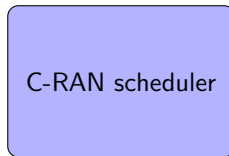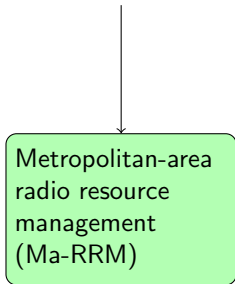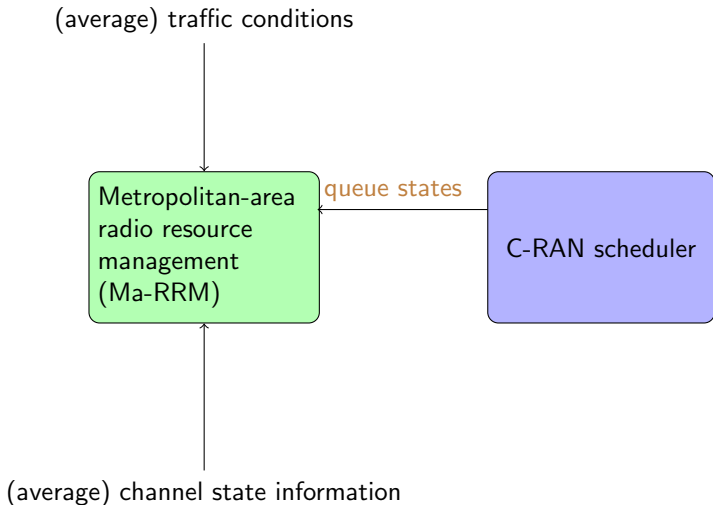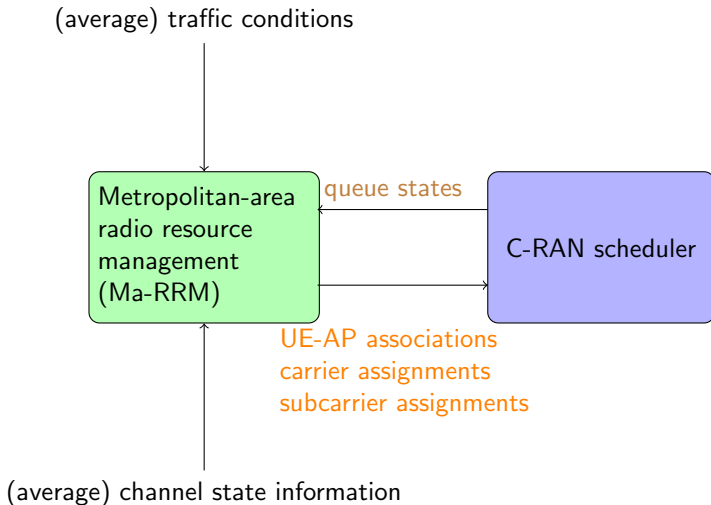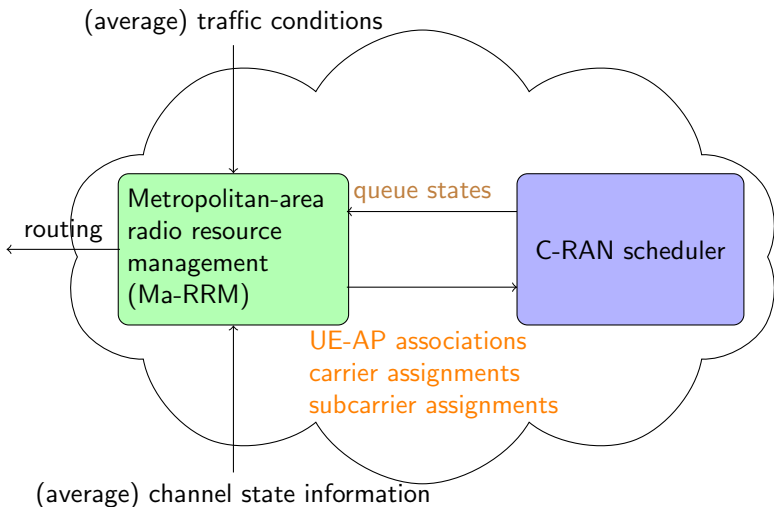
## Radio network model

# Orthogonal spectrum reuse

Background
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Spectrum management
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Optimized allocation
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Performance
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conclusion
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# Orthogonal spectrum reuse



spectrum (Hz)

Background
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Spectrum management
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Optimized allocation
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Performance
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conclusion
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## Orthogonal spectrum reuse



spectrum (Hz)

Background
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Spectrum management
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Performance
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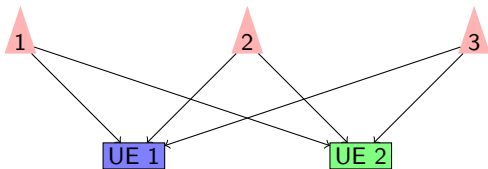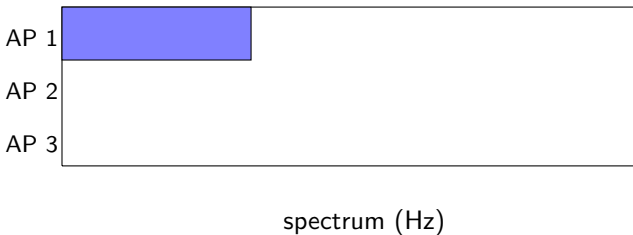
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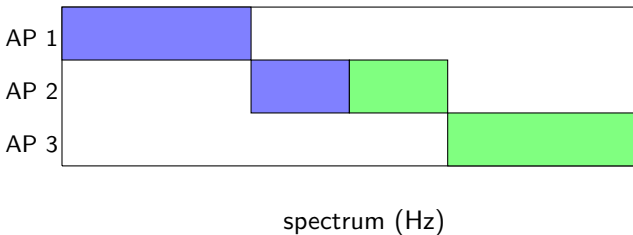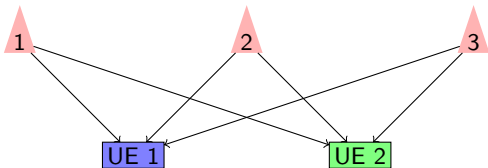


spectrum (Hz)

# Full spectrum reuse
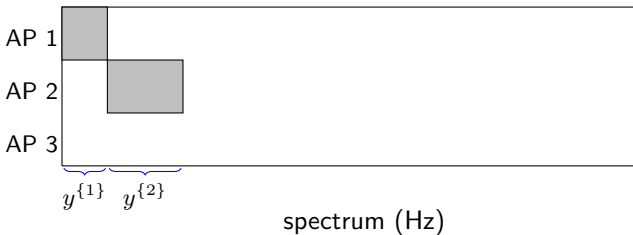
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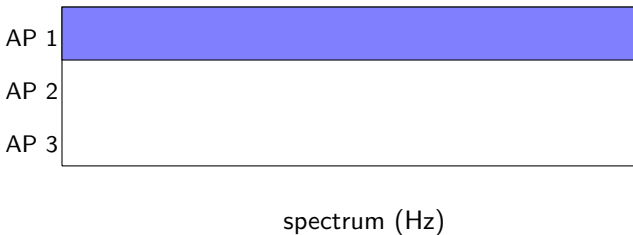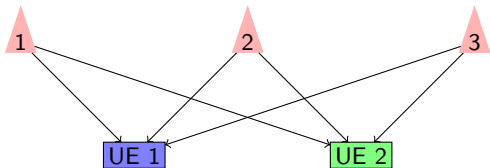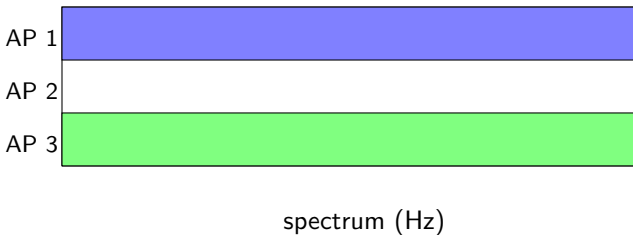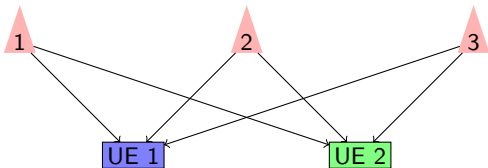


spectrum (Hz)

## Full spectrum reuse

# Fully flexible spectrum allocation
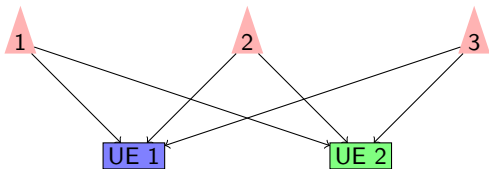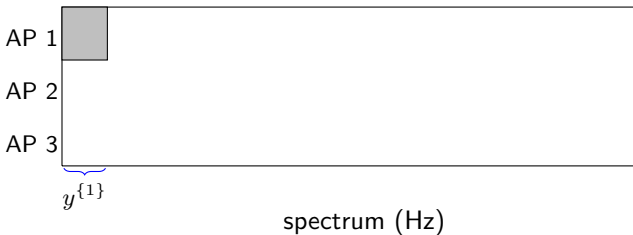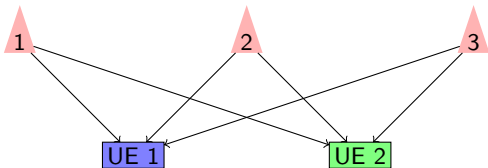
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spectrum (Hz)
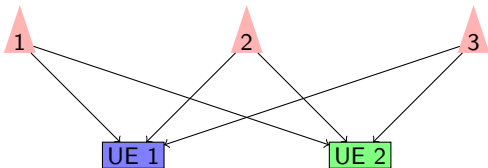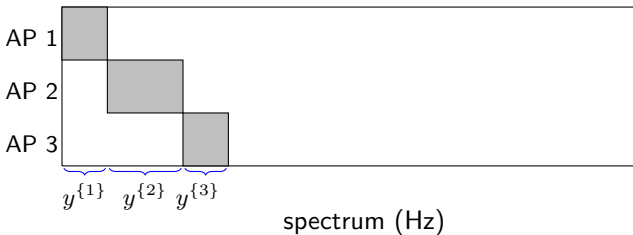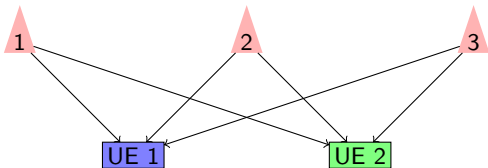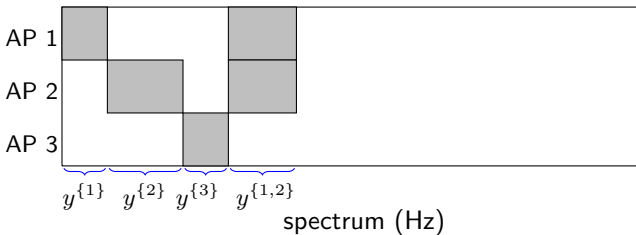
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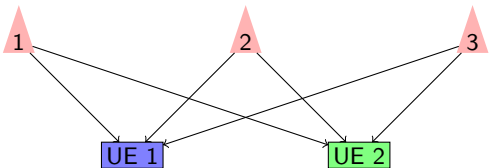
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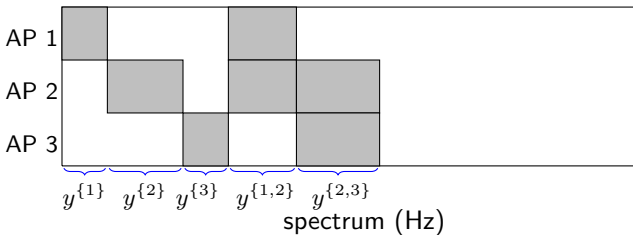
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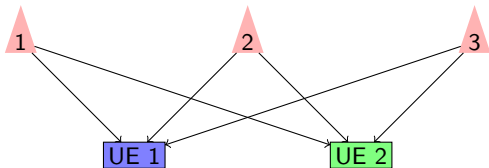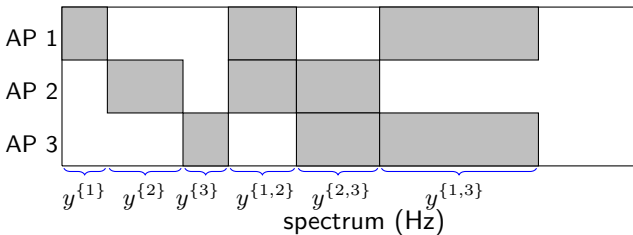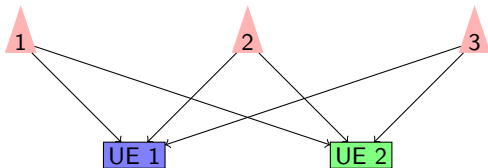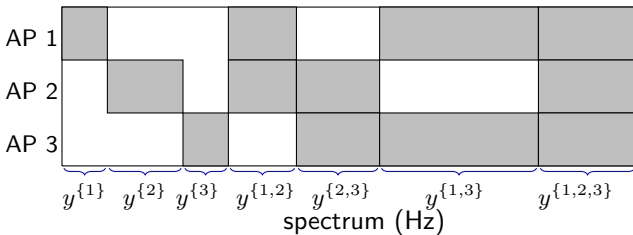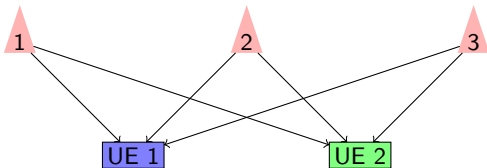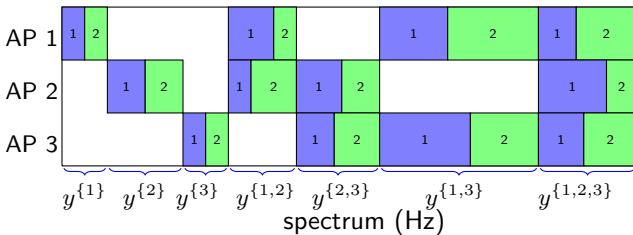# Fully flexible spectrum allocation

Background
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Spectrum management
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Optimized allocation
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Performance
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conclusion
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## The basic formulation

$$\underset{\boldsymbol{r},\boldsymbol{w},\boldsymbol{y}}{\text{maximize}} \ u(r_1,\ldots,r_k)$$

$$\text{subject to} \ r_j = \sum_{A \subset \{1,\ldots,n\}} \sum_{i \in A} s_{i \to j}^A w_{i \to j}^A, \quad j = 1,\ldots,k$$

$$\sum_{j=1}^{k} w_{i \to j}^A \le y^A, \quad A \subset \{1,\ldots,n\}, i \in A$$

$$\sum_{A \subset \{1,\ldots,n\}} y^A = 1$$

$$w_{i \to j}^A \ge 0, \quad j = 1,\ldots,k, \ A \subset \{1,\ldots,n\}, \ i \in A.$$

▶ It is a convex optimization problem.
▶ It has an optimal solution that activates at most $k$ patterns.
▶ It has $kn2^{n-1} + 2^n + k$ variables.
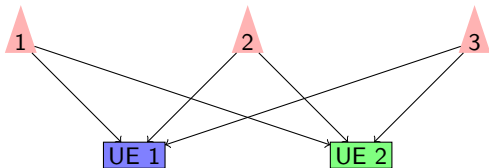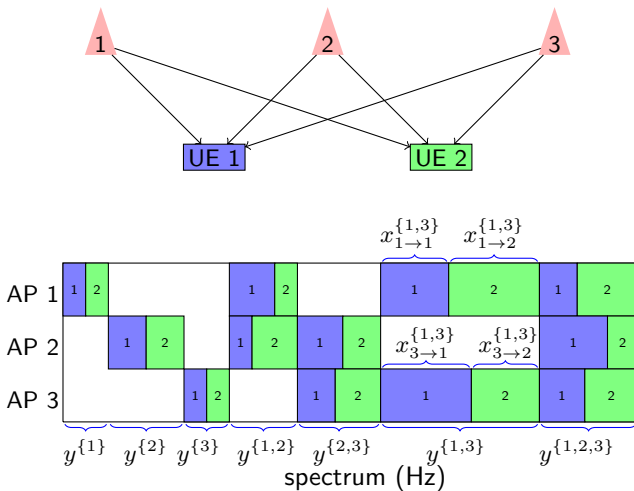
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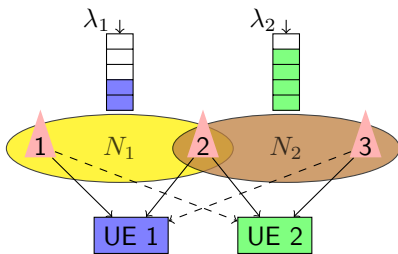
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Background
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Spectrum management
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Optimized allocation
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Performance
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conclusion
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# A user-centric scalable model



- ▶ Each UE can be served only by a cluster of APs in its neighborhood;
- ▶ Out-of-cluster APs treated as stationary noise sources;
- ▶ Equivalent reformulation as iterative binary linear programming with $O(k)$ variables with guaranteed optimality gap;
- ▶ Solved using a highly efficient iterative pattern-pursuit algorithm.

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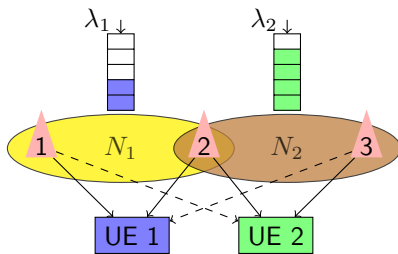
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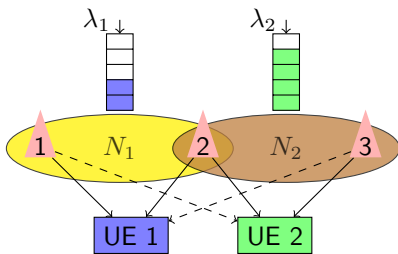
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# 1000 APs and 2500 UEs: topology and association
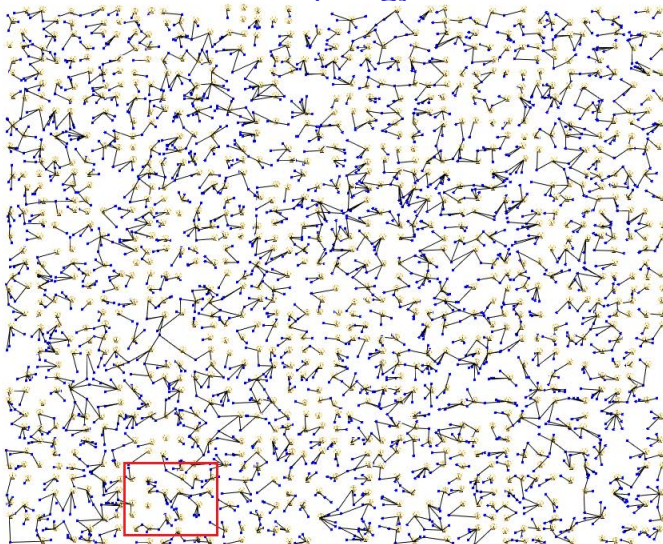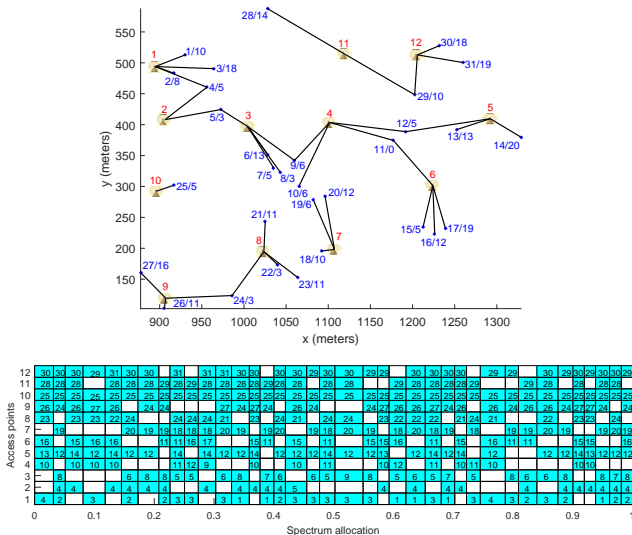
# Local topology and allocation

## Baseline schemes

▶ Full-spectrum reuse with strongest AP association;

▶ Full-spectrum reuse with optimal AP-UE association;

▶ A theoretical lower bound.

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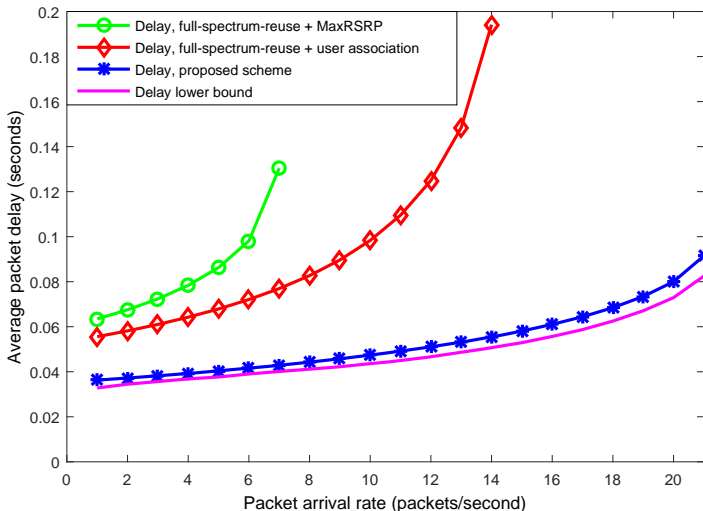- ▶ A theoretical lower bound.

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# 1000 APs and 2500 UEs: delays

# 1000 APs and 2500 UEs: packet-level simulation

# Conclusion

▶ A vision for metropolitan-area multiple-timescale resource management;

▶ A user-centric scalable model;

▶ A highly efficient iterative pattern-pursuit algorithm;

▶ Guaranteed optimality gap;

▶ The framework is potentially applicable to some other metropolitan-scale resource management problems.

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Background
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Spectrum management
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