MatchMaker: An Inter-operator Network Sharing Framework in Unlicensed Bands

Mohammed Hirzallah[1], Yong Xiao[2], and Marwan Krunz[1]

[1]The University of Arizona, Tucson, Arizona

[2]HUST, Wuhan, China

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Outline

Motivation - Network Sharing over Unlicensed Spectrum

MatchMaker – Overview and Architecture

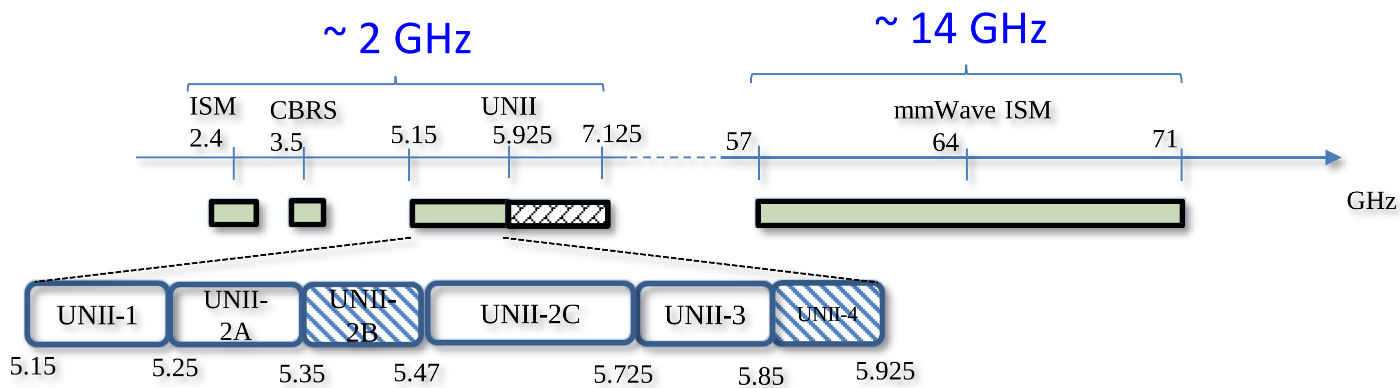
Problem Statement – Channel Assignment

Graph Coloring Evolution Algorithm

Performance Evaluation

5G NR Unlicensed (NR-U)

- Extends 3GPP 5G NR to unlicensed bands
- Initial interest in UNII bands at 5 GHz and 6 GHz bands

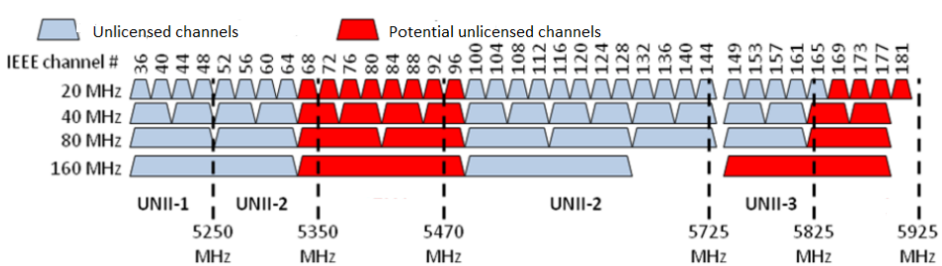


Issues:

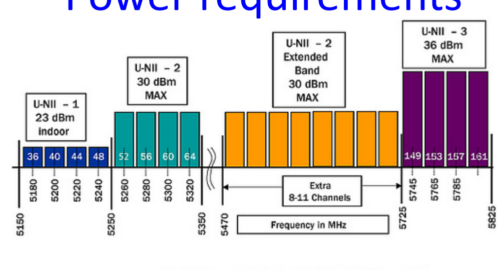
Fairness: How to achieve harmonious coexistence with Wi-Fi systems

Coverage and site restrictions: 10s to 100s of BS's needed to cover important sites (given UNII power masks) ➔ high cost

Channelization



Power requirements



Network Infrastructure Sharing

Infrastructure sharing enables 5G NR operation in sites with deployment restrictions, e.g., airports, malls, downtown areas, etc.

Challenges:

1) MNO privacy issues (e.g., traffic load, user locations, CSI, etc.)
2) Communication overhead between master operator (MOP) and MNOs

3GPP is currently limited to network sharing over licensed spectrum

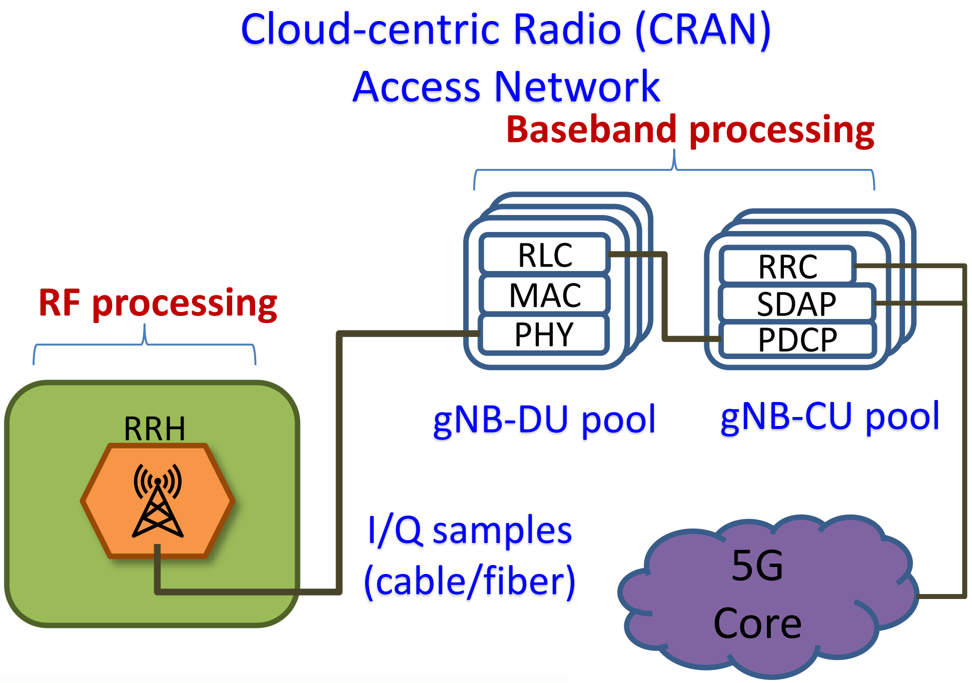
eMBB Services

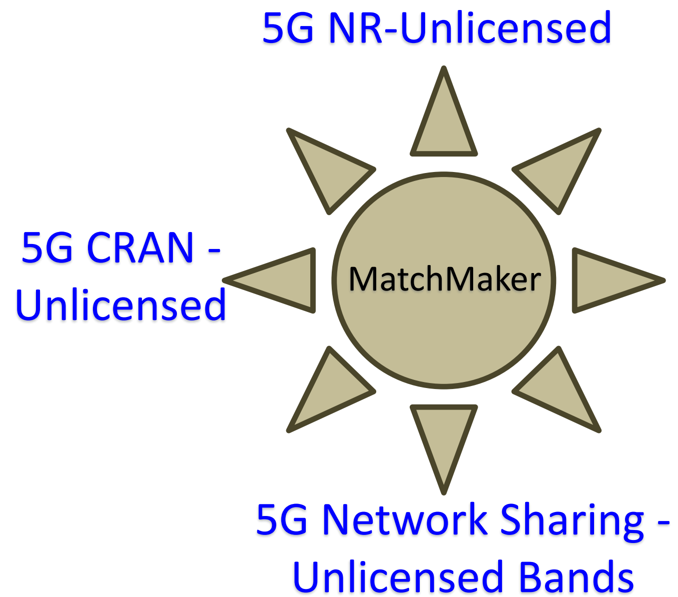
Airport authority deploys network and provides interfaces to MNOs

Proposed MatchMaker

Goals:

1. Introduce novel techniques for efficient network sharing between NR-U operators as part of a CRAN-based architecture
2. Exploit learning tools to ensure fair, efficient, and privacy-preserving channel assignment in the presence of coexisting NR-U/Wi-Fi systems





MatchMaker Architecture (1/2)

Shared network infrastructure domain:

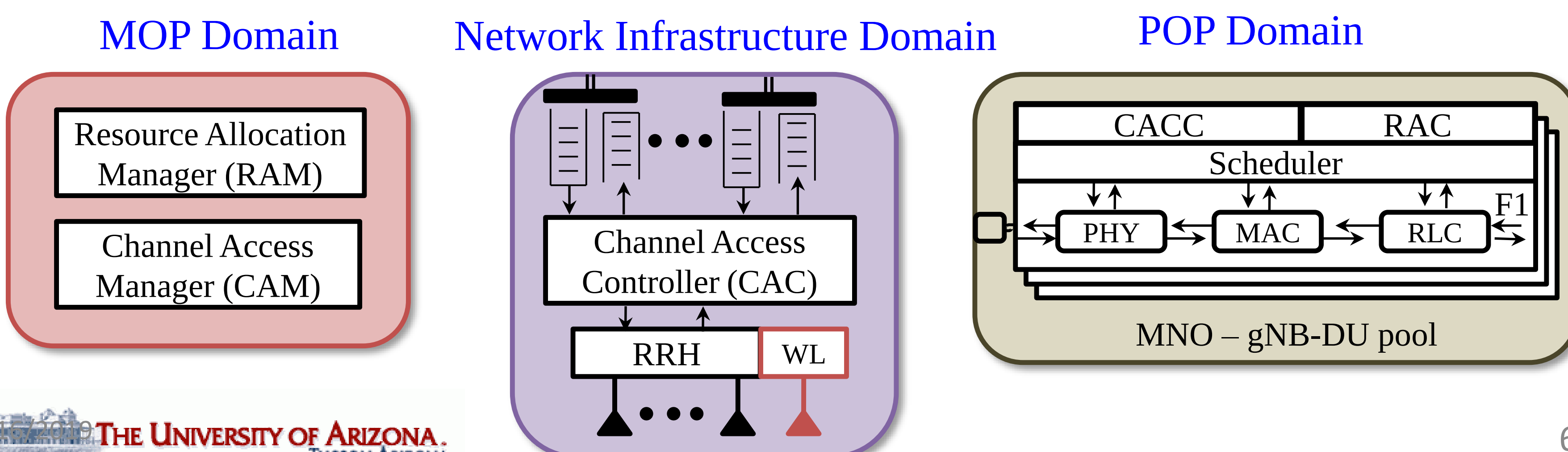
- RRH unit: Handles RF processing for MNOs' I/Q data
- Wi-Fi Listener (WL) unit: Monitors/estimates Wi-Fi performance
- CAC unit: Performs NR-U listen-before-talk (LBT) procedure

MOP domain:

- Manages resource allocation and channel access among MNOs

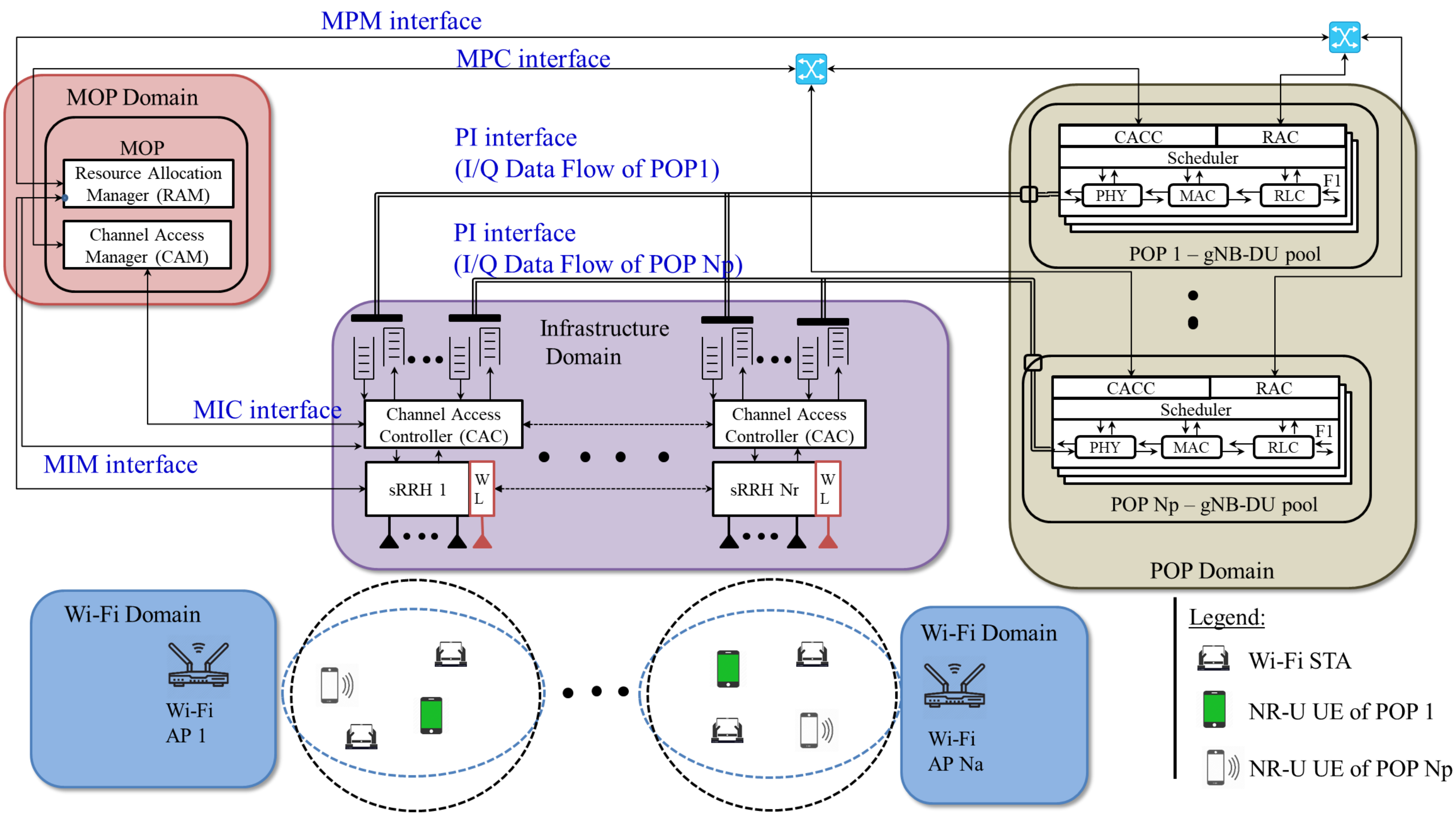
Participating operator (POP), i.e., MNO, domain:

- MNOs handle NR-U radio stack functions and most of PHY processing except for RF processing and LBT procedure



MatchMaker Architecture (2/2)

We define new interfaces & protocols to facilitate NR-U over shared infrastructure



Channel Assignment Problem

Consider n MNOs that share N_c channels with m Wi-Fi APs

<u>Goal</u> is to assign channels so as to maximize fairness subject to a constraint on the access delay

Define Utility vector $\bar{v}_k$ for channel k:

$$\bar{v}_k = < \frac{1}{D_{1,k}}, \cdots, \frac{1}{D_{n,k}}, \frac{1}{B_{1,k}}, \cdots, \frac{1}{B_{m,k}} >$$

$D_{j,k}$ is channel access delay for MNO j working on channel k

$B_{i,k}$ is channel access delay for Wi-Fi i system working on channel k

Alpha-Fairness metric $\boldsymbol{F}(\bar{\boldsymbol{v}}\,; \boldsymbol{\alpha})$ measures fairness among N agents:

$$\mathcal{F}(\bar{\nu}; \alpha) = \begin{cases} \sum_i^N \nu_i^{1-\alpha}/(1-\alpha) & , \alpha \neq 1 \\ \sum_i^N \log(\nu_i) & , \alpha = 1 \end{cases}$$

Channel Assignment Problem (cont.)

Maximize $\quad \sum_k F(\bar{v}_k; \alpha)$

$\{1_{j,k}\}$

s.t. $\quad D_{j,k} \le D_j^*, \quad$ for NR-U MNO j

$\quad B_{i,k} \le B_i^*, \quad$ for Wi-Fi system i

Maximum NR-U channel access delay

Maximum Wi-Fi channel access delay

Decision variables:
MNO j is assigned channel k

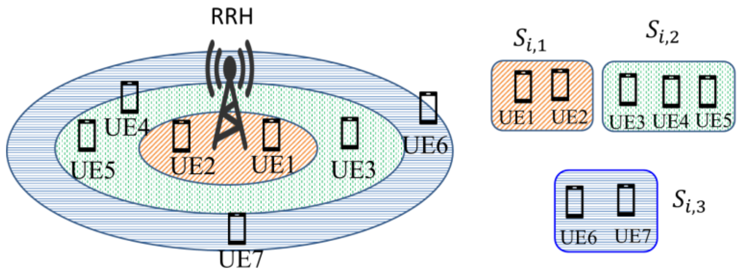
Solving above problem requires MNOs private info (e.g., traffic load, CSI, user locations, etc.) at MOP ➔ privacy concerns + high communication overhead

Instead, we rely on a heuristic approach based on graph coloring evolution

Highlights of GCE Algorithm

Exploit graph coloring evolution (GCE) algorithm to maximize fairness in channel assignment while constraining the maximum contention delay

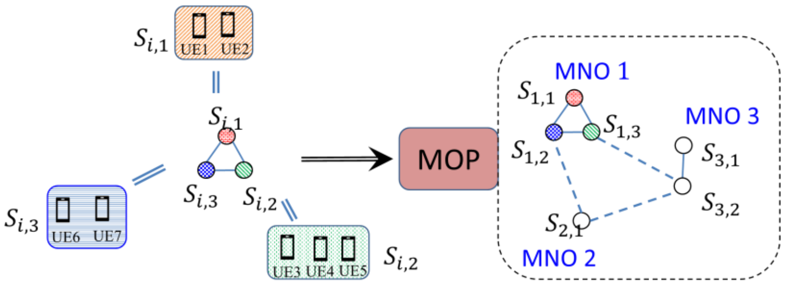
Step 1: Each MNO classifies its UEs into groups based on MNO's own (private) criterion, and assigns UEs to distinct channels



Intra-MNO channel assignment
for ith MNO, $i = 1, 2, \ldots$

Highlights of GCE Algorithm

Step 2: MNOs send requests to MOP, proposing access to certain unlicensed channels and to shared infrastructure



Step 3: MOP monitors MNOs' channel access delay & channel requests; it learns connectivity graph and interference seen by MNOs' UEs

$\Delta F_{i,k}$: Normalized differential improvement of Alpha-fairness caused by assigning MNO i to channel k

$$\Delta F_{i,k} = [F^{(t)}(\bar{v}_k;\alpha) - F^{(t-1)}(\bar{v}_k;\alpha)]/F^{(t-1)}(\bar{v}_k;\alpha)$$

Highlights of GCE Algorithm

Step 4: MOP accepts/rejects MNO's proposed channel assignment based on monitored channel access delays (for NR-U and Wi-Fi systems) and learned connectivity graph

Rejection Rule: Reject MNO's channel proposal that leads to least improvement in Alpha-fairness

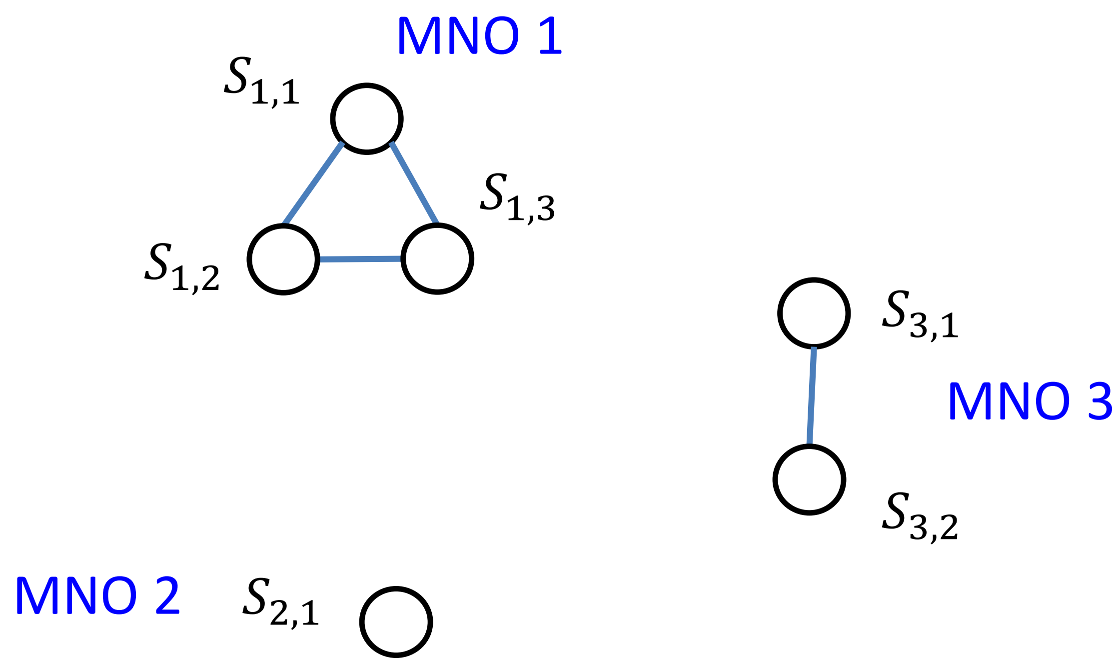
$$\text{Rejected-MNO} = \arg\min_{i} \{\Delta F_{i,k}\}$$

Update graph color and structure by adding edges between rejected vertex and other vertices of the same color

GCE Algorithm - Example

Three MNOs wish to have access to three channels: Channel ‘A’, ‘B’, and ‘C’

t = 0, MOP constructs non-colored connectivity graph with three disconnected cliques



Uncolored: No channel assigned

Green color: Channel A

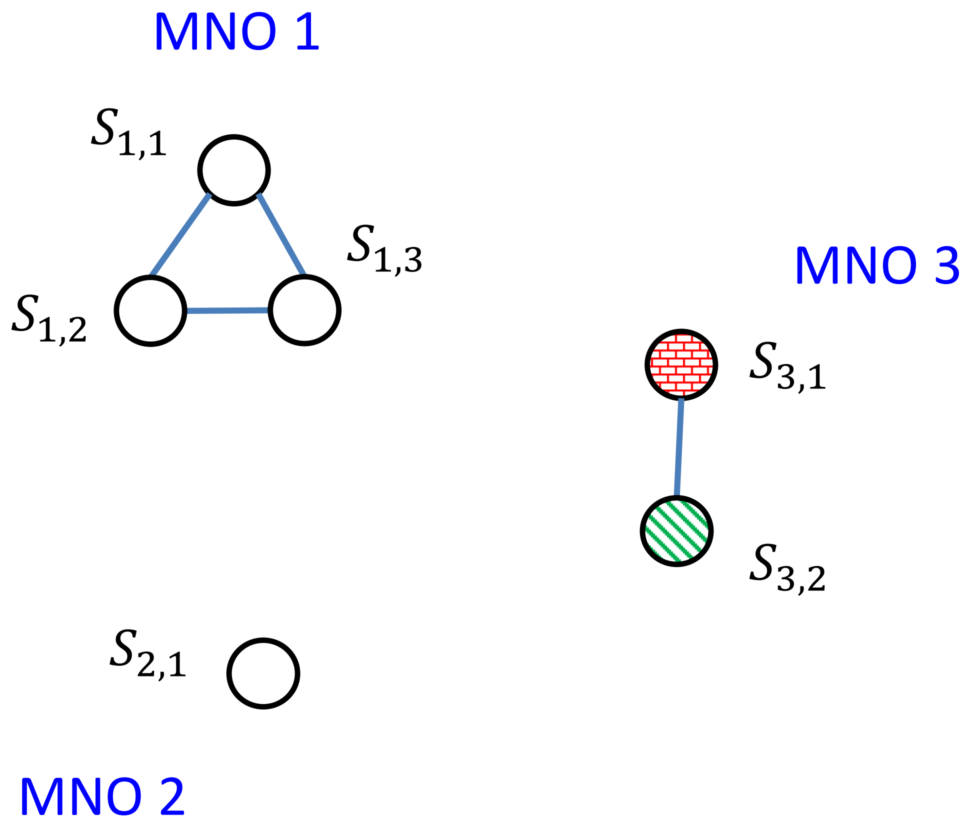
Red color: Channel B

Blue color: Channel C

GCE Algorithm - Example

t = 1,

- MNO3 proposes a coloring scheme for its clique



Uncolored: No channel assigned

Red color: Channel B

Green color: Channel A

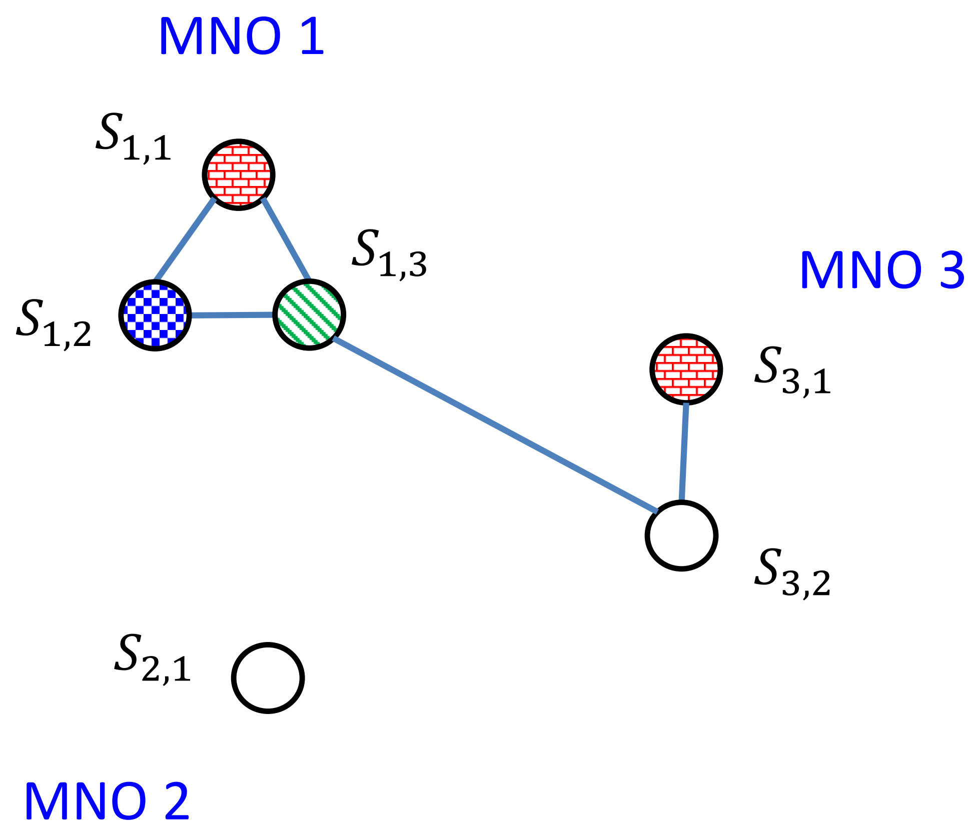
Blue color: Channel C

GCE Algorithm - Example

t = 2,

- MNO1 proposes a coloring scheme for its clique

- MOP rejects MNO3's proposal for $S_{3,2}$, and adds edge between $S_{3,2}$ and $S_{1,3}$



Uncolored: No channel assigned

Green color: Channel A

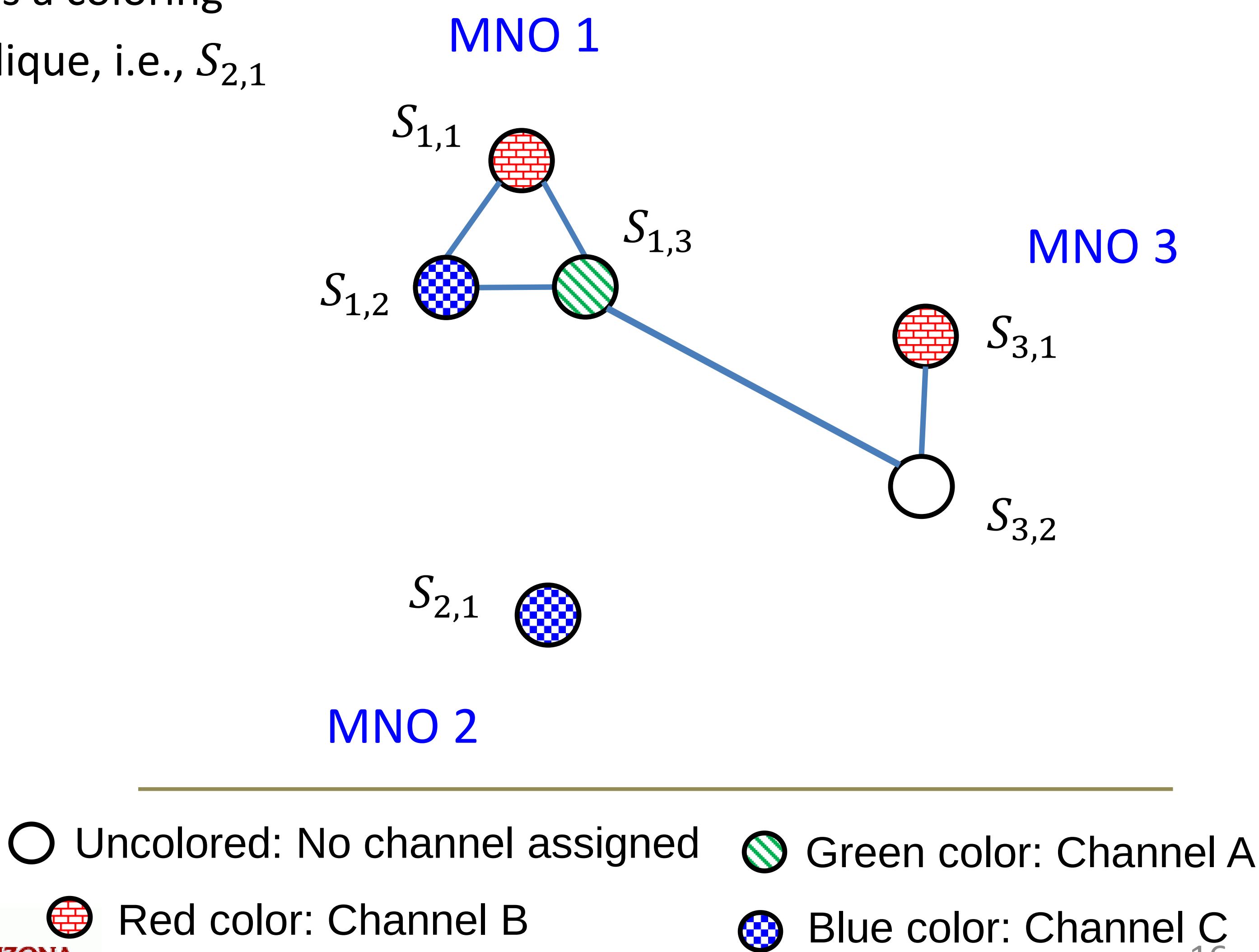
Red color: Channel B

Blue color: Channel C

GCE Algorithm - Example

t = 3,

- MNO2 proposes a coloring scheme for its clique, i.e., $S_{2,1}$

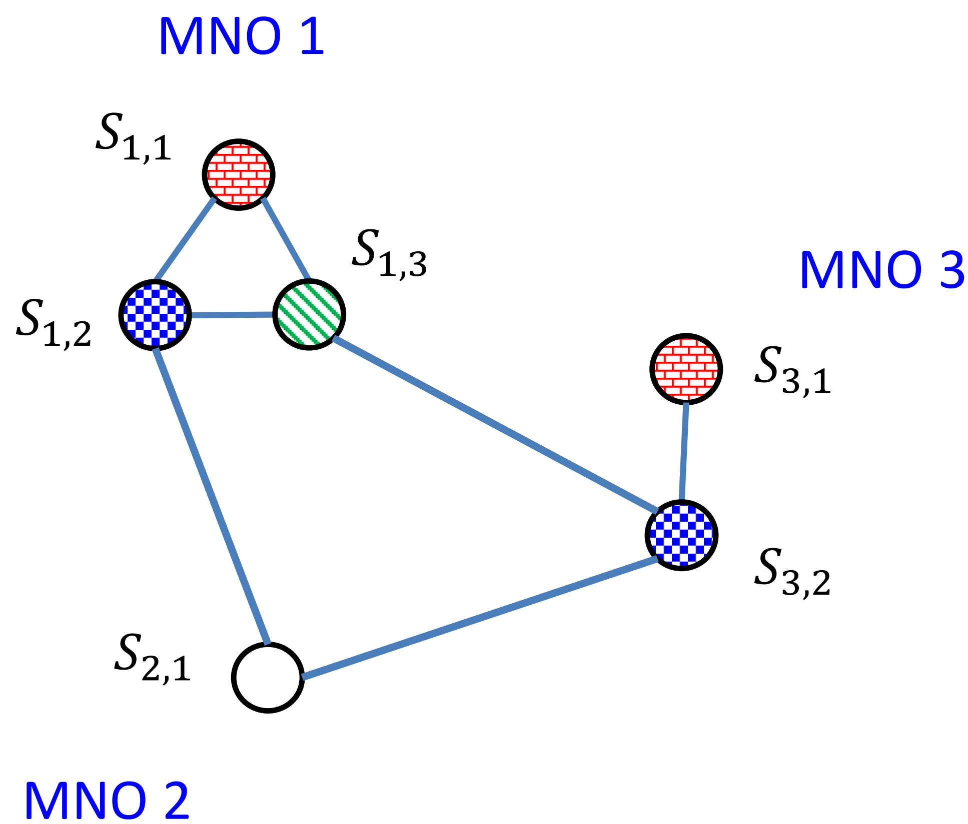


GCE Algorithm - Example

t = 4,

- MNO3 re-proposes a coloring scheme for its $S_{3,2}$

- MOP rejects MNO2's proposal for $S_{2,1}$, and adds edge between $S_{2,1}$ and $\{S_{1,2}, S_{3,2}\}$



Uncolored: No channel assigned

Green color: Channel A

Red color: Channel B

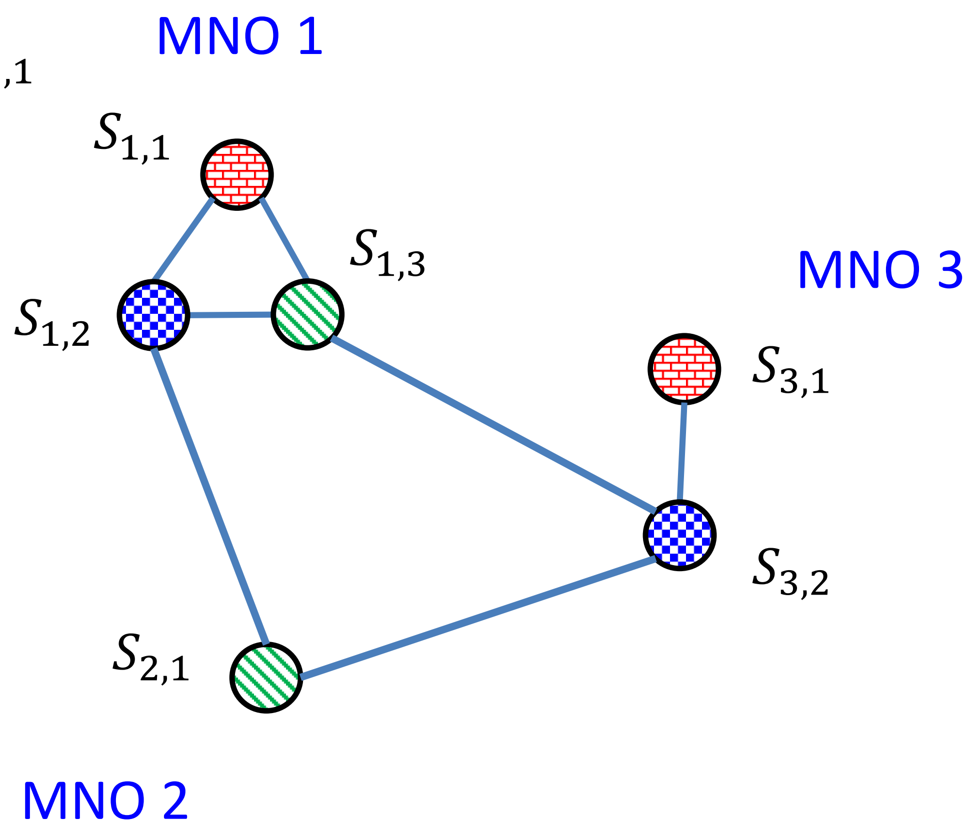
Blue color: Channel C

GCE Algorithm - Example

t = 5,

- MNO2 re-proposes new coloring scheme for its clique $S_{2,1}$

Algorithm terminates



Uncolored: No channel assigned

Red color: Channel B

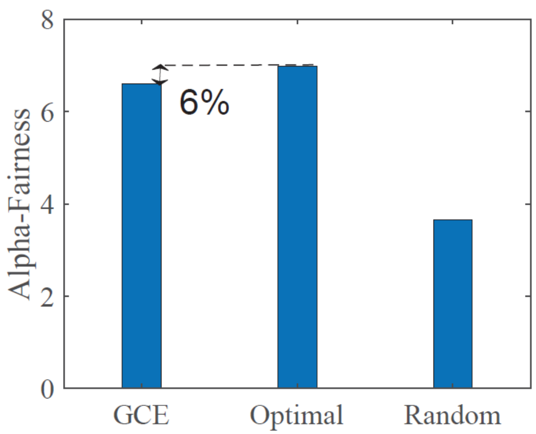
Green color: Channel A

Blue color: Channel C

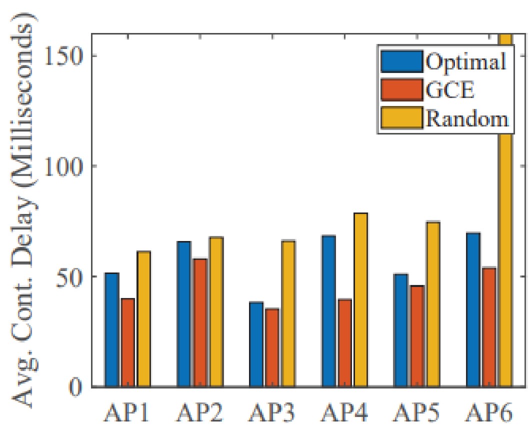
Performance Evaluation

- 6 Wi-Fi APs and 3 NR-U MNOs, sharing 3 channels over a square area of 140 meter length with each AP/MNO serving 6 users
- Maximum allowed contention delay for APs/MNOs is 80 milliseconds
- AP1/AP4 operate on CH 1; AP2/AP5 operate on CH 2; and AP3/AP6 operate on CH 3

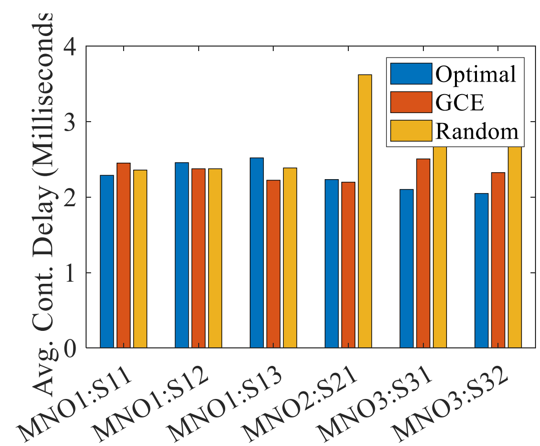
Proportional Fairness



Wi-Fi Contention Delay



NR-U Contention Delay




Thank you
QUESTIONS?