Coexistence-Aware Dynamic Channel Allocation for 3.5 GHz Shared Spectrum Systems

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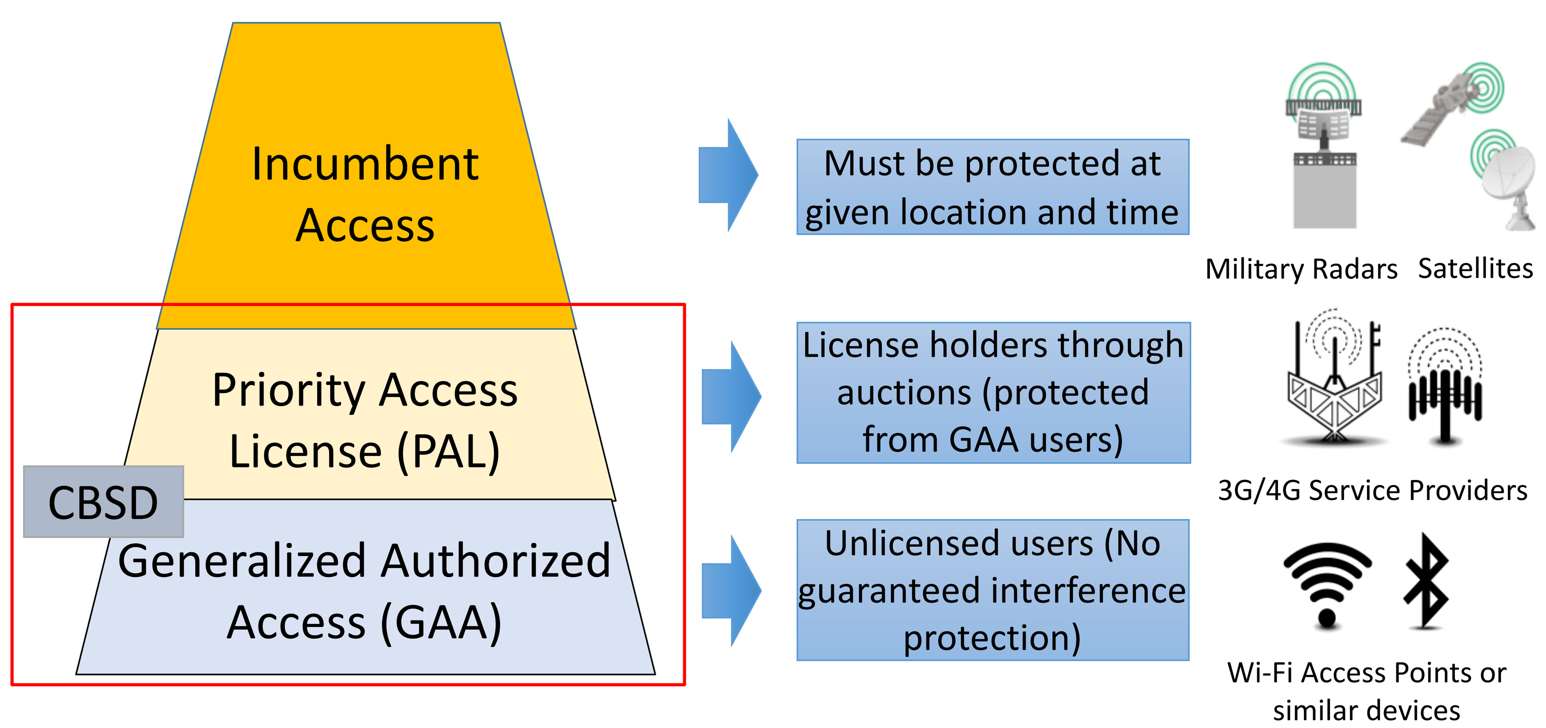
Introduction

- CBRS (Citizens Broadband Radio Service) band: 3550 – 3770 MHz.
- Spectrum Access Server (SAS) implements a three-tiered framework [1].
- First end-to-end trial of a live 3.5 GHz wireless comm. at Bell Labs [2].
- In this work, we introduce radio-channel-pair conflict graphs to capture interference, channel availability, channel contiguity and coexistence.
- We propose a super-radio formation algorithm to identify super-radios based on individual average traffic and carrier-sensing relationship.
- We formulate dynamic channel allocation (CA) as max-demand CA with a min-demand constraint and develop algorithms based on maximum weighted independent set (MWIS) [3] in graph theory.

Three-Tiered Spectrum Management Framework



- CBSD: Citizens Broadband Service Device
- 150 MHz → 15 10-MHz channels (7 channels reserved for PAL users)

Challenges in SAS-Assisted Dynamic Channel Allocation

- Spatial variations in channel availability due to exclusion zones of incumbents (and channel allocation of PAL users).
- Channel contiguity: radios like IEEE 802.11ac operate in a block of 10-MHz channels that are contiguous.
- Coexistence-awareness: multiple interfering GAA radios sharing the same channel(s) (assuming WiFi-like carrier-sensing mechanisms, e.g., CSMA/CA in WLAN, CSAT and LBT in LTE-U/LAA).

Example:

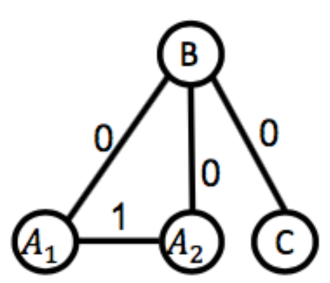


Fig. 1 – Interference graph: 3 CBSDs and 4 radios (A has two radios that cannot be assigned adjacent channels). 0 and 1 means co- and adj-channel interference.

Radio	Available Channels $\Gamma(i)$	Demands $D(i)$
A_1	{1,2}	{1}
A_2	{1,2}	{0,1}
B	{2,3}	{1,2}
C	{3,4,5}	{2,4}

Table 1 – Available channels and demands (i.e., requested amounts of channels) for each radio.

Coexistence-Aware Radio-Channel-Pair Conflict Graph – Example

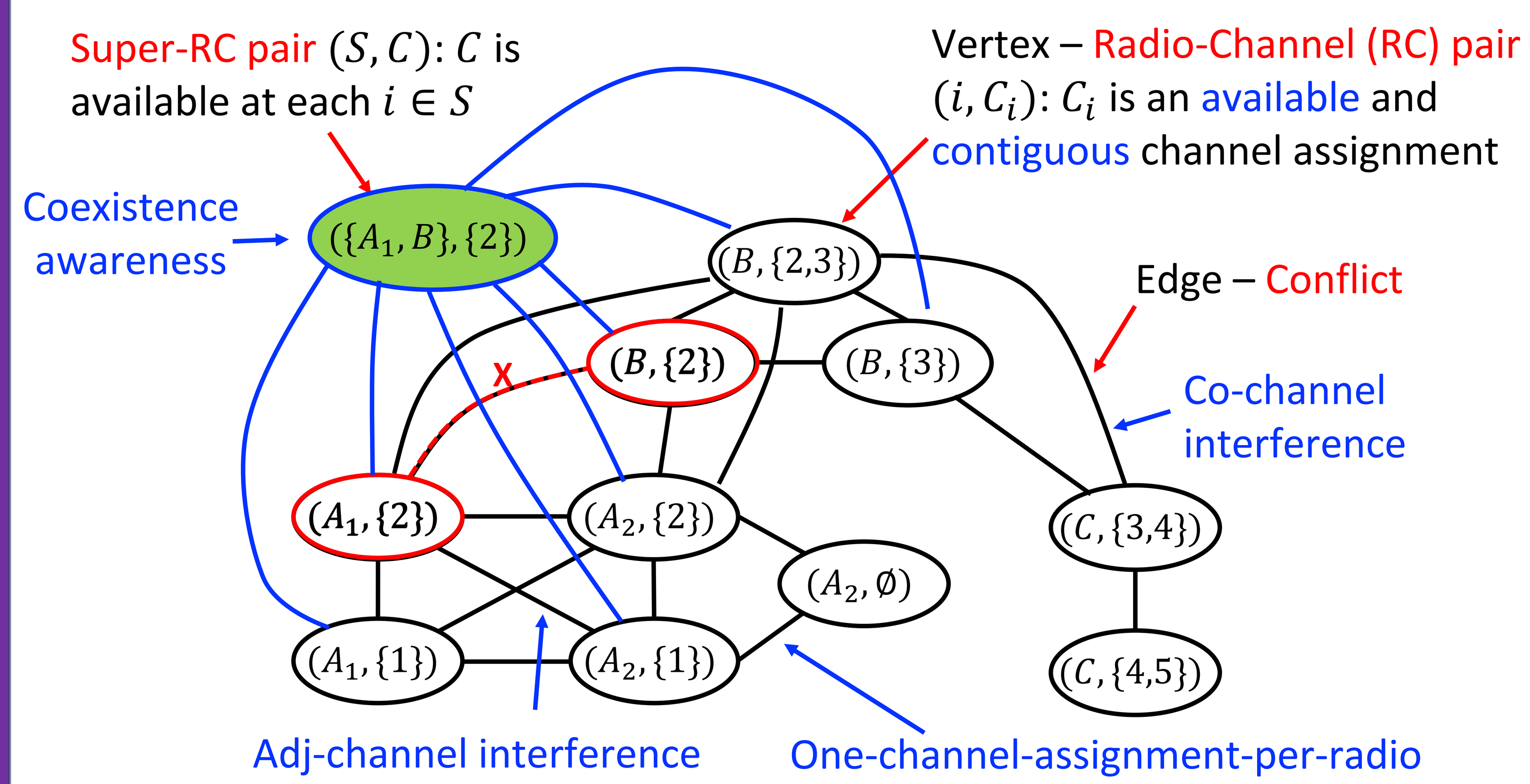
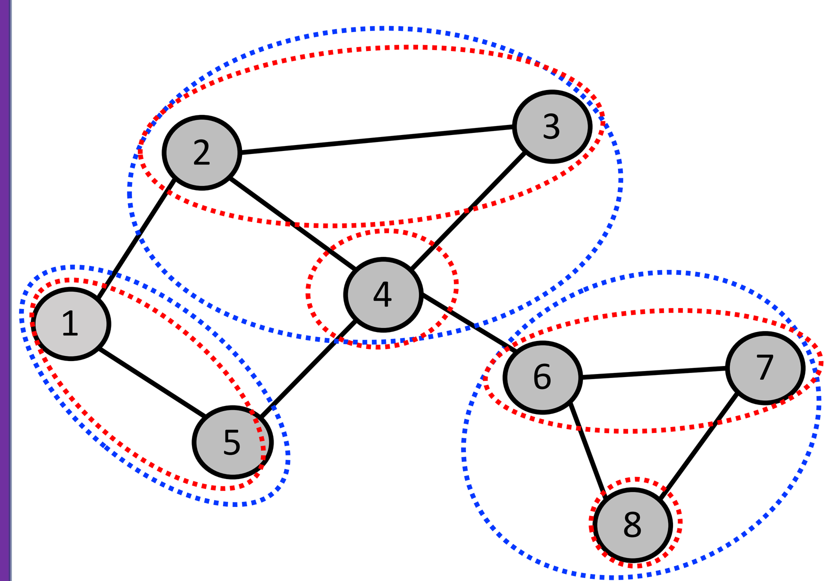


Fig. 2 – Proposed coexistence-aware RC-pair conflict graph representation.

- Non-contiguous channel demands can also be represented.
- # of vertices (w/o super-RC pairs) is $O(n \cdot N \cdot d_{max})$, where n is # of radios, N is # of channels, and d_{max} is the maximum # of requested channels (i.e., $D(i) = \{1,2 \ldots, d_{max}\}$ for each radio i).

Super-Radio Formation

- Super-radio: a set of radios that (1) have the same set of (contiguous) channels available, and (2) are within each other's carrier-sensing range.
- Input: an undirected graph – each vertex is a radio with CH C available and each edge means connected radios can sense each other.



Step 1: find cliques in a graph

- Clique: complete subgraph
- Each radio joins one clique

Step 2: balance traffic in each clique to avoid over-crowded super-radios

- Activity index $\alpha_i(C) \in (0,1]$
- Super-radio has a limit $\bar{\alpha}$ (e.g., 1.0)
- Put items with weights into bins with a capacity - Bin-packing problem

CA Problem Formulation

Problem formulation: given a conflict graph $G = (V, E)$ for n radios and a *weighting function* $W: V \mapsto \mathbb{R}_+$, SAS wants to find a scheme $I \subseteq V$ so as to

$$\max_{I \subseteq V} W(I) \text{ s.t. } |\cup_{v \in I} S(v)| = n, \text{ and } e(u, v) \notin E, \forall u, v \in I$$

where $S(v)$ is the set of radios at v.

Sample weighting functions:

- Linear: $W(S, C) = |S| \cdot |C|$ – total # of assigned channels
- Log: $W(S, C) = |S| \cdot (1 + \log(|C|))$ – "utility"; diminishing marginal values of getting additional channels.

Proposed CA Algorithms

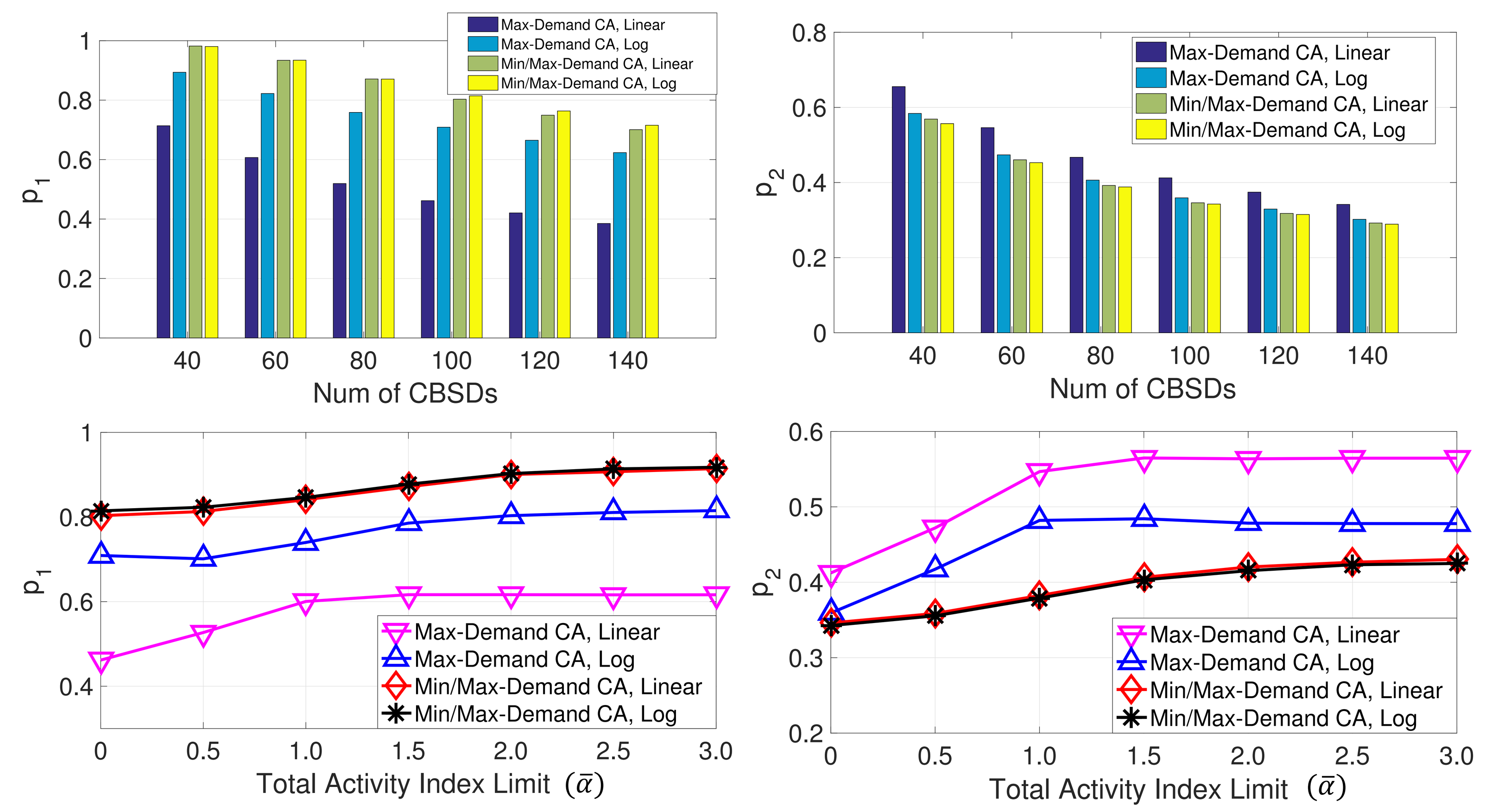
Proposed algorithms:

- Max-demand CA: classic MWIS problem [3] (ignoring the first min-demand constraint); NP-hard; heuristic-based algorithms can find approximate solutions.
- Min-/Max-demand CA: two-phase algorithm – meeting minimum demands in Phase I (with best efforts) and maximizing the total demand in Phase II; both phases are based on MWIS solutions.

Preliminary Results

- 100 outdoor WiFi APs [4] over a 2.3km-by-1.0km area as CBSDs. We randomly subsample or generate more if necessary. $\alpha_i(C) = \min(\frac{\alpha_i}{|C|}, 1)$.
- Two radios interfere if their service areas overlap. For simplicity, carrier-sensing range is the same with the radius of service area (approx. 170 m).
- Metrics:
  - p_1: min-demand service ratio, i.e., % of radios with min-demand serviced.
  - p_2: max-demand service ratio, i.e., % of total demand serviced.
  - Higher p_1 → more radios admitted; higher p_2 → more channels assigned.

Parameter	Value
# of channels	15
# of radios per CBSD	$U[1,2]$
Min. and max. demand	$U[1,2]$ and 4
Activity index (α_i)	$U[0,2]$
Tx power/min. service thr.	30/-80 dBm per 10MHz



Conclusion and Future Work

- Our generic RC-pair conflict graph representation captures various requirements, and enables graph-based CA formulation and algorithms.
- Channel allocation under fuzzy interference relationship.
- Joint channel and power allocation.
- Implementation and experimentation in Bell Labs testbed.

References

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[3] S.Sakaietal., "A note on greedy algorithms for the maximum weighted independent set problem," Discrete Applied Mathematics, 2003.

[4] "NYC Wi-Fi hotspot locations," https://nycopendata.socrata.com/Social- Services/NYC- Wi-Fi- Hotspot- Locations/a9we- mtpn/data, accessed: 2016-09-22.