Bandwidth Exchange for Fair Secondary Coexistence

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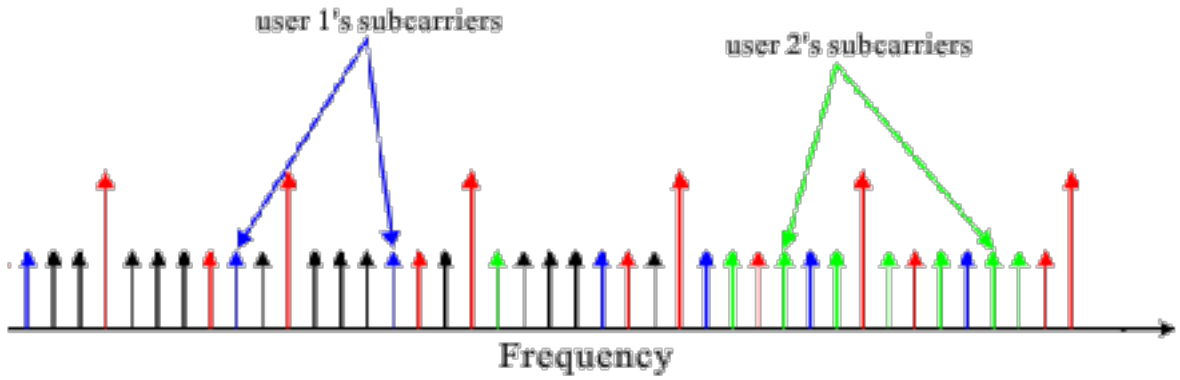
New FCC Ruling

- FCC released *Second Memorandum Opinion and Order* on Sept 23
  - White space officially becomes available
- A geo-location database approach to manage co-existence between primary and secondary users
  - PU's registered in the database for query: full service/low power TV stations, etc…
  - Unlicensed fixed TVBD's also register their operation
  - Sufficient protection for PU
- Coexistence between SU's undefined

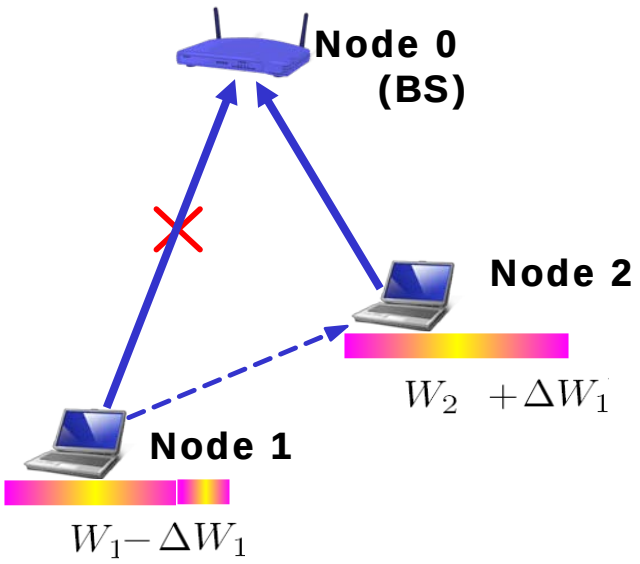
Secondary Coexistence

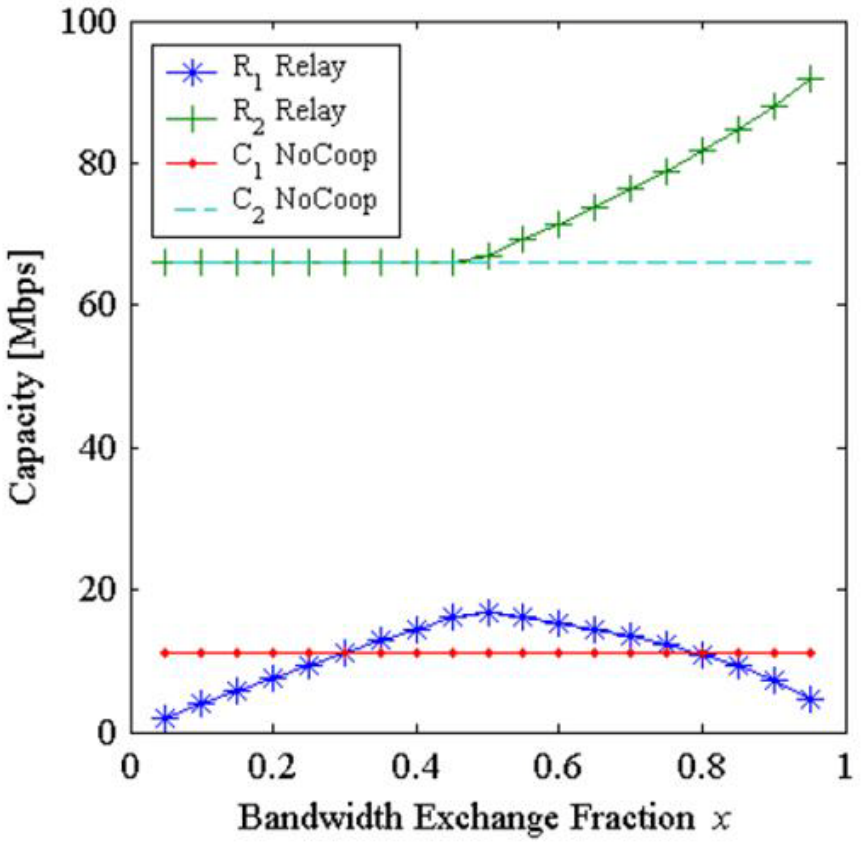
- How to trigger cooperative forwarding?
- How to avoid inter-SU interference?
- In this talk, we assume SU with cognitive radio capable of noncontiguous OFDM



Bandwidth Exchange

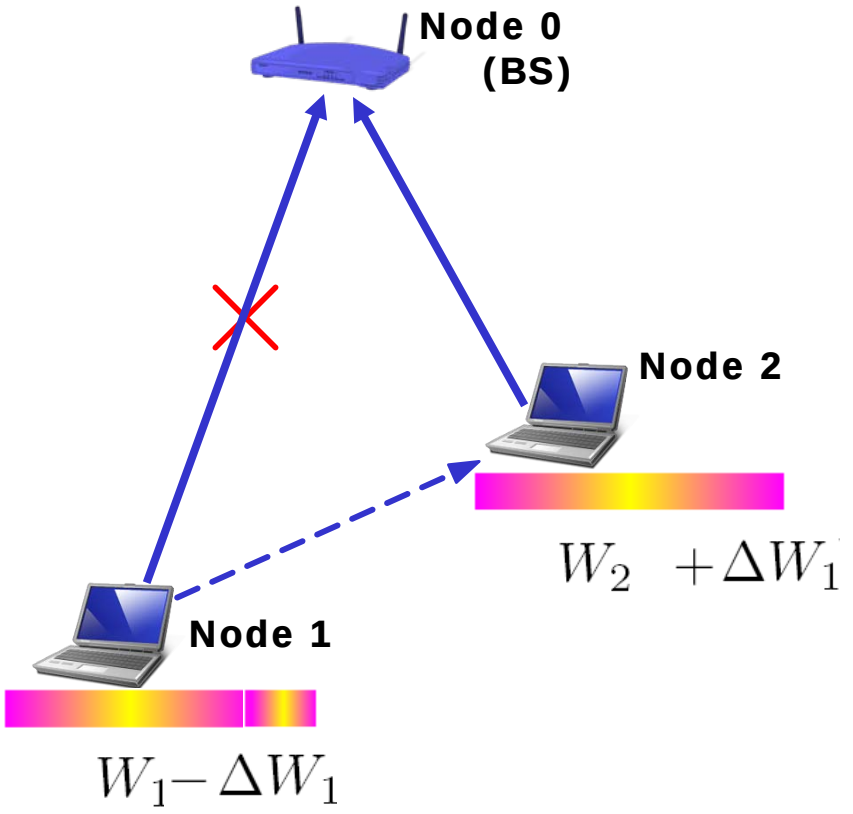
- Delegate faction of bandwidth as incentive
  - Exchange subcarriers in non-contiguous OFDMA [Zhang and Mandayam 2009]





BE for Two Nodes

- Request relay iff direct link rate below min required rate (outage)
- Request comes with an offer of extra bandwidth
- Remaining bandwidth sustains the source-relay link at source's min required rate
- Relay never cooperates if cooperation causes outage



Fairness and Efficiency of Secondary Coexistence

- BE provides an incentive mechanism
- Need a framework to ensure fairness and efficiency
- Nash Bargaining Solution (NBS)
  - Proportionally fair joint strategies
  - Pareto efficient

$$\text{maximize} \quad \prod_{i=1}^{N} u_i$$

utility compared to non-coop

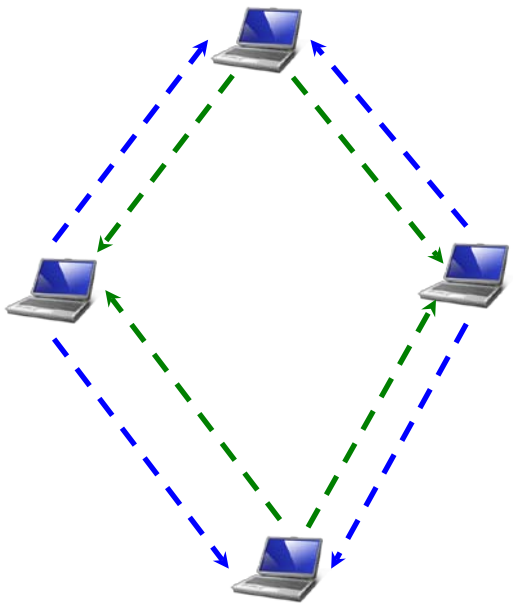
$$\text{subject to} \quad (u_1, u_2, \cdots u_N) \in C$$

feasible utilities with mixed strategies

  - Computationally intensive for more than two users

Pairwise NBS for Secondary Users

- Users only do pairwise bargaining
  - Broadcasts requests to all neighbors
  - Forwarder resolves multiple requests
  - Forwarders determine whether to cooperate based on pairwise NBS
  - Requester resolves multiple acknowledgements
- Advantage: low complexity, marginal performance drop
- Disadvantage: learning process needed for bargaining

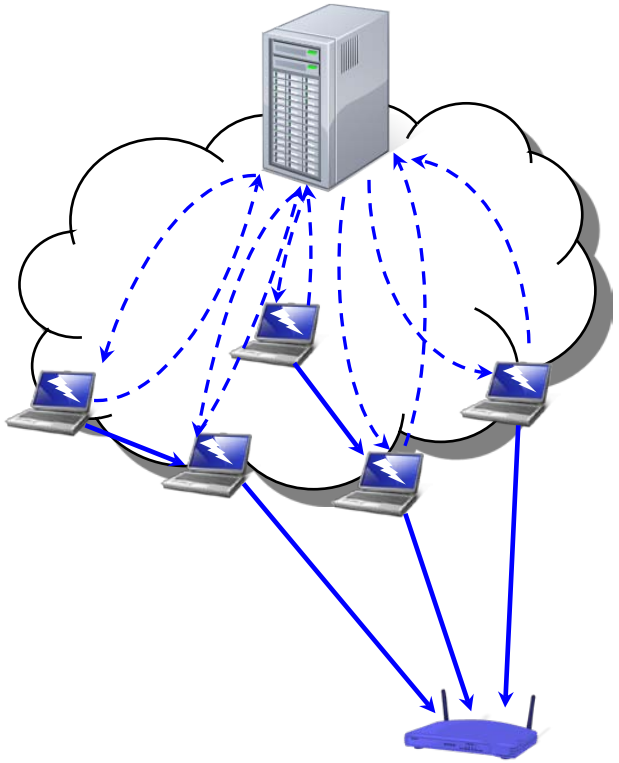


Design Parameters for Pairwise NBS

- Need to know certain parameters to implement pairwise NBS
- Channel and network state information
  - Outage Probabilities
  - Request Probabilities
  - Forwarding Cost
  - No-coop cost
- Learning these parameters takes time
- Can we leverage the database?

Database Assisted Pairwise Bargaining

- Every SU can calculate outage and rates with a geometric channel model
  - Location visible to DB
  - Can be disclosed to specific clan only
- Eliminate learning process.
  - Fast bargaining
  - Potential to support mobility



Query for peers' location from database → Retrieve location from database → Compute bargaining solution for BE → Start to cooperate

Simulation – Modified Hata Model

- Hata urban channel model
  - Applicable to 150MHz-1500MHz
  - Based on distance and antenna heights
  - Applicable to large cell
  - Used to calculate outage and forwarding cost
  - Δ is normal with 8dB standard deviation

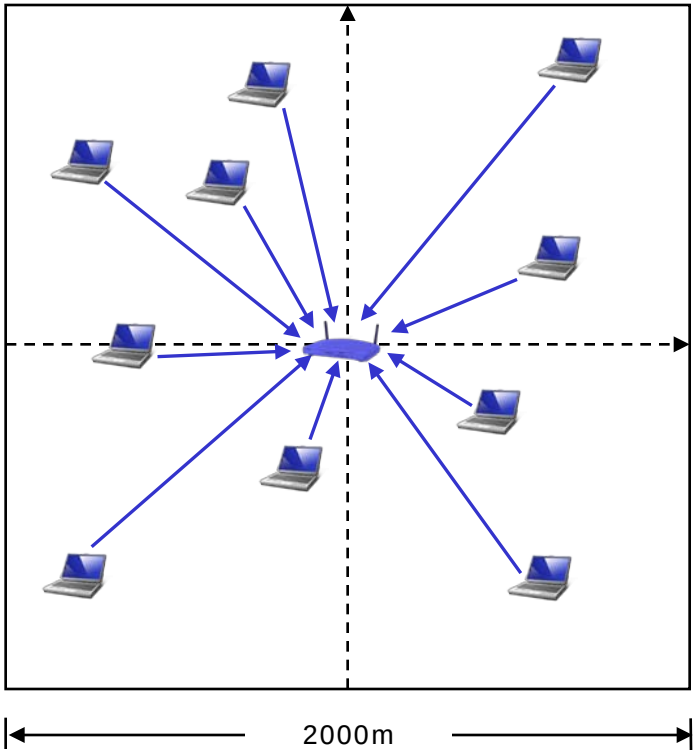
$$L = 69.55 + 26.16\log f - 13.82\log h_B - C_H + [44.9 - 6.55\log h_B]\log d + \Delta$$

$$C_H = 0.8 + (1.1\log f - 0.7)h_M - 1.56\log f$$

- Independent realization in each slot
- Same model for SU-to-SU and SU-to-BS
  - Future work, ITU model
  - Different models for SU and BS

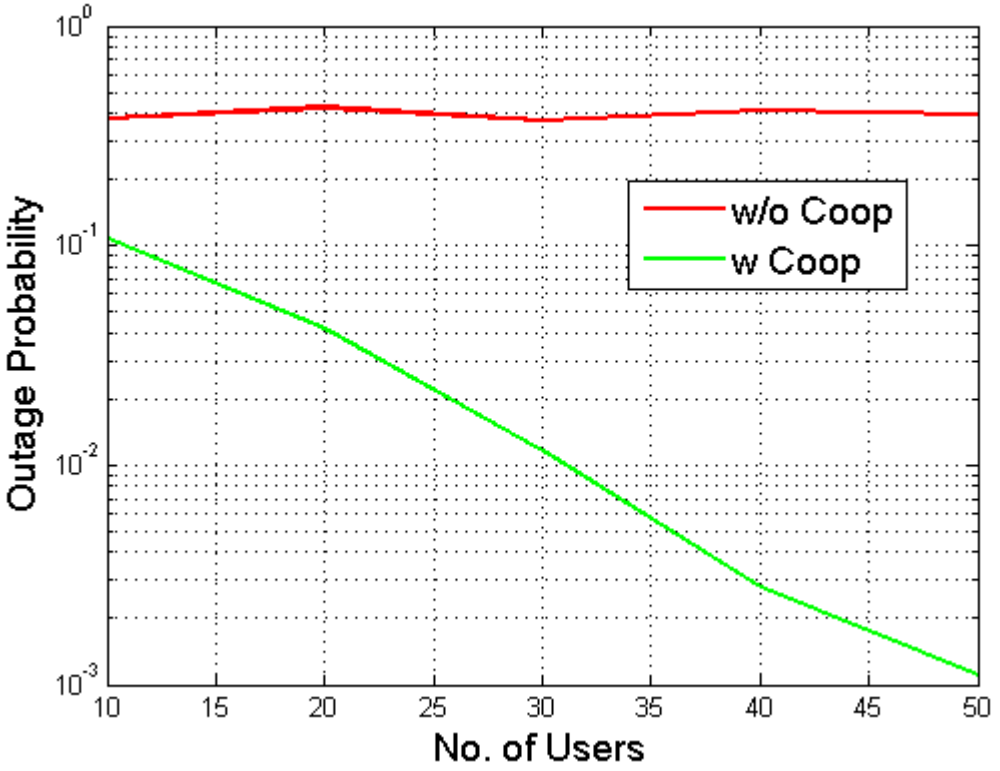
Simulation – Detailed Setup

- Randomly place 10, 20, 30, 40, 50 SU's in a 2000m x 2000m area
- Communicate to BS at origin
- OFDMA
  - 40 subcarriers/SU, 10KHz spacing
  - SU needs 10 subcarriers to stay connected
  - Subcarrier outage if pathloss>130dB
- Total BW = #SU x 400KHz
  - Maximum band used: 678-698MHz, Channel 48-51
- Height of antennas
  - 10m for BS, 1m for SU's



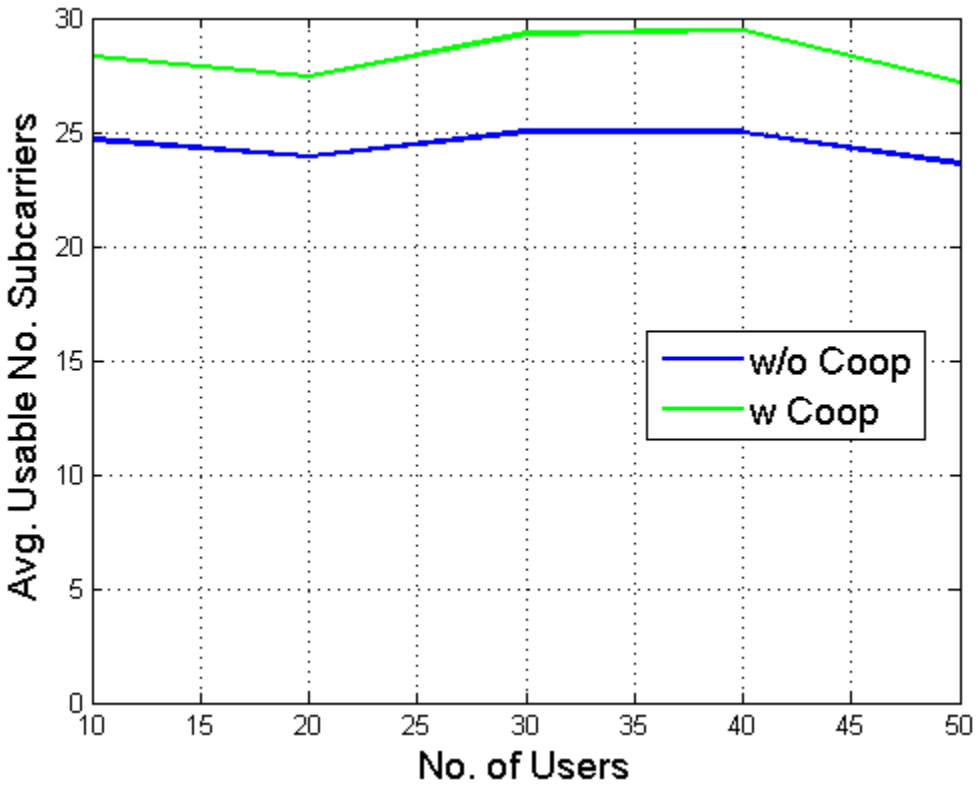
Outage Probability

- Without coop, average outage is constant (~0.2)
- With coop, average outage decreases fast as no. of users increases
- User Cooperation Diversity



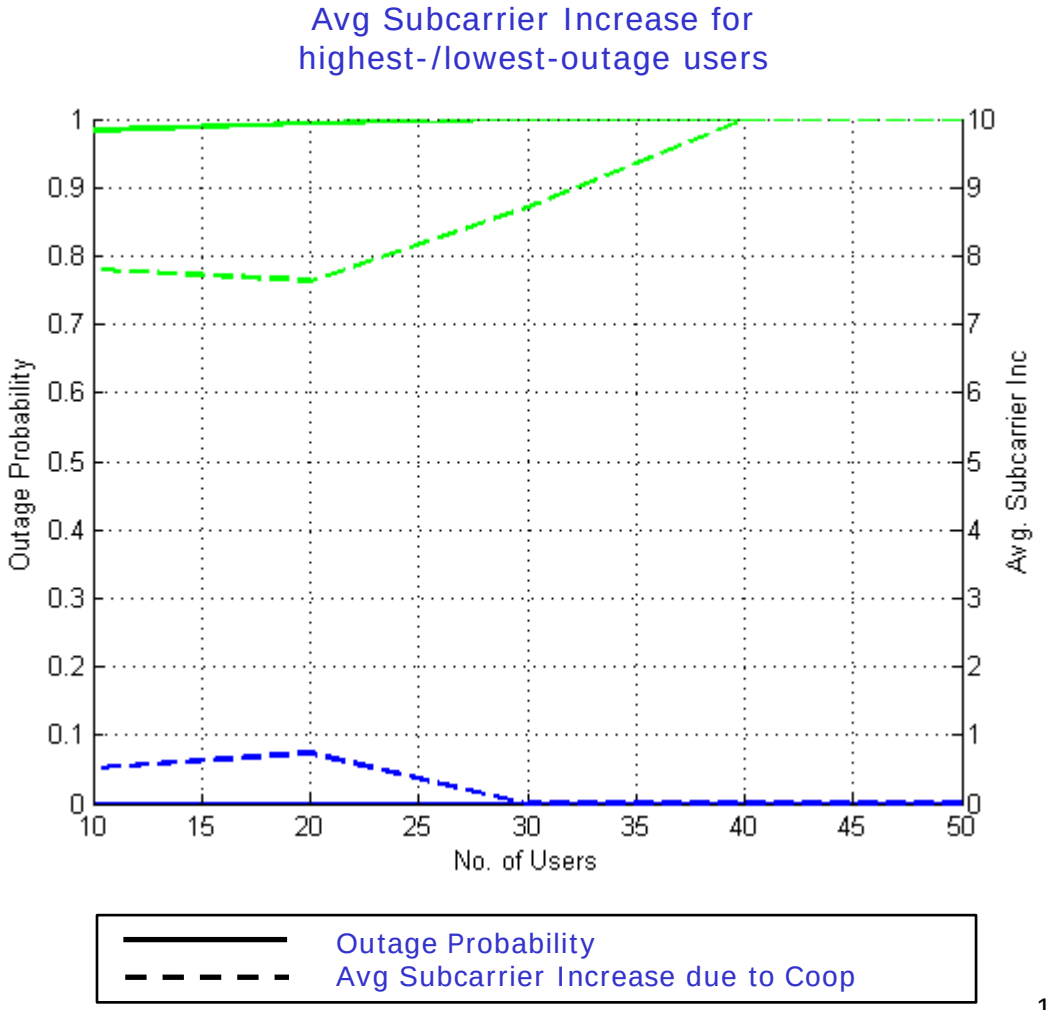
Average No. of Available Subcarriers

- On average coop gives everyone 4 additional subcarriers
  - Number scales with min required subcarriers
- We hope high-outage users gets more and low-outage users gets less
  - Fairness



Fairness

- Benefit of coop apparent with more users
- High outage users substantially benefits from coop
- Low outage users benefits less



Conclusion and Future Work

- BE + NBS provides solution to fair secondary user coexistence
  - Proportionally fair
  - Pareto efficient
- With database deployed, bargaining for coop becomes easy and fast
- Refine channel models for SU-to-SU & SU-to-BS
- Need to address protocol issues
  - Current ruling does not exclude the possibility
  - Security and privacy challenges