Cooperating Base Station Set Selection and Network Reconfiguration in Limited Backhaul Networks

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Introduction & Scenario

- Scenario: cellular network
  - Wireless access network
    - Coordinated Multi-Point (CoMP) transmission/reception (e.g. LTE-Advanced)
    - Joint processing (up 60% throughput improvement)
      - Multiple base stations (BSs) transmit data to a UE (user equipment)
      - BSs have to exchange synchronization information (→ latency?)
      - Transmitted data has to be present at all cooperating BSs (→ capacity?)
  - Wireline backhaul network
    - Passive optical networks (PONs)
    - Point-to-point links
    - Fixed topology
  - Network reconfiguration
    - Flexible capacity assignment (→ e.g. lightpaths, PtP links)
Problem: CBS Selection

- Cooperating base station set (CBS)
  - BSs participating in joint processing
  - 1 BS with controller role, n transmitting BSs (in total up to 5 BSs in urban scenario)
  - Constraints on (internal) capacity and latency

- Desired CBS
  - Derived from wireless channel properties
  - Removing BSs would decrease CoMP performance

- Feasible CBS
  - Feasible subset, according to backhaul network
Problem: CBS Selection

- Problem: some or all of the desired CBSs from wireless network may only be feasible as subsets in the wireline backhaul network.

- Possible solution so far: determine feasible CBSs from wireline backhaul network and limit possible CBSs to them.

- New solution: incorporate both wireless and wireline information in the CBS selection process

- Our new solution is threefold:
  1. Given the desired CBSs, determine feasible CBSs (may be subsets)
  2. Analyze infeasible BS
  3. Extend feasible subset by network reconfiguration
Feasible CBS selection

- Problem inputs
  - Backhaul graph (vertices $V$, edges $E$)
  - Edge annotations for available capacity and latency
  - Desired CBSs $W_i \subseteq V$
  - Vertex annotation for required capacity and maximum round-trip latency

- Problem outputs
  - Controller BS for each CBS $W_i$
  - Feasible subset of BSs for each CBS $W_i$
  - Information on infeasible BSs for each CBS $W_i$
  - Feasible routing paths within each CBS $W_i$

- Additional output: causes for infeasible BSs
  - capacity, latency or both
Feasible CBS Selection

- How to obtain the feasible CBSs?

- Linear optimization (MILP)
  - Optimal selection!
  - Long execution time, high memory usage

- CBS heuristic
  - Based on breadth first search (BFS)
    - Consider every vertex as potential controller
    - Determine potential routing paths by BFS
    - Select best candidate
  - Solution quality? Close to optimum?
  - Faster than optimization? Memory usage?

Detailed description in the paper!
Feasible CBS Selection

- Scenario: Mesh network, urban environment
- Cost models for CAPEX (equipment) and OPEX (energy consumption)
- Capacity demand at each BS $d$, UE radius $r$
- Details in the paper!
Infeasible CBS

- What to do if the complete desired CBS is not feasible? (= no feasible candidate for controller or infeasible routing)
  - Determine feasible subset
    - Possible with the heuristic → largest feasible subset
    - Likely decreased CoMP performance
  - Improve feasible subset by network reconfiguration
    - A larger subset will improve the CoMP performance
    - Ideally establish the full CBS

- Network reconfiguration
  - PONs: reassign wavelengths (WDM) or modify dynamic bandwidth allocation (TDM)
  - Enable additional microwave or FSO links
  - Network virtualization
(1) CoMP is required to fulfill service quality for UE
(2) determine desired CBS for UE based on wireless channel state
(3) use heuristic to determine feasible CBS
   • If the desired CBS is not completely feasible
(4) implement network reconfiguration
(5) Perform CoMP transmission/reception
Network Reconfiguration Benefits

- Scenario: Mesh network, urban environment
- Capacity demand at each BS $d$, UE radius $r$
- Key parameter: fraction of applied reconfiguration, suggested by the heuristic
- Result: linear relation between reconfiguration and feasibility
Network Reconfiguration Benefits

- Scenario: WDM-PON network, urban environment
- Capacity demand at each UE $u$, UE radius $r$
- Key parameter: number of UEs per BS
- Dashed lines: enabled network reconfiguration
- Result: network reconfiguration significantly increases CBS feasibility
Conclusion

- CBS selection method, including a fast heuristic, considering both…
  - … wireless characteristics (desired CBS)
  - … wireline characteristics (backhaul network)
- System architecture to integrate backhaul network reconfiguration into the CoMP process
- Simulative results

- Network reconfiguration can improve CoMP performance and helps to optimally exploit available backhaul network resources
CBS Heuristic

- **Maximum-Path BFS**
  - → start modified BFS from all vertices
  - output: BFS trees for all vertices

- **Intersect CBSs**
  - → intersect BFS trees and CBSs
  - output: candidate BFS trees for all CBSs

- **Back-Track BFS Trees**
  - → recheck constraints on candidate BFS trees
  - output: reduced candidate BFS trees for all CBSs

- **Intersect CBSs**
  - → recheck if BFS trees match CBSs
  - output: candidate BFS trees for all CBSs

- **Find Best BFS Trees**
  - → compare candidate BFS trees
  - output: one BFS trees for each feasible CBS

- **Analyze Graph**
  - → analyze infeasible CBSs
  - output: causes for CBS infeasibility
CBS Heuristic
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