Coordinated Multi-Point Transmission for Interference Mitigation in Cellular Distributed Antenna Systems

M.A.Sc. Thesis Defence

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July 20, 2011

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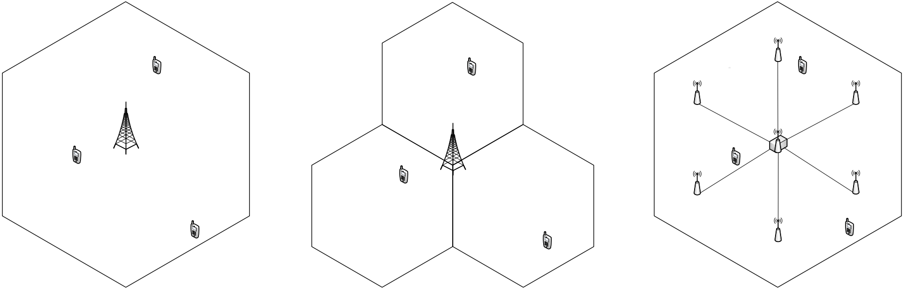
Outline

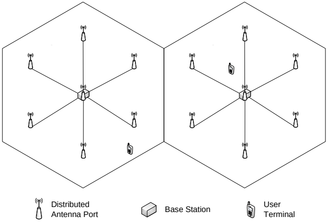
Introduction

- Future cellular systems expected to provide ubiquitous high data rate coverage to user terminals (UTs).
- In conventional systems, UTs near the cell periphery experience low rates due to distance-based attenuation and inter-cell interference.
- Performance loss due to distance-based attenuation can be overcome by dispersing the antennas over the coverage area.



Introduction (Cont.)

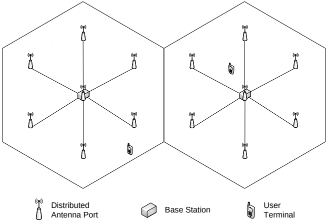
- The distributed antenna system (DAS) architecture does not inherently mitigate inter-cell interference.
- Coordinated multi-point (CoMP) transmission techniques can be used to serve UTs with multiple distributed antenna ports and to mitigate both intra-cell and inter-cell interference.



A distributed antenna port used in the Videotron 3G network in Montreal, Quebec (Source: Wikipedia).

Introduction (Cont.)

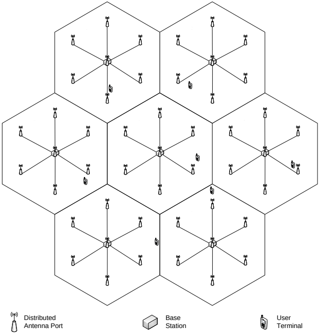
- Which ports should be selected and what should be their antenna weights in order to maximize
  - the aggregate spectral efficiency, or
  - the signal-to-interference-plus-noise ratio (SINR) of the UTs?



A distributed antenna port used in the Videotron 3G network in Montreal, Quebec (Source: Wikipedia).

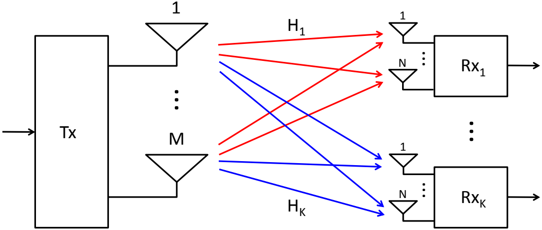
Related Literature: Distributed Antenna Systems

- [Saleh et al., 1987, Yanikomeroglu & Sousa, 1993]: Early works on the use of DAS for improving coverage in indoor wireless networks.
- [Roh & Paulraj, 2002, Xiao et al., 2003]: Showed that MIMO DAS can improve capacity in cellular networks.



Related Literature: MIMO Broadcast Channel

System with coordination among multiple transmitters (BSs or ports) can be modelled as a MIMO broadcast channel.



- [Costa, 1983, Weingarten et al., 2006]: Capacity-achieving scheme is dirty paper coding (DPC).
- [Caire & Shamai, 2003]: Proposed zero-forcing dirty paper coding (ZF-DPC) scheme.
- [Spencer et al., 2004]: Proposed block diagonalization (BD) scheme.

Chapter 3: Related Literature and Contributions

- [Wang et al., 2009]: Explored the performance of multi-user transmission schemes, including BD, for a single-cell DAS.
  - No port selection
  - Single-antenna UTs
- [Ling et al., 2010]: Investigated port selection for a multi-user DAS.
  - UTs orthogonalized using OFDM

Contributions:

- The ZF-DPC and BD schemes are extended to fit the cellular DAS architecture with port selection.
- Multiple ports transmit in a coordinated manner.
- Multi-cell coordination: Ports from different cells coordinate transmissions to UTs.

Coordinated Multi-Point Downlink Transmission Schemes

Goal: Coordinate the transmissions of multi-antenna ports to K multi-antenna UTs in each cell such that interference is mitigated.

For simplicity, ports are selected prior to antenna weight design.

DAS BD:

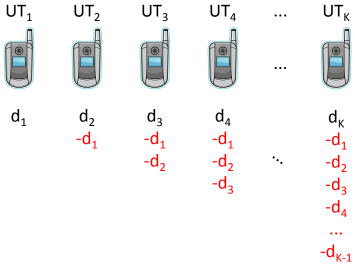
- Precoding matrix for each UT is designed such that interference to the other $K-1$ UTs is spatially pre-cancelled.
- Number of spatial degrees of freedom required to fully mitigate intra-cell interference is characterized.

$$N_r(K-1) < \min_{k=1,\ldots,K} (|\mathcal{C}_{km}| N_t), \quad m = 1, \ldots, M$$

Coordinated Multi-Point Downlink Transmission Schemes

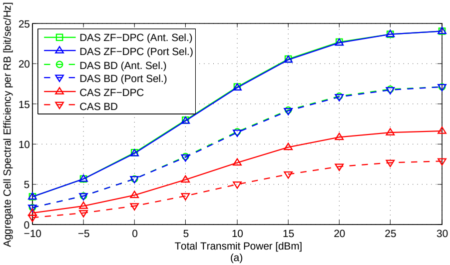
DAS ZF-DPC:

- UTs are arranged in an order denoted by permutation operator π.
- Successive encoding is used to generate the data vector of the $\pi(k)$-th UT.
  - Interference caused by transmissions intended for the UTs indexed between $\pi(1)$ and $\pi(k-1)$ is eliminated.

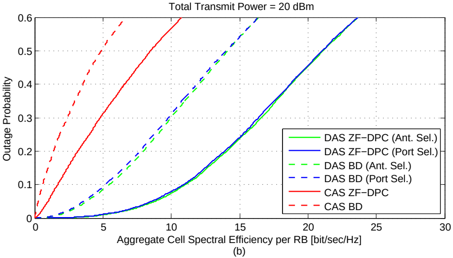


- Remaining interference is mitigated using a BD-based ZF technique.

Simulation Results

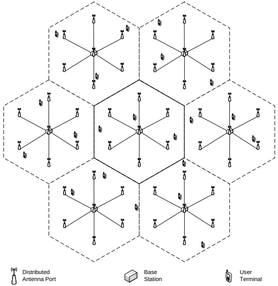


(a)



(b)

- Suburban macro-cell (NLoS)
- $d_{\text{BS-BS}} = 1299$ m
- $\sigma_s = 8$ dB
- $\sigma^2 = -114$ dBm
- $f_c = 2$ GHz
- drops $= 10000$
- $L = 7$
- $N_t = 2$
- $K = 3$
- $N_r = 2$



Chapter 4: Related Literature and Contributions

- [Choi & Andrews, 2007, Park et al., 2009]: Showed that proper selection and weighting of antenna ports can give significant performance improvement.
  - No coordination among BSs

Contributions:

- Goal is to *jointly* select the ports and their weights in a coordinated manner such that the minimum SINR of the UTs is maximized.
  - This joint optimization problem is NP-hard.
- A novel polynomial-complexity two-stage approach is proposed to obtain an approximate solution.
- Semidefinite relaxation and Gaussian randomization are used in each stage to obtain a close-to-optimal solution.

Coordinated Port Selection and Beam Steering Optimization

Goal: Select the ports and the beam steering coefficients that jointly maximize the minimum SINR.

Joint optimization problem:

$$\begin{aligned} \max_{\boldsymbol{\alpha},\mathbf{w}} \quad & \min_{m=1,\ldots,M} \ \mathrm{SINR}_m(\boldsymbol{\alpha},\mathbf{w}), \\ \text{subject to} \quad & \boldsymbol{\alpha} \in \{0,1\}^{LM}, \\ & \left|[\mathbf{w}]_q\right| = 1, \quad q = 1,\ldots,LM, \end{aligned}$$

where

- $\boldsymbol{\alpha}$ is a port state vector, and
- $\mathbf{w}$ is a beam steering coefficient vector.

This problem is non-convex, and in fact, **NP-hard**.

Coordinated Port Selection and Beam Steering Optimization (Cont.)

Joint Optimization Problem

$$\begin{aligned} \max_{\boldsymbol{\alpha},\mathbf{w}} \quad & \min_{m=1,\ldots,M} \ \mathrm{SINR}_m(\boldsymbol{\alpha},\mathbf{w}), \\ \text{subject to} \quad & \boldsymbol{\alpha} \in \{0,1\}^{LM}, \\ & \left|[\mathbf{w}]_q\right| = 1, \quad q = 1,\ldots,LM. \end{aligned}$$

First Stage

$$\begin{aligned} \max_{\boldsymbol{\alpha}} \quad & \min_{m=1,\ldots,M} \ \mathrm{SINR}_m(\boldsymbol{\alpha},\mathbf{w}_0), \\ \text{subject to} \quad & \boldsymbol{\alpha} \in \{0,1\}^{LM}. \end{aligned}$$

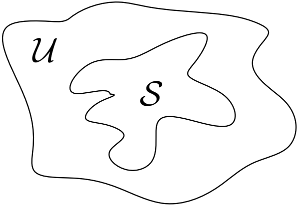
Second Stage

$$\begin{aligned} \max_{\mathbf{w}} \quad & \min_{m=1,\ldots,M} \ \mathrm{SINR}_m(\boldsymbol{\alpha}_0,\mathbf{w}), \\ & \left|[\mathbf{w}]_q\right| = 1, \quad q = 1,\ldots,LM. \end{aligned}$$

- Each of the two sub-problems is also NP-hard.
- Obtain a close-to-optimal solution to each sub-problem using the **semidefinite relaxation (SDR) based Gaussian randomization** technique.

Semidefinite Relaxation and Gaussian Randomization

1. Solve a relaxed version of the original problem.



$\mathcal{S}$: Constraint set of the original problem
$\mathcal{U}$: Constraint set of the relaxed problem

2. Generate samples from a Gaussian distribution that is characterized by the optimal solution to the relaxed problem.
   - Each sample represents a candidate solution to the original problem.

3. Choose candidate solution that yields the largest objective.

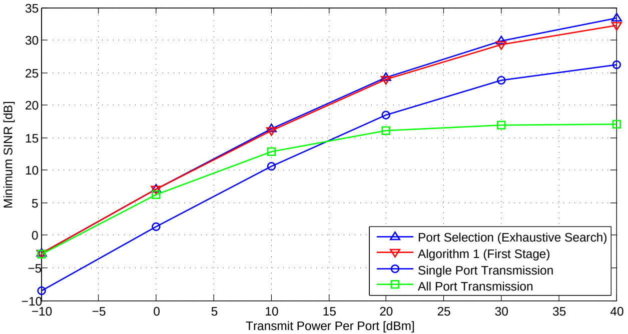
The SDR technique was used in [Karipidis et al., 2008] and [Chang et al., 2008] for the multicast transmit beamforming problem.

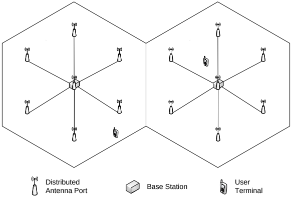
Coordinated Port Selection and Beam Steering Optimization (Cont.)

Two-stage approach for generating an approximate solution to the joint optimization problem:

- **Select** the $\hat{J} \leq J_1$ candidate port state vectors out of the J_1 vectors generated in the first stage that yield the largest minimum SINR.
- **Generate** a close-to-optimal beam steering coefficient vector for each of the $\hat{J}$ port state vectors using the second stage.
- **Choose** the approximate solution of the joint optimization problem to be the pair of port state vector and beam steering coefficient vector that jointly yield the largest objective.

Simulation Results (Stage 1)

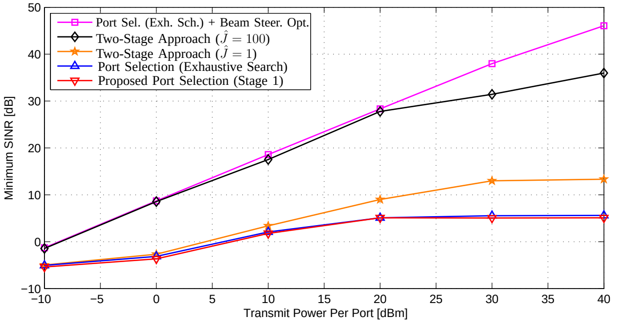


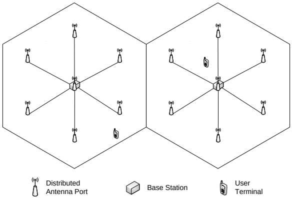


- Suburban macro-cell (NLoS)
- $d_{\text{BS-BS}} = 1299$ m
- $\sigma_s = 8$ dB
- $\sigma^2 = -114$ dBm
- $f_c = 2$ GHz

- $M = 2$
- $L = 7$
- drops $= 500$
- $J_1 = 100$

Simulation Results (Two-Stage Approach)





- Suburban macro-cell (NLoS)
- $d_{\text{BS-BS}} = 1299$ m
- $\sigma_s = 8$ dB
- $\sigma^2 = -114$ dBm
- $f_c = 2$ GHz

- $M = 2$
- $L = 7$
- $J_1 = 100$
- $J_2 = 100$

Summary

- Integrated CoMP transmission schemes into the DAS architecture.
- Chapter 3:
  - Developed extensions of the DAS ZF-DPC and DAS BD schemes to serve multiple UTs in a particular RB in each cell without intra-cell interference.
  - Extended these schemes to the multi-cell processing scenario.
- Chapter 4:
  - Considered coordinated joint selection and weighting of ports to maximize the minimum SINR of the UTs (NP-hard problem).
  - Developed a novel polynomial-complexity two-stage approach, which relies on the SDR-based Gaussian randomization technique, to obtain an approximate solution to the joint optimization problem.

Future Work

- Design transmission schemes such as DAS ZF-DPC and DAS BD with a per-port or per-antenna power constraint.
- Develop an algorithm that would allow the BSs to determine the port states and beam steering coefficients in a distributed manner.
- Joint optimization of the port states, beam steering coefficients, and the UT scheduling for a given set of RBs.
- Investigate the performance of CoMP schemes and algorithms in the presence of imperfect channel state information.

Publications and Submissions

Chapter 3:

- **Talha Ahmad**, Saad Al-Ahmadi, Halim Yanikomeroglu, and Gary Boudreau, "Downlink linear transmission schemes in a single-cell distributed antenna system with port selection," in *Proc. IEEE Veh. Technol. Conf.*, May 2011.

Chapter 4:

- **Talha Ahmad**, Ramy Gohary, Halim Yanikomeroglu, Saad Al-Ahmadi, and Gary Boudreau, "Coordinated port selection and beam steering optimization in a multi-cell distributed antenna system using semidefinite relaxation," under review in *IEEE Trans. Wireless Commun.*
- **Talha Ahmad**, Ramy Gohary, Halim Yanikomeroglu, Saad Al-Ahmadi, and Gary Boudreau, "Coordinated max-min fair port selection in a multi-cell distributed antenna system using semidefinite relaxation," submitted to *IEEE Globecom Workshop on Distributed Antenna Systems for Broadband Mobile Communications*, December 2011.

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