

Traffic Aware Precoder Design for Space Frequency Resource Allocation

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Section 1

Introduction

Introduction and Motivation

- ▶ Complex algorithms are adopted to maximize throughput to satisfy the data requirements from higher layers
- ▶ Available wireless resources are to be utilized efficiently to minimize the backlogged packets
- ▶ Spatial and Frequency resources are exploited to empty the packets waiting at the BSs
- ▶ We discuss precoder designs for multiple users MIMO-OFDM setup to minimize the number of queued packets

Section 2

System Model & Problem Formulation

Symbols used

- ▶ OFDM system with N sub-channels and N_B BSs, each equipped with N_T transmit antennas
- ▶ Let K be the total number of users with N_R antennas
- ▶ Let \mathcal{B} and \mathcal{U} denote the set of coordinating BSs and users in the system
- ▶ Let L be the total available spatial streams for a user k , given by $\min(N_T, N_R)$

System Model

- The l th spatial signal received on sub-channel n of user k is given by

$$\hat{d}_{l,k,n} = \mathbf{w}_{l,k,n}^H \mathbf{H}_{b_k,k,n} \mathbf{m}_{l,k,n} d_{l,k,n} + \mathbf{w}_{l,k,n}^H \mathbf{n}_{l,k,n} \\ + \mathbf{w}_{l,k,n}^H \sum_{i \in \mathcal{U} \setminus \{k\}} \mathbf{H}_{b_i,k,n} \sum_{j=1}^L \mathbf{m}_{j,i,n} d_{j,i,n} \quad (1)$$

- where $\mathbf{m}_{l,k,n}$ and $\mathbf{w}_{l,k,n}$ are transmit and receive beamformers corresponding to the l th spatial stream on the n th sub-channel of user k

System Model

- ▶ $\mathbf{H}_{b_k,k,n} \in \mathbb{C}^{N_R \times N_T}$ denotes the channel between BS b_k and user k
- ▶ $d_{l,k,n}$ and $n_{l,k,n}$ correspond to data symbol and equivalent noise on l th spatial stream of user k
- ▶ Using the above notations, the SINR seen by the l th spatial stream on the n th sub-channel for user k is given by

$$\gamma_{l,k,n} = \frac{|\mathbf{w}_{l,k,n}^H \mathbf{H}_{b_k,k,n} \mathbf{m}_{l,k,n}|^2}{\hat{N}_0 + \sum_{(j,i) \neq (l,k)} |\mathbf{w}_{l,k,n}^H \mathbf{H}_{b_j,k,n} \mathbf{m}_{j,i,n}|^2} \quad (2)$$

- ▶ where $\hat{N}_0 = \|\mathbf{w}_{l,k,n}^H \mathbf{n}_{l,k,n}\|^2$

Queueing Model

- ▶ Each user is associated with backlogged packets of size Q_k packets.
- ▶ Queued packets Q_k of each user follows dynamic equation at the i th instant as

$$Q_k(i+1) = \left[Q_k(i) - t_k(i) \right]^+ + \lambda_k(i) \quad (3)$$

- ▶ where $t_k = \sum_{n=1}^N \sum_{l=1}^L t_{l,k,n}$ denotes the total number of transmitted packets corresponding to user k in the previous i th instant
- ▶ λ_k represents the fresh arrivals of user k at BS b_k

Problem Formulation

- ▶ **Objective** - to minimize the number of backlogged packets waiting at BSs
- ▶ **Optimization variables** - transmit precoders and receive beamformers
- ▶ **MIMO-OFDM** - scheduling of users across sub-channels is inherently performed by precoders

Section 3

Centralized Solutions

Queue-Weighted Sum Rate Maximization (Q-WSRM)

- ▶ Q-WSRM formulation is the result of minimizing the conditional Lyapunov drift[†]
- ▶ Q-WSRM formulation is also called as back pressure algorithm, since it acts greedily in minimizing the backlogged packets at each instant

$$\underset{t_{l,k,n}}{\text{minimize}} \quad \sum_{k \in \mathcal{U}} \left\{ Q_k(i)^2 - Q_k(i-1)^2 \right\},$$

- ▶ where Q_k follows the dynamic Queue expression in (3)

[†]Neely, Michael J. "Stochastic network optimization with application to communication and queueing systems." Synthesis Lectures on Communication Networks 3.1 (2010): 1-211.

Queue-Weighted Sum Rate Maximization (Q-WSRM)

- Q-WSRM formulation, which is obtained by solving Lyapunov drift, is given by

$$\underset{t_{l,k,n}}{\text{maximize}} \quad \sum_{k \in \mathcal{U}} Q_k \left(\sum_{n=1}^N \sum_{l=1}^L t_{l,k,n} \right) \quad (4a)$$

$$\sum_{n=1}^N \sum_{l=1}^L t_{l,k,n} \leq Q_k / Q_{k,n} \quad (4b)$$

- Queue-Rate product is maximized
- Users with more number of backlogged packets are favored over good channel users

JSFRA Formulation (SINR Relaxation)

- ▶ Centralized Design - precoders are designed by a controller, which are then used by all BSs in \mathcal{B}
- ▶ The objective used to design transmit precoders is

$$v_k = \left| Q_k - \sum_{n=1}^N \sum_{l=1}^L t_{l,k,n} \right|^q \quad (5)$$

- ▶ To generalize the objective, we use $\tilde{v}_k \triangleq a_k^{\frac{1}{q}} v_k$, where a_k is arbitrary weights used control the priorities
- ▶ Exponent q plays different role based on the value it assumes
 - ▶ $\ell_{q=1}$ results in greedy allocation
 - ▶ $\ell_{q=2}$ ideal for the delay or buffer size limited scenarios
 - ▶ $\ell_{q=\infty}$ provides fair resource allocation in each transmission instant

JSFRA Formulation (SINR Relaxation)

- Optimization problem with queue difference objective is nonconvex due to the constraint

$$\underset{\mathbf{m}_{l,k,n}}{\text{minimize}} \quad \left| Q_k - \sum_{n=1}^N \sum_{l=1}^L \log(1 + \gamma_{l,k,n}) \right|^q \quad (6a)$$

$$\text{subject to} \quad \gamma_{l,k,n} \leq \frac{|\mathbf{w}_{l,k,n}^H \mathbf{H}_{b_k,k,n} \mathbf{m}_{l,k,n}|^2}{\beta_{l,k,n}} \quad (6b)$$

$$\dot{N}_0 + \sum_{(j,i) \neq (l,k)} |\mathbf{w}_{l,k,n}^H \mathbf{H}_{b_j,k,n} \mathbf{m}_{j,i,n}|^2 \leq \beta_{l,k,n} \quad (6c)$$

- The nonconvex constraints are approximated by sequence of convex subsets and solved iteratively by **successive convex approximation (SCA) method**
- Receive beamformers are designed by the MMSE receivers using the converged transmit precoders

JSFRA Formulation (MSE Reformulation)

- ▶ Alternatively, we solve the queue minimization problem by utilizing the relation between the MSE and the SINR as

$$\epsilon_{l,k,n} = (1 + \gamma_{l,k,n})^{-1} \quad (7)$$

- ▶ Equivalence is valid only when the receivers are designed with the mean squared error (MSE) objective, *i.e.*, using MMSE receivers
- ▶ Problem involves nonconvex constraint

$$t_{l,k,n} \leq -\log_2(\epsilon_{l,k,n}) \quad (8a)$$

$$\begin{aligned} \epsilon_{l,k,n} &= \mathbb{E}[(d_{l,k,n} - \hat{d}_{l,k,n})^2] = |1 - \mathbf{w}_{l,k,n}^H \mathbf{H}_{b_k,k,n} \mathbf{m}_{l,k,n}|^2 \\ &\quad + \sum_{(j,i) \neq (l,k)} |\mathbf{w}_{l,k,n}^H \mathbf{H}_{b_j,k,n} \mathbf{m}_{j,i,n}|^2 + \hat{N}_0 \end{aligned} \quad (8b)$$

JSFRA Formulation (MSE Reformulation)

- ▶ The nonconvex constraint is approximated by a sequence of convex constraints, which is performed using SCA technique
- ▶ The iterative procedure is carried out until convergence or for suitable number of iterations
- ▶ The above reformulation works only with the MMSE receiver

Centralized Solutions

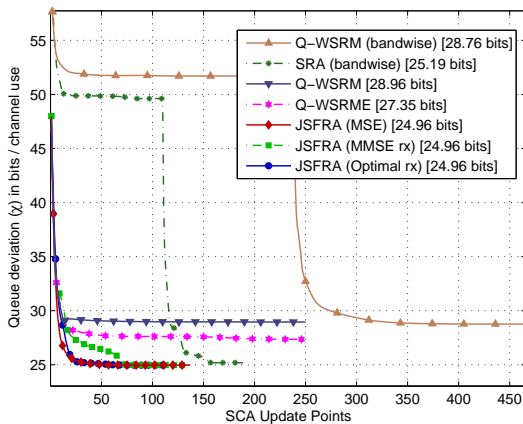


Figure: System Model - $\{N, N_B, K, N_T, N_R\} = \{2, 3, 9, 4, 2\}$

Section 4

Distributed Solutions

Distributed Methods

- ▶ **Small System - centralized approach is viable**, provided channel remains constant for multiple transmission slots
- ▶ However, overhead involved in the centralized design scales up significantly as the network size grows
- ▶ Distributed approaches based on primal decomposition or ADMM can be used to reduce the signaling requirements
- ▶ Signaling involved in the design of precoders are only **scalar interference variables**
- ▶ Approximated convex subproblem in each SCA step is performed via distributed methods

Primal Decomposition Method

- Precoder design is based on master-slave approach
- Interference to the neighboring BS users are **bounded by a scalar variable, treated as a constant in subproblems**
- The interference thresholds are determined by the master problem and used in each slave subproblem constraint as

$$\zeta_{l,k,n,b} \geq \sum_{i \in \mathcal{U}_b} \sum_{j=1}^L |\mathbf{w}_{l,k,n}^H \mathbf{H}_{b,k,n} \mathbf{m}_{j,i,n}|^2 \quad \forall b \in \bar{\mathcal{B}}_{b_k}. \quad (9)$$

ADMM based Decomposition Method

- ▶ The ADMM is superior to other distributed schemes in terms of the convergence speed
- ▶ ADMM includes an additional quadratic term

$$\|v_k\|_q + \sum_{l,k,n} \nu_{l,k,n}^{(j)} \left(\zeta_b - \zeta_b^{(j)} \right) + \frac{\rho}{2} \|\zeta_b - \zeta_b^{(j)}\|^2 \quad (10)$$

in objective, where $\zeta_b^{(j)}$ is global consensus variable

- ▶ $\zeta_{l,k,n,b}$ in (9) is **treated as an optimization variable in ADMM**
- ▶ Consensus variables are updated upon exchanging corresponding local $\zeta_{l,k,n,b}$'s among coordinating BSs

KKT based Distributed Solution

- ▶ Decentralization methods involve significant signaling exchanges via backhaul
- ▶ **Overhead is large for multi-antenna receivers** - iterative design should reduce the backlogged packets significantly in first few iterations
- ▶ To achieve that, we design precoders by solving the Karush-Kuhn-Tucker (KKT) equations of the JSFRA problem via MSE reformulation
- ▶ **Group update of all involved optimization variables** - to speed up the convergence of precoder design

Performance of Distributed Solutions

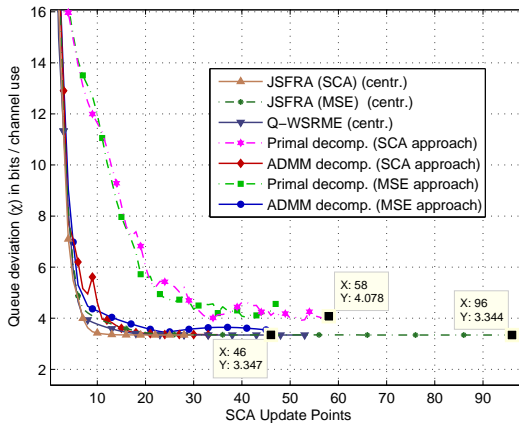


Figure: System Model - $\{N, N_B, K, N_T, N_R\} = \{3, 2, 8, 4, 1\}$

Performance of KKT based Approach

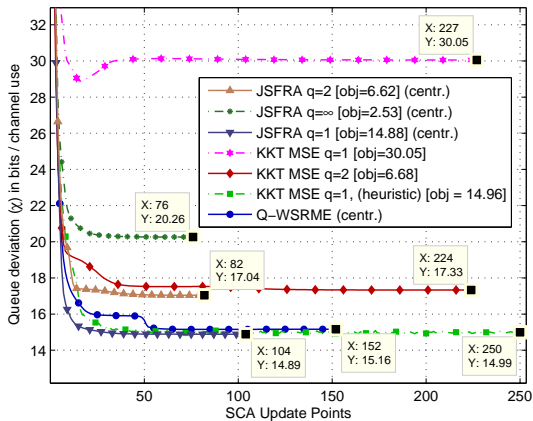


Figure: System Model - $\{N, N_B, K, N_T, N_R\} = \{5, 2, 8, 4, 1\}$

Section 5

Time Correlated Fading Performance

Time Correlated Fading - Centralized Performance

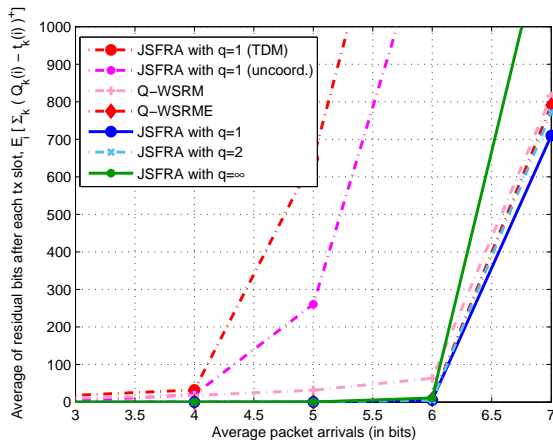


Figure: System Model - $\{N, N_B, K, N_R\} = \{3, 2, 8, 1\}$ after 250 transmissions

Section 6

Conclusions

Conclusions

- ▶ We studied cross layer problem of designing transmit and receive beamformers based on the number of residual packets
- ▶ Since the problem is nonconvex, we solve the problem iteratively by solving convex subproblems in each iteration
- ▶ We also proposed a practical way of implementing the precoder design in a distributed manner by solving the KKT expressions
- ▶ Extensions of the proposed work in time-correlated fading scenario with limited number of information exchange cycle is in progress

Questions !