Rate Constrained Power Control in Space-Time Coded Fading Ad-Hoc Networks

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Outline

- Problem Description
- Literature Review
- Contribution
- System Model
- Constrained Power Optimization
- Simulation Results
- Conclusions

Description and Contributions

- Minimize power consumption of wireless ad-hoc networks with multiple antenna nodes under throughput and QoS provisioning constraints

- Modeling the MIMO fading channel.
- Integrating a finite-sate MC model into power minimization problem of ad-hoc networks without incurring prohibitive overhead.
- Solving the problem with low complexity
- Investigating mobility effects.

SINR Model

- Instantaneous SINR for an $M_i \times N_i$ link i with transmission power P_i is defined as

$$SINR_i(t) = \frac{G_{ii}(t)\frac{P_i(t)}{M_i}\sum_{m=1}^{M_i}\sum_{n=1}^{N_i}F_{ii}^{(m,n)}(t)}{\sum_{j\neq i}G_{ij}(t)\frac{P_j(t)}{M_j}\sum_{m=1}^{M_j}\sum_{n=1}^{N_i}F_{ij}^{(m,n)}(t)+N_i n_i(t)}$$

- $G_{ij}(t)$ captures factors such as path loss, shadowing, and antenna gain. $F_{ij}^{(m,n)}(t)$ is the fading factor between transmitting antenna m of link j and receiving antenna n of link i.

Assumptions

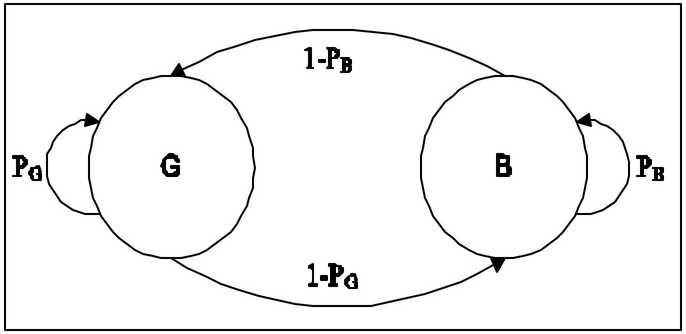
- Time shift correlations of fading factors over the same links are temporally correlated
- Time shift correlations of fading factors over different links are i.i.d
- Distribution of the white Gaussian noise is independent from the fading distributions
- F_{ij}'s have unit means so long as G_{ij}'s are appropriately scaled
- Wireless channel varies slowly with respect to the symbol interval.

Digital Channel Description

- Previously, we modeled the analog fading channel with a finite state MC.
- Gilbert-Elliott Error Model
  - Transition probabilities from Rayleigh stats
  - SER is a function of SINR, M, and N

$$P_G = g, \quad P_B = b,$$

$$SER_G << SER_B$$



Reception Probabilities

- What is the prob. of receiving exactly k UOIs from n transmitted UOIs?

$$P(n,k)=P(n,k,G)+P(n,k,B), \quad n\geq k>0$$

$$\begin{aligned}P(n,k,G)=&e_G[g\,P(n-1,k,G)+(1-b)P(n-1,k,B)]\\&+(1-e_G)[g\,P(n-1,k-1,G)+(1-b)P(n-1,k-1,B)]\end{aligned}$$

$$\begin{aligned}P(n,k,B)=&e_B[(1-g)P(n-1,k,G)+b\,P(n-1,k,B)]\\&+(1-e_B)[(1-g)P(n-1,k-1,G)+b\,P(n-1,k-1,B)]\end{aligned}$$

$$P(0,0,G)=g_{ss}=\frac{1-b}{2-g-b}, \quad P(0,0,B)=b_{ss}=\frac{1-g}{2-g-b},$$

$$P(1,0,G)=e_G[g\,g_{ss}+(1-b)b_{ss}], \quad P(1,0,B)=e_B[(1-g)g_{ss}+b\,b_{ss}]$$

MIMO Coding Effects

- We show that SER of 1xN MRC with M-PSK is

$$e\,(SINR, M, N) = \frac{M-1}{M} - \frac{1}{p}\sqrt{\frac{J}{1+J}}\Big\{\Big(\frac{p}{2} + \tan^{-1}x\Big)\sum_{j=0}^{N-1}\binom{2j}{j}\frac{1}{[4(1+J)]^{j}}$$

$$+\sin(\tan^{-1}x)\sum_{j=1}^{N-1}\sum_{i=1}^{j}\frac{s_{ij}}{(1+J)^{j}}[\cos(\tan^{-1}x)]^{2(j-i)+1}\Big\}$$

where

$$J = SINR\sin^{2}\left(\tfrac{p}{M}\right) \qquad x = \sqrt{\tfrac{J}{1+J}}\cot\tfrac{p}{M} \qquad s_{ij} = \frac{\binom{2j}{j}}{\binom{2(j-i)}{j-i}4^{i}[2(j-i)+1]}$$

- For an even N and considering the coding gain, the SER of 2 x N/2 STBC with M-PSK is calculated by replacing proper SINR for the SER of 1xN MRC

Channel Coding

- Utilize Reed-Solomon Codes
- Apply per state MIMO coding results, e.g., the 2x2 case w/ BPSK yields

$$e_{G,B} = \frac{1}{2} - \frac{1}{2}\sqrt{\frac{SNR_{G,B}}{1+SNR_{G,B}}}\left(\sum_{j=0}^{3}\binom{2j}{j}\frac{1}{[4(1+\mathrm{SNR}_{G,B})]^{j}}\right)$$

- Probability of Block Loss Conservative Estimate

$$\Psi(n,t_c,e_G,e_B,g,b) = 1 - \sum_{i=n-t_c}^{n} P(n,i) \qquad t_c = \left\lfloor \frac{n-k}{2} \right\rfloor$$

Optimization Problem

- Problem $\min_{P_i, M_i} \quad P_{\text{Total}} = \sum_{i=1}^{n} P_{\text{i}}$

$$\text{Subject To}: \quad \Psi_i \leq \Psi_{i,ub} \qquad i \in 1,\ldots,\text{n}$$

$$\sum_{i=1}^{n} R_i \geq R_{lb}$$

$$P_{i,lb} \leq P_i \leq P_{i,ub} \quad i \in 1,\ldots,\text{n}$$

where using adaptive modulation,

$$R_i = \frac{1}{T} \log_2 M_i$$

Optimization Solution

- Solution: SQP and KKT Equations

$$LG_P = \sum_{i=1}^{n} P_{\mathrm{i}} + m_i (\Psi_i - \Psi_{i,ub}) + l\,(R_{lb} - \sum_{i=1}^{n} R_i) + q_i (P_i - P_{i,ub})$$

$$\nabla LG_P(\Omega^*) = 0$$

$$m_i^* (\Psi_i^* - \Psi_{i,ub}) = 0$$

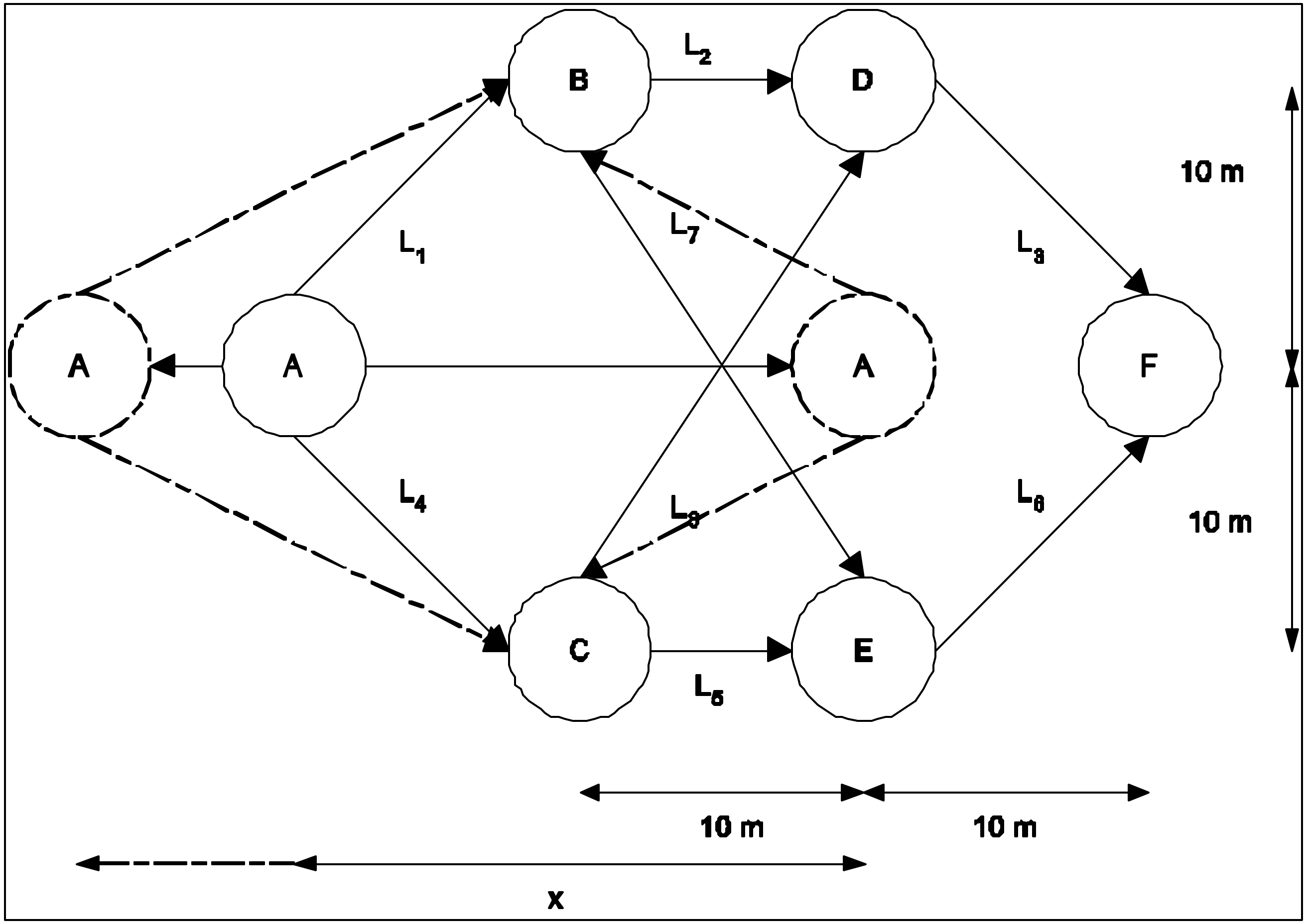
$$l^* (R_{lb} - \sum_{i=1}^{n} R_i^*) = 0$$

$$q_i^* (P_i^* - P_{i,ub}) = 0$$

$$m_i^*, l^*, q_i^* \geq 0$$

- Complexity $O(I\,d \log d)$

Mobile Topology



Parameter Settings

- Power Bounds: $P_{ub} = 1W \quad P_{lb} = 0.001W$
- Gain Matrix a function of x:

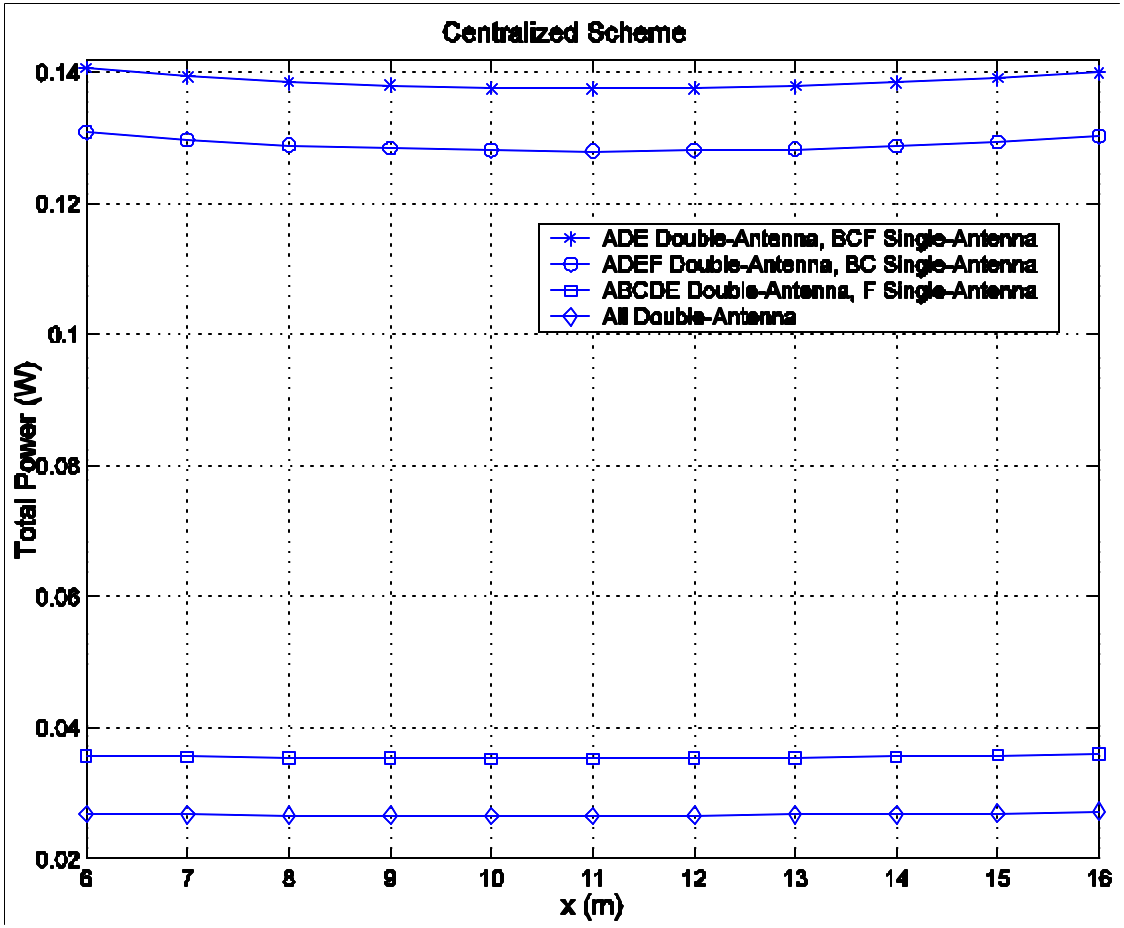
$$G = [G_{ij}], \quad G_{ii} = \frac{1}{d_{ii}^4}, \quad G_{ij} = \frac{h}{d_{ij}^4}$$

- Power: $P_i = 1W \quad E[n_i] = 10mW$
- Baseband: $\frac{1}{T} = 100KHz \quad RS(31,15)$
- Same Partitioning Thresholds:

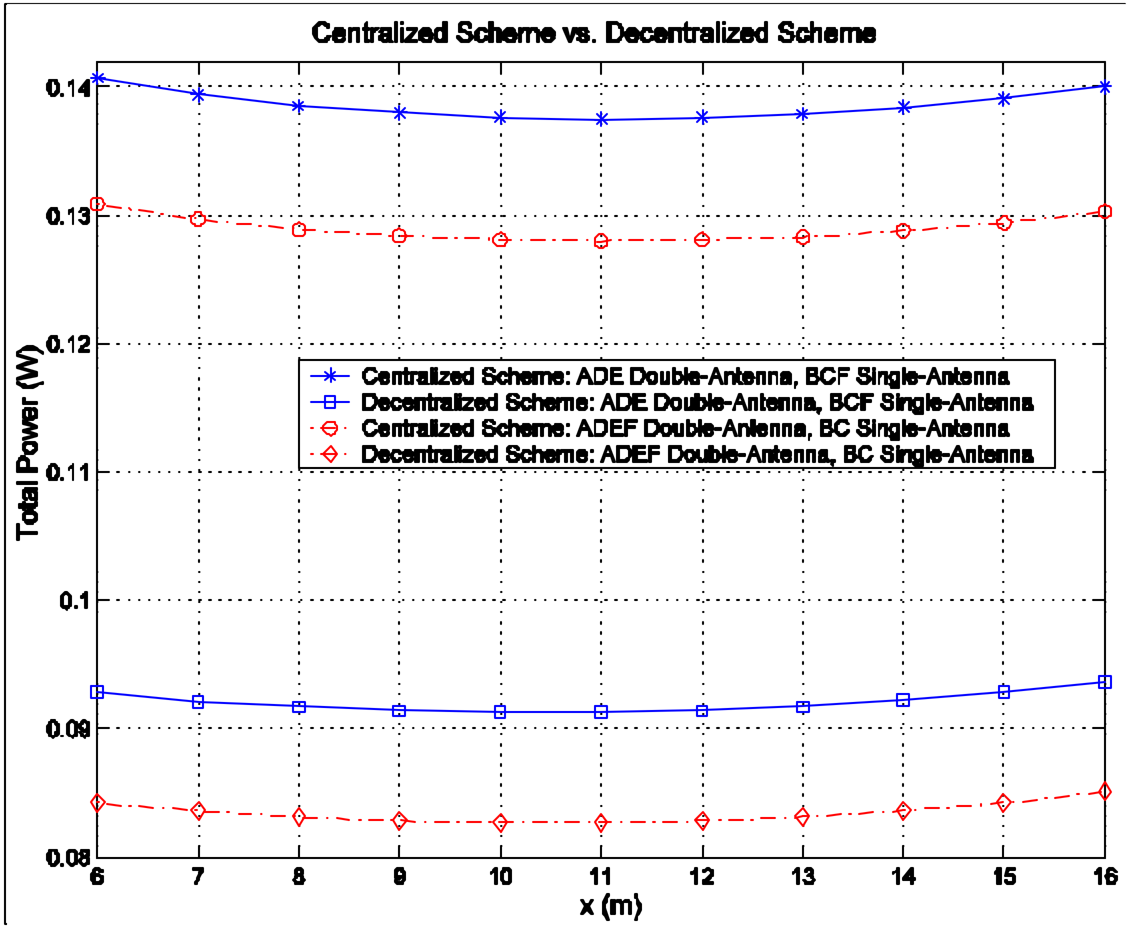
$$1 \times 1: \quad \{g, b\} = \{0.99873, 0.875\}$$

- Throughput Bound: $R_{lb} = 2Mbps$

Global (Centralized) Results



Global vs Local (per link) Results



Conclusion http://newport.eecs.uci.edu/~hyousefi/pub.html

- Summary:
  - MIMO Rayleigh fading modeling with finite-state MC
  - Providing an integrated system framework relating temporally correlated loss, modulation, channel coding, and antenna characteristics
  - Formulating and efficiently solving a QoS constrained power optimization problem
  - Numerically validating the results under mobility
- Future work:
  - Investigation of the problem for transmitting rich content
  - More Sophisticated QoS Metrics

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