Resource Allocation in Fading Ad-Hoc Networks

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Problem Description

- Wireless devices, ad-hoc networks
- Challenges: limited resources, QoS, wireless channel models
- Optimize some QoS metric under power constraints, or
- Minimize power consumption under QoS provisioning constraints

Literature Review

- Power control
  - [Ramanathan et al.] power control considering the network topology
  - [Hayajneh et al.] game-theoretic power control algorithm
- QoS provisioning
  - [Kulkarni et al.] Channel assignment scheme in Rayleigh fading ad-hoc networks
  - [Chiang et al.] Geometric Programming, resource allocation
- FSMC model
  - [Gilbert] 2-state MC
  - [Elliott] non-trivial per state error prob.
  - [Wang et al.] K-state MC to characterize the flat Rayleigh fading channel
  - [Tan et al.] validity of an amplitude-based FSMC

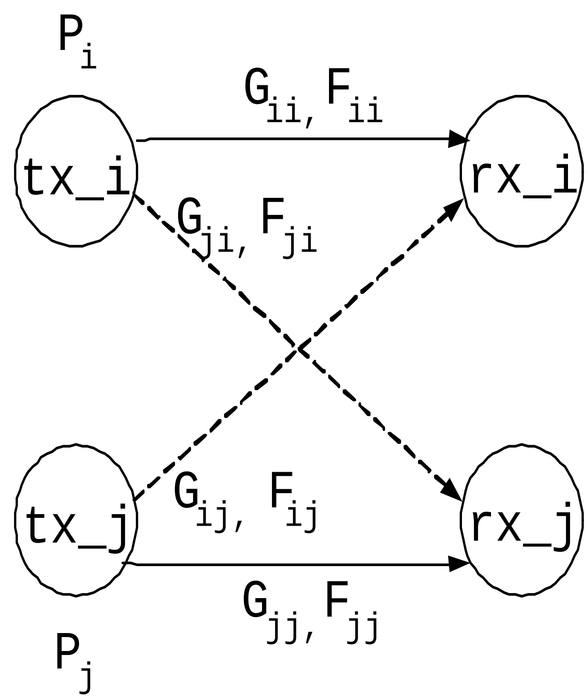
Contributions

- Integrating a FSMC model into resource allocation optimization problem without incurring prohibitive overhead.
- Considering temporally correlated block-loss probability as QoS metric.
- Easy extension to other channel models, e.g. Ricean, Nakagimi.

Received SIR – Definition

- n wireless links, labeled $L_1, \ldots, L_n$
- Desired signal of receiver i: $G_{ii}(t)P_i(t)F_{ii}(t)$
- Interferences from L_j's ($i \neq j$): $G_{ij}(t)P_j(t)F_{ij}(t)$
- Instantaneous SIR:

$$SIR_i(t) = \frac{G_{ii}(t)P_i(t)F_{ii}(t)}{\sum_{j \neq i} G_{ij}(t)P_j(t)F_{ij}(t) + N_i(t)}$$



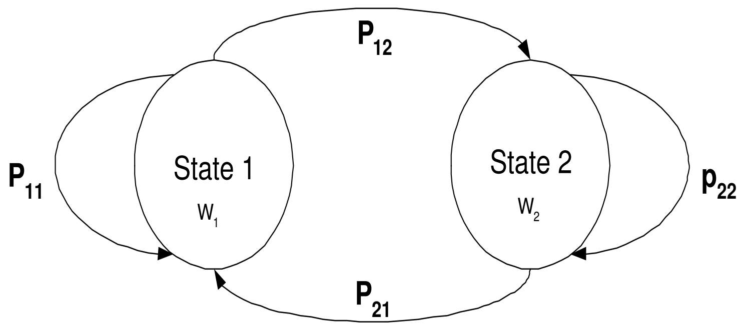
Received SIR – Assumptions

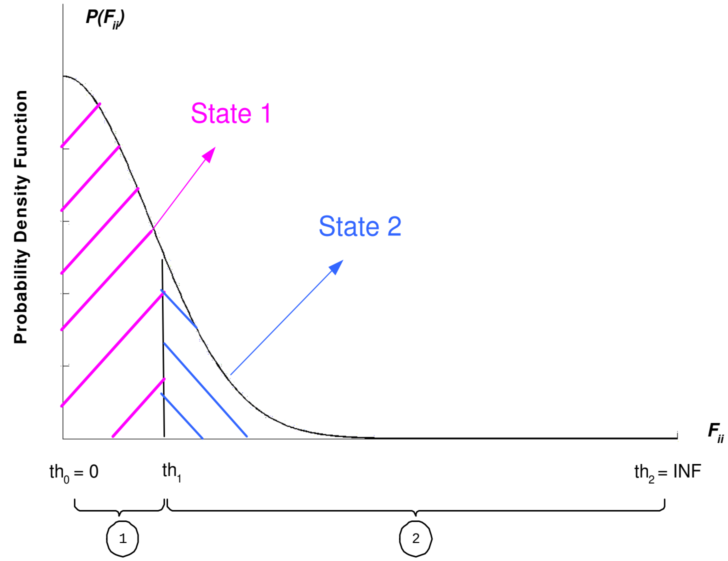
- Assumptions:
  - noise independent from fading factors
  - negligible noise w.r.t. interferences
  - F_{ij} has unit mean
  - F_{ij} independent from $F_{i'j'}$
  - fading slow w.r.t. symbol rate
- Avg. $SIR_i = \frac{E[G_{ii}P_iF_{ii}(t)]}{E[G_{ij}P_jF_{ij}(t)+N_i(t)]} = \frac{G_{ii}P_iF_{ii}}{\sum_{j\neq i} G_{ij}P_j}$

Received SIR – Statistics

- $S_o = \alpha S_i + N$, α complex Gaussian R.V.
- $r = |\alpha|$, $p(r_i)$, $p(r_i, r_{i'})$, [Jakes]
- $F_{ii} = r_{ii}^2$, $p(F_{ii})$, $p(F_{ii}, F_{i'i'})$
- FSMC Model to capture the temporal correlation

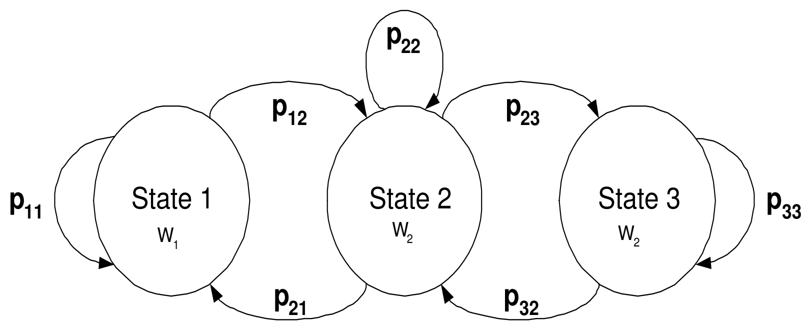
2-State Markov-Chain

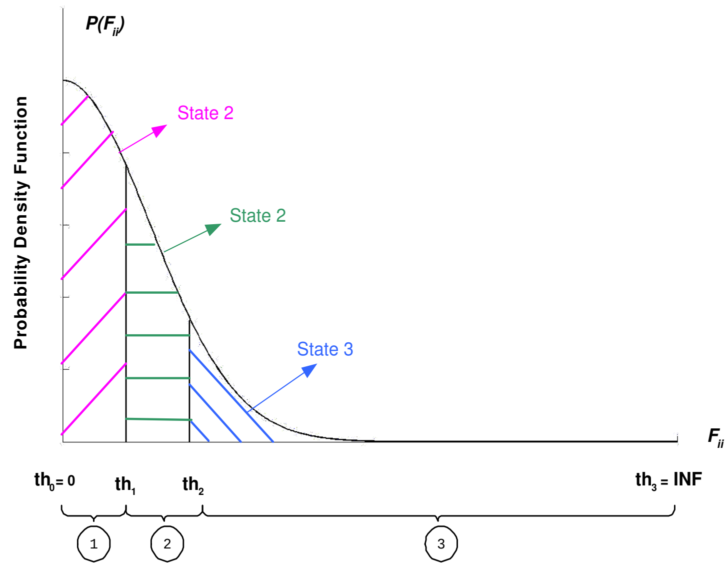




- thresholds $[th_0, th_1, th_2]$
- transitional prob. $\Pi_{2\times 2} = [P_{ss'}]$, Baye's Rule
- e.g. $P_{12} = \dfrac{\int_{th_0}^{th_1} \int_{th_1}^{th_2} p(F_{ii}F_{i'i'})dF_{ii}F_{i'i'}}{\int_{th_0}^{th_1} p(F_{ii})dF_{ii}}$
- $F_{ii,s} = E[F_{ii}(t)|in\ State\ s]$, $s = 1, 2 \rightarrow \quad SIR_{i,s}$

3-State Markov-Chain





- thresholds $[th_0, th_1, th_2, th_3]$
- transitional prob. $\Pi_{3\times3} = [P_{ss'}]$
- fading slow w.r.t. symbol rate, transitions between neighboring states only

BER, SER and Data Rate

- Adaptive Modulation, M-QAM, $M_{i,s}$
- $BER_{i,s} = 0.2 \exp(\frac{-1.6 SIR_{i,s}}{M_{i,s}-1})$

  curve-fitting for M-QAM, [Chung et al.]
- $SER_{i,s} = 1 - (1 - BER_{i,s})^{\log_2 M_{i,s}} \simeq \log_2 M_{i,s} BER_{i,s}$
- $R_i = \sum_{s=1}^{S} W_s R_{i,s} = \frac{1}{T} \sum_{s=1}^{S} W_s \log_2 M_{i,s}$

Block Loss Probability

- Loss effect compensation: Reed-Solomon Coder
- $R(b, k)$, $t_c = \lfloor \frac{b-k}{2} \rfloor$
- $\varphi(b, k) = \sum_{s=1}^{S} \varphi(b, k, s)$
- $\Psi = 1 - \sum_{k=b-t_c}^{b} \varphi(b, k)$
- Recursive formula, $\Psi = f(SER_s, MC)$

Problem Formulation and Solution

- Optimization problem:

$$\begin{aligned} \max_{M_{i,s},P_i} \quad & R_{total} = \sum_{i=1}^{n} R_i \\ Subject\ To: \quad & \Psi_i \leq \Psi_{i,ub} \quad \forall i \\ & R_{i,s} \geq R_{i,s,lb} \quad \forall i, s \\ & 0 \leq P_i \leq P_{i,ub} \quad \forall i \end{aligned}$$

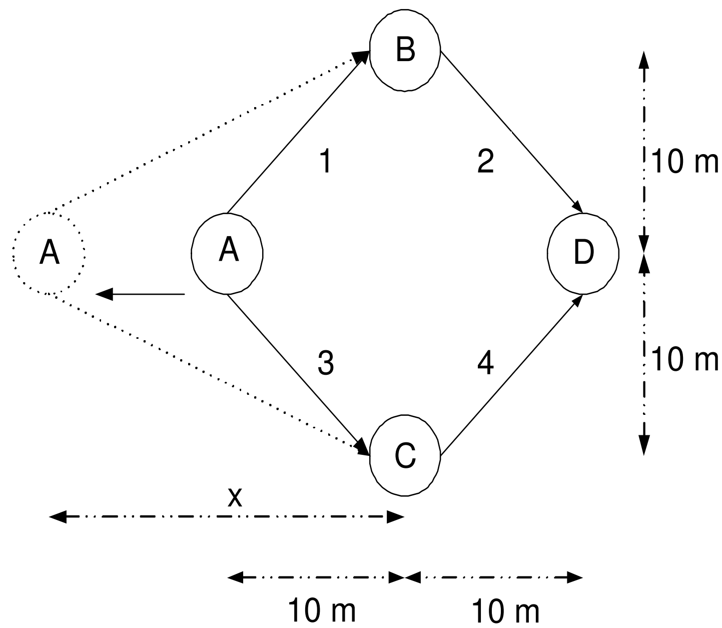
- Known CSI: $P_i, M_{i,s}$; Unknown CSI: P_i, M_i
- Lagrangian Theory and Sequential Quadratic Programming (SQP)

Numerical Results

- $\frac{1}{T} = 10kHz$, $P_i \leq 1W$, $R_i \geq 20kbps$, $RS(127, 63)$

- $G_{ij} = \frac{\eta}{d_{ij}^4}$, $\quad \eta = \frac{1}{200} \quad (i \neq j)$, $G_{ii} = \frac{1}{d_{ii}^4}$

$$\begin{bmatrix} 1/(x^2+100)^2 & 0 & \eta/(x^2+100)^2 & \eta/20^4 \\ \eta/(x+10)^4 & 1/200^2 & \eta/(x+10)^4 & \eta/20^4 \\ \eta/(x^2+100)^2 & \eta/20^4 & 1/(x^2+100)^2 & 0 \\ \eta/(x+10)^4 & \eta/200^2 & \eta/(x+10)^4 & 1/200^2 \end{bmatrix}$$



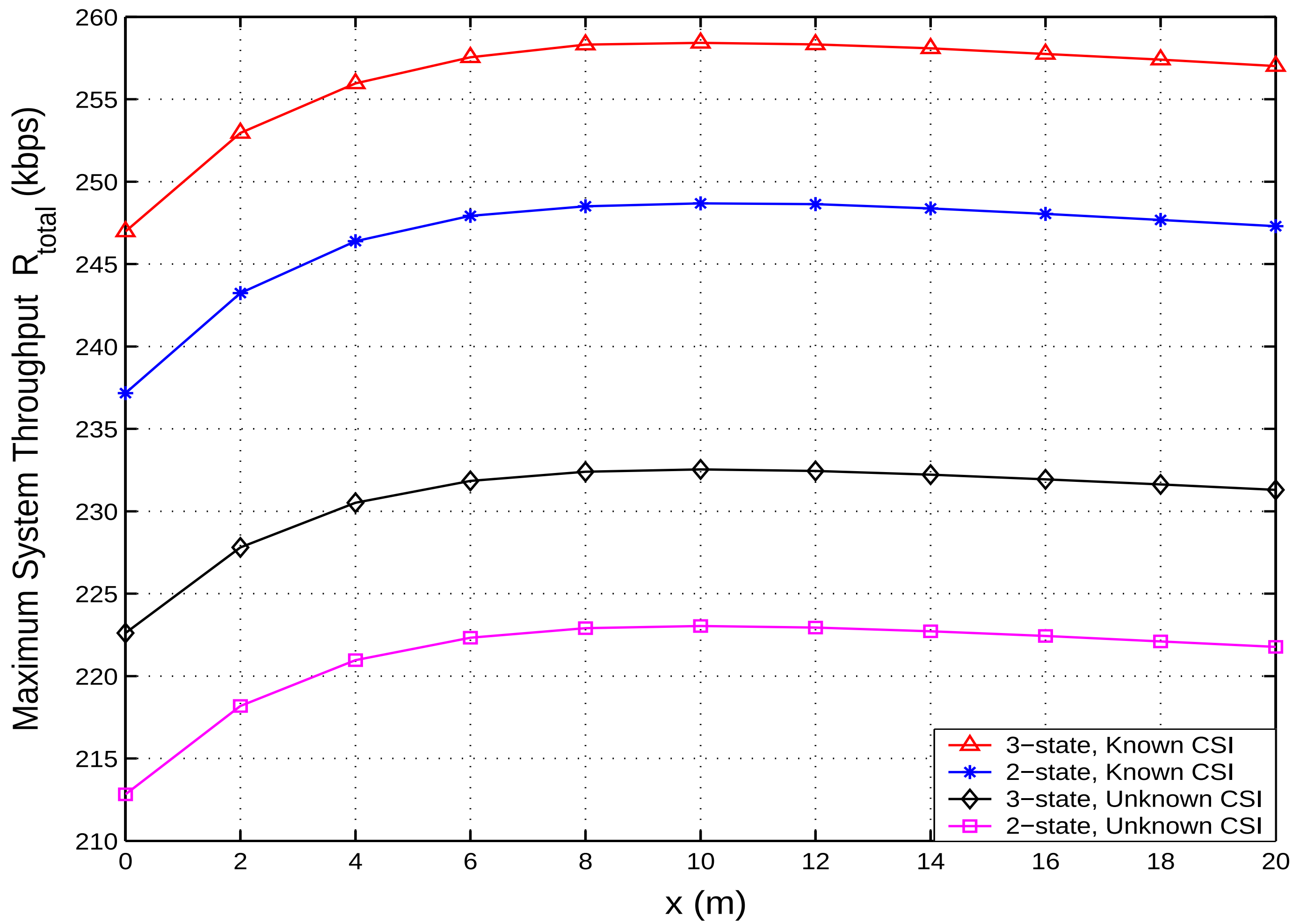
- $[0 \quad 0.69304 \quad 9]$ for 2-state

  $[0 \quad 0.4054 \quad 1.0983 \quad 9]$ for 3-state

- $\Pi_2 = \begin{bmatrix} 0.4085 & 0.5915 \\ 0.3755 & 0.6245 \end{bmatrix}$, [W1, W2]

  $\Pi_3 = \begin{bmatrix} 0.4688 & 0.5312 & 0 \\ 0.5312 & 0.2588 & 0.3872 \\ 0 & 0.3692 & 0.6308 \end{bmatrix}$, [W1, W2, W3]

Numerical Results (Cont'd)



Conclusions

- Integration of FSMC Model into resource allocation problem
- Block loss probability as a QoS metric to capture loss effect, modulation, and interferences
- Simulation results under mobility, 2-state vs 3-state, CSI vs no CSI
- Future work: multiple-antenna system

Thank You!