A Game-Theoretic Look at Joint Multi-Access, Power and Rate Control
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Objective and Motivation

Objective: Analyze a cross-layering problem in wireless ad hoc networks from the perspective of stochastic games
- Simple building block: Multi-Access Channel
- Joint Random Access & Power and Rate Control (MAC Layer) (Physical Layer)

Motivation: Wireless ad hoc networks consist of selfish (non-cooperative) nodes with conflicting interests:
- Intertwined conflicts of throughput, energy and delay
- Selfish behavior prevents cheating for channel access
- Inherently distributed and scalable

Random Access as a Stochastic Game

Single-cell system with classical uplink collision channel
- Multiple blocked nodes contending for single channel

Game with two actions: Transmitting or Waiting

Performance measures:
(a) throughput reward 1 for successful transmissions
(b) energy cost $e$ for transmission attempts
(c) discount future payoffs by $\delta$ for each slot of delay

State of Game: $n$ (number of backlogged nodes)

Given $n$, each user $i$ selects transmitting probability $p_{i,n}$
- (a) independently to maximize individual utility $u_{i,n}$
- (b) cooperatively to maximize total system utility $U_n$

Slotted collision channel model:
- Each packet arrives at a “new” transmitter node
- No new packet arrives until resolution of backlogged nodes

Capture: Multiple successful transmissions per slot
- Capture probability $q_k$: Probability that any transmitting node $i$ is successful for total of $k+1$ transmitting nodes

Error-free feedback:
(I) Channel Outputs: Success, Collision, Idle
(II) State of the Game $n$

Expected Utilities for Random Access Game

$$u_{i,n} = p_{i,n} u_{i,n}(T) + (1 - p_{i,n}) u_{i,n}(W)$$

Power Control and Rate Adaptation Game PRG ($n$)

Capture mechanism depends on powers & rates of nodes
- Given $n$, node $i$ selects power-rate pair $S_i \in J = E \times R$
- $E_i$ or $R_i$: Transmission power or rate of action $S_i$, $1 \leq i \leq |J|$
- $ER_{i,n}(S_i)$: Probability that node $i$ chooses action $S_i$ for state $n$
- Strategy: Given state $n$, any node $i$ selects $ER_{i,n}(S_i)$ to maximize its own utility $u_{i,n} = \sum_{S_i \in J} p_{i,n}(S_i) ER_{i,n}(S_i)$
- Energy cost: $\epsilon E_i$, if $R_i > 0$
- Reward for successful transmission: $R_i$

M-ary Quadrature Amplitude Modulation as rate control
- Selecting transmission rate $R$ bits per slot
- Employing m-ary QAM, $m = 2^k$ or waiting ($m = 1$)

Symmetric Nash Equilibrium for identical nodes:
- For $n \geq 1$, find $ER_{i,n}(S_i)$, $S_i \in J$, such that $u_{i,n}((x,y)), (x,y) \in J = u_{n}^*$ given $u^{*}_{n+1}$, $n-1 \geq k \geq 1$

Superior Performance of Power and Rate Control Games

Non-cooperative Eq. strategies of power & rate control
- Power Set $E = \{0,1,2,3,4,5\}$ unit power
- Rate Set $R = \{0,1,2,3,4\}$ (bits/packet) = 2, 4, 8, 16-QAM

Non-Cooperative Eq. strategies for random access $G(n)$
- Each user decides only to transmit or wait
- Averaged or optimized over possible powers and rates