Joint Multi-Access and Routing as a Stochastic Game for Relay Channel

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*Objective and Motivation **

- ***Objective***: Analyze cross-layering problems in ***wireless ad hoc networks*** from the perspective of stochastic games
  - Building block: ***Simple Relay Channel***

  - Joint Routing (*Network Layer*) & Random Access (*MAC Layer*)
- ***Motivation***: Wireless ad hoc networks consist of selfish (non-cooperative) nodes with conflicting interests:
  - Intertwined conflicts of ***throughput***, ***energy*** and ***delay***
  - More r***obust*** since selfish behavior prevents cheating for channel access purposes
  - Inherently ***distributed*** and ***scalable***

Simple Relay Channel Model

- One source (node 1), relay (node 2), destination (node 3)
  - Simplest form of multi-hop communication with 2 choices:
    - (a) ***Direct Communication***
      - Conflicting throughput interests
    - (b) ***Forwarding over relay node***
      - Not throughput or energy-efficient for relay node
      - Stimulation for cooperation is needed
  - ***Classical*** assumption: Nodes cooperate for relaying
  - ***New*** assumption: Relay generates packet for destination
- ***Classical Collision Channel*** Model:
  - Three channel outputs: ***Idle, Success***, or ***Collision***
  - Secondary packet conflicts ***not*** allowed
  - Simultaneous transmission and reception ***not*** allowed
- Relaying rule & reward-based ***stimulation*** for cooperation
  - If node 2 accepts packet of node 1:
    - Node 1 receives payoff c from node 2
    - Node 2 undertakes future rewards and costs
  - If node 2 rejects packet of node 1, a ***"collision"*** occurs

Network Model and Actions

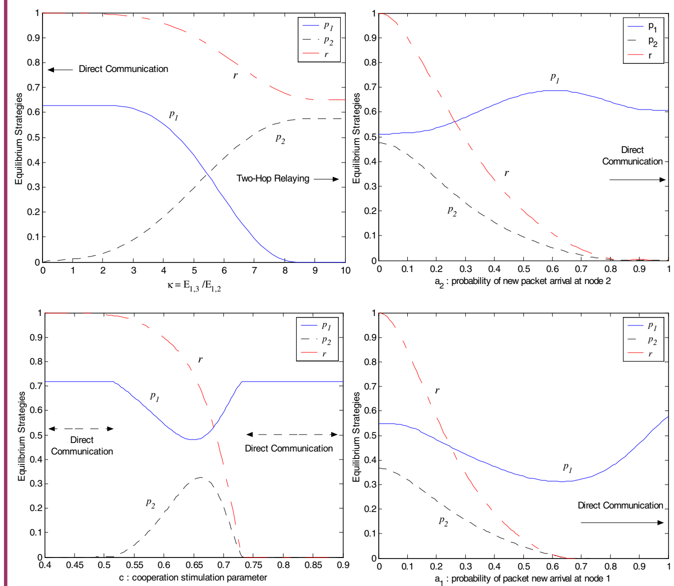
- Wireless ad-hoc network with three nodes:
  - ***Synchronous slotted*** system with queue sizes of one **1**
  - Nodes 1, 2 generate packets with probability a_1 and a_2
  - Transmitter has ***three*** possible actions at each time slot:
    - A_1 : Transmitting packet directly to destination
    - A_2 : Transmitting a packet to relay node
    - A_3 : Waiting
  - Relay node has ***four*** possible actions at each time slot:
    - Full Queue: B_1 : Direct transmission
      B_2 : Waiting
    - Empty Queue: C_1 : Accepting packet for forwarding
      C_2 : Rejecting packet for forwarding

Strategies, Utilities and Objectives

- Strategies: $\underline{s} = (\underline{s}_1, \underline{s}_2) = (p_1, p_2, q, r)$
  - p_1, p_2, q, r: probability of selecting actions A_1, A_1, B_1, C_1
- Costs and rewards :
  - ***Delay*** cost d for waiting or unsuccessful transmission
  - Energy cost $E_{i,j}$ for transmission from node i to node j
  - Reward 1 for delivering packet to common destination
- State : (Q_1, Q_2) , $Q_i = 1$ if queue of node i is full and
  $Q_i = 0$ if queue of node i is empty
  - At each slot, node i makes decision depending on Q_i
  - Expected ***stationary*** utility: $U_i(\underline{s}) = \sum_{k_j \in K} \pi_j(\underline{s}) E_i^u(k_j, \underline{s})$
  - ***Partially observable*** states $K = \{(0,0),(0,1),(1,0),(1,1)\}$
  - $\pi_j(\underline{s})$: Stationary probability of state k_j under strategy $\underline{s}$
  - $E_i^u(k_j, \underline{s})$: Immediate utility (reward - cost) expected by user i under strategy $\underline{s}$ at state k_j
- Objectives of nodes :
  - ***Non-cooperative***: Nodes independently select $\underline{s}_i$ to maximize individual utilities $U_i(\underline{s})$
  - ***Cooperative***: Nodes jointly select $\underline{s}$ to maximize the total system utility $U_1(\underline{s}) + U_2(\underline{s})$

Numerical Results

- Strategies in terms of $\kappa = E_{1,3} / E_{1,2}$, c, a_1 and a_2



- Expected utilities in selfish and social equilibrium:

$E_{1,2} = E_{2,3} = d = 0.1$, $a_1 = 0.25, c = 0.4$	$a_2 = 0$, $\kappa = 1$	$a_2 = 0.25$, $\kappa = 1$	$a_2 = 0$, $\kappa = 5$	$a_2 = 0.25$, $\kappa = 5$
$U_1 + U_2$ (Non-cooperative)	0.15	0.2425	0.1355	0.2383
$U_1 + U_2$ (Cooperative)	0.15	0.2637	0.1467	0.2546

- ***Result*** **:** Cooperation is better than selfish decisions

Possible Improvements

- Waiting for transmission of ***forwarded*** packets
- ***Immediate*** transmission of ***new*** and ***accepted*** packets

$E_{1,2} = E_{2,3} = d = 0.1$, $a_1 = 0.25, c = 0.4$	$a_2 = 0$, $\kappa = 1$	$a_2 = 0.25$, $\kappa = 1$	$a_2 = 0$, $\kappa = 5$	$a_2 = 0.25$, $\kappa = 5$
$U_1 + U_2$ (Non-cooperative)	0.15	0.2482	0.1474	0.2494
$U_1 + U_2$ (Cooperative)	0.15	0.2708	0.1496	0.2697

** The material presented in this poster is based on paper "A Game-Theoretic Look at Simple Relay Channel ", Yalin Evren Sagduyu, Anthony Ephremides, in Proc. WIOPT'04 , Mar. 2004.*