Learning algorithms for power and frequency allocation in clustered ad hoc networks

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Overview: The problem

Cluster frequency « coloring »

Flat network

Clustering

Cluster Head

Ch #1

Ch #2

Ch #3

Ch #4
Overview: The problem

- **Optimization problem**
  - Select the cluster frequency channel
    - That minimizes the total transmit power (all the clusters)
    - Subject to per-link SINR constraints
    - In a fully distributed way

- **Several possible solutions**
  - Multi-channels
    - Iterative Water-Filling
  - Single channel
    - GADIA
  - Game Theory-based
    - Reinforcement Learning
    - Trial and Error
Overview: Literature

- **Iterative Water-filling**
  - Individually optimum
  - No proof of convergence
  - Several results show its inefficiency in densely populated networks (Tragedy of the Commons)

- **GADIA**
  - Channel selected to minimize the global interference level
  - Convergence proved
  - Not adapt to set power and channel, requires distanced clusters

- **Reinforcement Learning**
  - Convergence proved
  - Slow convergence
  - Different training and exploitation periods
Moods

- c: content
- d: discontent
- w: watchful
- h: hopeful

**Trial and Error Learning**

(H. Peyton Young, 2009)

**Trial and Error: basic strategy**

**- Content**
  - Experiments new actions with probability \( \varepsilon \)

**- Discontent**
  - Experiments new actions

- C -> H: no experiment, utility increases
  - H -> C: if utility increases or equal
  - H -> W: if utility decreases
- C -> W: no experiment, utility decreases
  - W -> H: if utility increases
  - W -> C: if utility equal
  - W -> D: if utility decreases
From original TE to ad hoc networks…

First step

To
Trial and Error: Utility function

- Proposed solution: Trial and Error algorithm
  - Players: CHs
  - Actions: powers/frequencies
  - Utility for CH \#k:

\[
u_k(p) := \frac{1}{1 + |L_k| \beta} \left( 1 - \frac{p_k}{p_{\text{MAX}}} + \beta \sum_{\ell \in L_k} 1_{[\Gamma_\ell(p) > \Gamma_k]} \right)
\]

- Power minimization
- SINR constraints
Trial and Error: Theoretical Results

- **Theorem**
  - For $a^*$, if $a^*$ is a solution of the optimization problem and $a^*$ is a NE, then TE converges to $a^*$

- **Theorem**
  - For $a^*$, the TE converges to the NE where the largest set of nodes are simultaneously satisfied

- **Property**
  - TE selects among all the NE the one maximizing the Social Welfare
Issues

- Instability of the solution even if optimal
  - One parameter decides the experimentation frequency on both channels and power levels
  - Parameter fixed a priori
- Slow convergence
- Experimentation do not take “common sense” behavior
Solution: enhanced Trial and Error (ETE)

- Two different experimentation frequency
  - sets the experimentation frequency on the power levels
  - sets the experimentation frequency on the channels
  - is time-varying:

\[
\varepsilon_c(t) = \begin{cases} 
\max\left(\frac{\varepsilon_c(t-1)}{2}, \varepsilon_{\min}\right) & \text{if } \sum_{\ell \in L_k}^{\mathbb{1}_{\Gamma_c(p)=\Gamma_k}} = |L_k| \\
\varepsilon_c(0) & \text{otherwise}
\end{cases}
\]

- “Small” makes the channel-cluster association scheme stable
Enhanced Trial and Error

Solution: enhanced Trial and Error (ETE)

Smart probability distribution for power experimentation

- Content and \( \sum_{\ell \in L_k} 1_{[\Gamma_\ell(p) > \Gamma_k]} = |L_k| \): experiment only levels below

- Content and \( \sum_{\ell \in L_k} 1_{[\Gamma_\ell(p) > \Gamma_k]} < |L_k| \): experiment all levels

Discontent: \( p_k = \begin{cases} p_{\text{MAX}} & \text{with prob. } \min\left(\frac{C}{K}, 1\right) \\ 0 & \text{with prob. } \max\left(1 - \frac{C}{K}, 0\right) \end{cases} \)
Numerical Simulations

- Static dense scenario
  - Nodes fixed in a square area
  - 16 “square” clusters
  - 4 links per cluster
  - Channel-range: 2-18
  - Block fading channels
  - Rayleigh fading channels
Simulation results

- Dense scenario

![Graph showing expected average satisfaction vs. channels available. The graph plots a curve that increases as the number of channels available increases.]
Mobility scenario

- 4 clusters fixed
- 1 moving cluster
- 2 frequency channels
Channels and power levels – Mobility scenario

- Standard TE
- Enhanced TE
Enhanced Trial and Error - Conclusions

- Sets efficiently channel and power levels
- Requires only intra-cluster information
- Quickly adapts to changes in the network topology
- Quickly adapts to fading

- Thus looks adapted from a theoretical point of view
- And validated by simulations

**Using Matlab simulations!**

- Next challenge: make it work into a real system
- Ongoing implementation in a HiFi network simulator…