Myopic versus Clairvoyant Admission Policies in Wireless Networks

Pierre Coucheney, Emmanuel Hyon, Corinne Touati, Bruno Gaujal

INRIA - Alcatel Lucent Bell Labs

GameComm 2009
Motivation

Overlapping wireless technologies: LTE, Wifi, Wimax...
Recent mobiles are able to connect to several technologies.

Use:
- Multi-homing: several active connections at the same time.
- Vertical handover: switch of technology.

Benefits:
- For users: get access to high quality services.
- For providers: increase global traffic, avoid congestion.
Heterogeneous wireless system consisting of a single WiMAX cell and a set of WiFi hot-spots.
Admission Control Problem

Problem

The capacity system is limited ⇒ incoming mobile may be rejected ⇒ cost.

Need of admission control to minimize the mean sojourn time + sum of cost of each rejected call.

Find the optimal admission policy by using Markov Decision Process. Need to know statistics (input process, throughput delivered).

Question

Can the use of handover balance the unawareness of statistics?
Outline

1. Clairvoyant Solution to Admission Control Problem
2. Myopic Policy with Handover
3. Comparison between policies
4. Conclusion and future work
Outline

1. Clairvoyant Solution to Admission Control Problem
2. Myopic Policy with Handover
3. Comparison between policies
4. Conclusion and future work
Model

- $d_p^c(\ell)$: throughput offered to mobile $p$ on cell $c$ with load $\ell$.
- **Arrival process**: Poisson process.
- **Mobile call size**: exponentially distributed.
- **Policy $\pi$**: give the decision at each arrival (reject the mobile, accept it on a given cell) depending on the current state.

- **Instantaneous cost**: $\forall p, c_p(\pi) = \begin{cases} \frac{1}{\mu} \cdot \frac{1}{d_p^c(\pi)(\ell)} & \text{if } p \text{ is accepted}, \\ K & \text{otherwise.} \end{cases}$

- $\mathcal{P}(t)$: set of active mobiles at time $t$.

- **Performance of policy $\pi$**: $C_\pi = \lim_{T \to \infty} \frac{1}{T} \int_{t=0}^{T} \sum_{p \in \mathcal{P}_t} c_p(\pi) dt$. 
Remark:
Minimize the mean sojourn time is equivalent to minimize the mean number of mobiles.
Clairvoyant Policy Clrvt

\[ \text{Clrvt} \in \arg\min_{\pi} C_{\pi} \text{ (without handover)}. \]

**How to compute optimal policy?**

It is a semi Markov decision process. Solve Bellman equation by using value iteration algorithm.

**Remark**

The state space grows exponentially with the system size.
Outline

1. Clairvoyant Solution to Admission Control Problem
2. Myopic Policy with Handover
3. Comparison between policies
4. Conclusion and future work
Remark

If no rejection: minimize the mean sojourn time is equivalent to maximize the mean throughput.

Handvr policy, by using vertical handover, allocates mobiles to base stations in order to maximize the global throughput at each time regardless of the input process.
Repercussion Utility

- $s_p$: choice of mobile $p$.
- $\ell^c$: load (vector) on cell $c$: $(\ell^c)_p = \begin{cases} 1 & \text{if } s_p = c \\ 0 & \text{otherwise.} \end{cases}$
- $d_p(\ell^{sp})$: throughput of mobile $n$ given the load.

**Definition: repercussion utility.**

$$r_p(\ell^{sp}) = d_p(\ell^{sp}) - \sum_{q \neq p: s_q = s_p} d_q(\ell^{sp} - e_p) - d_q(\ell^{sp})$$
Property of Repercussion Utilities

- $q_{p,c} \overset{\text{def}}{=} \mathbb{P}[s_p = c]$.  
- $q_p$: strategy of mobile $p$.  
- $f_{p,c}(q)$: expected repercussion utility of mobile $p$ on cell $c$.  
- $F(q)$: global expected throughput.
Property of Repercussion Utilities

- $q_{p,c} \overset{\text{def}}{=} \mathbb{P}[s_p = c]$.  
- $q_p$: strategy of mobile $p$.  
- $f_{p,c}(q)$: expected repercussion utility of mobile $p$ on cell $c$.  
- $F(q)$: global expected throughput.

**Proposition**

The game with repercussion utilities is a potential game:

$$\frac{\partial F}{\partial q_{p,c}}(q) = f_{p,c}(q).$$
Algorithm

Idea:
Algorithm on \( q(t) \) approximating the replicator dynamics:

\[
\frac{dq_{p,c}}{dt} = q_{p,c} (f_{p,c}(q) - \sum_{c'} q_{p,c'} f_{p,c'}(q)).
\]

lies in \([0, 1]\)

Replicator dynamics related to potential games:
- Converges to a set of Nash equilibria.
- Potential is increasing along trajectories (Lyapunov function).
Algorithm

For all $p$:

- Choose initial strategy $q_p(0)$.
- At each time epoch $t$:
  - Choose $s_p$ according to $q_p(t)$.
  - Update: $q_{p,c}(t+1) = q_{p,c}(t) + \epsilon \left[ r_p(\ell^{s_p}) \cdot 1_{s_p = c} - q_{p,c}(t) \right]$. 

repercussion utility

Simple computation for the mobile.
Properties of the Algorithm

Theorem:

The algorithm:

1. converges to a pure strategy $q^*$.
2. $q^*$ is a pure Nash equilibrium for the game with repercussion utility.
3. $q^*$ is locally optimal for the maximization of the throughput (globally optimal for stable games).

Sketch of the proof:

- The algorithm is a stochastic approximation of the replicator dynamics.
- It weakly converges to asymptotically stable sets of RD, which are faces of stationary points of the dynamics.
- Constant step size ensures convergence to a vertex of the face (pure strategy).
Outline

1. Clairvoyant Solution to Admission Control Problem
2. Myopic Policy with Handover
3. Comparison between policies
4. Conclusion and future work
Policies

Without handover (admission control)

- **Clrvt**: minimizes the dynamic criterion (Markov Decision Process). Need to know statistics (arrival process, distribution of messages size).
- **Selfish**: an incoming mobile chooses the cell that maximizes its throughput (regardless of the input process).
- **Altr**: an incoming mobile chooses the cell that maximizes the global throughput (regardless of the input process).

With handover

- **Handvr**: our algorithm is run at each arrival or departure. The allocation is changed at each event. A mobile is rejected if the maximal capacity is reached.
Comparison between policies

Comparisons

Performance of policy $\pi$: $C_\pi = \lim_{T \to \infty} \frac{1}{T} \int_{t=0}^{T} \sum_{p \in P_t} c_p(\pi) dt$.

- $C_{Clrvt} \leq C_{Selfish}$
- $C_{Clrvt} \leq C_{Altr}$
- $C_{Handvr} \leq C_{Selfish}$
- $C_{Handvr} \leq C_{Altr}$
- No other possible comparisons.
Simulation Scenario

Capacity

The throughput offered to each mobile is at least $d_{min}$.
Efficiency loss in comparison to our algorithm. It is better than the Clrvt policy for low arrival rate.
Comparison between policies

Our algorithm and Clrvt policy have similar rejection rate.
Comparison between policies

<table>
<thead>
<tr>
<th>Number of mobiles</th>
<th>Arrival rate</th>
<th>Clrvt</th>
<th>Handvr</th>
<th>Altr</th>
<th>Selfish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>

Clrvt policy reject mobiles that degrade the global throughput.
The rejection rate of **Clrvt** is 0 in ring 1.
Comparison between policies

Rejection rate in ring 2

Arrival rate

Handvr
Selfish Altr
Clrvt

0
10
20
30
40
50
60
70
80
90

4  6  8  10  12  14  16  18  20  22

Clrvt
Handvr
Selfish
Altr

Pierre Coucheney (INRIA)
Myopic versus Clairvoyant policies
GameComm 2009
Efficiency loss in comparison to our algorithm. It is better than the Clrvt policy for high values of the rejection cost.
Comparison between policies

Rejection rate (%)

Convergence of Clrvt policy to the policy that minimizes the rejection rate.

Acknowledgments

Pierre Coucheney (INRIA)
Outline

1. Clairvoyant Solution to Admission Control Problem
2. Myopic Policy with Handover
3. Comparison between policies
4. Conclusion and future work
Main Ideas

- Using our algorithm allows to increase the performance by about 15% in comparison to naive policies (Selfish or Altruist).
- Regions of better performance:
Future Work

- Other policy: both handover and clairvoyant policy.
- Improve the model: mobility, kind of traffic, fairness between mobiles.