An Overview of Cross Layer Design & Optimization for Cognitive Radio Networks

Furqan Ahmed
COMNET, TKK
Nov 5, 2009
Agenda

• Motivation
• Cross Layer Approach for Wireless Networks
• Cross Layer Design for Cognitive Radio Networks
• Cross Layer Optimization for Cognitive Radio Networks
• Conclusions
Motivation: Why Cross Layer Design & Optimization

• Traditional Layered Design
  – Layers with definitions and tasks explicitly defined
  – Modularity
  – Standardization

• Possible Disadvantages?
  – Latency
  – Inefficiency
Cross Layer Approach for Wireless Networks

• Wireless networks
  – Rapid variations in channel
  – Fading, shadowing, mobility etc
  – Flexible architecture can take advantage of ‘good’ channel durations

• Cross layer Approach
  – Pass more information across layers
  – Blurring, changing or removing boundaries
Cross Layer Approach for Wireless Networks

• Different Cross Layer Architectures
  – Allow more information to flow upward or downward
  – Coupling of some of layers
  – Merging adjacent layers

• TCP over wireless links
  – Packet losses are always interpreted as effect of congestion in network.
  – Reason could be different like channel conditions etc.
  – Recently this problem has been solved by Explicit Congestion Notification, (ECN) mechanism[1]
Cross Layer Approach for Wireless Networks

- GPRS and EGPRS
  - GPRS: 4 different code rates between 0.5-1 according to channel quality
  - EGPRS: 2 different modulations with different coding rates
- Just having a Cross Layer Architecture is not sufficient!
  - Optimization
  - Adaptation
Cross Layer Design for Cognitive Radio Networks

- Cognitive Radio
  - Highly agile wireless platforms capable of autonomously choosing device parameters based on prevailing interference conditions

Processing cycle in cognitive radio network[2]
Cross Layer Design for Cognitive Radio Networks

- A cognitive network is a network with a cognitive process that can perceive the current network condition, and then plan, decide and act on those conditions.

- The network can learn from these adaptations and use them to make future decisions, all while taking into account the end-to-end goals.
Cross Layer Design for Cognitive Radio Networks

• Cognitive Engine takes input from various sources – sensing, overhead channels etc.
• Simultaneous optimization of multiple operating parameters across different OSI layers of device
• Each node has a cross layer optimization engine or cognitive engine
• Optimization based on a set of internal operating parameters across the different layers of wireless device in order to satisfy user requirements with as little resource as possible
Some possible adaptation parameters[3]

<table>
<thead>
<tr>
<th>Layer</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RF</strong></td>
<td>Antenna powers&lt;br&gt;Dynamic range&lt;br&gt;Pre-distortion parameter&lt;br&gt;Pre-equalization parameter</td>
</tr>
<tr>
<td>Physical layer</td>
<td>Transmit power&lt;br&gt;Digital modulation order&lt;br&gt;Carrier frequency&lt;br&gt;Operation bandwidth&lt;br&gt;Processing gain&lt;br&gt;Duty cycle&lt;br&gt;Waveform&lt;br&gt;Pulse shaping filter type&lt;br&gt;FFT size (for OFDM)&lt;br&gt;Cyclic prefix size (for OFDM)</td>
</tr>
<tr>
<td>Data link layer</td>
<td>Channel coding rate&lt;br&gt;Channel coding type&lt;br&gt;Packet size&lt;br&gt;Packet type&lt;br&gt;Data rate&lt;br&gt;Interleaving depth&lt;br&gt;Channel/Slot allocation&lt;br&gt;Carrier allocation (in multi-carrier systems)&lt;br&gt;MAC scheduling algorithm&lt;br&gt;Handover (Handoff)&lt;br&gt;Number of slots</td>
</tr>
<tr>
<td>Network</td>
<td>Routing algorithm/metric&lt;br&gt;Clustering parameters&lt;br&gt;Network scheduling algorithm</td>
</tr>
<tr>
<td>Transport</td>
<td>Congestion control parameters&lt;br&gt;Rate control parameters</td>
</tr>
<tr>
<td>Upper</td>
<td>Communication modes (simplex, duplex, etc.)&lt;br&gt;Source coding&lt;br&gt;Encryption&lt;br&gt;Service personalization</td>
</tr>
</tbody>
</table>
Cross Layer Optimization for Cognitive Radio Networks

• Optimization Problems
  – Finding a best possible solution from a set of solutions under given constraints
  – variables, objective functions and constraints

• General Form

  Find $x^*$ which
  minimizes $f(x)$
  subject to $c_i \leq X$, $i = 1, 2, \ldots, r$
  with $m_j(x) = Y$, $j = 1, 2, \ldots, h$, 
Cross Layer Optimization for Cognitive Radio Networks

• Multiple layers and multiple parameters
  – Constraints are defined by cognitive engine according to the environment and other inputs

• Different approaches for optimization
  – Single objective function
  – Multiple objective functions
  – Midstep (single objective function but variables from different layers)
Cross Layer Optimization for Cognitive Radio Networks

- Single objective optimization
  
  Find \( x^* \) which

  minimizes \( f(x) \)

  subject to \( c_i \leq X, \ i = 1, 2, \ldots, r \)

  with \( m_j(x) = Y, \ j = 1, 2, \ldots, h \),

- Multiple objective optimization

  Minimize \( F(x) = [f_1(x), f_2(x), \ldots, f_n(x)] \)

  subject to \( c_i \leq X, \ i = 1, 2, \ldots, r \)

  with \( m_j(x) = Y, \ j = 1, 2, \ldots, h \),
Cross Layer Optimization for Cognitive Radio Networks

- A midstep between single objective and multiple objective optimization
- Single objective function but parameters from different layers[3]
Cross Layer Optimization for Cognitive Radio Networks

- Enhancing performance of distributed cognitive radio network using a multiobjective formulation per cognitive radio node
  - Minimize BER, maximize throughput, minimize power usage and minimize interference with other nodes
  - Optimization function for one cognitive radio node is defined as[5]:
    \[ F(x) = \sum_{i} w_i f_i(x) \quad i \in \{P_e, TP, P, Int\} \]
    where \( P_e \) is the probability of bit error
    TP stands for throughput
    P for transmission power and Int for interference.
Conclusions

• Limitations of layered architectures for wireless networks has motivated use of cross layer design
• Cognitive radio has an inherent relationship with cross layer architecture
• Cognitive engine has key role in cross layer optimization of cognitive radio networks
• Multiple Objective Optimization can be challenging with increase in number of objectives and constraints
Thanks

Questions/Comments
References


