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

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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]

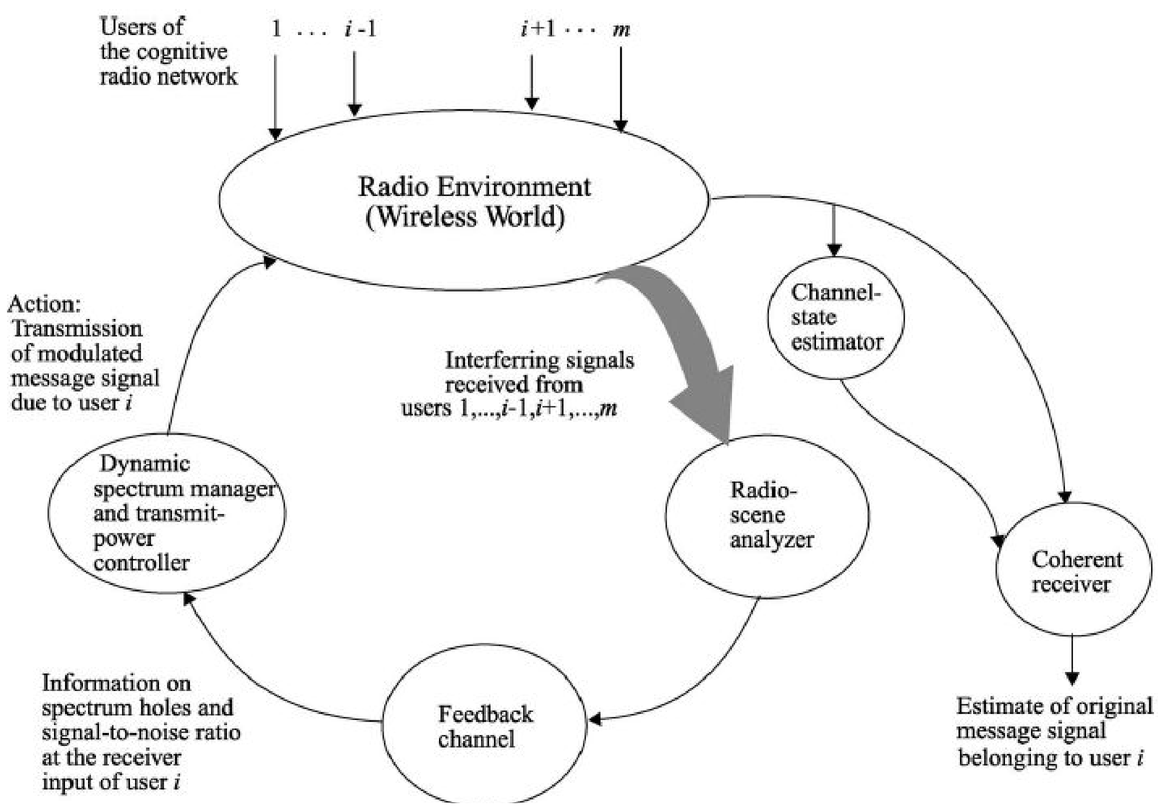
Cross Layer Approach for Wireless Networks

- 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

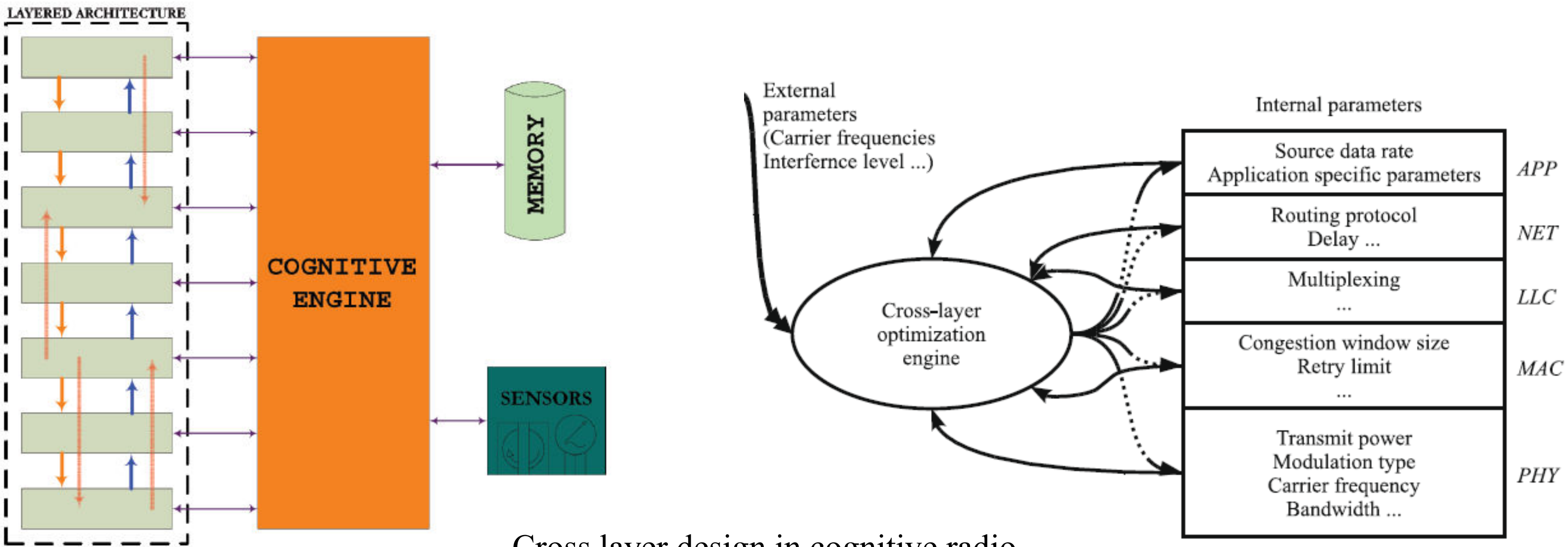
- Cognitive Radio
  - Highly agile wireless platforms capable of autonomously choosing device parameters based on prevailing interference conditions

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 in cognitive radio networks[3][4]

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]

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

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,....,r

with $m_j(x) = Y$, j = 1, 2,....,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 $c_i \leq X$, $i = 1, 2,....,r$

  with $m_j(x) = Y$, $j = 1, 2,....,h,$

- Multiple objective optimization

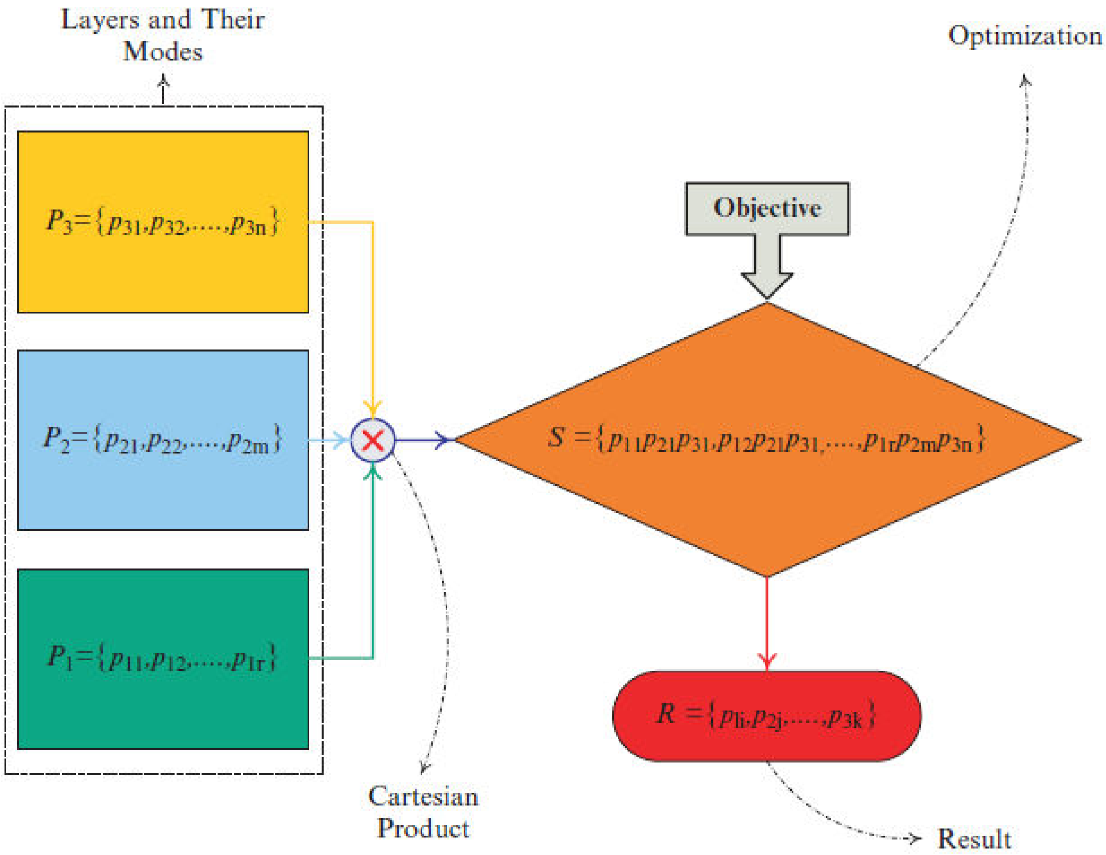
  Minimize $F(x) = [f_1(x), f_2(x)....f_n(x)]$

  subject to $c_i \leq X$, $i = 1, 2,....,r$

  with $m_j(x) = Y$, $j = 1, 2,....,h,$

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]:
  - $F(x)=\sum_i w_i f_i(x) \quad i€\{P_e, TP, P, Int\}$,

    where P_e is the probability of bit error

    TP stands for throughtput

    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

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2. P. Setoodeh and S. Haykin, Robust Transmit Power Control for Cognitive Radio, IEEE Proceedings, Vol. 97, No. 5, May 2009.
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