Cautionary Aspects of Cross Layer Design: Context, Architecture and Interactions

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Themes

- Setting the context
- Importance of Architecture
- Interactions and the Law of Unintended Consequences
- Concluding remarks
Wireless networks don’t come with links

- They are formed by nodes with radios
  - There is no \textit{a priori} notion of “links”
  - Nodes simply radiate energy
Nodes can cooperate in complex ways

Nodes in Group A cancel interference of Group B at Group C

... while Nodes in Group D amplify and forward packets from Group E to Group F

\[ \text{SINR} = \frac{\text{Signal}}{\text{Interference + Noise}} \]

One strategy: Increase Signal for Receiver
Instead, why not: Reduce Interference at Receiver

One strategy: Decode and forward
Instead, why not: Amplify and Forward
How should nodes cooperate?

- Some obvious choices
  - Should nodes relay packets?
  - Should they amplify and forward?
  - Or should they decode and forward?
  - Should they cancel interference for other nodes?
  - Or should they boost each other’s signals?
  - Should nodes simultaneously broadcast to a group of nodes?
  - Should those nodes then cooperatively broadcast to others?
  - What power should they use for any operation?
  - ...

- Or should they use much more sophisticated unthought of strategies?

  “There are more things in heaven and earth, Horatio, Than are dreamt of in your philosophy.”
  — Hamlet
On the optimality of the current proposal for ad hoc networks

- **Theorem: Xie and Kumar (2002)**
  - Multi-hop transport where
    - A packet is fully decoded at each hop
    - All interference from all other nodes is simply treated as noise
  - Is optimal up to a known multiplicative constant.
    (http://black.csl.uiuc.edu/~prkumar)

- **Properties**
  - Simple receivers
  - Simple multi-hop packet relaying scheme
  - Simple abstraction of “wires in space”

- This choice for the mode of operation gives rise to
  - Routing problem
  - Media access control problem
  - Power control problem
The importance of architecture

- Success of Internet is due to its architecture
  - Hierarchy of layers
  - Peer-to-peer protocols
  - Allows plug-and-play
  - Longevity
  - Important for proliferation of technology

- Success of serial computing
  - von Neumann bridge (Valiant)
  - Hardware designers and software designers need only to conform to abstractions of each other

- Control system paradigm
  - Plant and controller separation
Digital communication

- Shannon’s architecture

- Source code (Compression)
- Encode for the channel
- Channel
- Decode
- Source decode (Decompression)
Ever present tension between Performance and Architecture

- **Performance: The short term vision**
  - “Putting a link between layer A and layer B can improve performance by x%”
  - Consequences of this approach
    » Spaghetti code
    » Not modular
    » Not upgradeable
    » No longevity
    » High per unit cost
      - Value of a communication medium = Number of adoptees

- **Architecture: The long term view**
  » Mass production = Reduced cost over long term

- **Tension between Performance and Architecture**
Illustration by examples

- Example 1:
  Minimum hop routing over an Adaptive rate MAC

- Example 2:
  End-to-end feedback and topology control
Example 1
Adaptive Rate MAC

- **Idea:** Adapt transmission rate according to channel quality
  - Change modulation to get higher rate if channel is good
  - Could send multiple packets at higher rates (A suggested scheme)

- **Protocol details**
  - RTS/CTS and Broadcast packets sent at lowest rate
  - Receiver measures strength of RTS
  - Communicates rate to sender in CTS
  - DATA and ACK at that rate
One consequence: Interaction with Min Hop Routing Protocol

- Most current routing protocols are min hop
  - Consider DSDV for example
  - Chooses long hops
  - But long hops $\Rightarrow$ low signal strength $\Rightarrow$ low rates
Switching off adaptation is better

- In fact, plain 802.11 at 11Mbps gives higher end-to-end throughput
Verification by ns2 simulations

- Channel parameters such that at a fixed power level (0.28 W):
  - Distance of 0-99m $\Leftrightarrow$ 11 Mbps
  - 99-198m $\Leftrightarrow$ 5.5 Mbps
  - 199-250m $\Leftrightarrow$ 2 Mbps

- Scheme 1: Adaptive scheme (A suggested scheme)
  - Equal time share to each rate
  - Send 5 packets at 11Mbps, 3 at 5.5 Mbps or 1 at 2 Mbps

- Scheme 2: 11 Mbps 802.11 (no cross layer)
  - Send packets only if distance is < 100m
A linear topology

- 18 nodes equally spaced in a 1500m long rectangle, 400m wide
- One TCP connection from node 0 to 17, starting at time 50
- DSDV routing protocol
- Carrier sensing disabled
Random topology

- 50 randomly located nodes in 1000x200m
- 5 simultaneous TCP connections, between distant nodes
- DSDV routing protocol
- No carrier sensing
Example 2
End-to-end feedback and topology control

- Two loops
  - Loop 1: Power control to drive Number of 1-hop neighbors to Target_degree
  - Loop 2: Target_degree controlled to increase Average end-to-end network throughput

- Loosely based on a suggested scheme
Adaptation rules

- Loop 1:
  Adjust transmit power every 15s, to maintain \( \text{Out\_degree} = \text{Target\_degree} \)

- Loop 2:
  Target\_degree adaptation done every 90s
  - Rules for changing the Target\_degree
    » Repeat change (+1 or -1) if throughput increased on previous iterate
    » Reverse action if throughput decreased on previous iterate
    » Increase Target\_degree if throughput is zero
Details of system tested by simulation

- 23 nodes in 500x500 m area

- Each node has 5 discrete power levels
  - Corresponding to ranges of 100m, 140m, 180m, 220m and 250m
  - When the TwoRayGround propagation model is used

- One TCP connection from Node 0 to Node 3

- Power level 1 achieves Target_degree 5, even though the network is disconnected
Simulation topology
Consequence: Interaction with TCP dynamics

- Network may oscillate between connectivity and disconnectivity
- Bad for TCP
A random sample of cross layer design proposals

- Several suggestions for cross-layer design
  - Signal stability based routing
  - Transmit power based routing
  - Battery life based routing
  - Topology control using transmit power adjustment
  - Topology control using angle of arrival information
  - Power control by monitoring end-to-end throughput
  - Power control for energy efficiency
  - Traffic based sleeping strategies
  - TCP modifications for energy efficiency
  - Routing for improving network lifetime
  - Adaptive rate, adaptive power MAC protocols
  - QoS schemes based on routing and MAC parameters

- What are the consequences?
- What interactions are possible?
- What does the resulting code look like?
- What is the resulting architecture or lack of it?
- Longevity? Upkeep?
Themes

- Setting the context for cross-layer design optimization:
  - Infinitude of choices for operating wireless networks: What’s best?
  - A Theorem: The good news

- Importance of Architecture
  - Proliferation
  - Tension between performance and architecture
  - Longevity issue
    » Short term versus long term perspective

- Interactions and the Law of Unintended Consequences
  - Layers can interact
  - Loops can be formed
  - What is the nature of the interactions?

- Community needs to exercise caution before leaping into Cross-layer design

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Concluding remarks

- Architecture is important
  - Often neglected

- Interactions exist
  - Often neglected

- Need to change the thrust of the work in cross-layer design to a more holistic perspective
  - Design schemes which have no adverse interactions against other layer or cross-layer design now (holistic across layers)
  - Design schemes good against other future bright ideas in any cross-layer (holistic across time)
To obtain papers

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