Cross-Layering

Outline

XL.1 Introduction and motivation
XL.2 Cross-layer architecture
XL.3 Technical challenges
Cross-Layering
Introduction and Motivation

XL.1  Introduction and motivation
XL.2  Cross-layer architecture
XL.3  Technical challenges
Protocols and Services

Definition

• Protocol: rules for communication between entities
  - message format and sequence
    • information transfer (data plane)
    • signalling of control information (control plane)
    • monitoring and management (management plane)
  - definition of actions (state machine)

• Service
  - functional primitives provided by layer

• Interface
  - service interface to layers above and below

Proper design separates protocols from services
Protocol Layering

OSI Model

Send ES

7 application  ADU
6 presentation  PH APDU
5 session  SH PPDU
4 transport  TH SPDU TT
3 network  NH TPDU
2 link  LH NPDU LT
1 physical  coded LPDU

Receive ES

application  ADU
presentation  PH APDU
session  SH PPDU
transport  TH SPDU TT
network  NH TPDU
link  LH NPDU LT
physical  coded LPDU
Protocol Layering
Advantages and Disadvantages

• What are the advantages of layered protocol design?
  - divides comm. process to simpler & smaller components
  - independent protocol layer design
  - multi vendor development through standardisation
    • various hw and sw with various cost ($)

• What are the disadvantages?
  - performance in wireless environment
    • canonical example of TCP performance in wireless medium
  - inter-layer transfers involve non-trivial overhead
Cross-Layering

Motivation

- Cross-layering is to improve network performance
  - by violating layered architecture
- Cross-layering can:
  - improve TCP performance in wireless networks
    - distinguish between corruption and congestion
    - adapt transmission rate
  - increase the capacity of the network
    - e.g. resource allocation, FEC, ARQ, HARQ
  - optimise and adapt mobile application
    - application-physical or application-link
  - improves resiliency of network
    - context awareness and adaptability requires cross-layering
Cross-Layering

Architectural Model

- Layer boundaries are not clear
- Cross-layer model suggests coordination planes
- Each plane supports specific function
- The functions are:
  - security
  - QoS
  - energy
  - mobility
  - wireless link adaptation
- Objective of a function is coordination between layers
  - or this can be coordination between protocols
Protocol Layering
Orthogonal/Hybrid Layer/Plane Cube

L8
L7
L5
L4
L3
L2.5
L2
L1

social
application
session
transport
network
virtual link
link
MAC
physical

management
data plane
control plane

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MWN-XL-9
Cross-Layering

Related Research Projects

- PoMo
  - https://wiki.ittc.ku.edu/pomo_wiki/index.php/Main_Page
- ResumeNet
  - http://www.resumenet.eu/
- MobileMAN
  - http://cnd.iit.cnr.it/mobileMAN/
- TinyCubus
  - http://www.ipvs.uni-stuttgart.de/abteilungen/vs/forschung/projekte/tinycubus/start
- SEA
  - http://www.ist-sea.eu/
- ANA
  - http://www.ana-project.org
Cross-Layering
Cross-Layer Architecture

XL.1  Introduction and motivation
XL.2  Cross-layer architecture
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There are four types of design proposals [SM2005]

1. Creation of new interfaces
   - upward: from lower layer(s) to a higher layer
   - downward: from higher layer(s) to a lower layer
   - back and forth: iterative flow between two layers

2. Merging of adjacent layers
   - combine services of two layers: superlayer

3. Design coupling without new interfaces

4. Vertical calibration across layers
   - adjusting parameters across layers
Cross-Layer Management

Function Types

- Cross-layer interactions are managed by entities
- Entities are required for smooth system operation
- Entity functions can be:
  - controller
  - optimiser
  - scheduler
- “Oracle” in ETEN [KSE+2004] is an entity example
Cross-Layer Management

Types of Entities Based on Location

• Management entities can be placed various locations

• Types of entities according to their placement:
  – internal (i.e. within a node)
    • inter-layer (e.g. coordination manager)
    • intra-layer (e.g. scheduler and resource controller in 802.16e)
  – external (i.e. within the network)
    • centralised (e.g. BS MT relation in cellular telephony for QoS)
    • distributed (e.g. self-organisation in MANETs)
Cross-Layer Signalling

Signalling Mechanisms

• Cross-layer signalling adds overhead
• Cross-layer information transport mechanisms:
  - additional packet headers
  - option(s) field(s) in header
  - profiles and/or labels
  - cross-layer information provided by a network service
• Cross-layer signalling can be:
  - in-band or out-of-band
  - vertical or horizontal
• Cross-layer overhead types:
  - internal or external
Cross-Layer Model

E2E and HBH View

- E2E and HBH layers
Cross-Layer Model

Protocol Instance Model

- Node state
  - state machine
  - memory
- Node inputs/outputs
  - vertical data
  - p2p virtual data
  - context
  - horizontal signalling
  - cross-layer signalling
### Cross-Layer Example: Cross-Layering for Error Control

- **Functional alternatives**
  - N none
  - O open loop (FEC)
  - C closed loop (ARQ)
    - S&W, GB-N, SelRep

- **Location**
  - HBH
  - E2E

- **App requirements**
  - unreliable
  - quasi-reliable
  - reliable
### End-to-End Communication

**Knobs and Dials**

<table>
<thead>
<tr>
<th>Knobs ↓</th>
<th>Layer</th>
<th>Dials ↑</th>
</tr>
</thead>
<tbody>
<tr>
<td>service class</td>
<td>application</td>
<td>service characteristics</td>
</tr>
<tr>
<td>reliability mode</td>
<td>E2E transport</td>
<td>path char., geography</td>
</tr>
<tr>
<td>PoMo knobs, FD, motiv.</td>
<td>PoMo internetwork</td>
<td>realm characteristics</td>
</tr>
<tr>
<td>realm oper. parameters</td>
<td>network realm</td>
<td>link characteristics</td>
</tr>
<tr>
<td>link type and coding</td>
<td>HBH link</td>
<td></td>
</tr>
<tr>
<td>error control type/strength</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Knobs and dials between upper layers and PoMo**
  - support heterogeneous subnetworks
    - e.g. lossy wireless vs. reliable wired
  - explicit signalling of path diversity and multipath
    - geographic location of realms, nodes, channels
Cross-Layering
Technical Challenges

XL.1  Introduction and motivation
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Technical Challenges

Open Issues

• Some of the open challenges are:
  – interface standardisation
  – coexistence of different cross-layer designs
  – role of physical layer [SRK2003]
    • effect of multi-user diversity gain on capacity?
    • model channel characteristics that translate model in net. layer
    • design for less complex multicarrier systems
Technical Challenges

Design Considerations

• Designer should consider [KK2005]
  – performance gain vs. good architectural design
  – unintended interactions between layers
  – represent protocol interactions via dependency graphs
  – stability: due to changing a variable by two control loops

• Cross-layer design can be evaluated based on:
  – objective function (e.g. delay incurred)
  – state selection (e.g. overhead incurred)
  – level of modularity (e.g. manageability)
Cross-Layering

Conclusions

• Cross-layering increases network performance
  - by exploiting interactions among protocol layers

• It adds complexity to system design

• Cross-layer architecture should be designed carefully
  - its design is harder due to additional interactions
  - unbridled design can lead to spaghetti design [KK2005]

• Standardisation of interfaces is a challenge
Cross-Layering

Further Reading

- [KSE+2004]
  Krishnan, Sterbenz, Eddy, Partridge, and Allman,
  “Explicit transport error notification (ETEN) for error-prone wireless and satellite networks”
  *Computer Networks*, October 2004, Volume 46, No. 3

- [LSS2006]
  Lin, Shroff, Eddy, and Srikant,
  “A Tutorial on Cross-Layer Optimization in Wireless Networks”
  *IEEE JSAC*, August 2006, Volume 24, No. 8
Cross-Layering

Further Reading

• [KK2005]
  Kawadia, and Kumar,
  “A Cautionary Perspective on Cross-Layer Design”
  *IEEE Wireless Com.*, Feb. 2005, Volume 12, No. 1

• [SRK2003]
  Shakkottai, Rappaport, and Karlsson,
  “Cross-Layer Design in Wireless Networks”
Cross-Layering

Further Reading

• [SM2005]
  Srivastava, and Motani,
  “Cross-Layer Design: A Survey and the Road Ahead”

• [CMT+2004]
  Conti, Maselli, Turi, and Giordano,
  “Cross-Layering in Mobile Ad Hoc Network Design”
  *IEEE Computer*, Feb. 2004, Volume 37, No. 2
Some materials in these foils is based on

- [FGA2008]

Foukalas, Gazis, and Alonistioti,

“Cross-Layer Design Proposals for Wireless Mobile Networks: A Survey and Taxonomy”

*IEEE Communications Surveys and Tutorials*,

1st Quarter 2008, Volume 10, No. 1