Some issues in Cross-Layer Architecture in Mobile Ad Hoc Networks

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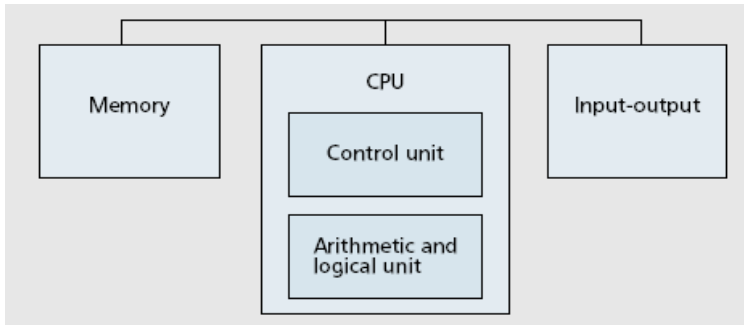
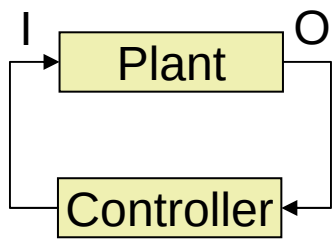
Importance of a Good Architectural Design

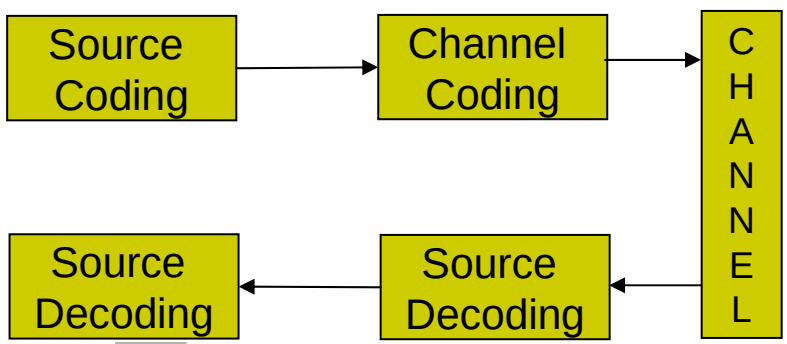
- The Von Neumann Architecture
  - Separation between software and hardware (Bridge)



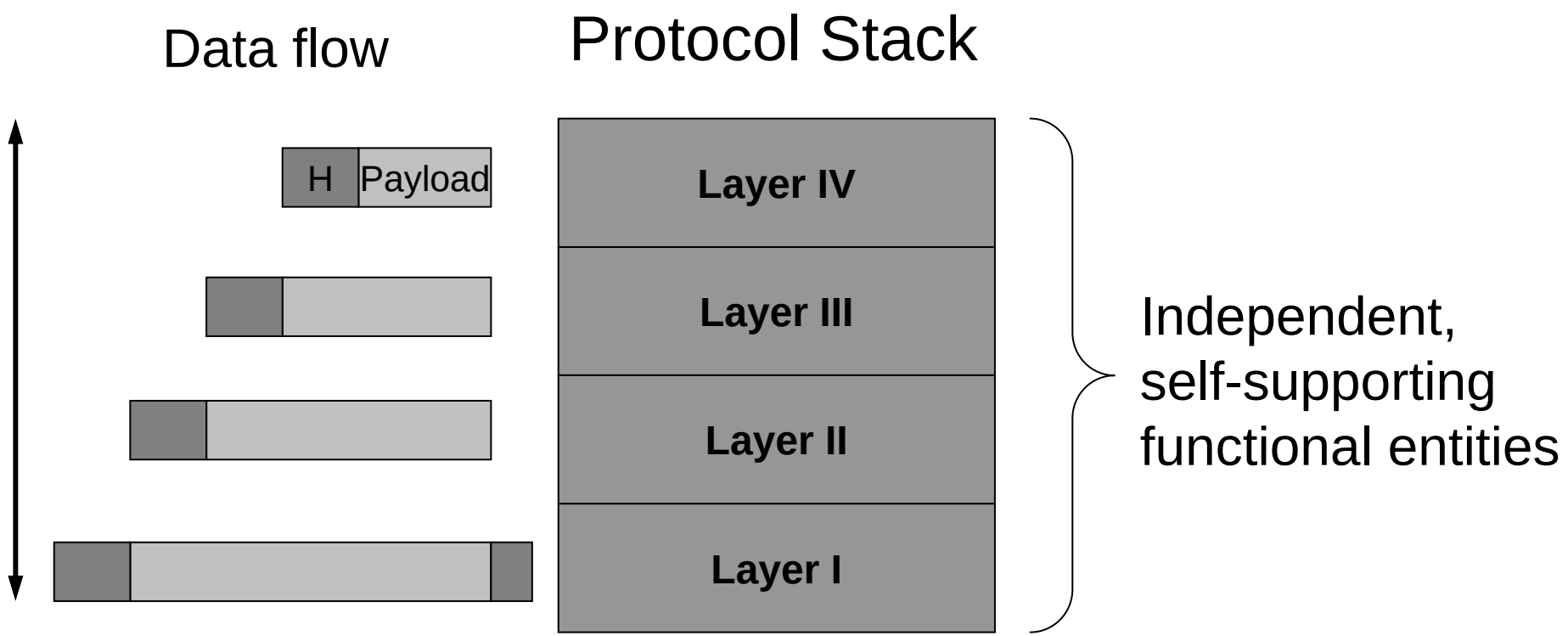
- Feedback Control System
  - Separation between plant and controller



- The Shannon Digital Communication System Architecture
  - Separation between source coding and channel coding



Layered Network Architecture (OSI)



Layer triggers is used to notify events between layers in this architecture
For instance, congestion notification triggers by IP layer to TCP

Advantages, But …

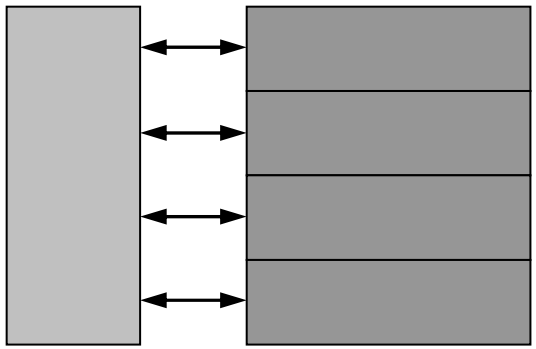
- Low complexity
- Modular and upgradeable (low maintenance)
  - Longevity → proliferation, and thereby cost-effective
  - Allow to construct network stack tailored towards different network environments
- Easy to standardize
  - Due to inter-layer interoperability and peer-to-peer principles
- However, the underlying assumptions are:
  - Each layer can be optimized independently
  - This assumption turns out to be not true in dynamic environments
    - Channel quality changes
    - Routing changes
    - QoS requirements changes
- Alternative solution is cross layer architecture

Concept of Cross-Layering

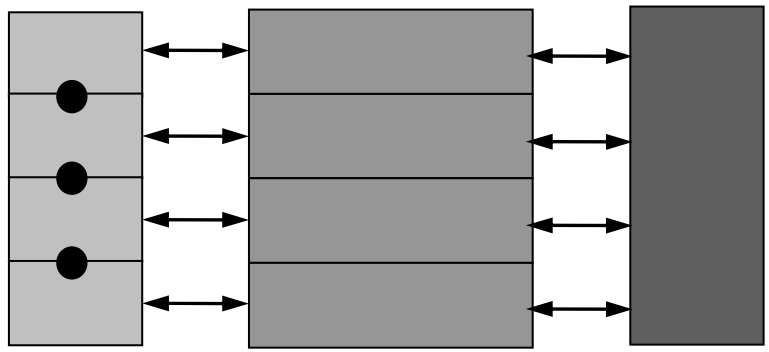
- Not a replacement of a layered architecture
- Not a combination of a layered functionalities
- It is about sharing the information amongst different layers for adaptations
- However, this process has to be coordinated to
  - Avoid unintended or unnecessary consequence
  - Control process dependency relationship
  - Enforce timescale separation between different process
  - Establish stability due to loop formation
- For instance, optimization processes at different layers could go in opposite directions
  - Power control and routing
  - Energy efficiency and delay performance

Cross Layer Architectures

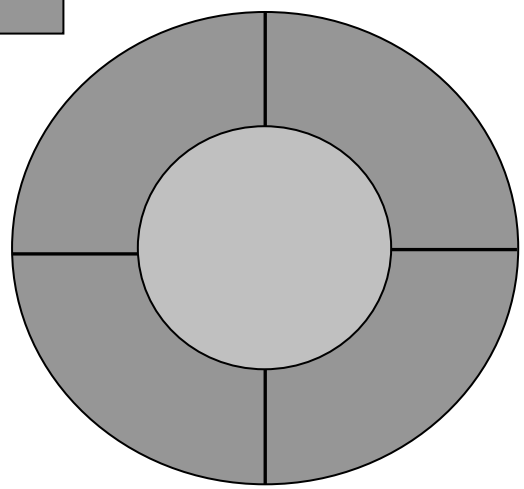
MobileMan

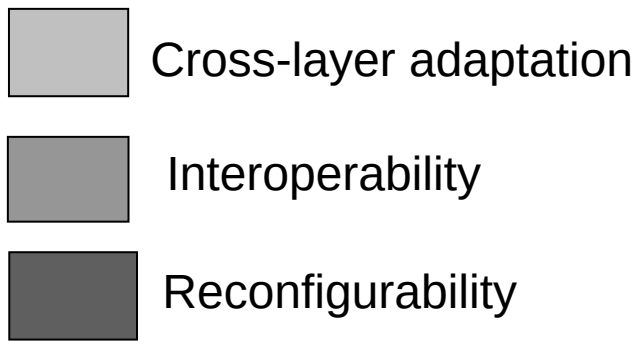


WIDENS



GRACE

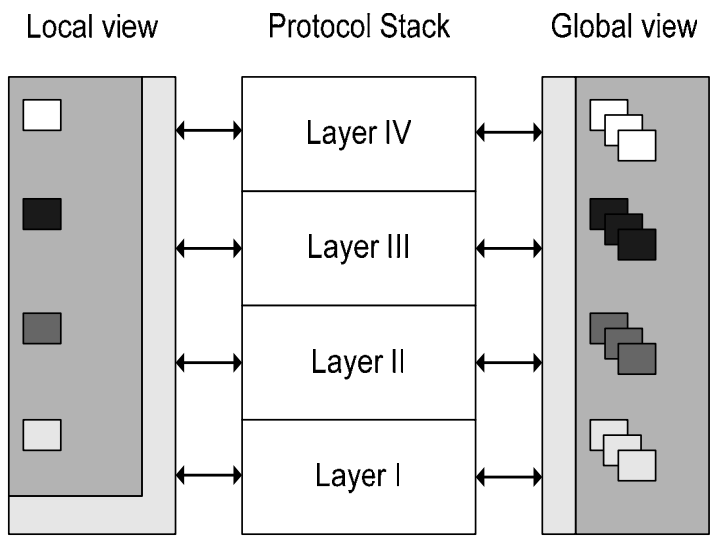




These architectures provide protocol optimization w.r.t. local state information

Cross Layer Architectures

- Local actions are lightweight but they lack accuracy and ultimately efficiency
- Network-wide, global actions are expensive but often not avoidable
- CrossTalk bases local actions on global knowledge to achieve global objectives



CrossTalk[winter05]

Cross Layer Architectures

- Think globally, act locally [streenstrup]
  - Requires network cooperation
  - Local action requires global knowledge
  - Beware of their different timescales to maintain stability
  - Global knowledge must be determined as a function of network condition
  - Such global knowledge is then feedbacked to local decisions iteratively

Cross-Layer Design: Pros & Cons

- Exploit the inter-layer interactions
- Adaptability across layers through exchanged information
  - If the local adaptation is not sufficient, state information are cross-layered to other layer for more specific or general response
- Protocol optimization
  - Depends on the system constraint !
- Joint optimization across layers lead to more complex algorithm
  - Difficult to characterize
- May cause unnecessary optimization affecting the regular functionality of the layer whose functionality was insufficient
- May cause loops
  - Spaghetti like design

Comparison

	Layered	Cross-Layer
Advantages	Reduced design complexity	Various ways to improve adaptability & performance
	Improved maintainability	
	Modularity	
Disadvantage	Leaves out certain performance & adaptability Improvements	Cautious design is necessary
Preferable	Large & Reliable Networks	Wireless Mobile Networks

To Layer or Not to Layer?

- In a dynamic environment, should we keep a layered network architecture or instead all layers have to be integrated and jointly optimized ?
  - Fully integrated approach is impractical
    - In terms of implementation, debugging, upgrading, and standardization
  - Hence, keep the layer approach for mainlining the interoperability, while taking into account the cross-layering for joint optimization
- Questions:
  - What is the appropriate cross-layer architectures?
  - What information should be exchanged across layers?
  - How should that information be used for adaptation ?
  - Note: Trade-off between performance and architecture

Cross Layer Adaptations

- Physical Layer
  - Channel state and BER
- MAC Layer
  - Link quality
  - Neighborhood info
  - Battery level
- Network Layer
  - Network topology
  - Traffic volume
  - QoS requirements
- Transport Layer
  - Packet loss rate
- Application Layer
  - Scenarios parameters
  - User capacity
  - System Constraints

- Physical Layer
  - Coding and modulation
- MAC Layer
  - Retransmission policy
  - fragmentation
  - Scheduling (incl. coding rate)
  - Power control
- Network Layer
  - Routing policy
  - Switching interface (channel)
- Transport Layer
  - Congestion window size
- Application Layer
  - Rate adaptation

Reconfigurability w.r.t. the Network Constraints

- How should global system constraints and characteristics be factored into protocol functionalities at each layer?
  - Need for Reconfigurability

Conclusion

- Interoperability, cross-layering and reconfigurability are three important concept of today's systems
- Cross-layering is a key design choice for improving network performance in dynamic environments
- Some cautionary perspective must be taken into account
  - Setting the context of cross-layer optimization