A cautionary perspective on cross-layer design**

Philippe Mary

IETR UMR 6164/ INSA Rennes
20 av. des Buttes de Coësmes, CS 70839, F-35708 Rennes.

Intro and references

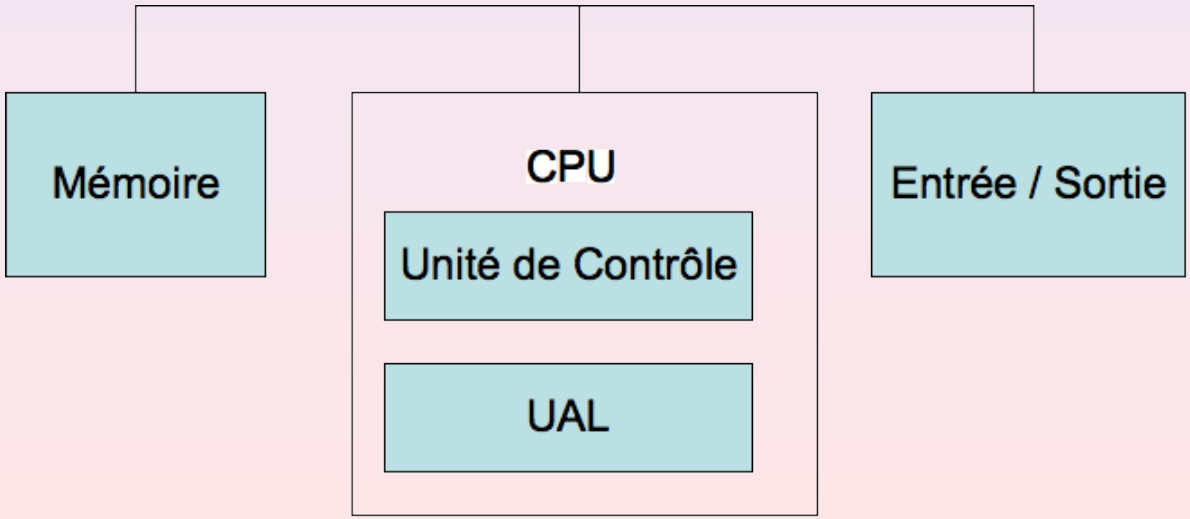
- Cross-layer in the networks : substantial gains !
- OSI model always here
  - Cross-Layer is not against the layered model ! !
- Does the X-layer design always increase the performance ?
  - Relevant criteria for the performance evaluation ? (which layer)
- **V. Kawadia, P. R. Kumar, "A Cautionary Perspective on Cross-Layer Design", *IEEE Wireless Commun.*, vol. 12, no. 1, Feb. 2005.

Proliferation vs Optimization

- Communication systems are desired sustainable over the *long term*
  - Layered architecture for the evolution
- On the other hand, need to optimize the wireless systems
  - Often at the price of a good system architecture
- Performance optimization : *short term gain*
- Layered architecture : *sustainability of the system*
  - Modularity : independent protocol development
  - Warrant proliferation (ex : 802.11)
  - Independent layer update

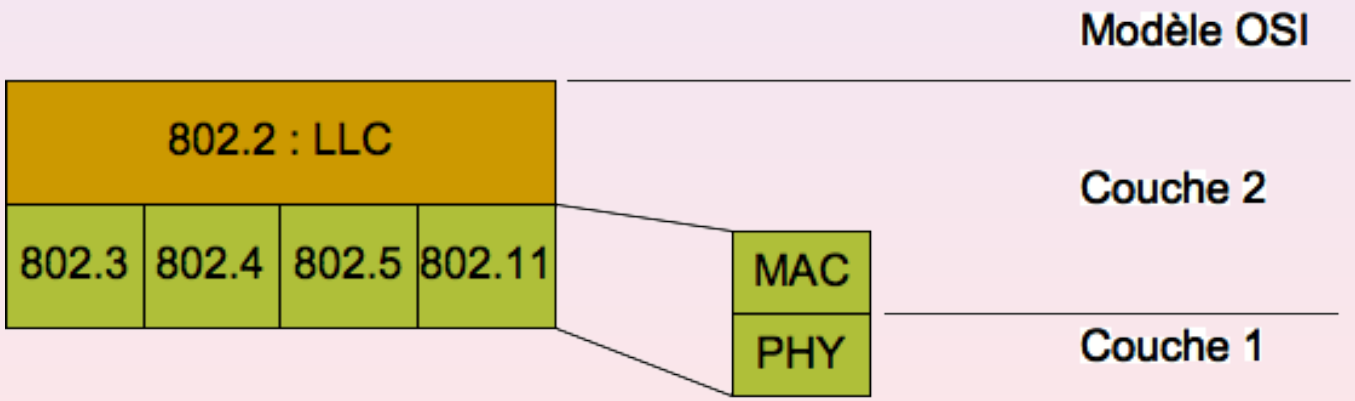
Von Neumann architecture

- Heart of computer
- Obvious structure retrospectively
- Division *logiciel/matériel* : the most important and the most fundamental
  - Hardware and software engineers can work independently



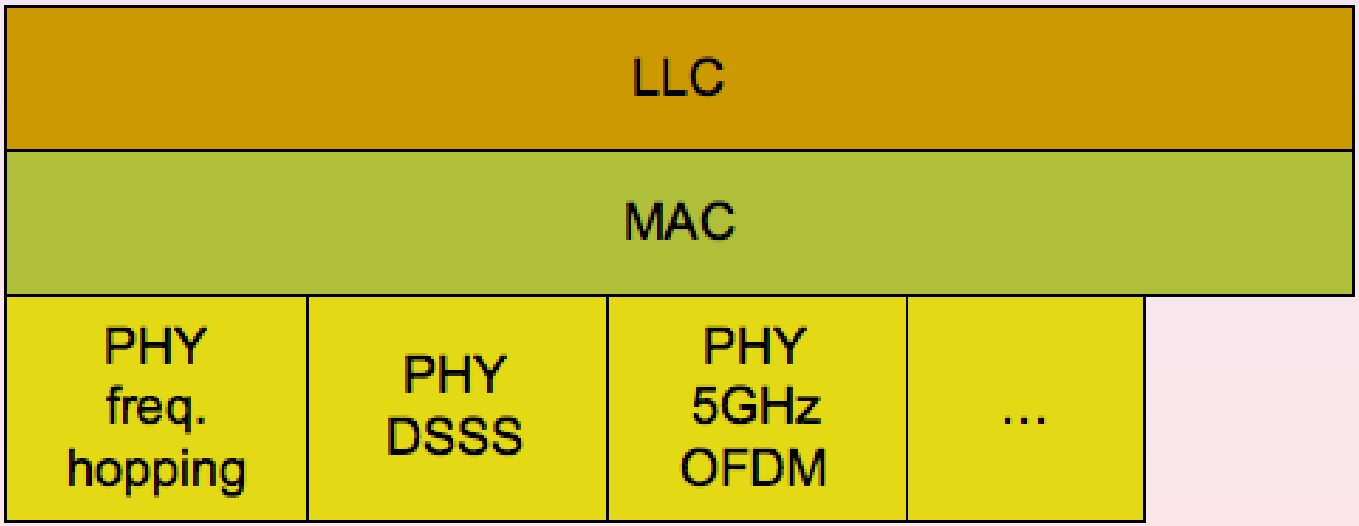
OSI – TCP/IP architectures

- Internet : sustainable and improvable architecture
- 802 standard family : Link layer and PHY
- LLC (Logical Link Control) : one for all medium



WLAN architecture

- Several PHY layers for 802.11
- Common MAC and LLC => modularity
- Proliferation of products derived from 802.11 standards



Joint source-channel coding

- 1948 : Fundamental Shannon theorem on channel capacity
- Constructive proof for the division of source and channel coding
- Advantages
  - Source coding => specific for an application
  - Channel coding => related to the environment
  - => channel coding scheme may not be changed according to the kind of data
- However, substantial gains can be obtained for joint source-channel coding (often related to an application)

Architecture consideration for wireless networks

- Multi-hop networks
  - Which relaying techniques ? (A-F, D-F)
  - Radio technology is broadcast per nature => interference
    - How dealing with interference ? consider it as noise or not ?
  - MAC : May control the number of interferer
  - Routing

Multi-hop networks

- Assumption : channel with exponential attenuation
- Theoreme [Kumar2004] : D-F strategy optimal w.r.t. transport capacity (interference = bruit)
  - Transport capacity in $O(n)$
- 1st remark : suggest that multi-hop D-F be thought as a layer
- Transport function necessary to ensure an end-to-end reliable "pipe"
  - Layer organization seems natural

Issues of cross-layer

- X-layer interactions may impact other layers
- X-layer implementation may yield to unnecessary dependence for the functionality
  - Impact of the algorithm on layers *a priori* non concerned ?
- What is the impact on the network when several x-layer designs are implemented ?
  - Extremely difficult to predict
  - Can we mathematically model the phenomena ?
- We must pay attention on the impact of x-layer designs on the other layers

Rate-Adaptive MAC and Minimum-Hop Routing

- Increase the data rate when the channel is good
- Modification of the MAC IEEE 802.11 protocol
  - RTS/CTS : minimal rate
  - RSSI on RTS packets => allocate the maximal rate according to the RSSI
- For nodes close to each others => important data rate
- Several packets can be sent for each time slot reservation if good channel
- Minimum-hop routing protocol (DSDV)
  - *Hello packet* sent with a low rate => high propagation distance

Adaptive rate MAC vs IEEE 802.11 MAC

- Simple IEEE 802.11b MAC :
  - 11 Mb/s between 0 and 100 m
  - 0 Mb/s farther

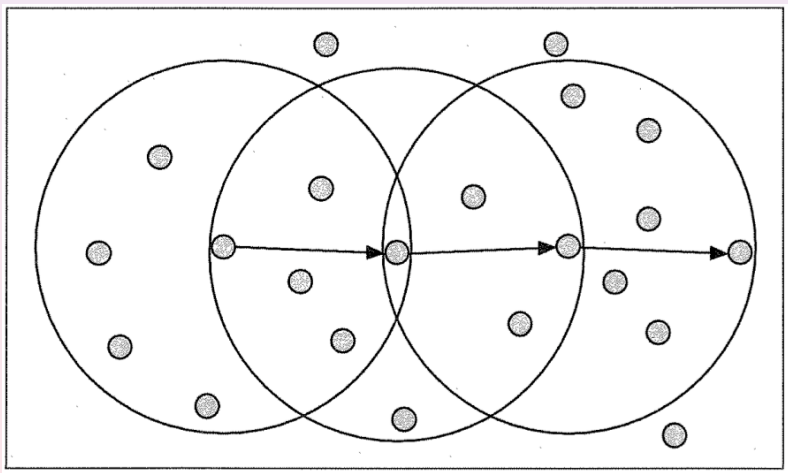


Figure 5. *DSDV chooses a small number of long hops, which give a lower data rate when an adaptive rate MAC is used.*

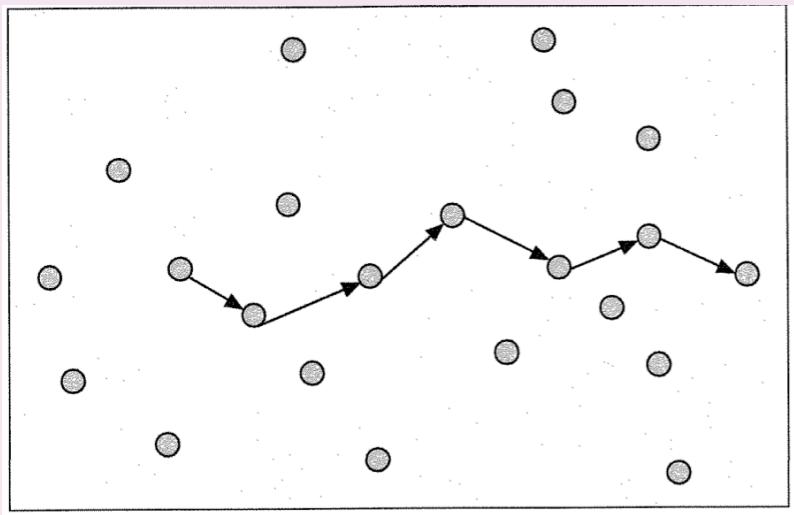


Figure 6. *Plain IEEE 802.11 causes short hops of higher data rate to be used.*

Linear topology

- 18 nodes in a straight line with equal distance hop
- DSDV routing protocols and TCP connection

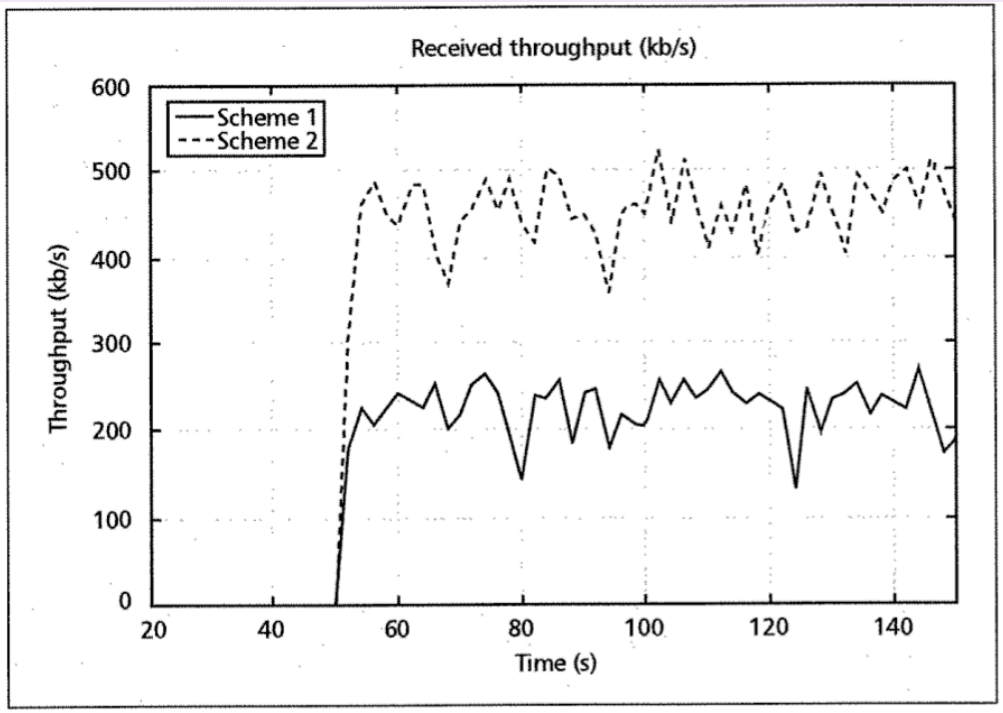


Figure 7. *Comparing scheme 1 (adaptive-rate MAC) and scheme 2 (plain IEEE 802.11) for the 18-node linear topology.*

Random topology

- 50 nodes randomly set in the plane (1000m×200m)
- DSDV routing and 5 TCP connexions are started between nodes

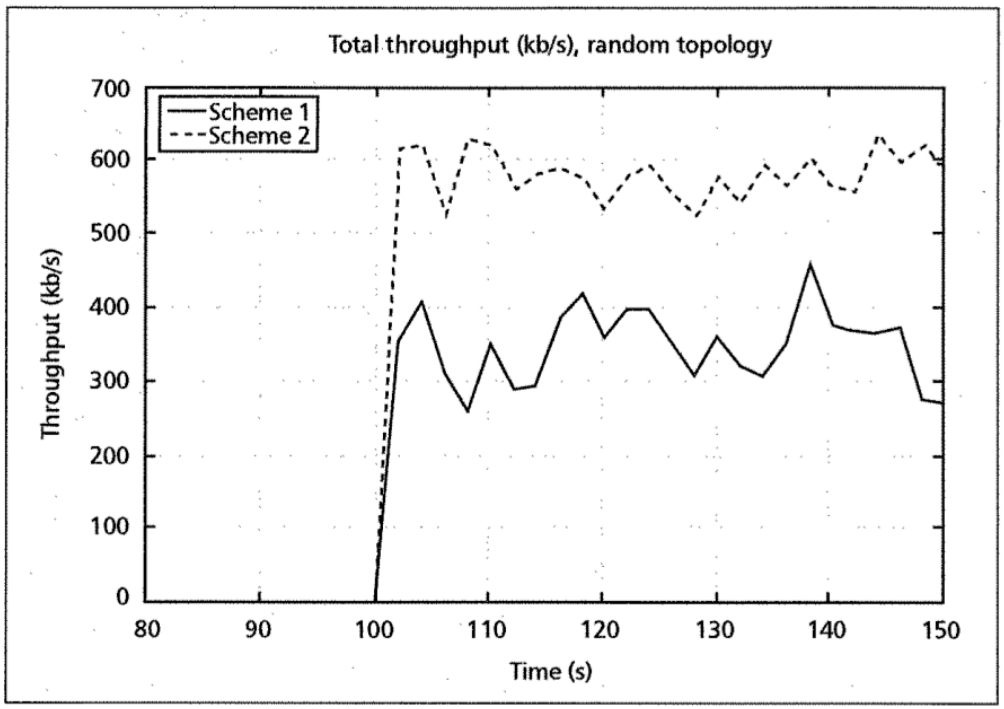


Figure 9. *Comparison of Adaptive Rate MAC (Scheme 1) and plain IEEE 802.11 (Scheme 2) for the topology shown in Fig. 8.*

Conclusions

- Unexpected effect emphasized
  - Classic MAC protocol is better than the x-layer optimization
- Attention : the presented optimization is not bad but leads to counter performances !
- Routing protocol is surely the trouble
  - Search for other routing criterium than the *minimum-hop*
- We must pay attention to the x-layer designs consequences
  - Dependency
  - Stability