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# The Cross-Layer Paradigm In Next Generation Internet: Open Issues & Future Perspectives

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# Goal

- To provide a survey of cross-layering solutions in today's networks
- To analyze the cross-layer paradigm and identify the key issues
- To outline promising scenarios where cross-layering could be successful


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# Layering & Cross-Layering

- Layering (ISO/OSI – TCP/IP)
  - Enable fast development of interoperable systems, but...
  - ... limited performance of the overall architecture, due to the lack of coordination among protocols

- Cross-Layering
  - A recent design principle: allow coordination, interaction and joint design of protocols crossing different layers
  - It seems appropriate for specific scenarios, such as wireless, where independent layer design may be sub-optimal
  - Advantages demonstrated per case and “ad hoc” but not systematically

# Which is the penetration of cross-layering in current networks?

- "Implicit" in all IP networks:
  - ARP
- "Explicit" in wireless networks
  - Layered paradigm works poorly in wireless networks, due to:
    - User / Node Mobility
    - Limited data transfer performance
    - Low energy efficiency
    - Quality of Service (QoS) requirements
  - Tighter integration among the layers is required for QoS, congestion control, handover

# The wireless scenario

| Technology | Mobility | Data transfer performance | | Energy consumption/ battery life | Quality of Service | Cross-Layer Design Penetration |
|---|---|---|---|---|---|---|
| | | Physical rate | Spectrum efficiency | | | |
| 2G (GSM) | Global roaming | 9.6 – 57.6 Kb/s | 5 bit/s/Hz | Days | High | High |
| 3G (UMTS) | | 384 Kb/s (mo 2Mb/s (statio | 2.88 s/Hz | | | |
| 3G LTE | | 100 Mb/s | s/Hz | | | |
| Fixed WiMAX (802.16-2004) | | 10 Mb/s (max up to 70 | bit/s/Hz | | | Medium |
| Mobile WiMAX (802.16e-2005) | | 2-3 Mb/s (max up to 15 | s/Hz | | | |
| 802.11b | | 11 Mbps | 55 | | | Low |
| 802.11a/g | | 54 Mbps | .7 | | | |
| 802.11n | | 250 Mbps | 22 | | | |
| Bluetooth (2.0) | Fixed | Up to 2.1 M | s/Hz | Hours | Low | Low |
| UWB | | 675 Mb/s | 1 bit/s/Hz | | | |


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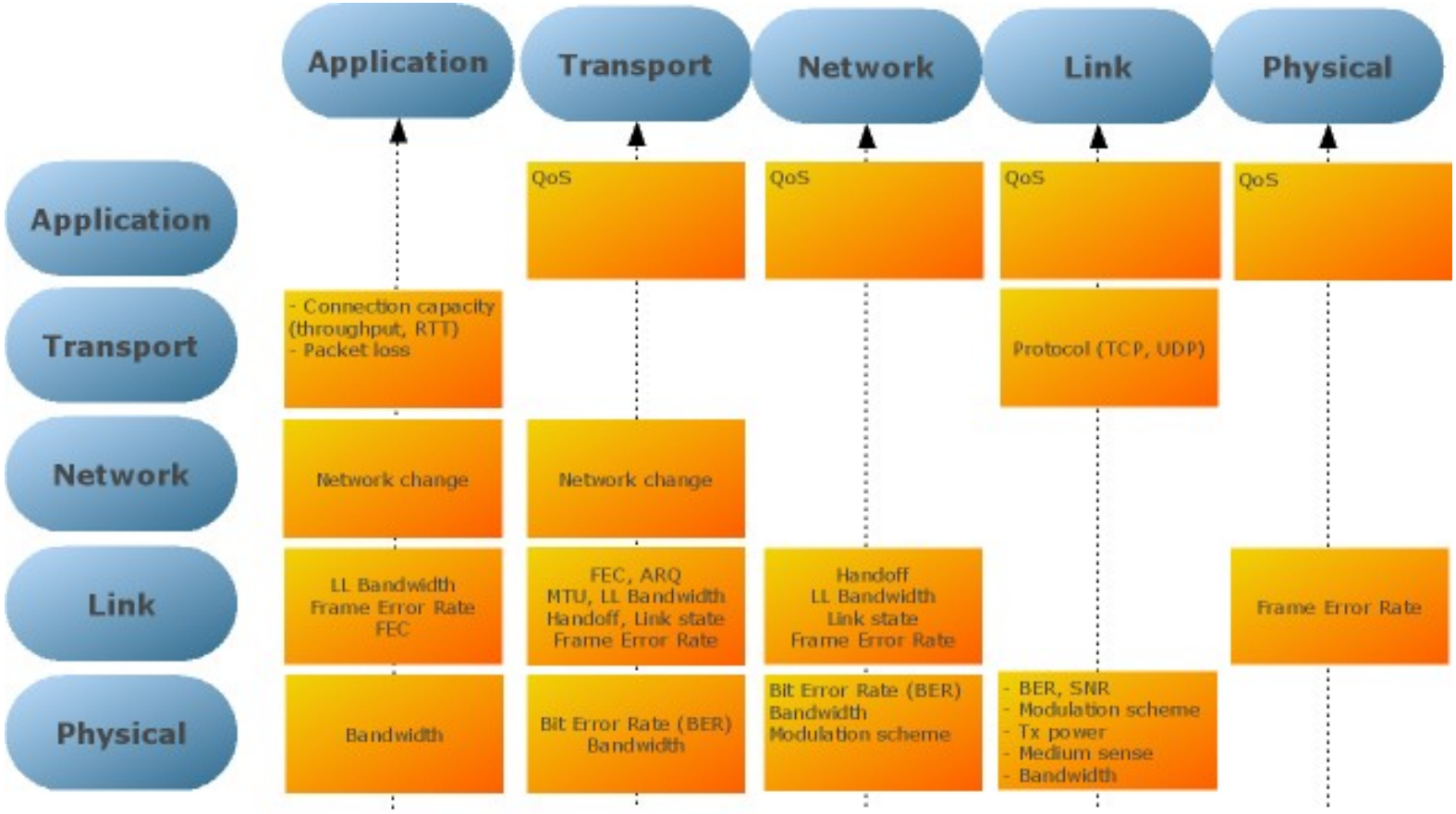
# Possible Cross-layer Interactions





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# Key Issues

- Cross-layering vs. layering
  - Need to be cautious [*]
  - Cost-benefit analysis
  - Dependant on the scenario
- Design framework
  - No “unifying theory”
  - No formal modeling
- Signaling
  - Internal or network-wide

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[*] V. Kawada, and P.R. Kumar, “A Cautionary Perspective on Cross-Layer Design,” IEEE Wireless Communications, Vol. 12, No. 1, pp. 3-11, Feb. 2005.


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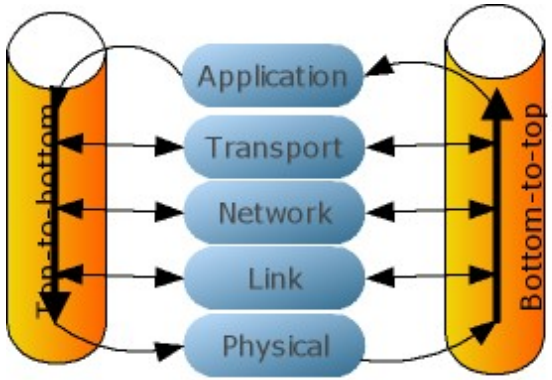
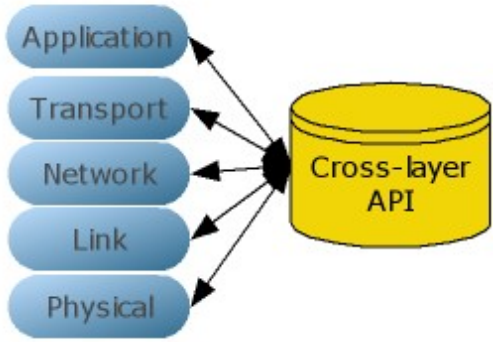
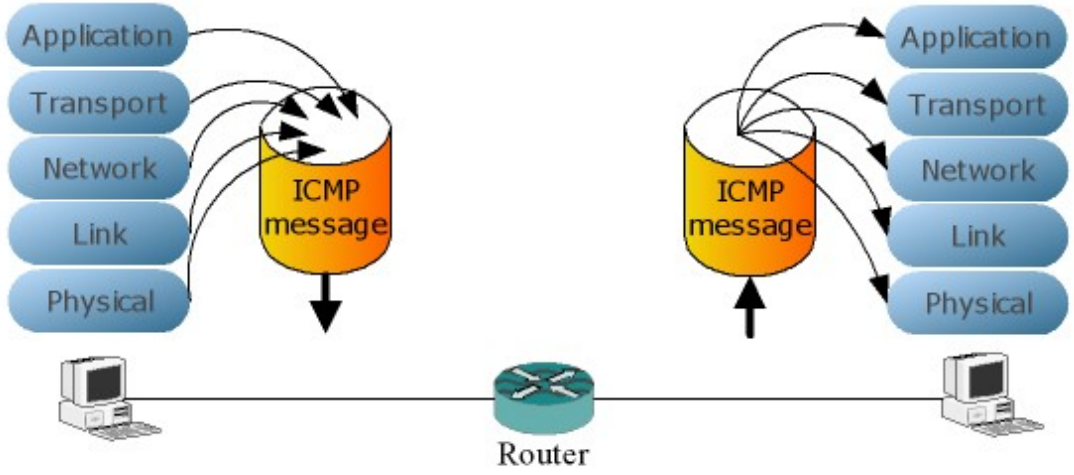
# CL Signaling Architectures




a) Packet structure




b) Cross-layer interfacing




c) Cross-layer networking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# CL Signaling Architectures

| Cross-Layer Signaling Method | Scope | Propagation Latency | Communication Overhead | Processing Overhead | Direction of signaling | Packet Dependant | Requires Standardi-zation |
|---|---|---|---|---|---|---|---|
| **Interlayer Signaling Pipe** | | | | | | | |
| Packet Headers | Local | Medium | High | Medium | Path dependant | √ | √ |
| Packet Structures | Local | Medium | High | Medium | Path dependant | √ | × |
| **Direct Interlayer Communication** | | | | | | | |
| ICMP messages | Local | Low | Medium | High | Path independent | × | √ |
| Callback functions | Local | Low | Low | Low | Path independent | × | × |
| **Central Cross-layer Plane** | Local | Low | Low | Low | Path independent | × | × |
| **Network-wide Cross-layer Signaling** | | | | | | | |
| Packet Headers | Local/Network-wide | High | Low | Medium | Path dependant | √ | √ |
| ICMP messages | Local/Network-wide | High | High | High | Path independent | × | √ |
| | | | | | | | |

D. Kliazovich, M. Devetsikiotis, F. Granelli, “Formal Methods in Cross-Layer Modeling and Optimization of Wireless Networks: State-of-the-art and Future Directions,” to appear in “Heterogeneous Next Generation Networking: Innovations and Platform”, Edited by: Prof. Stavros Kotsopoulos and Dr. Konstantinos Ioannou.

# Distributed Cross-Layering

- Idea: Extend the idea of protocol stack modularity making it network-wide – Distributed Protocol Stacks
- Details
  - Each functional block of the protocol stack (a protocol layer or its part) can be abstracted into a separate module and implemented at a different node in the network
  - Communication between host protocol stack and removed module is performed using a custom “lightweight” protocol
- Application
  - Move protocol stack functions that generate high communication overhead into the network core behind the bottleneck link
  - Caution: not all the protocol stack functions can be abstracted and separated


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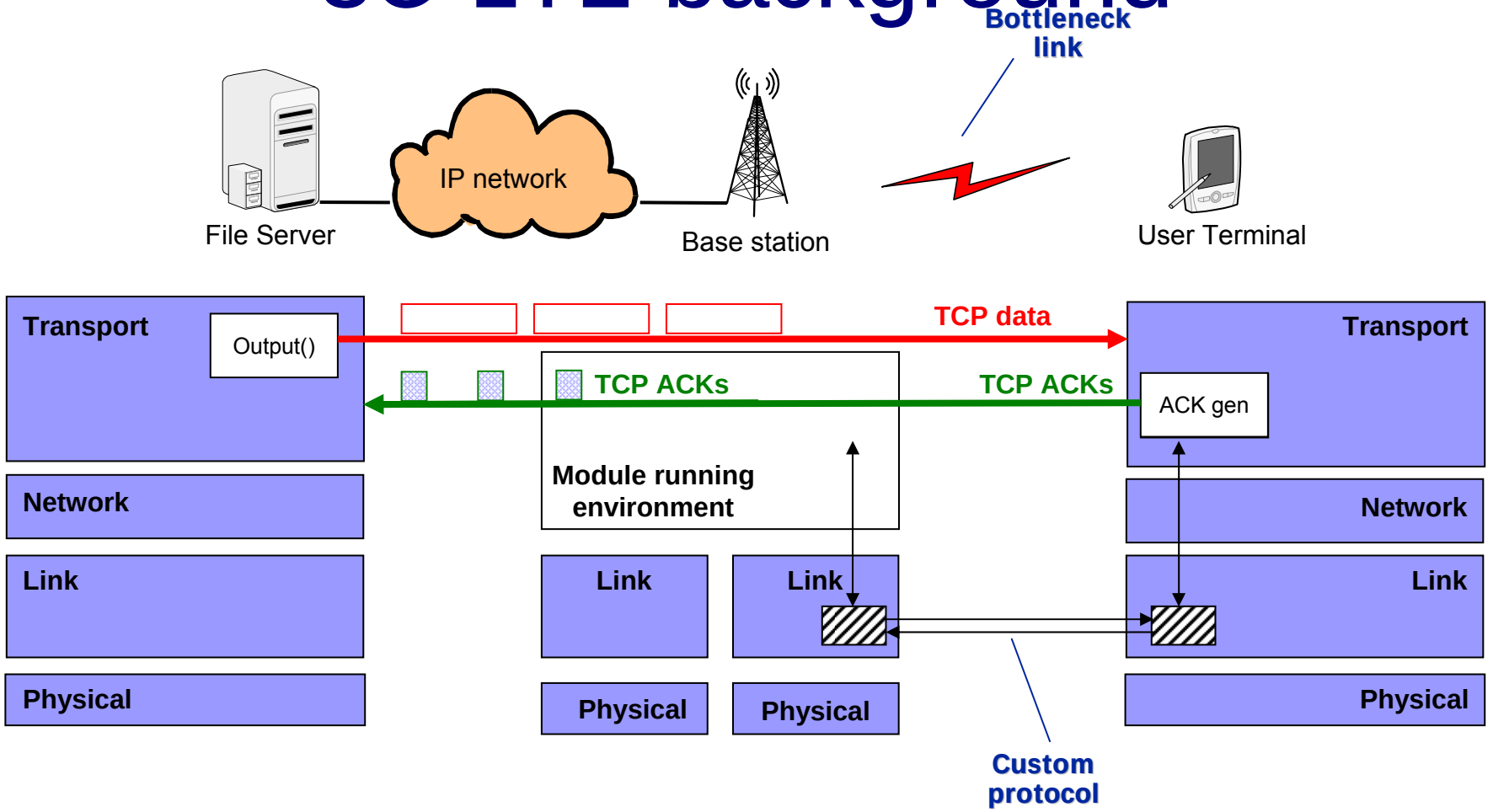
# 3G LTE background



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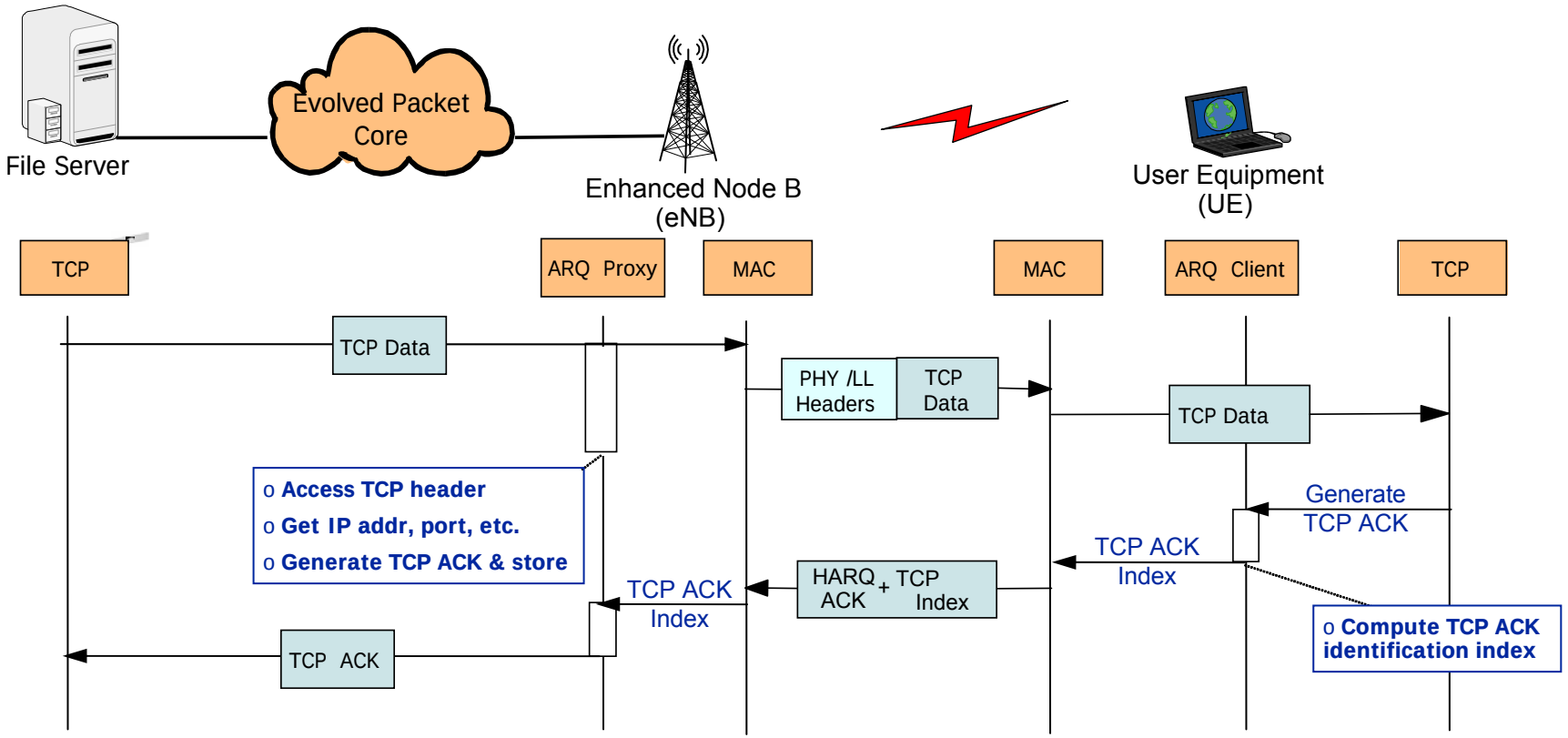
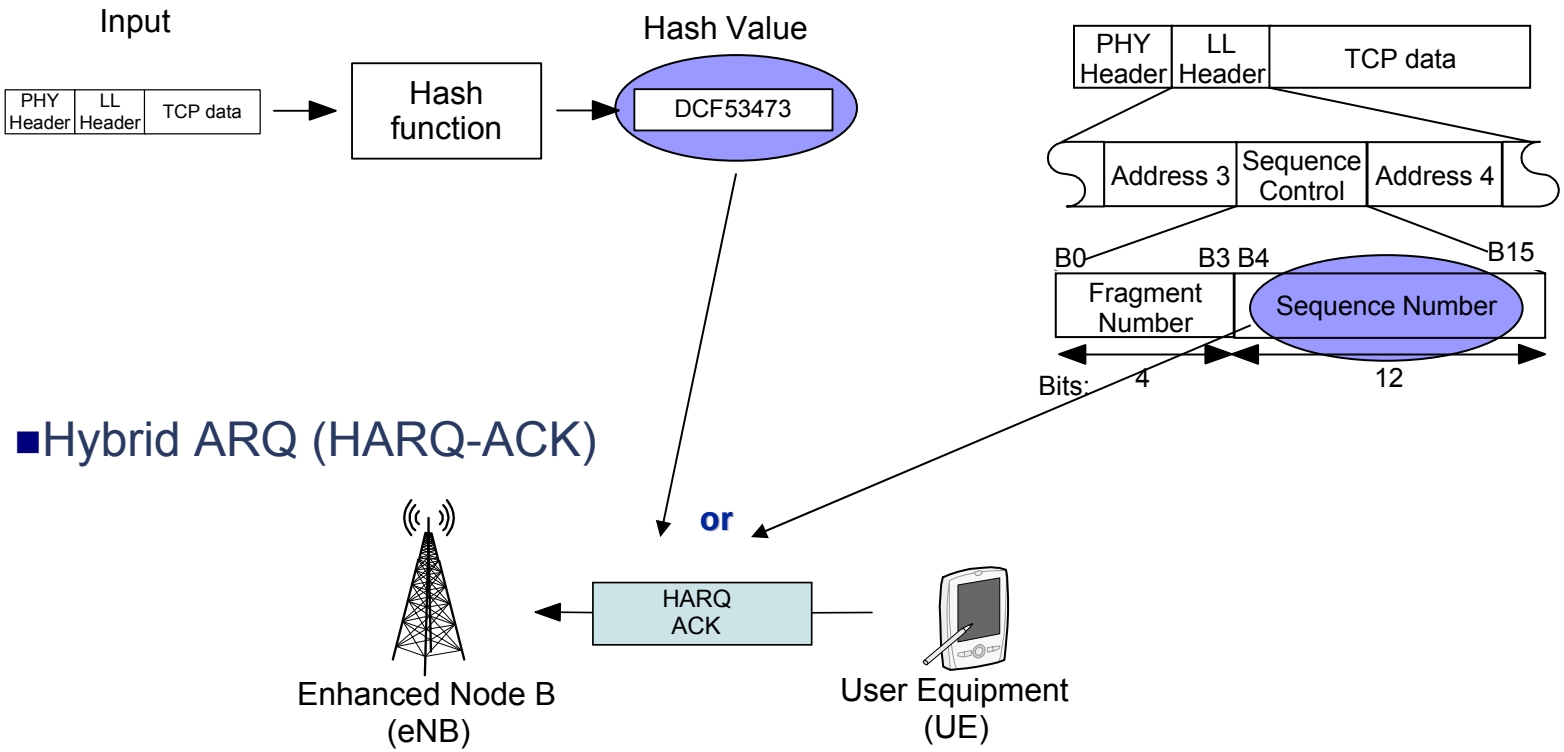
# ARQ Proxy - Approach




D. Kliazovich, F. Granelli, S. Redana, N. Riato, "Cross-Layer Error Control Optimization in 3G LTE," Globecom 2007.

# ARQ Proxy – Packet Identification

- 3G LTE: Hash values
- WiFi: Frame Sequence Numbers




- Hybrid ARQ (HARQ-ACK)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# Conclusions

- Cross-Layering represents a promising design paradigm, especially in wireless networks
- Fine tuning and optimization in complex scenarios require some sort of cross-layering, at the expense of interoperability
- Cross-layer signaling has a high potential
  - “Distributing” the protocol stack
  - Cognitive networking


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