Workshop on Quality of Service in Geographically Distributed Systems

A research perspective on the adaptive protocols' architectures and system infrastructures to support QoS in wireless communication systems

Lorenzo Donatiello, Luciano Bononi

{donat, bononi}@cs.unibo.it

Department of Computer Science
University of Bologna

Presentation outline

- **The QoS perspective in Wireless Systems**
  - System and scenario characterization
  - Design of protocols' and systems' architectures
  - The "Adaptive" and "cross-layering" concepts
- **QoS oriented design goals**
  - to provide some performance guarantee to the user…
  - …over "best effort" infrastructure
- **The MAC level perspective**
  - solutions proposed and results obtained
- **The Network level perspective**
  - Adaptive Clustering and Routing
  - Cross-layering
- **The modeling and simulation perspective**
  - Efficient tools for analysis of complex systems
- **comments and conclusions**

The QoS perspective in Wireless Systems

- **The Quality of Service in Wireless Systems**
  - ***It depends on the scenario…***
    - **Mobility**
      - **Static vs. dynamic**
      - **Group vs. single**
      - **Pattern-based vs. unpredictable**
    - **Nodes' heterogeneity**
      - **Resources (energy, bandwidth, neighbors…)**
      - **Capabilities (computation, gateway, AP…)**
      - **Control (centralized, distributed, hybrid)**
    - **Network infrastructure**
      - **Single-hop vs. multi-hop (Wireless Internet)**
      - **Distributed (ad hoc) vs. infrastructure vs. hybrid**
  - ***…and service and/or application needs***
    - **Min Bandwidth**
    - **Max Delay (or jitter)**
    - **Real Time…**
  - ***The role of Protocols***

The QoS perspective in Wireless Systems

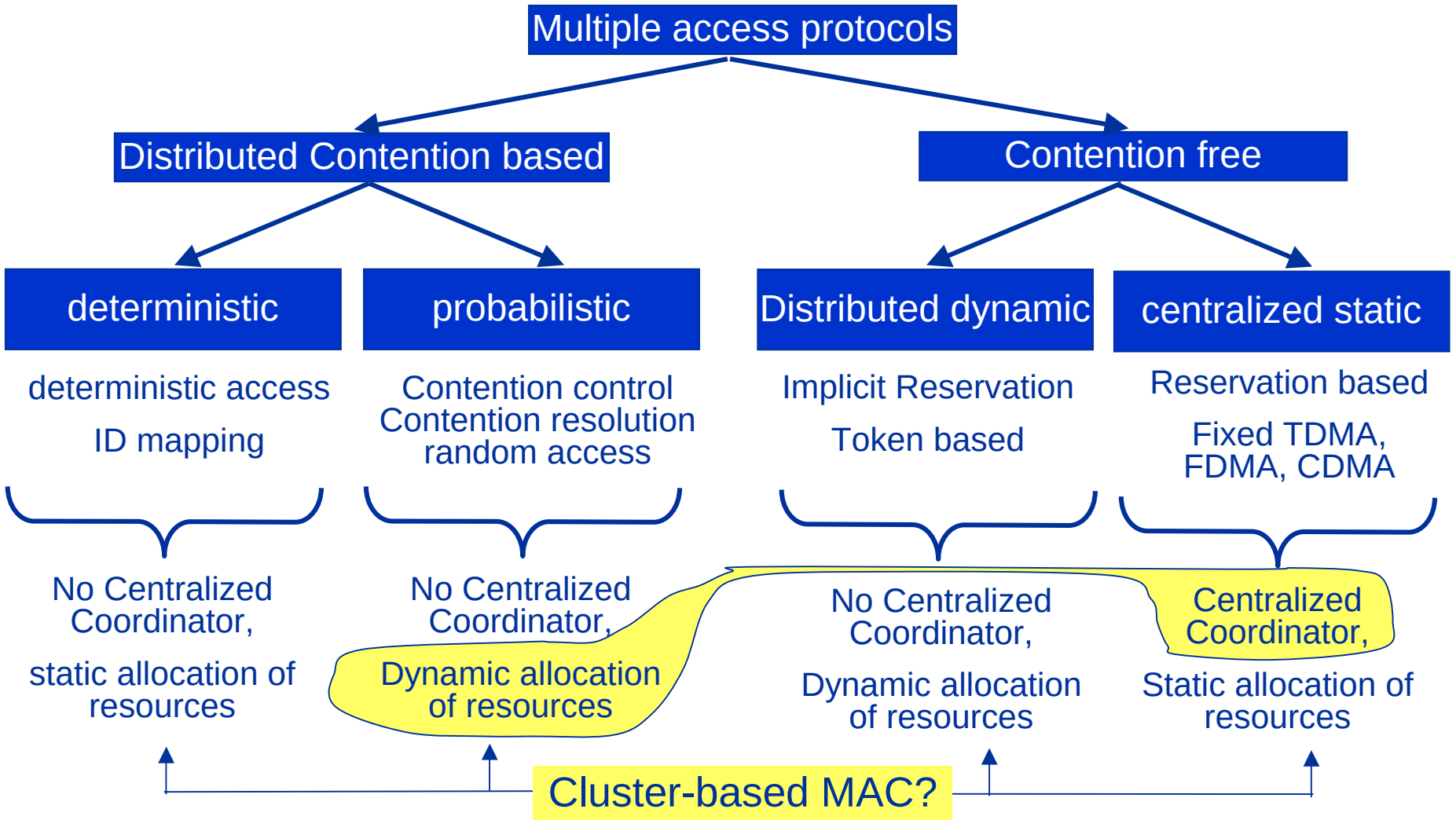
- **The Protocols' role in supporting the QoS principle**
  - ***governing the system architecture***
    - Node roles
    - Layered communication
  - ***absorbing the system dynamics (adaptive protocols)***
    - e.g. dynamic clustering
    - e.g. variable resources
    - e.g. variable application needs
  - ***optimizing the resource sharing and utilization***
    - e.g. Medium Access Control
      - Distributed vs. centralized
    - e.g. Scheduling strategies and resource allocation
      - Static vs. dynamic (reservation, service admission)
      - Priority-based vs. flat
    - e.g. Remote execution
  - ***Protocol Architecture (e.g. ISO/OSI RM)***
    - (limited) feedback-based protocols
    - Cross layering

e.g. the MAC layer in wireless networks

- The wireless MAC layer roles
  - *Access control to shared channel(s)*
    - Natural broadcast of wireless transmission
    - Collision of signal: a time/space problem
    - Who transmits when? (and where)?
      - Avoid collisions (no Collision Detection)
  - *Scarce resources utilization*
    - Channel capacity and battery power
  - *performance and QoS*
    - System level and (or vs?) user level
  - *Frame organization, and intra-, inter-layer information management*
    - Cross layering principles for adaptive behavior?
    - Risk for “spaghetti design” [Kumar2003]

[Kumar2003] V. Kawadia, P.R. Kumar, "A Cautionary Perspective on Cross Layer Design", 2003

Wireless MAC protocols' classification



Evolutionary perspective of distributed MAC

- Distributed, contention-based wireless MAC Problem:
  - the frame vulnerability (collision risk)
  - Needs resolution in distributed way (no centralized coordinator)
- a **time domain problem**
  - Aloha [Abramson1970]: no coordination
  - Slotted Aloha
  - CSMA [Kleinrock1975]: listen before to transmit
  - Slotted CSMA
  - CSMA/CD: listen before and while transmitting
    - *(unpractical in wireless scenarios)*
    - *CSMA/CA + contention resolution (reactive resolution of collisions)*
    - *CSMA/CA + contention control (preventive/reactive reduction of risk of collisions)*

[Abramson1970]
N. Abramson, ``The ALOHA system - another alternative for computer communications'', Proc. Fall Joint Comput. Conf. AFIPS, 1970

[Kleinrock1975]
L. Kleinrock, F.A. Tobagi ``Packet Switching in Radio Channels: Part I - Carrier Sense Multiple-Access modes and their throughput-delay characteristics'', IEEE Transactions on Communications, Vol Com-23, No. 12, pp.1400-1416, 1975

Evolutionary perspective of distributed MAC

- Distributed, contention-based wireless MAC Problem:
  - the frame vulnerability (collision risk)
  - Needs resolution in distributed way (no centralized coordinator)
- ...and also a **Space domain problem**
  - MACA [Karn1990]: RTS/CTS, no carrier sense (MACA-BI, RIMA...)
  - MACAW [Bharghavan et al.1994]: RTS/CTS, carrier sense and immediate ACK (more reliable and efficient Link Layer Control)
  - FAMA [Fullmer et al.1995]: RTS/CTS, carrier sense + other stuff
- Main solution: RTS/CTS mechanism
  - Today under some criticisms

[Karn1990]
P. Karn, ""MACA - A new Channel Access Method for Packet Radio", proc. 9-th Computer Networking Conference, September 1990

[Bharghavan et al. 1994]
V. Bharghavan, A. Demers, S. Shenker, and L. Zhang, "MACAW: A Media Access Protocol for Wireless LAN's," proc. ACM SIGCOMM'94, pp.212-225, London, 1994

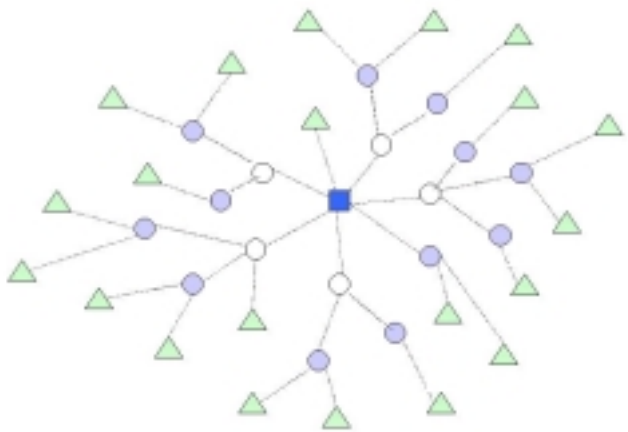
[Fullmer et al. 1995]
C.L. Fullmer, J.J. Garcia-Luna-Aceves, "Floor Acquisition Multiple Access (FAMA) for Packet Radio Networks", Proc. ACM Sigcomm'95 Cambridge, MA, 1995

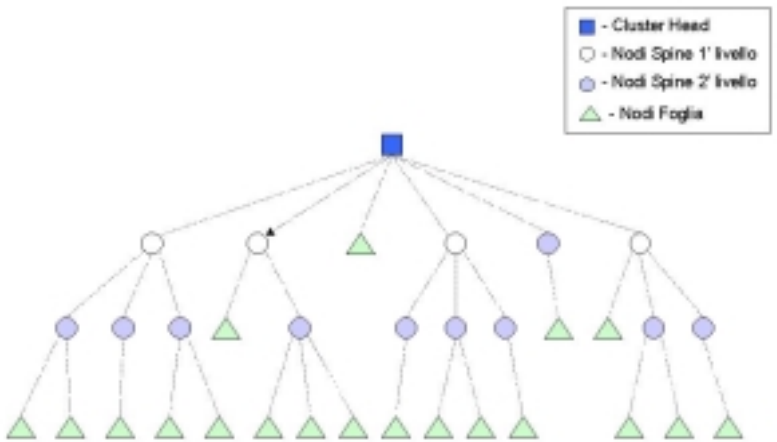
Ongoing activities with effects on QoS

- **Exploiting new Clustering schemes...**
  - Based on Energy, Mobility and Connectivity factors
  - Dynamic, adaptive, Spine-based network infrastructures
- **...supported by new MAC: Differentiated DCF (DDCF) access scheme**
  - (Pseudo)-distributed management
  - Exploit differentiated IFS (like in IEEE802.11e) for priority management related to cluster-based node roles
- **Adaptive Protocol Framework**
  - Cross layering principle (shared information repository)
    - Inter-protocol layer and inter-node
  - Coordination languages and tuple spaces
- **Multipoll–based solutions**
  - Priority nodes administrate local access scheduling
- **Intra-stream and inter-stream self-contention in multi-hop paths**
  - Distributed contention management and flow synchronization
    - avoid frame flows to collide (auto-interference)
- **Modified NAV policy**
  - Enhancement of low power techniques for distributed nodes
- **...and more upcomings and expected!**

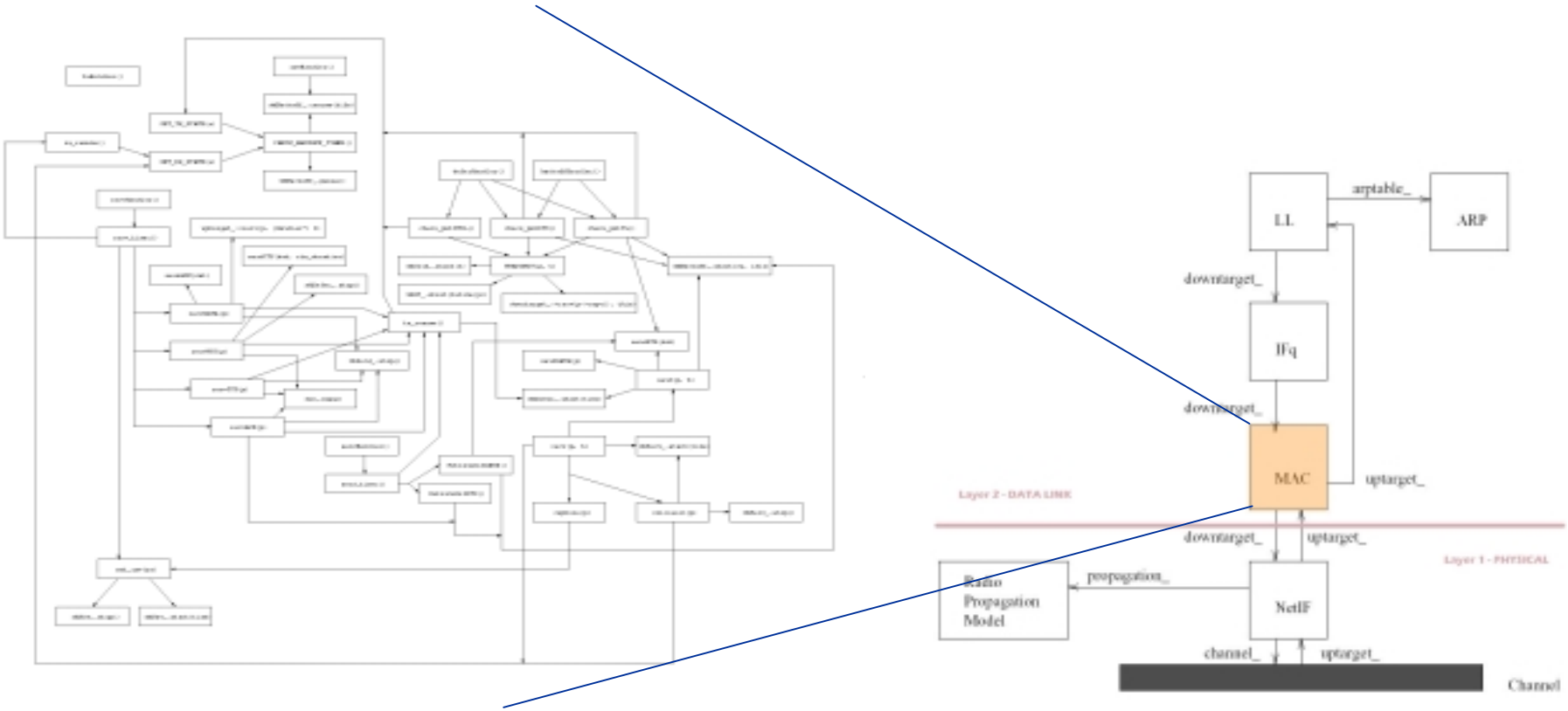
DDCF access scheme over clustered networks

- **Differentiated DCF-like (DDCF) access scheme**
  - Exploit differentiated IFS (like in IEEE802.11e) for cluster-based roles
    - Not only for local queues contention, but for cluster contention
    - Nodes with high priority role capture the channel under the contention viewpoint



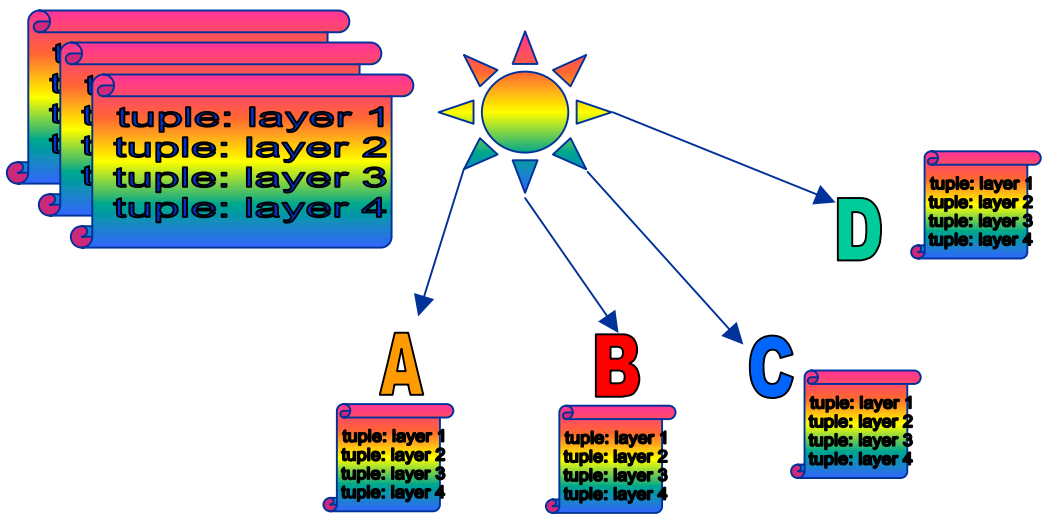


MAC design and modeling (simulation)



Cross layering protocol framework

- **Adaptive protocols**
  - Limited feedback vs. local information sharing
- Adaptive protocol suite based on:
  - Tuple spaces theory (lightweight information coding)
    - Distributed repository for control and management information
  - Coordination languages (primitives for tuple management)
    - Tuple gathering and tuple production (inference)
    - Inter-protocol layer and inter-host management

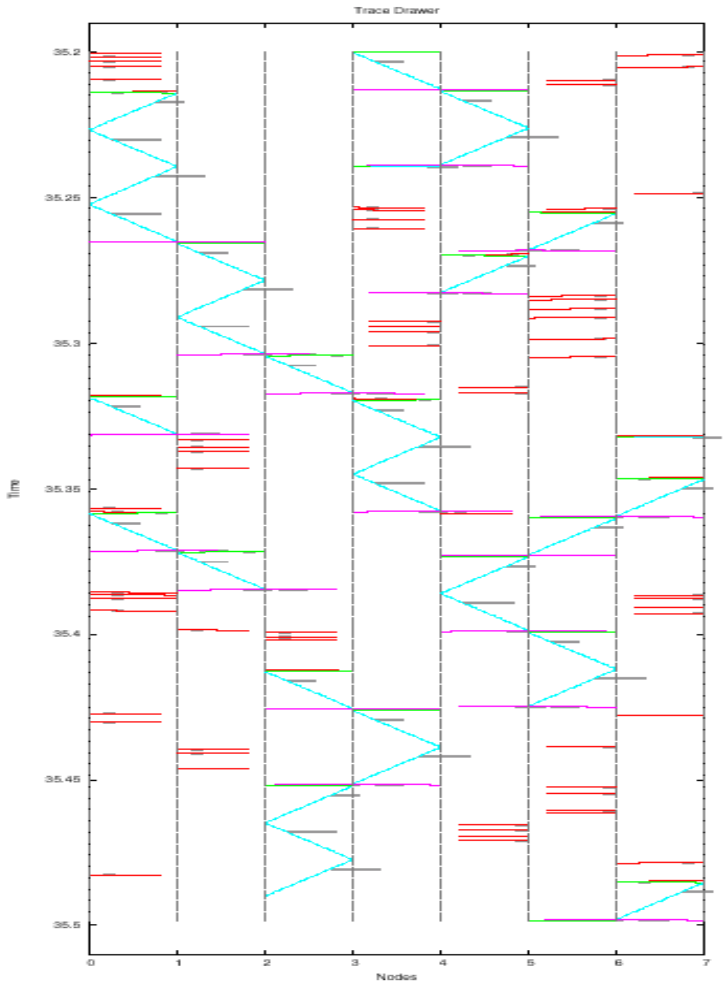


Ad hoc Multi-hop: Time/Space problems

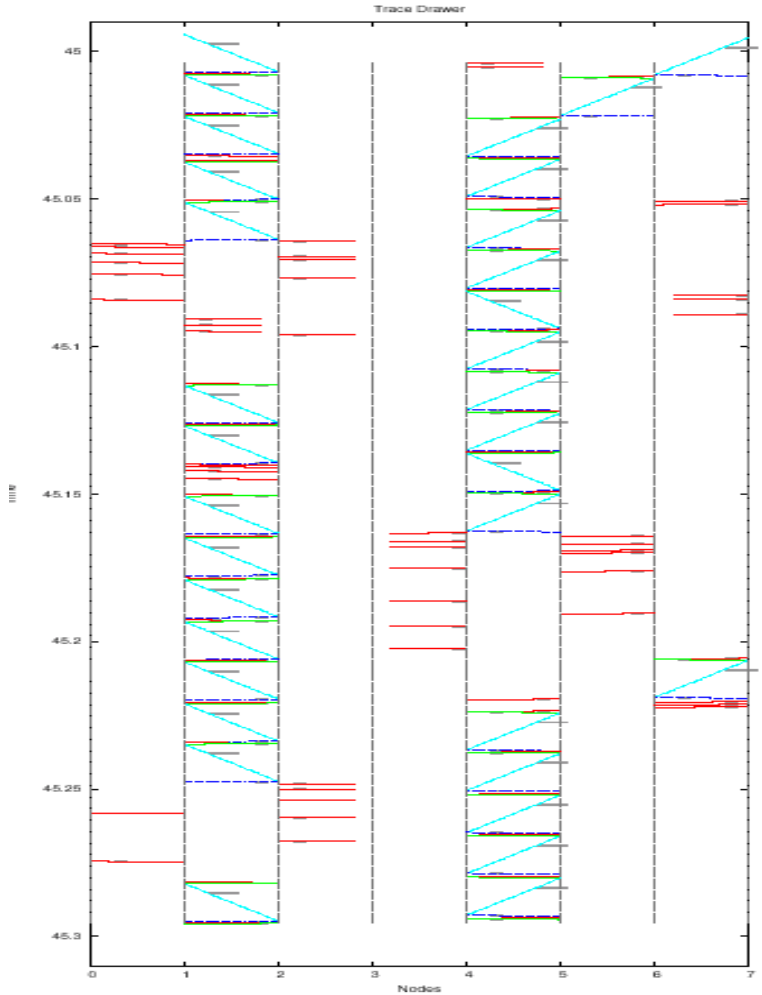
- A bi-directional chain of MAC frames
  - TCP streams (Data + Ack)
- Self-contention (MAC layer problem)
  - Inter-stream self-contention (Data vs. Ack TCP streams)
  - Intra-stream self-contention (same TCP stream)
  - How to obtain coordination?
  - New proposed solutions
    - *Fast forward*
    - *Quick exchange*
    - *Flow numbering (pre-routing at the MAC layer???)*
    - *Frame transmission by forward invitation*

Ad hoc Multi-hop: Time/Space problems

New multi-hop IEEE802.11 MAC

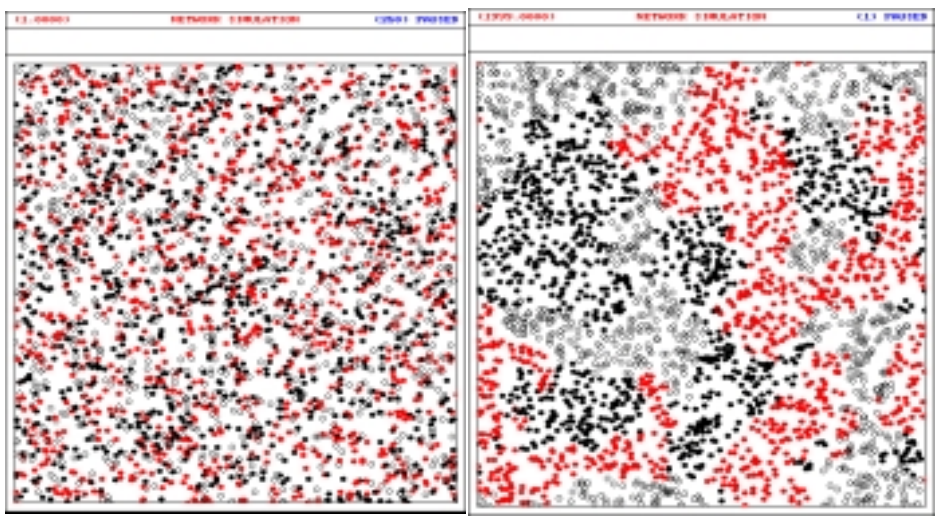


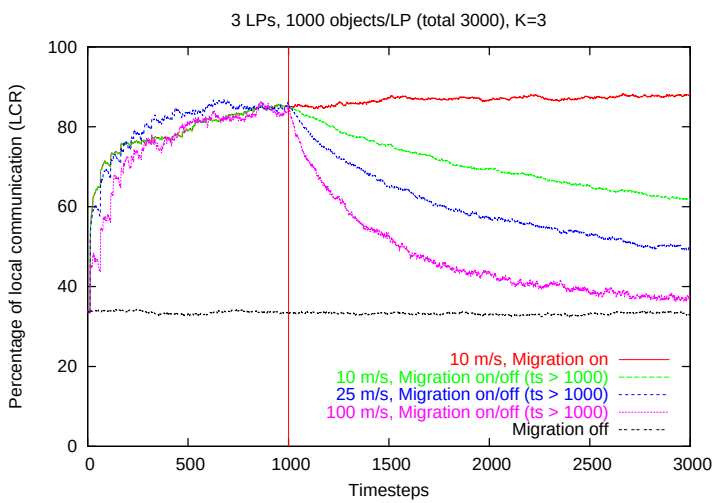
Multi-hop IEEE 802.11 MAC



Efficient simulation of wireless systems

- Wireless models require complex and scalable design
- Parallel and Distributed Simulation to overcome the memory and computation bottleneck
  - *Communication bottleneck*
  - *Optimization of PDES framework based on HLA (IEEE 1516): ARTIS + GAIA*





Conclusion

- Design and investigation of MAC, Clustering (and Routing) protocols for wireless systems
  - to support cluster-based infrastructures (*)
  - supported by cluster-based infrastructures (*)
  - possible extension of Wireless Internet Hot Spots
    - *Distributed services, location dependency, epidemic and cooperative*
  - Research oriented to QoS support
  - Focus on “adaptive” and “cross layering” design
- Centralized and distributed (hybrid) approach
  - Middleware support for Protocol framework (*)
- Integration with fixed infrastructure networks
- compliance with Standards
  - ...good for interoperability and deployment

(*) In cooperation with STMicroelectronics