Cross-Layer Networking Protocol Design for Ubiquitous Home Service

-- Hierarchical Cross-Layer Fuzzy Control

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Outline

- Introduction
  - Property of “U” Networks
  - Solution: HCLFC! Why HCLC?
- Hierarchical Cross-Layer Fuzzy Control (HCLFC)
  - System Architecture
- Case Studies
  - IEEE 802.11e WLAN & MANET
  - WiMAX Guaranteed QoS scheduling and Fair Resource Allocation
  - Generic PHY-APP cross-layer
- Implementation in SoC/Embedded Systems
- Conclusion and Future work

Introduction

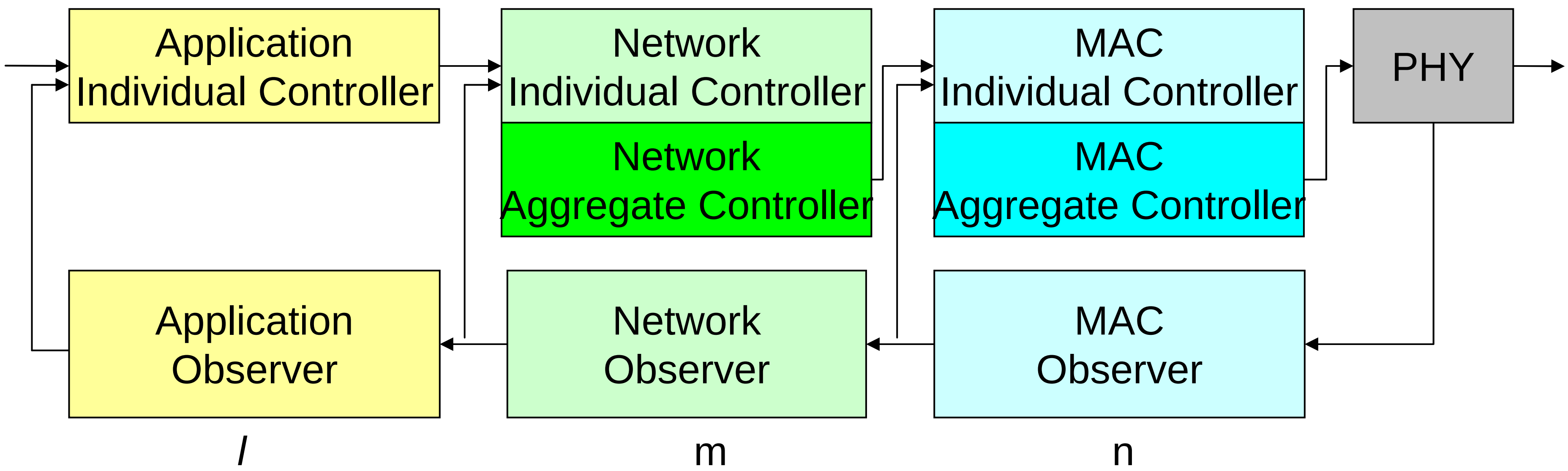
- Ubiquitous Home/Residential Networks
  - Ad hoc, mobile, wireless, with lots of scenarios and uncertain dynamics
  - No exact model !!
- What's problem of present cross-layer designs?
  - Mobile environment needs adaptive systems
  - Uncertainty and conflictions lead to failure of optimization steps

Introduction

- Hierarchical cross-layer fuzzy control (HCLFC)
  - Fuzzy control adapts system to mobile environment
  - Hierarchical cross-layering reduces time complexity
  - Fuzzy decision making deal with uncertainty and conflictions

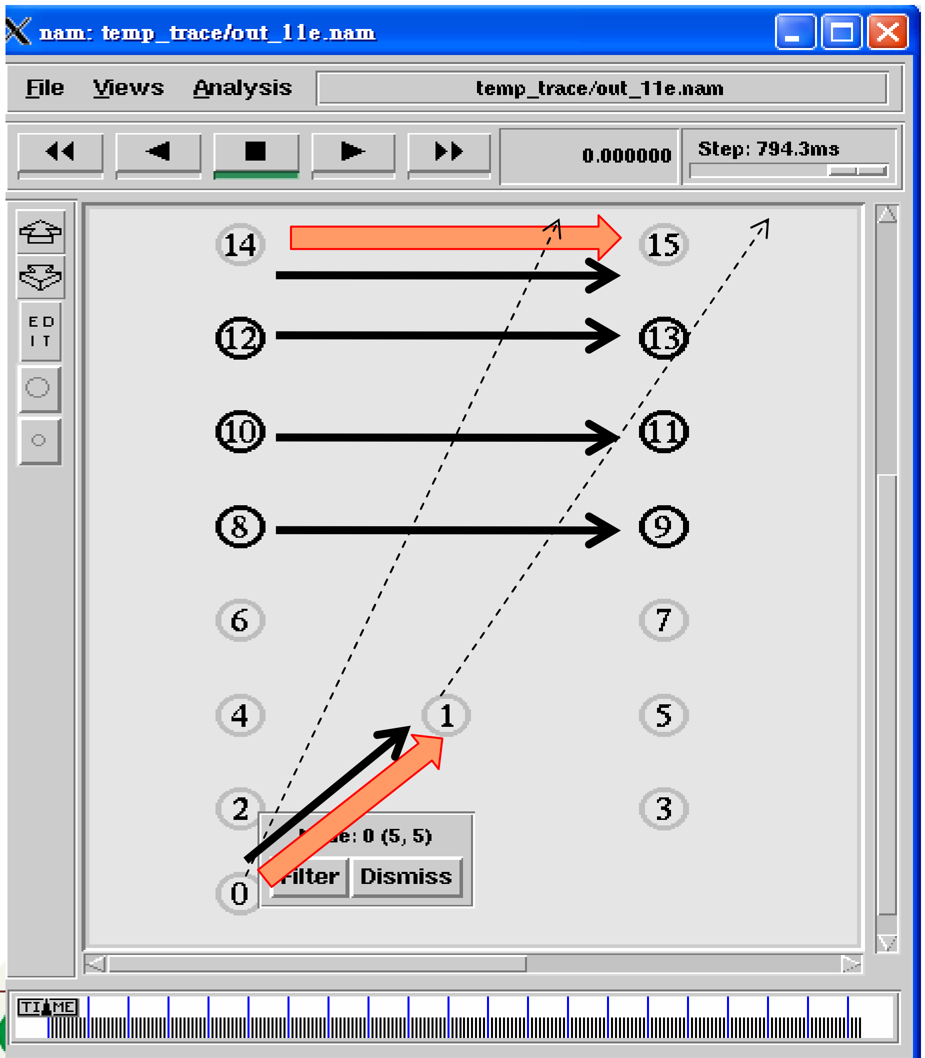
HCLFC Architecture

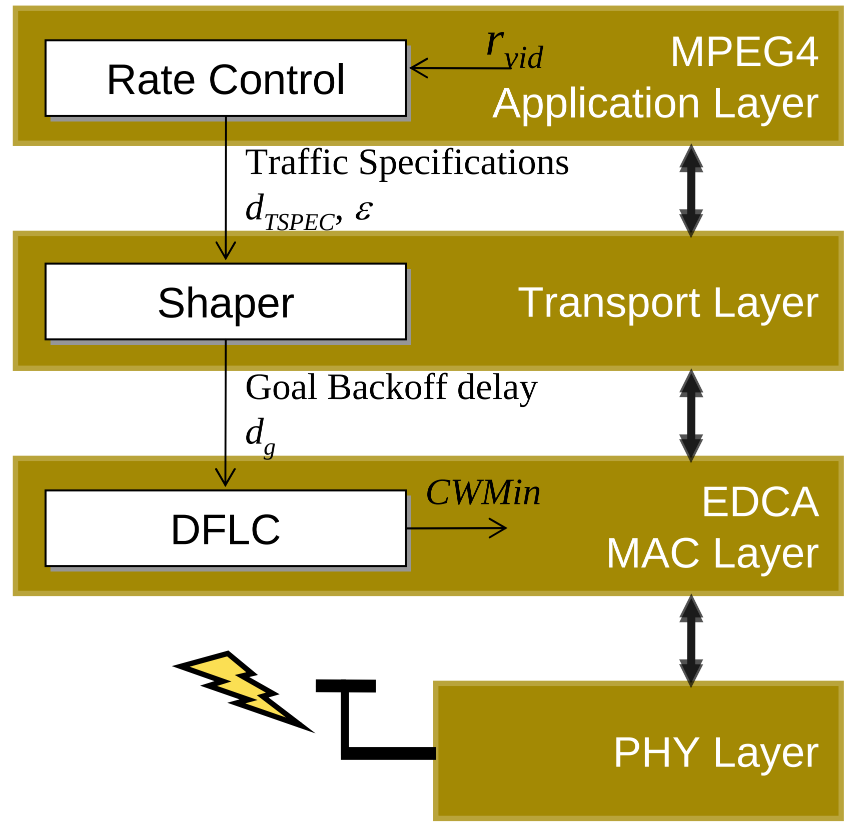
$v_1 = < u_1 >$ $v_2 = < u_1', u_2 >$ $v_3 = < u_1'', u_2, u_3 >$



- Individual Controller IC
  - Accomplish fuzzy control
  - Adopt fuzzy individual decision making
- Aggregate Controller AC
  - Adopt fuzzy multistage decision making
  - Resolve conflictions among ICs
- Complexity
  - Use (l+m+n) to tackle l×m×n
  - Hierarchical Fuzzy Control
  - Simple rule base at each layer

Case Study 1 -- IEEE 802.11e MANET



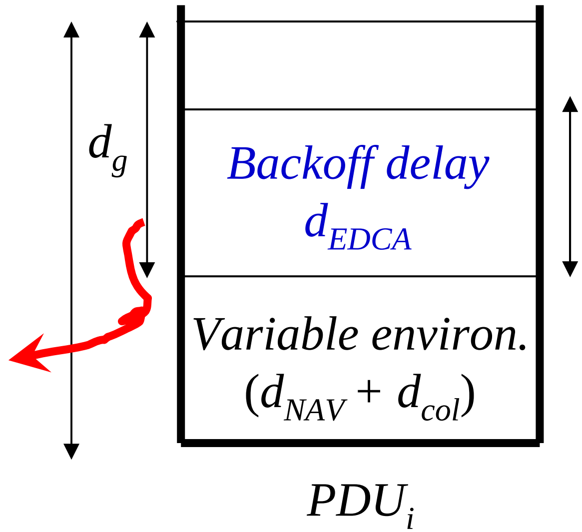


HCLFC for 802.11e MANET

Cross-layering of HCLFC Layer Controllers

Application SVC :
Variable TSPEC

Transport:
Shaper of intermediate ad hoc links



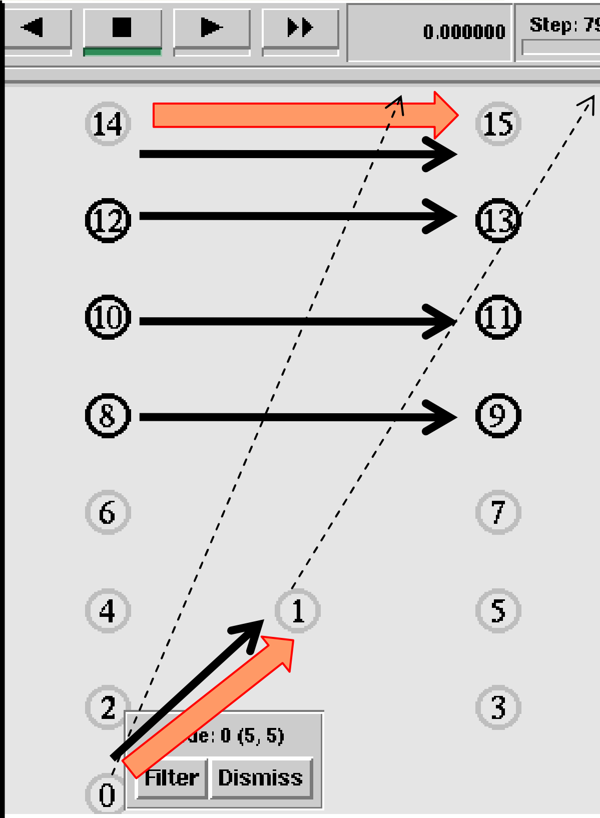
MAC layer:
backoff delay

$\forall$ IC, the fuzzy control is only partially known:

$$u = -1, \quad -a < \dot{\xi}_1 < \dot{\xi}_2 < -b < 0$$
$$u = 0, \quad \dot{\xi}_1 = \dot{\xi}_2 = 0$$
$$u = 1, \quad 0 < b < \dot{\xi}_1 < \dot{\xi}_2 < a$$

Simulation

	MPEG4 Video	Background
Transport protocol	UDP	UCP
Routing protocol	**AODV/DSDV**	**AODV/DSDV**
Access Category	2	0
CWmin	**HCLFC control**	31
CWmax	1023	1023
AIFS	2	3
MPDU	< 1028 bytes	1500 bytes
Sending rate	Max 960 kb/s	300 kb/s
Max allowable delay	< 96 ms	best effort
Codec/video sender	EvalVid [9][10]	
GoP	CIF 30 fps I, P, B	
MPEG parameter file	Ver. 906	



-------------> Moving direction

MPEG 4, max 960kbps

Background, 300kbps

Fairness and Average PSNRs of MPEG-4 Streams

<table>
<tr><td colspan="3">Case 0: Average PSNR (dB) – Only one MPEG-4 stream without any background traffic.</td></tr>
<tr><td colspan="3">EDCA 0→1 = 36.5 (ideal streaming performance)</td></tr>
<tr><td colspan="3">Case 1: Average PSNR (dB) -- single MPEG-4 stream 0→1 with background traffics: 0→1, 2→3, 4→5, 6→7, 14→15 F</td></tr>
<tr><td colspan="3">DCF 0→1 = 20.6</td></tr>
<tr><td colspan="3">EDCA 0→1 = 29.0</td></tr>
<tr><td colspan="3">EDCA 0→1 = 36.47 (FC) (μ_{bk}, σ_{bk}) =(1051, 140)</td></tr>
<tr><td colspan="3">Case 2: Average PSNR (dB) --Two co-existent MPEG-4 streams 0→1 and 14→15 with background traffics: 2→3, 4→5, 6→7, 8→9, 14→15</td></tr>
<tr><td>DCF 0→1 = 24.6
EDCA 14→15 = 27.7
(μ_{bk}, σ_{bk}) =(641, 116)</td><td colspan="2">DCF 0→1 = 26.0
EDCA 14→15= 36.1 (FC)
(μ_{bk}, σ_{bk}) =(632, 132)
Even help non-FC</td></tr>
<tr><td colspan="3">Case 3: Average PSNR (dB) --Two co-existent MPEG-4 streams 0→1 and 14→15 with background traffics: 0→1, 2→3, 4→5, 6→7, 14→15</td></tr>
<tr><td>EDCA 0→1 = 27.3
EDCA 14→15 = 31.2
(μ_{bk}, σ_{bk}) =(584, 118)</td><td>EDCA 0→1 = 36.5 (FC)
EDCA 14→15 = 27.2
(μ_{bk}, σ_{bk}) =(533, 123)
saturated</td><td>EDCA 0→1 = 36.1 (FC)
EDCA 14→15 = 35.6 (FC)
(μ_{bk}, σ_{bk}) =(545, 163)</td></tr>
</table>

What WLAN MANET Merits from HCLFC

- *Adaptive to uncertain dynamics*
  - *Upper layers control variable fuzzy consequences of MAC layer fuzzy control*
  - Support *dynamic* TSPEC for network dynamics and uncertainty
- *QoS Guarantee and Fairness*
  - Not only "Same priority = same throughput" (most articles), but also:
  - HCLFC helps non-HCLFC (actively helps)
  - Low priority flows: Little sacrificed (better resource utilization)
- *Low Complexity, Hi-Flexibility, Hi-Scalability*

Case Study 2 – WiMAX OFDMA Systems

- GQFR --
  - **G**uaranteed **Q**oS Scheduling
  - **F**air **R**esource Allocation
- HCLFC control
  - Application-Transport-MAC-PHY
- Low implementation complexity
- Flexibility
- Scalability

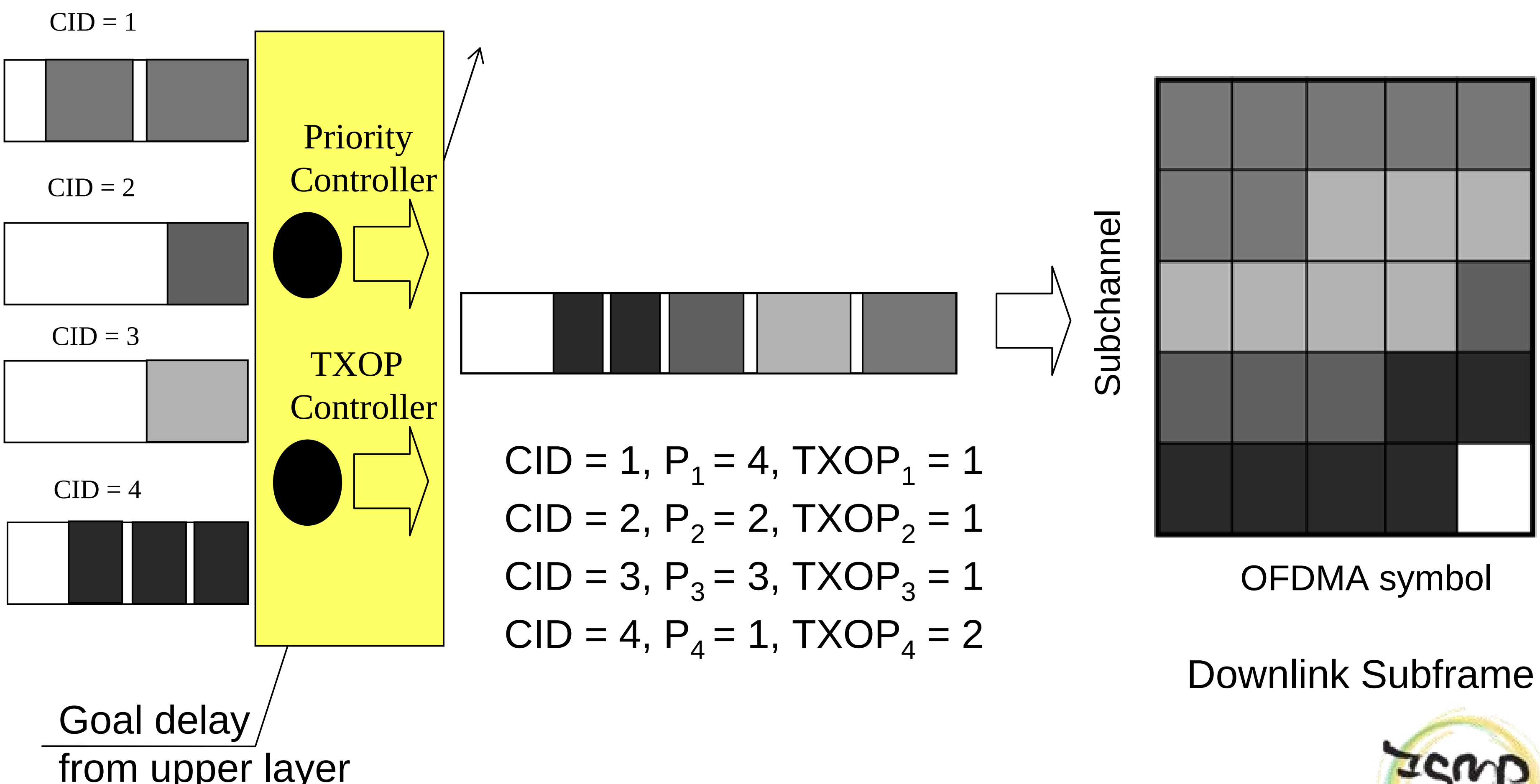
Resource allocation

- Why not use optimization theory? Why not utility-based?
  - Advantage
    - Maximize system throughput
  - Disadvantage
    - High computing complexity
    - Limited capacity of MAP message
    - Exact objective function and constraints are impossible
- Why not priority-based method?
  - Advantage
    - Low computing complexity
  - Disadvantage
    - Not real QoS guarantees since not about jitter
    - No fairness

Service Classes in WiMAX

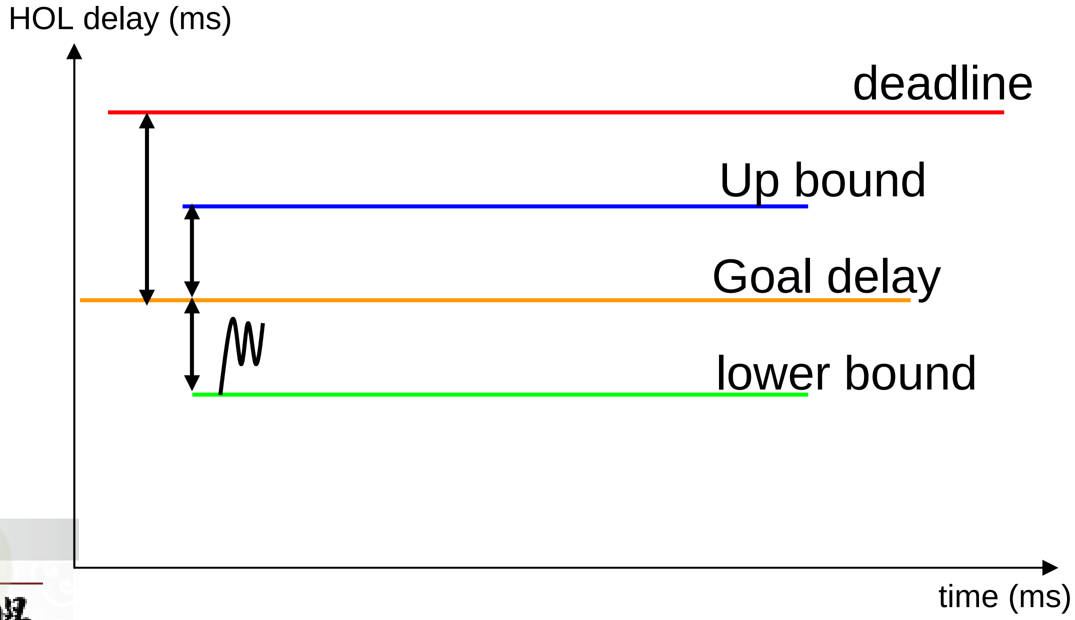
- Unsolicited Grant Service (UGS)
  - Maximum Latency
  - Tolerated Jitter
- Real-time Polling Service (rtPS)
  - Maximum Latency
  - Tolerated Jitter (extended rtPS)
- Non-real-time Polling Service (nrtPS)
  - Minimum Reserved Traffic Rate
- Best Effort (BE)

GQFR Concept



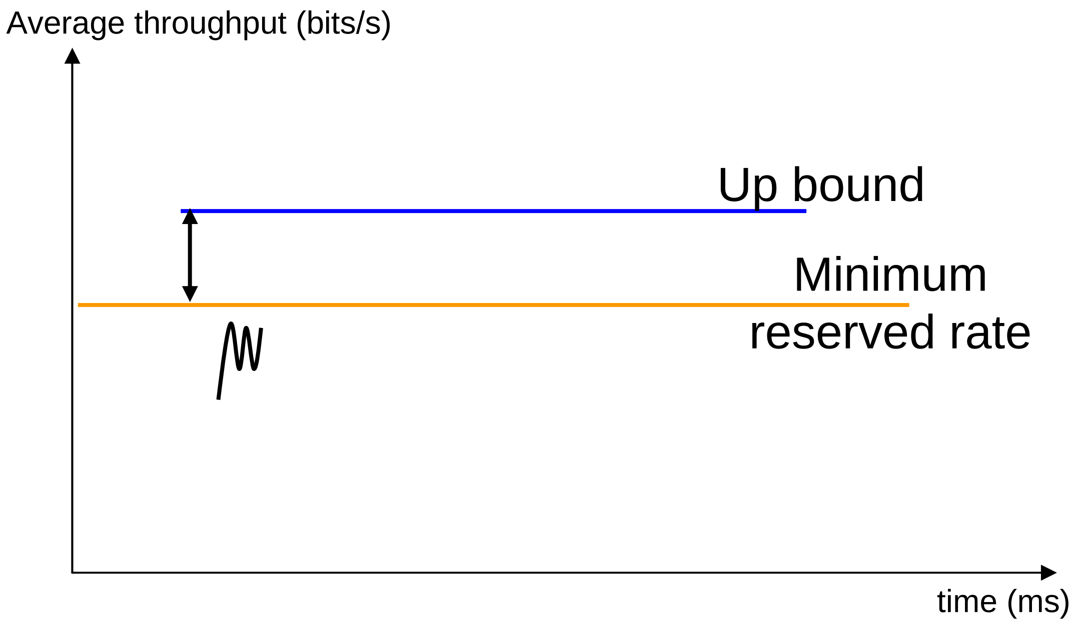
HCLFC Design for rtPS

- Multimedia coding (e.g. SVC) control at application layer
- Goal delay controller at transport layer
- Priority controller at MAC layer
- TXOP controller at MAC layer
- Modulation control at PHY layer



HCLFC Design for nrtPS

- Priority controller
- TXOP controller



Simulations

Scenario 1: 8 connections in 1Mbps, 10 connections in 500 kbps, and 2 connections in 250kbps. (rtPS only)

Check: The guarantees of maximum latency, tolerated jitter, loss rate, and fair resource allocation for rtPS connections

Scenario 2: 2 real-time connections in 1Mbps, 8 real-time connections in 500 kbps, 5 nrtPS connections in 1Mbps, and 5 nrtPS connections in 500 kbps. (rtPS+nrtPS)

Check: the guarantees of minimum reserved rate and fair resource allocation for nrtPS connections

Scenario 3:

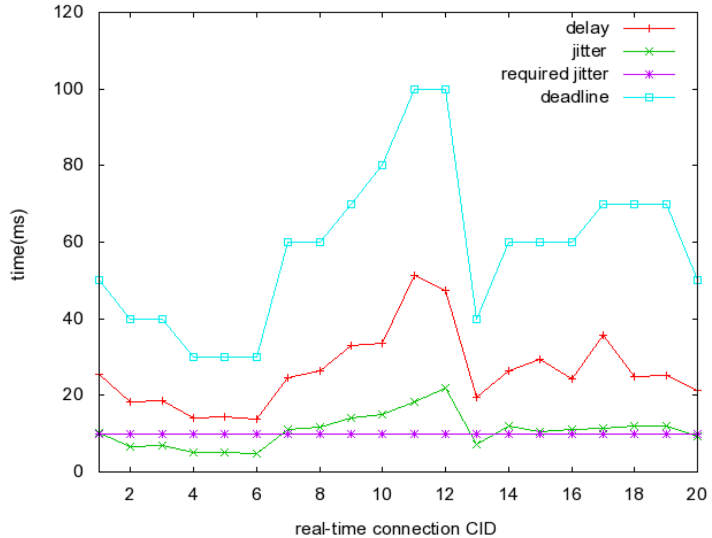
1 real-time connection in 1Mbps, 9 real-time connections in 500 kbps, 3 nrtPS connections in 750 kbps, 2 nrtPS connections in 500 kbps, 5 nrtPS connections in 1Mbps and 10 BE connections in 100 kbps. (rtPS+nrtPS+BE)

Check: fairness to low priority connections

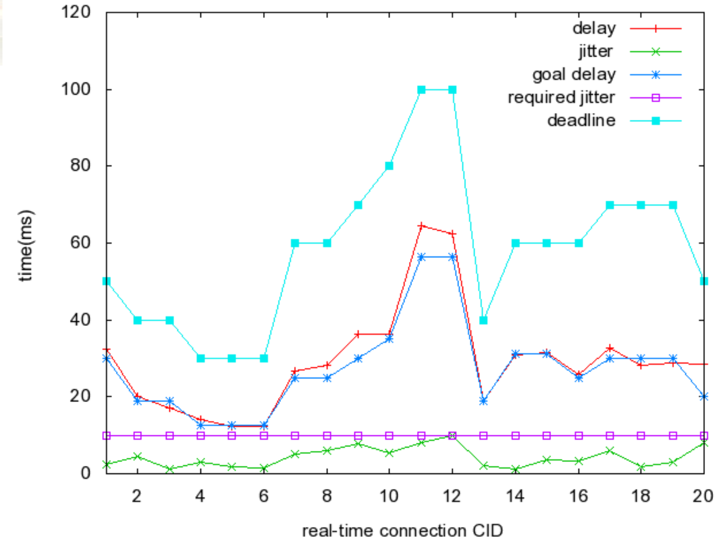
TABLE I. Simulation parameters

Parameter	Value
System bandwidth	10MHz
Frame duration	5ms
OFDM FFT	1024
Number of subchannel	30
Numner of OFDM symbol for DL	28

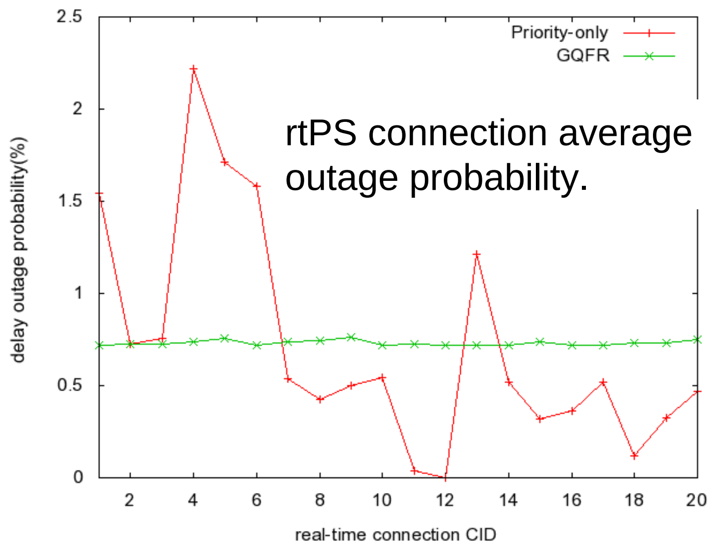
Simulation Results



Real-time connections in priority-only scheduling methods.



Real-time connections in GQFR.



rtPS connection average outage probability.

Scenario 1: (rtPS only) the guarantees of maximum latency, tolerated jitter, loss rate, and fair resource allocation

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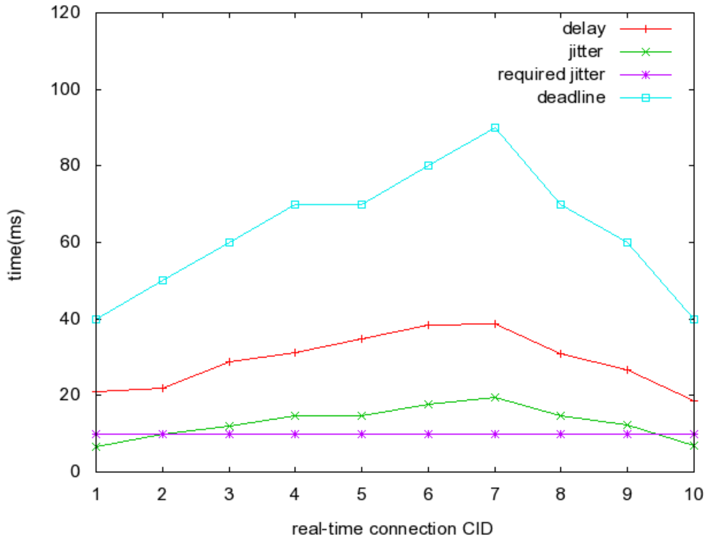
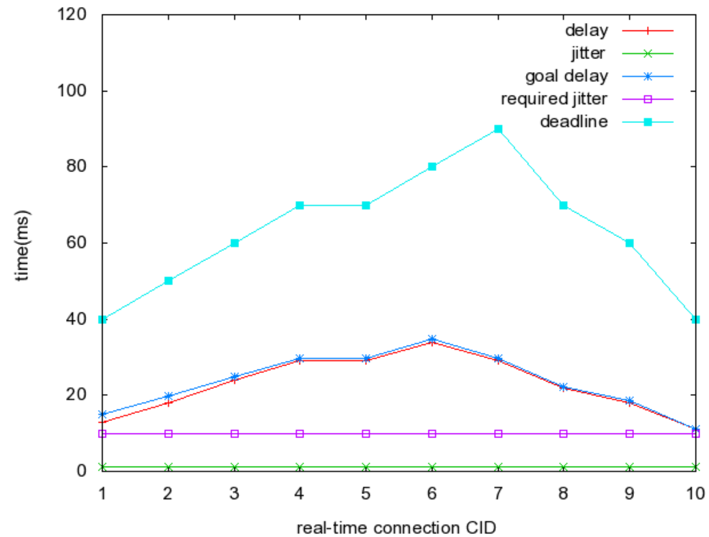
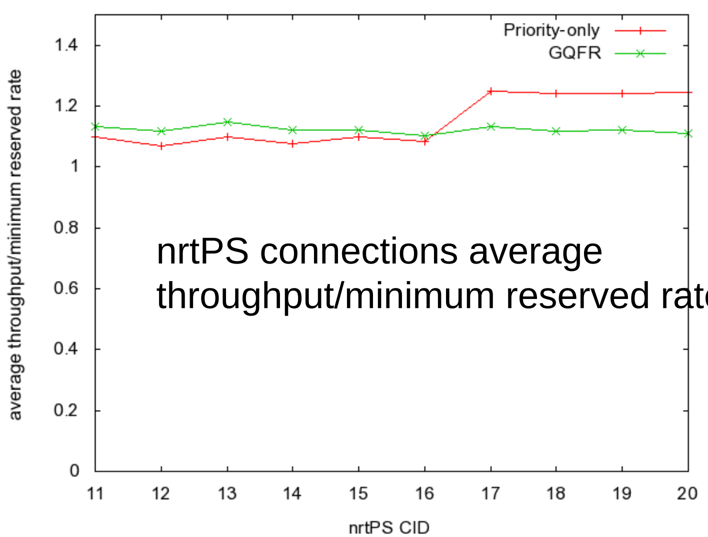
Simulation Results



Real-time connections in priority-only scheduling method.



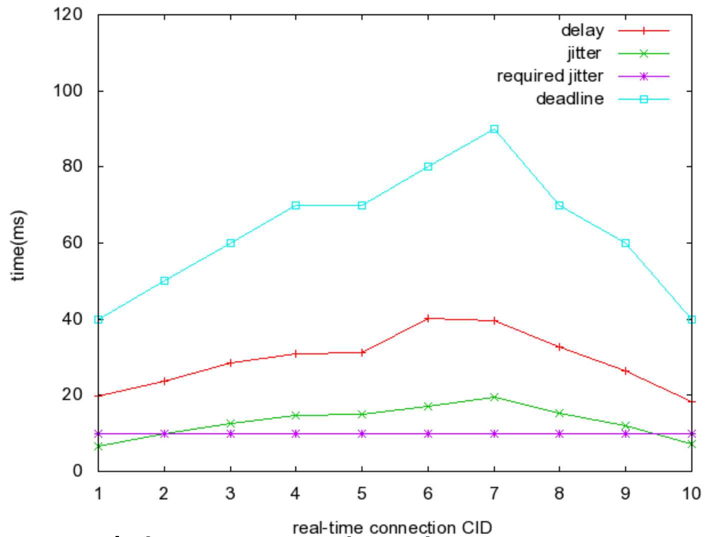
Real-time connections in GQFR.



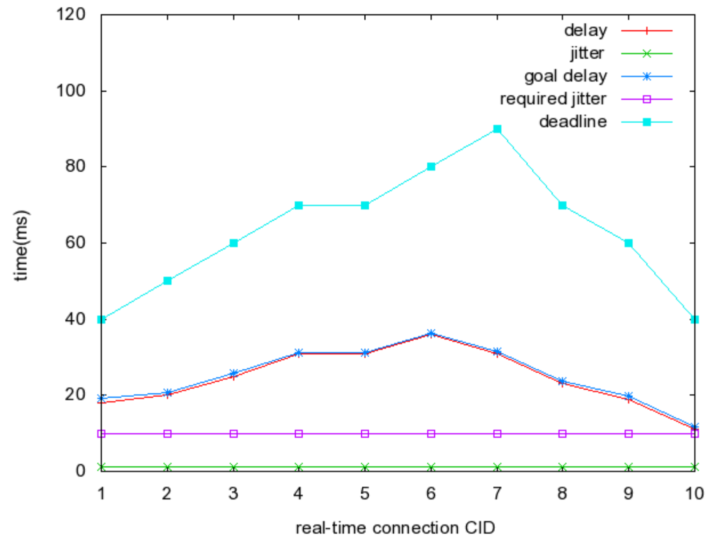
nrtPS connections average throughput/minimum reserved rate.

Scenario 2: (rtPS+nrtPS) the guarantees of minimum reserved rate and fair resource allocation

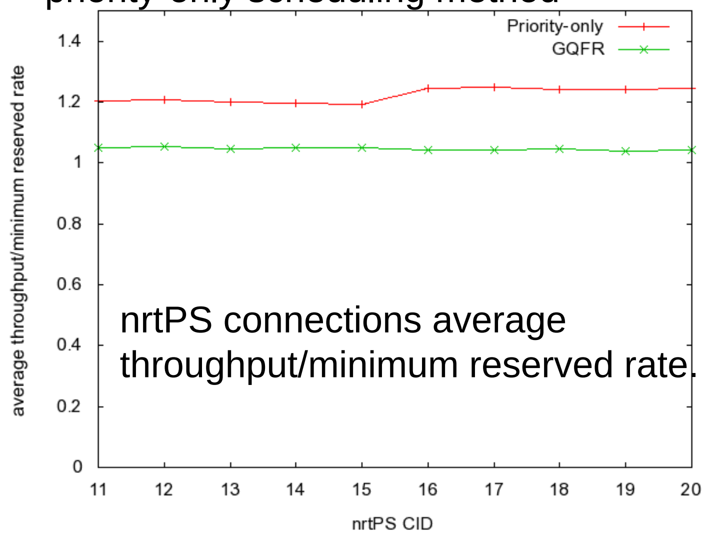
Simulation Results



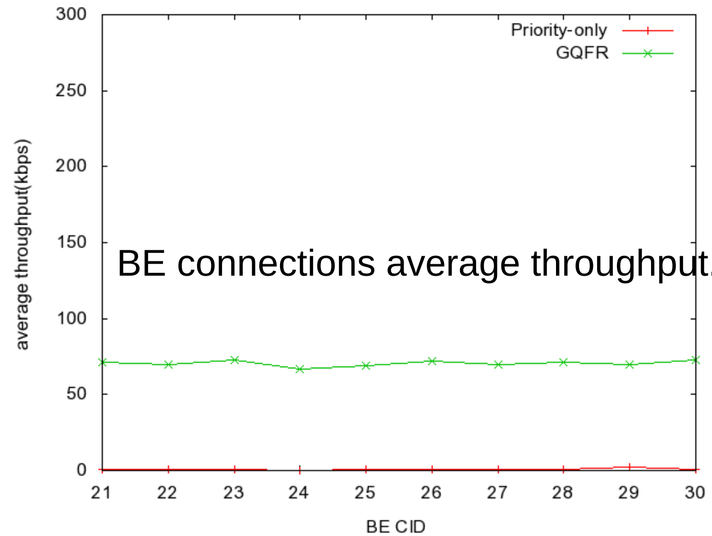
Real-time connections in priority-only scheduling method



Real-time connections in GQFR.



nrtPS connections average throughput/minimum reserved rate.



BE connections average throughput.

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Scenario 3: . (rtPS+nrtPS+BE) fair resource allocation

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Case Study 3 -- Generic PHY-APP Cross-Layer Control

REQUIRED PARAMETER	Application Layer	PHY Layer
Symbol	IC_{APP}	IC_{PHY}
Objective	PER	Throughput
Goal value	< 0.1 + 0.01	→4
Tolerated bound	0.01	0.1
Control parameter	Packet length	Modulation
Control actions	{*1/2, *1, *2}	{Lower, Same, Higher}

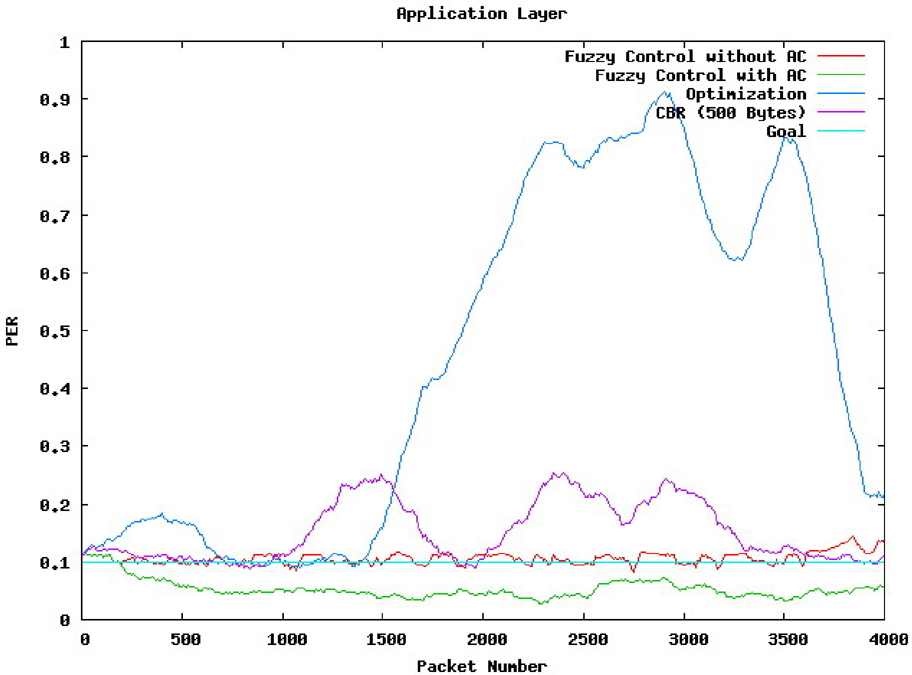
PARAMETER	Value
Goal Throughput	4 (∞)
Tolerated bound of goal loss	0.1
Initial modulation	QPSK
Worst modulation	BPSK
Best modulation	16QAM

PARAMETER	Value
Loss rate	<0.1
Tolerated bound of loss	0.01
Initial packet length	500 (Bytes)
Maximum packet length	1536 (Bytes)
Minimum packet length	26 (Bytes)
Total packet amount	4000

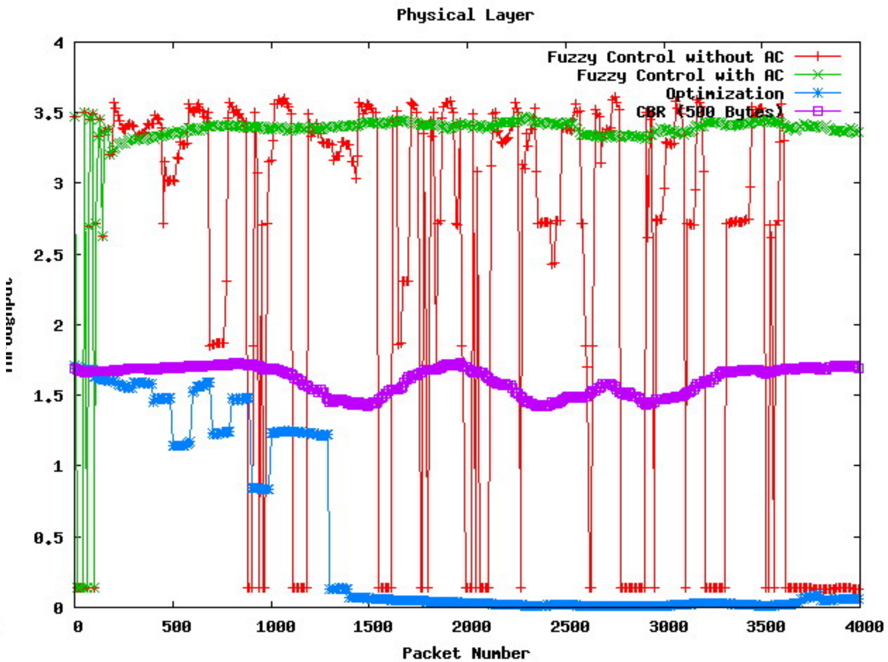
Aggregate

$$\begin{array}{c|ccc} & S_1 & M_1 & L_1 \\ \hline S_2 & M_2 & S_2 & S_2 \\ M_2 & L_2 & M_2 & S_2 \\ L_2 & L_2 & L_2 & M_2 \end{array}$$

Simulations Results



Loss rate



Throughput

Two layers control wi/wo AC_1

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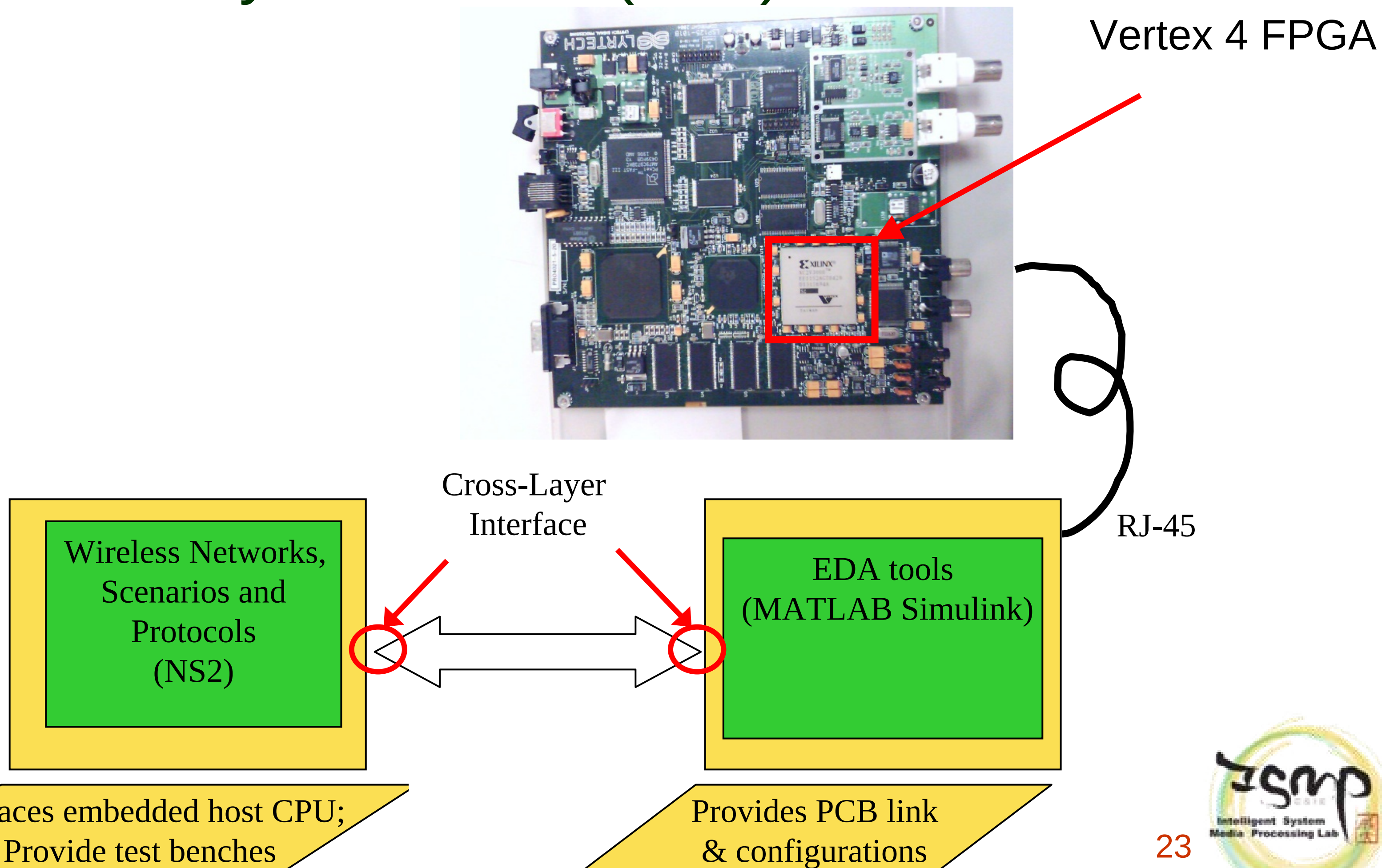
Implementation in SoC/Embedded Systems

- Electronic System Level (ESL) Verification



Conclusion

- HCLFC is a generic solution to ubiquitous networks
- HCLFC is a paradigm of cross-layer networking protocol design
- HCLFC features
  - Scalability
  - Low complexity
  - QoS guarantee
  - Fairness
  - Cognizance of uncertain dynamics

Future Work

- Higher-type and higher-level fuzzy sets to accommodate more general situations.
  - Cross Heterogeneous networks
- Multi-dimensional control for multi-objective at the same layer
  - We already have individual controllers for energy, security, and reliability purposes
  - Aggregating all the objectives is the focus of cross-layer design if using HCLFC.