Design and Verification of Real-Time and Communicating Software

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I

INTRODUCTION

Design

- Define properties, scenarios or services
- Design Phases
  - Spec, Val, Impl, Test
- Hierarchy of Design Steps
  - Mechanisms, components, modules, levels, etc

- Using models
  - Physical and Logical models
  - Software and Hierarchical models

System Models

- Basic Models
  - Extended (Timed, etc) Petri Nets
  - Extended State Machines
  - Extended Process Algebra
- Description Techniques
  - Formal: Estelle, SDL, Lotos (FDTs for Protocols)
    - Estelle and SDL, Extended State Machine oriented
    - Lotos, Extended Process Algebra oriented
  - Semi-Formal:
    - UML (the pioneer)
    - AADL, SysML, UML2 (Object oriented, including SDL)

From Design to Verification

- **For Each phase/level, as soon as possible, using a global model/representation of the system,**

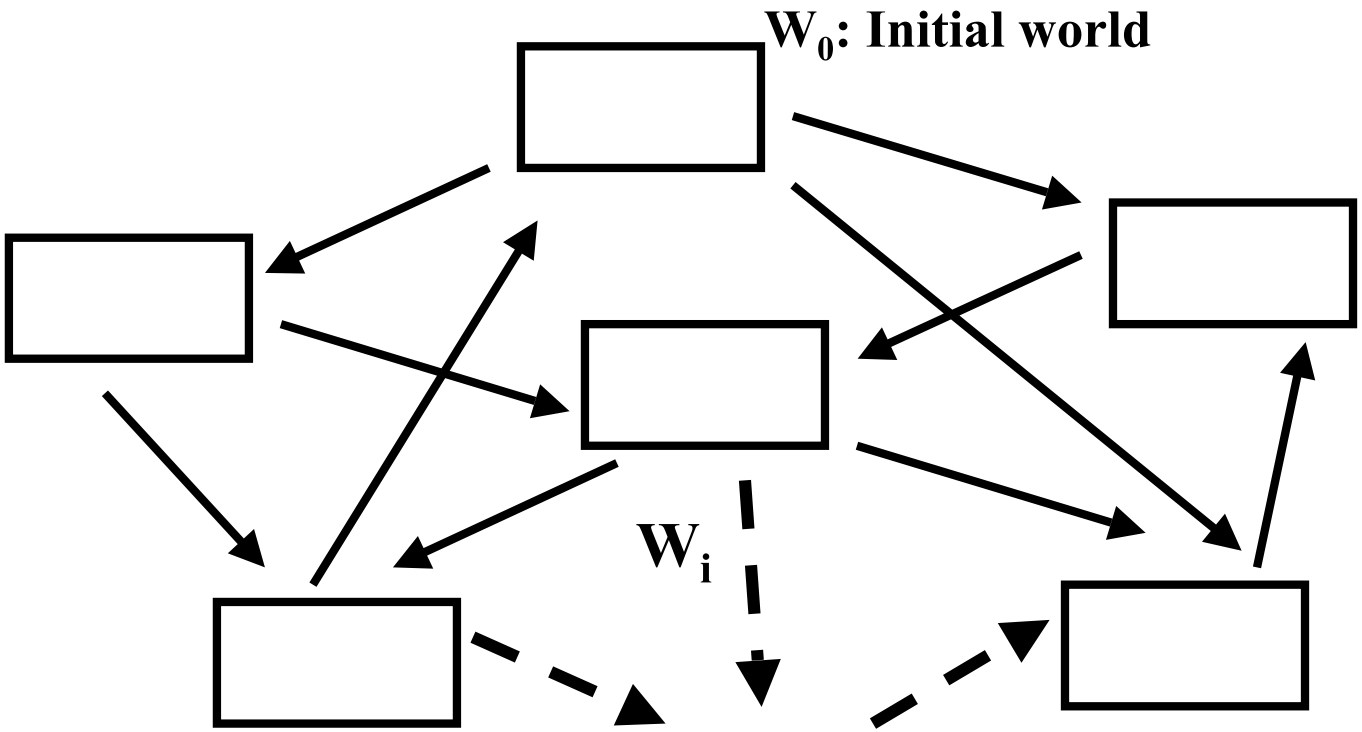
  Verify or Simulate its behaviour

- **Verification based on Modal Logic**
  - **Because values of propositions evolve dynamically**
  - **Axiomatic proofs not automatic and difficult**
  - **Semantic proofs from Kripke Structure**

- **Kripke Structure (set of connected Worlds)**
  - **Primitive Predicate symbols (p, q, r,…)**
  - **Interpretations for p, ~p, and, or, .. for a world W_i**
  - **Modalities from a set of worlds connected by a relation R**

Semantics in Modal Logic

- The worlds are the system states
- R is accessibility relation between worlds (global behaviour)
- Technical approaches and tools based on the graph (whatever defined) by (Linear or) Branching Modal Logic



From Telecommunications to Embedded and Internet Systems

- **Embedded Systems**
  - Architectures
  - Behaviour
  - Properties (functional and non functional (time, energy, ...))
  - Models, Verification, Evaluation
- **Internet Systems**
  - Architectures
  - Behaviour and Performances
  - (Minimal) Acceptable Non Optimal design : Best Effort
  - Simulations (mainly of implementations)

II
EMBEDDED SYSTEMS

Embbeded systems based on

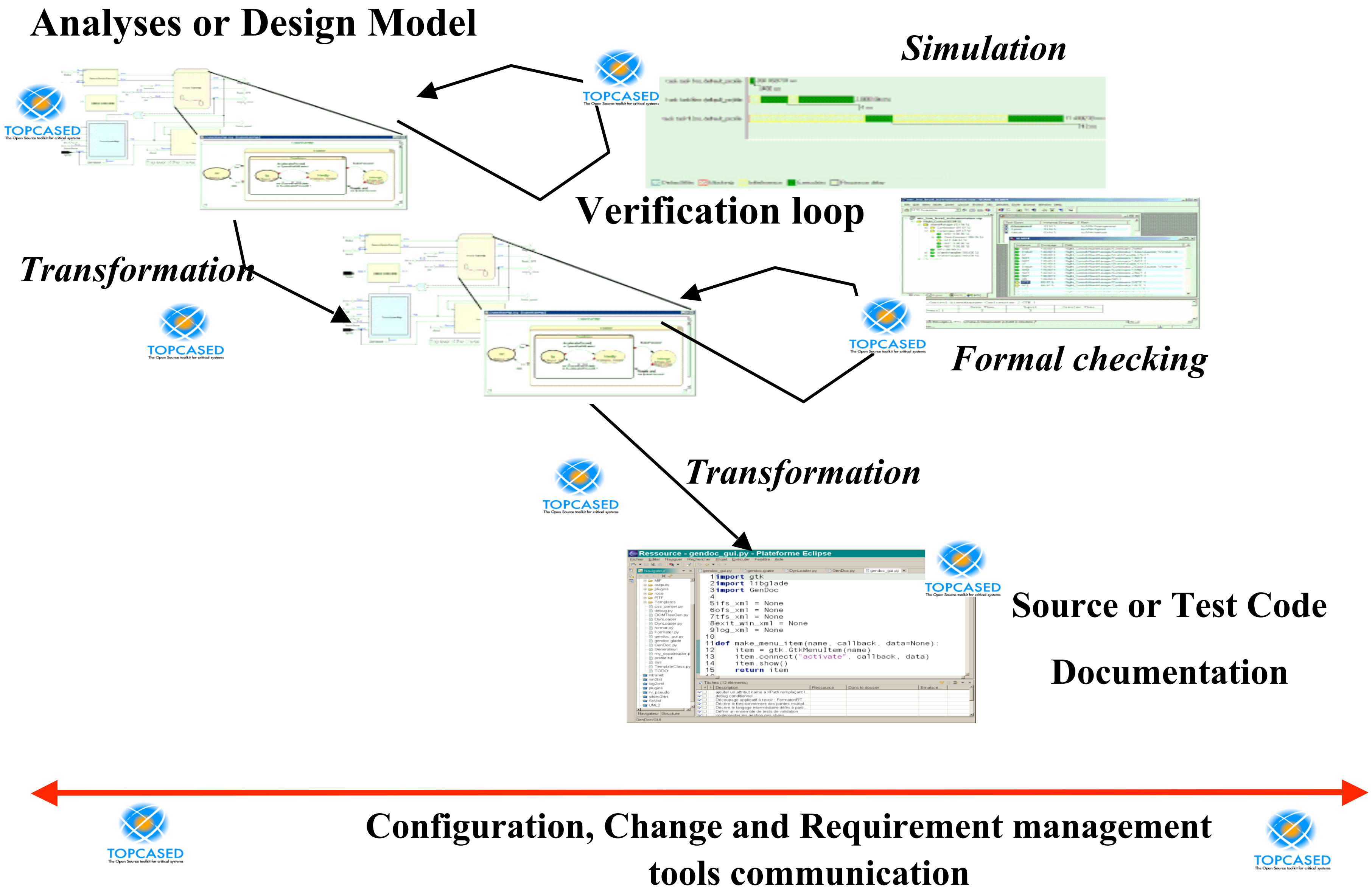
- System Specification and Requirements
- Design steps
  - Technologies to mechanisms
  - to equipments to architectures
- Models
- Verification
  - Full behaviour and Properties
  - Automatic by Tools

- Design supports
  - Formal, Verified Designs, e.g. TOPCASED

TOPCASED Project Overview

- Open Source system development environment
- Implementing an integrated model-based development process
  - from system specification
  - to the final product, including formal verification.
- Reduce development costs by optimised process and tools
- Integrate MDE and formal verification by
  - Meta-Modeling, Process modeling
  - Model Verification, simulation, static analysis
  - Model Transformations

TOPCASED



Analyses or Design Model
Simulation
Verification loop
Transformation
Formal checking
Transformation
Source or Test Code
Documentation
Configuration, Change and Requirement management
tools communication

Intermediate Langage : Fiacre

(Meta)-modeller

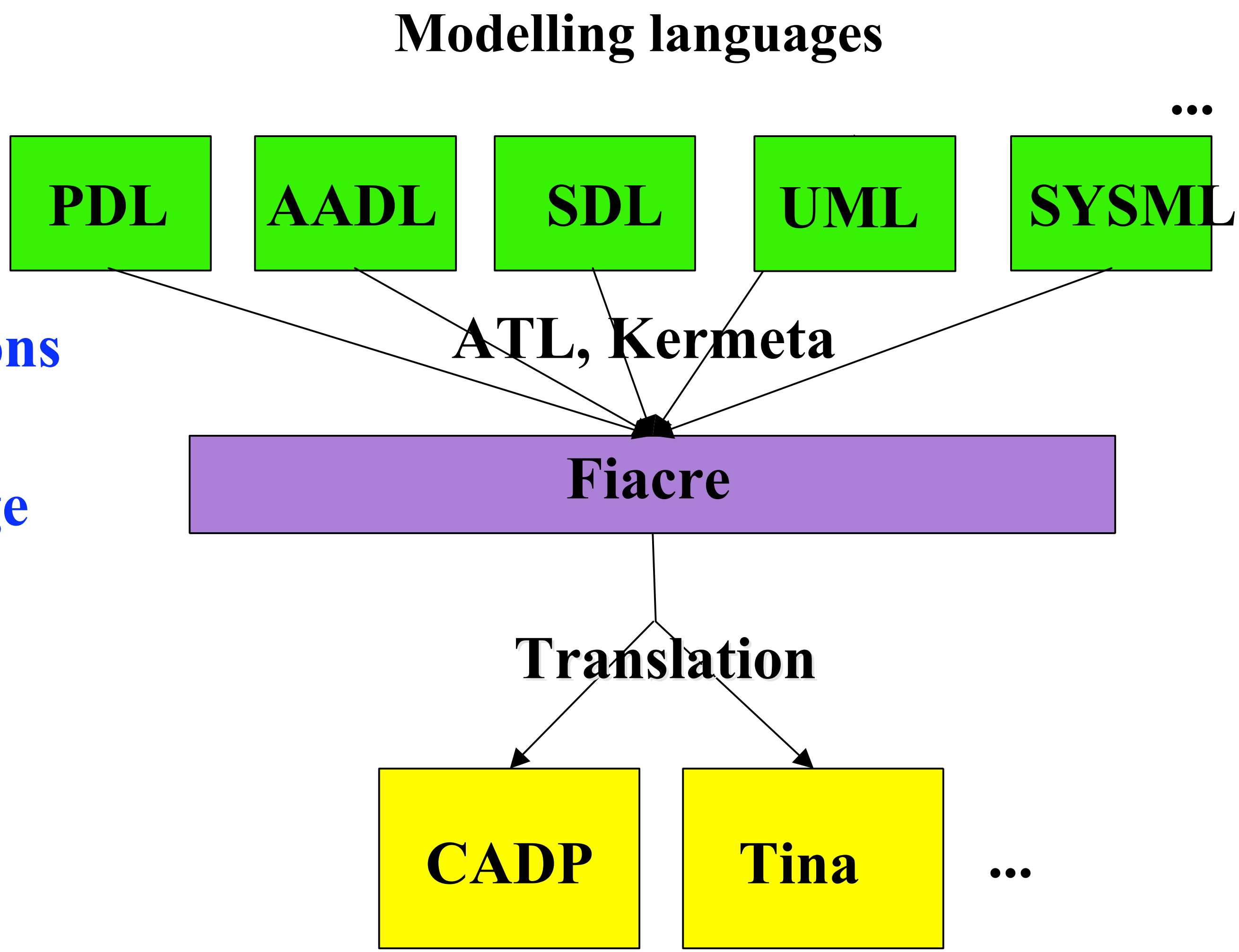
Editors

Model Transformations

Intermediate language

Compilers

Model-Checkers
Simulators



Fiacre Example

```
type request is union get_sum, get_value of index end ...

process ATM [req : in request, resp : out nat] is
states ready, send_sum, send_value
var c : request, i : index, sum : nat, val : data := [6, 2, 7, 9]
init to ready
```

```
from ready
    req ?c
    case c of
            get_sum → to send_sum
    |   get_value (i) → to send_value
    end
```

```
from send_value
    resp !val[i];
    to ready
```

```
from send_sum
    sum, i := 0, 0;
    while i < 3 do
      sum, i := sum + val[i], i + 1
    end;
    sum := sum + val[i];
    resp !sum;
    to ready
```

Verification by PN Based models and TINA

- **Including Time**
  - Time Petri Nets (intervals on transitions)
  - Analysis based on State Classes (symbolic, DBMs)
- **And Priorities**
- **And Suspension/Resumption**
  - Time Petri Nets + Stopwatches
  - State Classes + Over-approximations
- **And Data**
  - Time Transition Systems (TS + Time) & High Level Descript

TINA Tool box (Time PN Analyser)

nd :

Editor

Import/export

Simulator

tina : State spaces

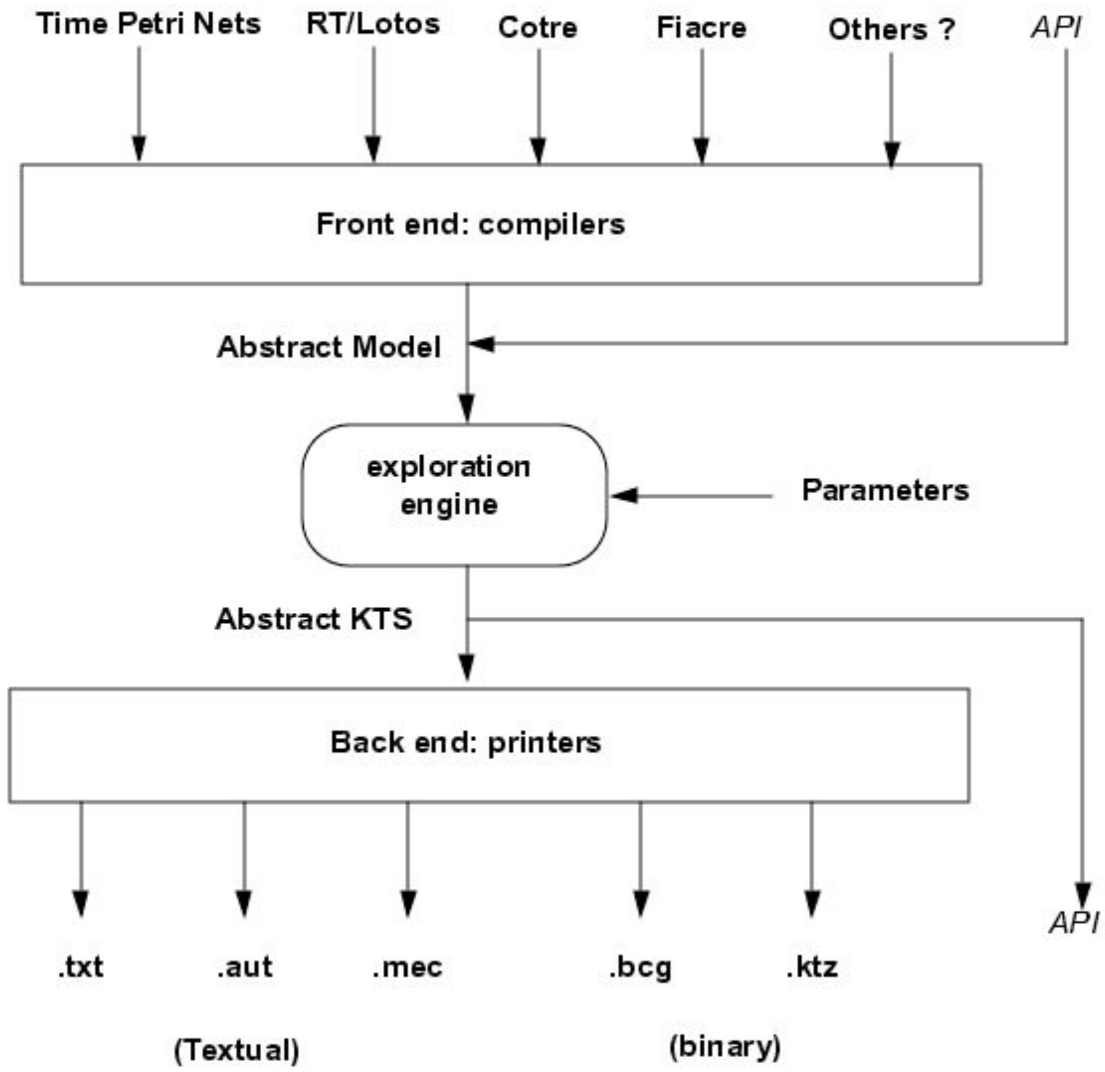
selt : LTL model-checker

struct : Structural Analysis

plan : Path Analysis

ktzio : LTS Conversions

ndrio : Net Conversions



III
INTERNET SYSTEMS

Internet Systems

- **Two approaches**
  - 1. from architecture to layers
  - 1. from layers to entities1
  - 2. from mechanisms to protocols
  - 2. From protocols to entities2
- **Design efforts**
  - From Best-Effort to QoS Internet &
  - to Guaranteed QoS, e.g. EuQoS

QoS Internet

- From QoS Applications
- How to derive networks and architectures
- satisfying QoS Bandwidth and Time requirements

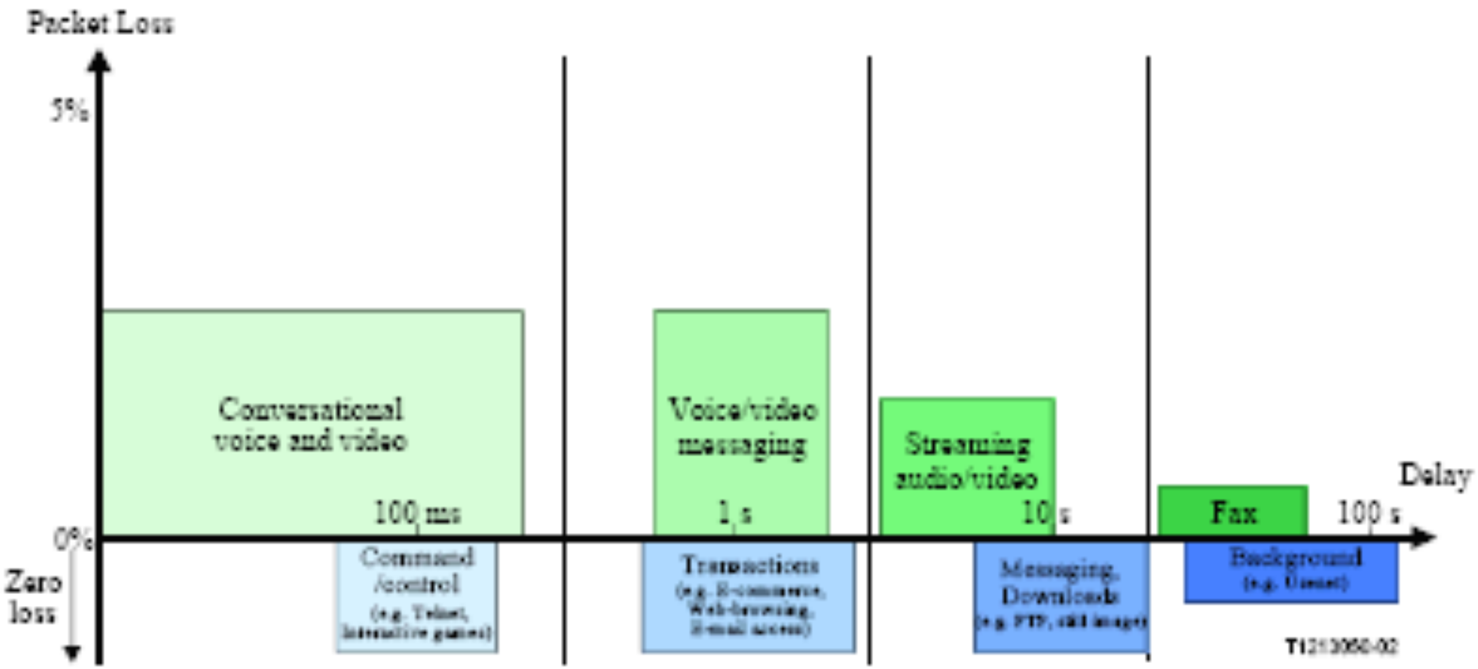
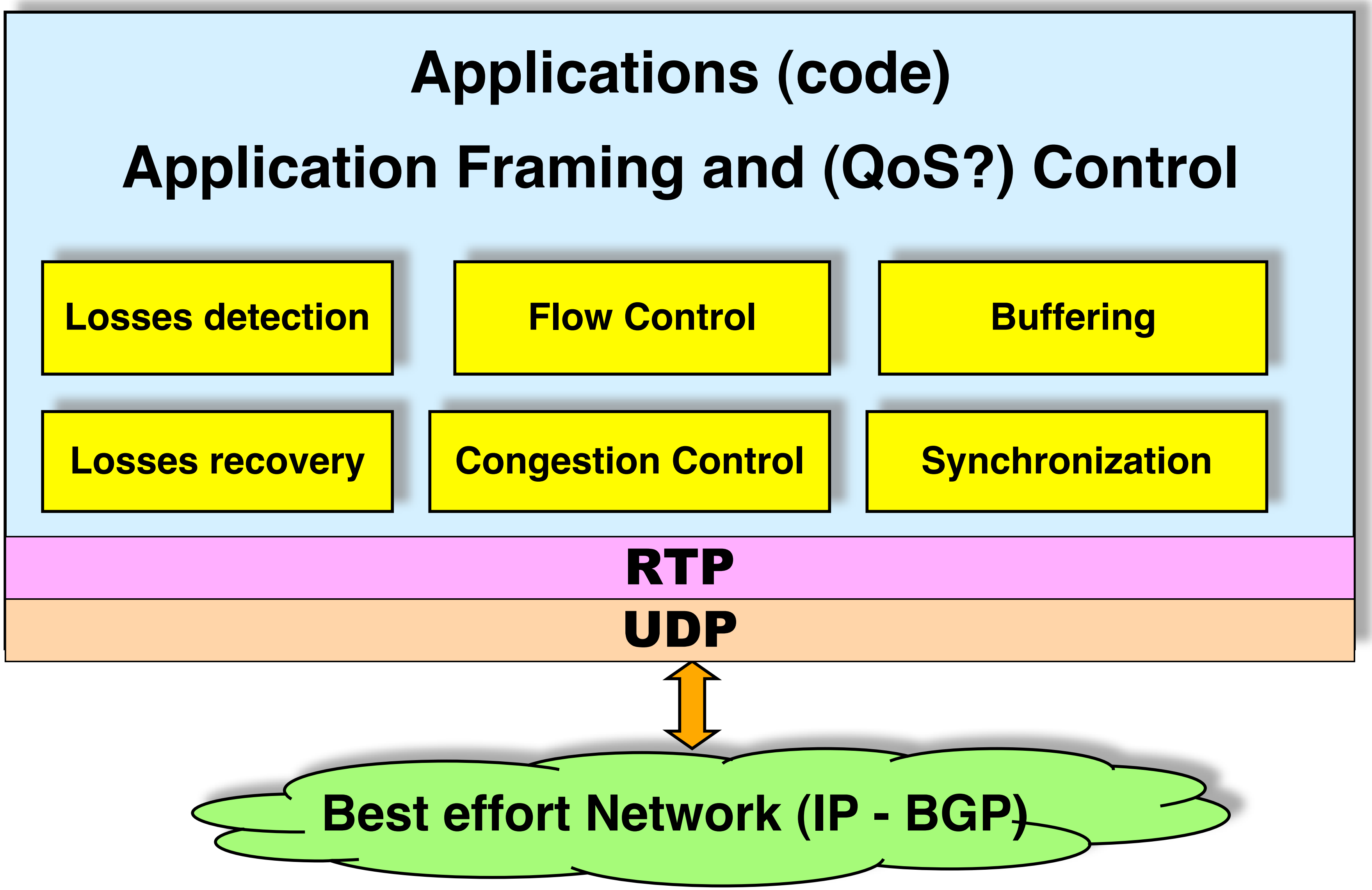


Figure 1/G.1010 – Mapping of user-centric QoS requirements

A Best-Effort MULTIMEDIA Architecture



The 3 QoS internet Approaches

1. Network Overprovisionning

2. Optimised Best-Effort mechanisms, protocols and architectures

3. New Internet Architectures to guarantee the QoS

QoS Optimisation

- **Start from Best-Effort Internet**
  - **without modifying the architecture principles**
  - **using resources/bandwidth available**
  - **analysing and improving present solutions**
- **Modify mechanisms and protocols**
  - **modify applications (adaptativity, new codecs,…)**
  - **optimise architecture (proxys,…)**
  - **define new protocols (Transport Layer: DCCP,…)**
- **But still Best-effort (No guarantee)**

QoS (hard) Guarantee

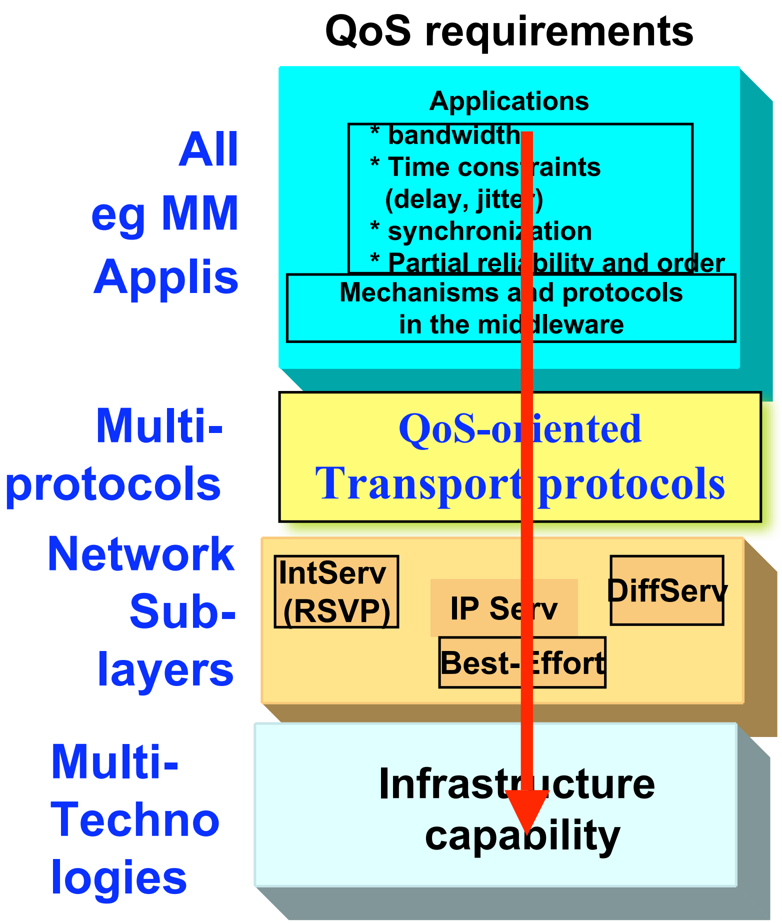
New requirements

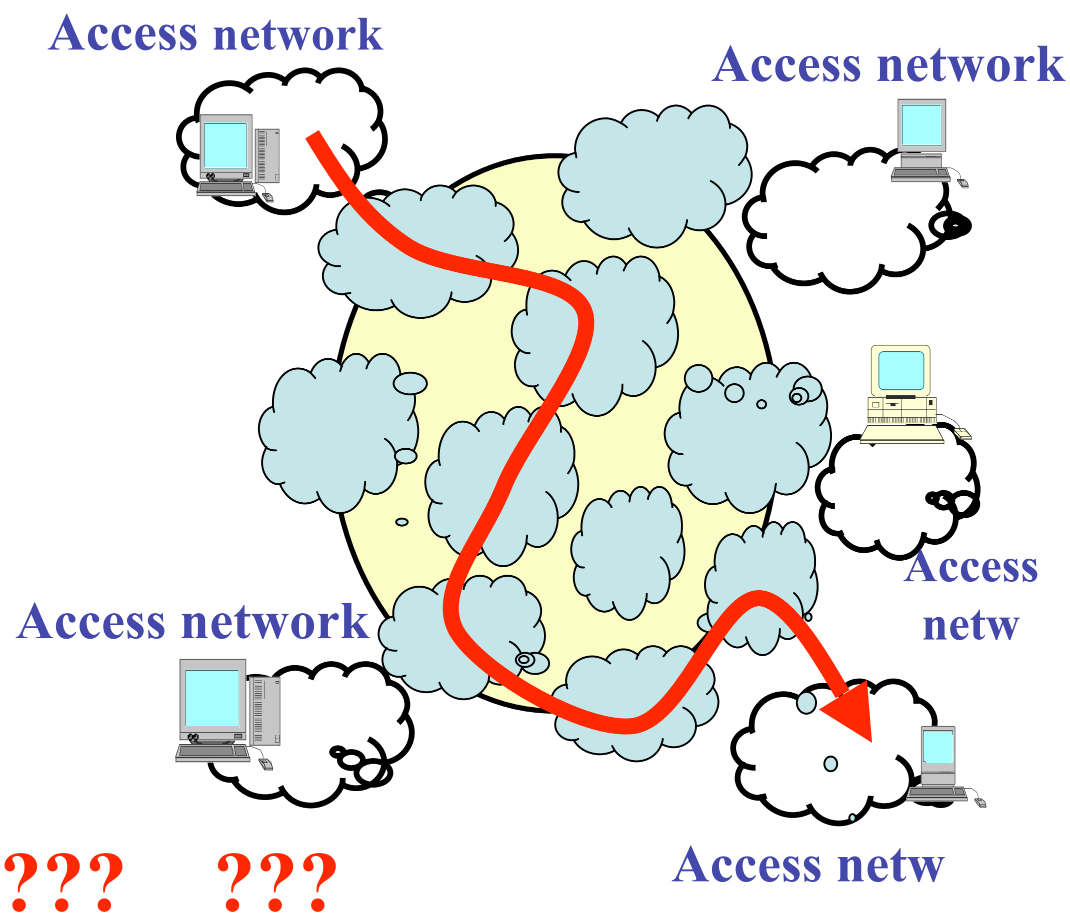
- **Master the Internet**
- **Be as General and Open as the present Internet**
- **Propose new mechanisms, protocols, architectures**
- **Handle sessions and resources**

Main problems

- **Resulting Complexity ?**
- **Difficulty of Deployment wrt the present internet ?**

Vertical (Applis-to-Networks) and Horizontal (Host-to-Host) problems





A lot of work done (for QoS)

- Many mechanisms and protocols
- Many partial architectures

But HOW to INTEGRATE

- in a globally coherent
- and easy to deploy way
- from User to User :
  - Performing mechanisms
  - Their efficient composition in needed protocols
  - ALL protocols, e.g. data and services

EuQoS : Design Meta-Rules

- **Design the complete architecture**

  Mechanisms designed isolated from global context have a low probability to lead to satisfactory solution

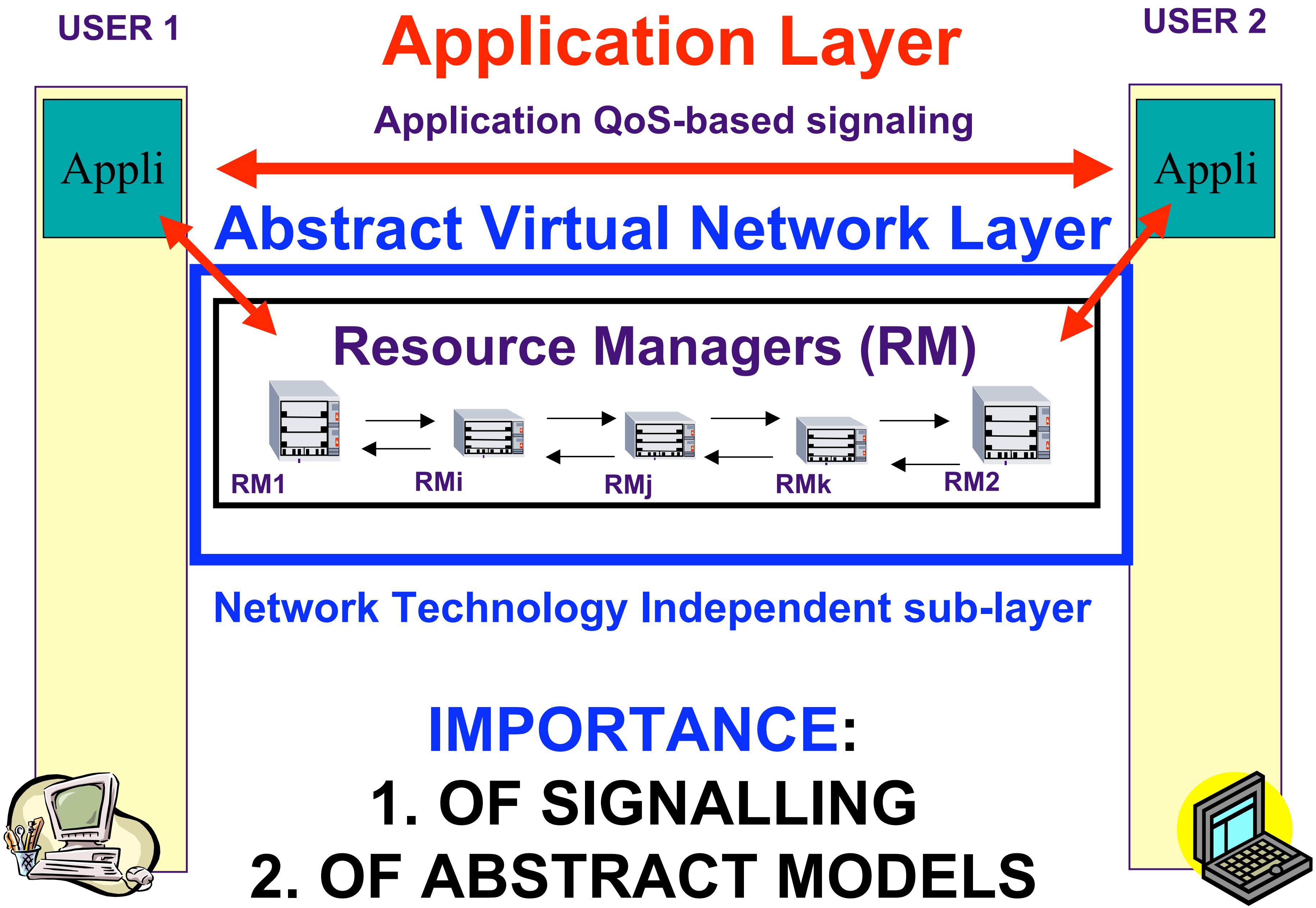
- **End2End identical solutions cannot work**

  given the complex and geographical topology, the approach must handle diversity

- **Only key Signalling/Interfaces to be defined**

  Freedom to be given to designers in each technology to develop their most efficient solutions

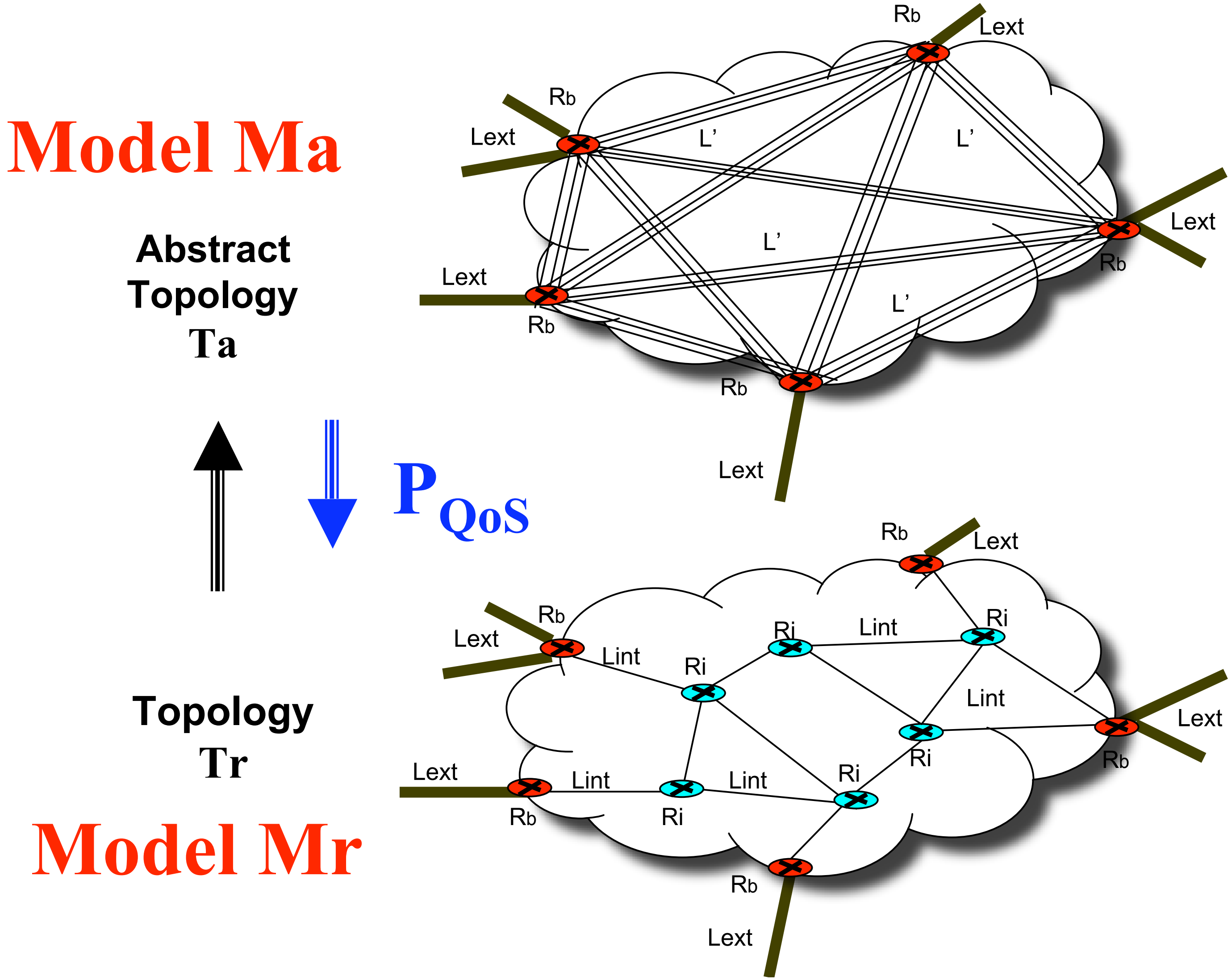
=> Virtualize and Abstract Domains

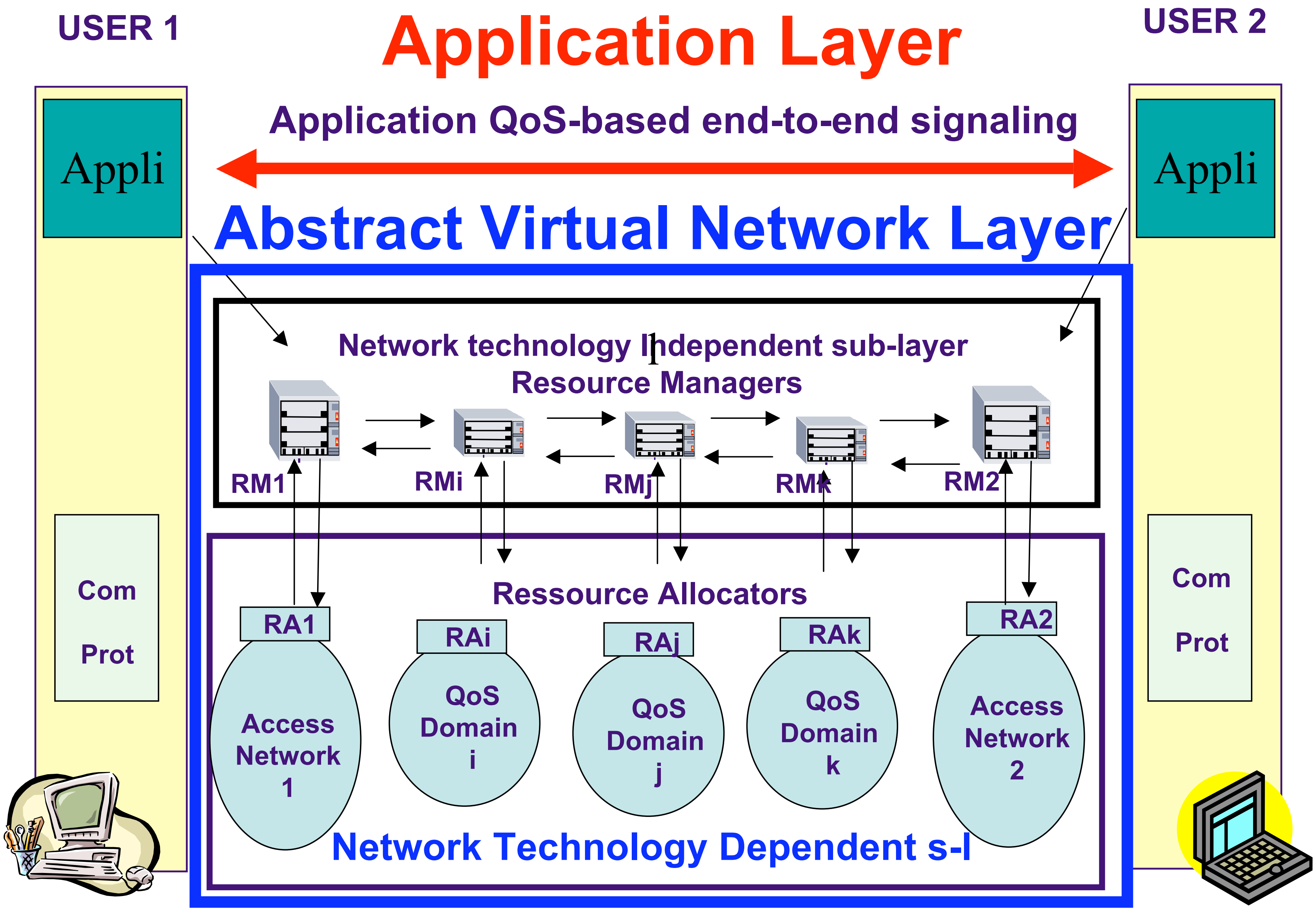

USER 1
Application Layer
USER 2
Application QoS-based signaling
Appli
Appli
Abstract Virtual Network Layer
Resource Managers (RM)
RM1
RMi
RMj
RMk
RM2
Network Technology Independent sub-layer
IMPORTANCE:
1. OF SIGNALLING
2. OF ABSTRACT MODELS

Abstract Models in RMs

Ex: F (Border Routers)

such that : P_{QoS} on Ta(Ma) => P_{QoS} on Tr(Mr)




USER 1
Application Layer
USER 2
Application QoS-based end-to-end signaling
Appli
Appli
Abstract Virtual Network Layer
Network technology Independent sub-layer
Resource Managers
RM1
RMi
RMj
RMk
RM2
Com
Prot
Com
Prot
Ressource Allocators
RA1
RAi
RAj
RAk
RA2
Access Network 1
QoS Domain i
QoS Domain j
QoS Domain k
Access Network 2
Network Technology Dependent s-l

Main Design Steps

1. Independence of :
   - Applications wrt Virtual networks wrt
   - Virtual networks wrt Technologies
   - Signaling wrt Data Plane

2. Integration of Applis with
   - QoS Invocation (Admission Control)

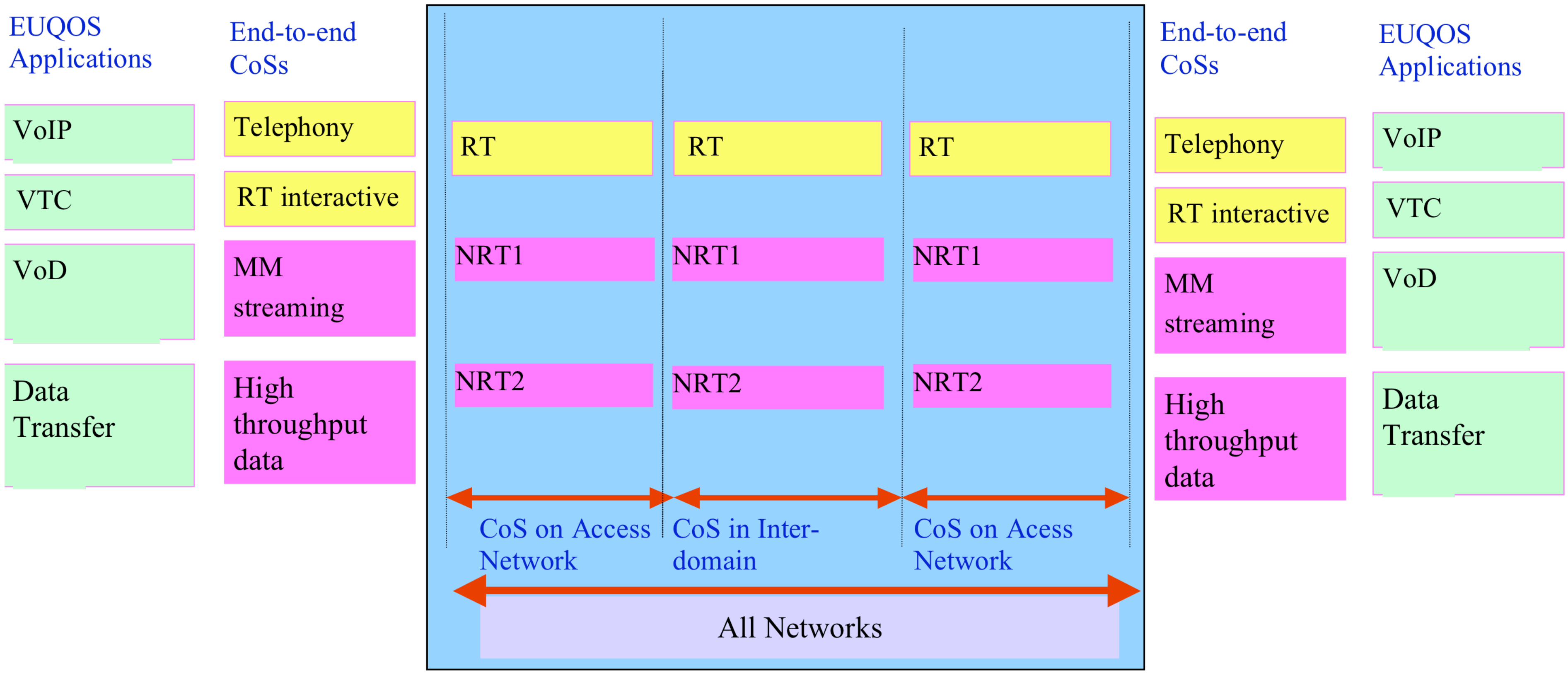
   - Defined full Architecture
   - Linked to main present solutions
   - Linked to scalability

   - QoS Network layer : CoS (Classes of Services)
   - QoS Signalling
   - QoS Transport layers

QoS Network Layer: Classes of Services

Classes of Service	EQ-CoS CoSs
RT	Maximum Bandwidth = G
NRT	Minimum Bandwidth = g
BE	No guarantee

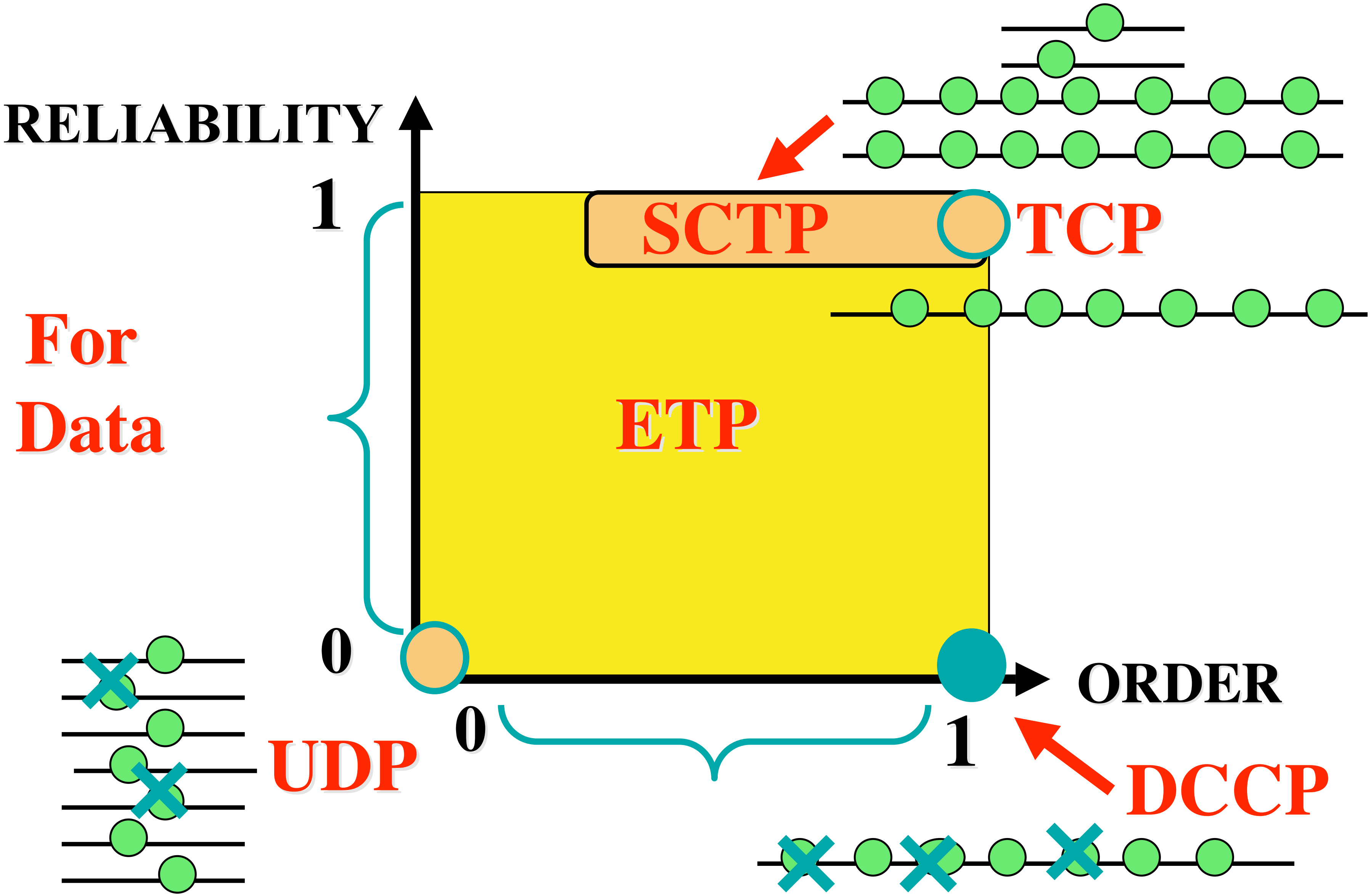
E2E CoSs – aggregated QoS and CoSs for EuQoS



QoS EuQoS SIGNALING (EQ)

- **Appli-to-Appli coding: EQ-SDP**
- **Appli-to-Appli QoS: EQ-SIP**
- **Appli-to-Virtual network : EQ-QoD**
- **Virtual Network CoS: EQ-NSIS**
- **Virtual-to-Real networks: COPS**
- **3 classes QoS Routing: EQ-BGP**
- **End-to-End path: EQ-path**
- **Telcos MPLS integration: EQ-PCE**

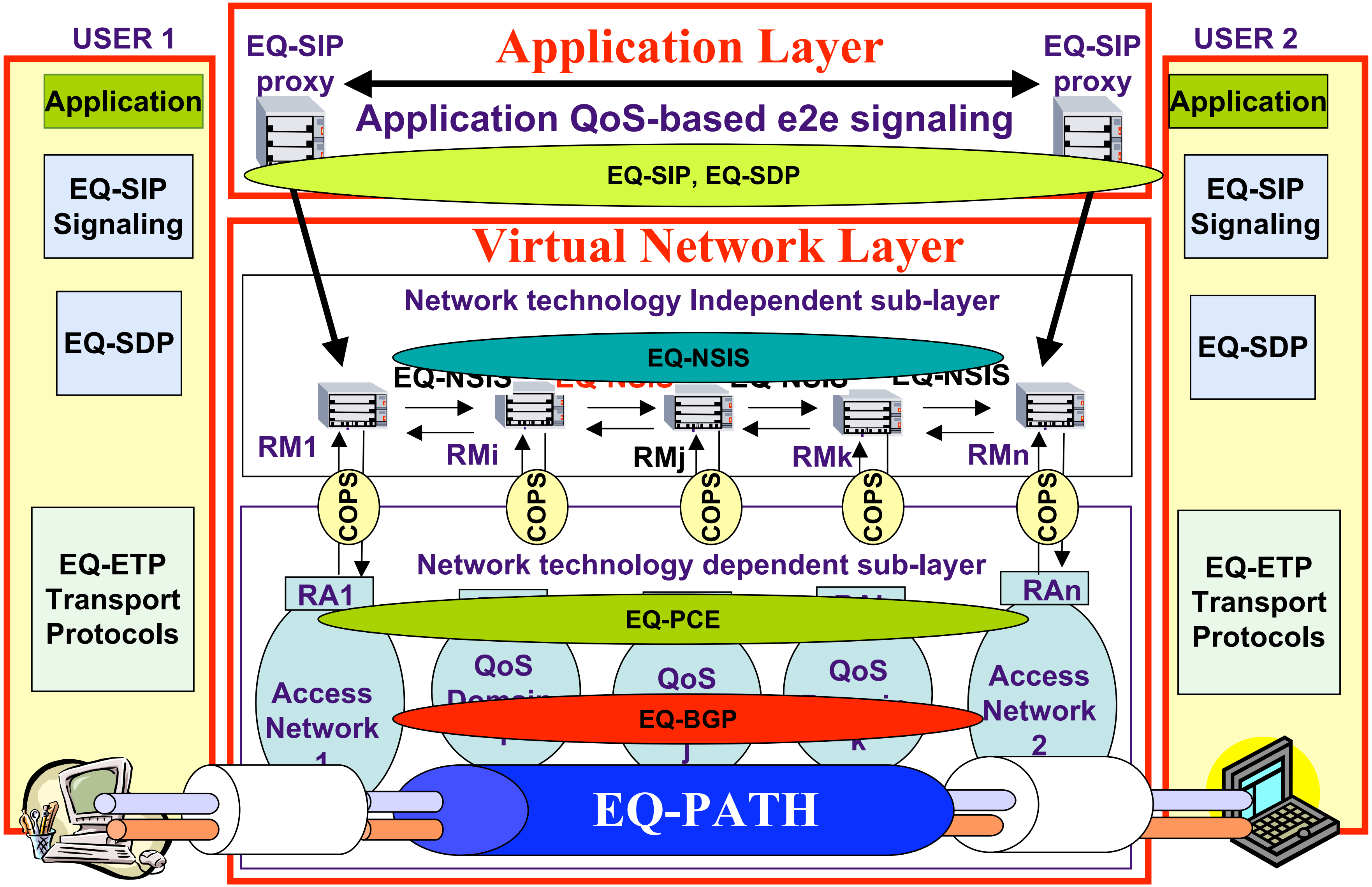
QoS Optimised Transport Layer: ETP



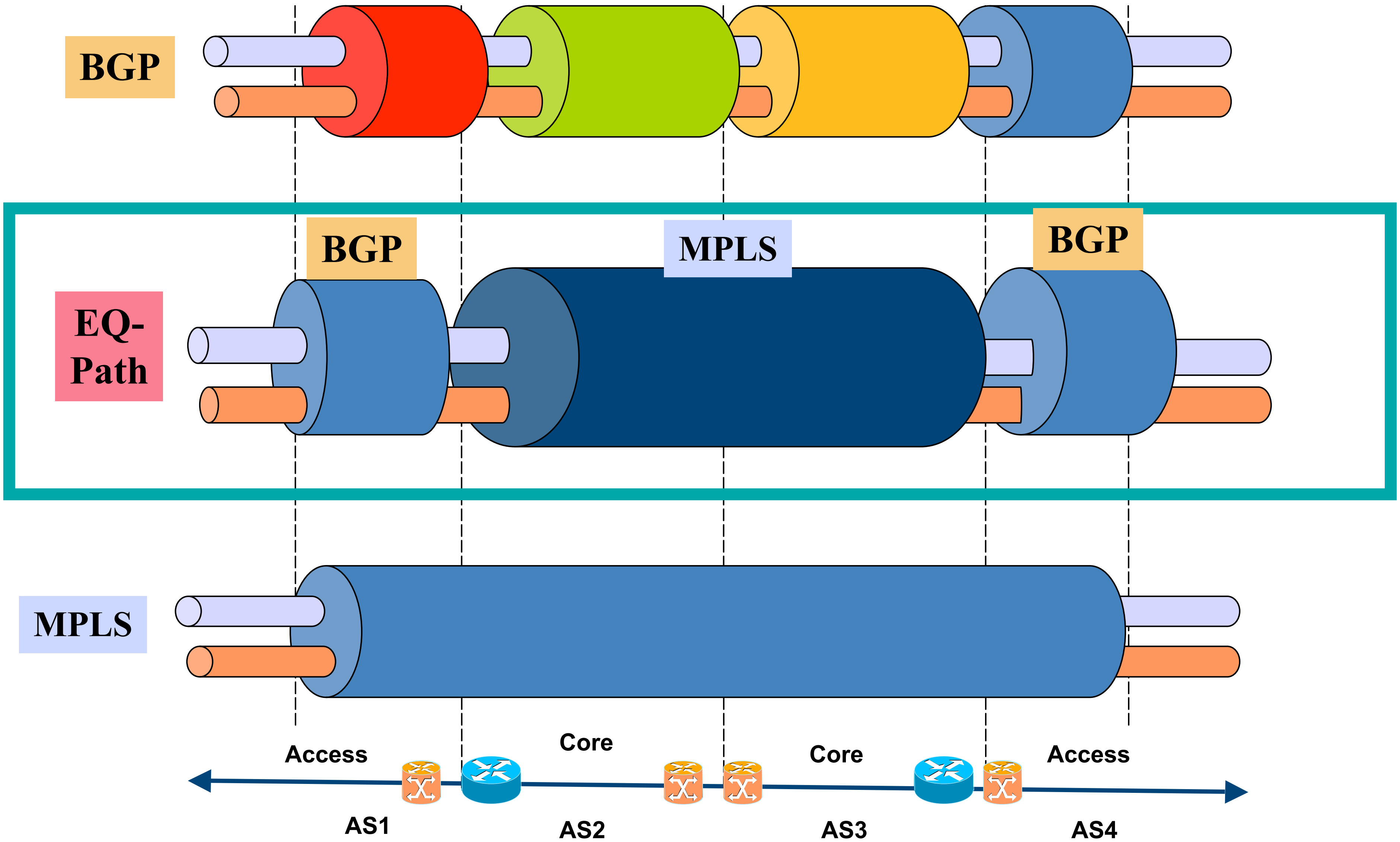
EuQoS EQ-ETP services

Application profile / Network Classes of Service	**Streams** *Error tolerant e.g. VoD*	**Non-Streams** *Error intolerant e.g. file transf*
RT	**ETP=UDP[RC]**	**ETP[EC]**
NRT	**ETP[gTFRC]**	**ETP[gTFRC+EC]**
BE	**ETP[TFRC+DT]**	**ETP[TFRC+DT+EC]**

Full EuQoS Architecture



The EQ-Path includig domains (BGP-based) and sets of domains (MPLS-PCE)



IV
CONCLUSION

The Future of Embedded systems

- Types of systems
  - From SW (timed models) to SW/HW (hybrid systems)
  - Systems of Systems
  - Mobile Systems
  - Distributed and Networked Systems
- Properties, Algorithms and Tools
  - Quantitative analysis
    - Schedulability analysis, consumption
  - High level constructs integrating formal models
  - Scalability: Managing Combinatorial Explosion
    - Compositional verification
    - Parallel model-checking
    - Abstractions (e.g. preserving properties), etc

The Future of Internet systems

- **Full mobility**
- **Network of the future (e.g. GENI, FIRE)**
- **Internet Virtualisation**
  - **Virtualised routers able to run in parallel a set of different protocols**
- **Application-aware networking**
- **Sensor networks and ad-hoc networks**
- **Internet of the Things**
  - **=> importance of the sensor & things (values, etc)**
- **Real-Time internet**

Integration

To Go from Embedded system

to a (given) sub-set of the Future Internet

- **Include some Sensors and Things, with mobility**
- **Define Real-Time protocols from Applications**

- **Integrate Multilayering and Composability**
- **Develop Easily Verifiable Methodology**

(Extending adequate methods and tools)

MERCI