Modelling & Control of Large Scale Telecommunication Networks

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LAAS & QoS Design

Research at LAAS-CNRS

Research in this domain
started at LAAS-CNRS in 1978

Researchers :

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PhD Students :

JM. Enjalbert, *C. Bockstal, O. Brun,* F. Camps, D. Gauchard, *A. Rachdi*, S. Richard, C. Fortuny, *Z. Benhamouda*, I. Bonatti ...

Collaborations :

UC Berkeley, Univ. Campinas, TCD Dublin, CWI, ISIMA, INRIA, CNET, FT, ATT, BT, SFR, EADS, Vodafone, Alcatel, Ericsson, Samsung ... + ANR, Esprit, Eureka projects

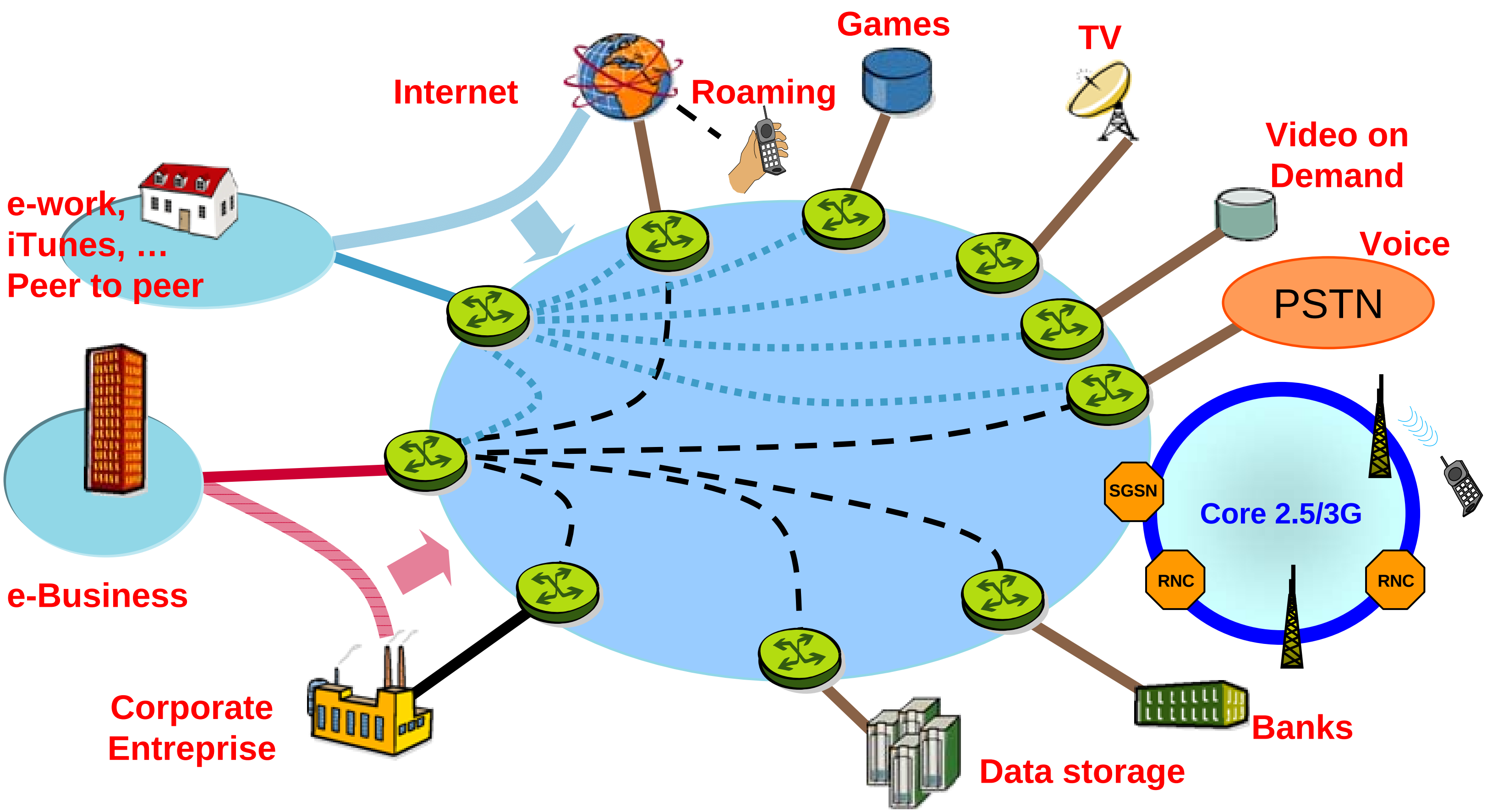
Networks :
Complex Systems to be Controlled

Operators of Telecommunication Networks try to accommodate emerging technologies, new products & Services, whilst retaining :

- Quality of Service
- CAPEX and OPEX Savings

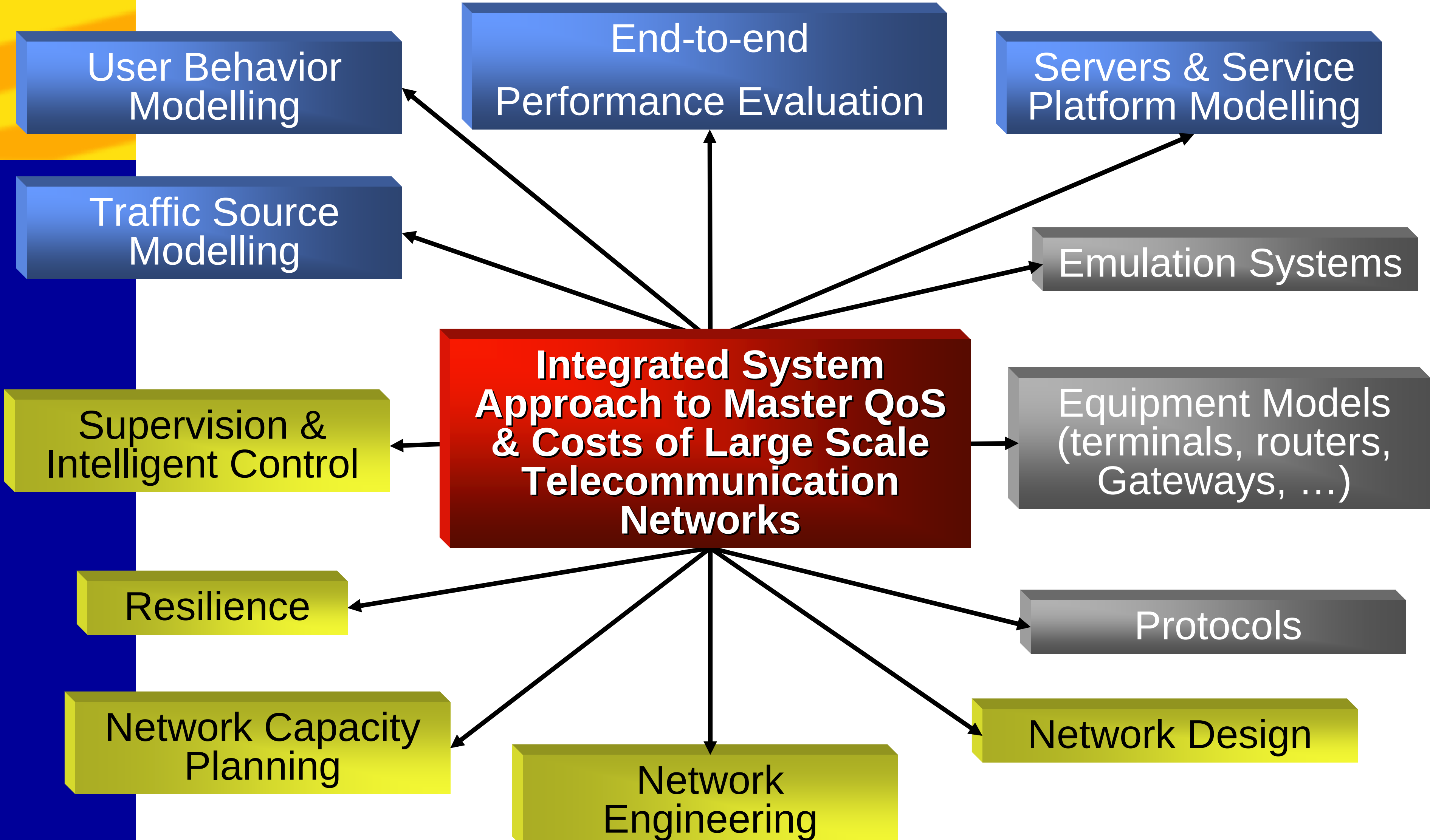
in a Controlled Fashion

Networks are Complex Systems difficult to Control



Heterogeneous technologies & Protocols, complex applications & traffic patterns, size of the system (topology and flows) make the challenge difficult from a theoritical and technical point of view.

Integrated System Approach



End-To-End Performance Evaluation

The Modelling Challenge

Complex Stochastic Processes →

- Even with Poisson input assumptions, traffic do not remain Poisson in the system
- Build approximations preserving accuracy
- Conceive a simulation paradigm :
  - suitable for (quasi) real time optimisation
  - Scalable for very large scale systems (number nodes, links and flows)

Possible Modelling Approaches

Network Models

Analytical Models
Discrete Event Models
Hybrid Models

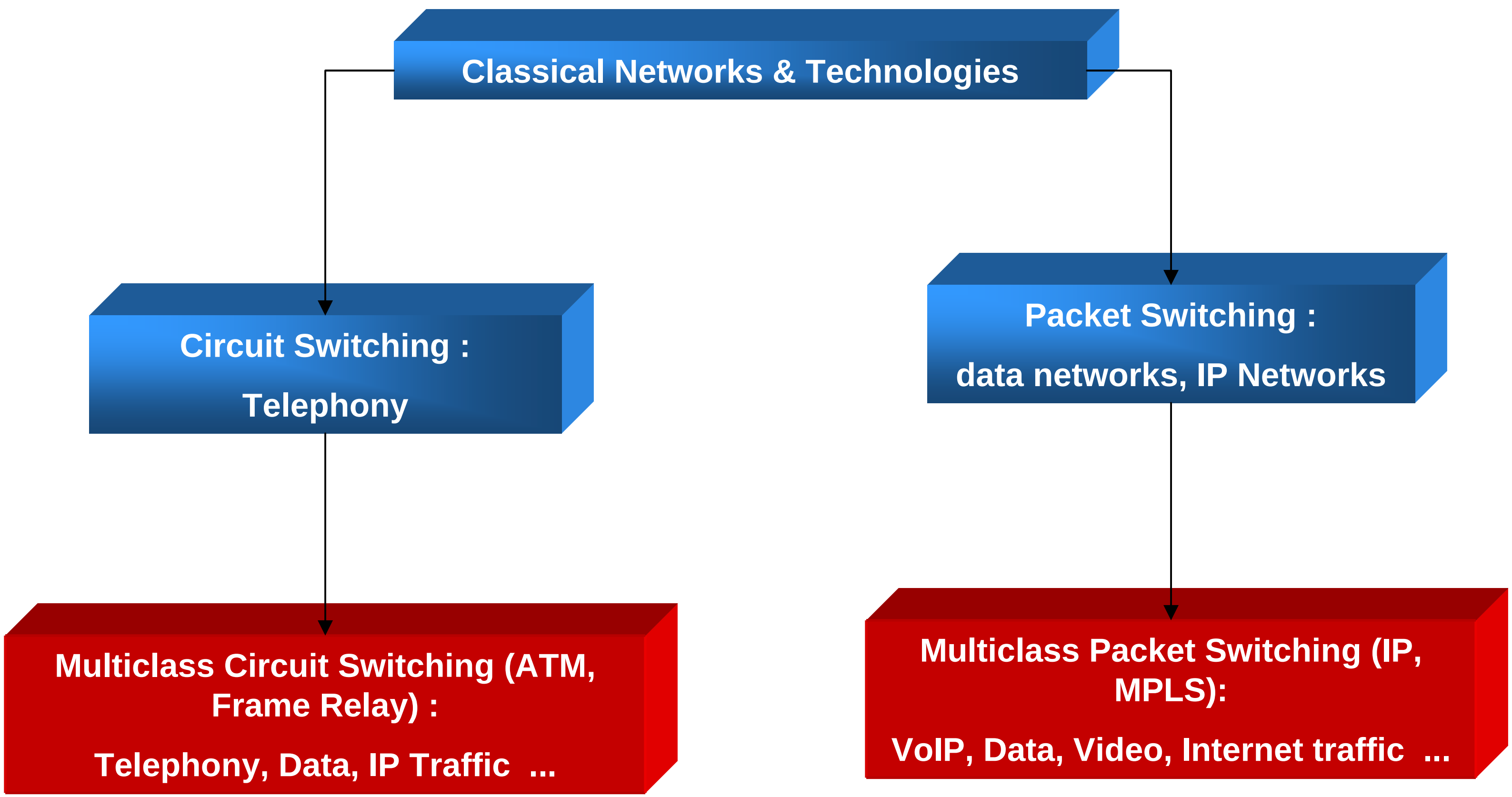
Discrete Event : general approach, « microscopic » modelling, precise but…
--> prohibitive computation times (nb of events)
--> not suitable for optimisation

Analytic : probability distributions, precise, fast computation times, but…

--> not able to model any process

Hybrid : the key solution for modelling large scale complex networks.

End-to-End Performance Evaluation: Convergence of Two Worlds



Traffic Differential Modelling

- Exact equations solved by means of approximations:

$$\frac{dN(t)}{dt} = \sum_{n(t)} n(t) \frac{dP[n(t)]}{dt} = IR(t) - OR(t)$$

Functions I and OR are non-linear and may depend on:

λ_{ji} : arrival rate of flow j on resource i

μ_{ji} : service rate for flow j at resource i

Ga : arrival distribution

Gs : service distribution

P : queue parameters

R : routing of flows

S : packet scheduling and buffer management policies

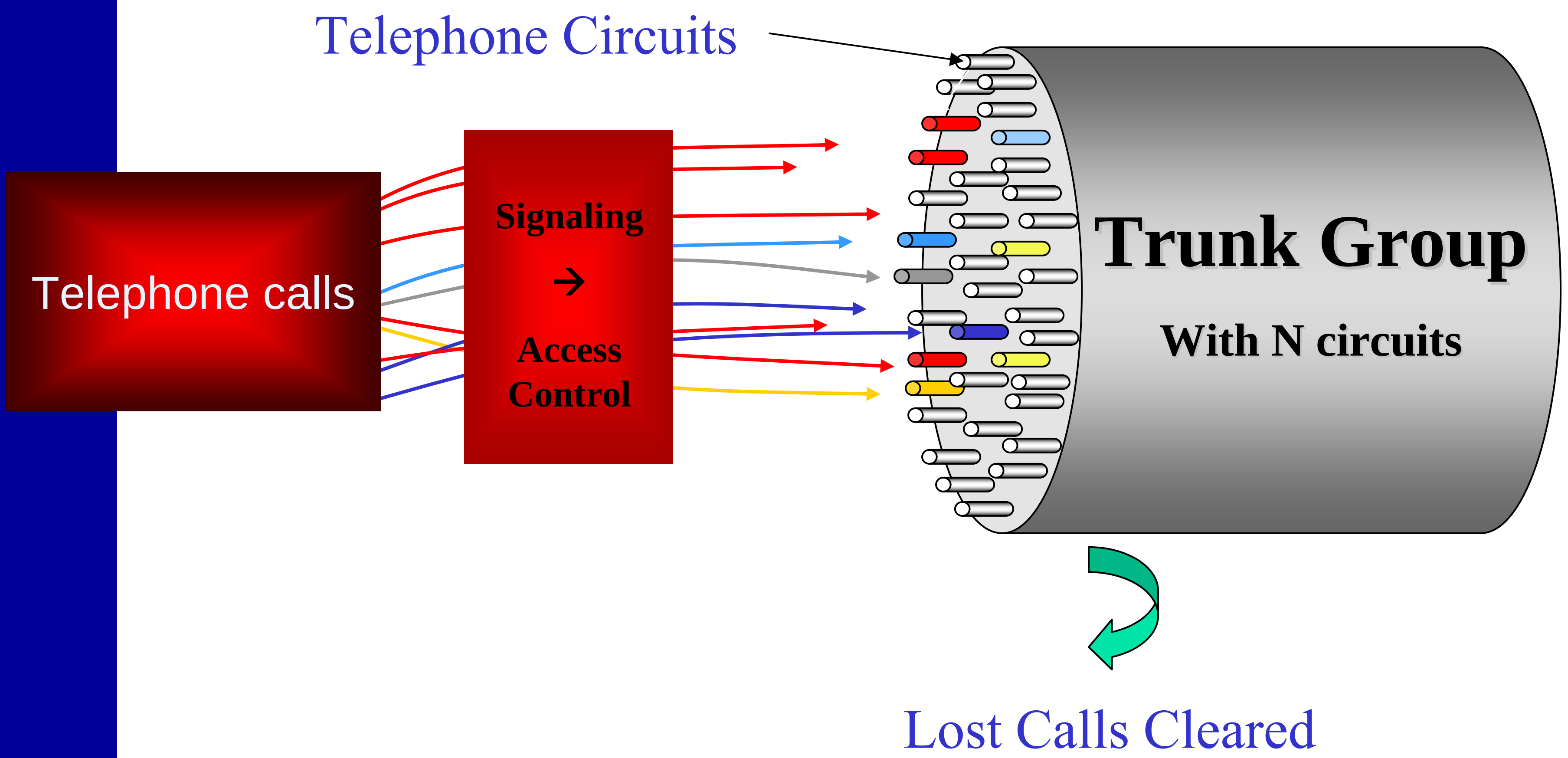
- Global Dynamic coupling of flow equations in a network:

$dX_i/dt = F_i\ (X_i(t)\ ,\ \mathbf{X_k(t)},\ \ldots)$ ou $dX_i/dt = F_i\ (X_i(t)\ ,\ \mathbf{X\ (t-\tau)},\ \ldots)$

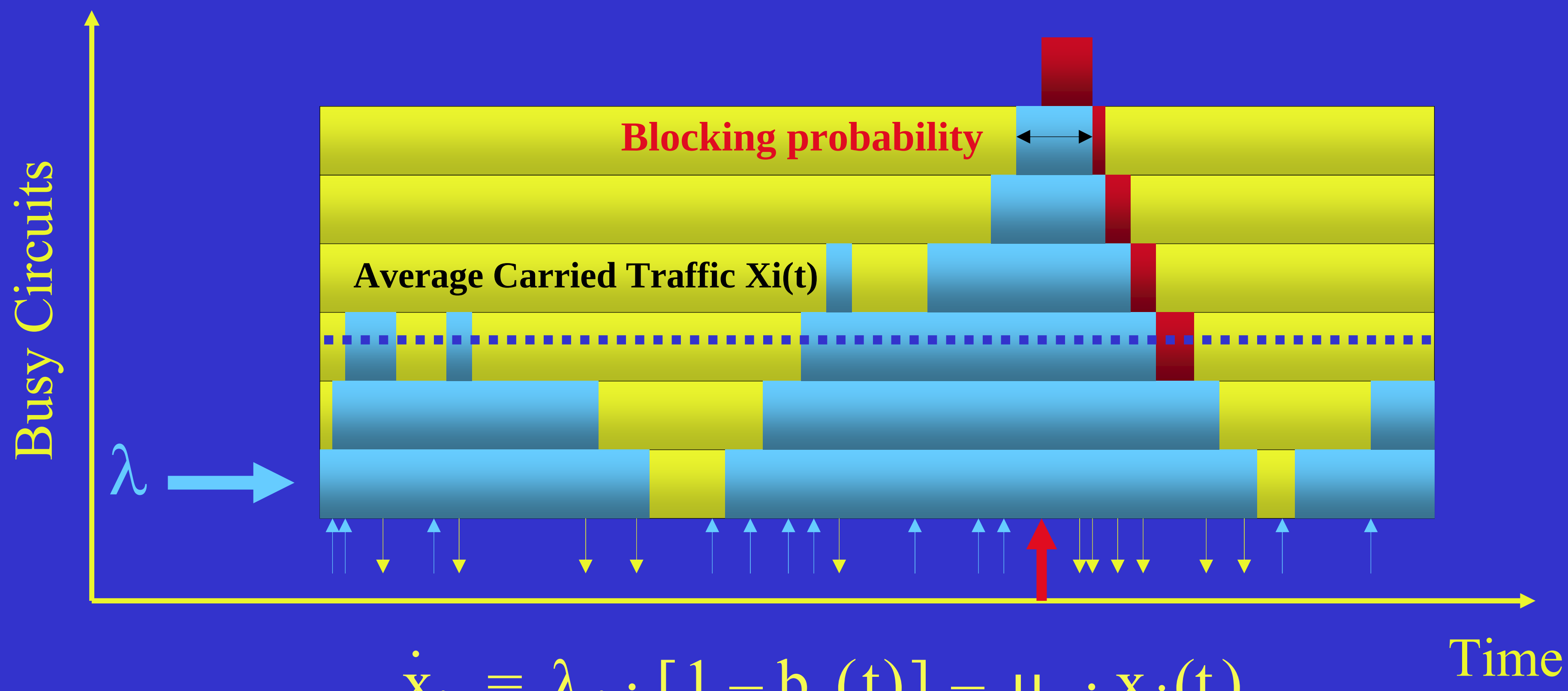
Cicuit Switching

The basic Erlang B Model

Poisson Arrivals and Exponential Holding Times



Circuit Switching in Telephony

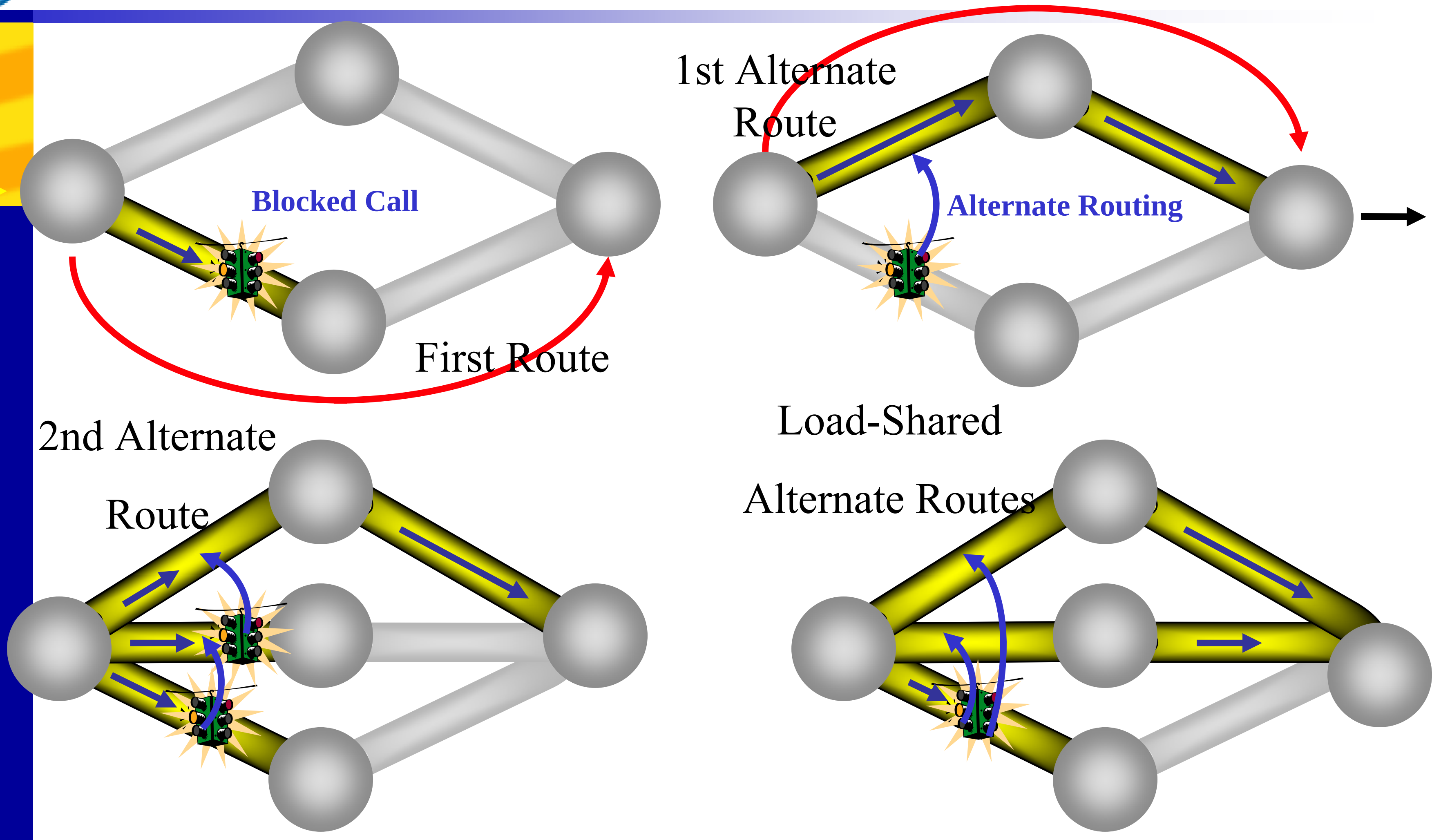


$$\dot{x}_i = \lambda_i \cdot [1 - b(t)] - \mu \cdot x_i(t)$$

- Call arrival
- Call departure
- Call blocked and cleared

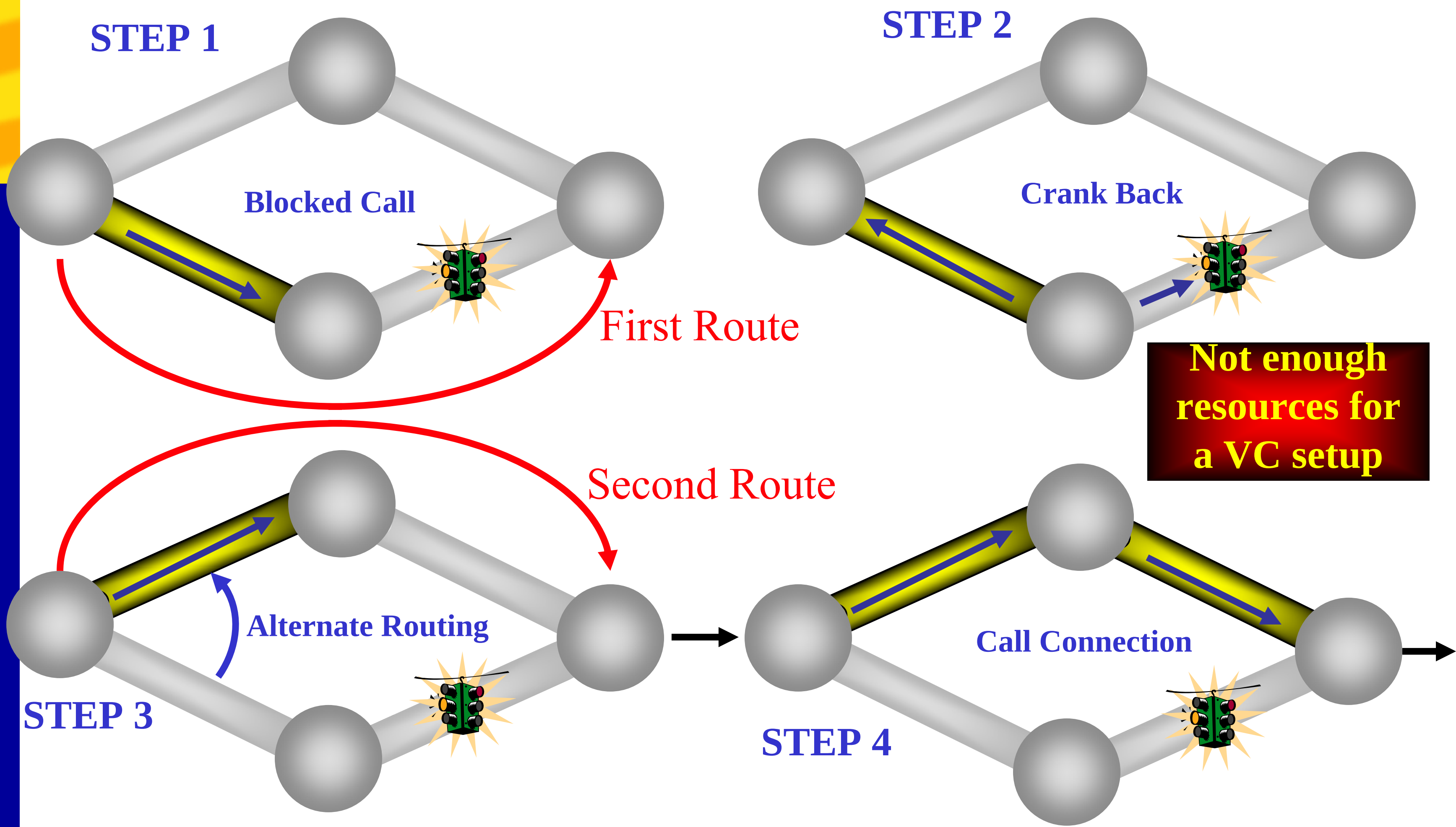
- State of the trunk
- State if the blocked call would have been carried

Alternate Routing



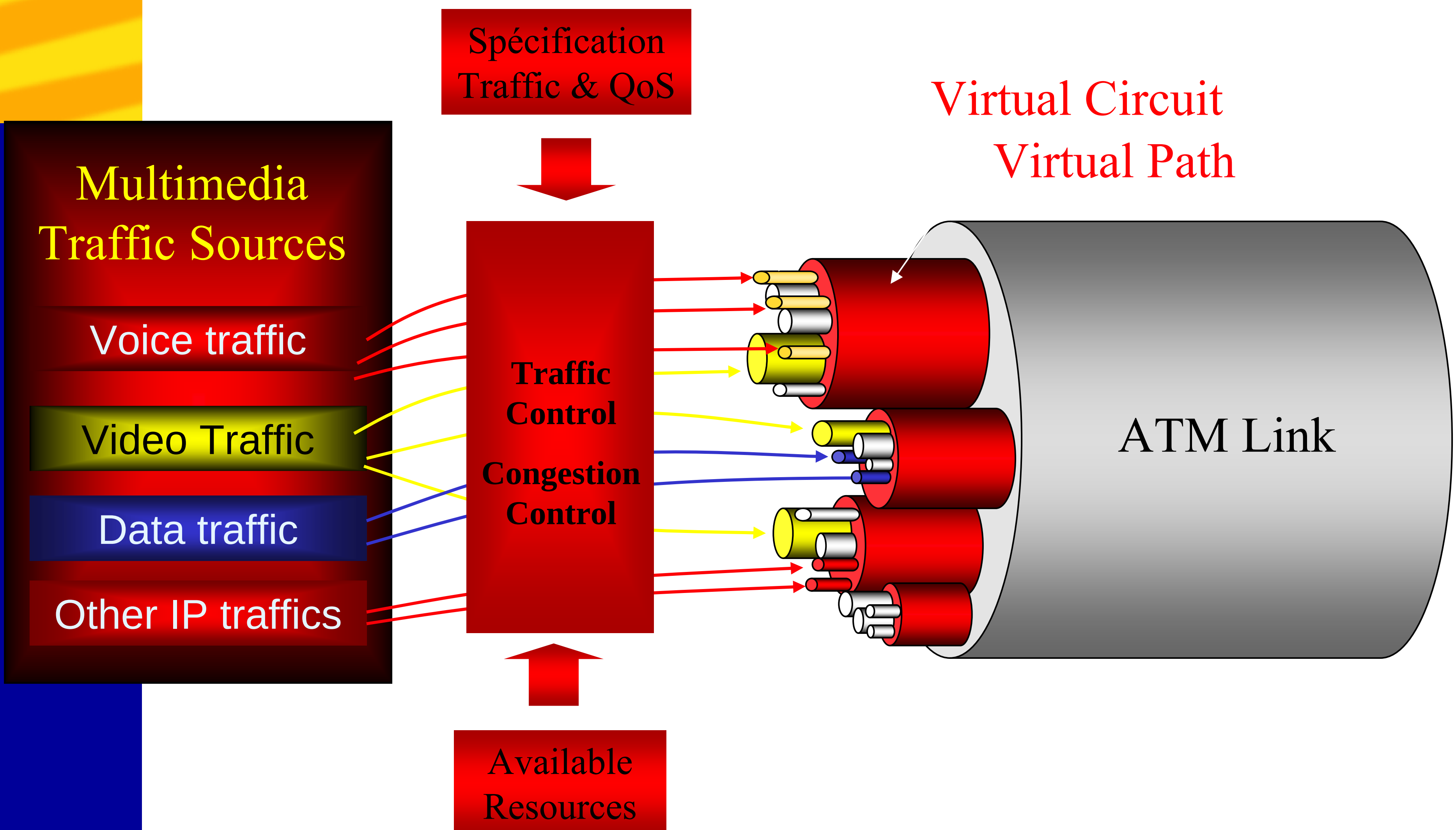
New Generalised Erlang-B Formula for alternate routing policies

Crank Back Routing

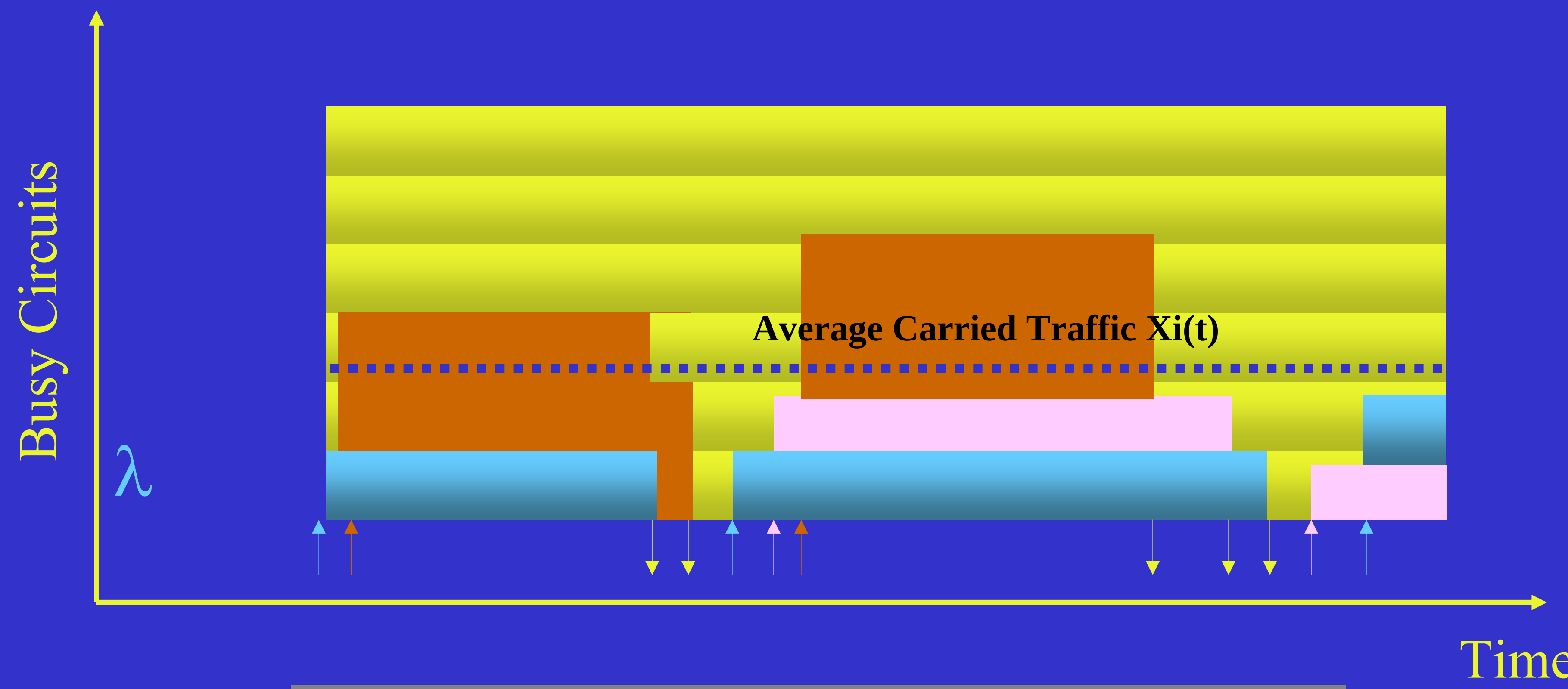


Approximation of crank-back blocking is done via a mixed approach combining an Equivalent Trunk & differential model.

Multiclass Circuit System : Example of ATM links

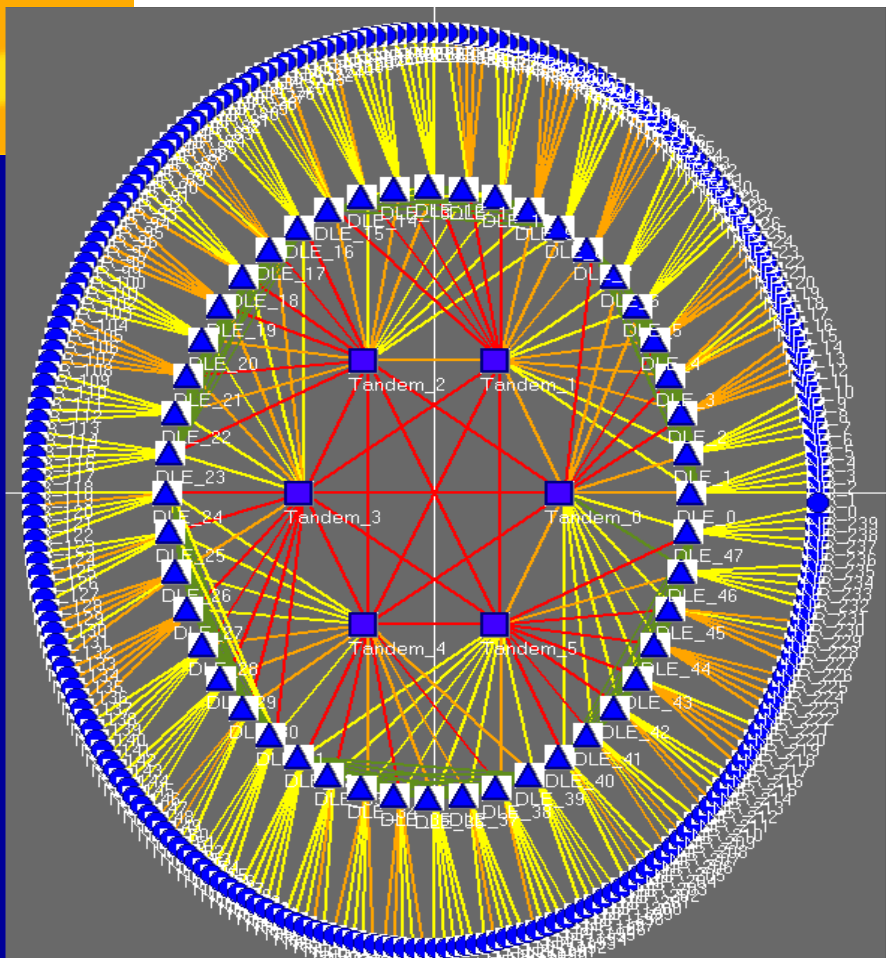


Multiclass Circuit Switching



$$\dot{x}_i = \lambda_i \cdot [1 - b_i(t)] - \mu_i \cdot x_i(t)$$

Telecommunication Networks are very Large Scale Systems



Typical Topology of a hierarchical network

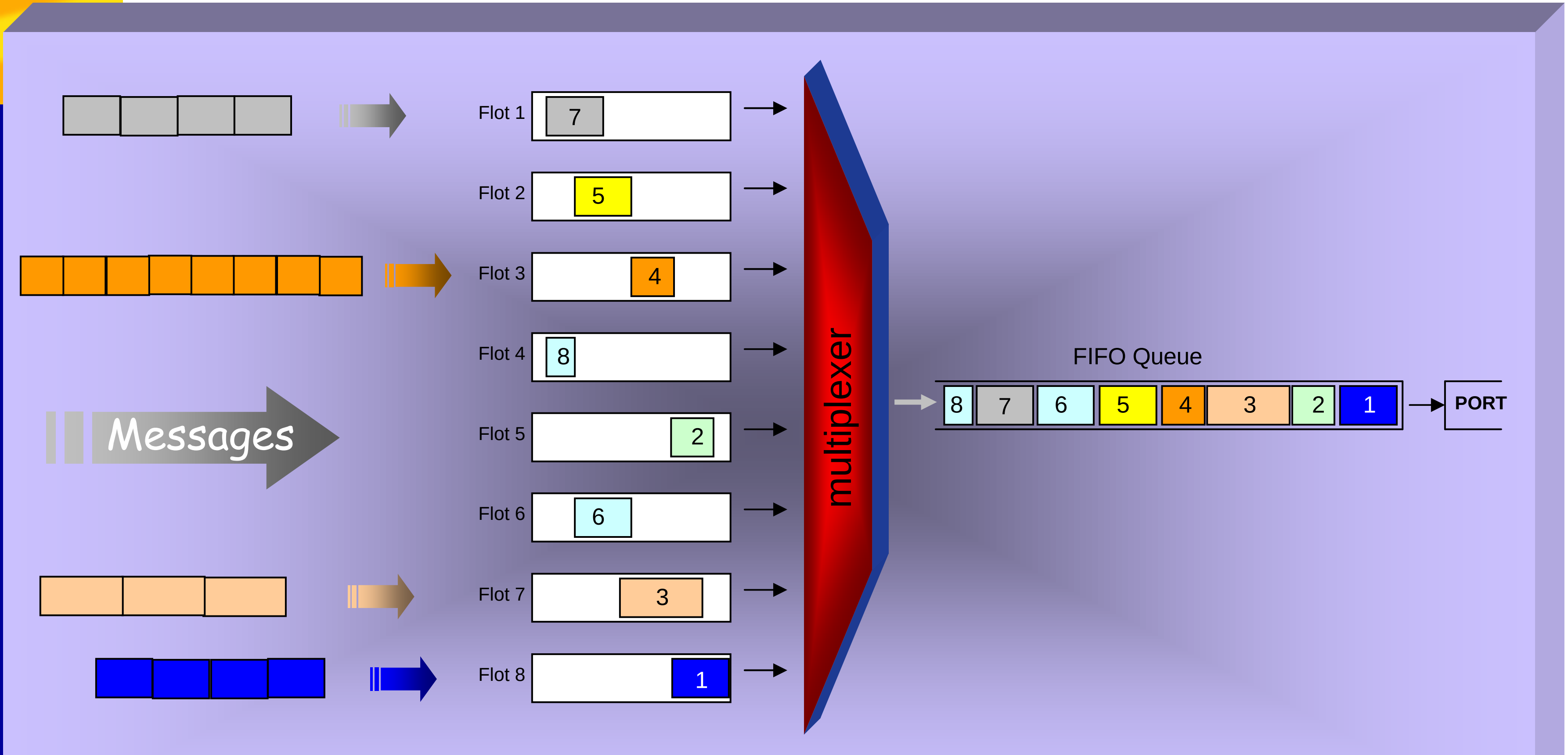
Differential models are implemented in the Software NEST (QOS DESIGN).

NEST is used in the real time planning tool of the whole BT telephone Network

- Differential system of equation is built and then solved for millions of equations :
  - >> 1 million flows,
  - >> 40.000 links,
  - >> 18.000 nodes.
- Computation kernel is Parallelised on a SUN cluster (Message passing & Multithreading)

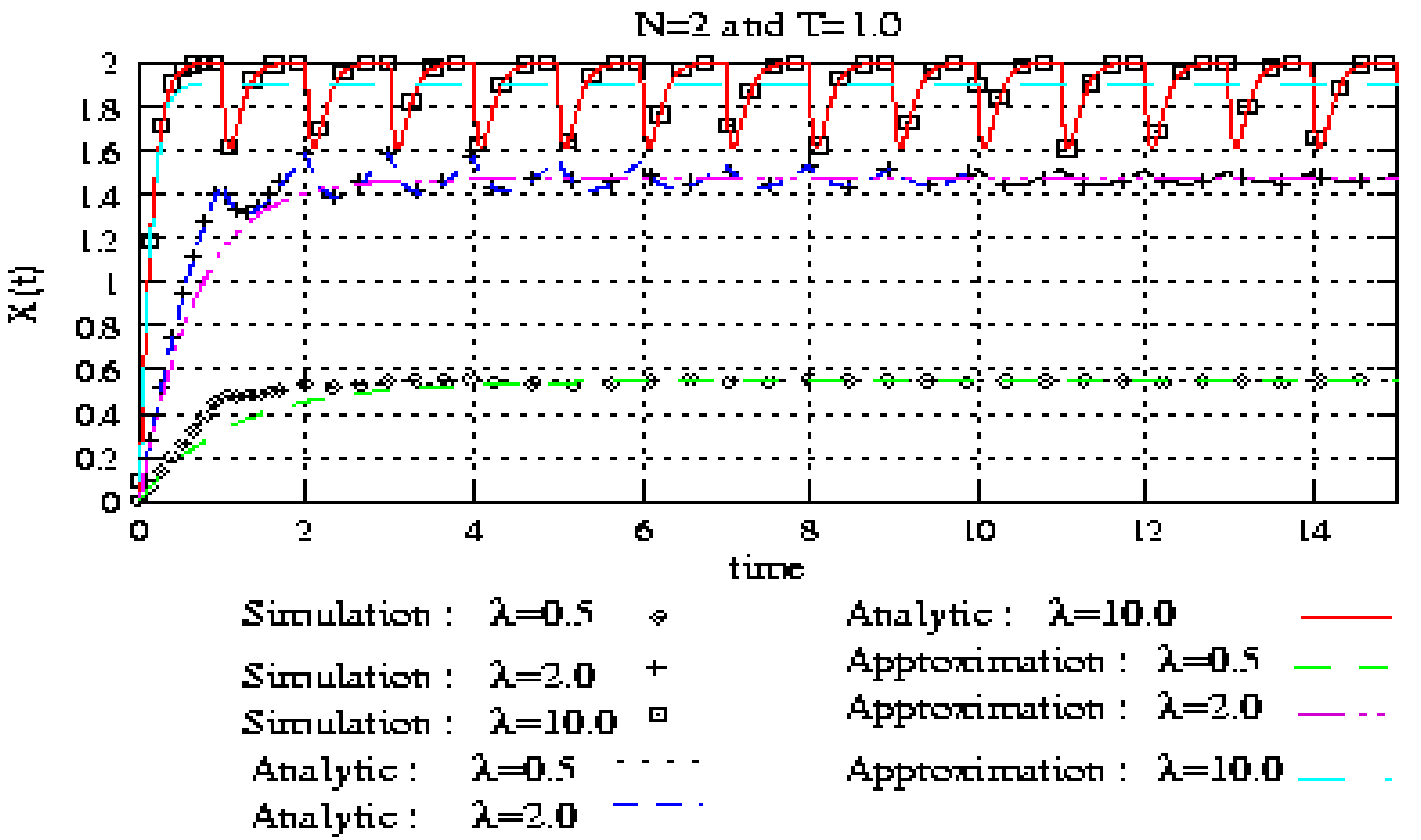
Packet Switching

A simple FIFO Queue

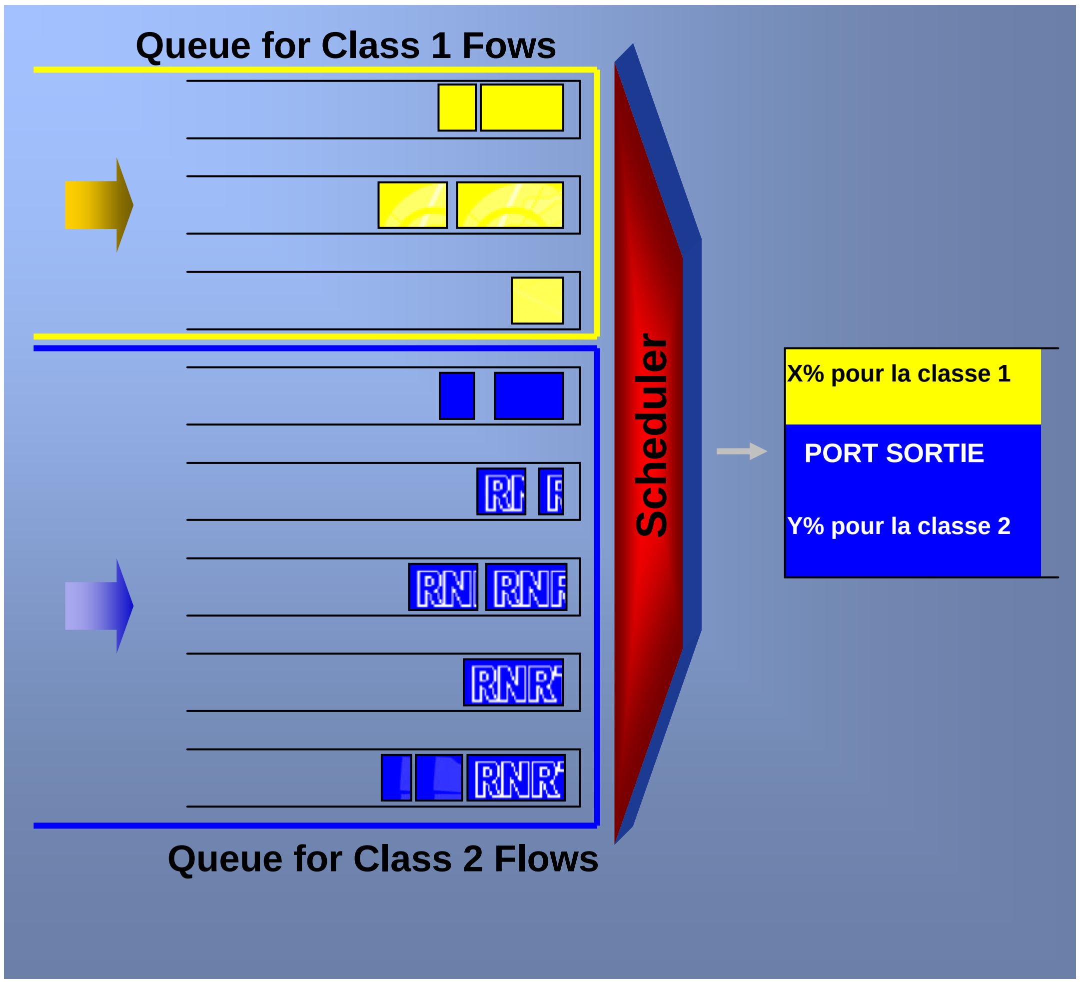


Packet Multiplexing in a single fifo queue

New Theoretical Results for transient M/D/1/N (t) queues
Exact – Simulation - Approximations



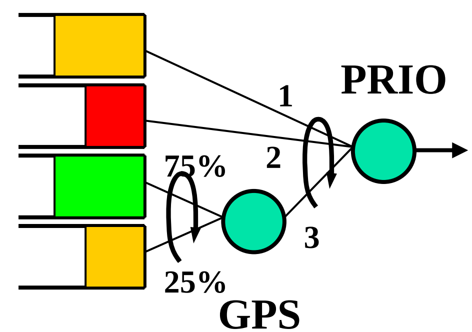
Packet scheduling with « Fair Queueing » (CBFQ) and Priority Queueing



$M^k/G/1/\infty$ GPS + Prio

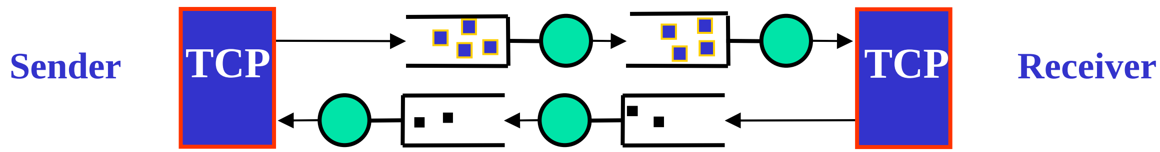
multi-flot, multi-file à ordonnancement :

- GPS (partage équitable pondéré)
- Priorité



Differential Modelling of TCP Connexions

> 90% of Internet Data Traffic (www, mail) is without transmission errors



Acknowledge Receipt (ACK)

3 Basics steps in the TCP Automata :

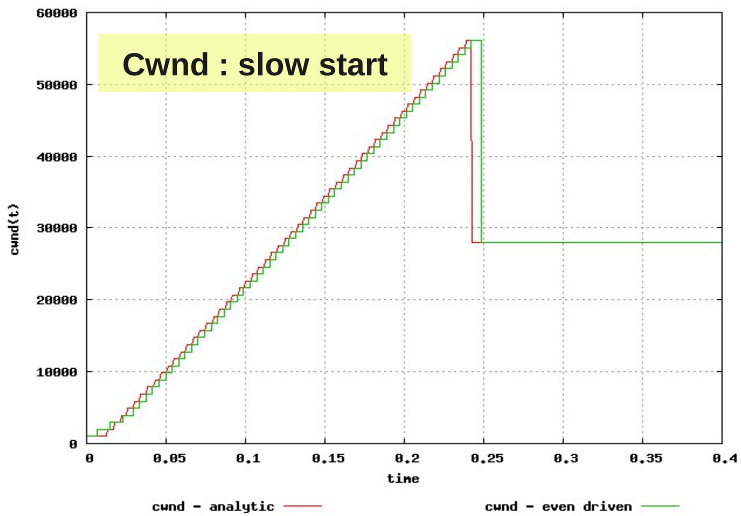
- *Slow-Start* (Bandwidth Discovery)
- *Congestion Avoidance* (Steady State Behavior)
- *Retransmission* of lost packets

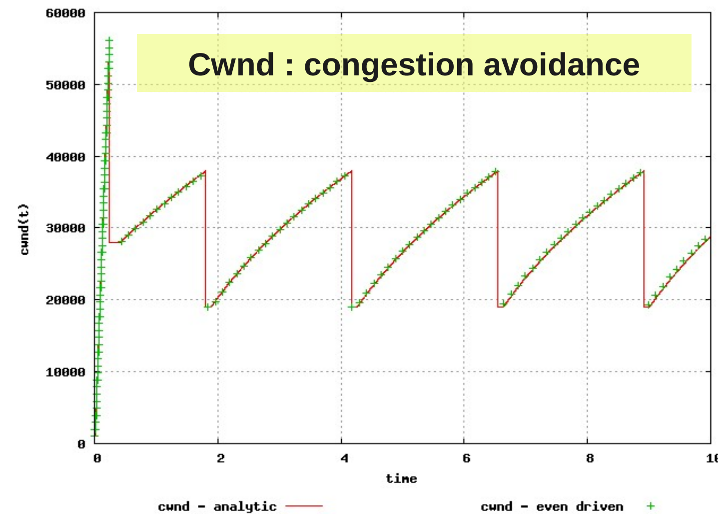
Several Algorithms are used in the Internet :

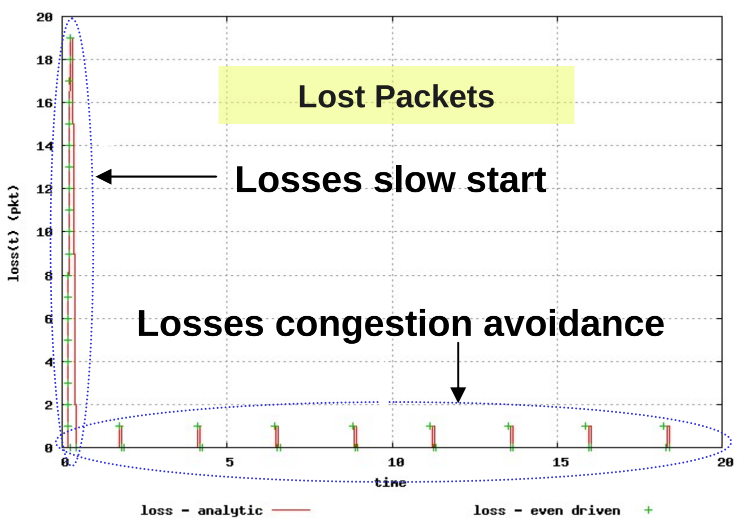
- *Reno*
- *NewReno*
- *SACK*

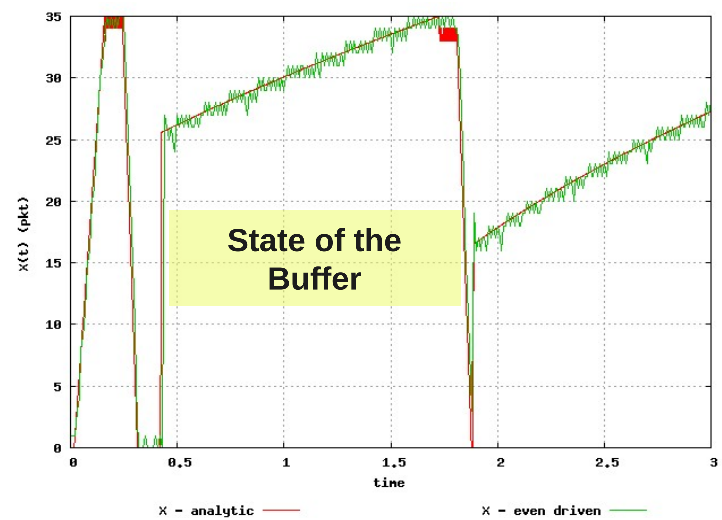
Real TCP / Differential TCP (New Reno)

Transient









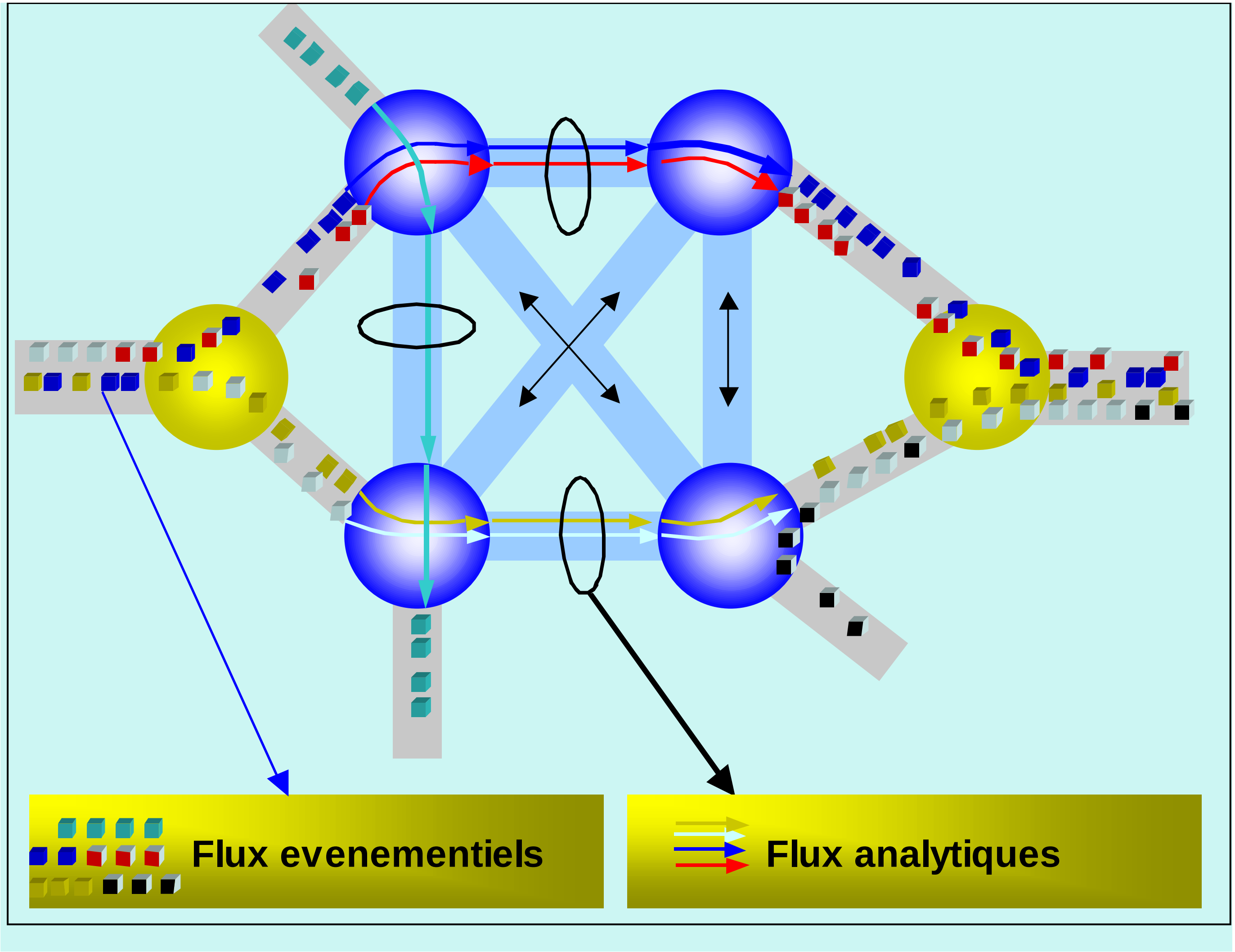
The Hybrid Concept

- The same simulation kernel enables :
  - a complete analytical simulation,
  - a complete discrete event simulation,
  - or any combination of hybrid solution.

- The software generates automatically all equations (differential equations) associated to all flows on all resources of the network.

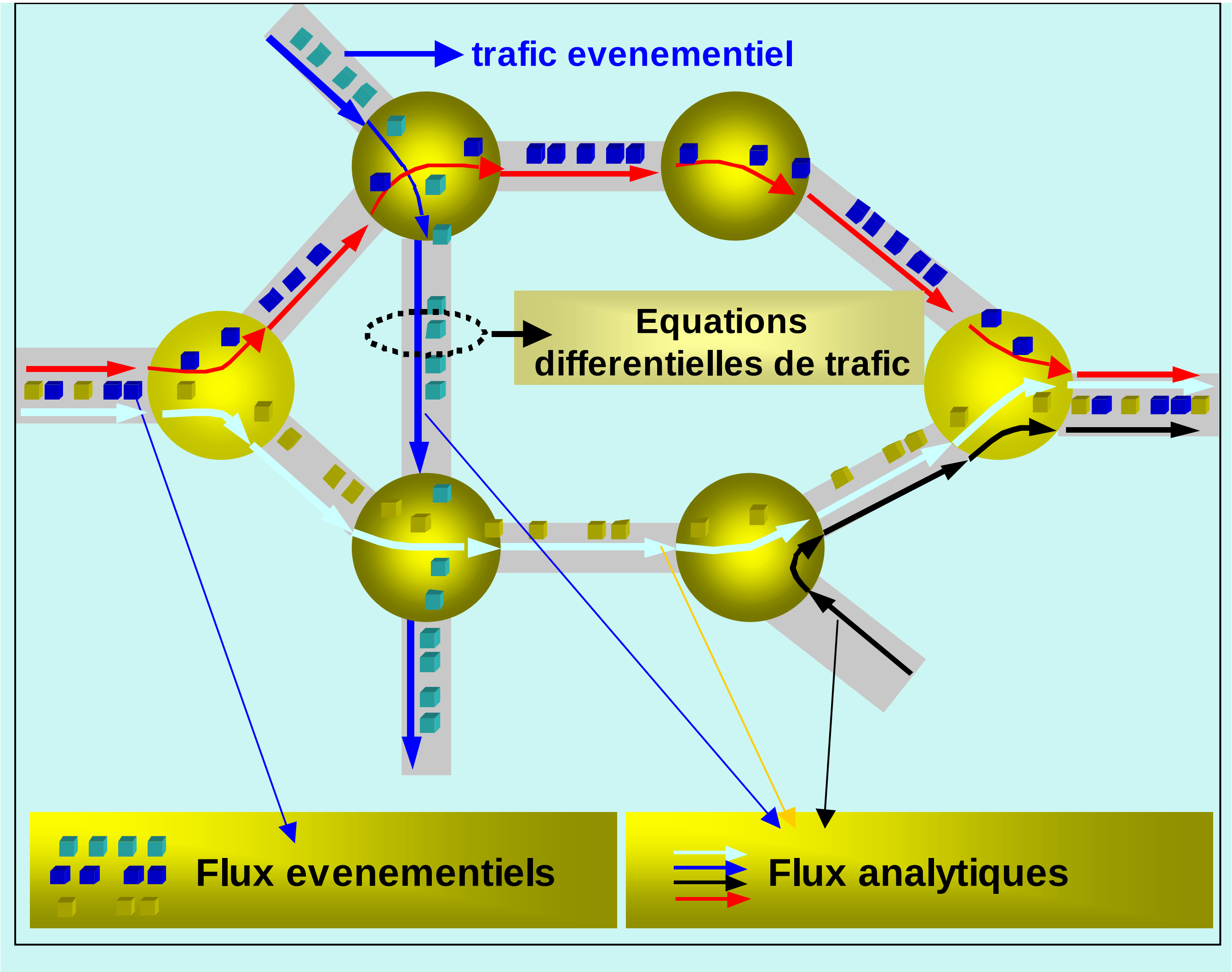
- Two Hybrid Principles:
  - Hybrid Interconnection
  - Hybrid Superposition

Hybrid Interconnections



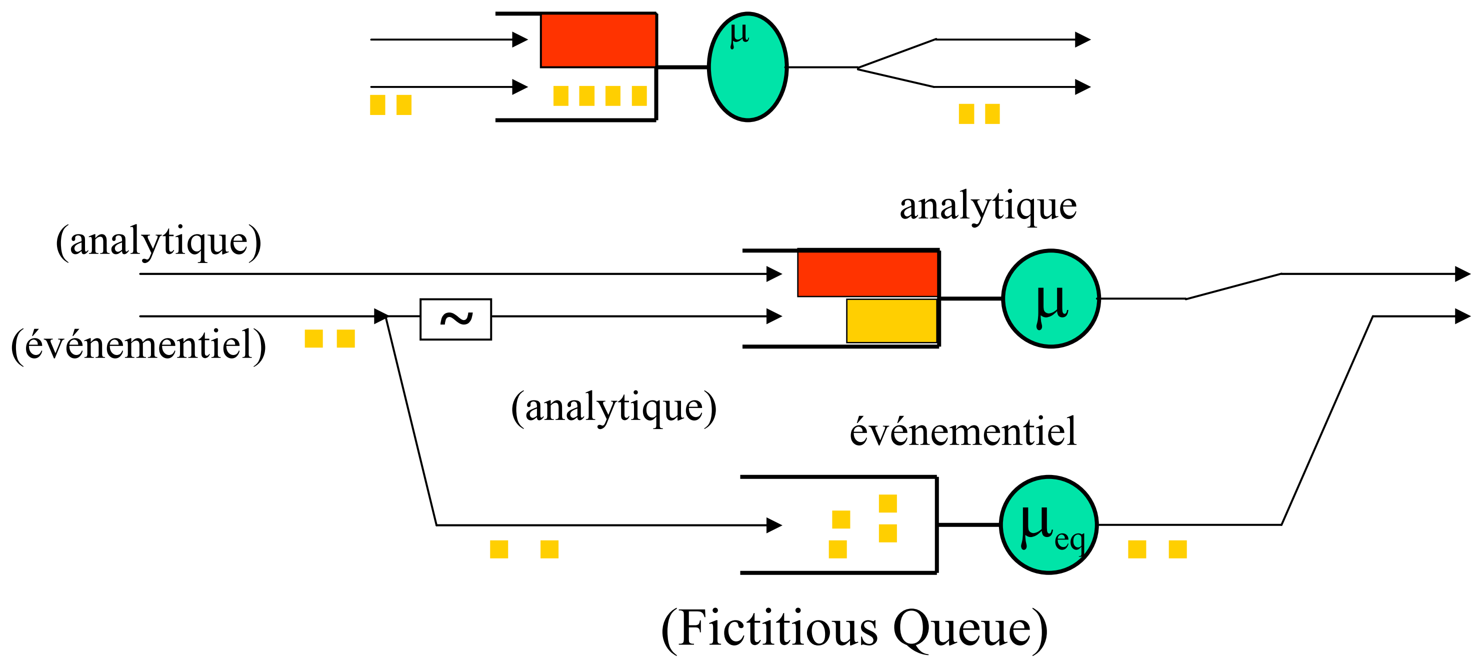
Network Core : All is analytic

Hybrid Superposition



Network : Large number of analytical flows and few discrete flows

Hybrid Superposition
- International Patent -

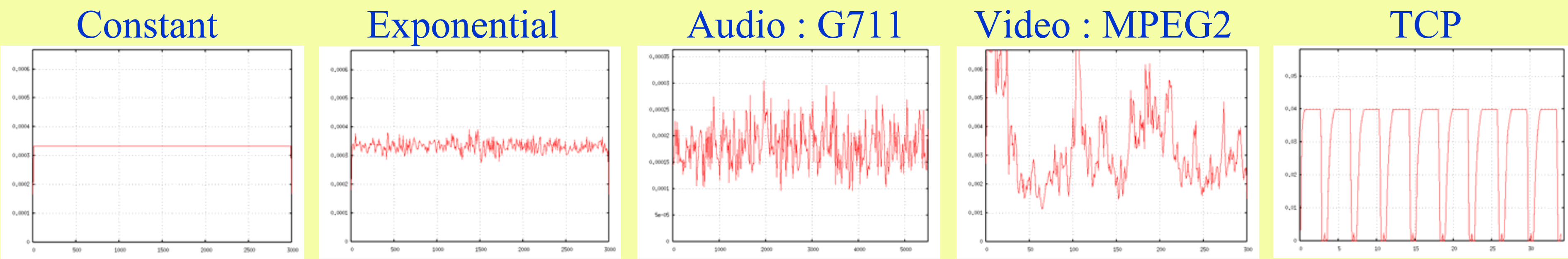


Every Δt →

- Rate measures on Dicrete event flows
- Aggregation and solution of the global analytic queue
- Computation of residual service time associated to discrete event flow $\mu_{eq}(t)$
- Simulation in a fictitious queue with equivalent service time $\mu_{eq}(t)$

Traffic Source Modeling

Voice, Video, Data …



Instantaneous rate of various multimedia sources

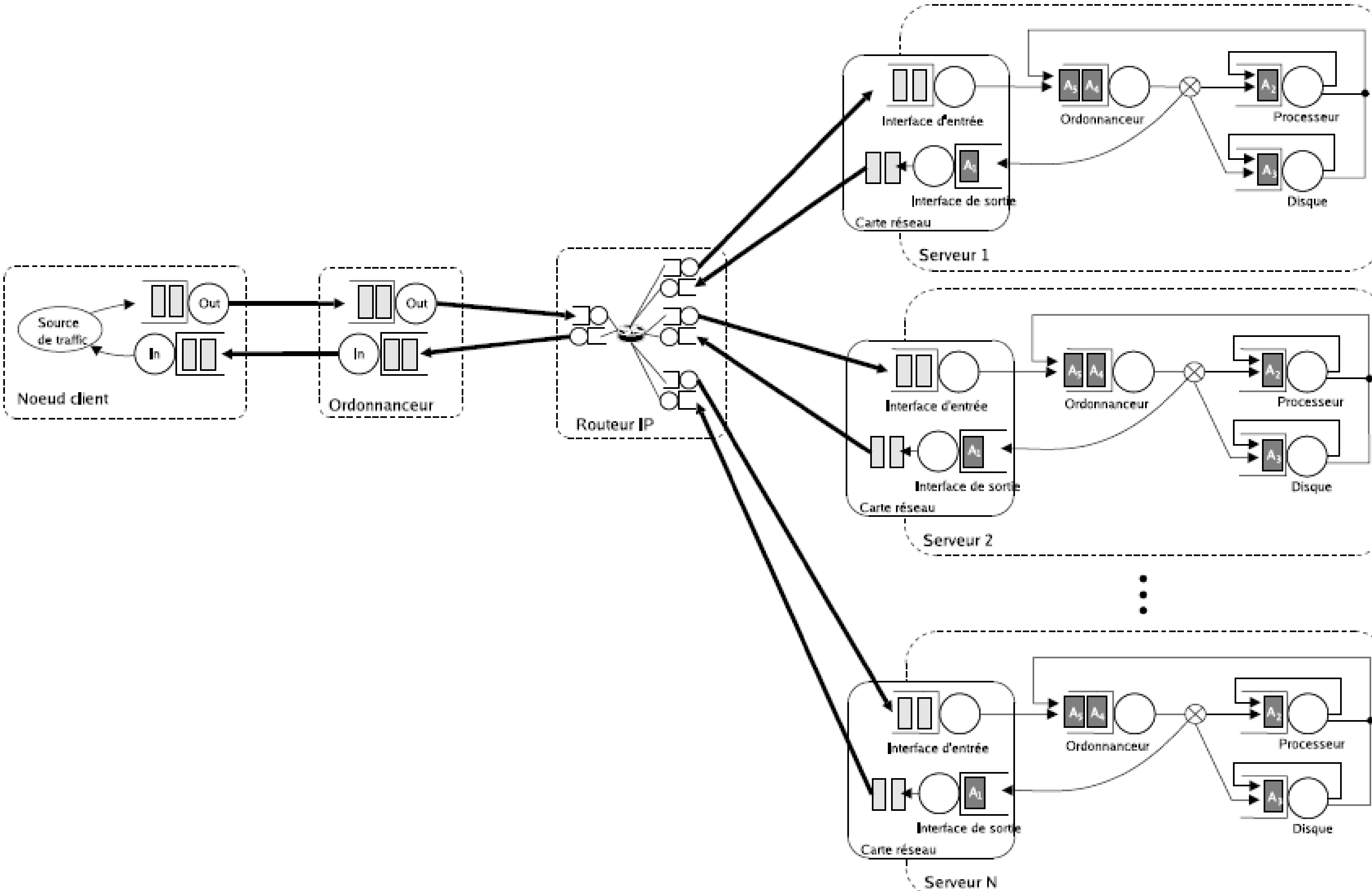
In these graph, all sources have emitted the same amount of Data !

Stochastic Models based on :

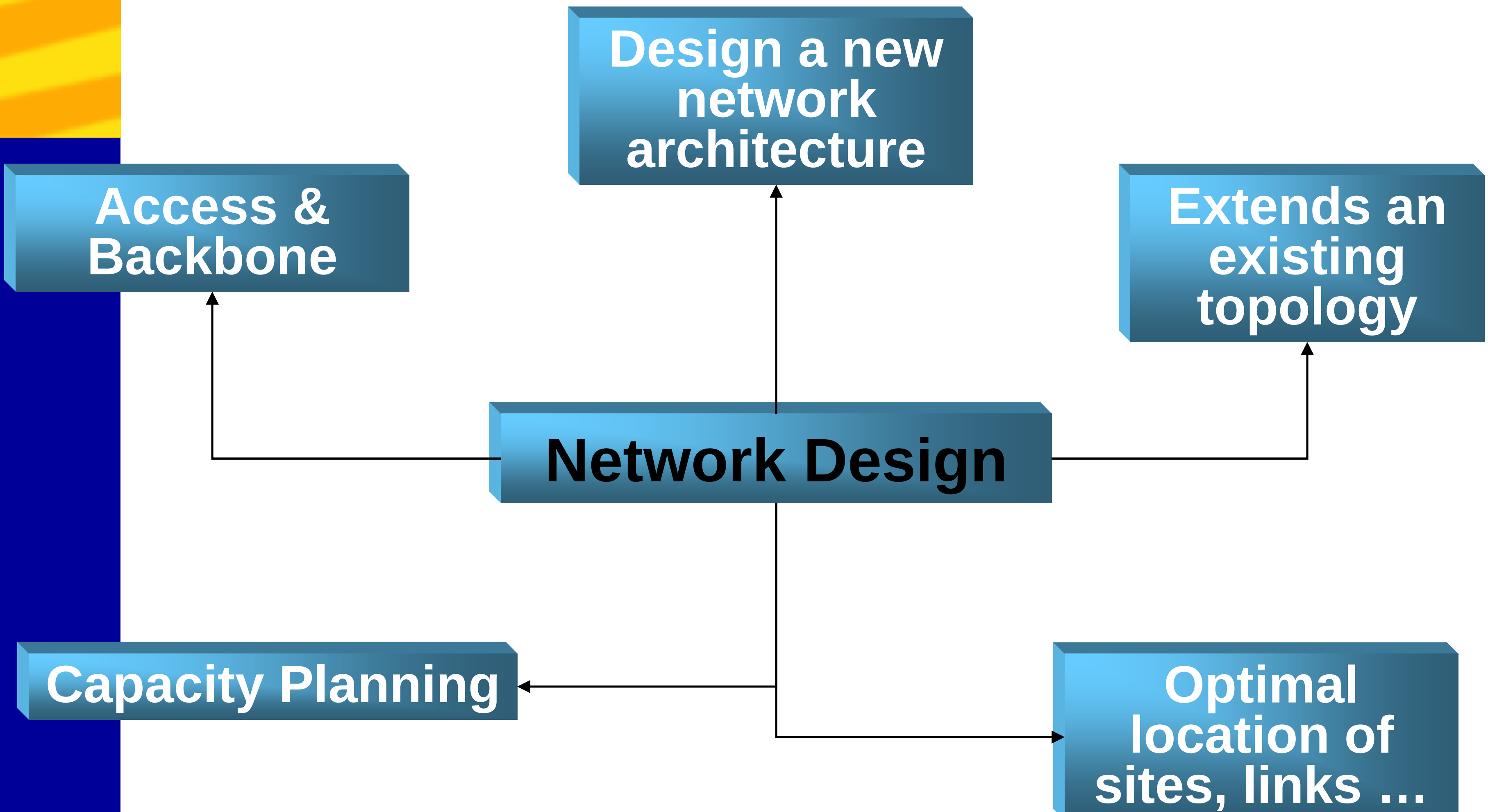
Distributions : Gauss, LogNormal, Normal, Pareto, Weibull ....

On-Off process, $MG\infty$, IPP

Current Research: Service Platform Modeling



Network Design
&
Engineering


Design a new network architecture
Access & Backbone
Extends an existing topology
Network Design
Capacity Planning
Optimal location of sites, links …

Equipments

Cards :

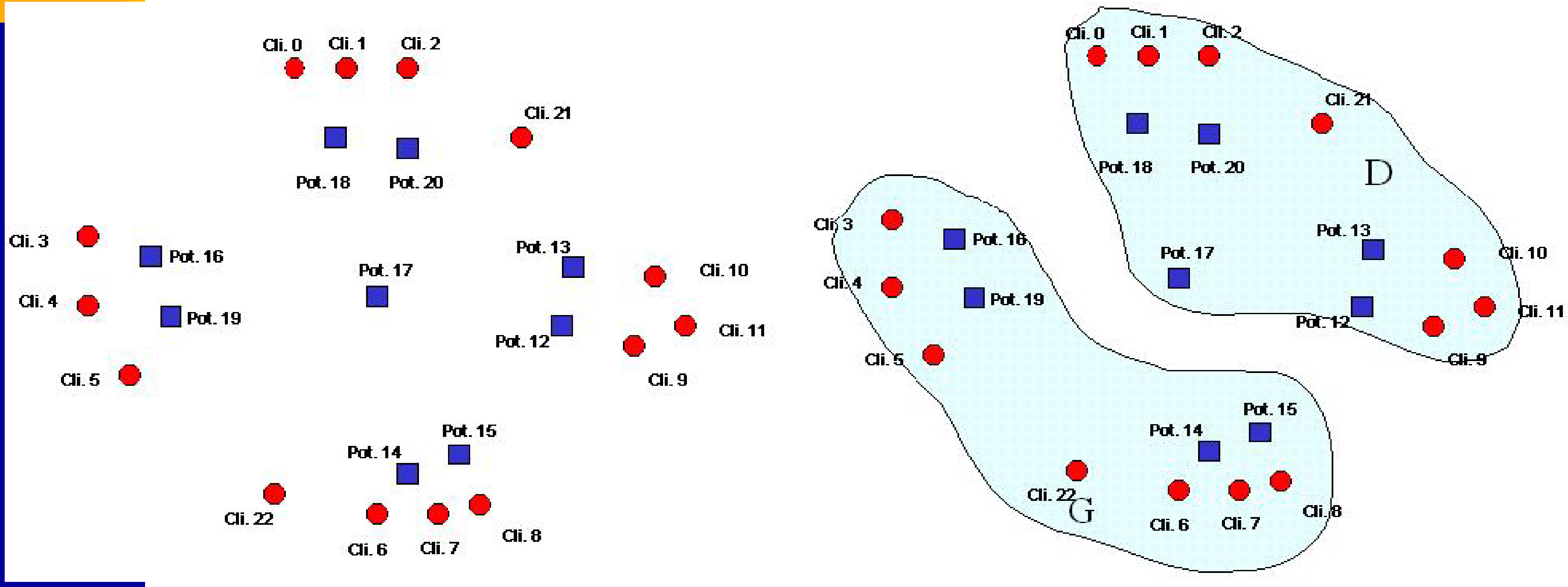
- Number of ports.
- Rate per port.
- Price.

Routers:

- Number of slots.
- Total Rate.
- Prce.

Building an Optimal Topology?

Clustering Approach by SearchCutExplore



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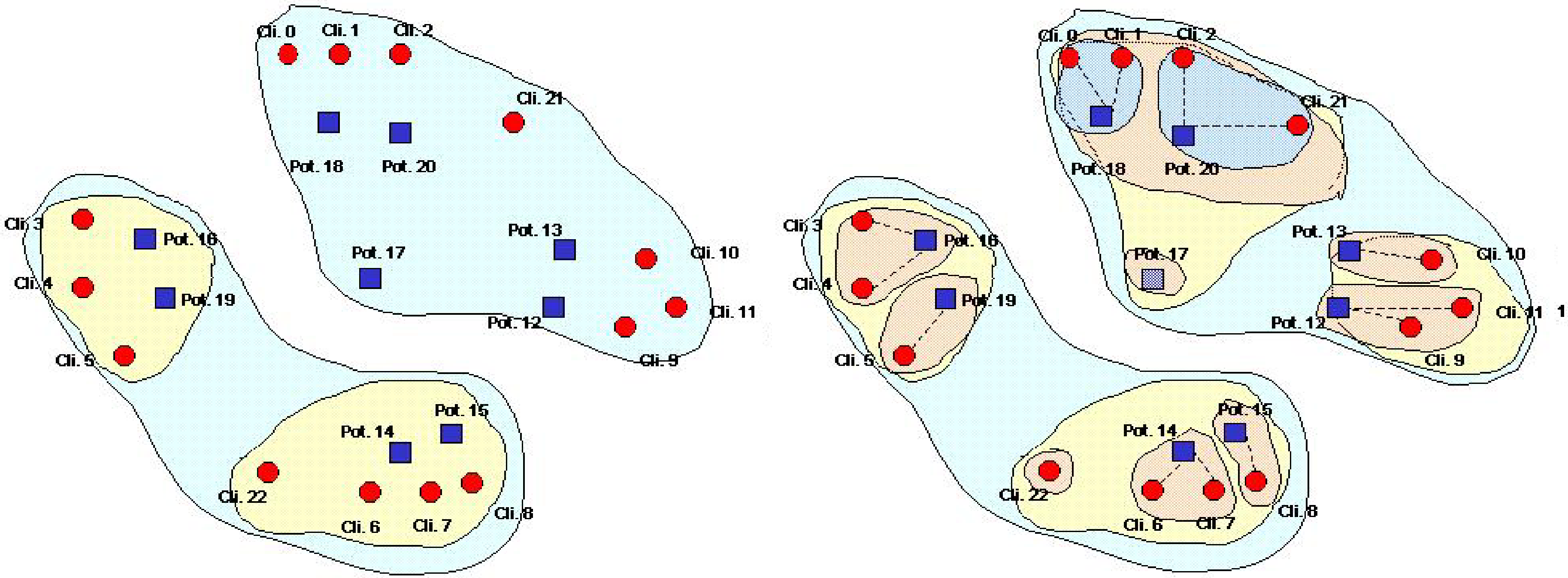
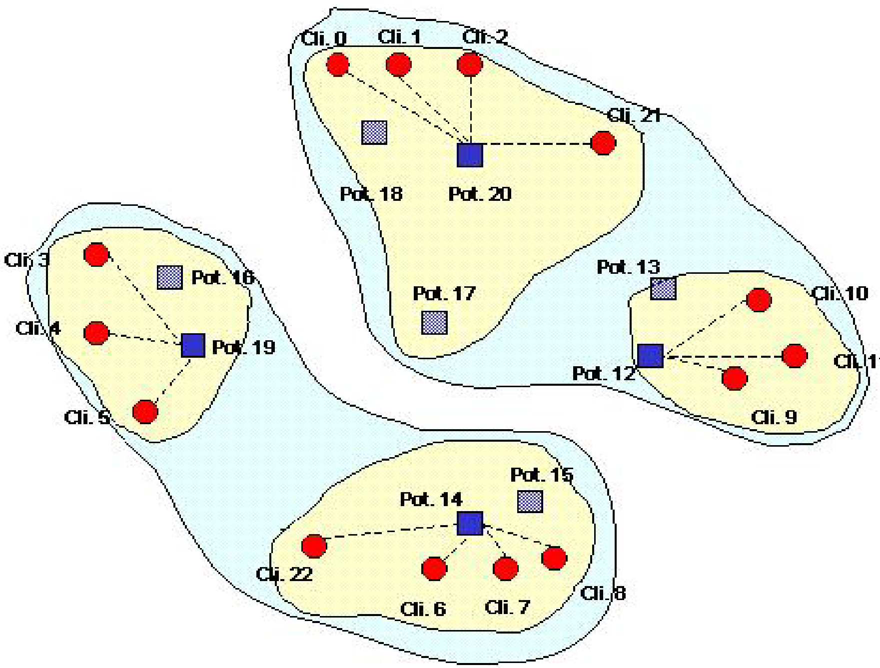
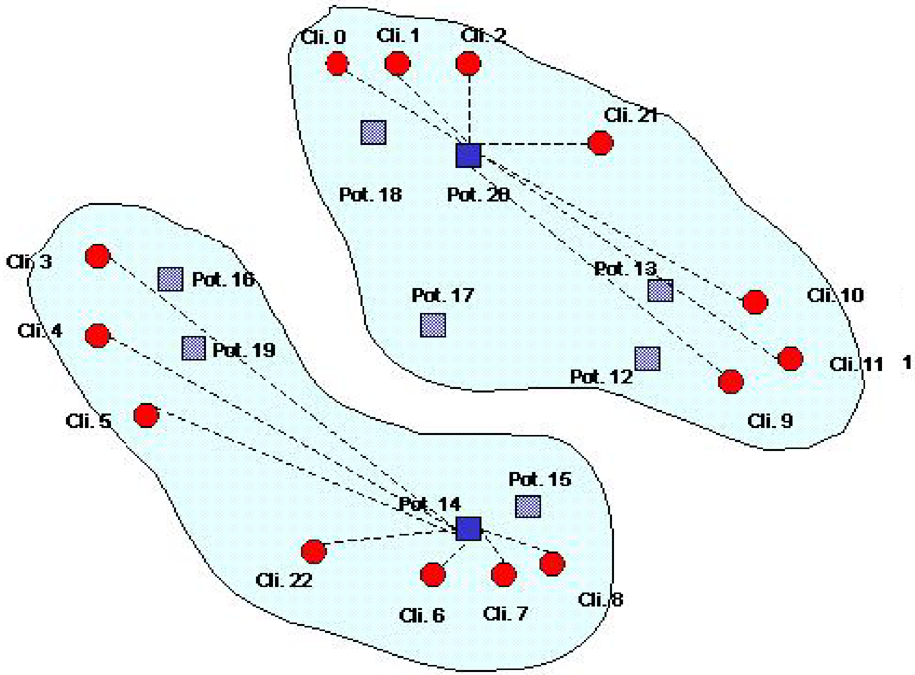
Clustering Approach by SearchCutExplore



Building an Optimal Topology?

Clustering Approach by SearchCutExplore





Building an Optimal Topology?

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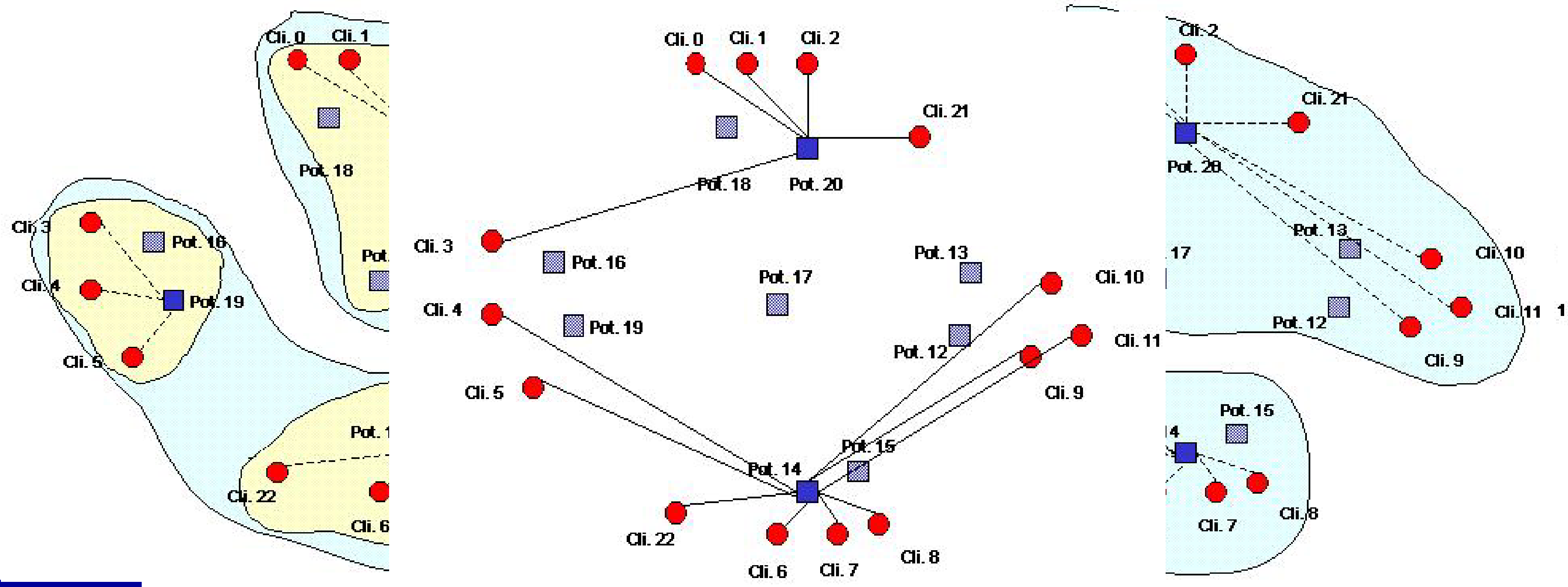
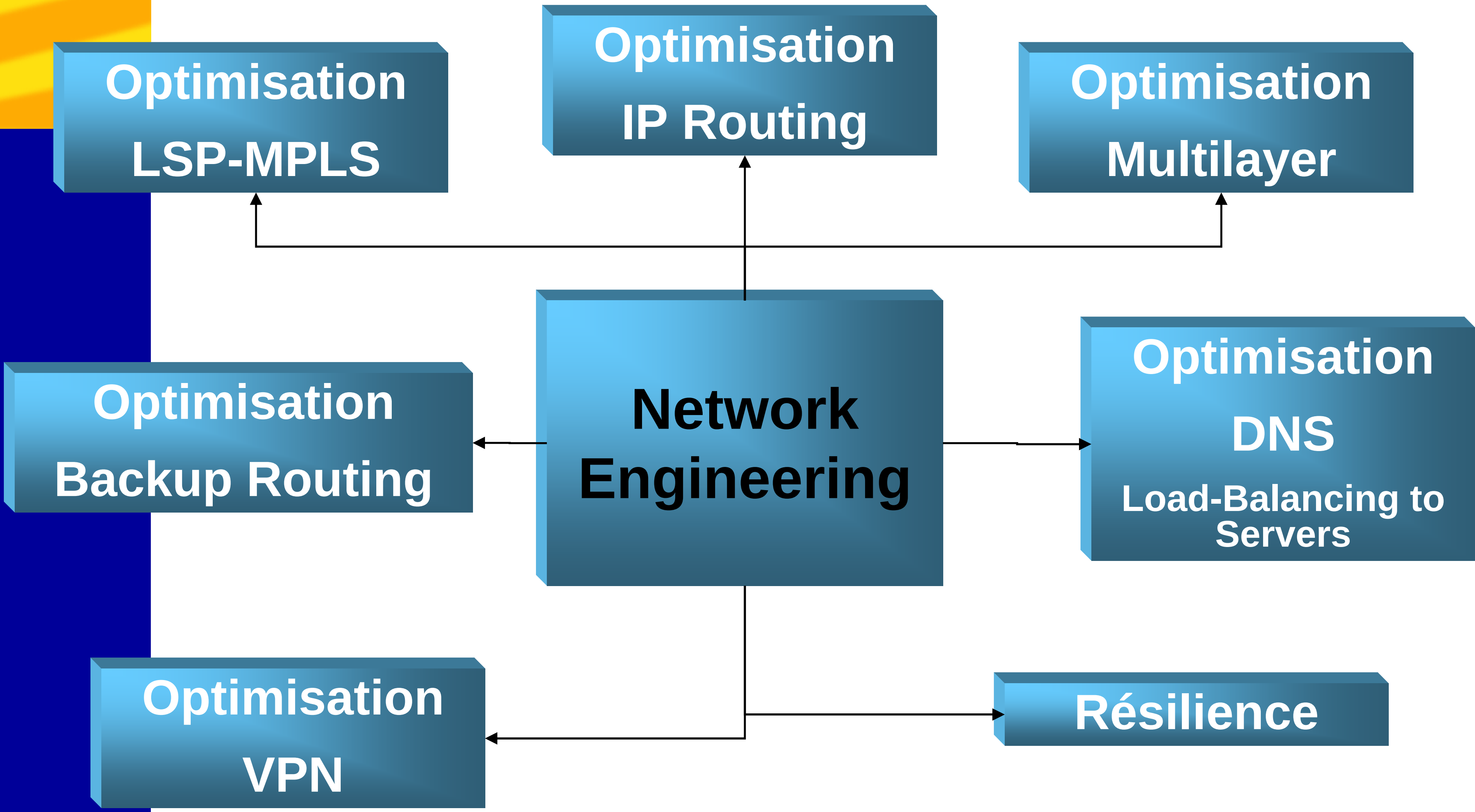
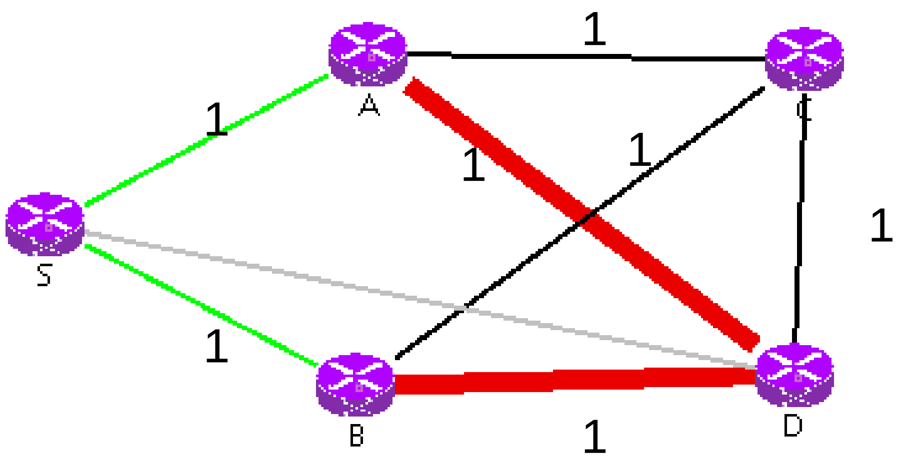
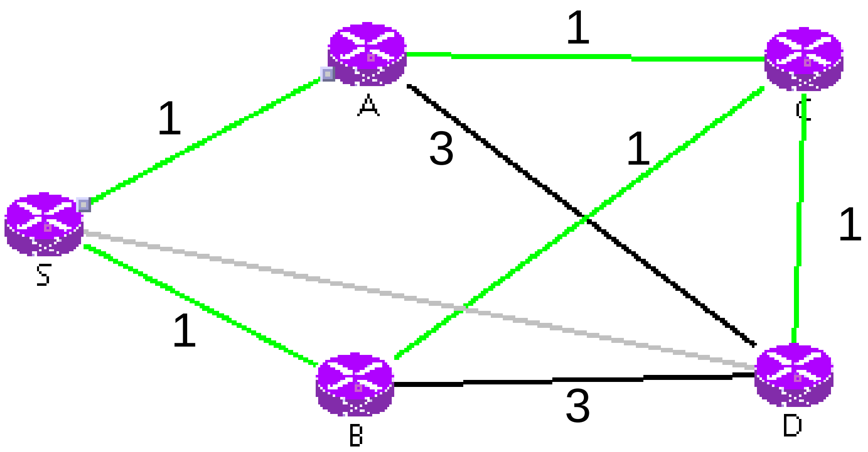



Optimisation
IP Routing
Optimisation
LSP-MPLS
Optimisation
Multilayer
Optimisation
Backup Routing
Network
Engineering
Optimisation
DNS
Load-Balancing to Servers
Optimisation
VPN
Résilience

IP Routing Metric Optimisation



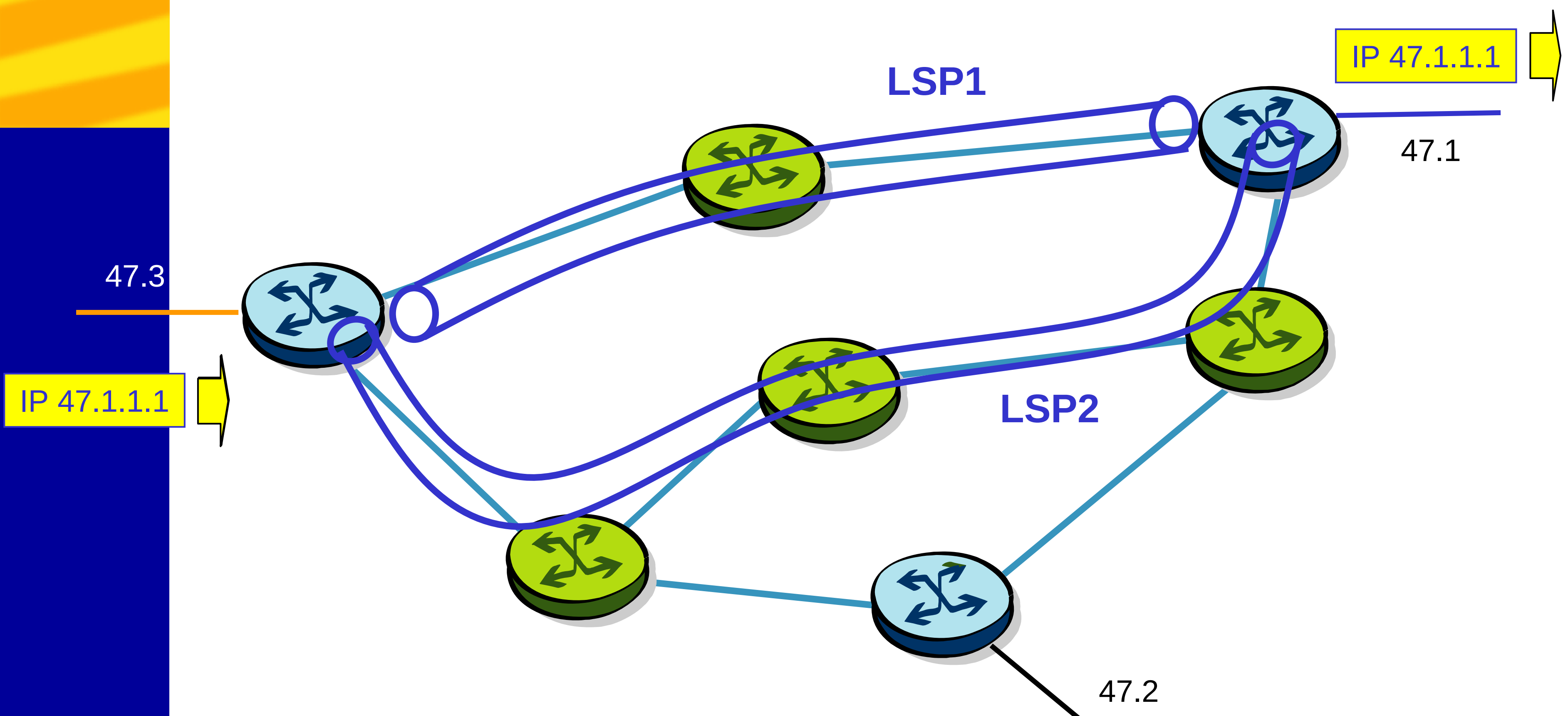
Optimal Metric ?

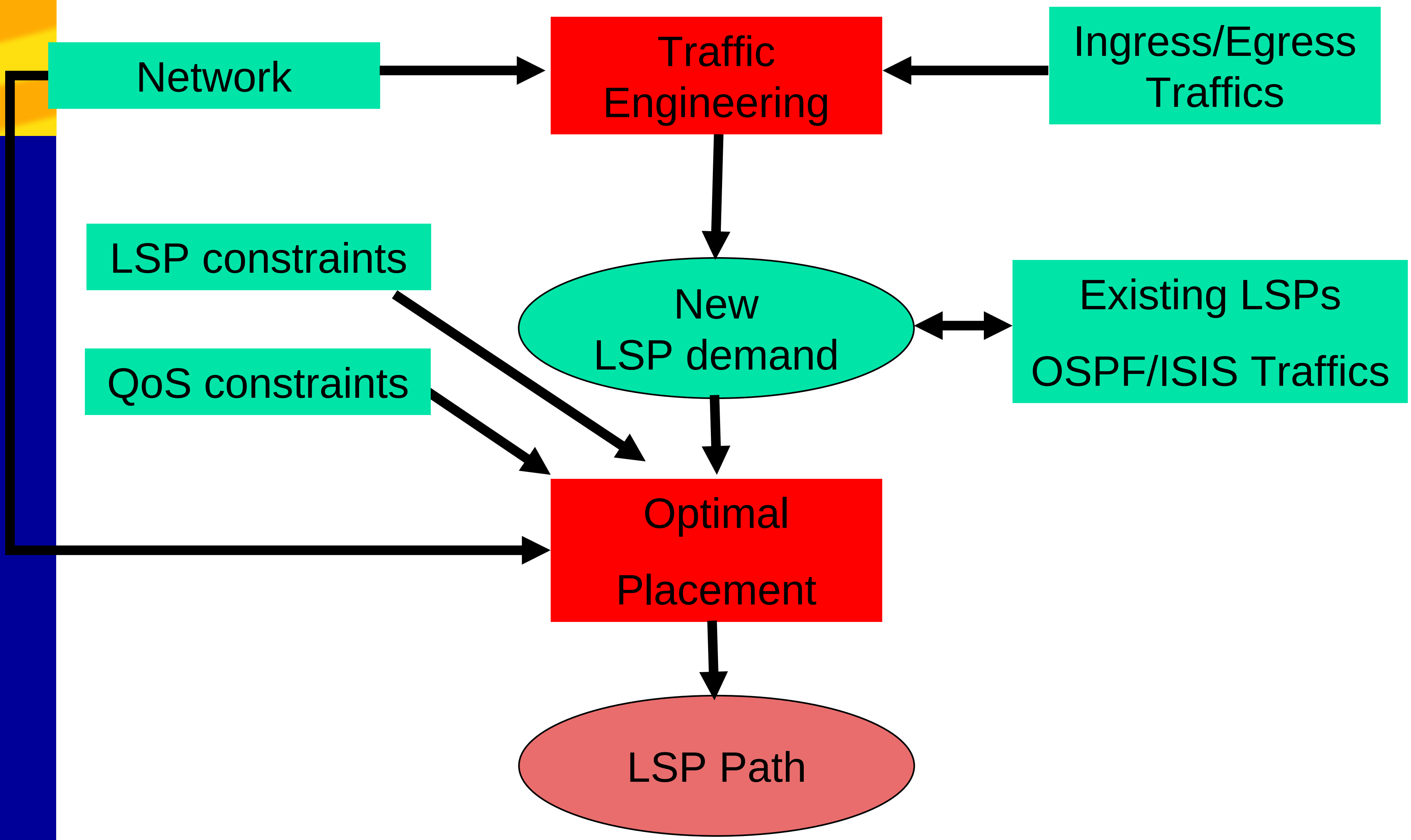


Example : OSPF Routing Performances

	Unit Metrics	Ct/Link BW Metrics	Optimised Metrics
Average End-To-End Residual Capacity	31.25 Mbit/sec	11.25 Mbit/sec	35.583 Mbit/sec
Average end-to-end Delay	1.8753 ms	1.9179 ms	**0.95 ms**
Interface without traffic	8	14	8
Average Interface utilisation	0.2995	0.267	0.32
Min Interface utilisation	0	0	0
Max Interface utilisation	0.9375	0.9375	0.6875

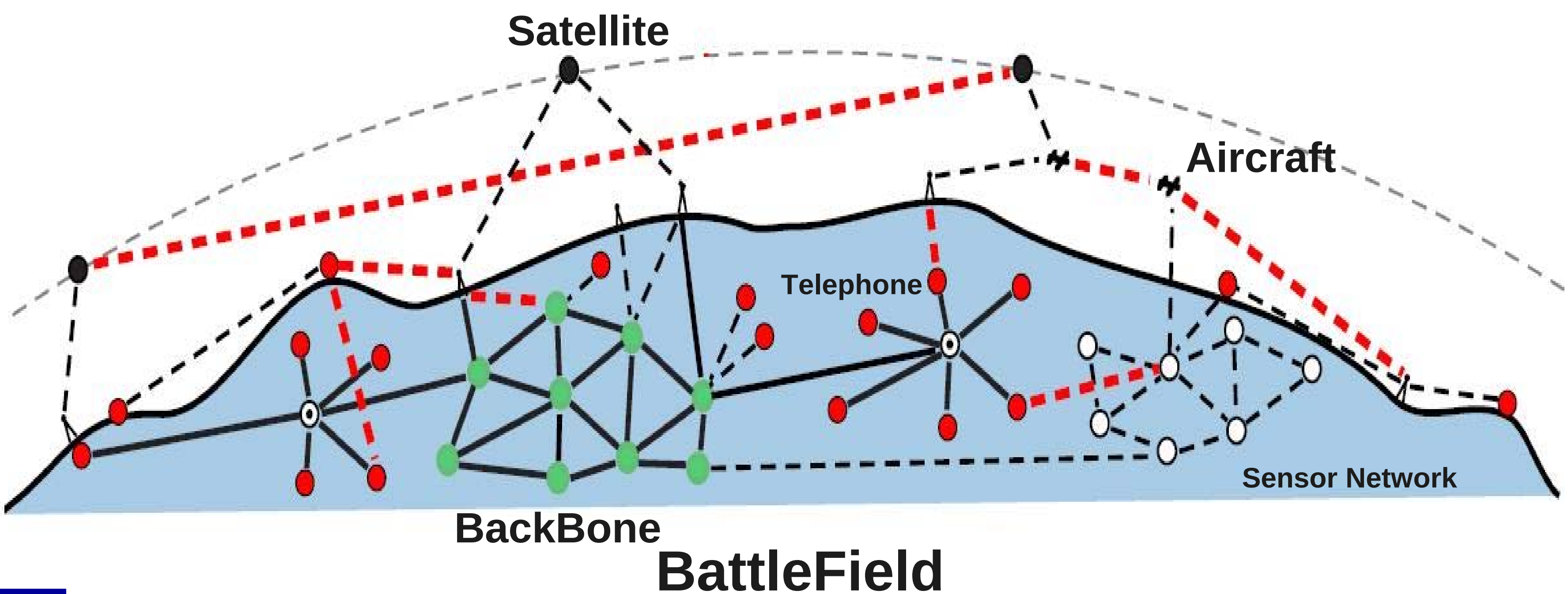
MPLS Switching



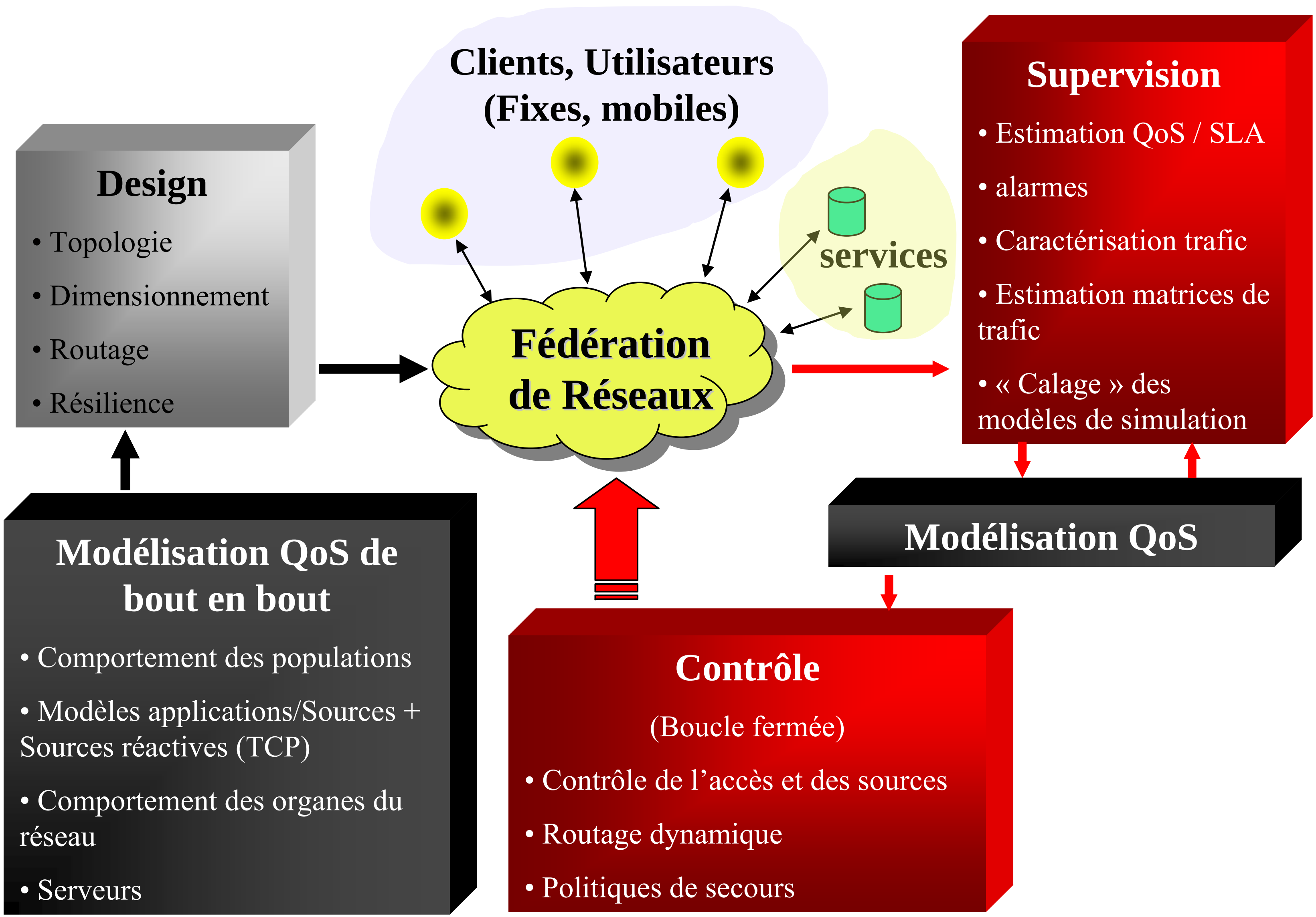

Network
Traffic Engineering
Ingress/Egress Traffics
LSP constraints
New LSP demand
Existing LSPs
OSPF/ISIS Traffics
QoS constraints
Optimal Placement
LSP Path

Current Research : Dynamic Networks (Planning & Control)

- **Heterogeneous Interconnected Networks (wired networks, mobiles, satellites …), with Dynamic Topologies**
- **Dynamic Routing, backup scenarii …**



Current Research : Supervision & Control



QoS DESIGN Company

- Spin-Off created in 2004
  - 3 founders (CNRS) + 5 employees
  - Several consultants + Sale Agents
  - Patents
  - > 2 M€ invested in 4 years in research and technology development

- First Customers : Several Corporate Entreprises
- Partnership with LAAS-CNRS
- 4 National awards:

V^{ème} Concours National de l'Innovation-ANVAR, 23ème Concours Régional de l'Innovation, « Best Innovative IT » at Capital IT Paris 2005, Trophée de l'économie numérique

NEST™ Software Suite

Network Engineering & Simulation Tool

- NEST IP-MPLS
- NEST Mobile
- NEST Designer
- NEST VPN
- NEST Traffic Simulation

QoS Design Partners & Customers

Défense Nationale (DIRISI)
Alcatel CIT
British Telecom
SFR
Maroc telecom
Nextiraone
DGAC
EADS DS

Sodielec
AIRBUS
DCNS

Projet PRAI GRID-MIP
Projet ANR-RNRT AVIPS
Projet ANR-RNTL Satrimmap
Projet TVProdNext, Labellisé EUREKA
Centre d’Excellence SUN
Collaborations Universitaires

Questions ?

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