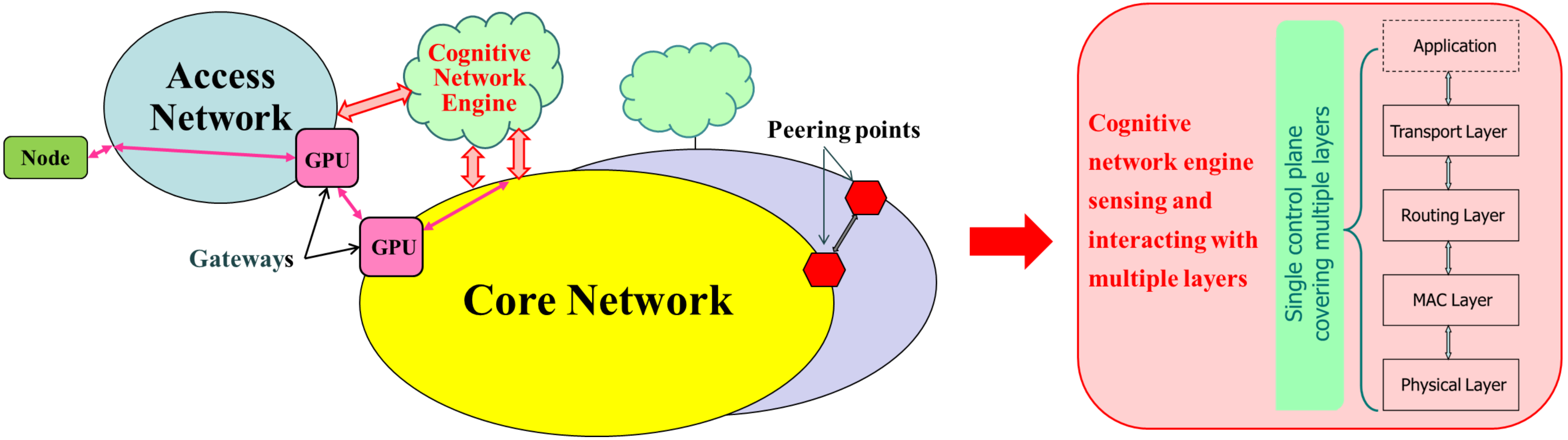
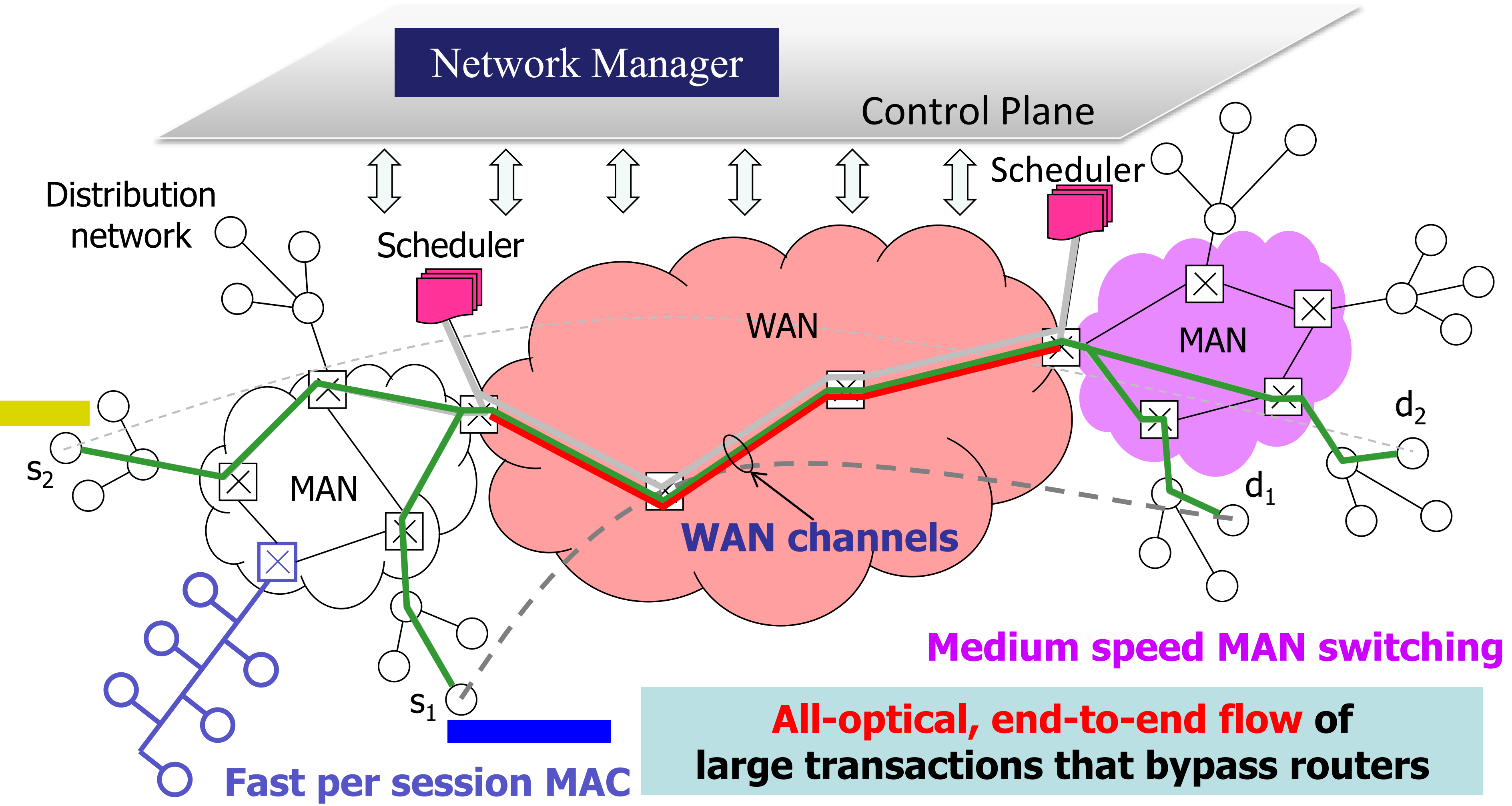
Cognitive Networking: Vincent Chan MIT



CN is a network with a cognitive process that can perceive current network conditions, plan, decide, act on those conditions, learn from the consequences of its actions, all while following end-to-end goals.

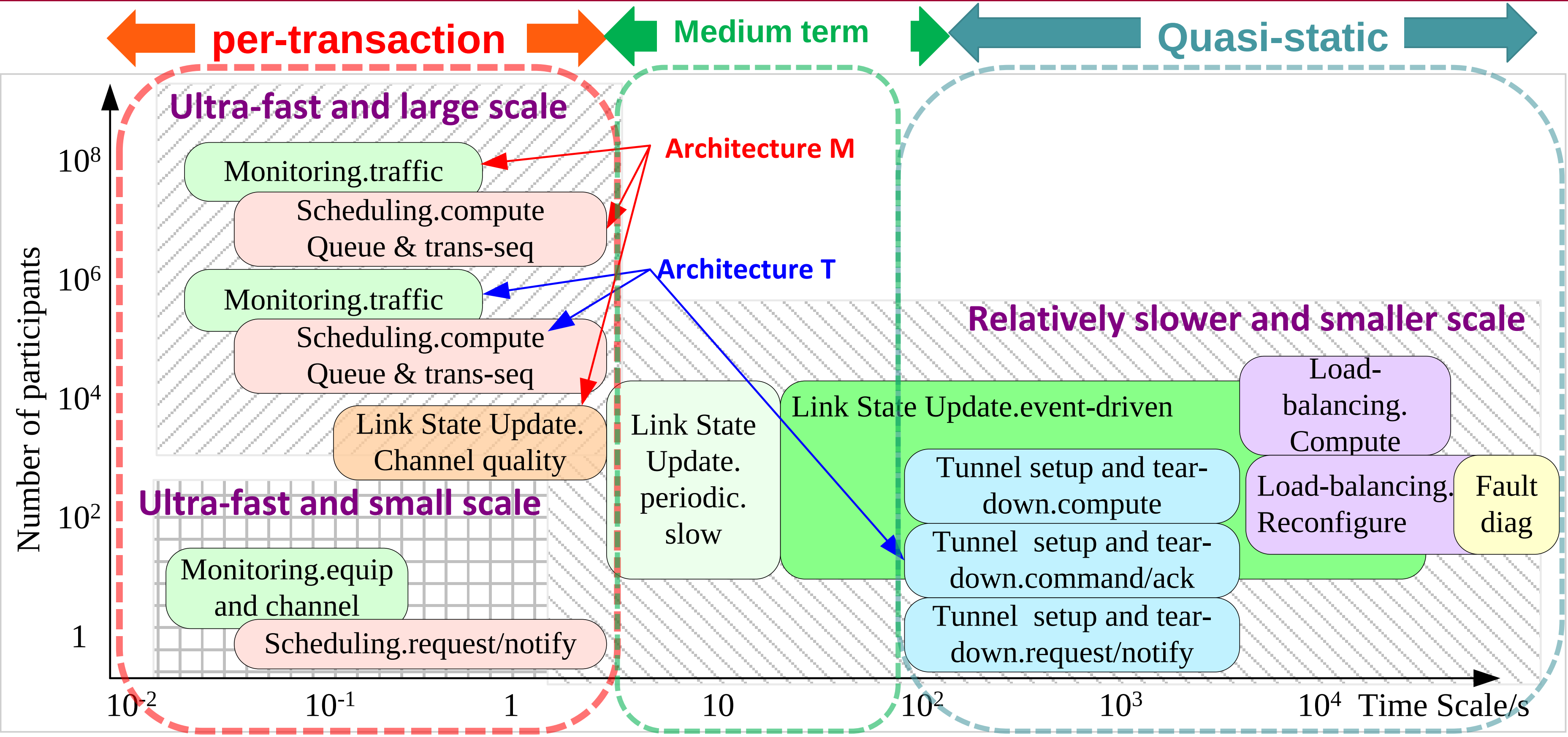
The cognition loop, senses the environment, plans actions according to input from sensors and network policies, decides which scenario fits best its end-to-end purpose using a reasoning engine, and finally acts on the chosen scenario. The system learns from the past (situations, plans, decisions, actions) and uses this knowledge to improve the decisions in the future.

Optical Flow Switching - most dynamic agile circuits



- Dynamic per flow (1-10^4S) scheduling prevents collisions
- Off-band signaling for reservation, scheduling, setup (< 100ms)

Time scale of protocol and control plane functions



- Fast (< 1s)
  - MAC, Scheduling function – complexity, control traffic
  - Fast link state update
- Slower
  - Slower link state update, fault diagnosis, load balancing, reconfigurations, etc

Scheduling dominates the dynamic NMC efforts

Why are we in trouble?

US backbone network* ~

X10^3 current traffic

* J. M. Simmons, *Optical network design and planning.* New York: Springer, 2008..

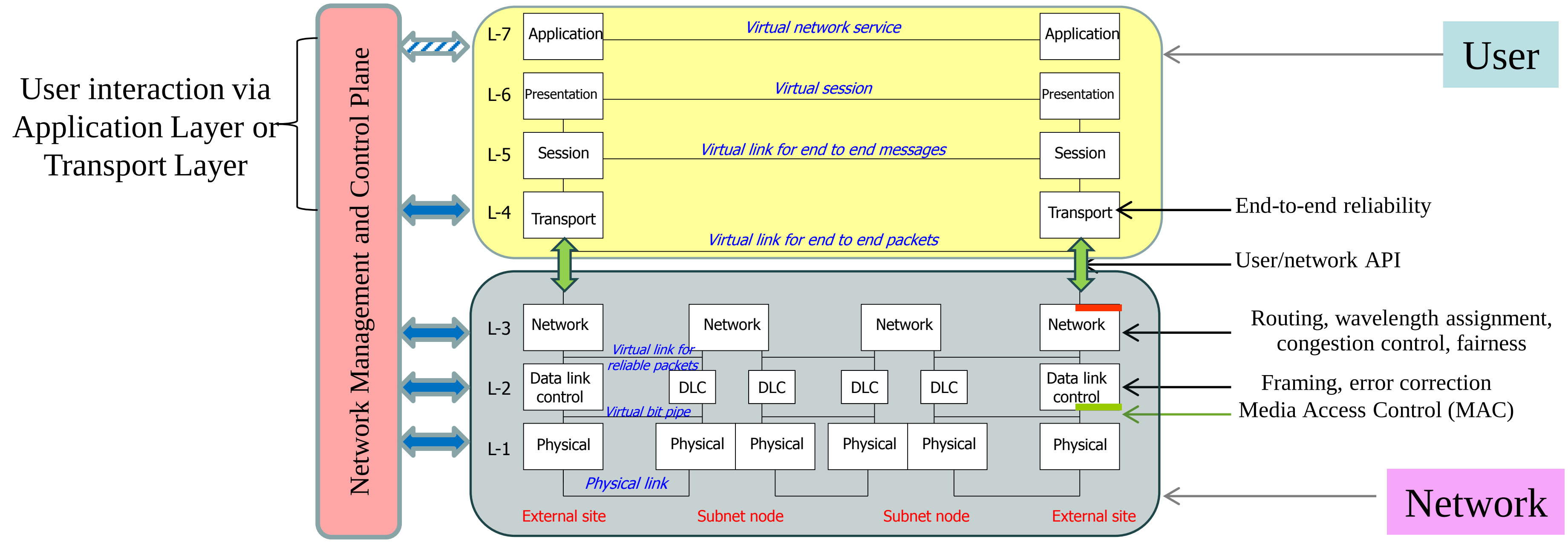
- # of nodes: $N_V = 60$
- # of edges: $N_E = 77$
- Average node degree: $\bar{\Delta} = 2.6$
- # of hops: $\bar{H} = 4$
- # of wavelengths/edge: Λ
- # of schedule-holders/edge: N_s

- For Architecture T (Tunneled)
  - # of tunnels/edge:
    $$D = \frac{N_V(N_V-1)\bar{H}}{2N_E} \approx 92$$
  - # of wavelengths/tunnel:
    $$\Lambda_T = \frac{\Lambda}{92}$$
  - # of schedule-holders/tunnel:
    $$N_{sT} = \frac{N_s}{92}$$

N_E x Λ ~ $10^{5\text{-}7}$ Link State packet/S ~ 1- 300 Gbps

We can slow down the control plane by physical architecture only so much

Control plane interactions with different layers of network



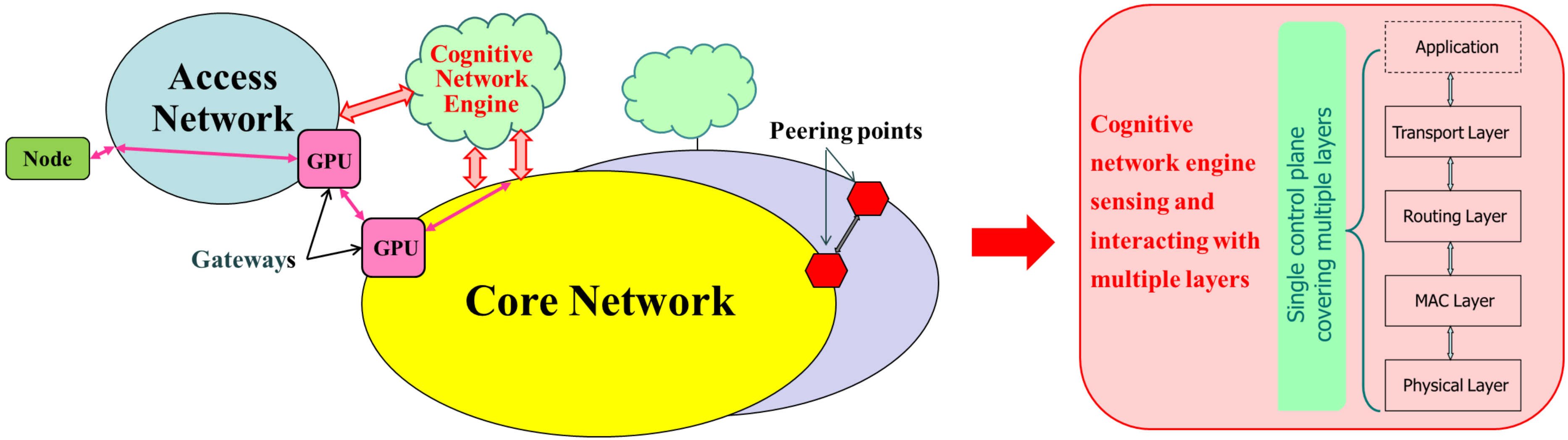
- Control plane never used to interact with user part of the network protocol stack
- Interactions necessitated by **elephants** OFS flows
- Complexity can blow up fast for a large scale network
  - Peak control traffic ~300Gbps
  - Peak processing load
  - Many SDN concepts not scalable
  - **Detractors complain about complexities**

Peak Processing Power	FIFO-EA		Mathematically-Optimum	
	Meshed	Tunneled	Meshed	Tunneled
Centralized	37.2 GIPS	0.1 GIPS	1.2×10^{23} GIPS	0.1 GIPS
Distributed	0.6 GIPS	1.7 MIPS	1.9×10^{21} GIPS	1.7 MIPS

< Intel i7 Hex Core CPU: 177.73 GIPS
3 orders of magnitude difference

Super computer for 12 min

Cognitive Networking



1. Infer network state based on traffic and active probing
2. Inference on sparse and stale data
3. Decisions on load balancing, reconfiguration, restoration
4. Predict intention of user and take or recommend appropriate actions
5. Detect security related anomalies in network and react automatically

Optical Flow Switching with Very Fast Setup

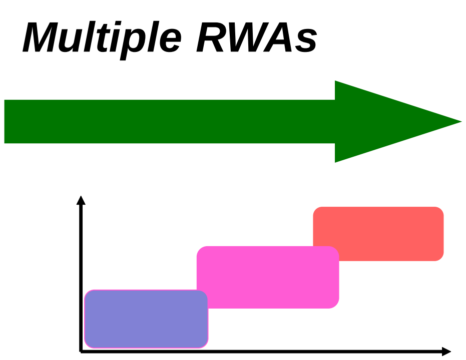
Ultra-fast setup of flows employs slow/centralized and fast/distributed processes:

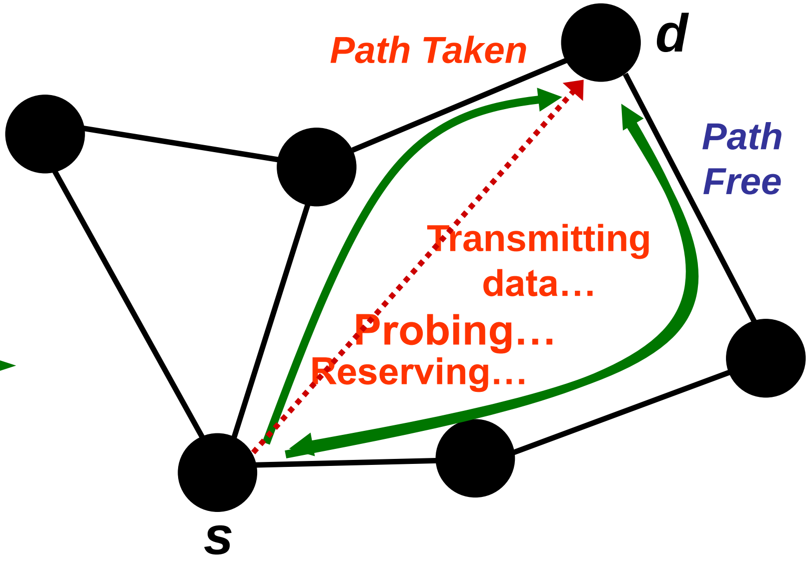
• Network resource and candidate routing and wavelength assignments are centrally computed and disseminated periodically (on the order of seconds)

• Upon request for service, i) probe availability of multiple paths; ii) one available path is reserved; iii) data is sent

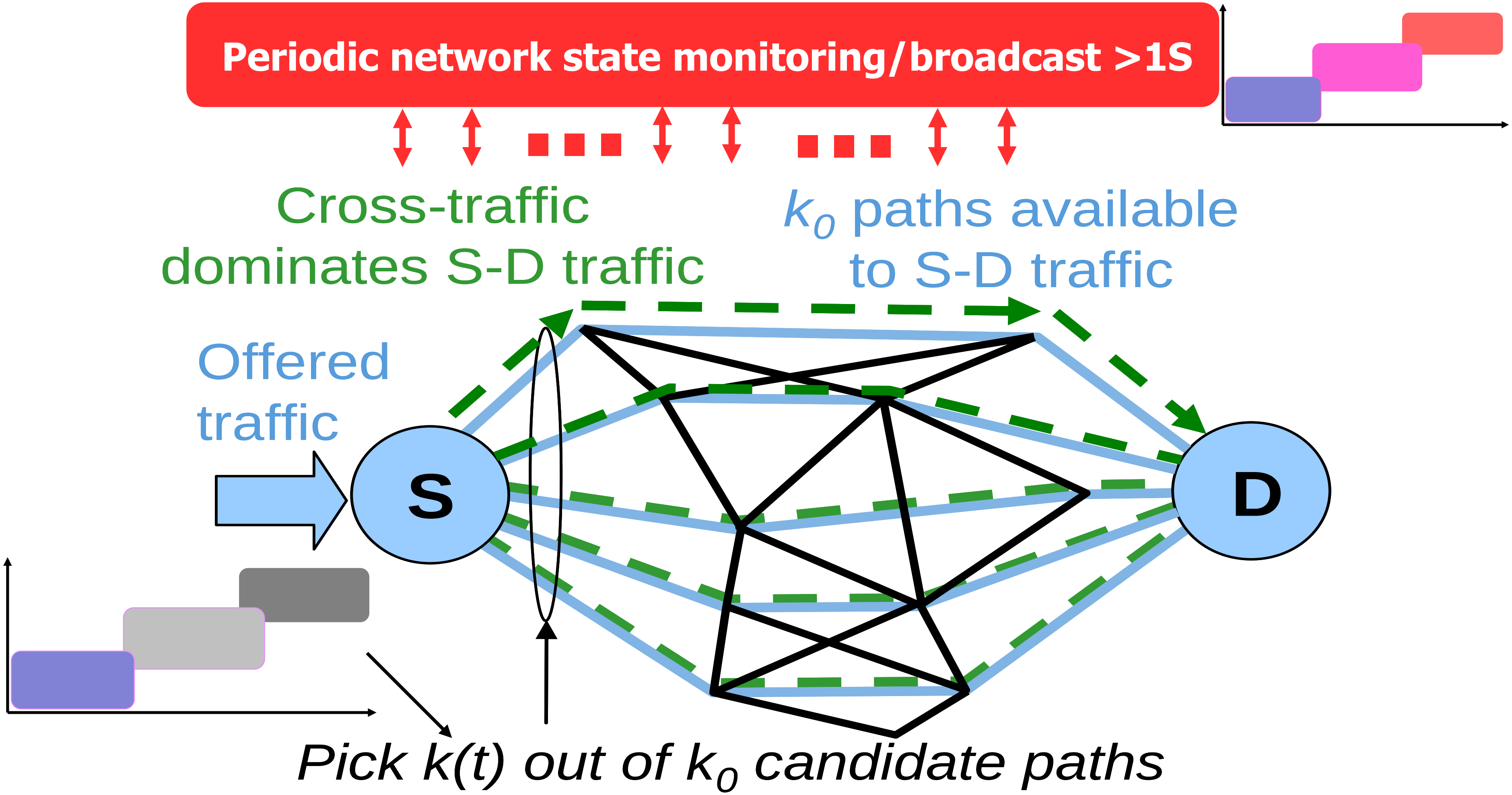
→ ***Setup Time = Roundtrip Time***
+ Hardware Setting Time

Centralized net management periodically broadcast open paths





OFS Network Management for Very Fast Setup
with periodically pre-computed and broadcast paths

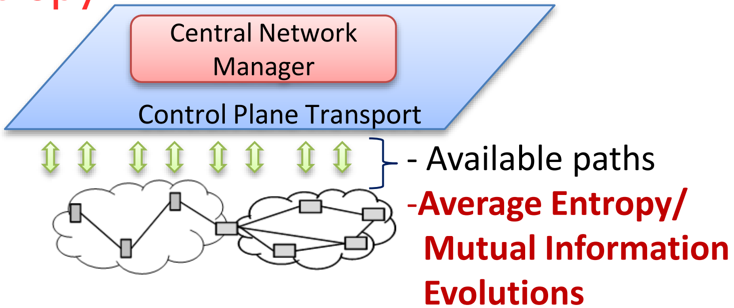


Probing (1RTT~20mS) necessary due to slightly stale state information
reduce network management and control traffic from 10 → 1Gbps (→100Mbps?)

OFS with Ultra-Fast Setup

scalable multi-path probing using entropy (sub-network temperature)

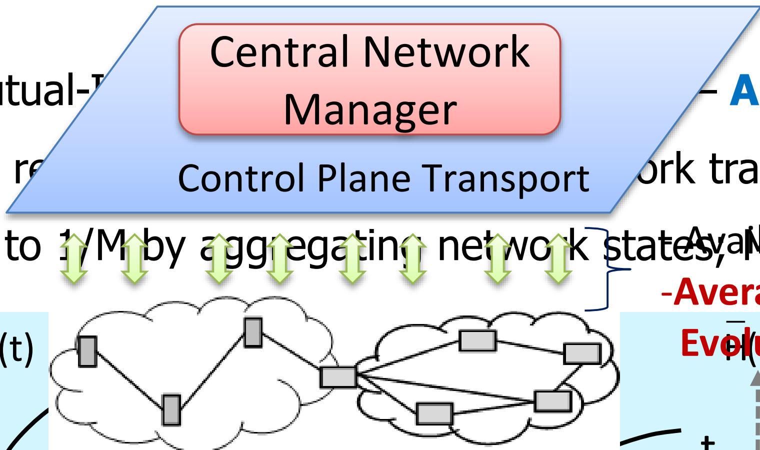
1. Heuristic algorithm: probe K_p paths with least entropy
2. Avoid high entropy (hot) regions
3. Broadcast at two time scales:

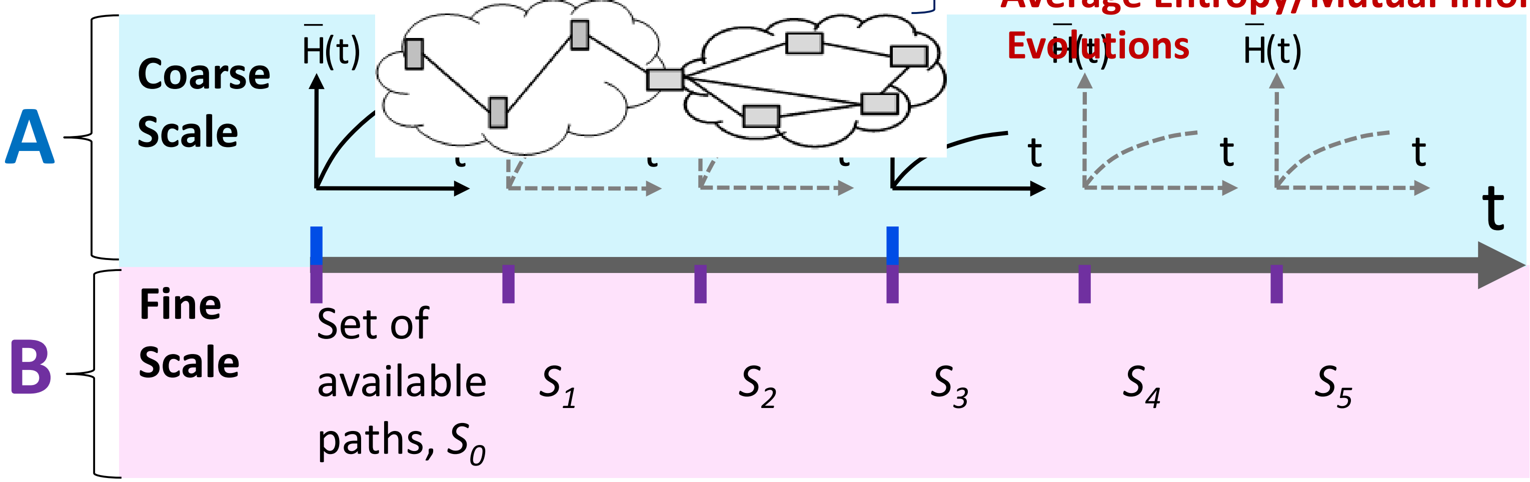


- Fine scale: Set of available paths– **B**
- Coarse scale:

  Average entropy/Mutual-I… – **A**

  - Update rate is re… …ork traffic dynamics
  - Traffic reduce to 1/M by aggregating network states, M=degree of aggregation





Globecom ONS1P:Fast Scheduling for Optical Flow Switching, Lei Zhang, Vincent Chan.

Deciding on # of paths to probe based on sampled entropy

Solution *The upper bound of the expected number paths to probe is,*

Zhang Lei

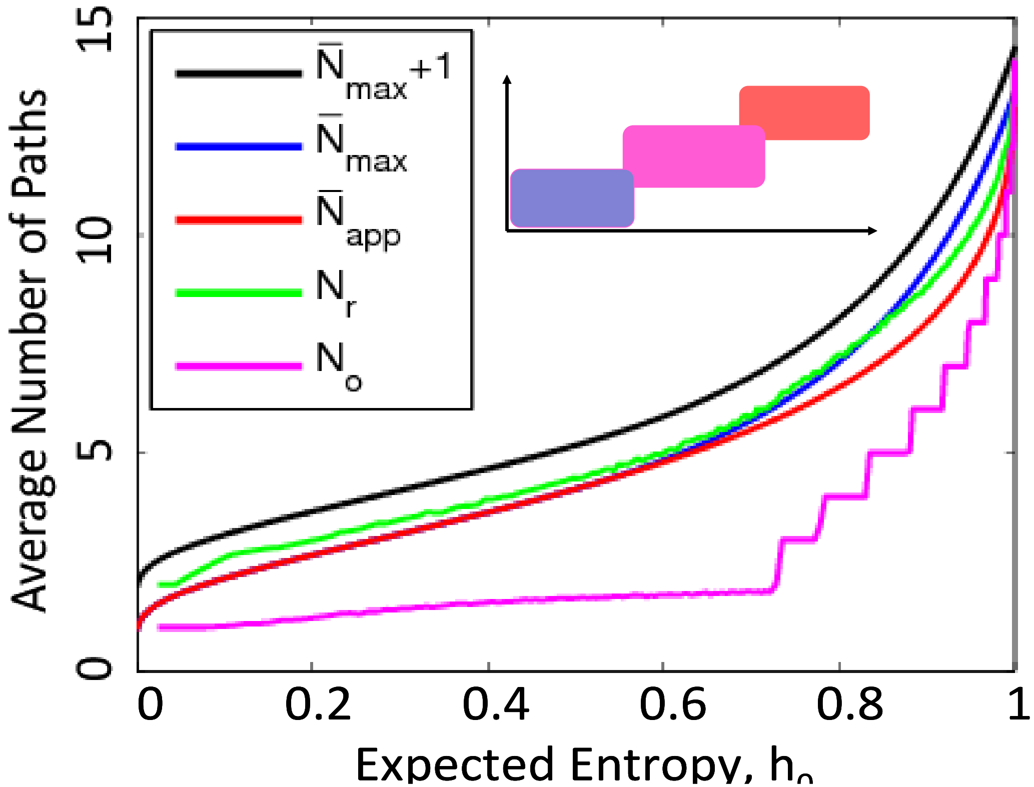
$$\bar{N}_{max} = \begin{cases} \dfrac{-\log_2(P_B)}{-\log_2[H_b^{-1}(h_0)]} & if \quad h_0 \le h_A \\ \dfrac{-\log_2(P_B)}{\dfrac{(1-h_0)\{-\log_2[H_b^{-1}(h_0)]\} + h_0 - h_A}{1-h_A}} & if \quad h_0 > h_A \end{cases}$$

where $h_A = 0.4967$.

An approximation of the upper bound is

$$\bar{N}_{app} = \frac{-\log_2(P_B)}{-\log_2[H_b^{-1}(h_0)]}$$

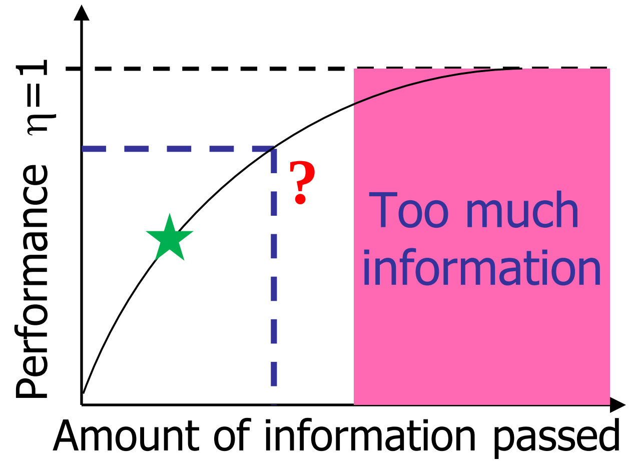
The upper bound of the expected number of paths to probe to achieve target blocking probability 10^{-4}, and its approximation.



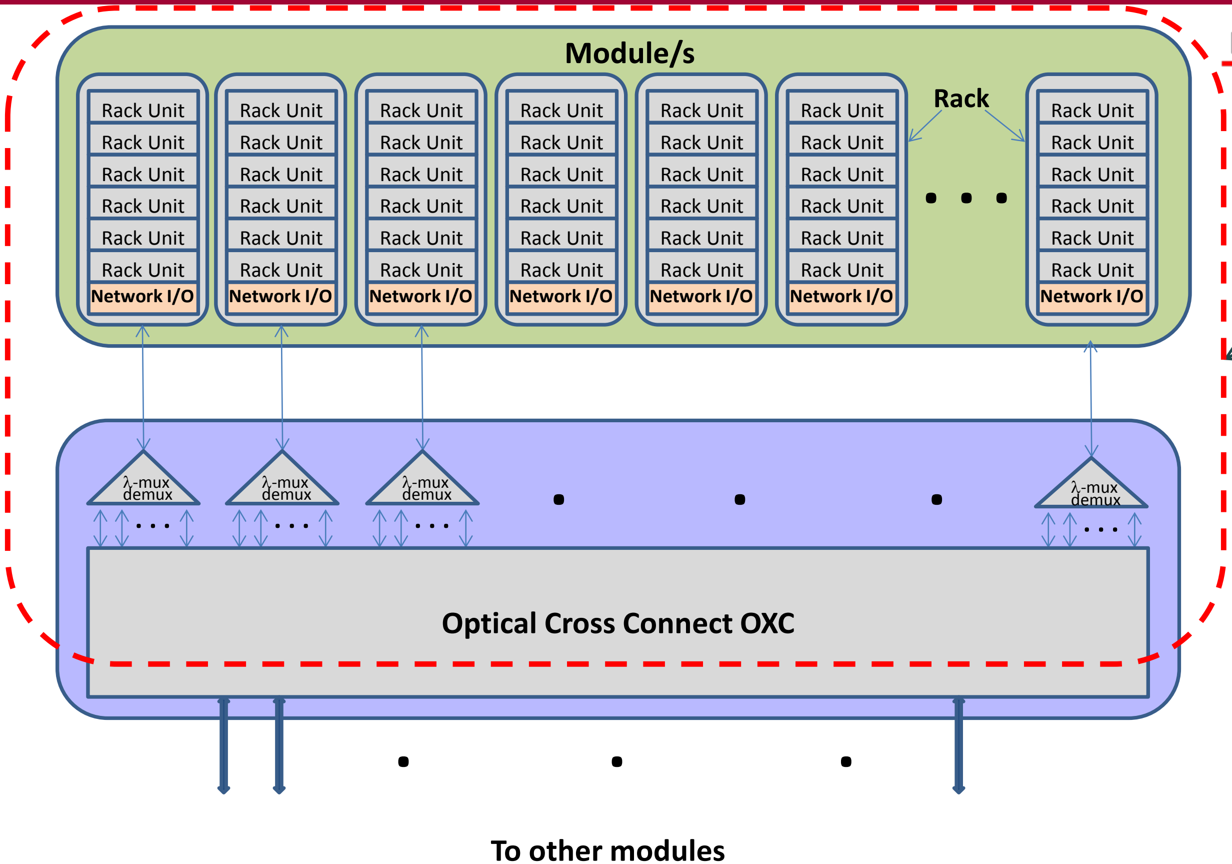
Algorithm traffic statistics and topology independent

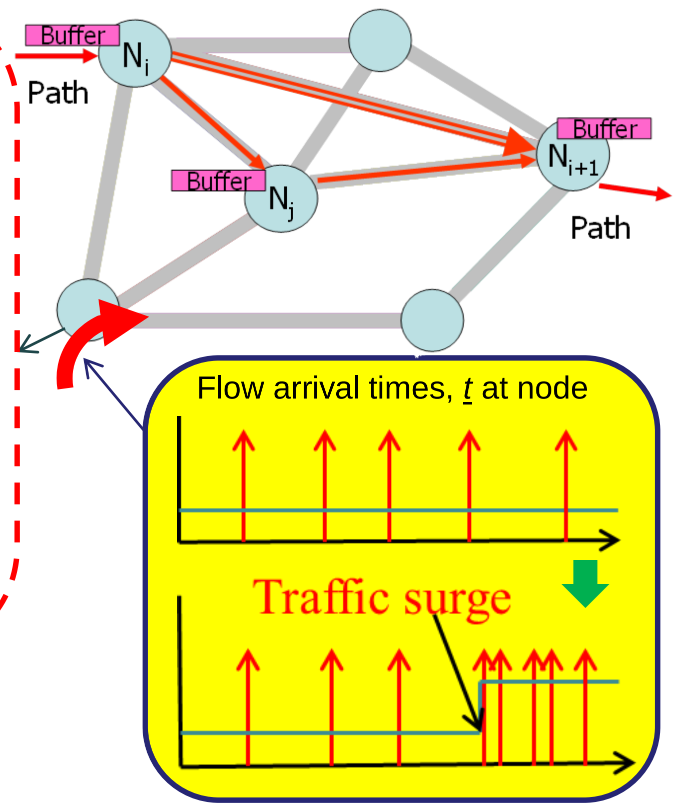
What statistical parameters of the network are needed for proper operations

- Statistical properties of link layers affects upper layer performance
- What is needed in the abstraction of the physical layer and DLC so the upper layer can be properly designed and performance optimized?
- How much of the link state in Layer 3 needs to be passed to the Network Management and Contorl system
- Too much information will overwhelm the upper layers
- Too little information may prevent network from operating efficiently
- How much is sensible?
- What is the simplest abstract model?
- Must keep **scalability** so cannot be too complicated



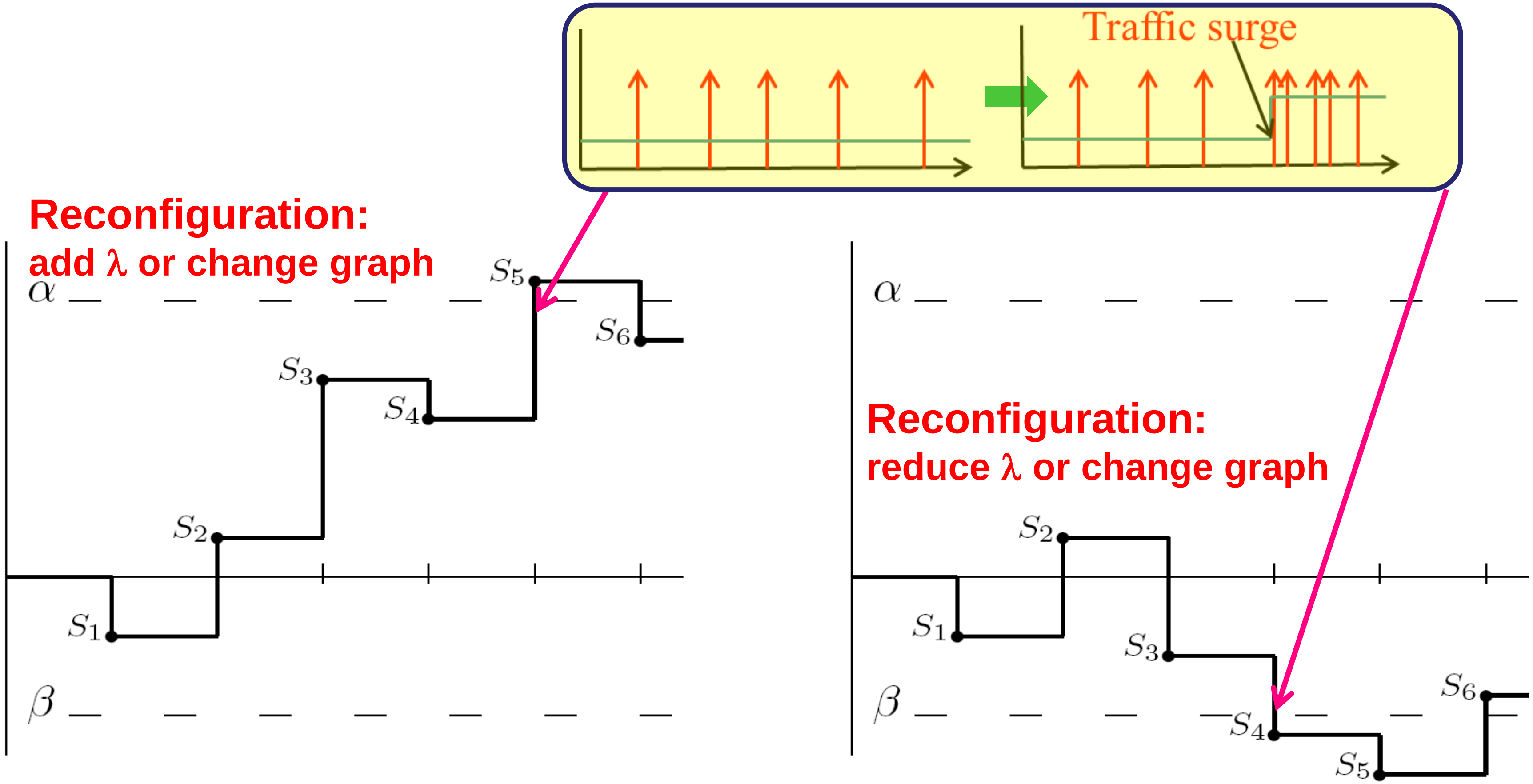
Fast reconfiguration of network topology via λ switching





- The optical cross-connect has degree Δ, connection graph selectable via λ switching, acquisition time < 1mS
- Estimate traffic rate from arrivals, cognitive techniques to infer change
- Trigger reconfiguration, reducing hop count and preventing congestion

Cognitive "Stopping trial" and MAP techniques to trigger reconfigurations



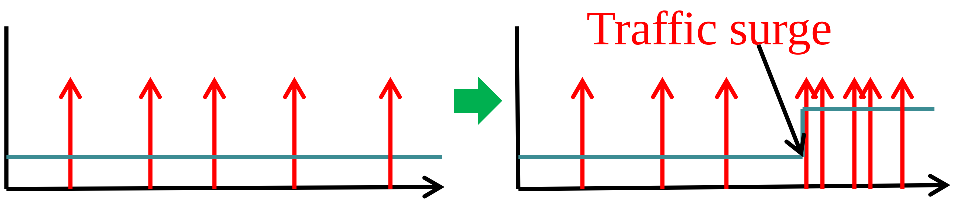
"Stopping Trial" technique to trigger reconfiguration using the Log-likelihood functions $l_{ij}(t)$ to pick Δ nodes with largest values to connect to (maximum likelihood, MAP rule)

Using thresholds α and β prevents hair-triggers on noisy data

Chernoff bound yields tightest exponential bound on ROC, "receiver operating characteristics"

CN: dynamic adaptive load balancing and congestion control

Packet arrival times, t at hub access point (AP)



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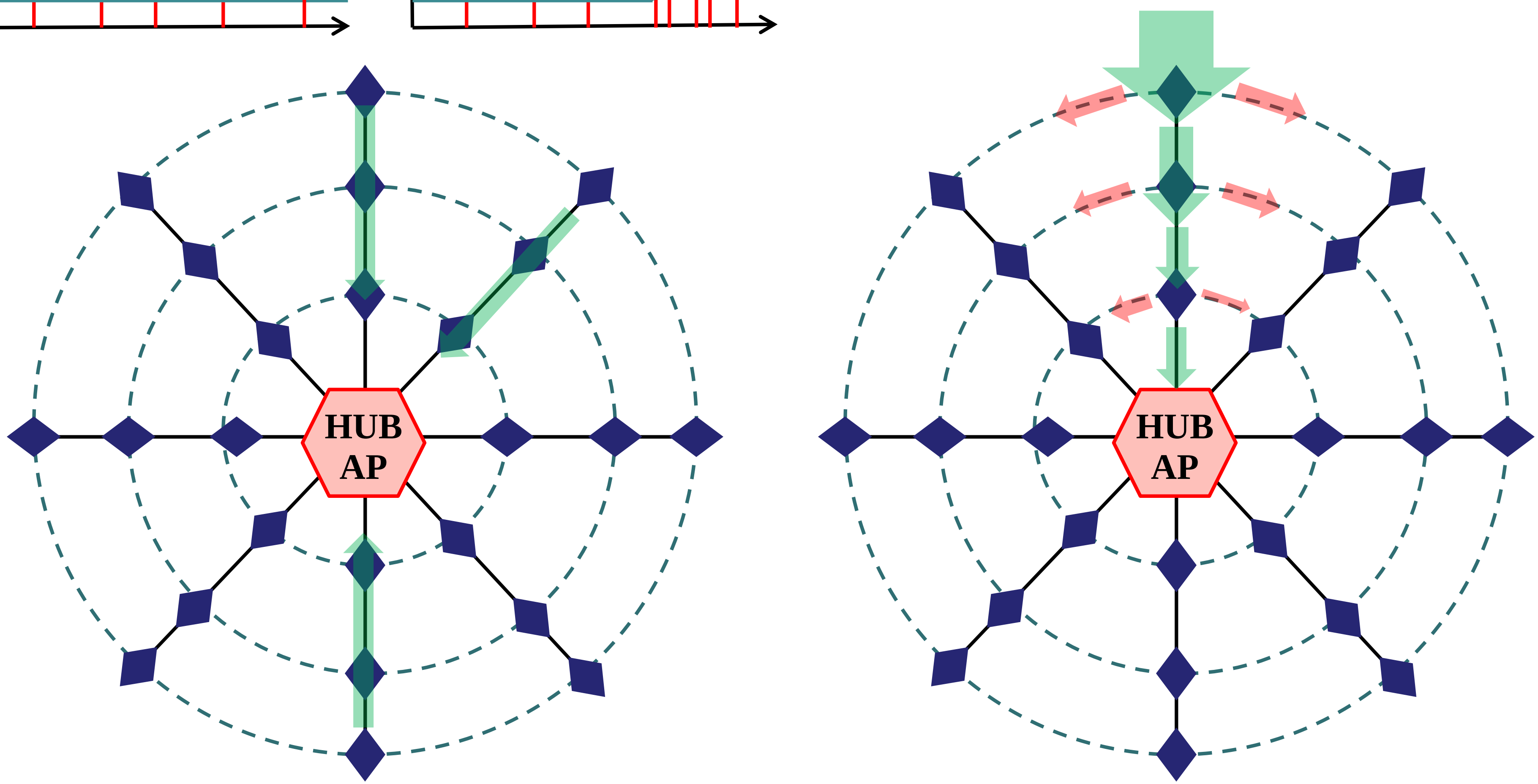
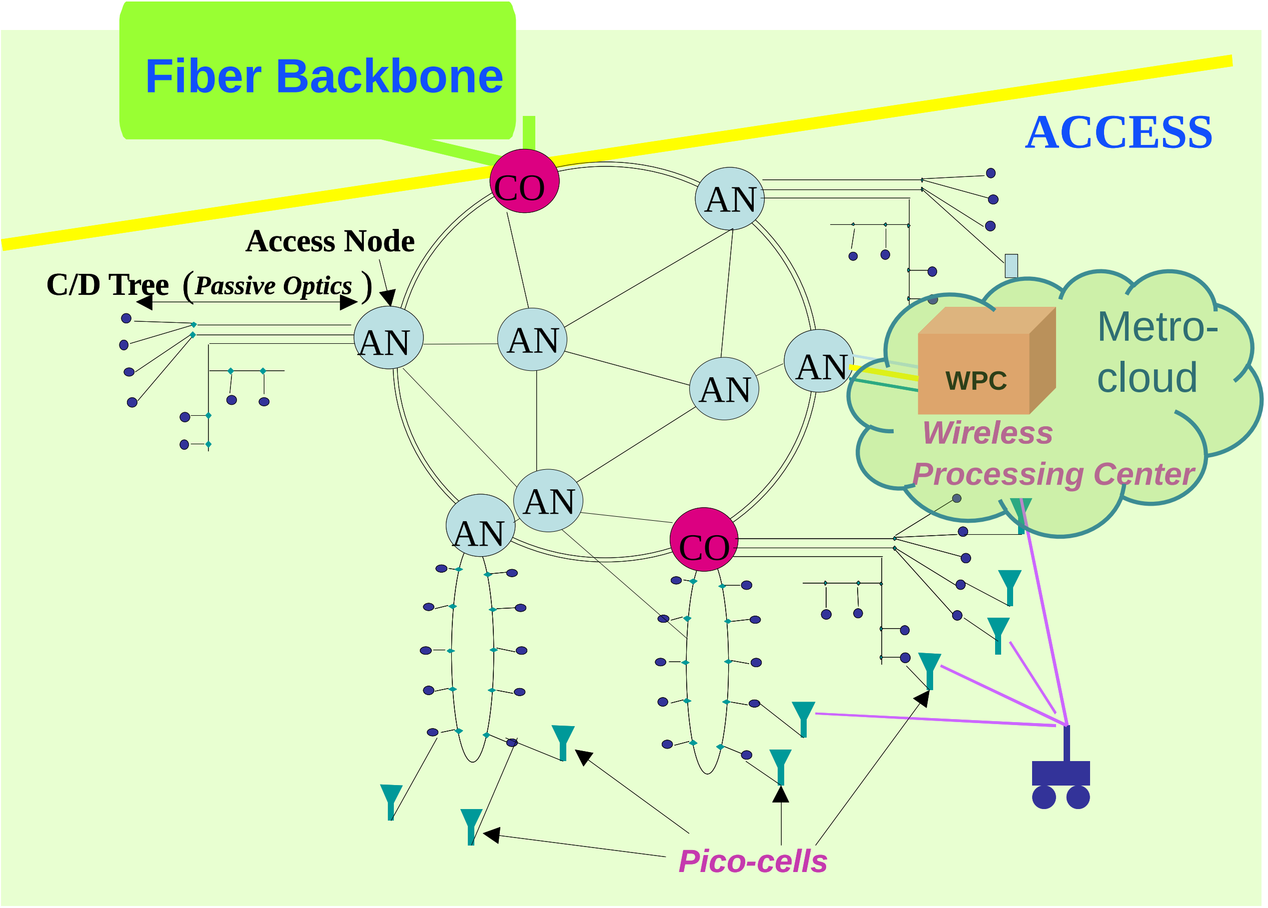


Architecture concept of future wireless

Old (expensive) communication techniques replaced by new network and computing algorithms and low cost technology innovations:→ 10X data rates



Fiber backhaul

Digital transfer of RF signals to processing center

Spatial and temporal multipath resolution

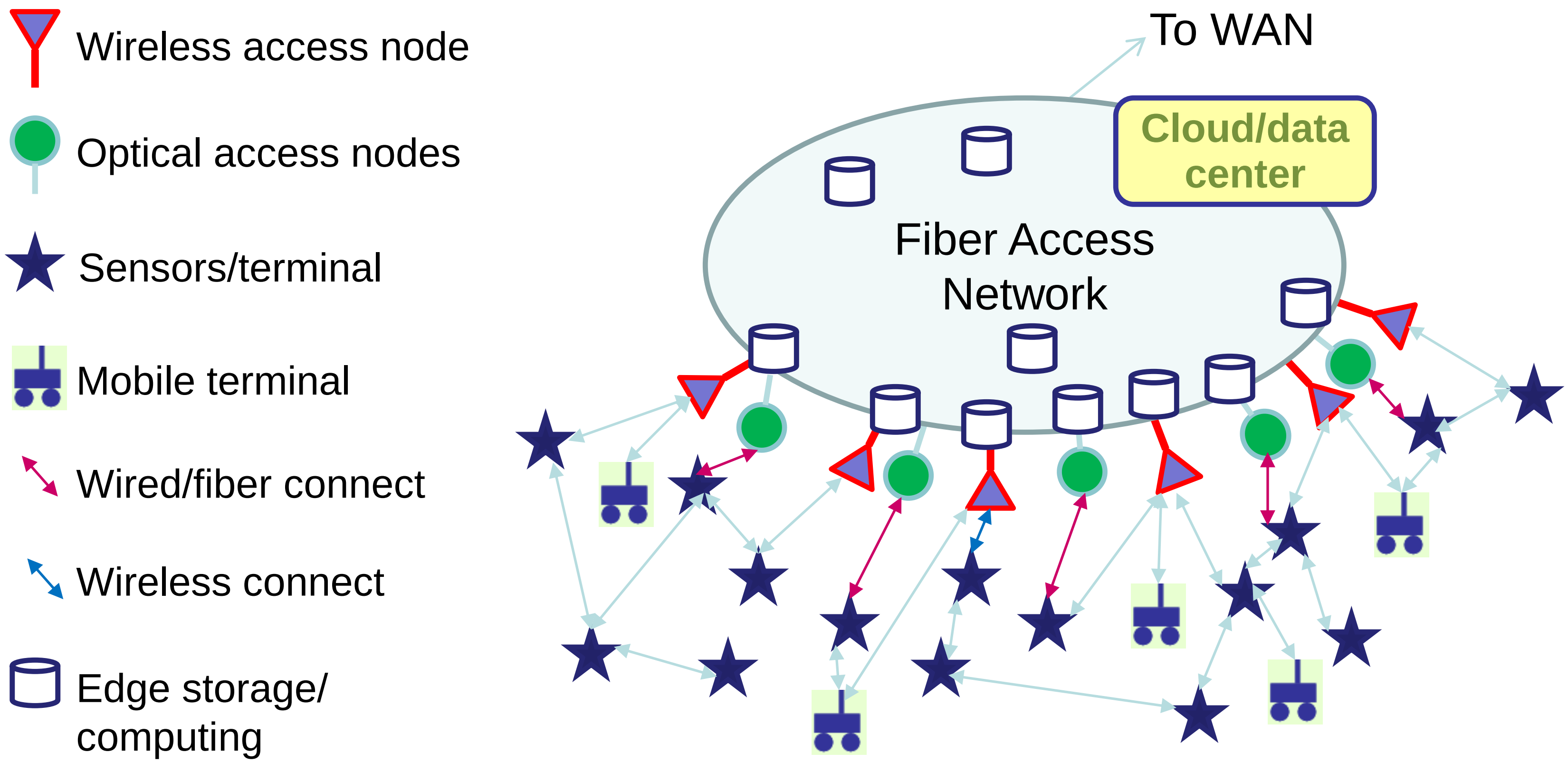
Antenna processing:

- increased rates
- maintain connectivity
- stabilizes routing and transport layer protocols

Key innovations:

- Massively parallel low cost computing cloud
- Low cost high speed ADC
- Fast algorithms

IoT Networking and Storage/Computing Concept



1. Security
2. Composable sensors/API/middle-ware/storage/computation for new applications
3. Cross correlation for reliability and monitoring of cyber physical systems.