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Shortest Path Bridges Without Routing (All-path)

(beyond link-state routing in shortest path bridges)

***Exploring Paths instead of Computing Paths** in Data Centers, Enterprise and Audio Video Bridges*

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Outline

- Our Research Statement (*Switches shall not route*)
- A bit of history. From transparent bridges to shortest path bridges. *(mixing up again layers 2 and 3)*
- Path Exploration versus Path Computation (SPB)
- All-Path family of protocols
  - ARP-Path, Flow-Path, Bridge-Path, Path-Moose
  - Results *(native load distribution, lower latencies)*
  - Openflow **and** All-path
- Publications and Implementations
- Conclusion

Our Research Statement

- Develop Advanced Ethernet Switched Networks
  - Simplicity as a requirement for scalability
  - Architectural consistency with bridges.
    - No Router inside the Switch
      - Avoid “hybrids” as much as possible
    - Coherence with existing transparent bridge mechanisms
  - Core-island compatibility with standard bridges is sufficient
    - Like RSTP and 802.1 protocols (point to point links required)
    - Full miscibility of advanced and new bridges adds too much complexity and departs from Ethernet (e.g. TRILL header)

Our Research Statement

- Applicable to Wired and Wireless Networks
  - But 802.1 and 802.11 architectures are too different!
    - Access Points functionality has little relation with bridge architecture
  - Now, integration is ongoing at IEEE (Klein's BSS Bridging 2012)
    - 802.1 BSS Bridging. Seamless coexistence of 802.1 and 802.11 networks.
    - The whole BSS is modeled as a distributed bridge overlaying the 802.11 protocol
    - Access Point acts as the Bridge's Control Plane
    - Stations act as Bridge Ports
  - Protocols for wired switches will likely run on hybrid networks without modification (e.g. All-path)

http://www.ieee802.org/1/files/public/docs2012/avb-phkl-80211-bss-bridging-0512-v1.pdf

Our main contributions in Advanced Ethernet Switches (2004-2013)

- AMSTP (2004)/Abridges. IEEE LCN 2004.
  - Supersimplified self configuring MSTP protocol.
- All-Path protocols family 2010-2013
  - *This* presentation
- Torii-HLMAC (2011-2013). (Improvement and generalization of Portland for Data Center)
  - *Presented at Forum 1A by Elisa Rojas.*
    - *Also without link-state routing*

Our approach to Shortest Path Bridges

- Look for **Pure Bridging Mechanisms**
  - *Bridging = Flooding frames + address learning*
  - Loop prevention needed (active topology of tree/s)
- If a broadcast frame is flooded over **All** links
  - We can find the shortest path to destination easily
- How do we prevent loops?
  - **Lock** source address learnt to the port of first arrival.
  - **Discard** all frames with this MAC source address received at other ports.
  - It is a kind of Reverse Path Forwarding at layer two

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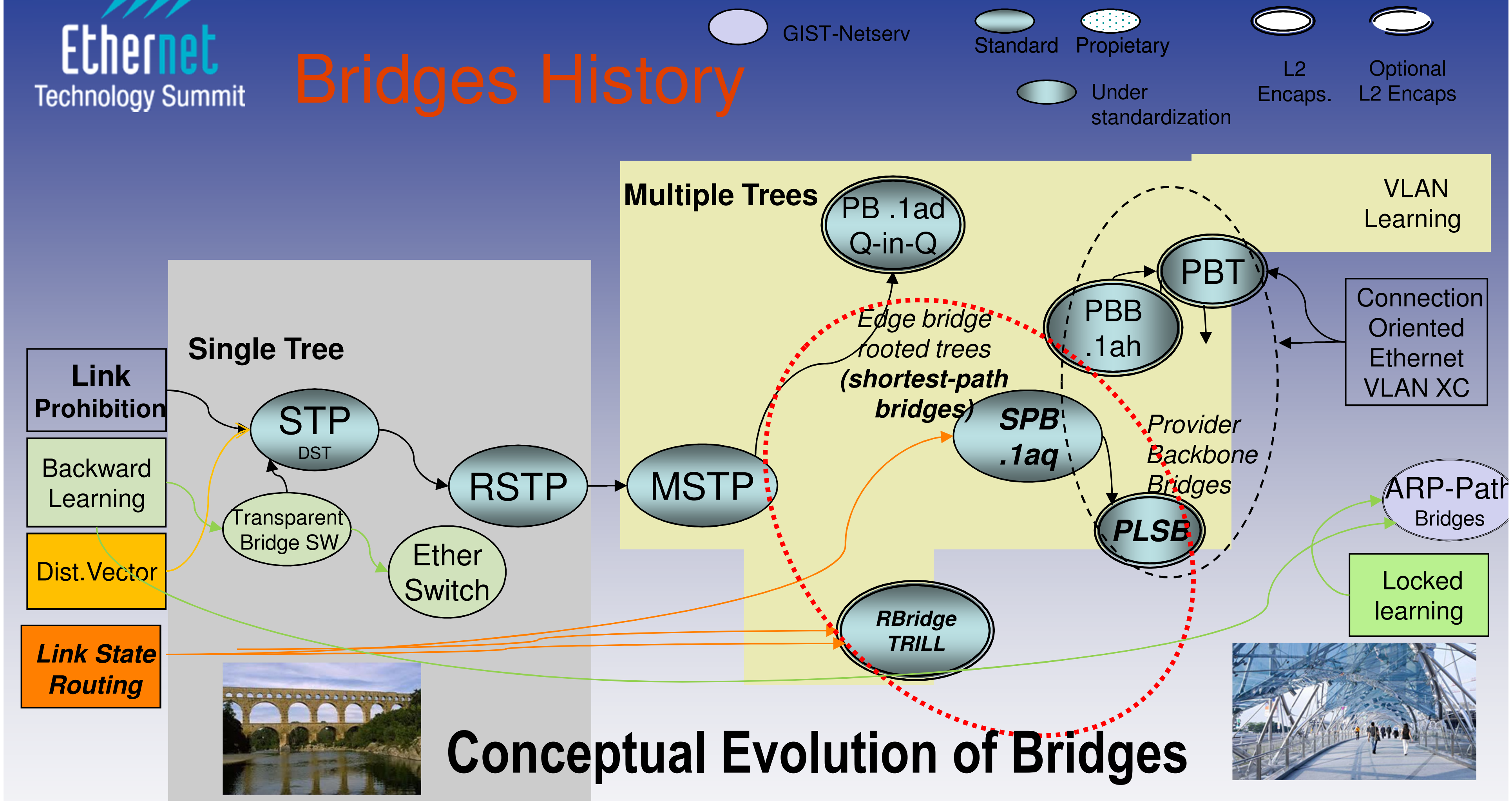
Bridges History



From single to multiple spanning tree protocols, then link-state computation of shortest path trees

1984 1991 1994 1998 2000 2002 2003 2004 2005 2006 2007 2008

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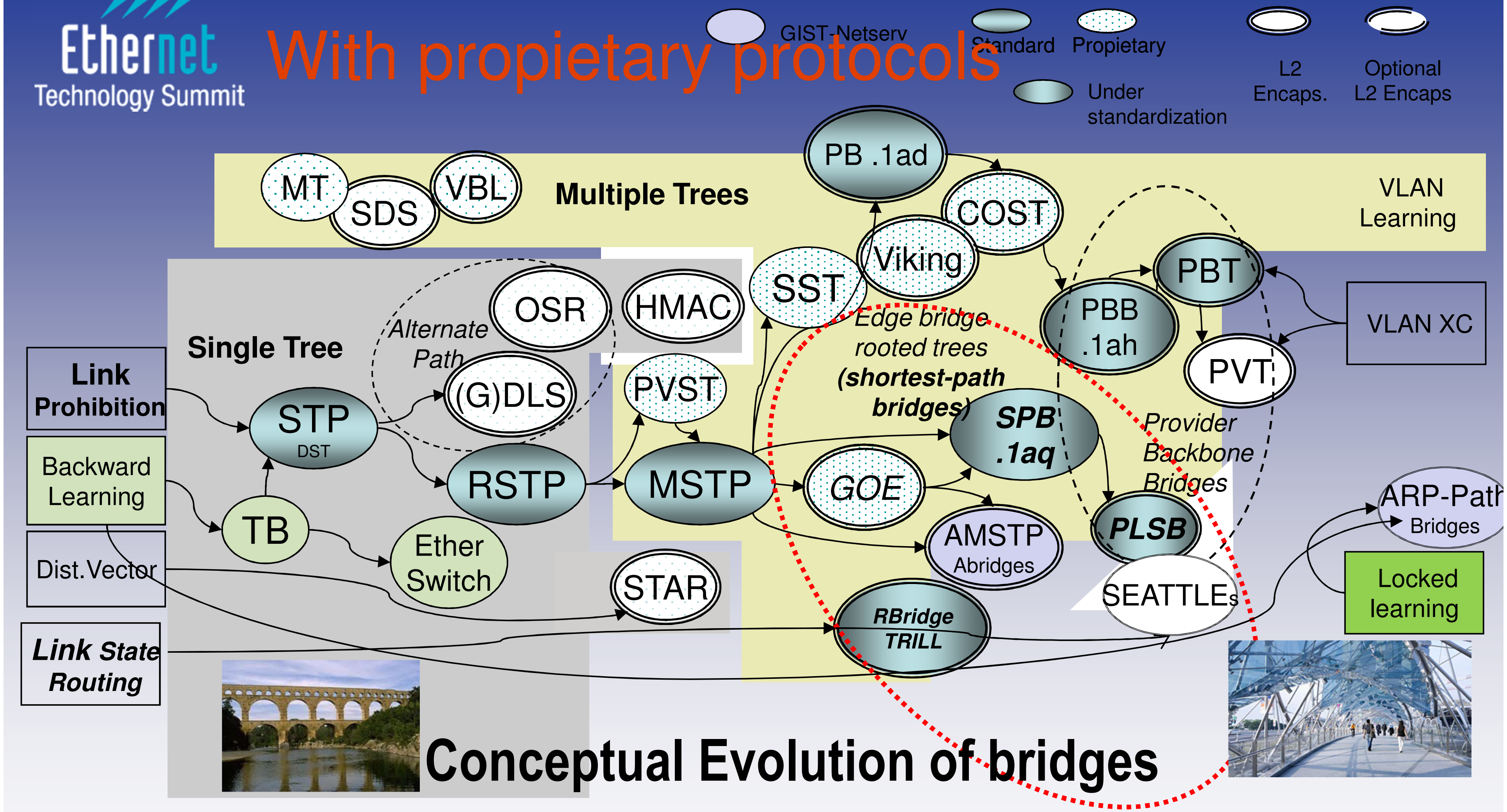
With propietary protocols



From single to multiple spanning tree protocols, then link-state build of shortest path trees

1984 1991 1994 1998 2000 2002 2003 2004 2005 2006 2007 2008

Shortest Path Bridging history

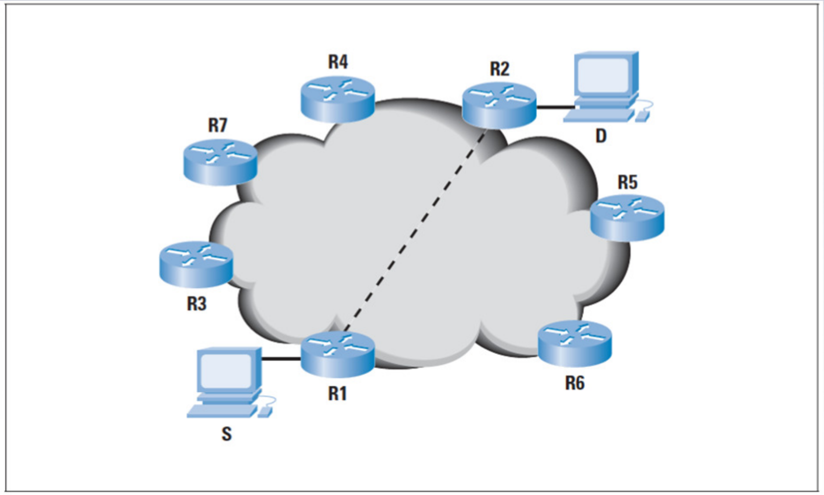
- How did Shortest Path Bridges start?
  - Need for single IP subnet at campus networks
    - Avoid IP addresses administration (even with DHCP)
    - Key for Data Centers: virtual servers move frequently
  - RSTP blocks links, MSTP is too complex to configure
- "Link-state routing protocols are fast and proven"
- Then: "Let us use them also at layer 2"
- Implicit assumption: ***" Bridges will never be as good as hybrids of bridge and router"*** ***(… unless you think outside the box!)***

Shortest Path Bridging

- Current situation: Two competing standards
- But **both use the Link-state Routing** paradigm for Shortest Path Bridging
  - – IEEE 802.1aq SPB Standard uses a IS-IS L2 variant
  - – TRILL Rbridges (IETF) also use IS-IS Layer 2 variant
- Problems
  - SPB 802.1aq focused on provider networks (tagging)
    - – Not focused in data centers and enterprise networks
    - – Interest seen on SPBM (MAC in MAC), but not on SPBV
  - TRILL is not a fully satisfying alternative
    - – Simplicity was lost to get full miscibility with std bridges(IMHO)
    - – Misalignment with existing ASICs and IEEE 802.1

Enterprise networks

- Transparent Interconnection of Lots of Links (TRILL) – Routing Bridges (RBridges)
  - TRILL header (modified at each hop)
  - IS-IS
  - Layer 2 and ½
- Manufacturer support?



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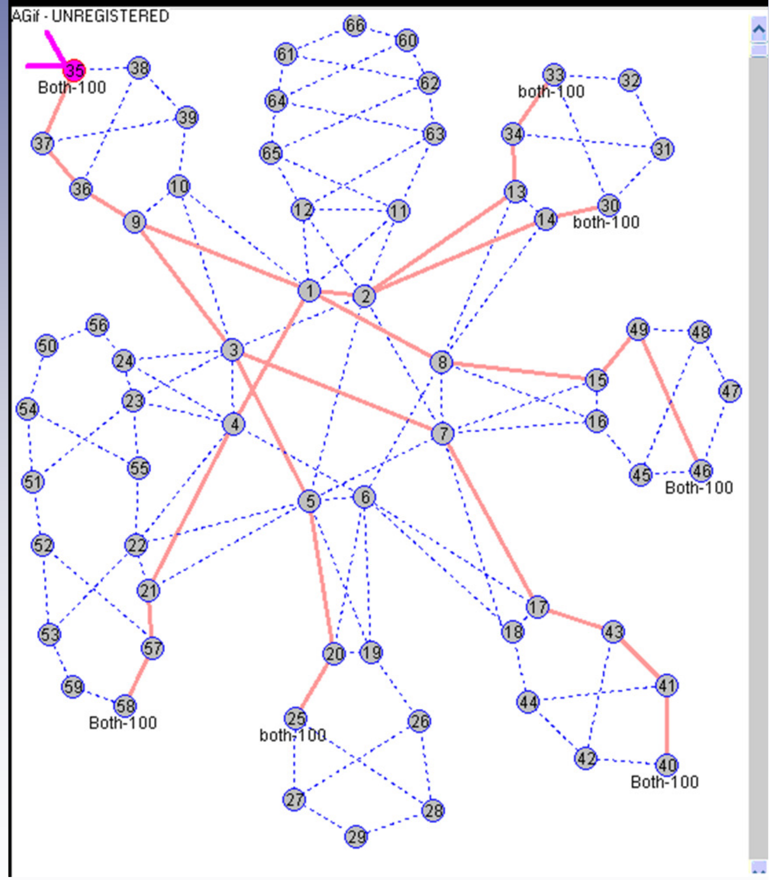
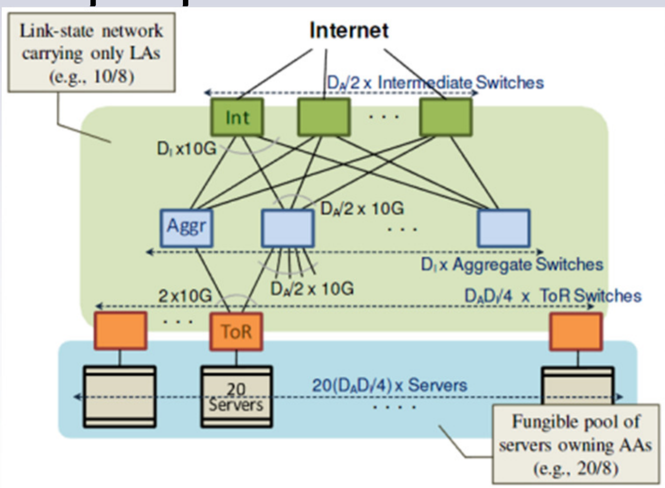
Enterprise networks

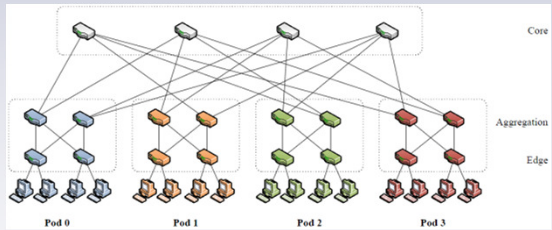
- Shortest Path Bridging (SPB)
  - Path congruency as a must
    - – Needed for loop prevention
  - IS-IS modified
    - – Path Vector
    - – Complexity escalates
      - – With multipath (N**3) and congruency requirements
    - – ECMT
  - SPBM/SPBV

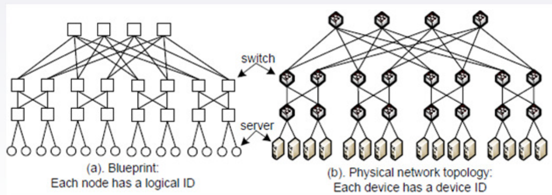


Data center networks

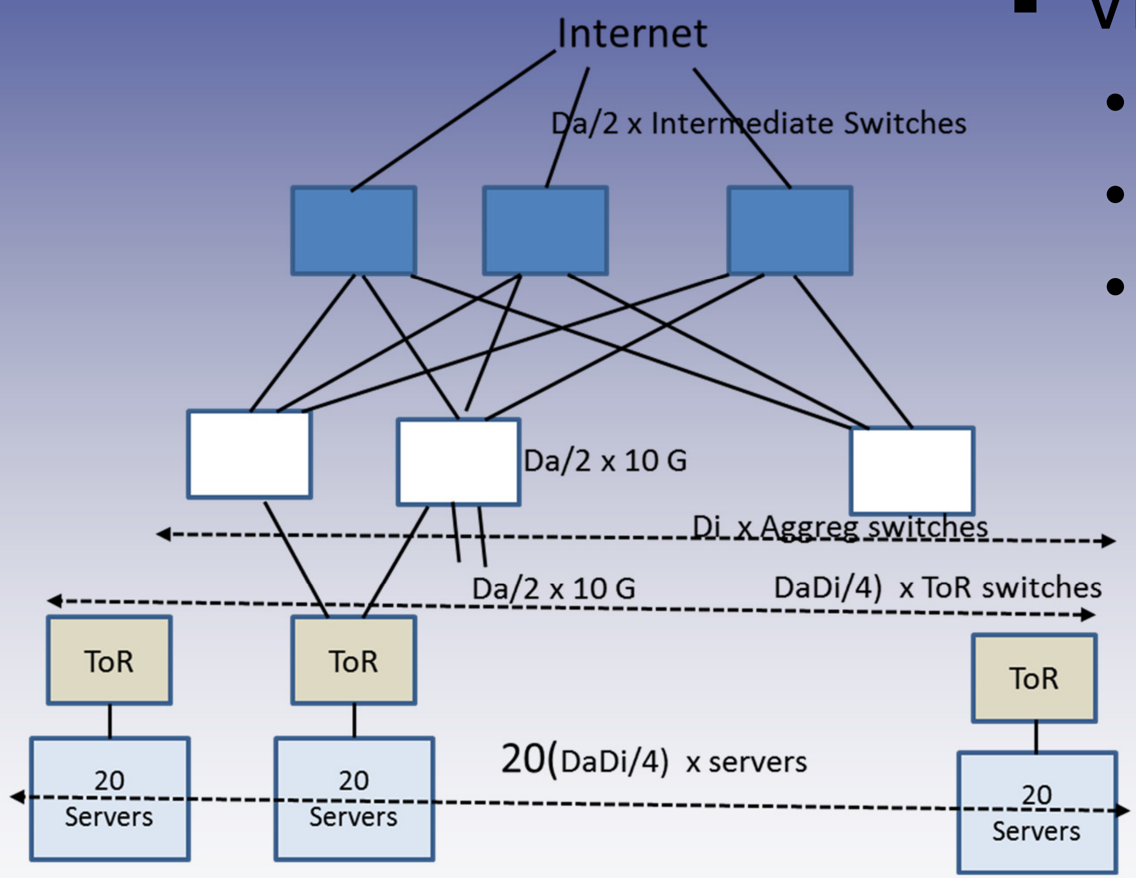
- **Data center** networks are increasingly relying on **Ethernet** and flat layer two networks
  - Due to its excellent price, performance ratio and configuration convenience
- Recent architecture proposals:
  - **VL2**
  - **PortLand**
  - **DAC**
    - Blueprint





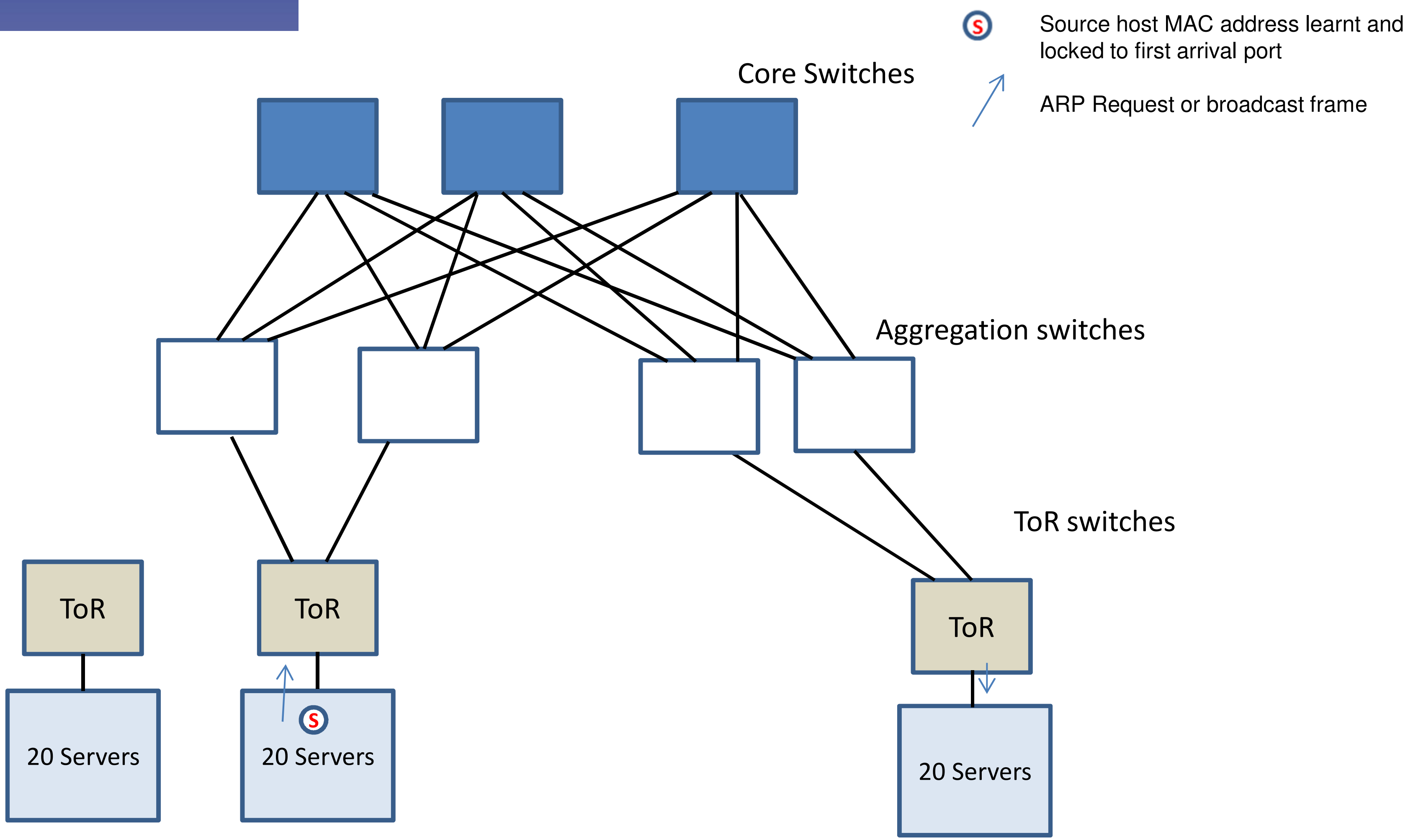


Data Center network example:VL2

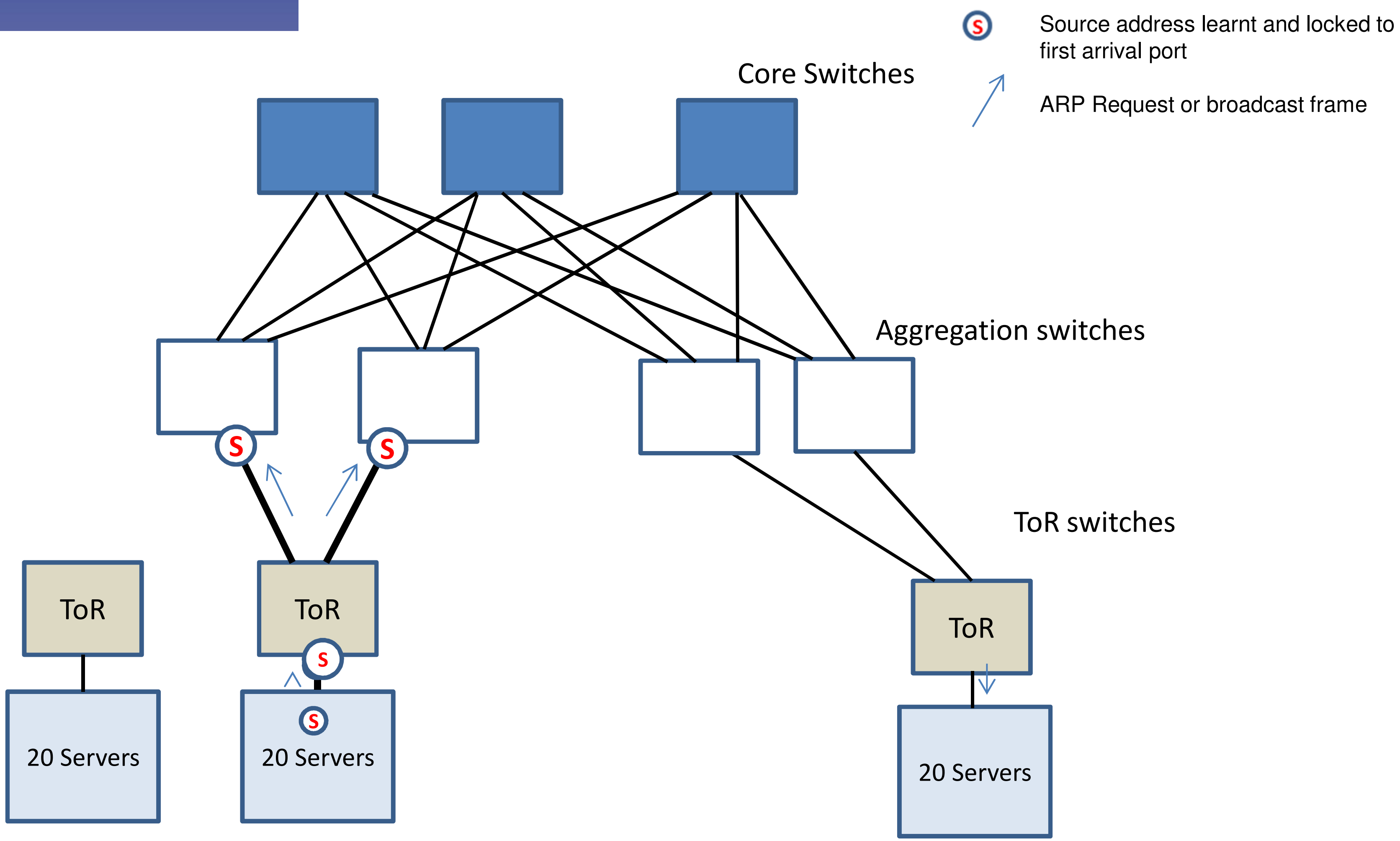


- VL2 folded Clos
  - Commodity switches
  - Valiant Load Balancing
  - Distributed directory
    - Manages IPs

Path Exploration without loops in a VL2 Data Center network



Path Exploration without loops in a VL2 Data Center network



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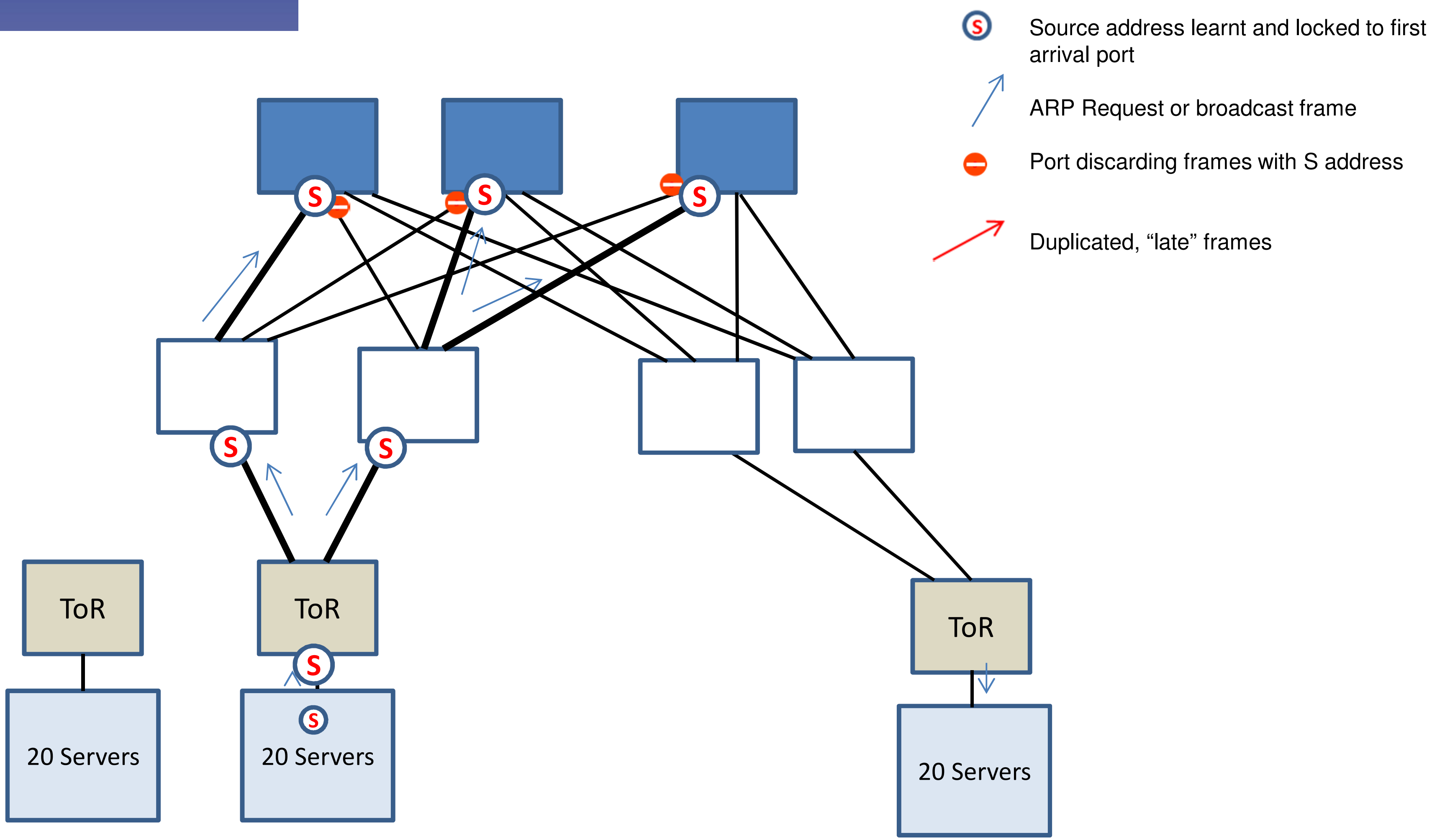

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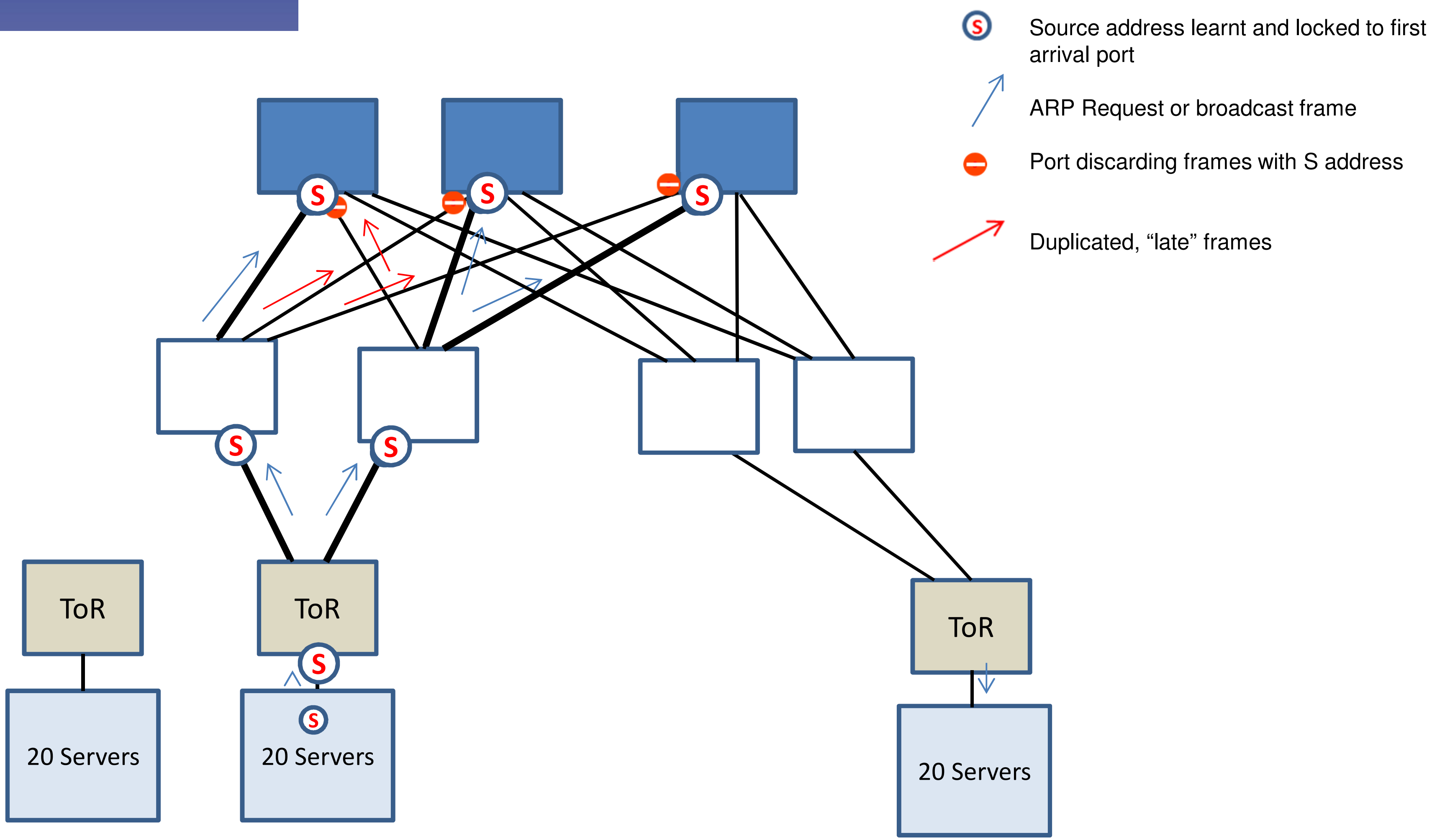

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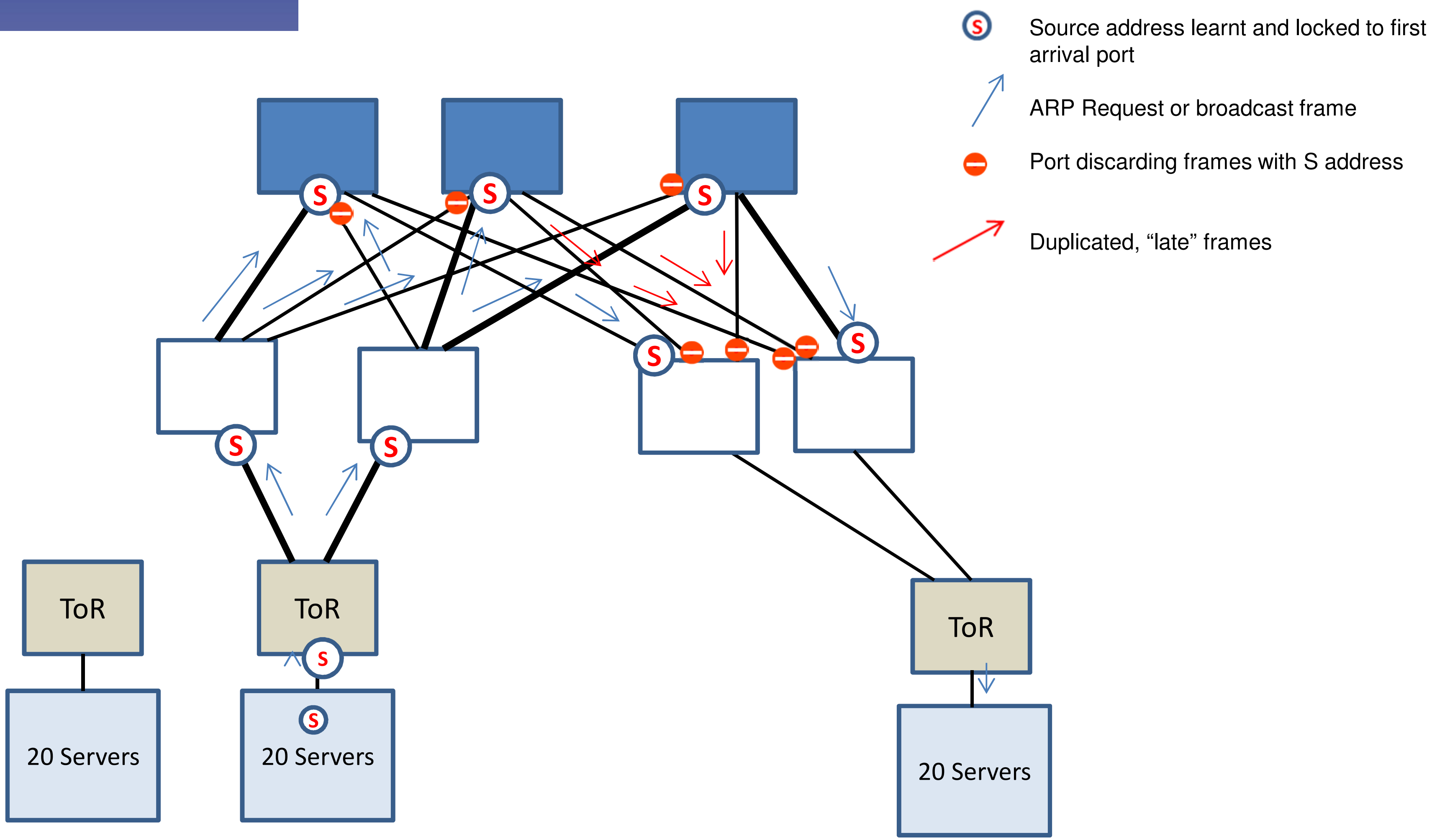

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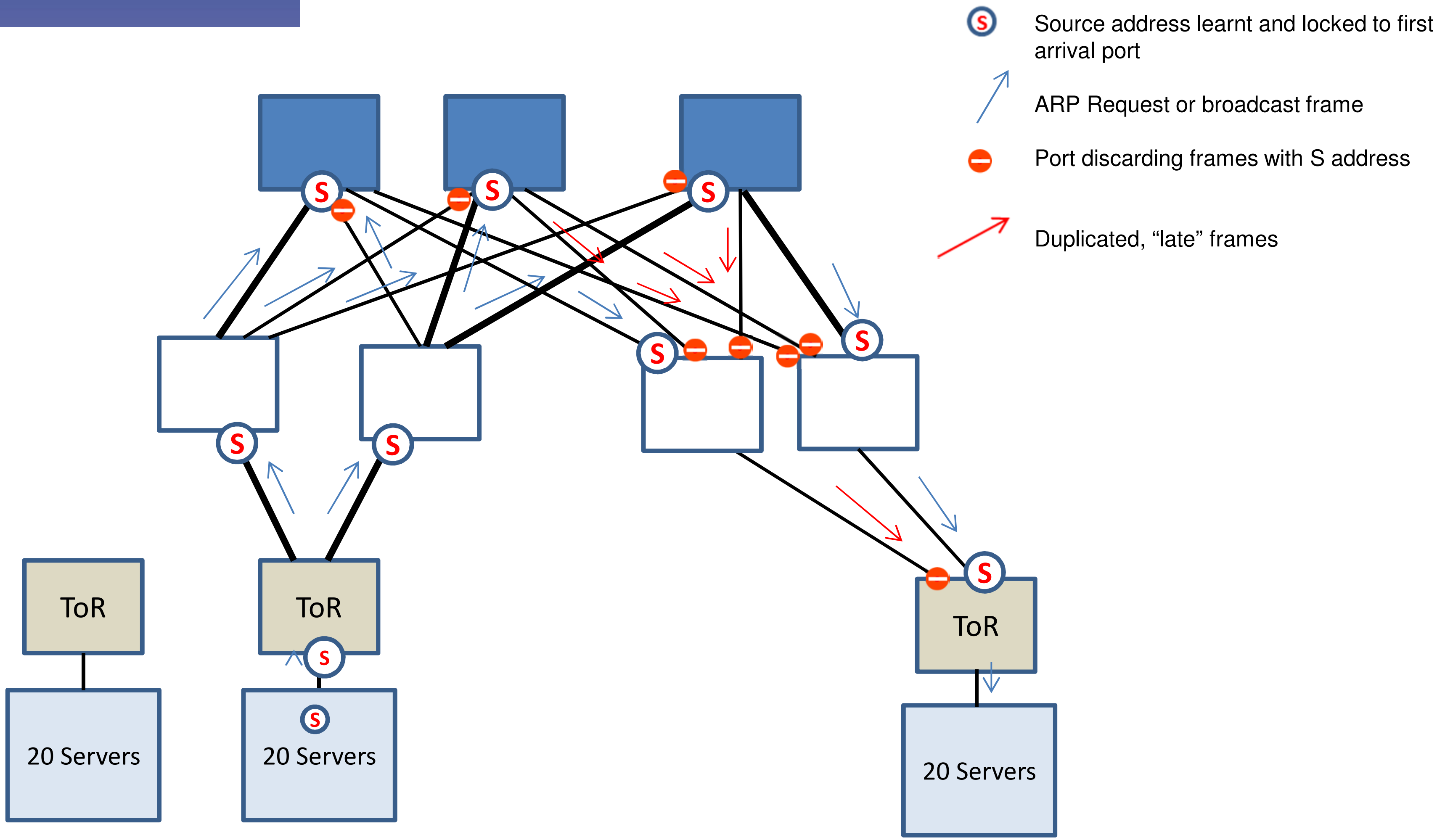

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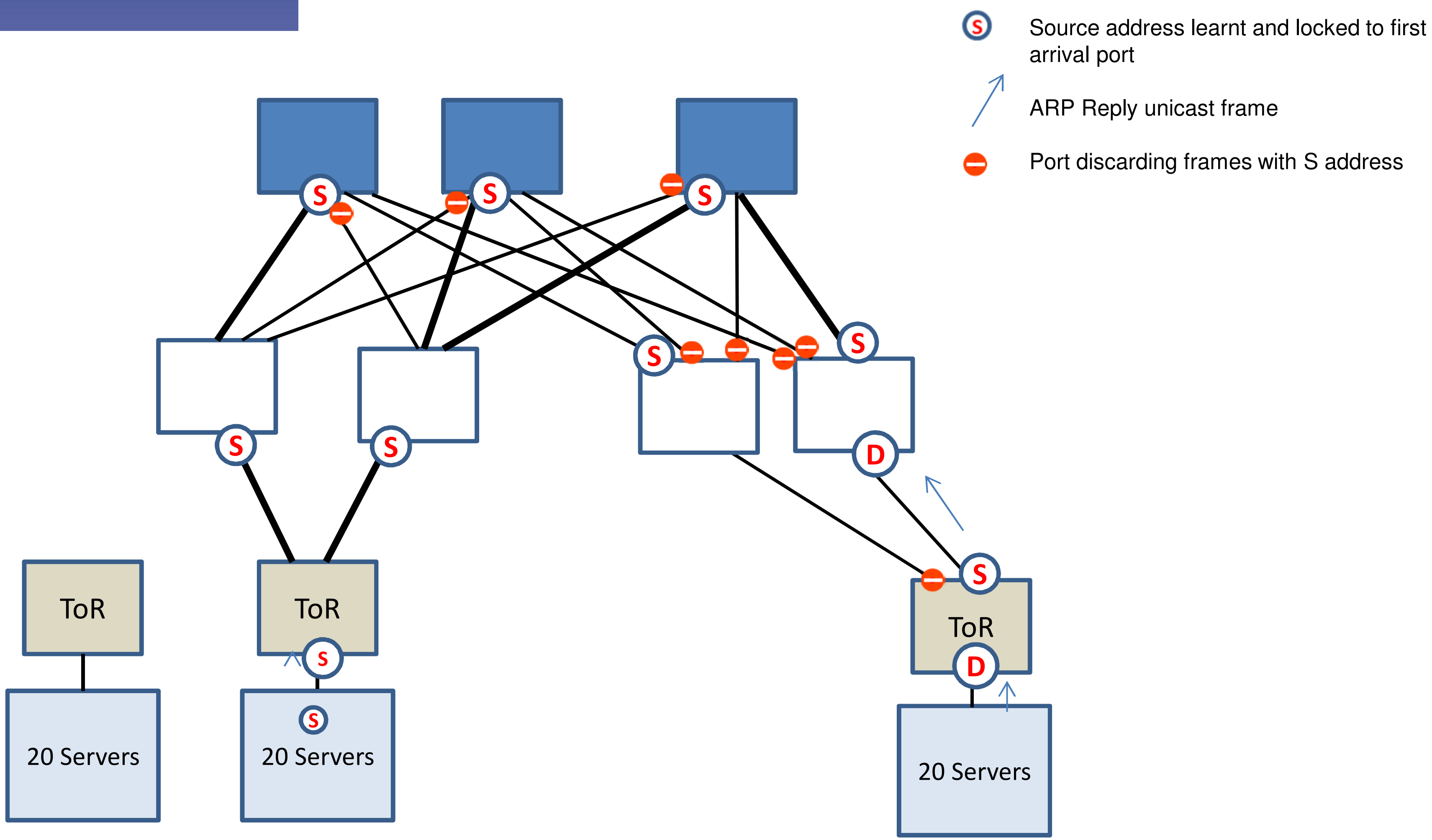
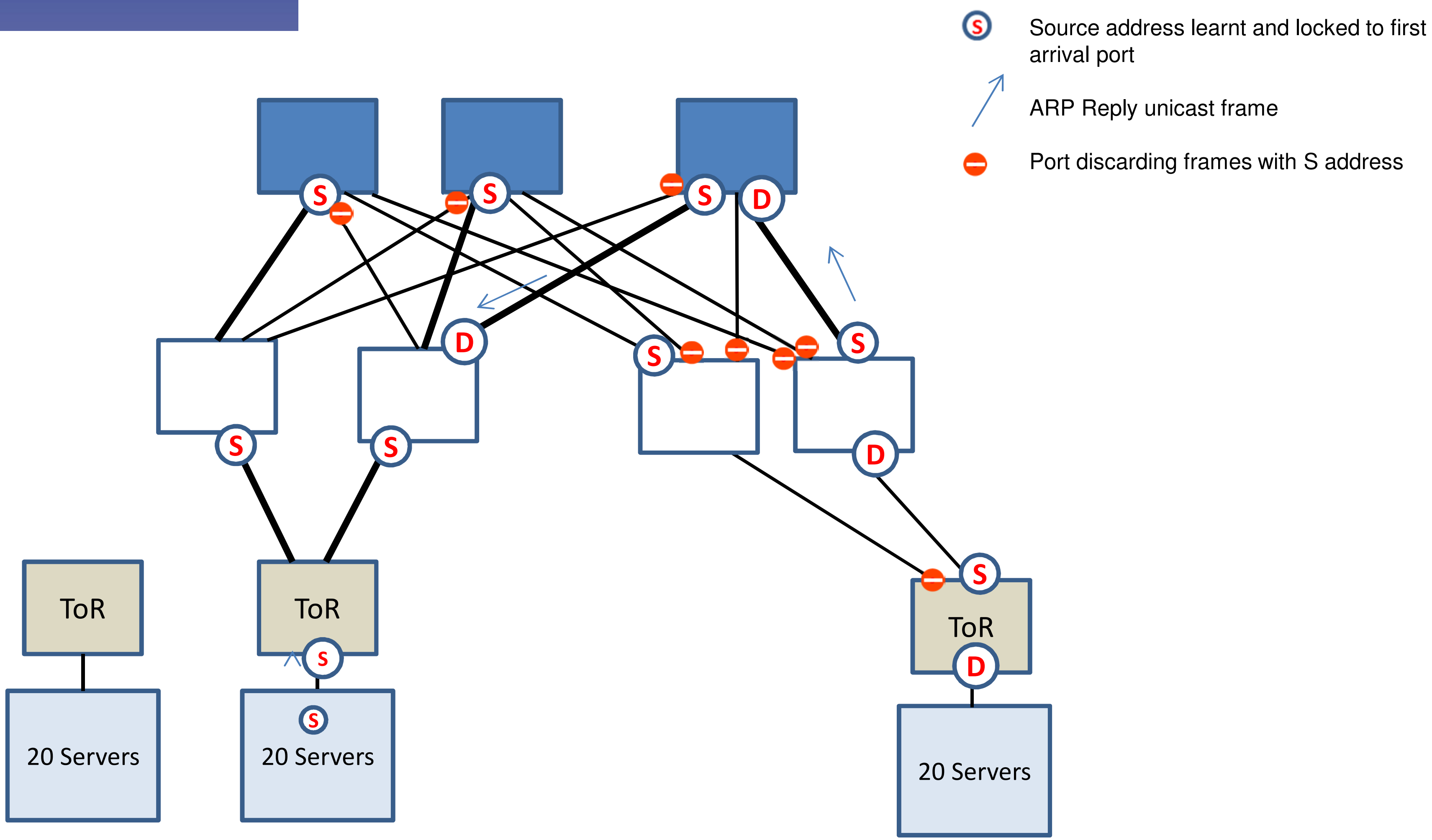
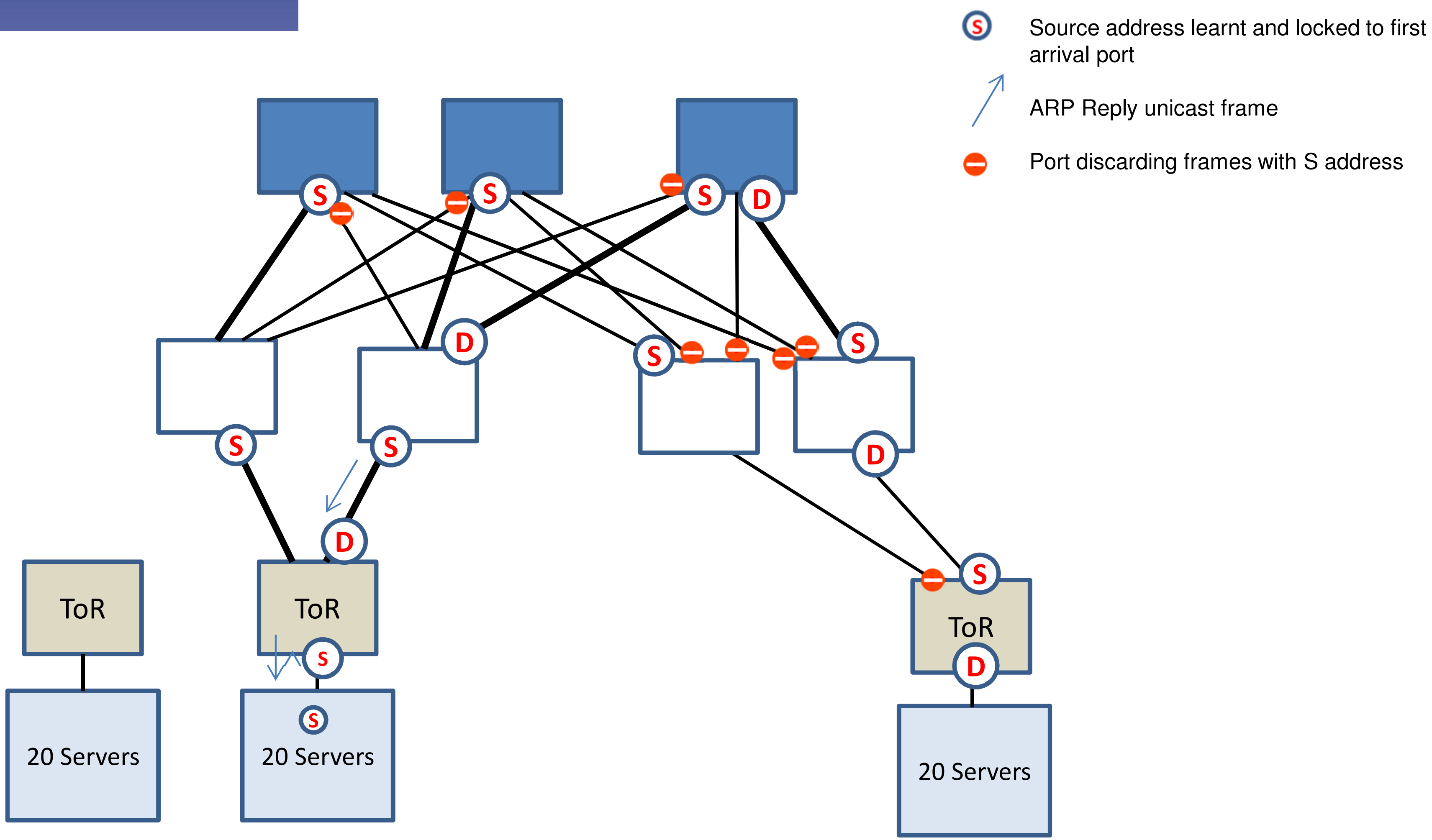


Path Exploration without loops in a VL2 Data Center network

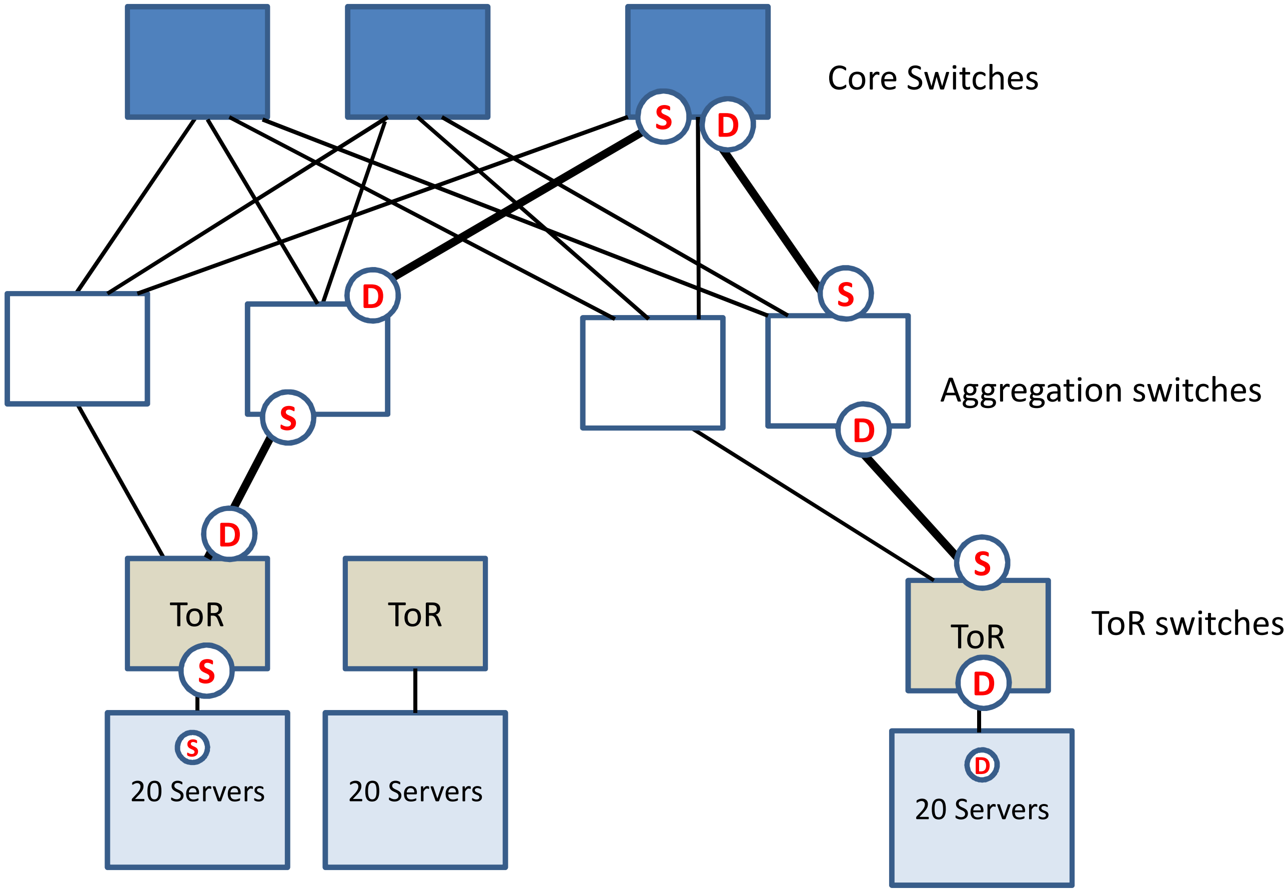


Path Exploration without loops in a VL2 Data Center network



Path Exploration without loops in a VL2 Data Center network

Addresses not refreshed expire at unused branches
Path completed in both directions



Path Exploration without loops in a VL2 Data Center network

Addresses not refreshed expire at unused branches
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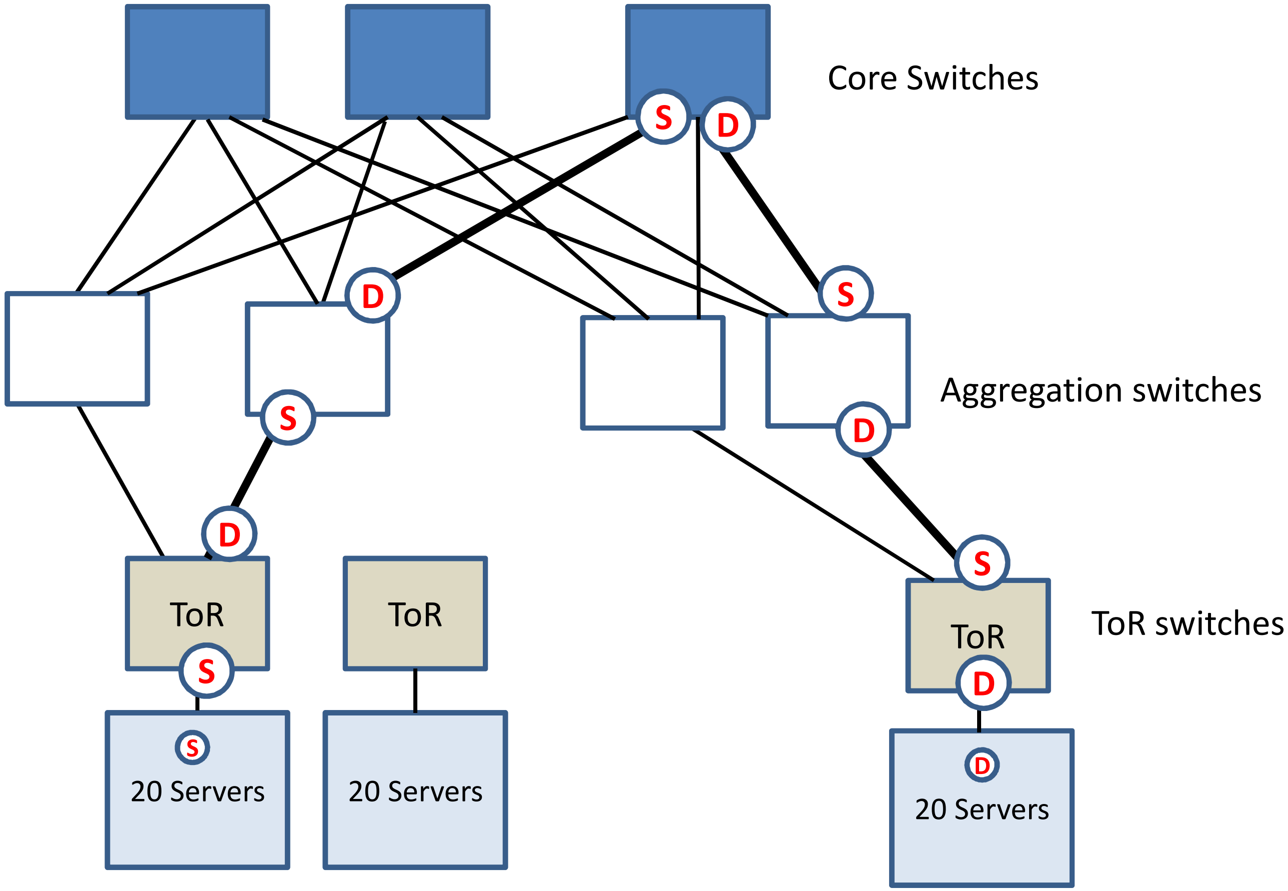


Path Computation vs Path Exploration

- Complex path computation
  - powerful processors avail.
- Path diversity (ECMP) increases complexity

- Multicast complexity
- VLAN IDs linked to trees

- Simple path discovery
  - Flooding and learning
- Native path diversity
  - Load adaptive routing
- Varied path granularity
  - Per host, per flow, per bridge.
- Simple multicast
  - Instantaneous building of source rooted trees
  - Straightforward IGMP snooping
- VLAN, tag independent

Path Computation vs Path Exploration

	Link State (SPB)	All Path
Forwarding state (CAM)	*O(b+h)*	*O(h)*
Routing state	*O(b*d+h)*	≤ *O(h)*
Number of messages	*O(b*E)*	Standard ARP messages + extra flood: *h*(E-N+1)*
Computational complexity	*O(b*log(b) +h)*	One CAM look-up (MAC, port)
Convergence time	*O(path length bs)*	*Negligible (extra processing of ARP at ARP Path bridges)*
Fault recovery	Messages O(2*E) Time *O(path length bs)* Recompute *O(b*log(b))*	Messages *O(2*E*hostlink)* Time *O(path length bs)* Recompute *O(b)*
Path diversity	*O(b*b*log(b))*	*O(b)*

All-Path protocols family

- ARP-Path
  - The initial protocol: host-oriented. Per host, on-demand paths. Learns source (SA) MAC addresses.
- Flow-Path
  - Follows the basics of ARP-Path but it's flow-oriented
    - Learns SA-DA address tuples
- Bridge-Path (& Path-Moose)
  - Instead of building paths between hosts (like ARP-Path and Flow-Path), they create paths/trees between edge bridges for added scalability

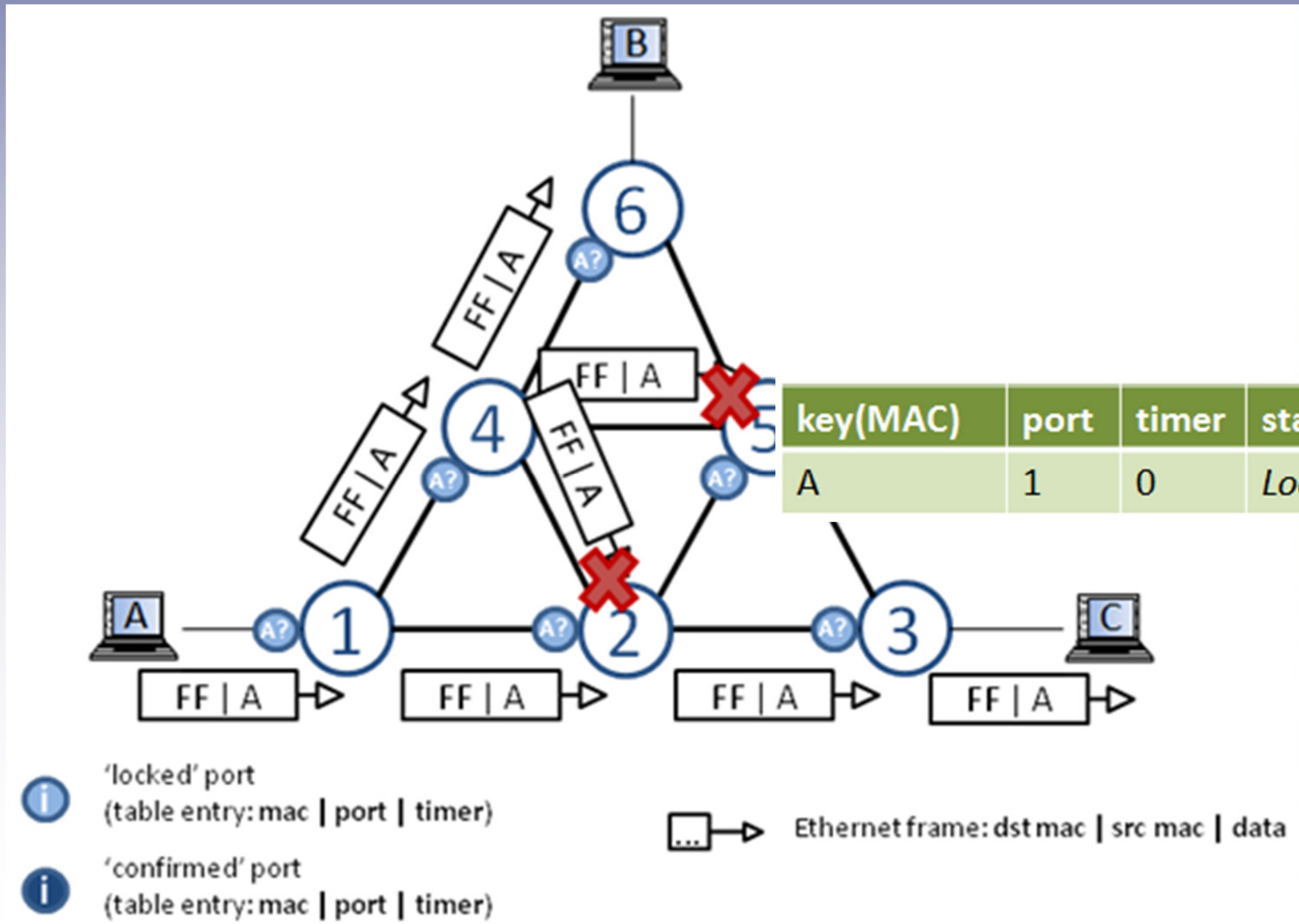
ARP-Path

- Features:
  - Zero configuration
  - Source address learning (SA)
  - Low latency paths
  - Load balancing
  - Pure bridging protocol → learns by snooping broadcast messages
  - Path symmetry not guaranteed

How does ARP-Path work ? (video)

- *(Click on link below to see the video)* https://www.youtube.com/watch?v=IhwCYAu_E7E

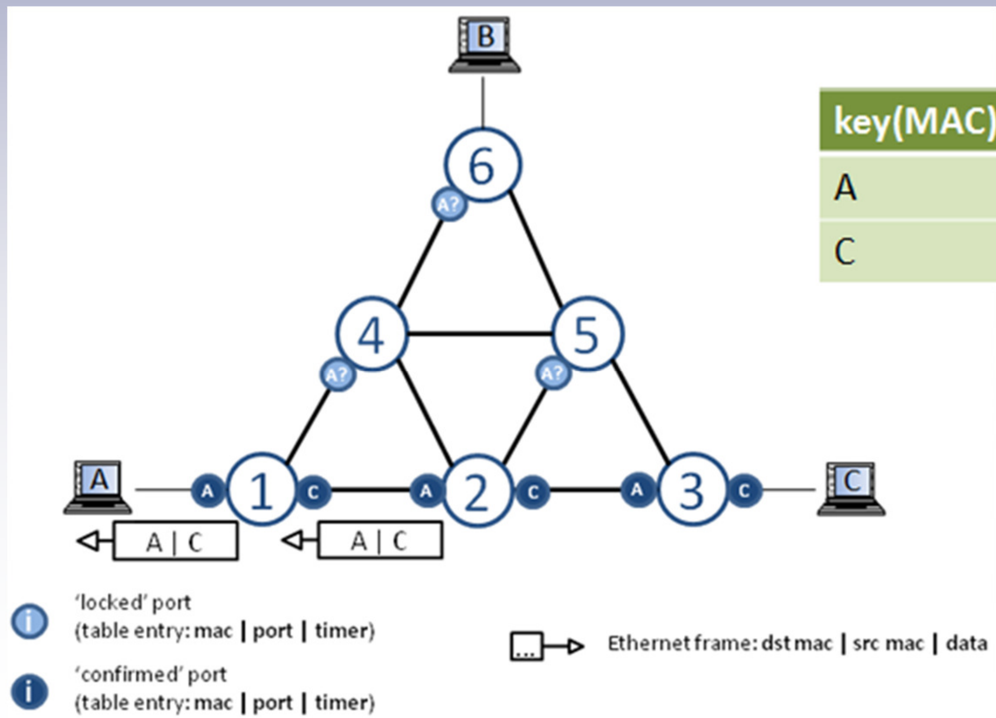
ARP-Path 1.0 (aka FastPath) Path discovery (ARP Request)



key(MAC)	port	timer	state
A	1	0	*Locked*

ARP-Path

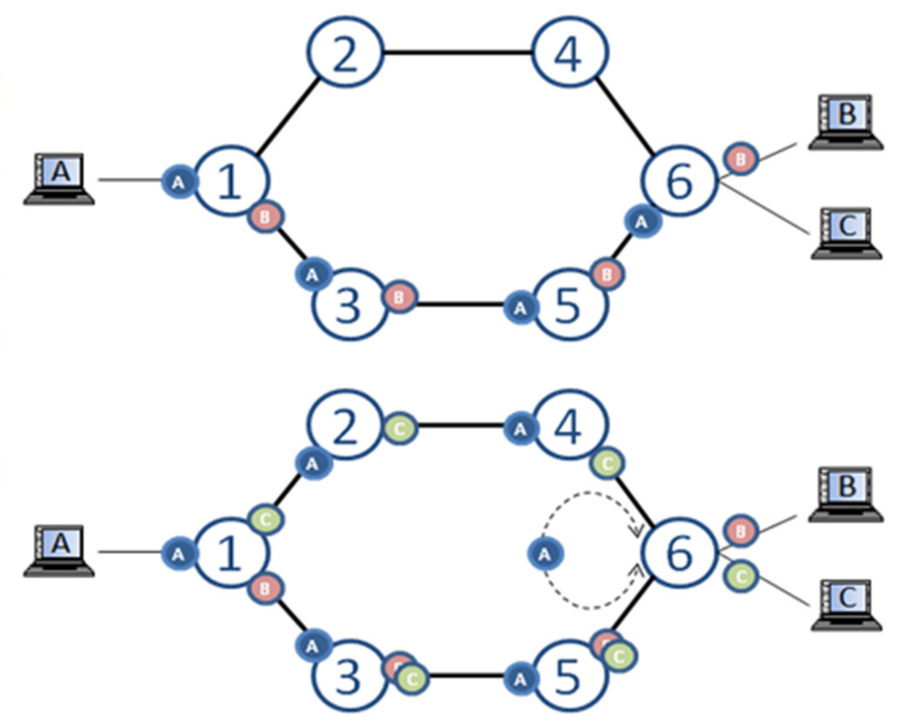
- ARP-Path 1.0 (FastPath)
  - Path confirmation (ARP Reply)



key(MAC)	port	timer	state
A	1	0	*Confirmed*
C	2	0	*Confirmed*

ARP-Path

- ARP-Path 1.0 (FastPath) has some issues
  - Backwards learning refresh → Path symmetry needed
  - Some paths oscillate
  - Confirmation → Repair flag

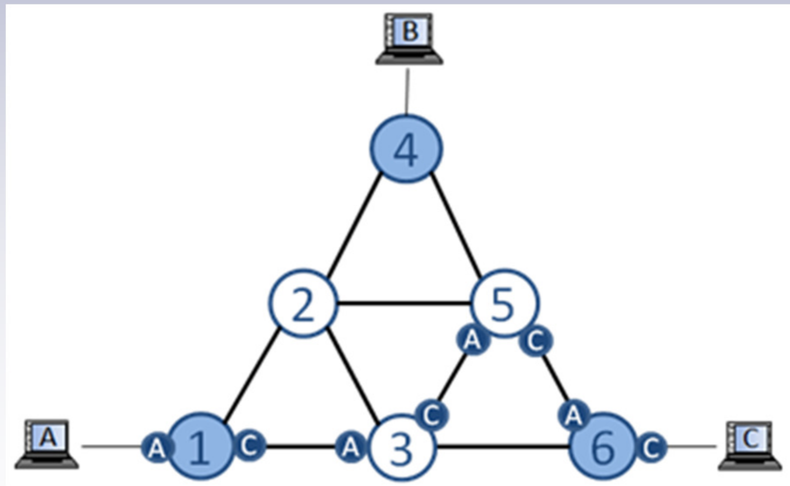


ARP-Path improved version

- ARP-Path 3.0 (alternative unidirectional)
  - Paths tend to be stable (just changed by repair)
    - No oscillations
    - No risk of transient frame disorder

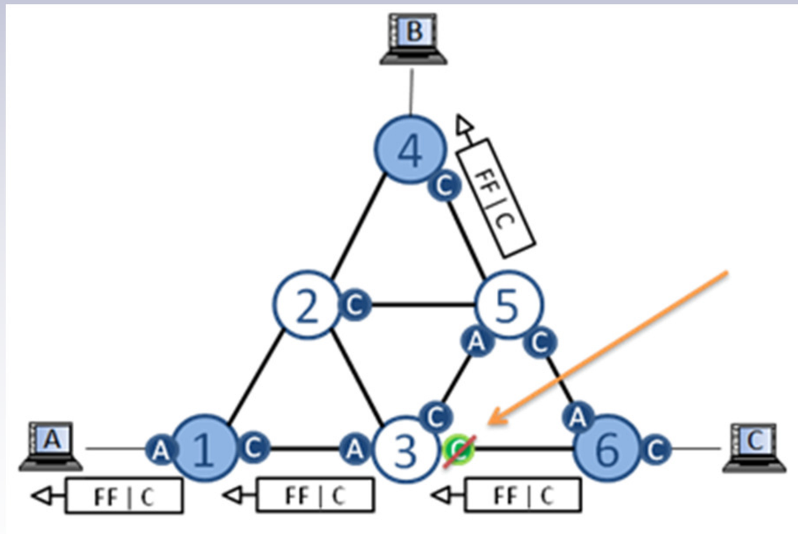
ARP-Path

- ARP-Path 3.0 (alternative unidirectional)
  - Discovery and path creation works as in 2.0 when there are no paths



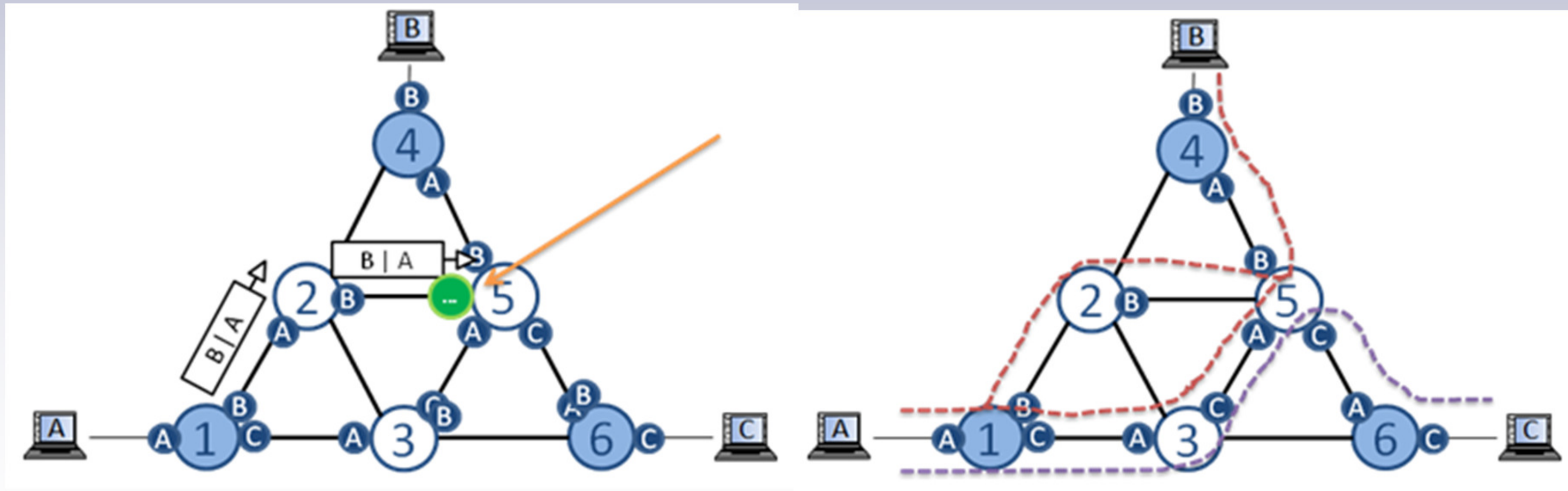
ARP-Path

- ARP-Path 3.0 (alternative unidirectional)
  - Discovery and source path creation (ARP Request)



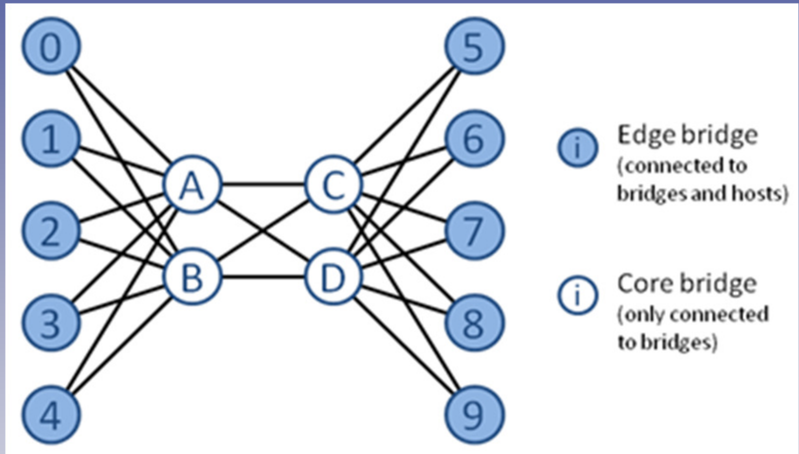
ARP-Path

- ARP-Path 3.0 (alternative unidirectional)
  - Destination path creation (ARP Reply)



ARP-Path

- Low latency paths:
  - OMNeT++

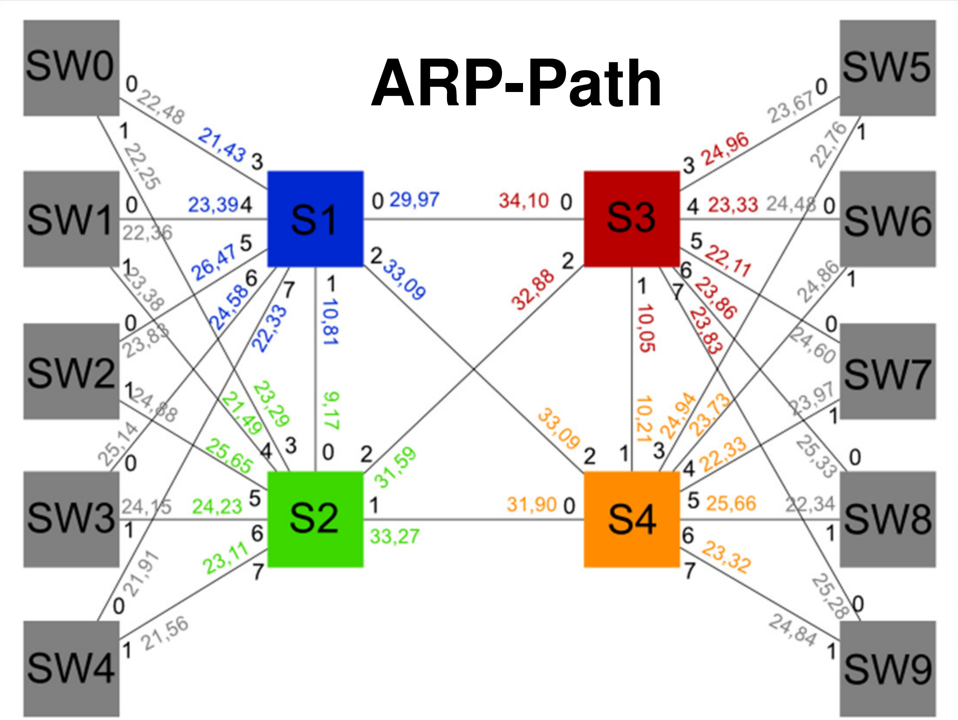


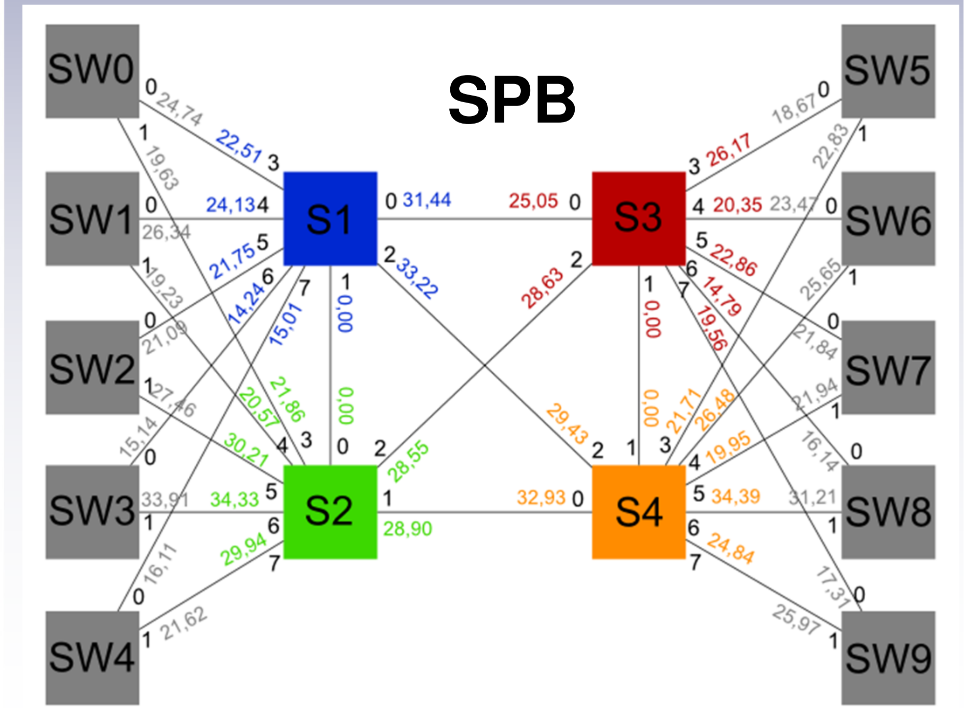
5000s/1.6s/Uniforme	Latencia máxima	Latencia mínima	Latencia media
SPB	1,884 ms	0,021 ms	0,335 ms
ARP-Path	0,811 ms	0,022 ms	0,343 ms

5000s/1.6s/No unif. (peso 100 en 1 host)	Latencia máxima	Latencia mínima	Latencia media
SPB	0,789 ms	0,038 ms	0,333 ms
ARP-Path	0,665 ms	0,041 ms	0,333 ms

ARP-Path better than plain SPB

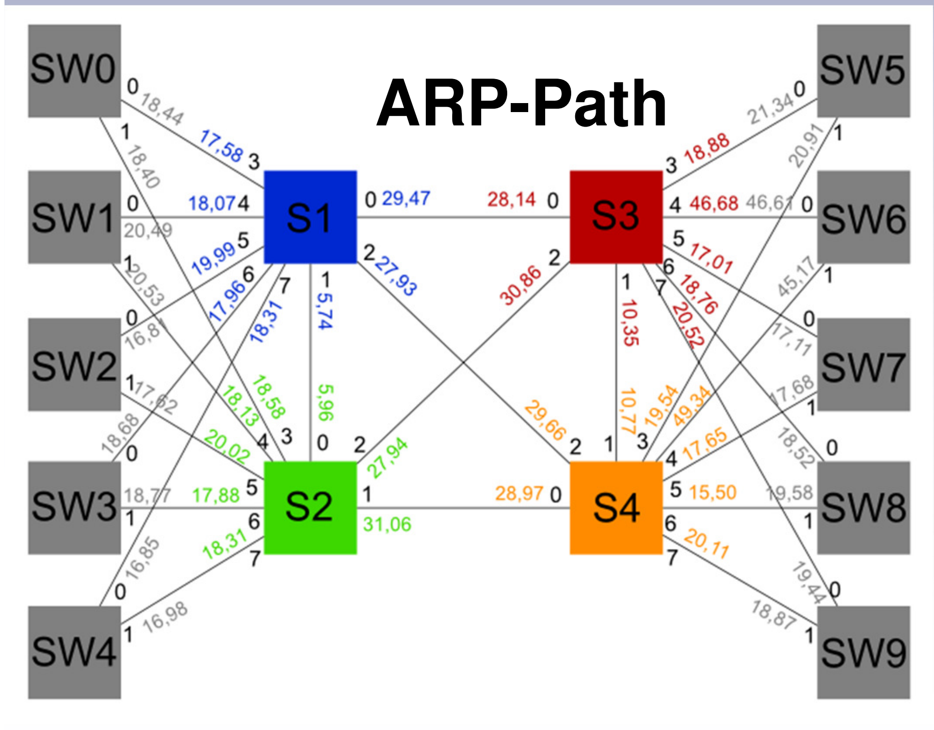
- Load balancing: ARP-path vs *plain* SPB (no ECMP) . Link utilization (%).
  - OMNeT++ (Random uniform traffic)

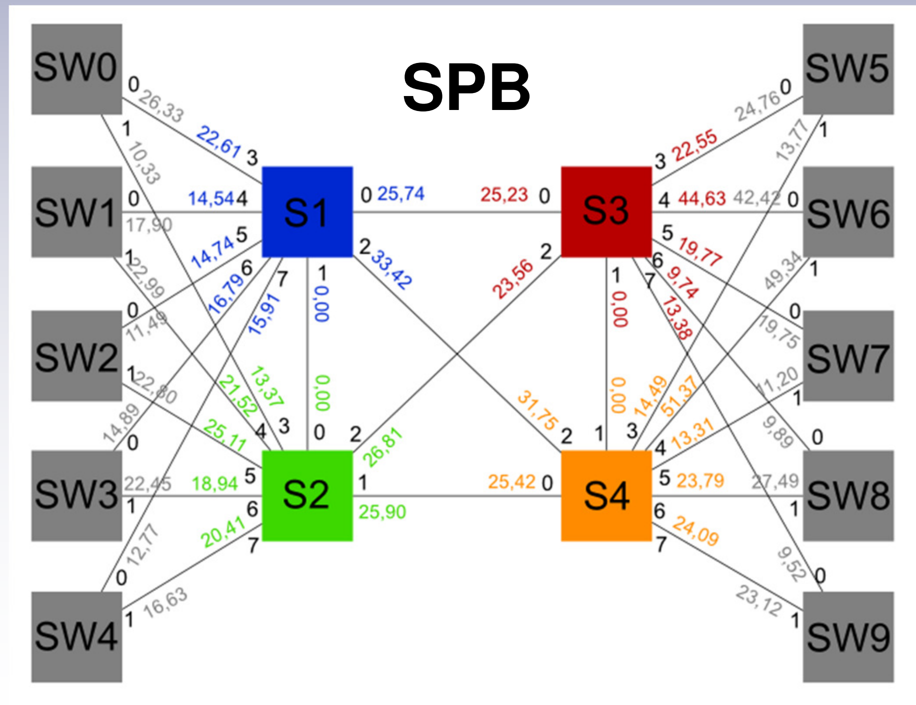




ARP-Path

- Load balancing: ARP-path vs *plain* SPB (no ECMP)
  - OMNeT++ (host at SW6 more traffic weight)





ARP-Path Latencies

- Fig. 3a) Average delay in ARP-Path and SPB is quite similar, but in some cases average delay in SPB is undesirably higher than ARP-Path.
- Fig. 3b). Maximum delays in plain SPB are much higher than those obtained in ARP-Path (more than an order of magnitude).

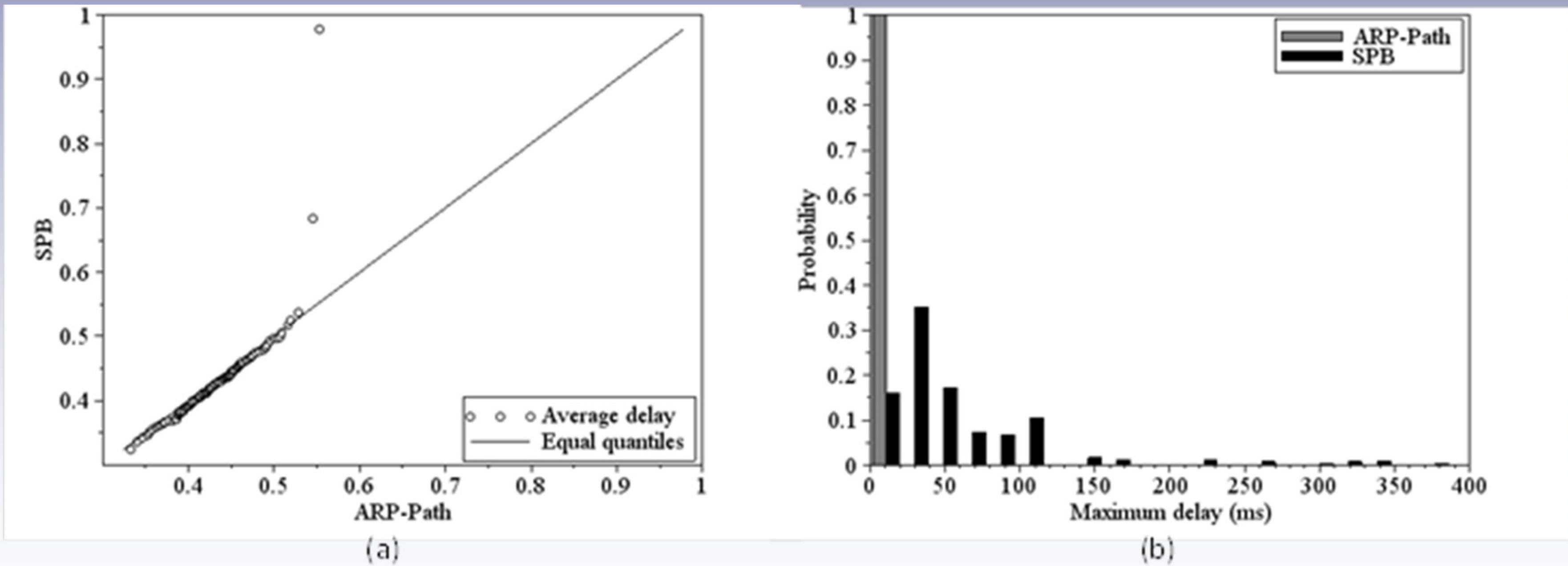


Figure 3. Packet Latencies for λ^{-1} = 0.4s. a) Q-Q plot for average delay; b) Probability density function for

ARP-Path distributes also at low loads

- Hosts conn. to left and right switches of 3x3 square mesh
- All-to-all traffic matrix
- OMNET++ simulat.
- Traffic is evenly distributed
  - Load adaptive routing

0	51.9 18.42 18.59	1	24.9 19.43 18.62	2
48.1 18.15 18.76		27.6 22.10 26.43		24.9 19.38 18.69
3	29.0 21.60 21.94	4	29.4 22.18 22.46	5
19.4 18.57 18.76		27.1 21.91 22.07		53.8 18.66 19.01
6	19.4 19.10 18.64	7	46.2 19.01 18.35	8

48.1 Percentage of routes between 0-8 using the link

18.15 Link utilization at receiver port (average)

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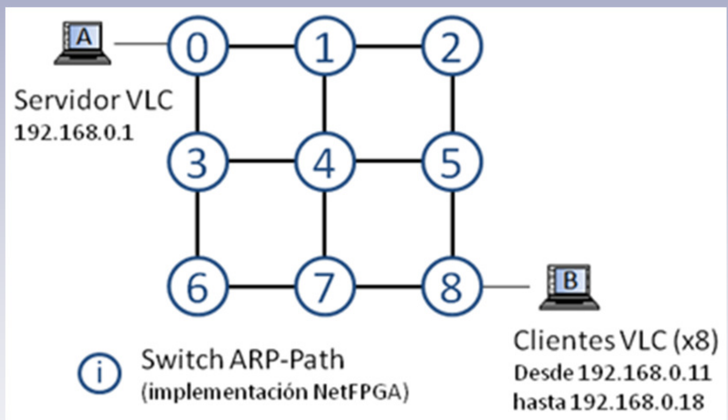
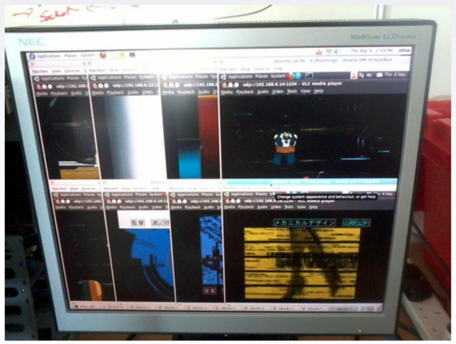
ARP-Path: path diversity (videos) even with very low loads

- Load balancing:
  - NetFPGA implementation





0	46,9	1	21,9	2
	0,00		0,00	
	0,00		0,00	
53,1		25,0		21,9
0,00		0,00		0,00
0,00		0,00		0,00
3	34,4	4	25,0	5
	0,00		0,00	
	0,00		0,00	
18,8		34,4		46,9
0,00		0,00		0,00
0,00		0,00		0,00
6	18,8	7	53,1	8
	0,00		0,00	
	0,00		0,00	

0,0 Percentage of routes using the link

0,0 Link utilization at receiver port (average)

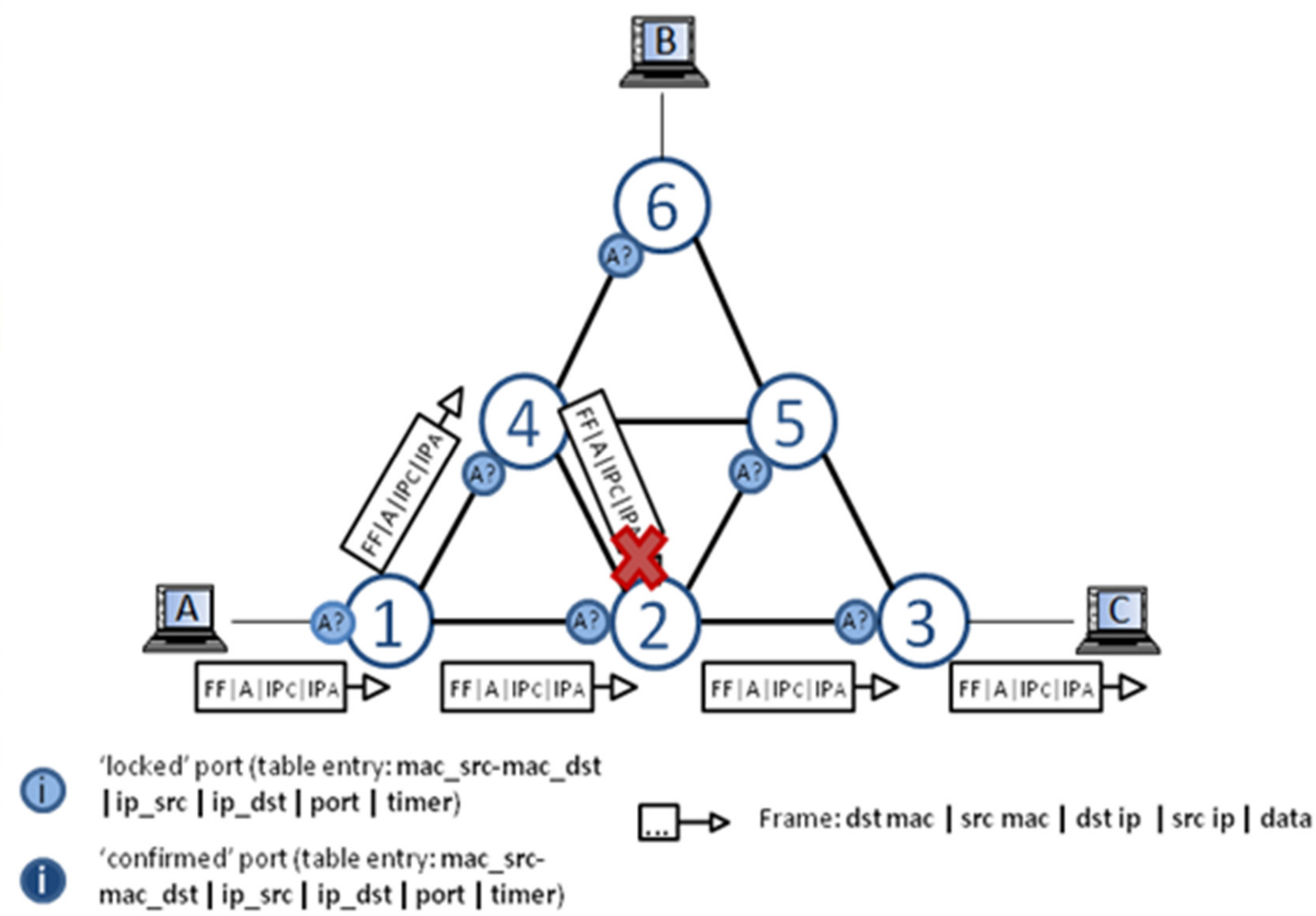
ARP-Path Implementations

- Pinging times:
  - Linux/Soekris(100Mbps): ~0,9ms
  - OpenFlow/Mininet(Virtual): ~0,05 ms
  - OpenFlow/NetFPGA(1Gbps): ~0,6 ms
  - OpenFlow/Linux(100Mbps): ~3ms
  - OpenFlow/NECswitch(1Gbps): ~0,6ms
  - NetFPGA(1Gbps): ~0,6ms

Flow-Path

key(src-dst)	srcIP	dstIP	port	timer	state
A-FF	IP_A	IP_C	1	0	*Locked*

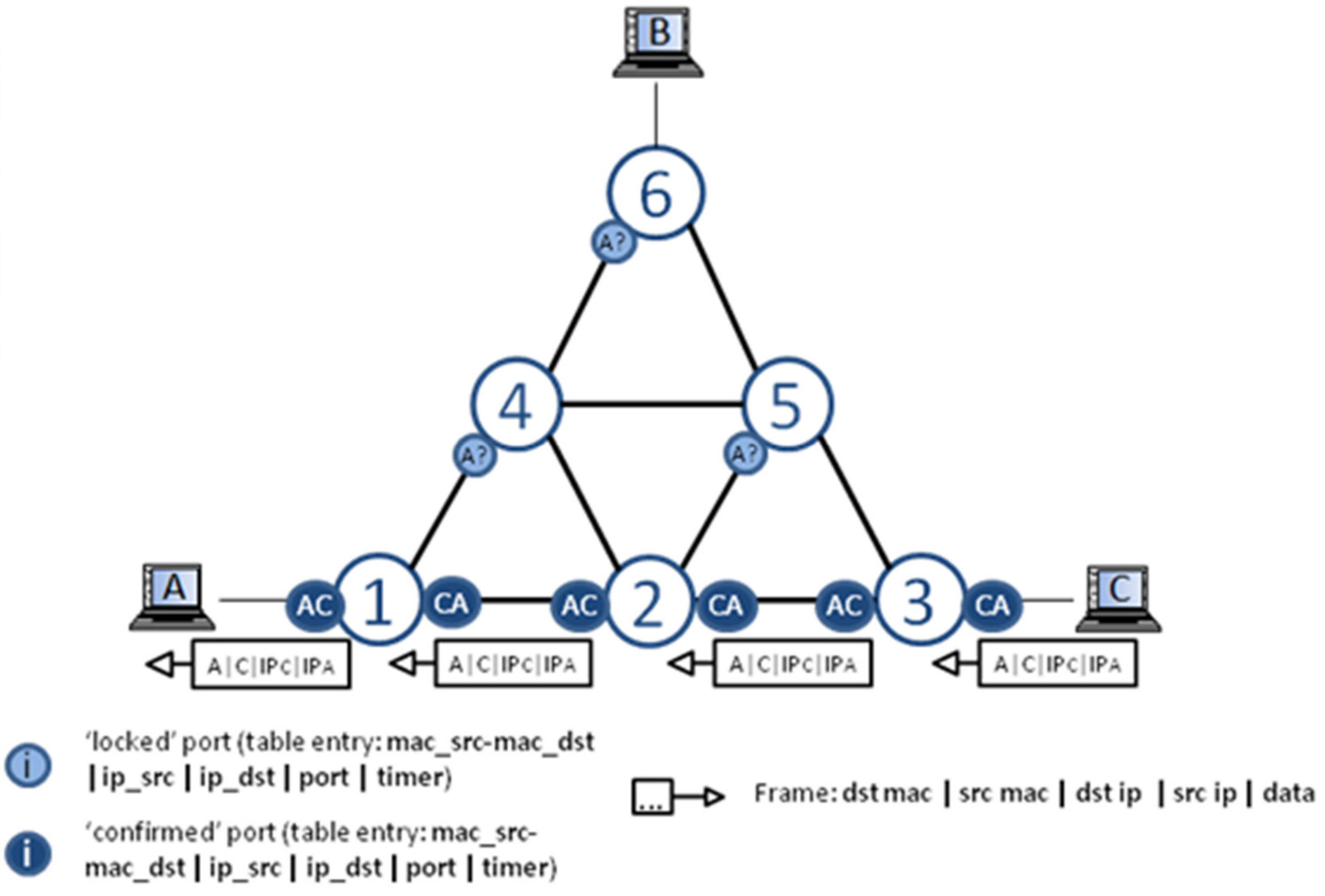
- Paths are created per flow:
- Path discovery (ARP Request)



Flow-Path

key(src-dst)	srcIP	dstIP	port	timer	state
A-C	IP_A	IP_C	1	0	*Confirmed*
C-A	IP_A	IP_C	2	0	*Confirmed*

- Paths are created per flow:
  - Path confirmation (ARP Reply)



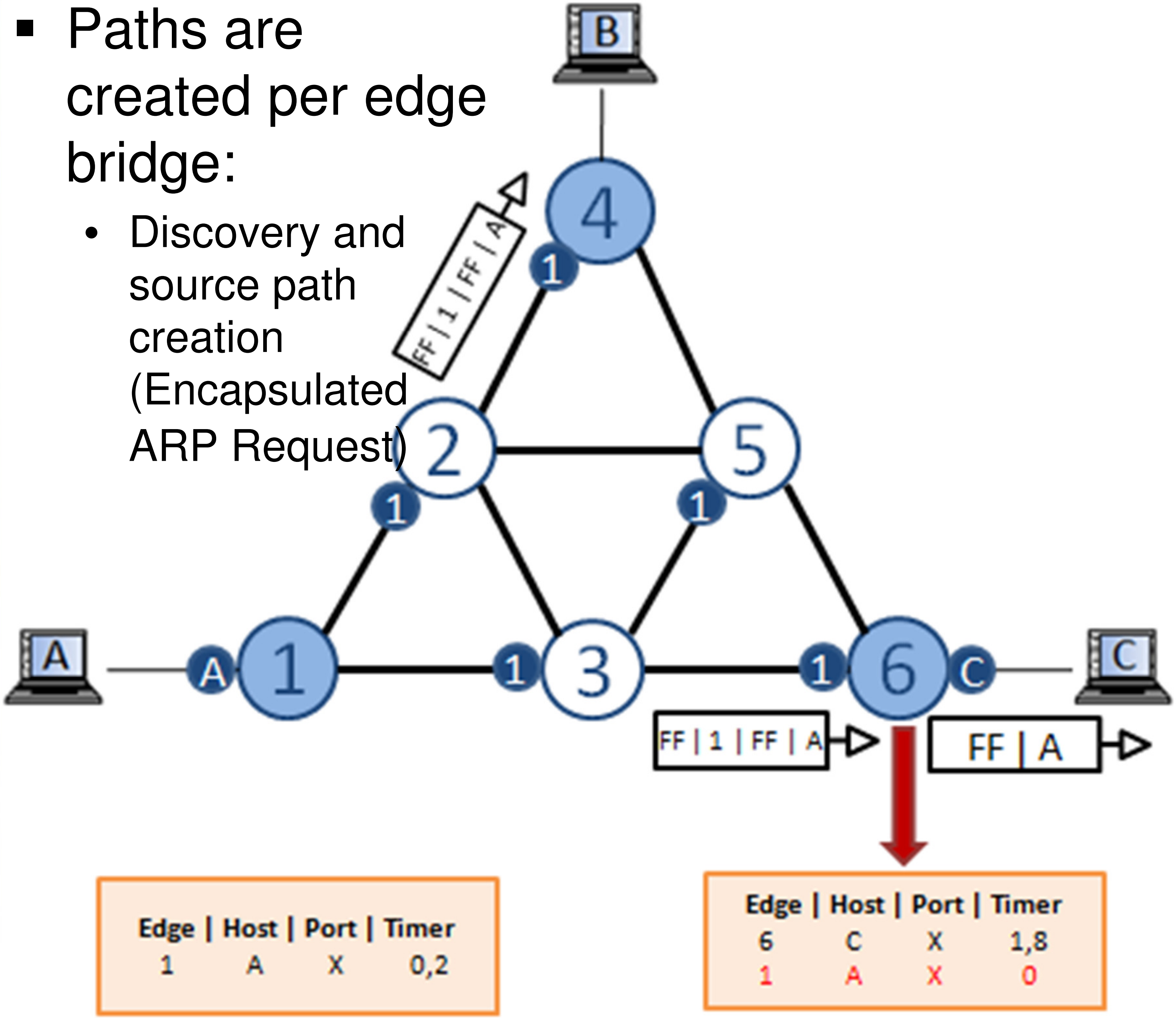
Flow-path versus ARP-path

- Flow-path Advantages
  - Guaranteed path symmetry
  - Even better load balancing: finer granularity
- Disadvantages
  - Increased stored state *O(flows)*

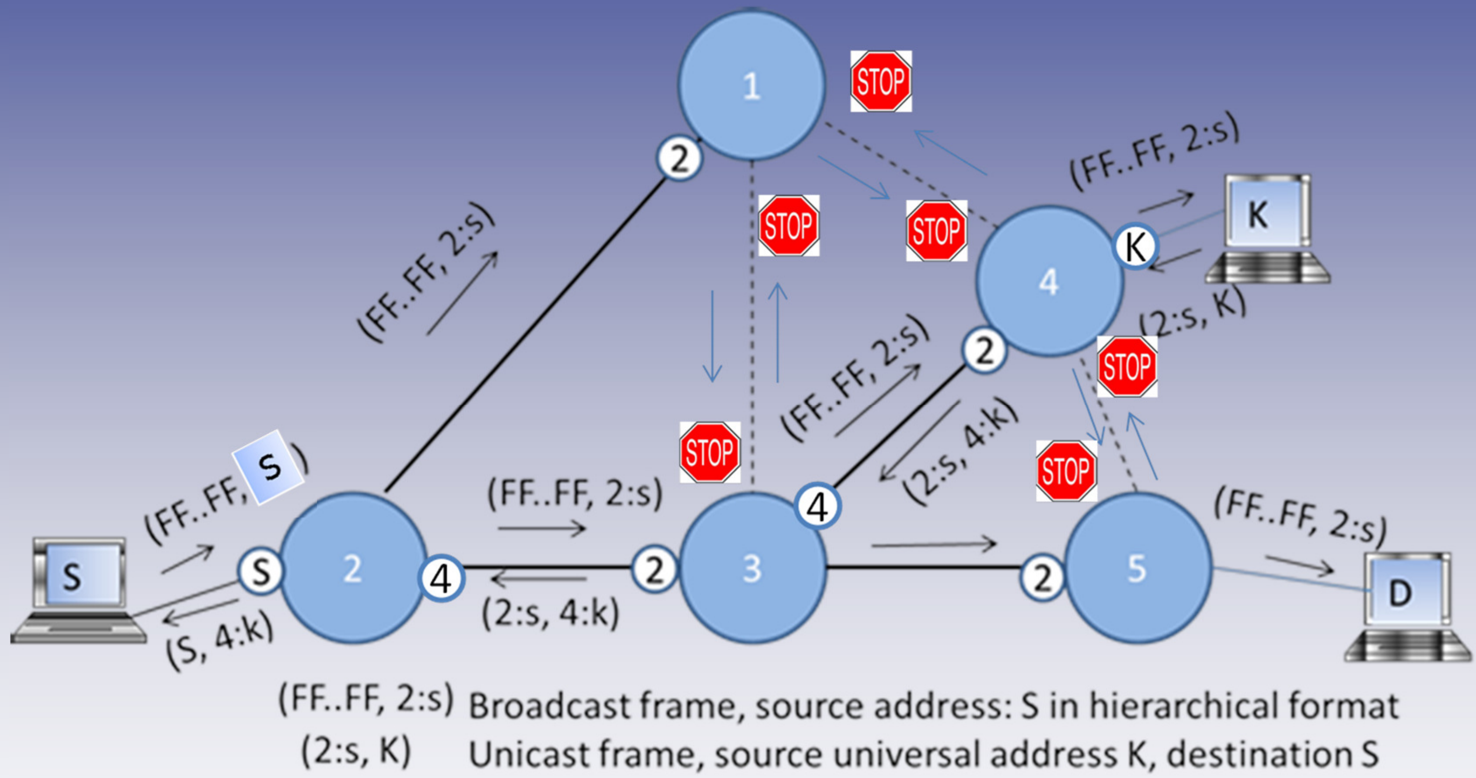
Bridge-Path (MAC in MAC, Path-Moose)

- Paths/trees are created per edge bridge
  - Less table entries → better scalability
  - Worsens path diversity and load balancing
    - Can be improved with multipath (and more table entries)
    - Using simultaneous, two-level path granularity (bridge-hosts)
- Variants:
  - ARP-Path MAC-in-MAC encapsulation
    - Also ARP-Path VLAN (like SPBV).
  - Path-Moose (NAT of MACs at edge bridges)
    - local host MAC address = *BridgeID:HostID*

- Paths are created per edge bridge:
  - Discovery and source path creation (Encapsulated ARP Request)



Path-Moose *(NAT of MACs= BridgeID:hostID, MAC(S) changed to 2:s at edge bridge 2)*



Setting a path and a tree rooted at bridge 2 with ARP Request from S to K and ARP Reply (K,S), learning BridgeID 2.

Ref.: "Path-Moose: A Scalable All-Path Bridging Protocol". G. Ibáñez et al. IEICE Transactions on Communications. March 2013.

Publications and Implementations

- 2010
  - *Fast Path Ethernet Switching: On-demand, Efficient Transparent Bridges for Data Center and Campus Networks. IEEE LANMAN Workshop May 2010.*
  - "*A Simple, Zero-configuration, Low Latency, Bridging Protocol*". LCN demos. Denver, oct. 2010. Best demo award.
    - ARP-path implementation on Openflow/NetFPGA switch implementation

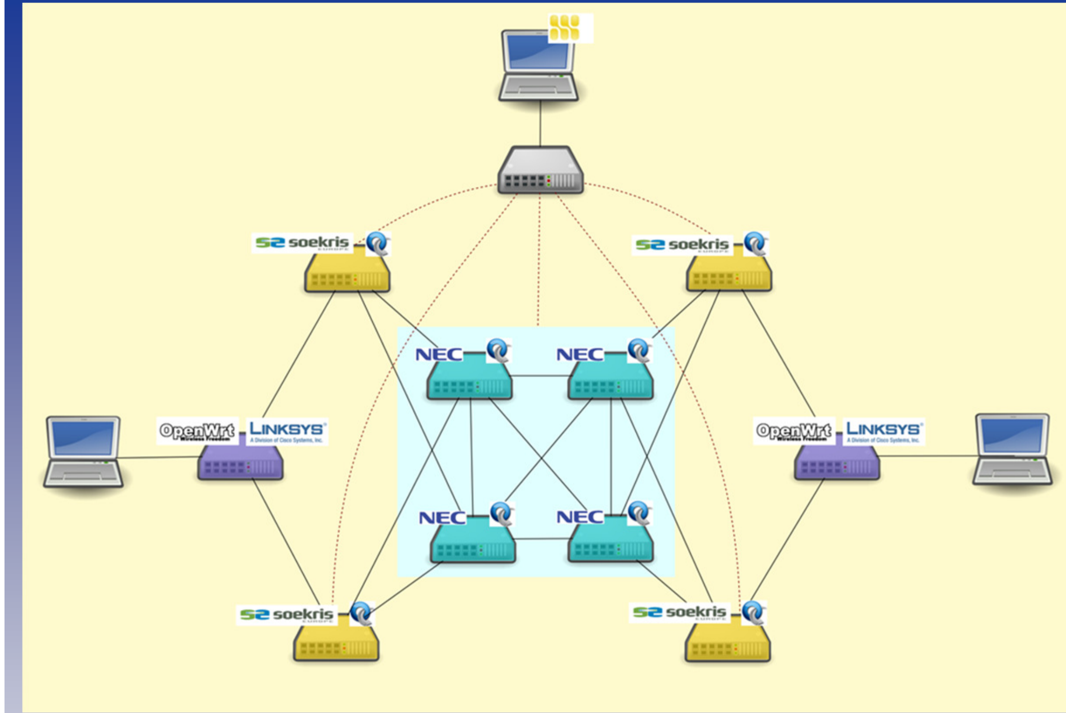
- Acknowledgement: Jad Naous (Ph.D. Stanford) for Open flow and NetFPGA implementations

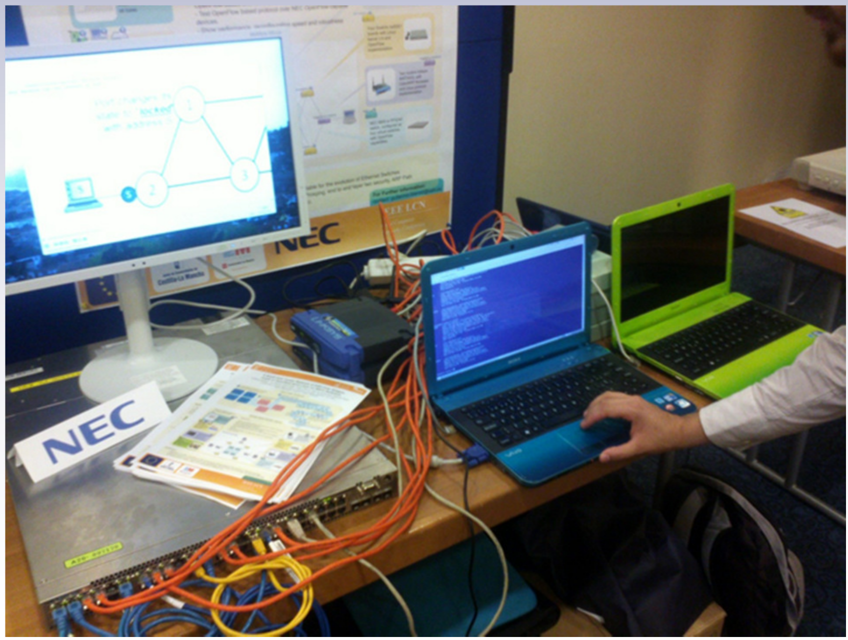
All-path on Openflow

- Early implementation of All-path protocol was in Openflow (2010), for proof-of-concept.
  - Fully operative on diverse Openflow switches
- All-path protocols best suited to either fully distributed networks or hybrids (with SDN)
  - Hybrid:
    - Basic All-path functionality in the switches for basic path exploration and forwarding
    - Complementary functions performed at SDN controller: path resiliency, additional routing, reconfiguration.

All-path on Openflow Switches

LCN 2011
(Bonn)
NEC and other Openflow Switches





- 4 NEC Openflow capable switches
- 4 Soekris boards (OF)
- 2 Open-WRT Linksys routers (Linux implementation)
- One Openflow (NOX) controller

Publications and Implementations

- 2011
  - "*Implementation of ARP-Path Low Latency Bridges in Linux and OpenFlow/NetFPGA*". HPSR 2011, Cartagena, April 2011.
  - *ARP Path: ARP-based Shortest Path Bridges. IEEE Communication Letters. July 2011*
  - "*Implementing ARP-Path Low Latency Bridges in NetFPGA*". SIGCOMM demos. Toronto (CA), August 2011.
  - "*A Small Data Center Network of ARP-Path Bridges made of Openflow Switches*". (In collaboration with NEC Europe) LCN demos. Bonn, 2011.

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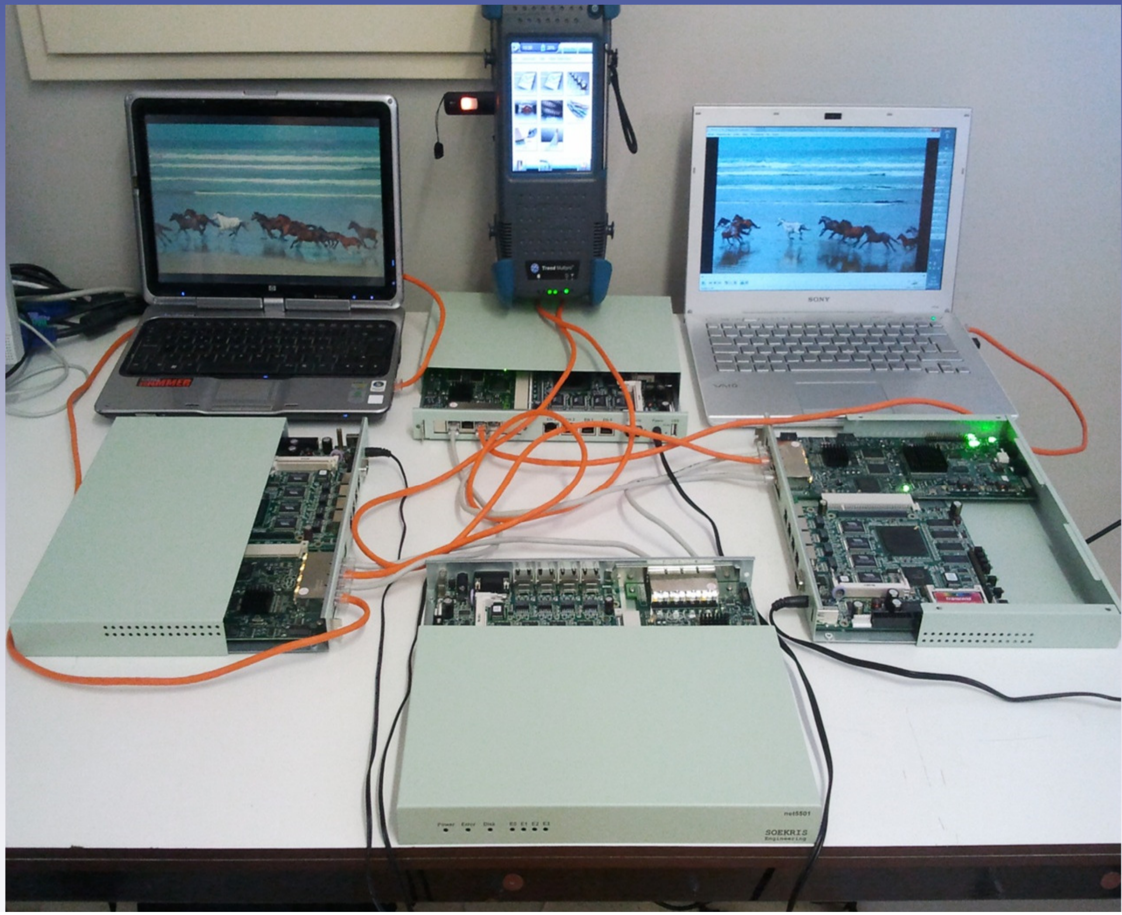
Sigcomm 2011(Toronto)

- 4 **NetFPGAs** on a PC
- Hardware: Verilog implementation
- Comparison with STP
- Robustness, path repair

Publications and Implementations

- 2012
  - *"Dynamic Load Routing/Path Diversity in a Network of ARP-Path NetFPGA Switches". LCN 2012 demo.*
  - *"Flow-Path: An AllPath Flow-based Protocol". LCN 2012.*
- 2013.
  - *"Path-Moose: A Scalable All-Path Bridging Protocol". IEICE Transactions on Communications. March 2013.*
  - *"Evaluating Native Load Distribution of ARP-Path Bridging Protocol in Mesh and Data Center". ICC 2013. Budapest, June 2013.*
  - *"All-path Bridging: Path Exploration as an Efficient Alternative to Path Computation in Bridging Standards". IEEE Workshop on Telecommunication Standards. June 2013.*

NetFPGA implementation LCN 2012



- 4 **NetFPGAs**
  - With Soekris board
- Full hardware implementation (Verilog)
- Load distribution
- Full infrastructure utilization vs STP
- Fully transparent

Future Work

- Implementation in Virtualized bridged networks and combinations with SDN (OpenvSwitch,…)
- Multicast and broadcast traffics optimization.
- Audio Video Bridges
- Bridge-path: Coexistence of different path granularities (per host,per bridge)
- Deep evaluation and adaptation to data center reqs.
- Integration on hybrid wired-wireless (802.1/.11)networks

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Conclusion

- Path exploration is effective for switches:
  - **Minimizes maximum frame latencies vs. plain SPB**
  - **Load adaptive routing (native path diversity)**
    - basic protocol uses **per-host *just-in-time* path selection**
    - **Instant adaptation to traffic load**
- Path is not **predictable** (not computed) but the protocol is **resilient:** (SPB/TRILL aren't fully predictable either)
  - Even if only a path to destination remains, it will be selected
- All-Path protocols **show a way for the evolution of the transparent bridge paradigm**
  - On a pure bridging basis, proven by implementations.
- Combines well with Openflow

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Thank you for your attention

Questions?

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