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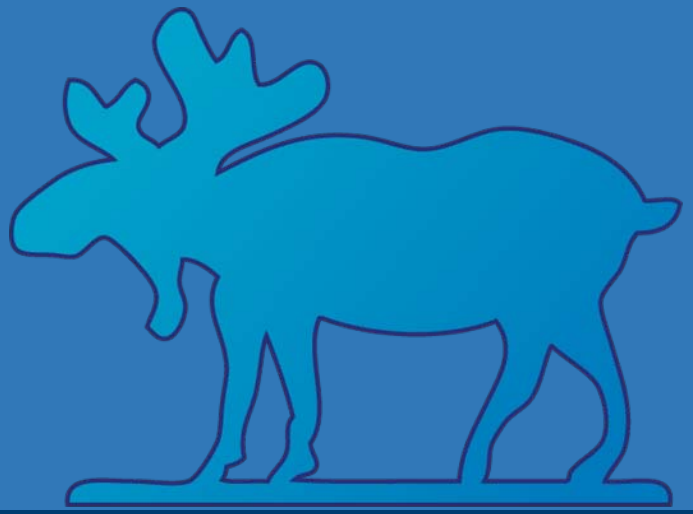
Addressing the Scalability of Ethernet with MOOSE



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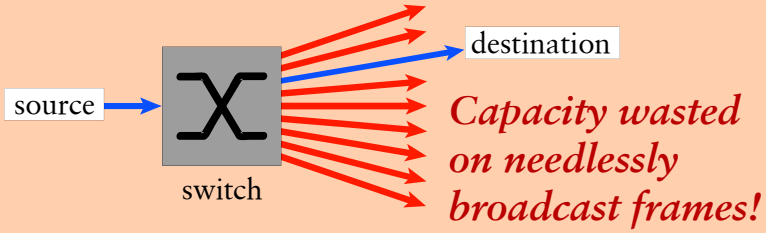
Ethernet in the data centre

- **1970s protocol; still ubiquitous**
  - Usually used with IP, but not always (ATA-over-Ethernet)
- **Density of Ethernet addresses is increasing**
  - Larger data centres, more devices, more NICs
  - Virtualisation: each VM has a unique Ethernet address
    - (or more than one!)

Why not Ethernet?

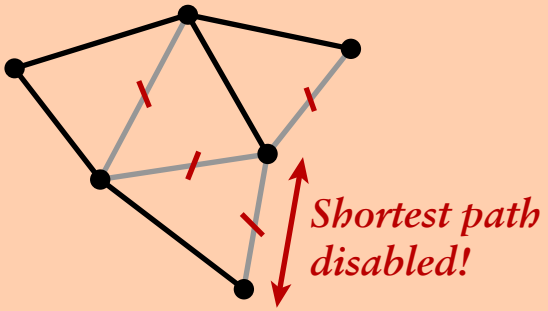
Heavy use of broadcast

Broadcast ARP required for interaction with IP



On large networks, broadcast can overwhelm slower links e.g. wireless

Inefficient routing: Spanning Tree

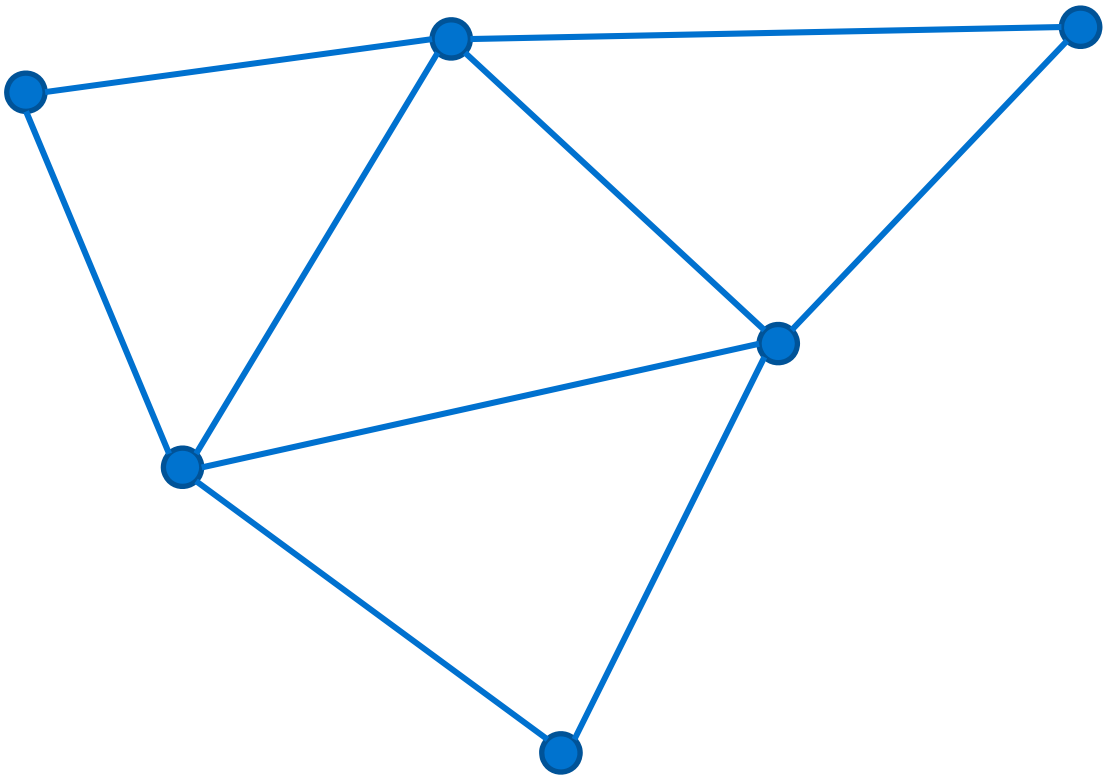


Switches' address tables

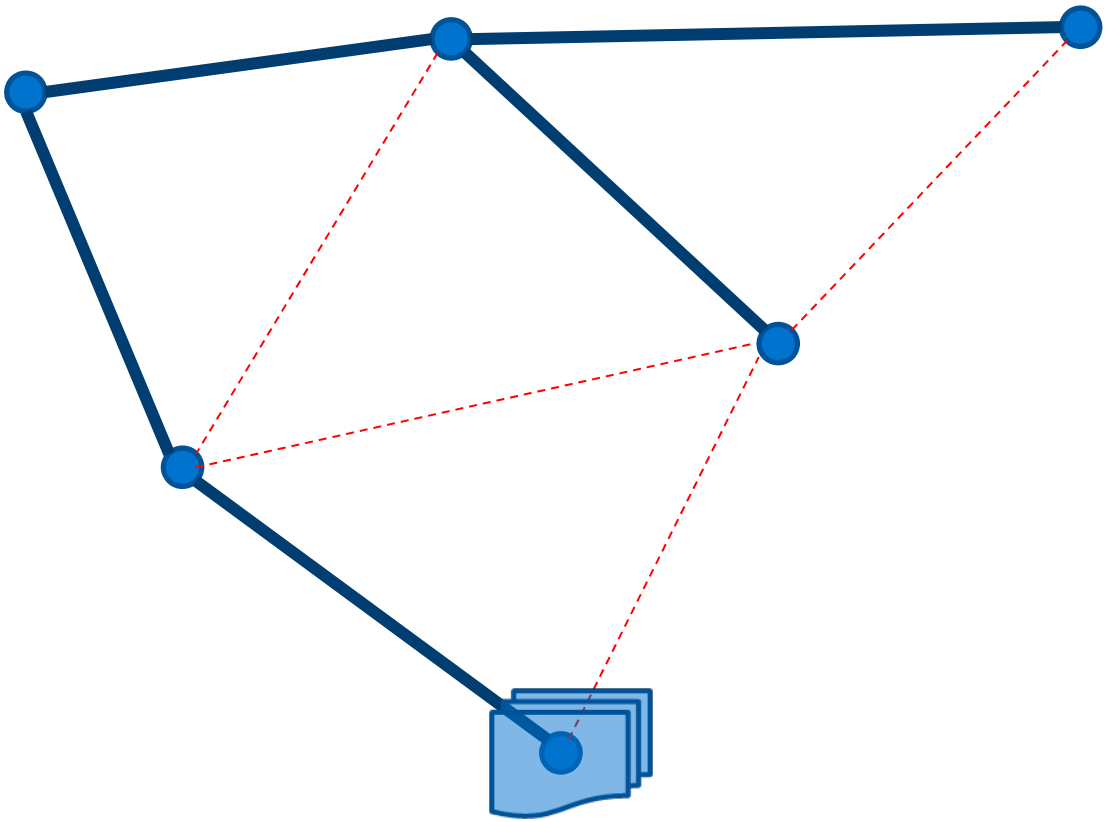
MAC address	Port
01:23:45:67:89:ab	12
00:a1:b2:c3:d4:e5	16
…	…

- Maintained by every switch
- Automatically learned
- Table capacity: ~16000 addresses
- *Full table results in unreliability, or at best heavy flooding*

Spanning tree switching illustrated

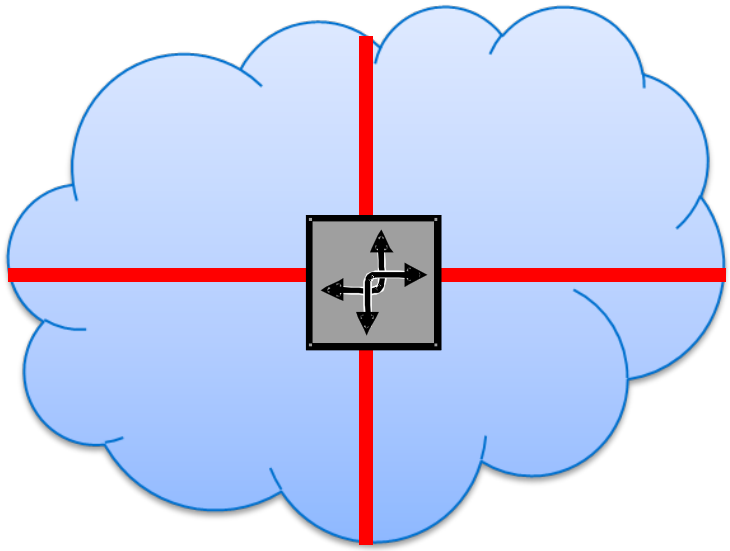


Spanning tree switching illustrated

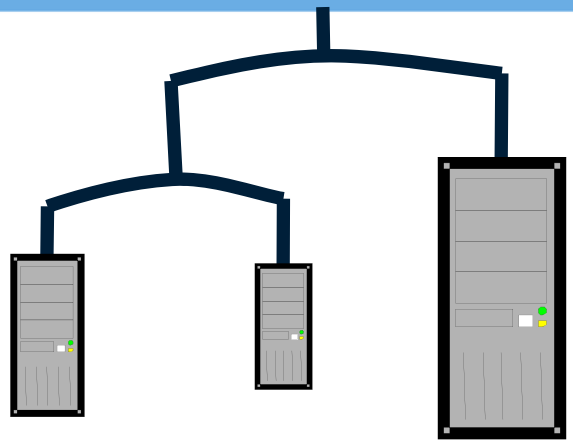


Ethernet in the data centre: divide and conquer?

- **Traditional solution: artificially subdivide network** at the IP layer: subnetting and routing
  - Administrative burden
  - More expensive equipment
  - Hampers mobility
    - IP Mobility has not (yet) taken off
  - Scalability problems remain within each subnet



Ethernet in the data centre: ...mobility?



- **Mobility *is* relevant in the data centre**
  - Seamless virtual machine migration
  - Easy deployment:
    no location-dependent configuration
- **...and between data centres**
  - Large multi-data-centre WANs are becoming common
- **Ethernet is pretty good at mobility**

Large networks

- **Converged airport network**
  - Must support diverse commodity equipment
  - Roaming required throughout entire airport complex
  - Ideally, would use one large Ethernet-like network

- This work funded by “The INtelligent Airport” UK EPSRC project

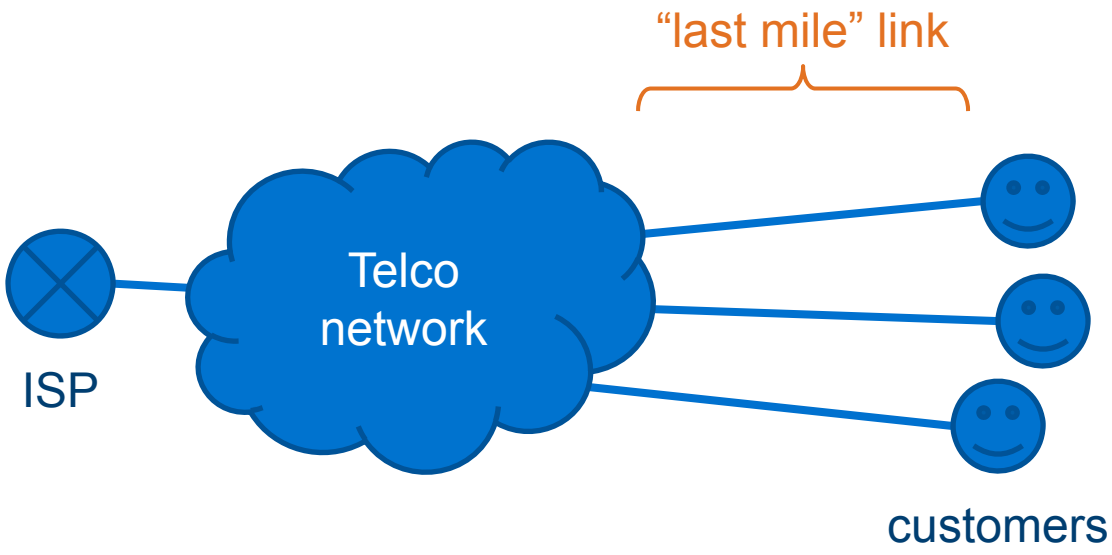
Large networks

- **Airports have surpassed the capabilities of Ethernet**
  - London Heathrow Airport: Terminal 5 alone is too big
  - MPLS-VPLS: similar problems to IP subnetting
    - VPLS adds more complexity:
      - LERs map every destination MAC address to a LSP: up to *O*(hosts)
      - LSRs map every LSP to a next hop: could be *O*(hosts^2) in core!
    - Encapsulation does not help

Geographically-diverse networks

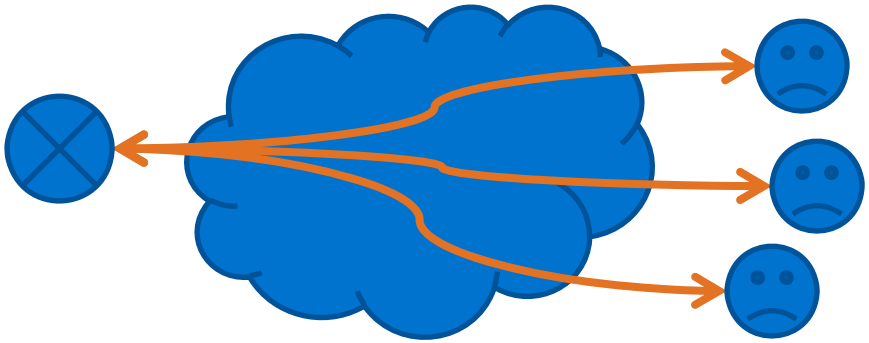
Fibre-to-the-Premises

- Currently, Ethernet is only used for small deployments



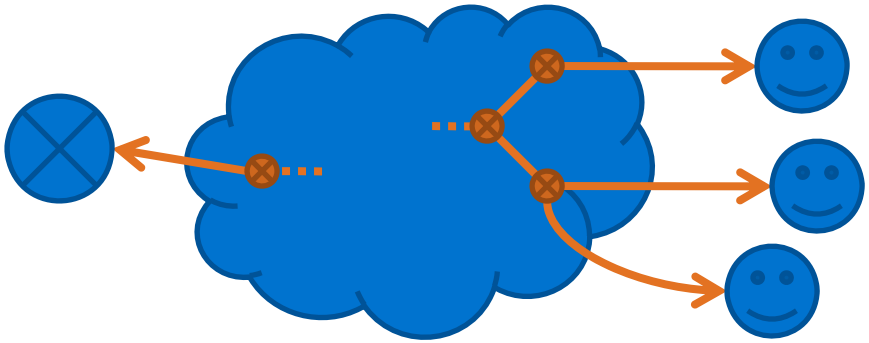
Geographically-diverse networks

Now:



- Everything goes via circuit to ISP
- Legacy reasons (dial-up, ATM)
- Nonsensical for peer-to-peer use
- Bottleneck becoming significant as number of customers and capacity of links increase

Future:



- In the UK: BT 21CN
- Take advantage of fully-switched infrastructure
- Peer-to-peer traffic travels directly between customers
- Data link layer protocol is crucial

The underlying problem with Ethernet

MAC addresses provide

no location information

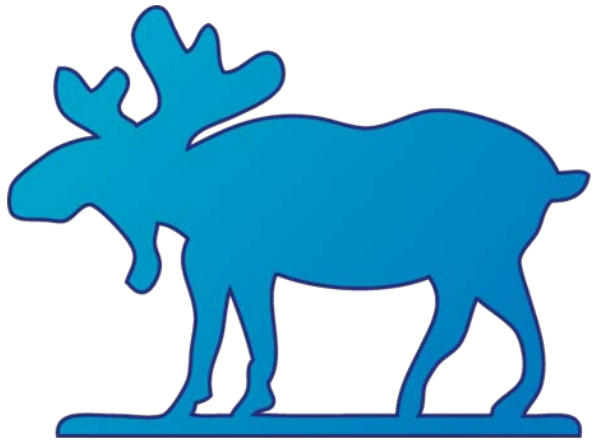
Flat vs. Hierarchical address spaces

- **Flat-addressed Ethernet:** manufacturer-assigned MAC address valid anywhere on any network
  - But every switch must discover and store the location of every host
- **Hierarchical addresses:** address depends on location
  - Route frames according to successive stages of hierarchy
  - No large forwarding databases needed
- **LAAs?** High administrative overhead if done manually

MOOSE: *Multi-level Origin-Organised Scalable Ethernet*

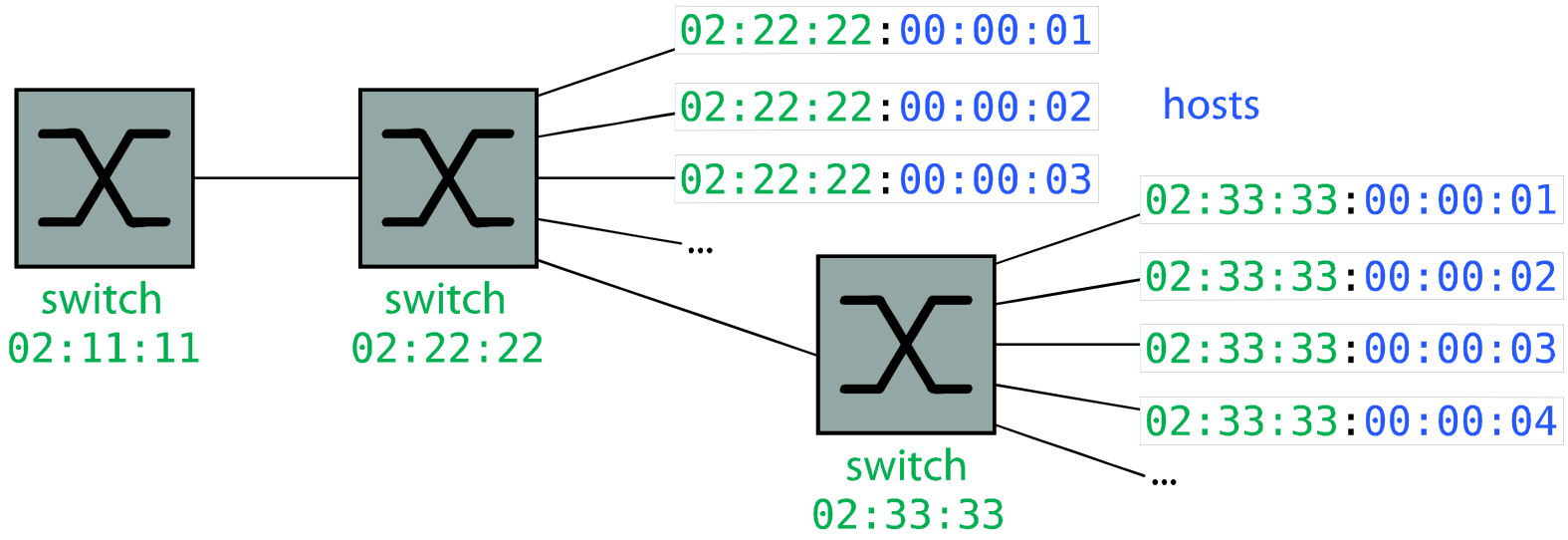
A new way to switch Ethernet

- Perform MAC address rewriting on ingress
- Enforce dynamic hierarchical addressing
- No host configuration required



- *Good platform for shortest-path routing*
- ***Appears to connected equipment as standard Ethernet***

MOOSE: *Multi-level Origin-Organised Scalable Ethernet*

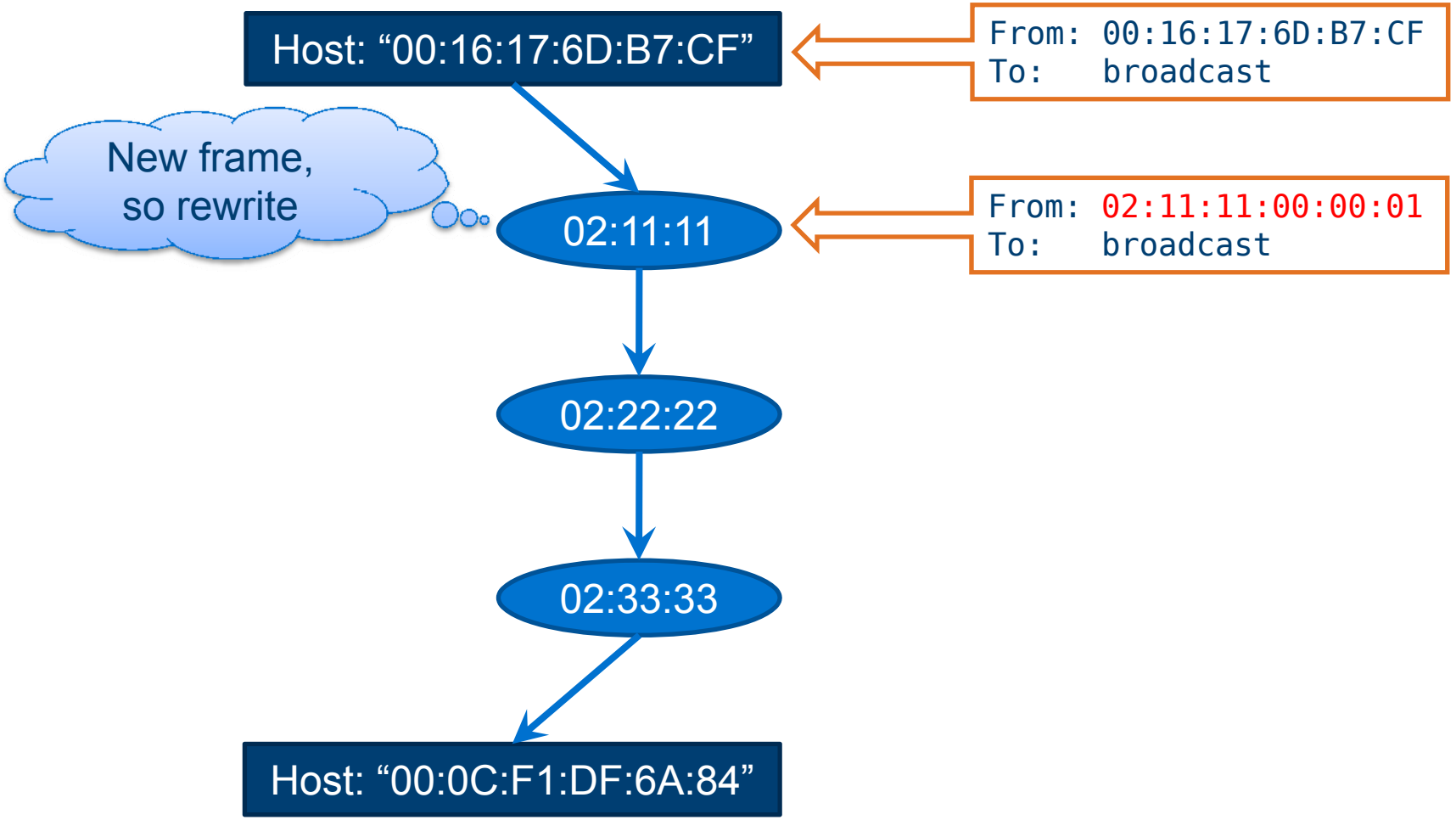


- **Switches assign each host a MOOSE address = switch ID . host ID**
  (MOOSE address must form a valid unicast LAA: two bits in switch ID fixed)
- Placed in source field in Ethernet header as each frame enters the network
  (no encapsulation, therefore no costly rewriting of destination address!)

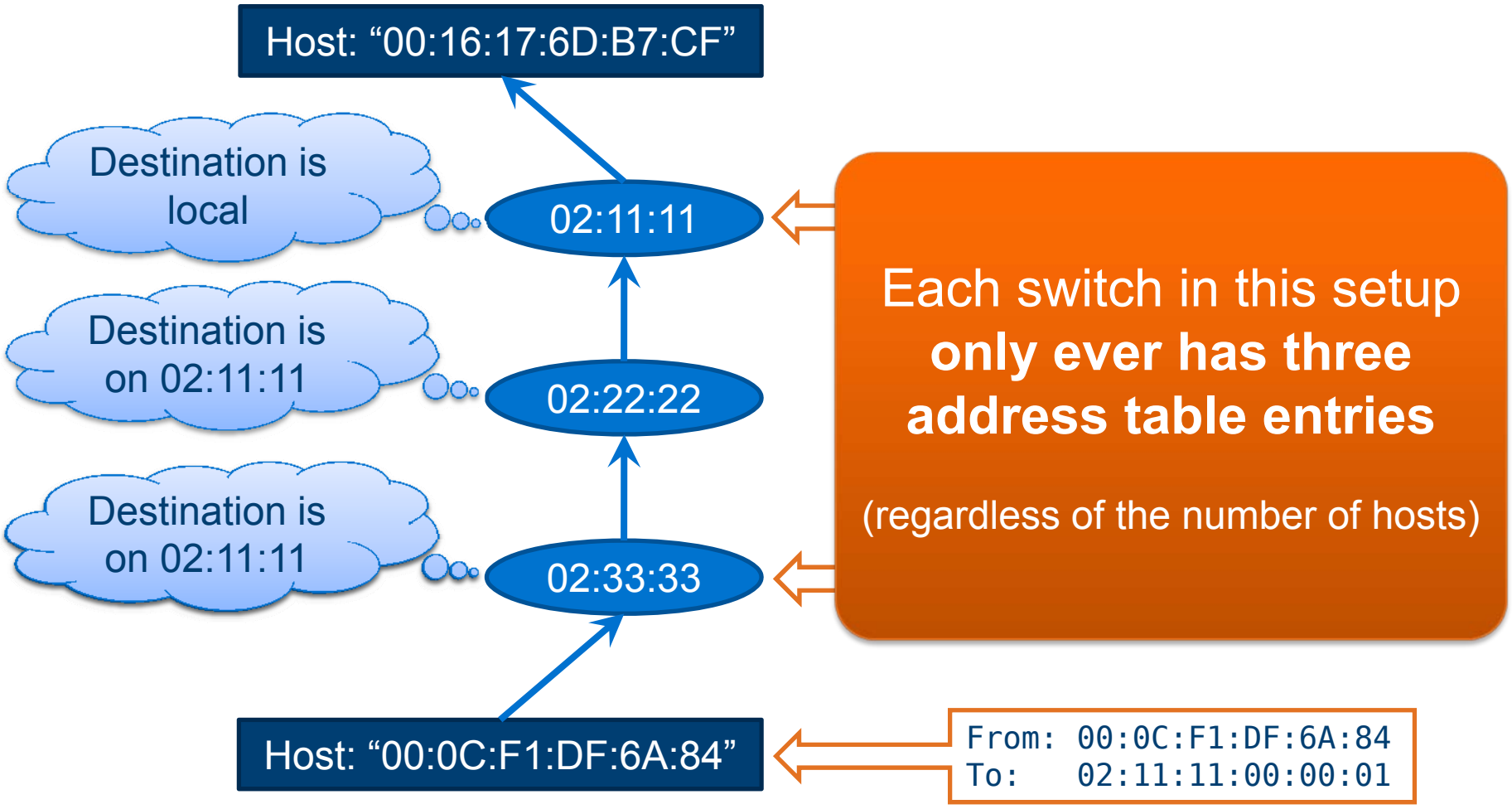
Allocation of host identifiers

- **Only the switch which allocates a host ID ever uses it for switching** (more distant switches just use the switch ID)
- Therefore the detail of how host IDs are allocated can vary between switches
  - Sequential assignment
  - Port number and sequential portion
    (isolates address exhaustion attacks)
  - Hash of manufacturer-assigned MAC address
    (deterministic: recoverable after crash)

The journey of a frame

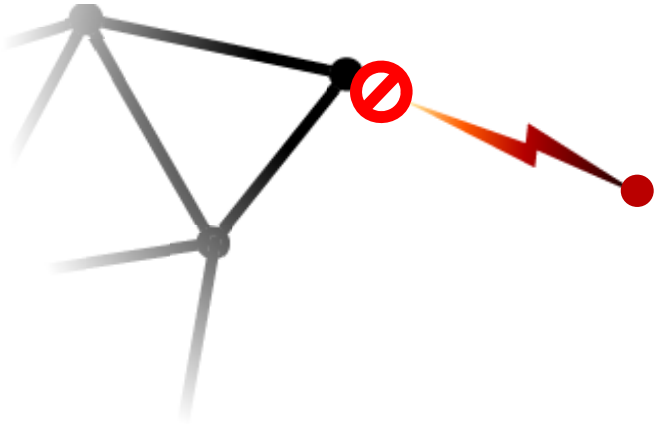


The return journey of a frame



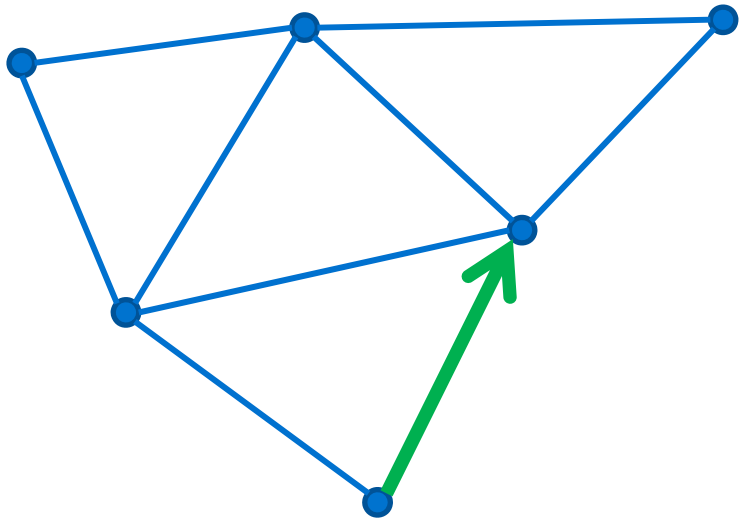
Security and isolation benefits

- **The number of switch IDs is predictable, unlike the number of MAC addresses**
  - Address flooding attacks are ineffective
  - Resilience of dynamic networks (e.g. wireless) is increased
- **Host-specified MAC address is not used for switching**
  - Spoofing is ineffective



Shortest path routing

- **MOOSE switch ≈ layer 3 router**
  - One “subnet” per switch
    - `02:11:11:00:00:00/24`
    - Don’t advertise individual MAC addresses!
  - Run a routing protocol between switches, e.g. OSPF variant
    - OSPF-OMP may be particularly desirable: optimised multipath routing for increased performance



Beyond unicast

- **Broadcast: unfortunate legacy**
  - DHCP, ARP, NBNS, NTP, plethora of discovery protocols...
  - Deduce spanning tree using reverse path forwarding (PIM): no explicit spanning tree protocol
  - Can optimise away most common sources, however
- **Multicast and anycast for free**
  - SEATTLE suggested generalised VLANs (“groups”) to emulate multicast
  - Multicast-aware routing protocol can provide a true L2 multicast feature

ELK: Enhanced Lookup

- **General-purpose directory service**
  - Master database: held on one or more servers in core of network
  - Slaves can be held near edge of network to reduce load on masters
    - Read: anycast to nearest slave
    - Write: multicast to all masters
    - Entire herd of ELK kept in sync by masters via multicast + unicast

Photo: “Majestic Elk” by CaptPiper. Used under Creative Commons license.
http://www.flickr.com/photos/piper/798173545/

ELK: Enhanced Lookup

- **Primary aim: handle ARP & DHCP without broadcast**
  - ELK stores (MAC address, IP address) tuples
    - Learned from sources of ARP queries
    - Acts as DHCP server, populating directory as it grants leases
  - Edge switch intercepts broadcast ARP / DHCP query and converts into anycast ELK query
  - ELK is not guaranteed to know the answer, but it usually will
    - (ARP request for long-idle host that isn't using DHCP)

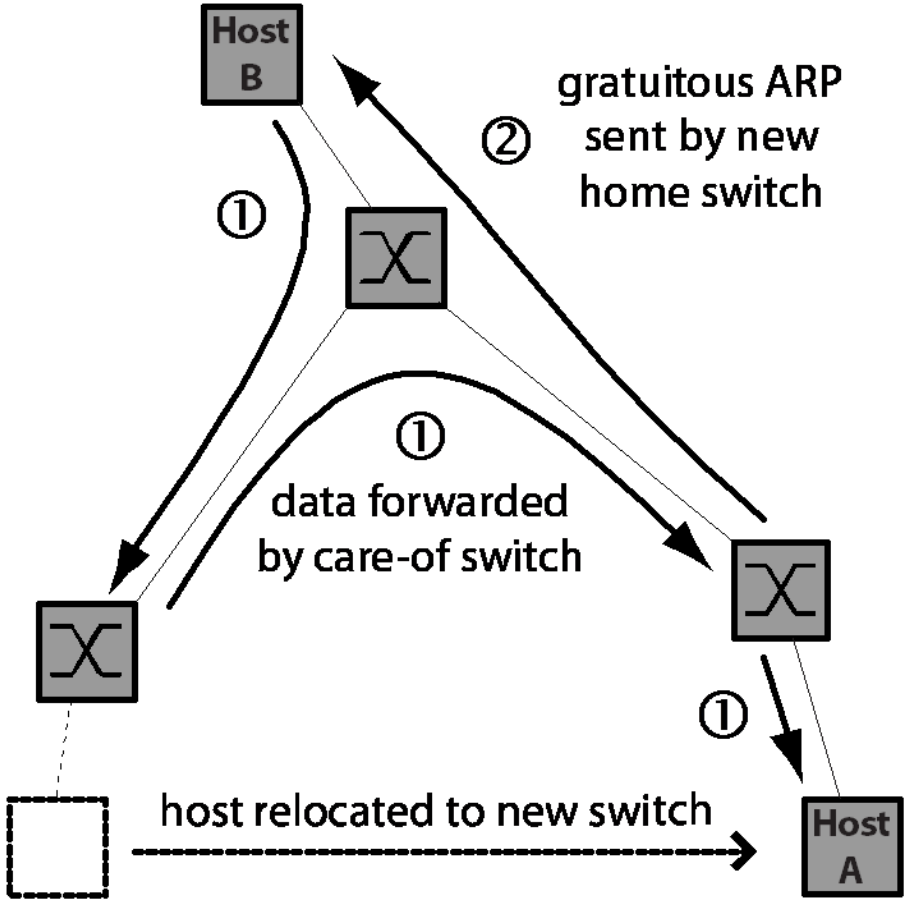
Mobility

If a host moves, it is allocated a new MOOSE address by its new switch

- Other hosts may have the old address in ARP caches

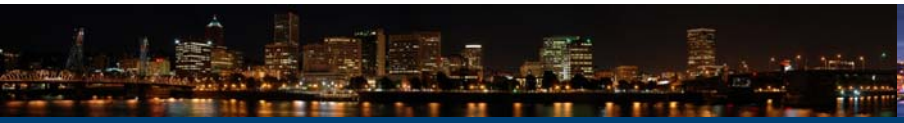
  1) **Forward frames**, IP Mobility style
     (new switch discovers host's old location by querying other switches for its real MAC address)

  2) **Gratuitous ARP**,
     Xen VM migration style



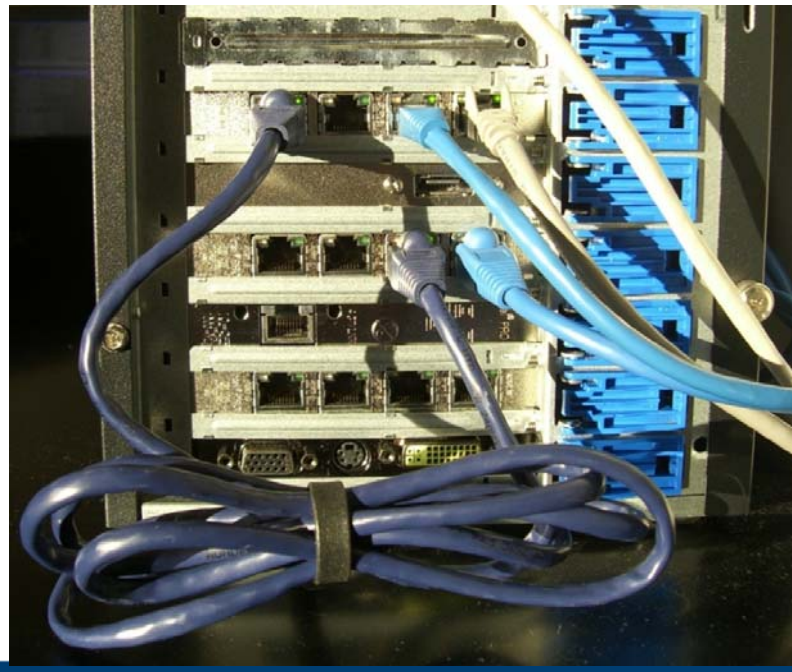
Related work

- **Encapsulation**
  (MPLS-VPLS, IEEE TRILL, ...)
  - Destination address lookup: Big lookup tables
- **Domain-narrowing**
  (PortLand – Mysore *et al.*, UCSD)
  - Is everything *really* a strict tree topology?
- **Complete redesign**
  (Myers *et al*.)
  - To be accepted, must be Ethernet-compatible
- **DHT for host location**
  (SEATTLE – Kim *et al.*, Princeton)
  - Unpredictable performance; topology changes are costly

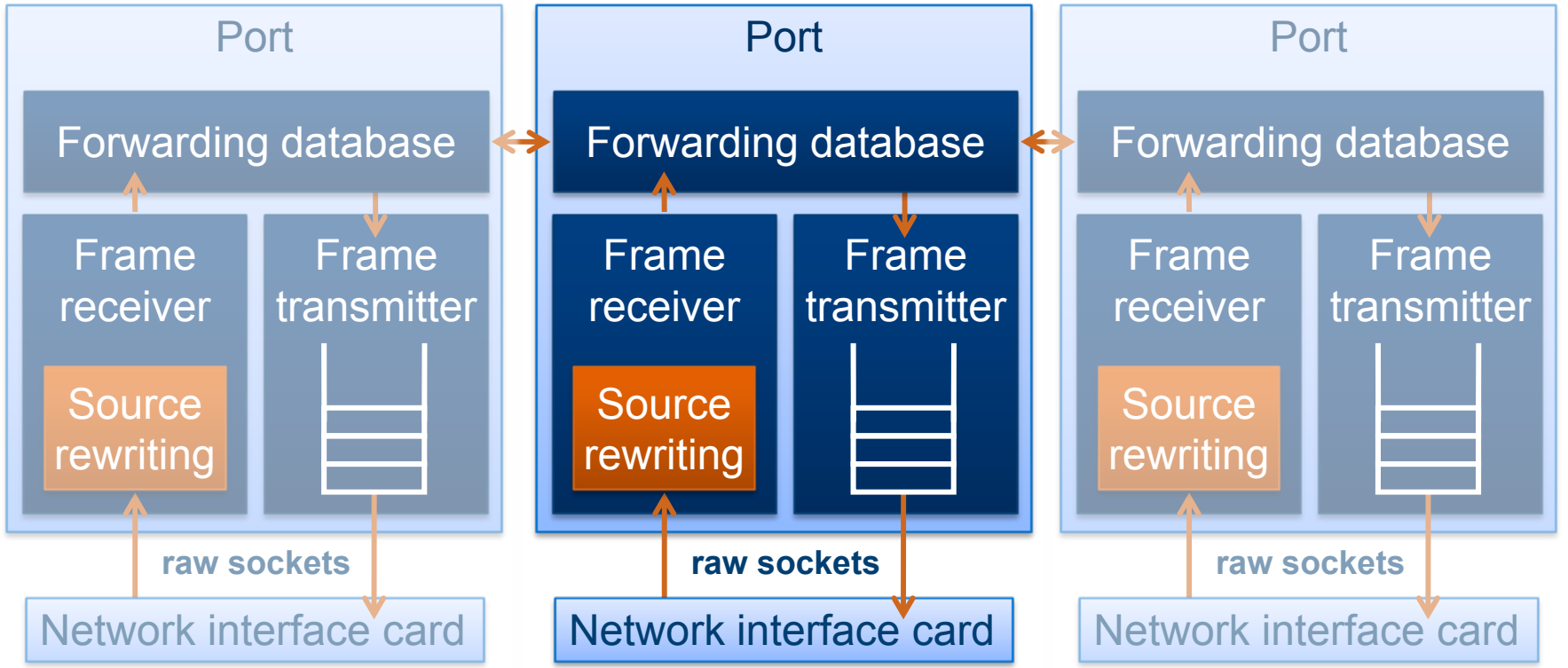



Prototype implementation

- **Proof-of-concept in threaded, object-oriented Python**
  - Designed for clarity and to mimic a potential hardware design
    - Modularity
    - Separation of control and data planes
  - Capable of up to 100 Mbps switching on a modern PC
  - Could theoretically handle very large number of nodes



Prototype implementation: Data plane



Prototype implementation: Data plane

- **Two forwarding databases:**
  - Locally-connected hosts (MAC address, host ID, Port)
  - Remote switches (switch ID, Port)
- **Inside the Frame Receiver:**
  1) Received frame from raw socket packaged in Frame object
  2) DHCP or ARP? Send to control plane ("software")
  3) Rewrite source if not already MOOSE
     - Allocate host ID if necessary: port number, sequential ID
  4) Update locally-connected-host forwarding database
  5) Consult relevant forwarding database for output Port; enqueue frame with that Port's Frame Transmitter

Prototype implementation: Control plane

- **Separate thread**
- **Routing protocol: PWOSPF**
  - Only for proof-of-concept: real implementation would likely need OSPF's authentication features etc.
  - Map switch IDs onto PWOSPF's 4-byte address fields by padding RHS with null bytes
    - `02.11.11.00/24`
  - Maintain Ports' remote-switches forwarding databases
    (routing tables, really)

Prototype evaluation

Unmodified PC's ARP cache:

```
Address          HWtype  HWaddress           Iface
10.100.11.1      ether   02:00:0c:01:00:01   eth1
10.100.11.3      ether   02:00:0a:01:00:01   eth1
10.100.11.4      ether   02:00:0a:03:00:01   eth1
10.100.11.8      ether   02:00:0b:02:00:01   eth1
```

- **Virtual network (Xen)**
  - Six virtual switches, 10 VMs each: MOOSE vs. Linux bridging
    - Linux bridge FDBs: 60 entries on each switch: ***O*(hosts)**
    - MOOSE FDBs: 5 switch entries + 10 host entries on each switch: the latter will remain constant in larger deployments, so ***O*(switches)**

Future work

- **NetFPGA implementation**
  - (Dan Wagner-Hall)
- **Enterprise Ethernet features**
  - Quality-of-Service
  - 802.1Q-compatible VLANs: opportunities to explore

Final thoughts

- **Ethernet: another 35 years?**
  - Not an ideal starting point, but it's what we've got
  - If it is to last, it needs to scale yet remain compatible
  - MOOSE is a simple, novel and easily-implementable approach
    - *Address the cause, not the symptom*

"we choose to achieve reliability through simplicity"

– Robert M. Metcalfe and David R. Boggs

Thank you

http://www.cl.cam.ac.uk/~mas90/MOOSE/

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Related work

- **Encapsulation-based solutions:**
  (MPLS-VPLS, Hadžić, SmartBridge, Rbridges / IEEE TRILL, ...)
  - Effective shortest-path routing, but...
  - Big lookup tables everywhere
  - Replace one scalability problem with another
- **Complete redesigns:** (Myers et al.)
  - The only “perfect” solution
  - But to be accepted, must be Ethernet-compatible

Related work: domain-narrowing

- **PortLand:** (Mysore *et al.*, UCSD)
  - Observe that data centres are usually “fat trees”
  - Optimise for strict hierarchical network
  - *No provision for other topologies*
    - Real deployments may come unstuck
  - Consider entire network to be a single fabric

Related work: SEATTLE (Kim *et al.*, Princeton)

- **Forward frames through a Distributed Hash Table (DHT)**
  - Elegant idea; effectively solves most of the problems
- **But, likely to cause unpredictable performance**
  - DHTs are variable-latency
  - May forward some hosts' frames through distant, slow switches
  - Cache mitigates this to an extent, but could be flooded

Related work: SEATTLE (Kim *et al.*, Princeton)

- **Topology changes are very expensive**
  (when the set of reachable switches changes)
  - *Any* such change leads to DHT reorganisation
  - ...Which involves switches throughout the network

- **Data plane complexity:**
  - SEATTLE switch must do much more for each frame than Ethernet
    - (MOOSE's data plane is quite simple)