Cloud networking (VITMMA02)
DC network topology, Ethernet extensions

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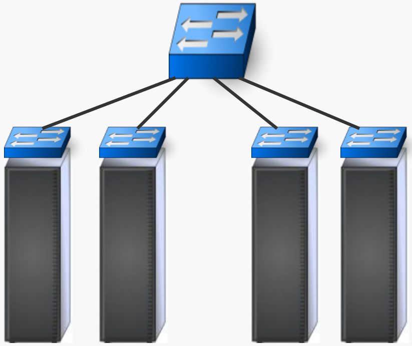
Data Center Traffic Patterns

- Traffic flow
  - north-south: between servers and core switch
  - east-west: between servers
    - e.g. VM migration, storage replication
- Request-response communication
  - before: a client request is responded by a single server
  - today: a client request is responded by many interactions of servers
    - e.g. a Google map search request
      - send information to a local search engine
      - based on the result, gather appropriate map data from map server
      - search, retrieve and display relative nearby places
      - retrieve related information about the client based on recent web transactions
      - send targeted advertisement

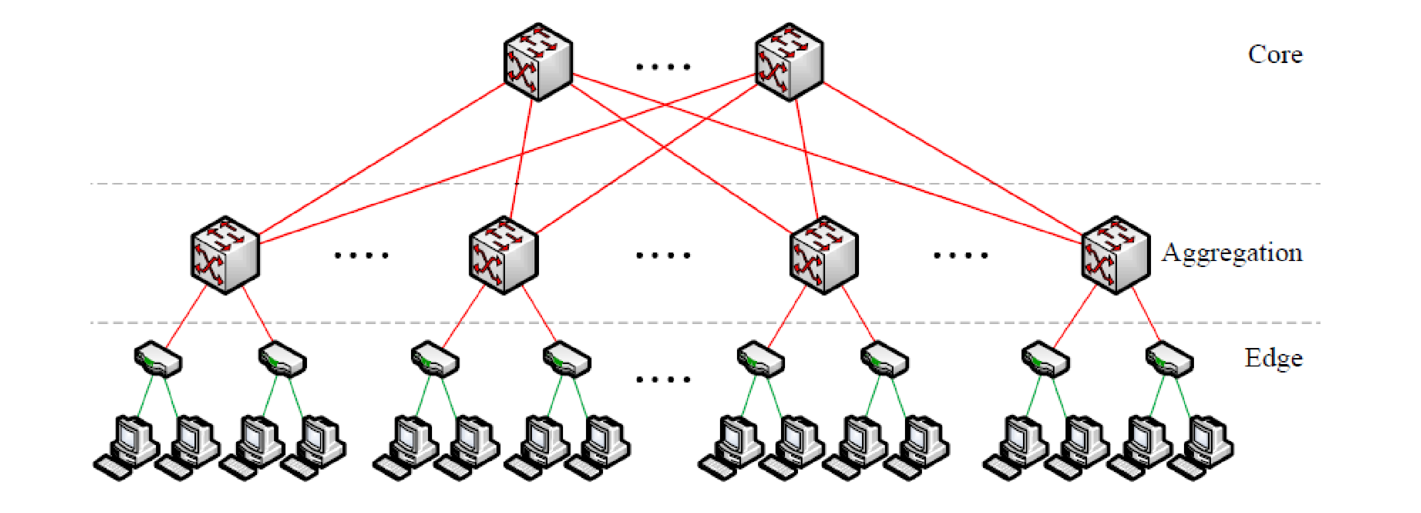
Network Topology

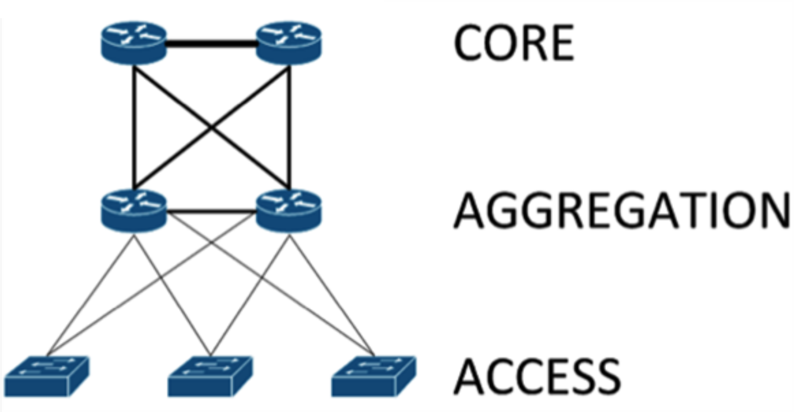
- 3 level hierarchy: ToR, aggregation, core switch
- flat (ter) topology, 2 levels: ToR and core switch
  - single large core switch: expensive, limited number of ports
    - e.g. price of a 128 port GbE switch is approx. 100-times of a 48 port switch



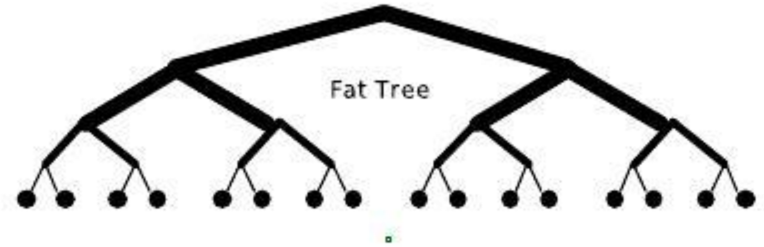
Network Topology

- Redundancy and/or load balancing
  - dual star

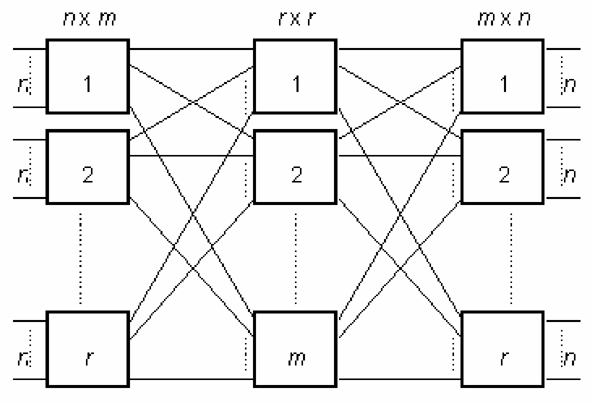




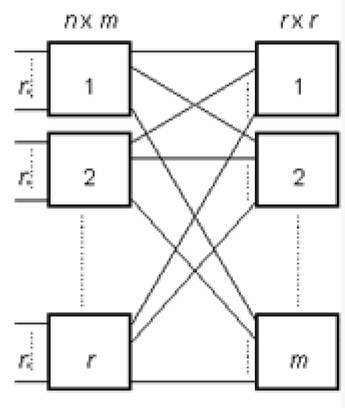
Fat-tree topology



- Fat-tree
  - 1:1 oversubscription
  - bandwidth is added up on higher levels
  - different port numbers
  - multistage switching
  - Charles Clos 1952, for telephone switching system

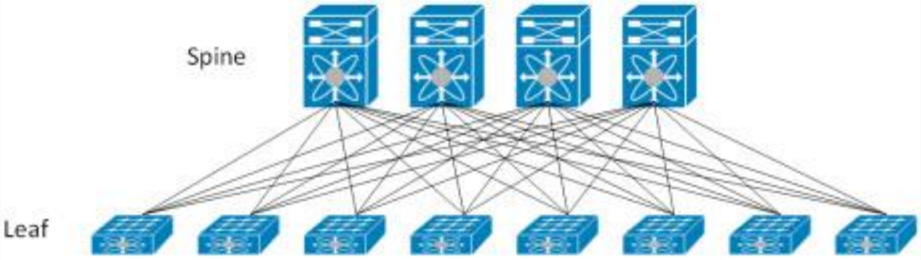


- Folded multistage switching
  - folded Clos
  - merged input and output
  - also called fat-tree



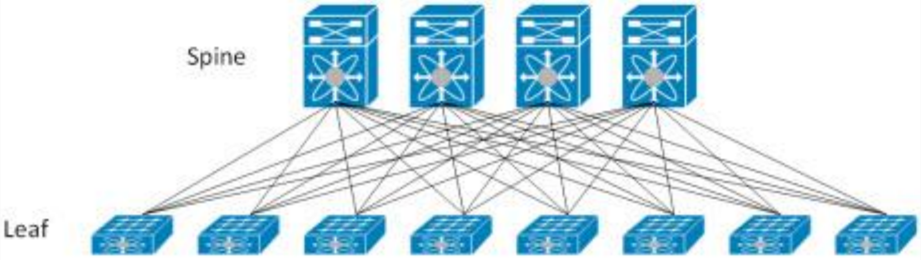
Fat-tree topology in the data center

- full mesh: complex cabling
- leaf and spine switches
- load balancing by spine switches, ECMP
- can be built by identical switches with N ports
  - leaf ports: N/2 downstream, N/2 upstream (max. N/2 spine switches) – 1:1 oversubscription
    - that's why it is called fat-tree
  - spine: N ports ⇨ max. N leaf switches
  - altogether up to
    - 1.5xN switches
    - NxN/2 servers connected to leaf switches



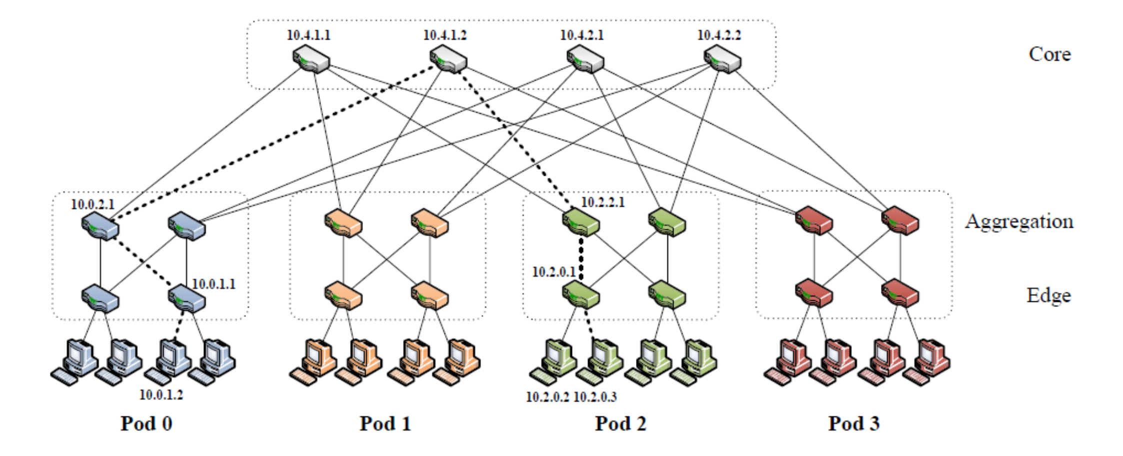
Fat-tree topology in the data center

- Load balancing
  - ideal case: traffic is distributed uniformly on spine switches
  - reality
    - flow based load balancing
      - round robin
      - hash
    - jumbo frames (9kB)
    - leaf switches are uncoordinated
- Resiliency
  - spine switch failure
    - all connections are up but with reduced bandwidth
  - leaf switch failure
    - connected servers are unavailable
    - protection: multi-homing = dual NIC, each connected to different leaf switch



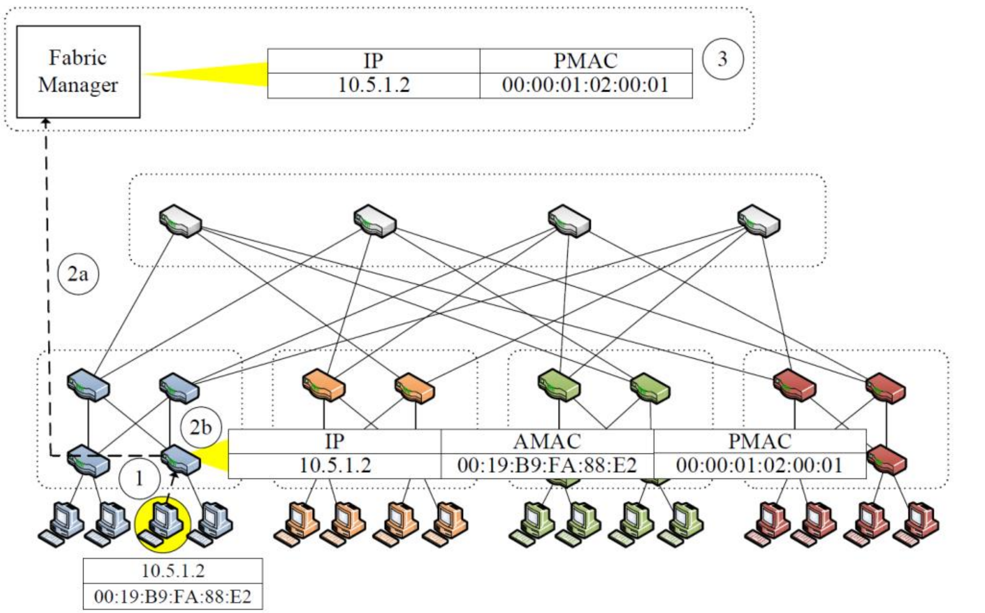
Fat-tree topology in the data center

- A topology scheme
  - switches with k ports
  - k pod (group)
  - k/2 edge and aggr. switch / pod
  - core switches connected to each pod
    - in k/2 units via aggr. switches
  - k * k/2 * k/2 = $k^3/4$ servers
  - k*k+ $(k/2)^2$ = 5/4 k^2 switches
  - $(k/2)^2$ ECMP path
  - figure: k=4
  - k=48
    - 27 648 servers
    - 2 880 switches
    - 576 ECMP path



Addressing based on L2 topology

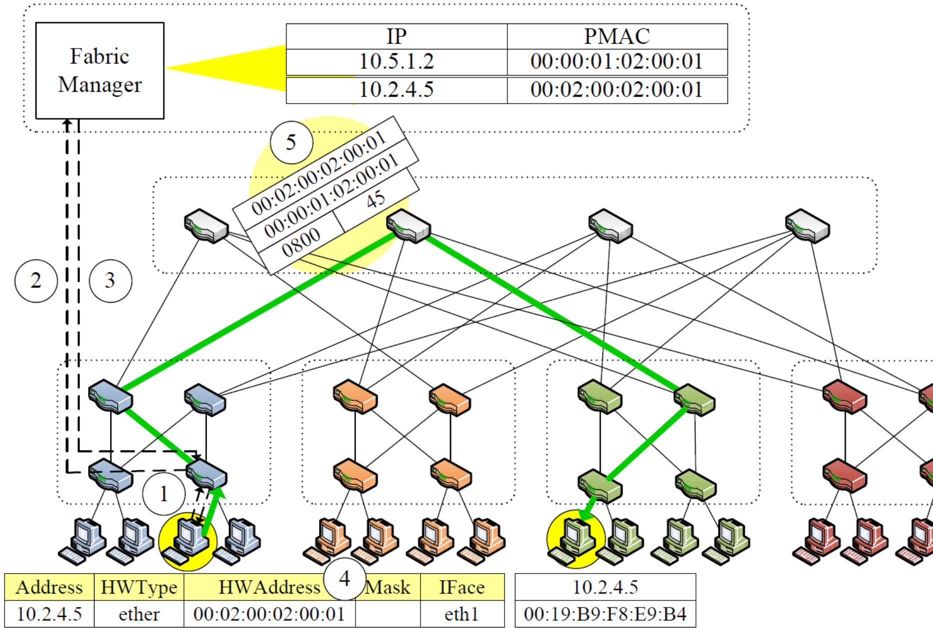
- Portland
- Pseudo MAC (PMAC)
  - topology based:
    - pod:position:port:vmid
- Fabric manager
  - handling ARP requests
- Location Discovery Protocol



IP	PMAC
10.5.1.2	00:00:01:02:00:01

IP	AMAC	PMAC
10.5.1.2	00:19:B9:FA:88:E2	00:00:01:02:00:01

10.5.1.2	
00:19:B9:FA:88:E2	



IP	PMAC
10.5.1.2	00:00:01:02:00:01
10.2.4.5	00:02:00:02:00:01

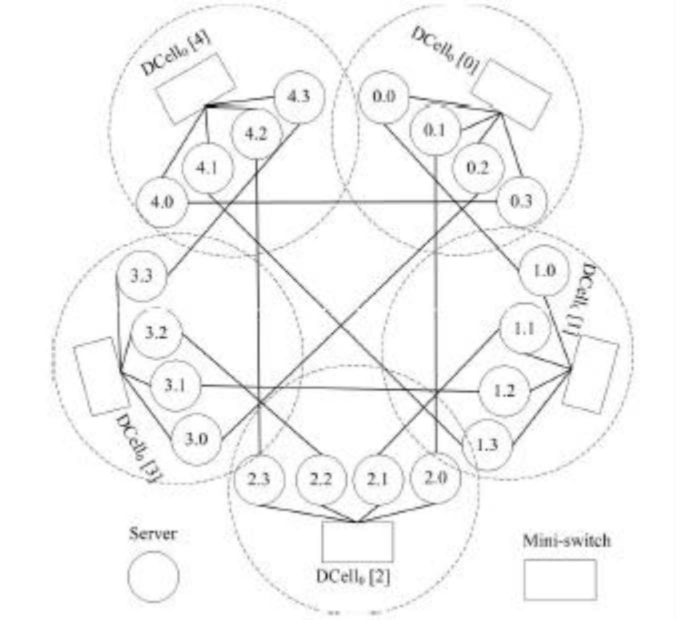
00:02:00:02:00:01	
00:00:01:02:00:01	
0800	45

Address	HWType	HWAddress	Mask	IFace
10.2.4.5	ether	00:02:00:02:00:01		eth1

10.2.4.5	
00:19:B9:F8:E9:B4	

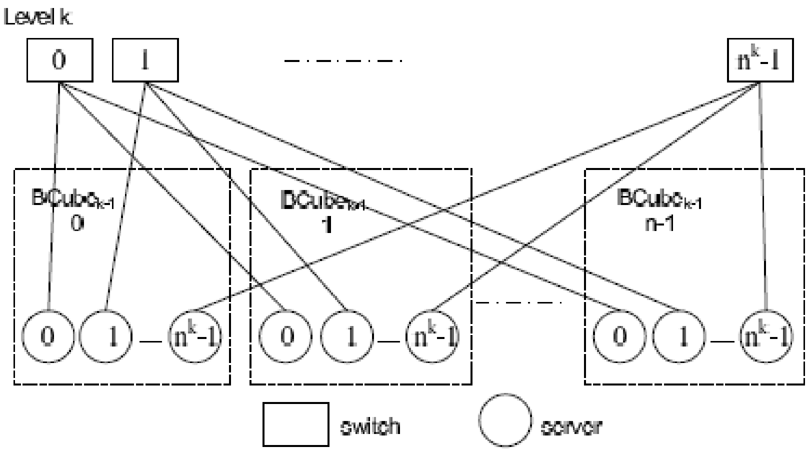
Hybrid networks: servers and switches

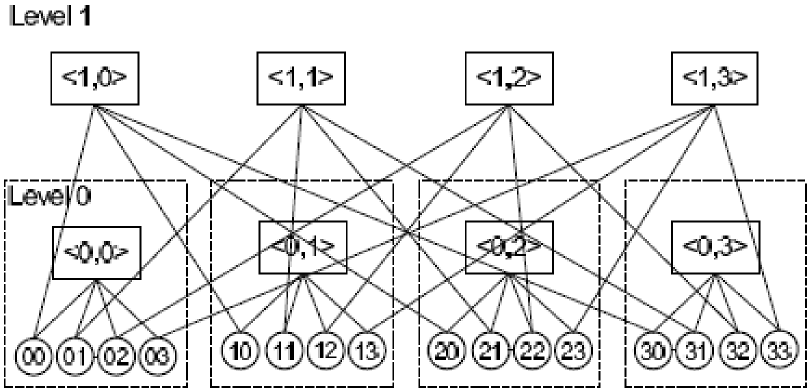
- Recursive topology model: DCell
- Incremental expansion
- Levels
  - 0. level: **n** server and **1** switch
  - k+1. level: (# of k. level servers +1) level k cells connected in full mesh
- Hybrid networking
  - intra-cell: via switch
  - inter-cell: servers are used as routers
    - at first the route between the same level cells containing the source and destination is determined, then the intra-cell route
    - not a min hop routing
- Robust
  - many alternative routes
- Performance
  - bandwidth depends on the size of the network
  - more intermediate hops



Hybrid networks: servers and switches

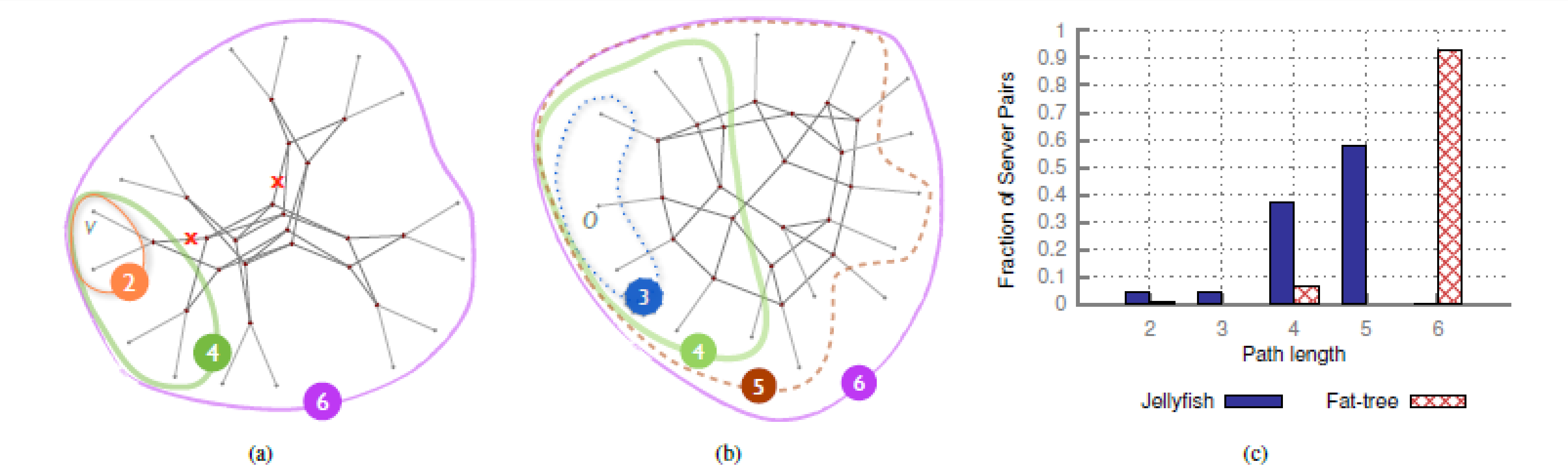
- BCube: for modular data center units installed into containers
  - number of servers in the order of 1000s
- Properties
  - graceful degradation in case of failure
  - small diameter network
  - a lot of parallel connections between servers
  - source routing
    - multipath
    - network probes
- Recursive topology model
  - Levels
    - 0.: **n** servers interconnected by a n port switch
    - k.: **n** k-1. level BCube and $\mathbf{n^k}$ n port switch
  - k. level
    - $\mathbf{n^{k+1}}$ server
    - servers: k+1 port
    - k+1 level from switches, $\mathbf{n^k}$ n port switch at each level





Jellyfish topology

- ToR switches connected by a random graph
- Incremental expansion
- Switches with different port numbers
- Advantages
  - average path length is smaller
  - with the same number of switches more servers are connected compared to fat-tree topology

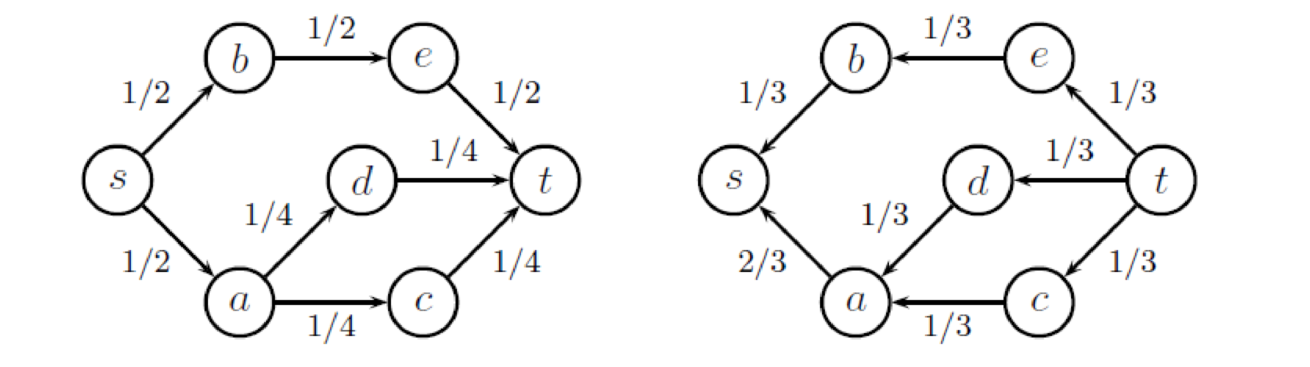


Improving network utilization

- Ethernet Spanning Tree Protocol
  - spanning tree: unused links
  - Rapid STP (RSTP)
  - Multiple STP (MSTP)
  - ideal for arbitrary and changing topologies
- But not ideal for data centers
  - structured and not frequently changing
  - new standards
    - Equal Cost MultiPath (ECMP) routing
    - Shortest Path Bridging (SPB)
    - Transparent Interconnection of Lots of Links (TRILL)

ECMP

- Equal Cost MultiPath



- Layer3 routing or tunneling between Layer2 domains
  - L2 over L3
- generally not used in networks
  - if routes join before the destination, only the complexity is enlarged, but not the bandwidth utilization
  - virtual network ⇔ physical network

Sources

- Radhika Niranjan Mysore, Andreas Pamboris, Nathan Farrington, Nelson Huang, Pardis Miri, Sivasankar Radhakrishnan, Vikram Subramanya, and Amin Vahdat. PortLand: a scalable fault-tolerant layer 2 data center network fabric. *SIGCOMM Comput. Commun. Rev.* 39, 4 (August 2009)
- Ankit Singla, Chi-Yao Hong, Lucian Popa, and P. Brighten Godfrey. 2012. Jellyfish: networking data centers randomly. In *Proceedings of the 9th USENIX conference on Networked Systems Design and Implementation* (NSDI'12). USENIX Association, Berkeley, CA, USA.