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data centers' architecture

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Description	Data Centers' Routing: Multipath, Fat-Trees

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Multi-Path

in a nutshell

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Multi-Path

- data center architectures allow to establish several paths between pairs of nodes
- Multi-Path routing is used to
  - distribute and balance the traffic among different paths
  - increase the fault tolerance

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Multi-Path

- allows to have more than one next-hop for the same prefix in the FIB (Forwarding Information Base)
- needs kernel support
  - the main OSes and routers support it
- different usage policies can be applied
- packets of the same *flow* should use the same path
  - reordering packets is computationally heavy

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Equal-Cost Multi-Path (ECMP)

- a specific approach to Multi-Path
- exploits paths to the same destination that have the same “cost”
  - e.g., same IGP cost, same number of hops
- allows to choose among the available paths in a uniform way
- often used in Fat-Tree data centers
  - we’ll get there in a couple of slides

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how packets are forwarded

- for each packet, the kernel decides the FIB entry to be used
- different policies are allowed
  - hash-based policy
    - Layer-3 hash (src IP, dst IP)
    - Layer-4 hash (src IP, dst IP, src port, dst port, protocol)
  - round-robin

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Hyper-scale Data Centers

main concepts

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a high-level architecture

- Internet connections
  - multiple redundant high-speed fiber optic links
- fabric
  - infrastructure designed to transport packets between servers and between servers and Internet
- server farm
  - host applications and services

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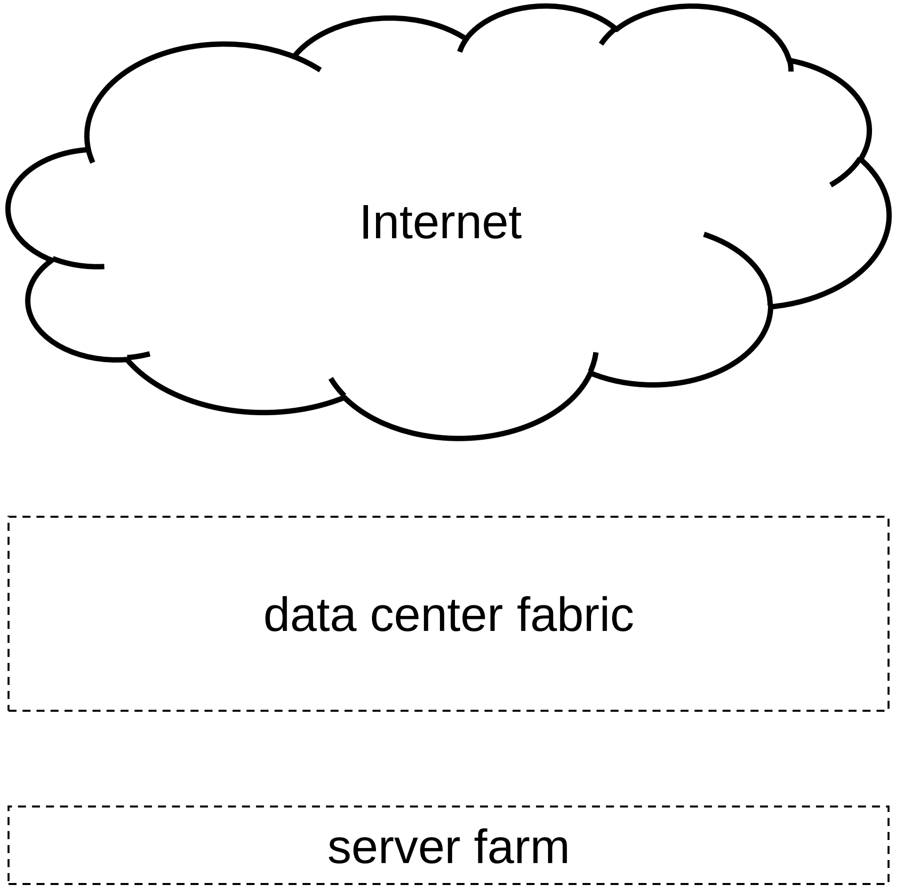
a high-level architecture



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fabric architecture

why Fat-Trees?

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overview – fabric architecture

- real-life data centers
- service model
- data center network
  - traffic flow directions
  - requirements
  - components
  - topologies

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real data center information – figures

- links are fiber optic links
- each link in the fabric is at least at 100Gb/s
- each switch is at least of 64 ports
- about 5,000 switches/routers
- about 60,000 servers

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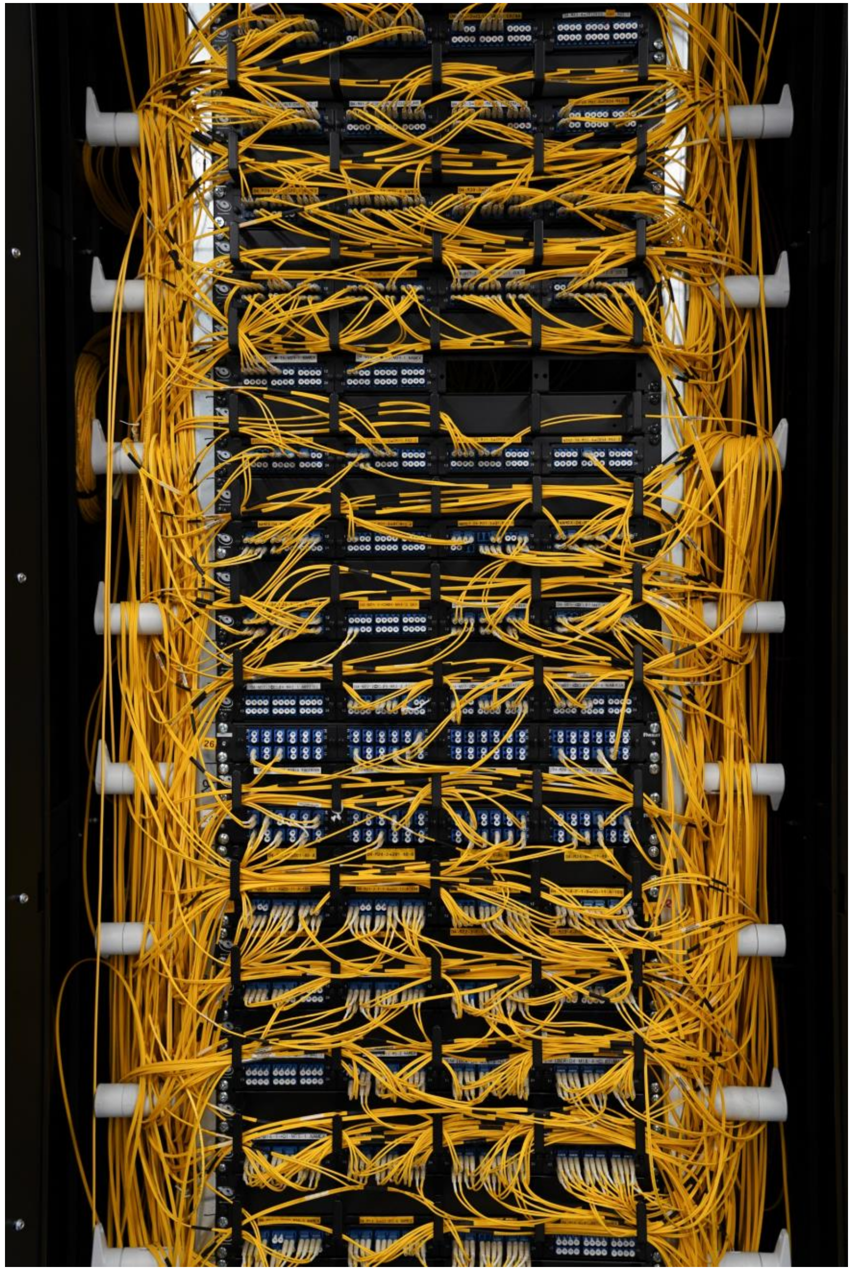

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data center failures – yearly report

statistics by Google (2008) in a *portion* of data center composed of 1,800 servers:

- 1,000 individual machine (switch/router or server) failures
- thousands of hard drive failure
- 1 power distribution unit failure
  - down for 500/1000 machines for 6 hours
- 1 cluster complete rewire (not simultaneously)

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data center service models

- three different service models
  - on-premise data centers
    - built, owned and operated by a company
    - often housed in a building of the organization
  - colocation data centers
    - built and owned by a company that rents space within the data center to other companies
      - the hosting company manages the infrastructure (building, cooling, bandwidth, security etc.)
      - the hosted companies provides the components, including servers, storage, and firewalls
  - cloud data centers
    - applications and data are hosted by a cloud service provider such as Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP)

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traffic flows inside a data center

- two types of flows can be identified
  - traffic exiting or entering the data center
    - also called “north-south traffic”
    - data sent/received via Internet
  - server-to-server communications
    - also called “east-west traffic”: in data center schemata servers are typically drawn side-by-side
    - primarily, supports micro-services and distributed architectures

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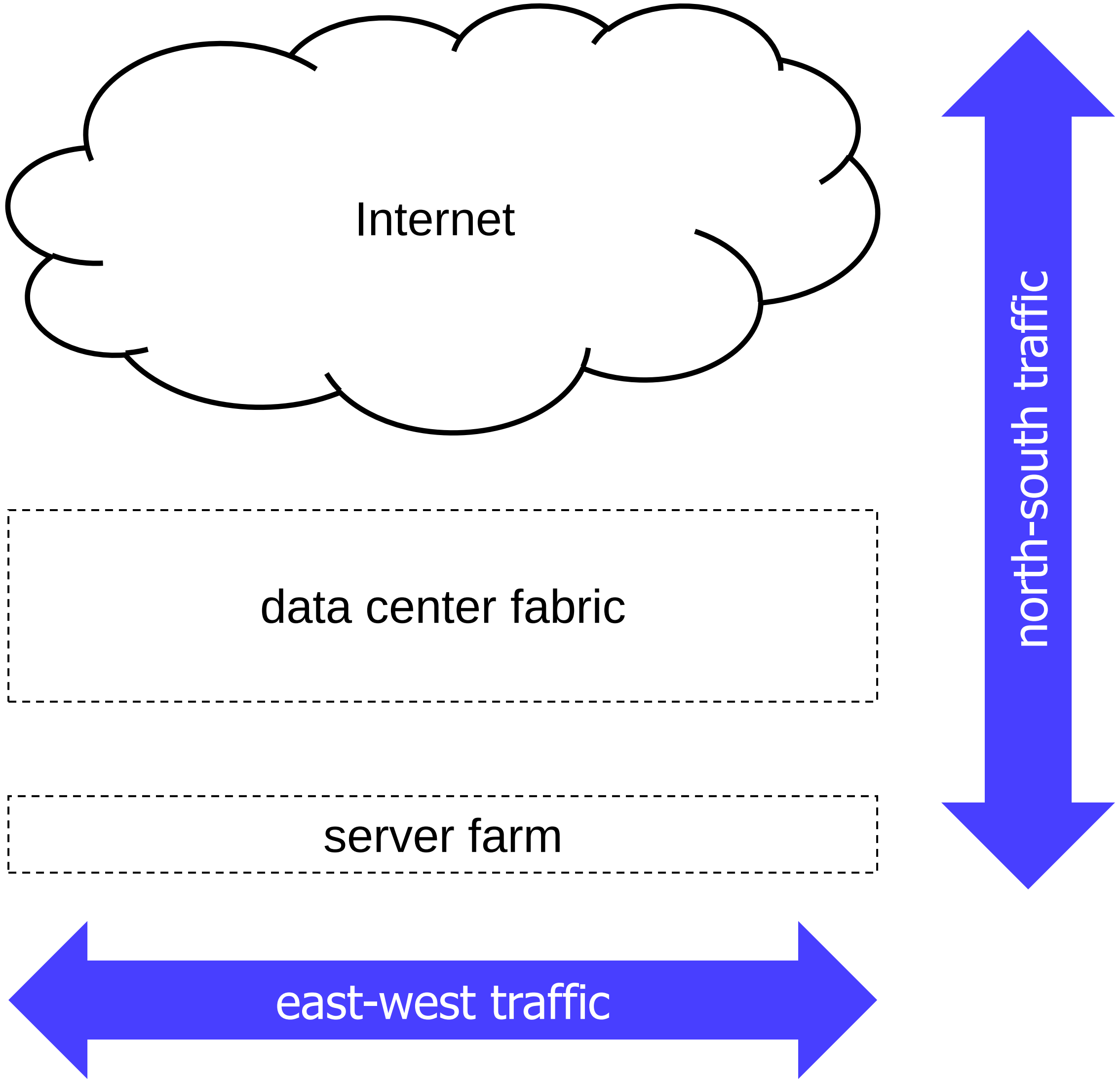
traffic flows inside a data center



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data center network requirements

- support high-bandwidth server-to-server communication
  - applications that rely on cluster computations, such as Hadoop or Spark, can involve hundreds or thousands of servers
  - customer's containers/virtual machines (VMs) are distributed across multiple servers but need to communicate seamlessly
  - microservice architectures heavily rely on server-to-server communication
- scale
  - data centers range from a few hundred to a hundred thousand servers in a single physical location
- resilience
  - data center applications are designed to work in presence of failures

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data center network components

- data center nodes can be connected by using two network component types
  - specialized hardware
    - proprietary hardware that can scale to clusters of thousands of nodes with high bandwidth
      - e.g., Google Jupiter and InfiniBand switches
    - expensive option
  - commodity switches and routers
    - cheap option
    - widely adopted, this is the option we consider in the following

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topology requirements

- scalability
  - it should be possible to expand the data center
  - in other words, it must be possible to buy and deploy hardware similar to the one already deployed
- bandwidth
  - hosts in the fabric should communicate with each other using the full bandwidth of their NICs

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data center network topologies

- several topologies have been proposed
  - Clos
  - Fat-Tree
  - VL2
  - Jellyfish
  - Xpander
  - DCell
  - ...

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Clos topology

- invented by Edson Erwin in 1938 to address scalability issues in telephone networking
  - formalized by Charles Clos in 1953
- the original problem was allowing N contemporary connections from N input lines to N output lines without using a single crossbar switch

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Fat-Tree topology

- Fat-Trees were originally introduced by Charles Leiserson in 1985
- the Fat-Tree is a special case of a Clos
- typical Fat-Tree architectures today consist of three level of nodes (switches/routers)
- high redundancy
- constant *bisection* of the available bandwidth
- typically, nodes have the same characteristics
  - easier to stock spare equipments

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Fat-Tree parameters

- the Fat-Tree is a modular topology
- two parameters define a Fat-Tree
  - *radix* of the nodes (even number, denoted by 2K)
    - number of available ports
  - *redundancy factor* (denoted by R)
- usually, if the radix of a node is 2K it has K connections towards the north and K connections towards the south
  - different choices are possible, but not considered here

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Fat-Tree nodes

- Leaf
  - node connected to the server farm
- Spine
  - node north of Leaves and south of ToF nodes
- Point of Delivery (PoD)
  - set of fully interconnected Leaves and Spines
- Top of Fabric (ToF)
  - set of top nodes that provide inter-PoD communication

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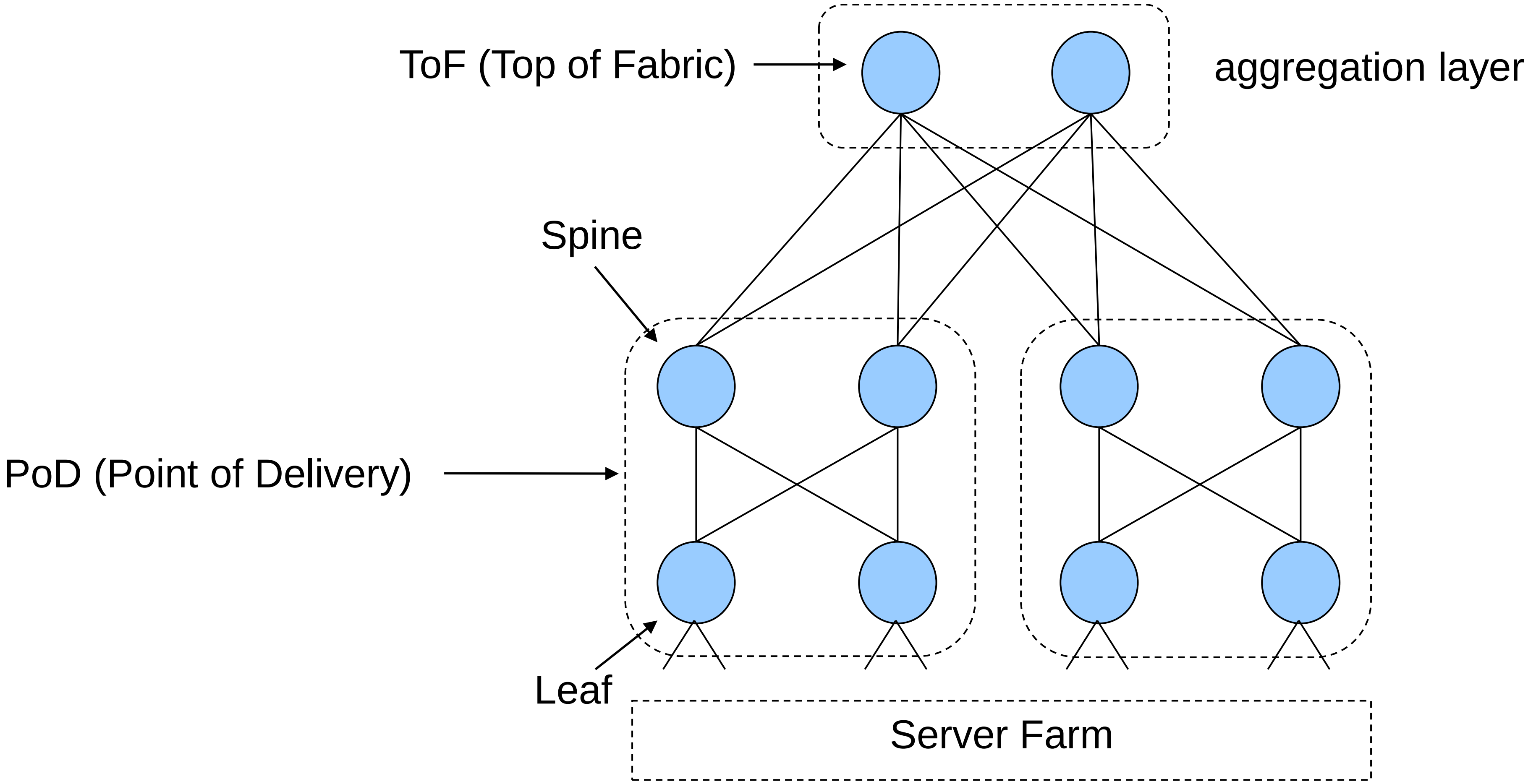
an example of Fat-Tree: FT(K=2,R=2)



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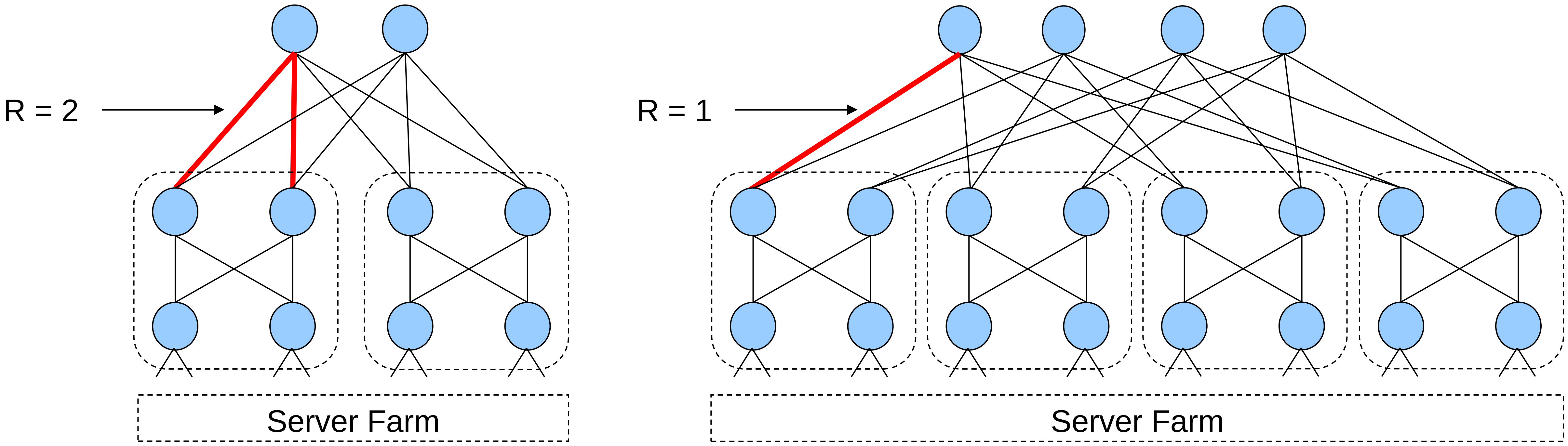
redundancy factor (R)

- number of links between a ToF node and a PoD
- allow to connect more PoDs reducing the redundancy



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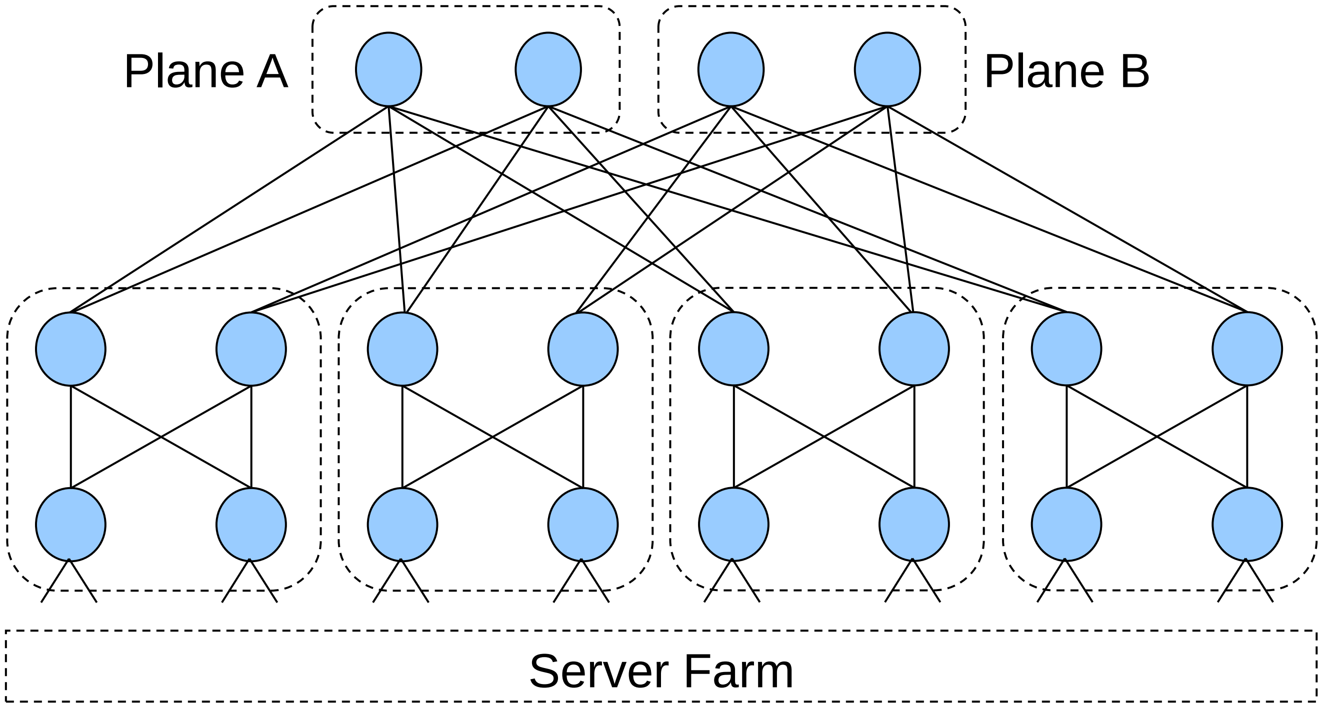
multi-plane Fat-Tree

- when K≠R the Fat-Tree is called *multi-plane*
- the ToF nodes are partitioned in sets called *planes*



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example of a multi-plane Fat-Tree

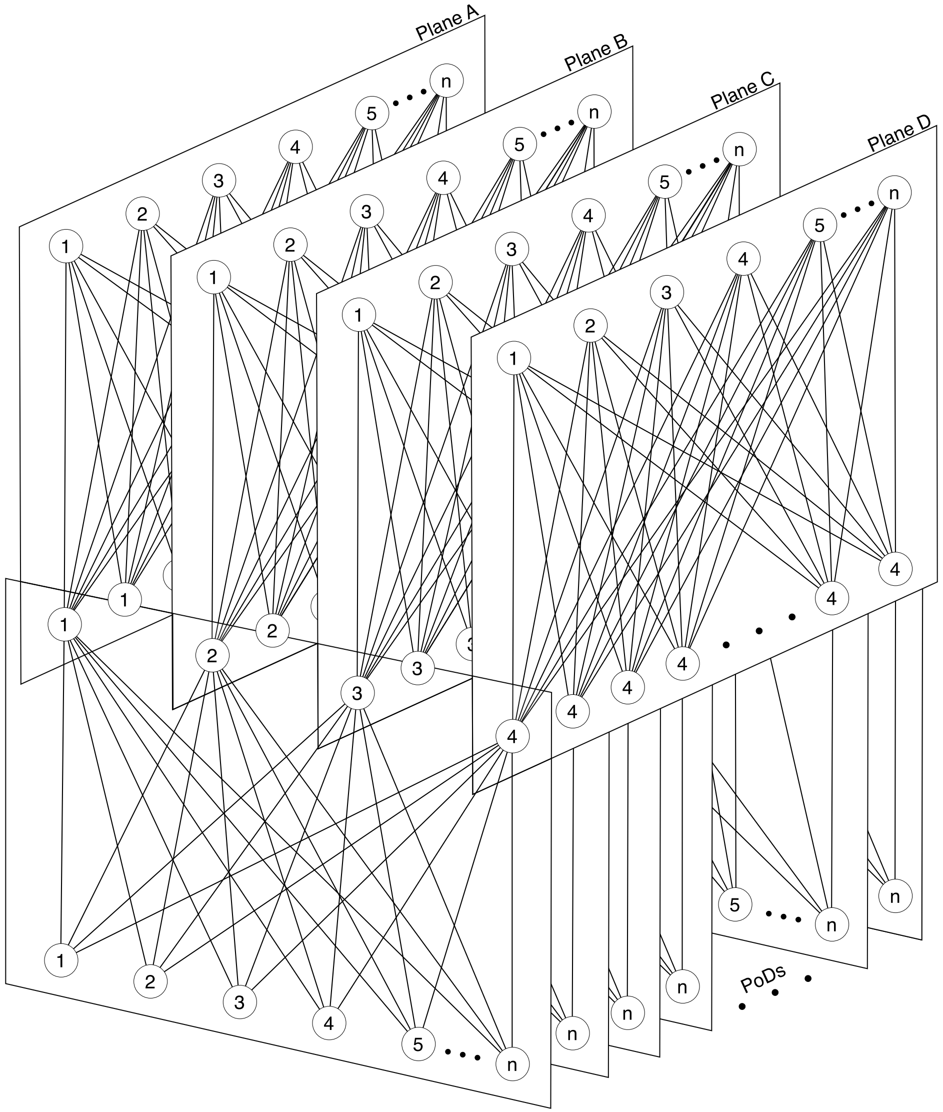

diagram from the
IETF RIFT Draft

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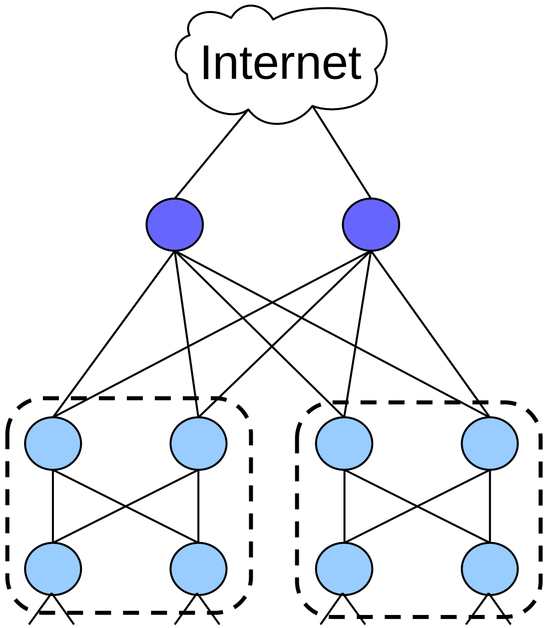
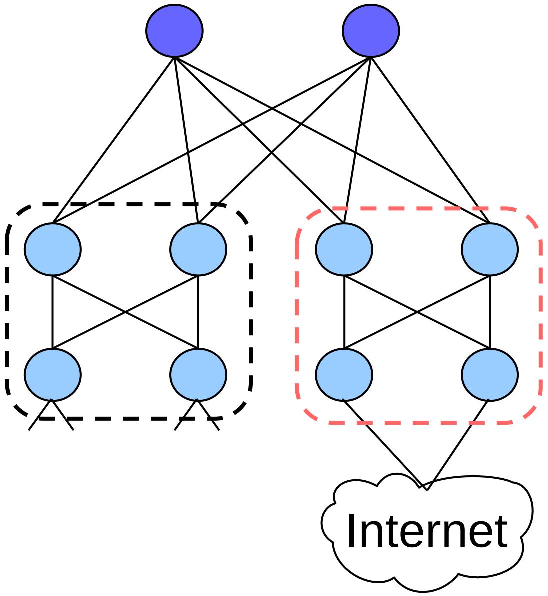
connecting a Fat-Tree to the Internet

- two strategies
  - usage of a dedicated PoD
  - usage of ToFs





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bibliography and further readings

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