Analyzing Routers and Networks:

Routers Evaluation using Test Equipment

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Lecture at SFU

Vancouver, March 13th, 2003

Agilent Technologies Inc.

- Hewlett & Packard
  started 60 years ago
- Agilent spin off
  1999
- http:\\www.agilent.com
- Divisions
  e.g. products

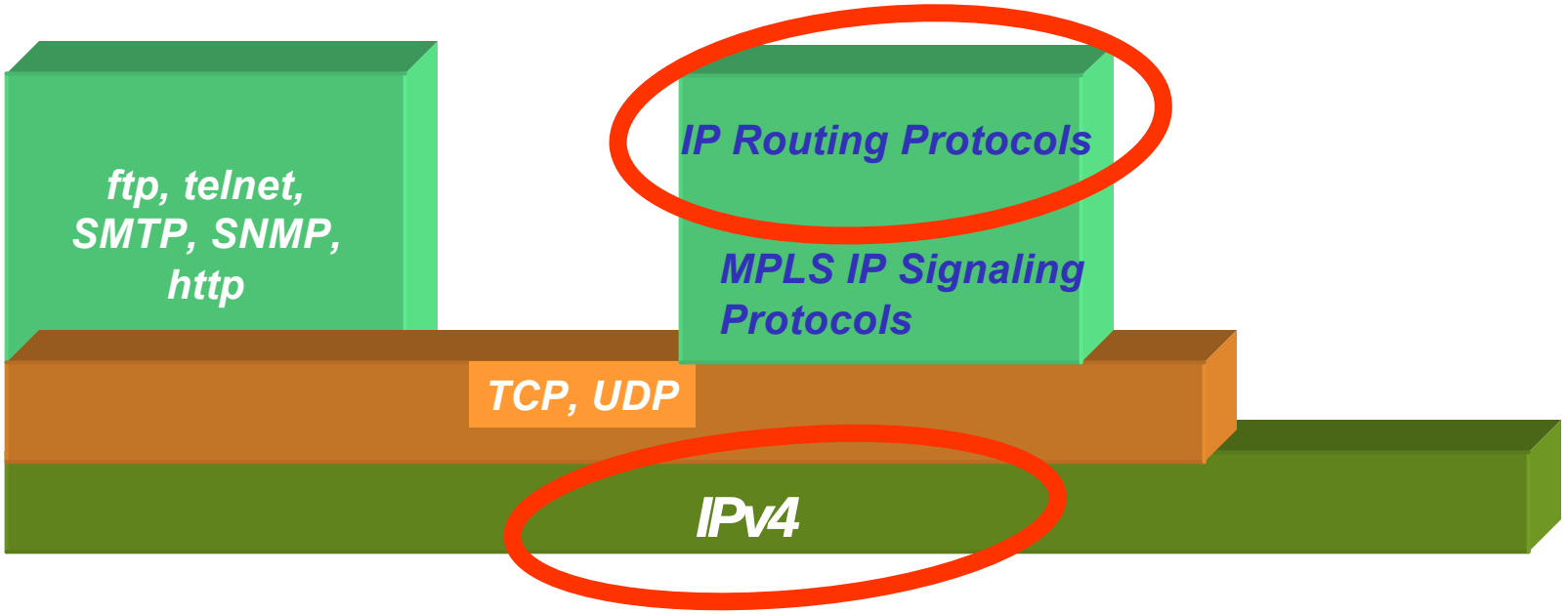
- Test & Measurement Equipment
  e.g. Oscilloscopes
  Digital Multimeter
- Life Sciences & Chemical Analysis
  e.g. DNA Microarray
  Cancer Research
- Automated Test Equipment
  e.g. X-ray Tests
  Printed Circuits Test Automation
- Semi-conductor Products
  e.g. Protocol Layer ICs
  Fiber Optics, Physical Layer
- Communications Solutions
  e.g. Wireless
  Network Management
  RouterTester

Overview

- Packet Forwarding ⇦
- IP Network Routing Protocols ⇦
- Inside a Router
- How to Evaluate a Router
  - Conformance Tests
  - Resilience Tests
- Test & Measurement Equipment
- Test Case:
  - Route Convergence
- Data Plane Testing
- Summary

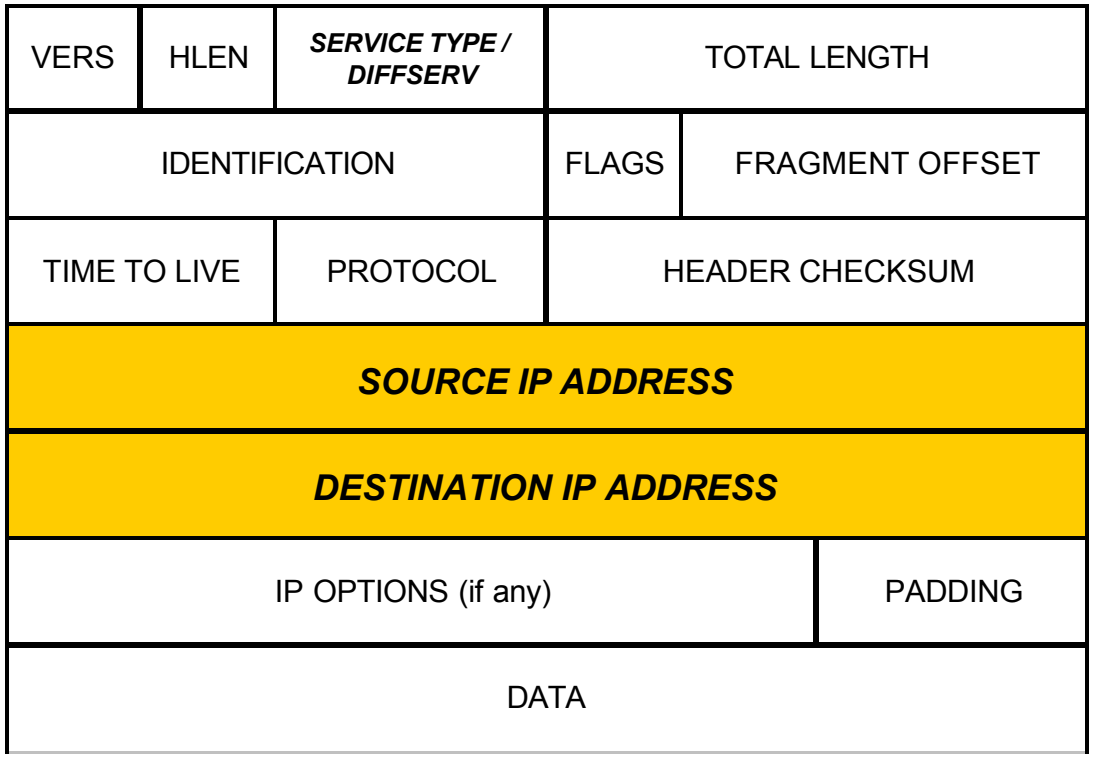
Internet

- architecture
- a protocol stack
- network-wide addressing



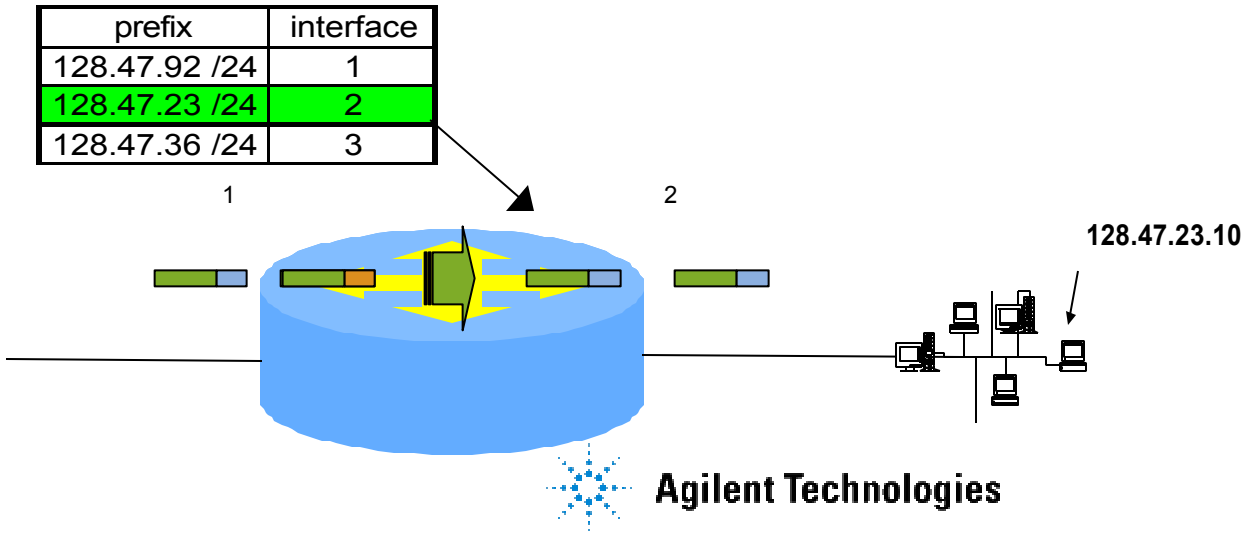
The Internet Protocol v4 (IPv4) packet

- Source and destination addresses indicate endpoints
- Host address e.g. 128.47.23.10
- Network prefixes contained in the routing table e.g. 128.47.23/24

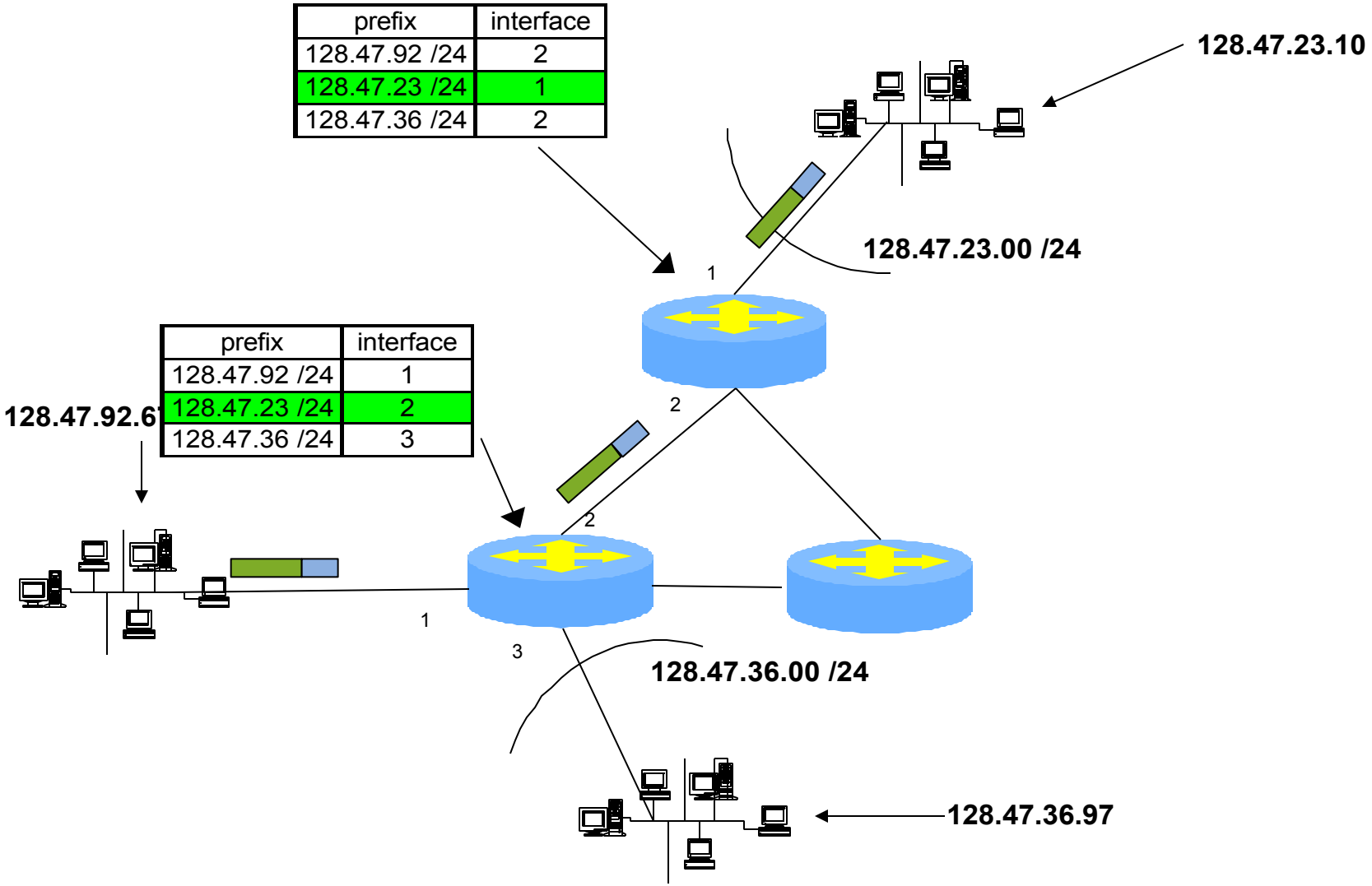


Router IP Packet Forwarding

- a router receives an IP packet
- verifies header checksum
- forwarding table lookup to find the output interface:
  search for the network prefix of the longest length
- moves the packet to the output interface
- transmits the packet



Routing an IP packet



Routing and Forwarding Tables

- Mapping between the **IP prefix** and router's **output interface**
- Particular to the **router**
- Router's own model of the network – **synchronization** with the others.

- Example: **Link failure** recovery

- Routing protocols update the **routing table**.
- **Forwarding table** is used for address lookups.
- Forwarding table(s) is a copy of the routing table.

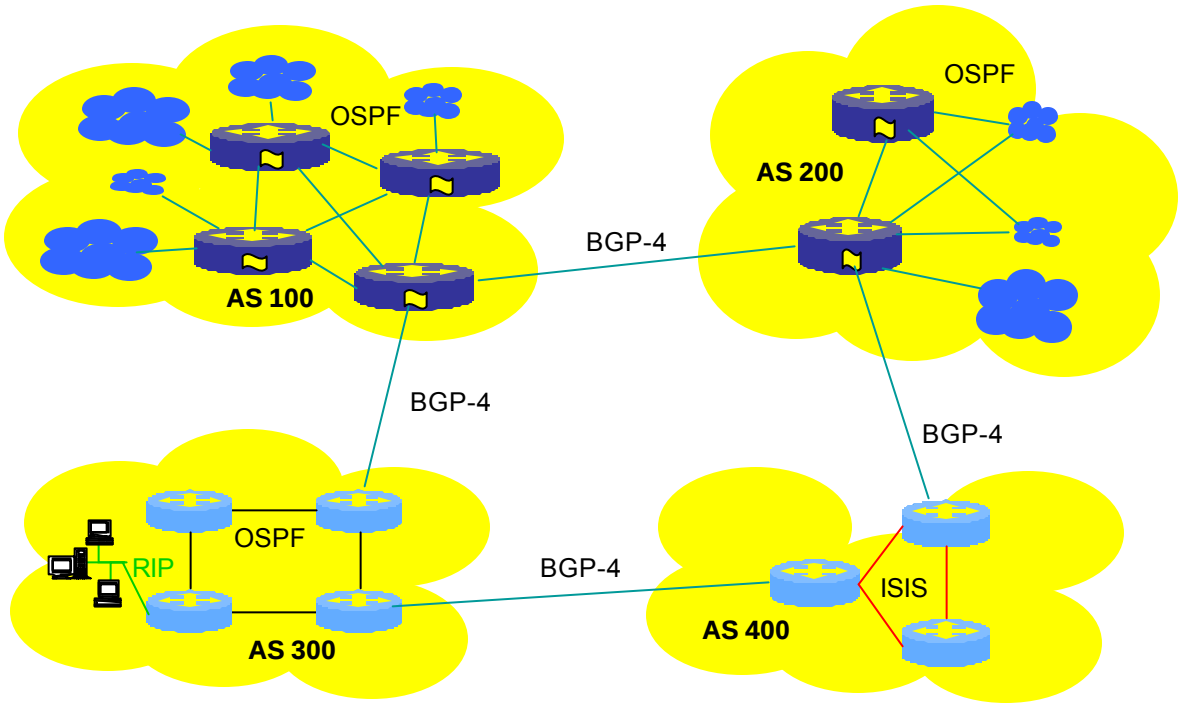
IP Routing Protocols

- IETF RFC standards
- Interior Gateway Protocols (IGP)
  - OSPF - Open Shortest Path First !!!
  - RIP - Route Information Protocol
  - ISIS - Intermediate System to Intermediate System
- Across routing domains
  - BGP4 - Border Gateway Protocol !!!

- Components of the Routing Protocols
  - Communication protocol (stack exemplified earlier)
  - Information data field carries info on the routing: syntax and semantics of the data

IP Routing Protocols

The Internet is divided into Autonomous Systems (ASs)



Protocols inside the AS:

- OSPF
- IS-IS
- RIP
- I-BGP4

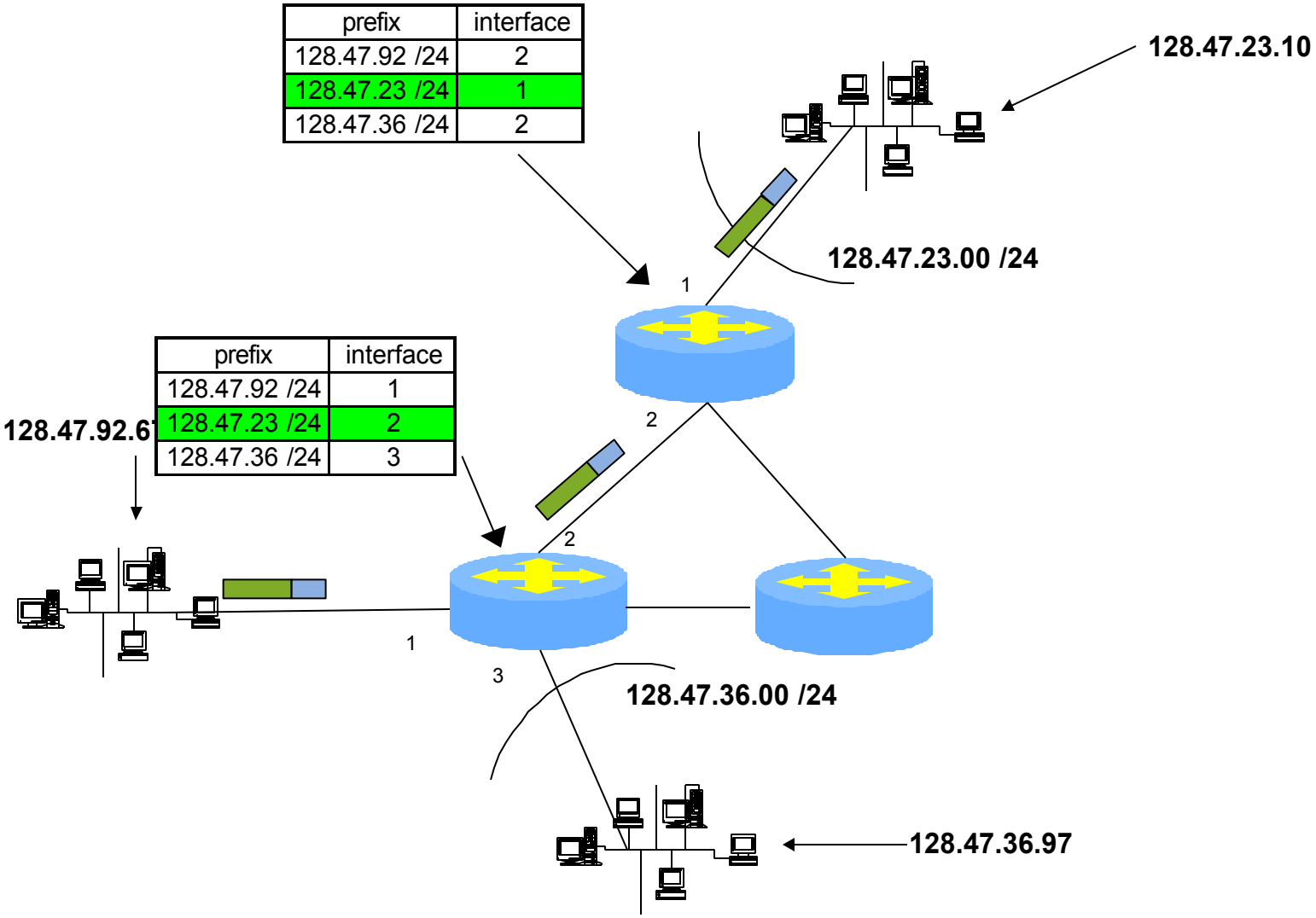
Protocols between ASs:

- E-BGP4

Routing and Forwarding Tables (advanced)

- **IPv4 !!!**
  Mapping between the IPv4 prefix and router's output interface
- **IPv6**
  Mapping between the IPv6 prefix and router's output interface
- **MPLS**
  (Multiprotocol Label Switching)
  Mapping between the incoming MPLS label and outgoing MPLS label and mapping onto the router's output interface
- **Multicast**
  (based on IPv4)
  Mapping between the multicast address and router's output interface

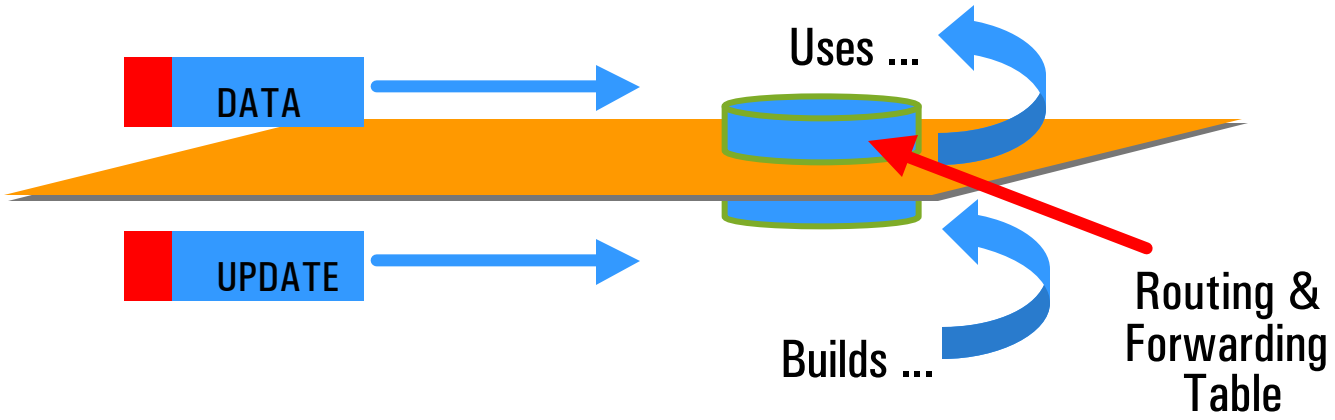
Routing an IP packet (repeated)



IP Data Plane / Control Plane

Data plane

- packet forwarding



Routing in the Control Plane

- processes routing protocol messages
- builds routing and forwarding table
- advertises routing information to other routers.

Overview

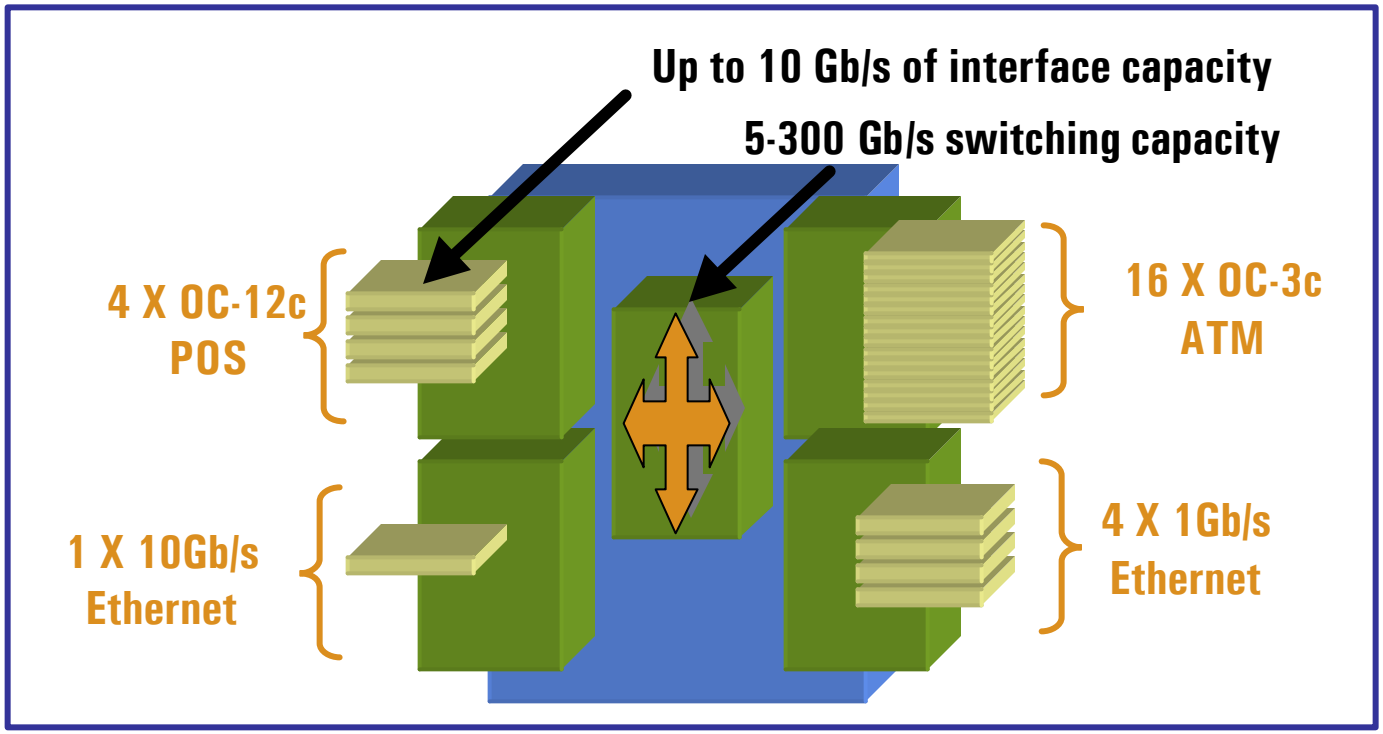
- Packet Forwarding
- IP Network Routing Protocols
- Inside a Router 
- How to Evaluate a Router
  - Conformance Tests
  - Resilience Tests
- Test & Measurement Equipment
- Test Case:
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Inside the Router

- router architectures
- functional blocks of a router
- mechanisms within each block

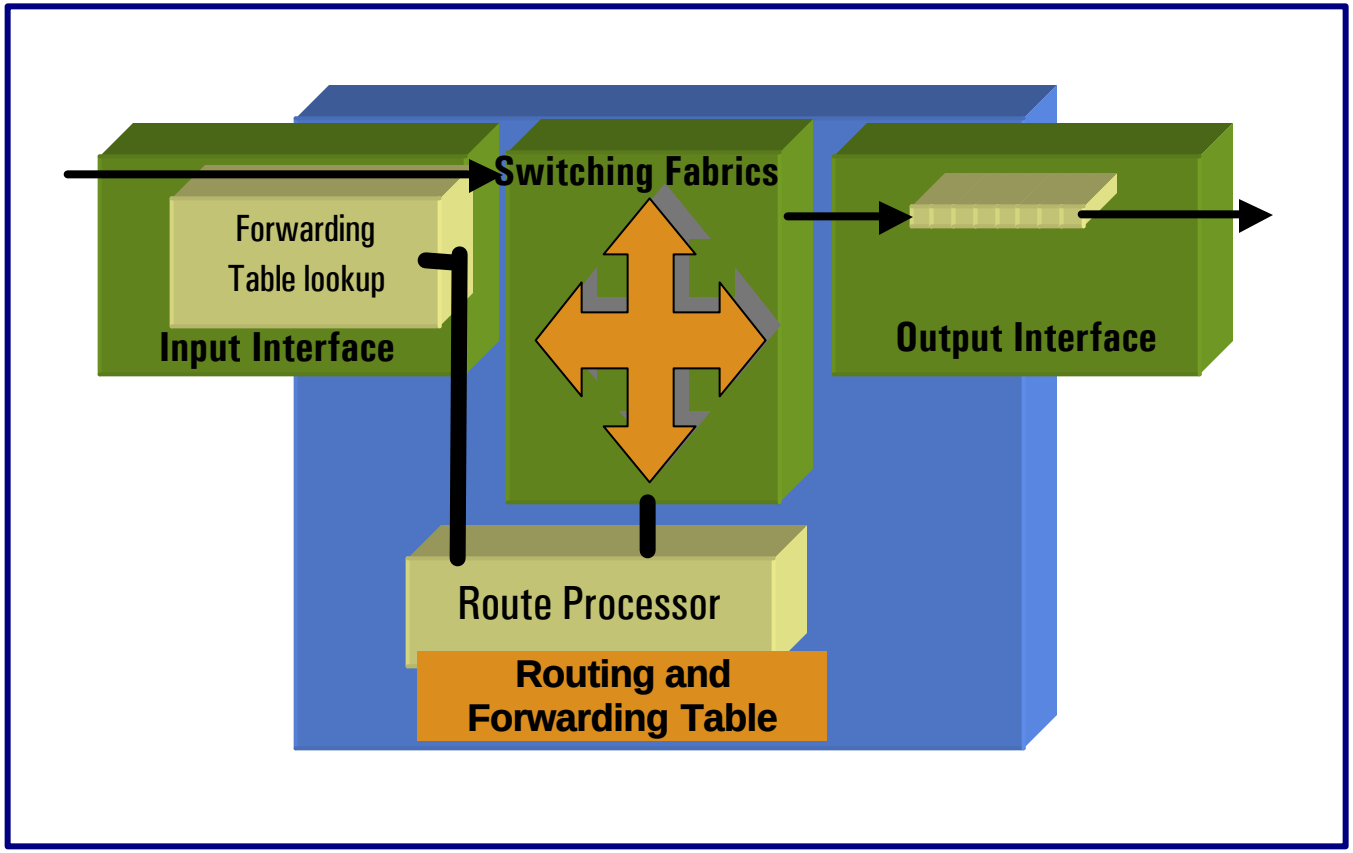
Inside the Router: Router Interfaces

- Interface: logical
- Port: physical interface



Inside a Router

- IP packet path: Basic functions

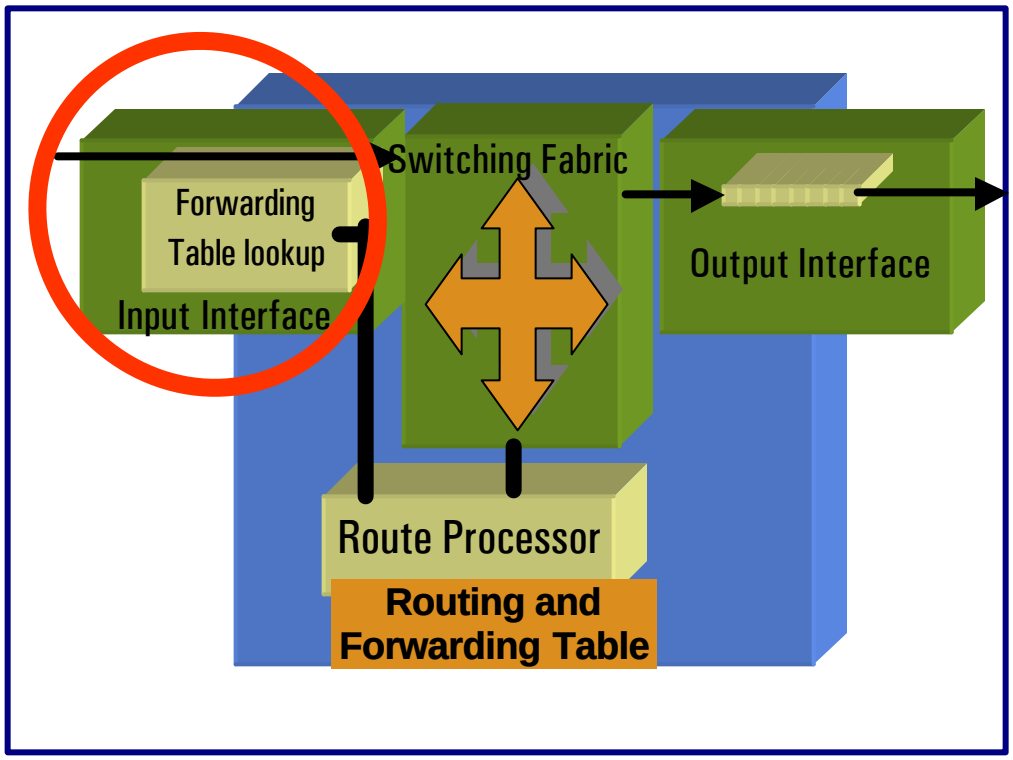


Input Interface

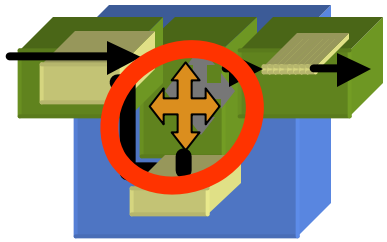
- IP packet address lookups

Metrics:

- speed of destination address lookups



Switching Fabrics

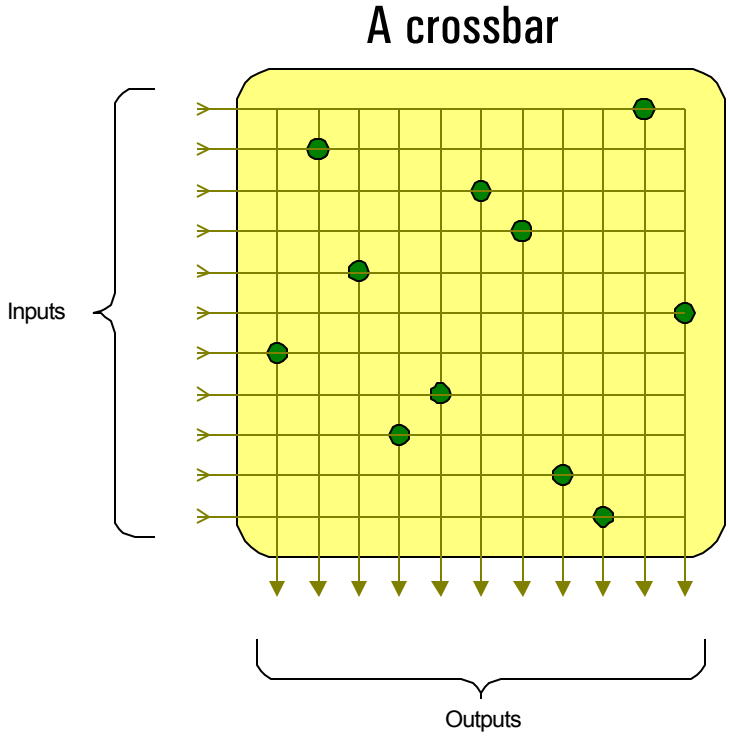


E.g. crossbar architecture:

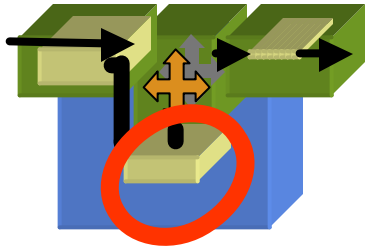
- switch from any input to any output
- requires scheduling and typically input buffering
- scales further than shared memory

Metrics:

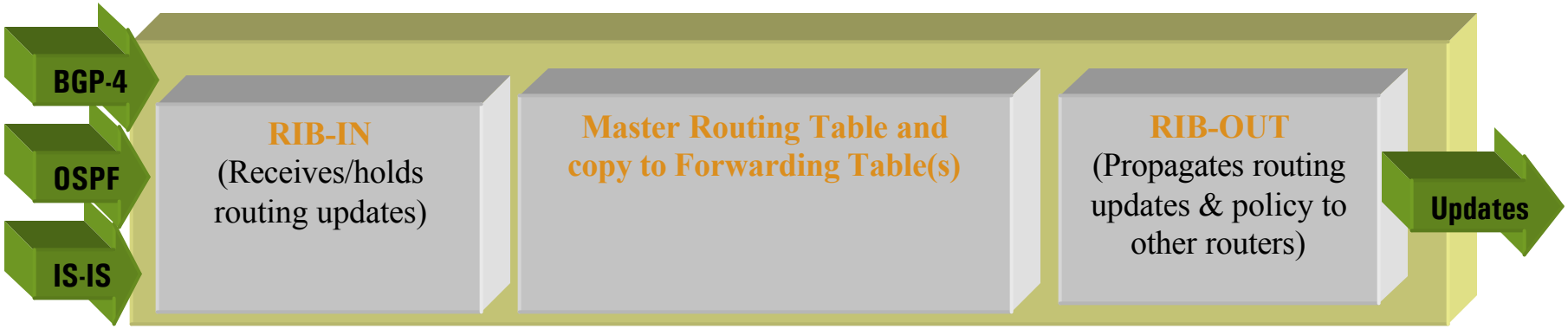
- maximum rate at which packets can be switched from all interfaces



Route Processor



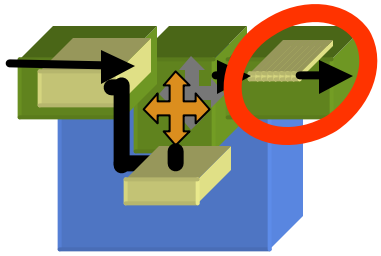
- **Route Processing:**
  - Management of routing table, routing information bases (RIB) & route advertisement



- **Metrics:**
  - Routing protocol conformance
  - Functional testing of protocols
  - How does routing instability effect forwarding performance?
    - Robustness to route flaps
    - Route convergence

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Output Interface
(advanced: DiffServ networks)



- Output interface
  - Output queues for QoS provisioning to FEC (forwarding equivalence class in DiffServ networks)
    - incl. RED (random early detect)
- Input interface:
  - QoS functions
    - Traffic policing etc.

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Router Evaluation

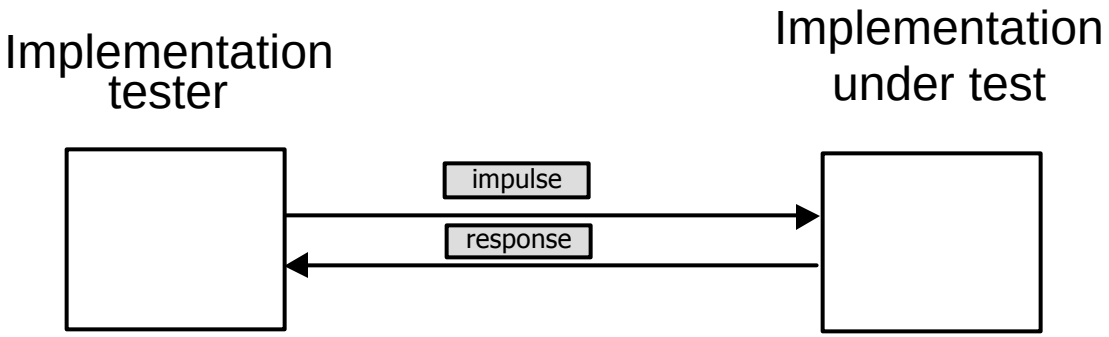
- **Performance Measures**
  - Throughput
  - Loss
  - Packet delay
  - Convergence !!!
  - Fast reroute
  - Resilience !!!
  - RT size

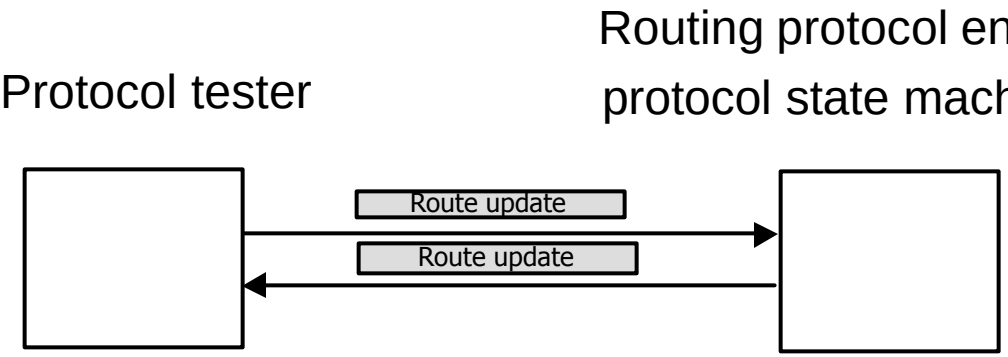
- **Functional**
  - Conformance to rfc !!! ⇦
  - Interoperability

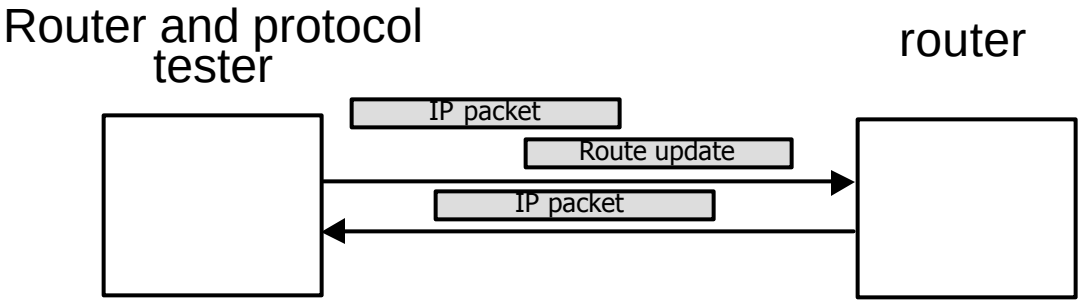
- **Electrical/Optical**

IEEE Comm. Magazine : protocols on ICs

Protocol Conformance Test







General

- Black box

Examples

- Do control protocols conform to RFC standards
- Is the routing table updated?

Protocol Conformance Test (cont.)

- Automated test of impulses & responses
- Compare the response to the expected one.

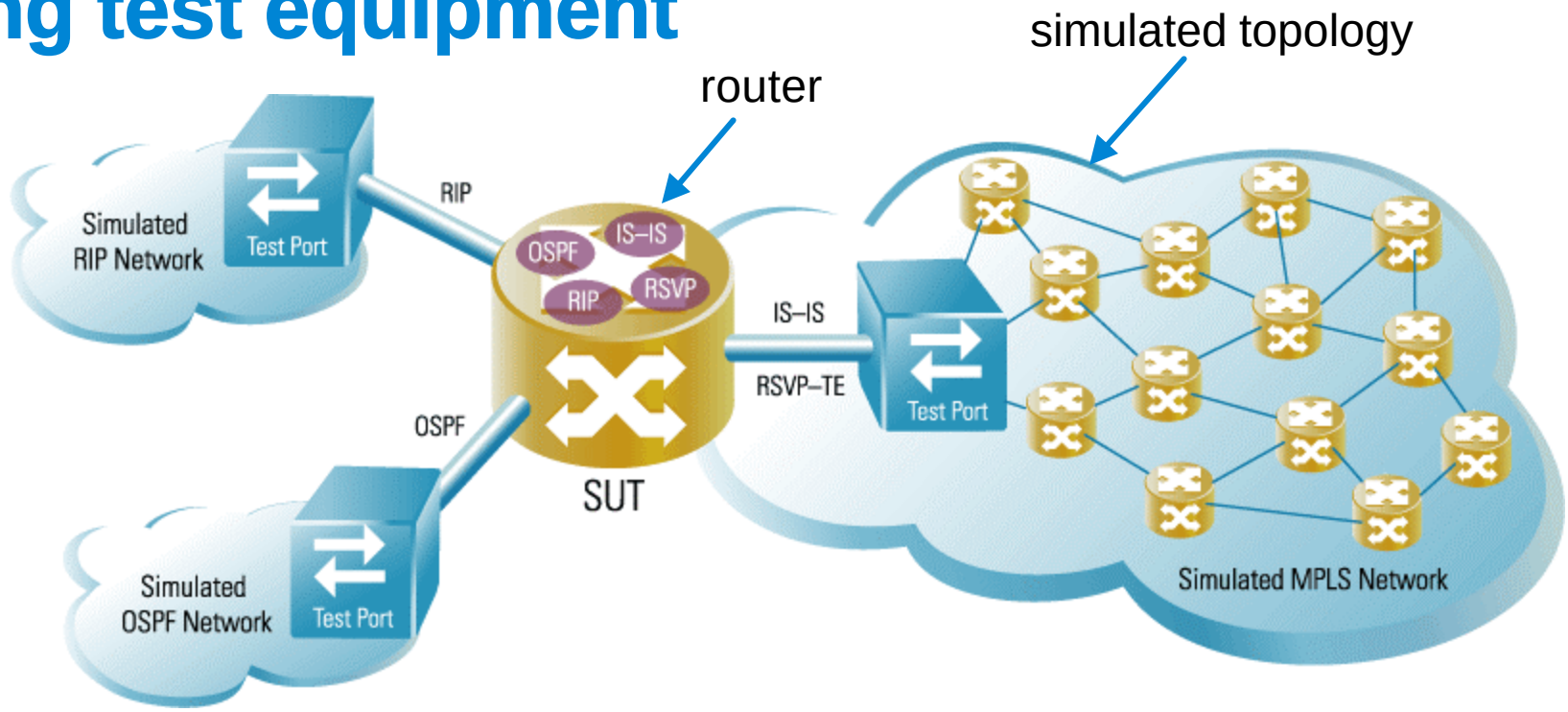
- Each protocol entity implementation conformance testing is an **NP complete problem** I.e. not fully doable

- The implementation under test response depends on the state in which the protocol state machine receives the impulse as well on how it reached that state.

Router Evaluation

- **Performance Measures**
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A resilience scenario using test equipment



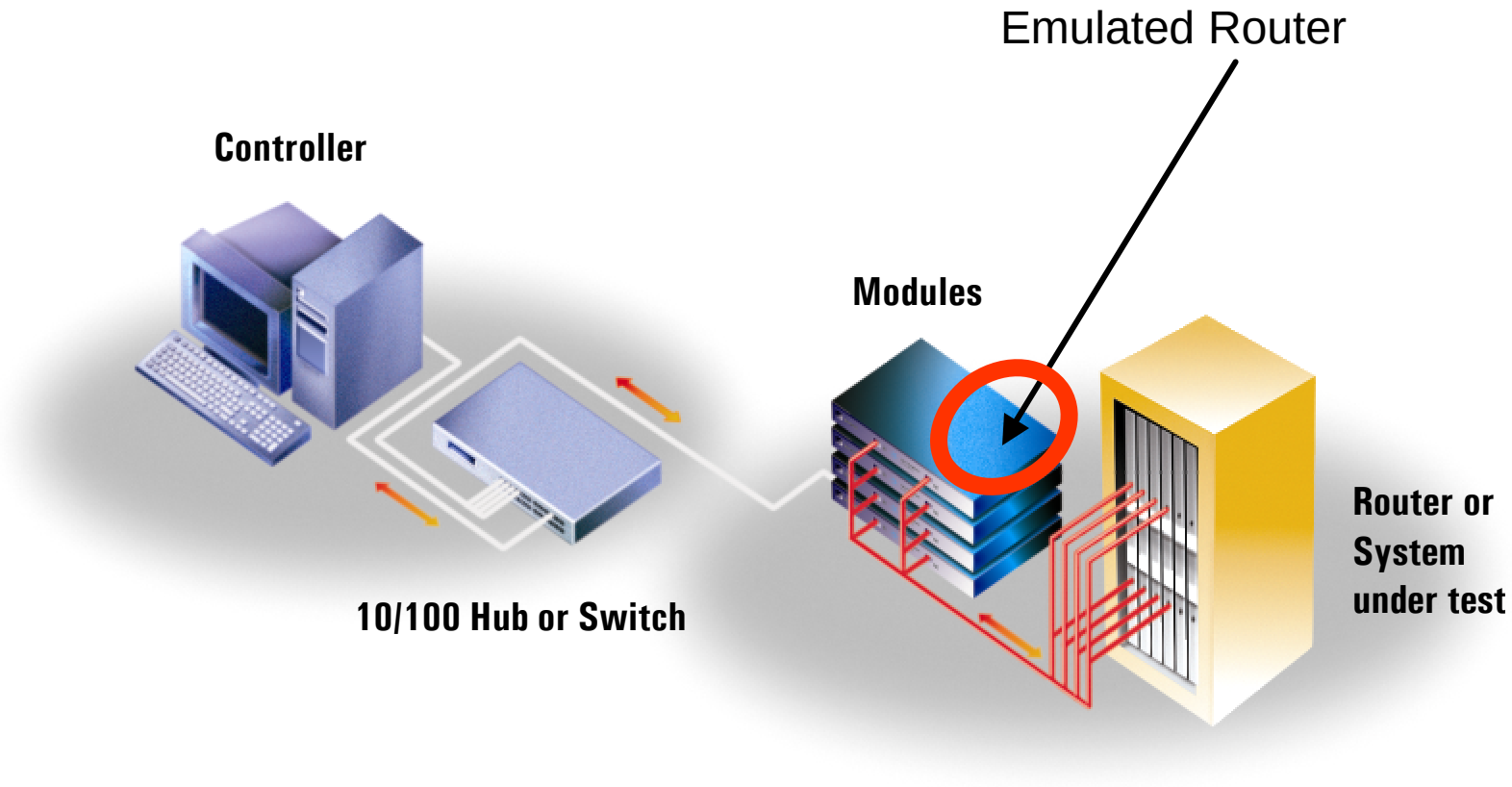
- Test equipment is used to simulate Internet Topologies: control and data plane.
- E.g. router power off and then on
- Transient time to stable state: control and data plane.

Q

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Router Test Equipment: RouterTester



- A router is emulated behind each port

How to Analyze the Routers

Methods

- Analytic Methods:
  - Queuing Theory
  - Optimization on Graphs
- Simulation Methods
  - Simulation Tools
- Empirical Methods !!!

Aim

- Router Manufacturer Lab
- ISP (Internet Service Provider)

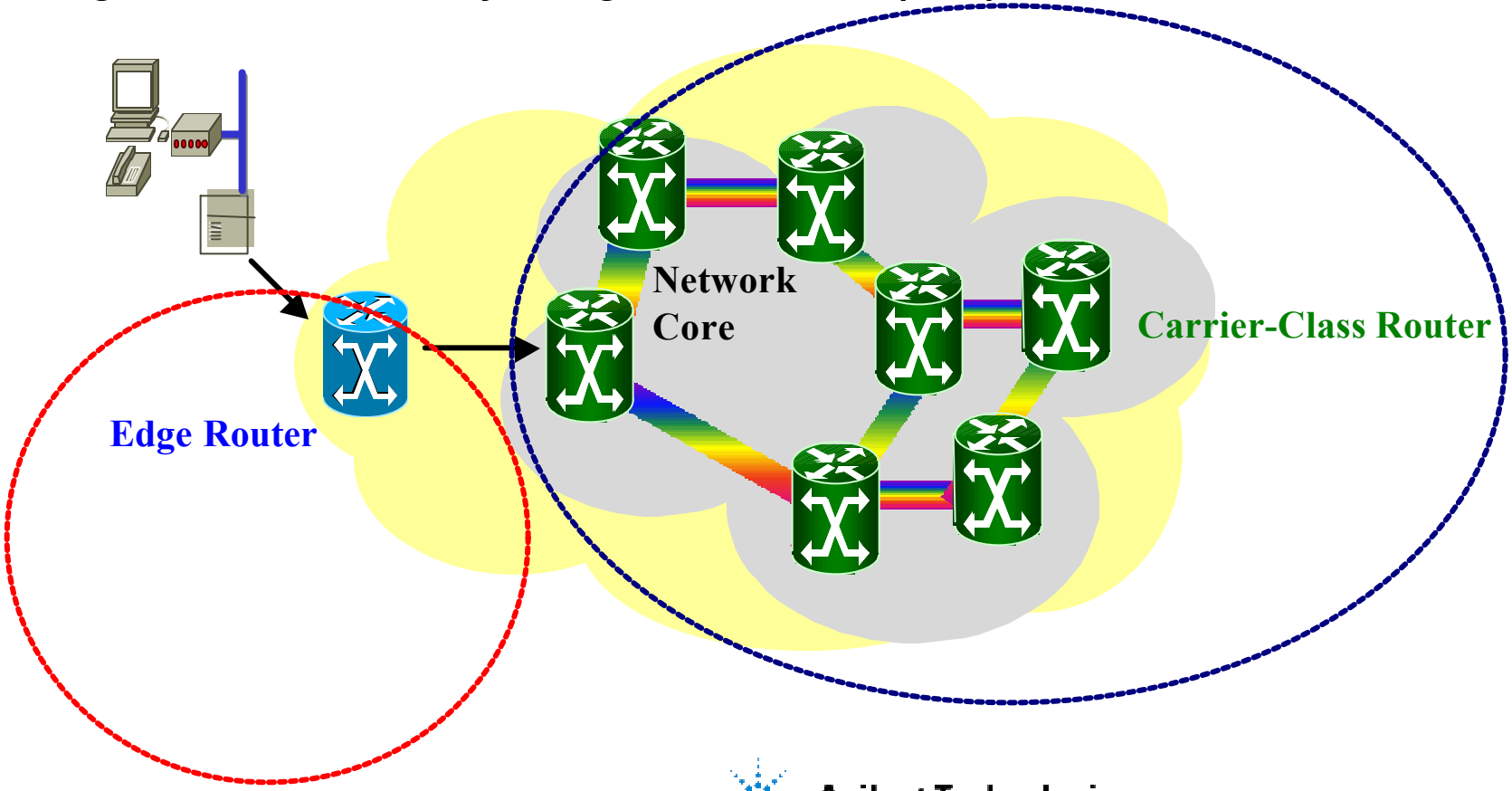
Empirical Method

Test and measurement equipment and methods

- emulating a router
- traffic generation
- statistics collection
- negative testing
- diagnostics and analysis tool
- simulated topology
- routing and signaling protocols of the control plane
- conformance tester
- through API or GUI

Routers in the Networks Evaluation

- Core Routers: routing table lookup, forwarding throughput
- Edge Routers: many neighbors, multiple protocol entities



Performance Evaluation Methodology

- Performance measures
- Measurement algorithm
- Test case
- Automation using API (applications programming interface)
- Execution
- Interpretation and analysis of the results

- Performance evaluation of Test Equipment itself.

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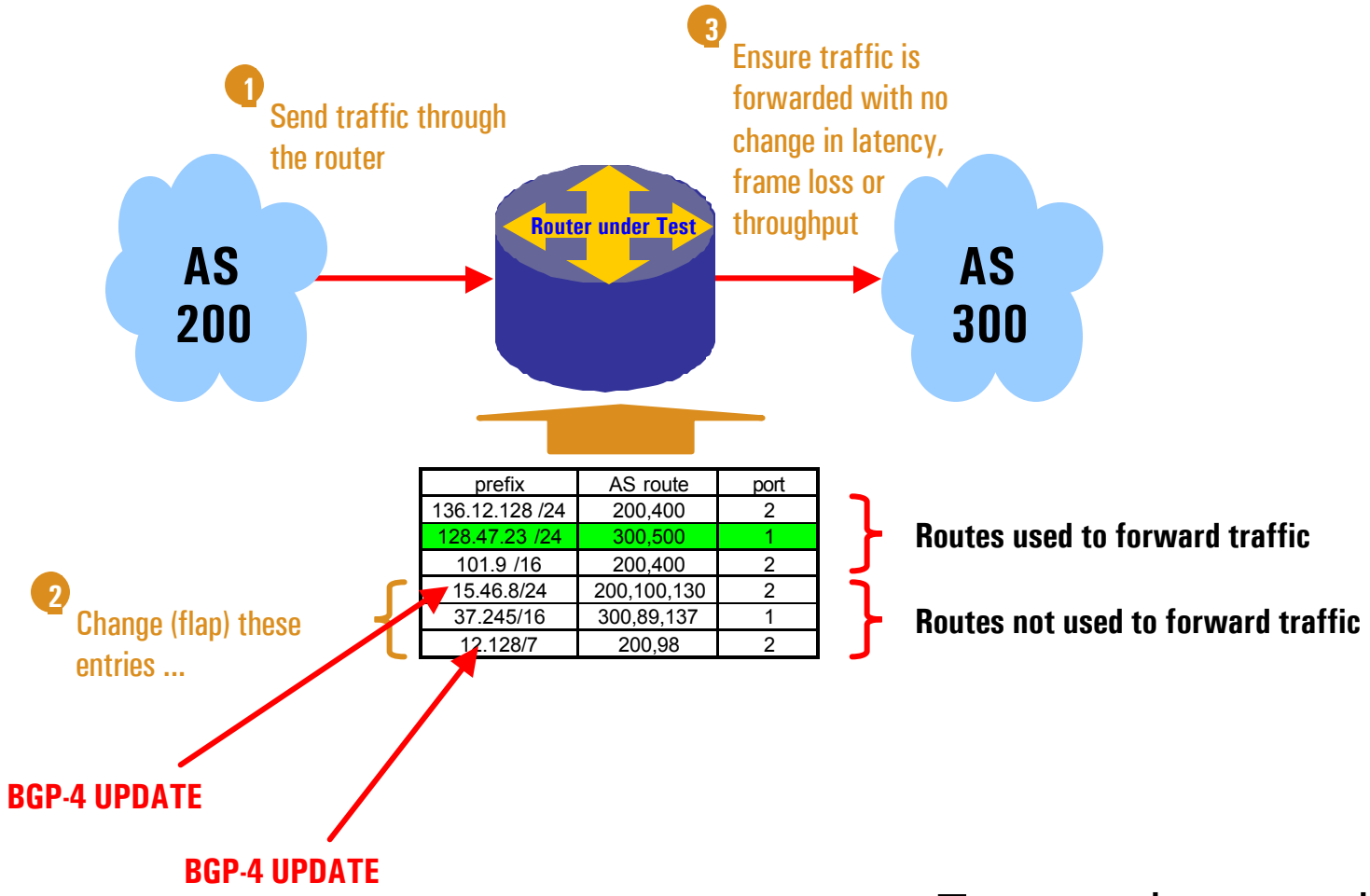
Router Evaluation

- **Performance Measures**
  - Throughput
  - Loss
  - Packet delay
  - Convergence !!! ⇦
  - Fast reroute
  - Resilience !!!
  - RT size
- **Functional**
  - Conformance to rfc !!!
  - Interoperability
- **Electrical/Optical**

Forwarding performance during routing instability

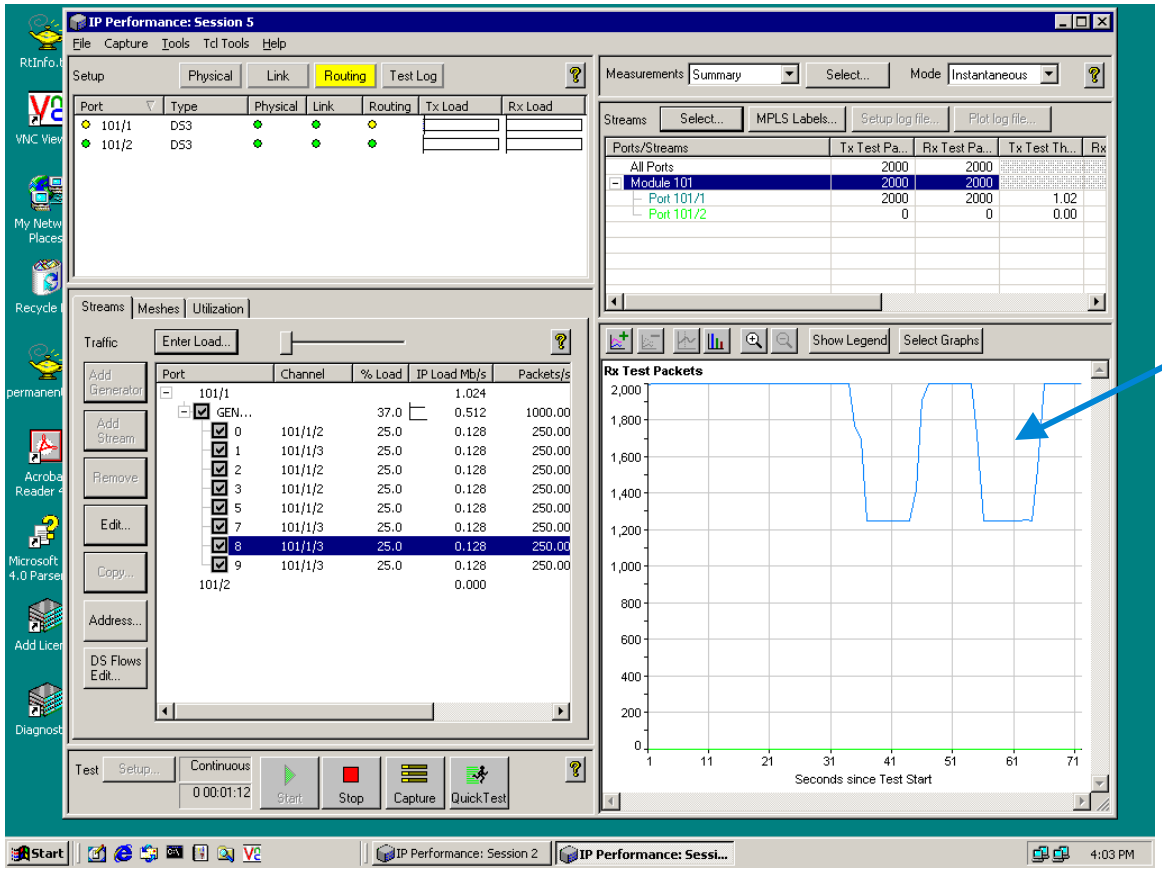
- **Route flaps**
  - Forwarding table entries not used for data forwarding are dynamically changed
  - Forces router to continuously recalculate and rebuild forwarding tables
  - Useful for benchmarking effect on forwarding performance of routers
- **Route convergence**
  - Measures the effect on traffic forwarded by a router when routes change
  - Measure packet loss, and time for packets to be directed to another interface

Route Flapping



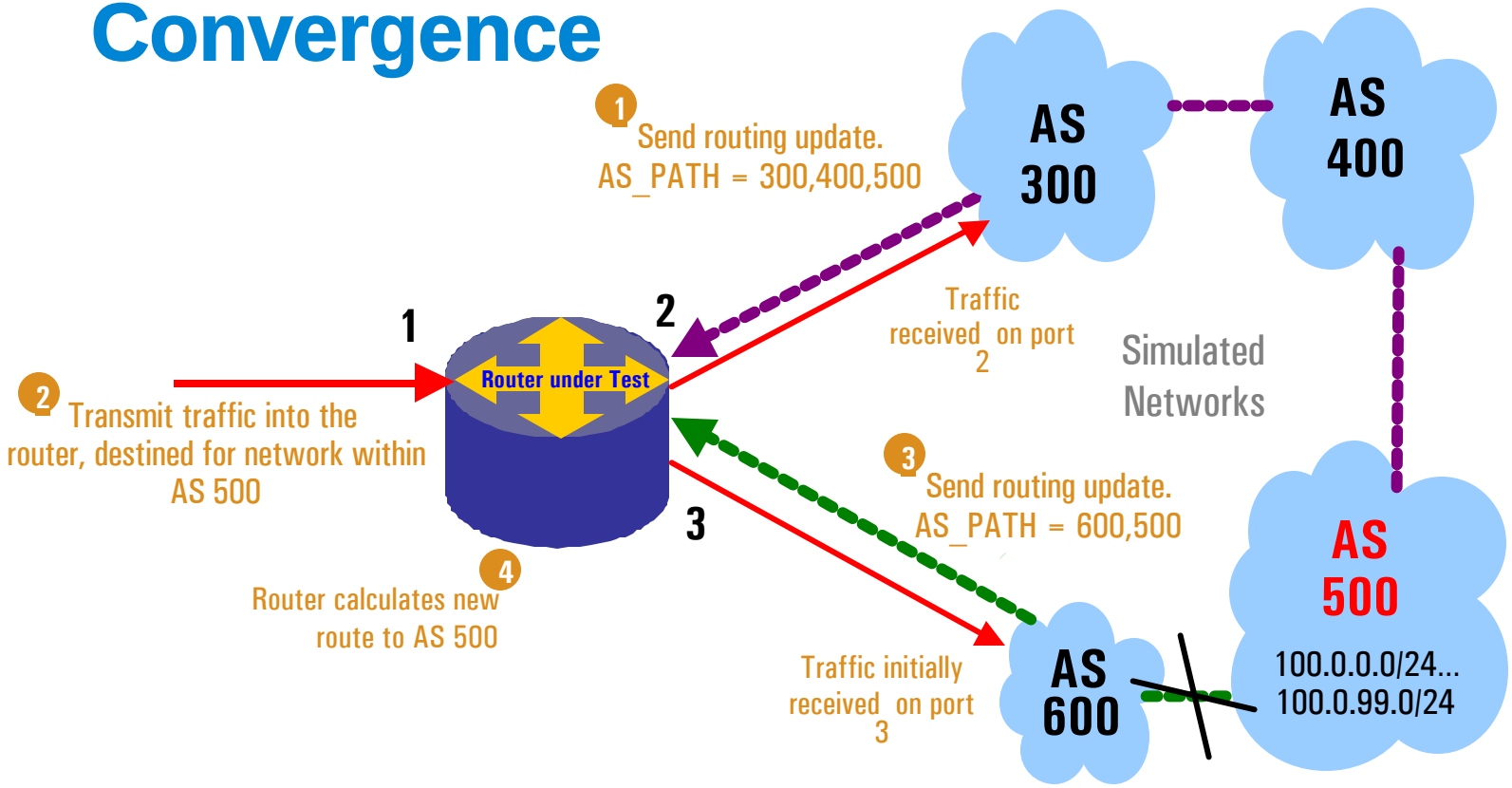
- Expected: no packet loss

Route Flapping



Packets Rx

Route Convergence



- Measure: transient time
  packet loss

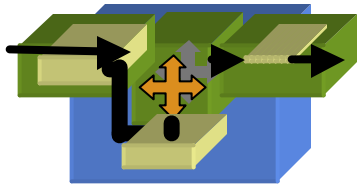
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Data Plane Testing

- Measures: packet *throughput, loss, delay and ipdv*
- traffic mesh
- traffic load
- constant and burst traffic
- packet contents (e.g. IP, TCP, or UDP)
- source, destination addresses
- TOS (type of service)
- standard often referred to is RFC 2544
- often referred to in the industry as “packet blasting”
- time stamps

Summary
Routers Evaluation



- **IP forwarding**
- **Routers architecture**

- Performance Measures
  - Throughput, Loss
  - Packet delay
  - Convergence !!!
  - Resilience !!!
- Functional
  - Conformance to rfc !!!
  - Interoperability

- Test and measurement equipment and methods
  - Emulating a router
  - Traffic generation
  - Statistics collection
  - Negative testing
  - Diagnostics and analysis tool
  - Simulated topology
  - Routing and signaling protocols of the control plane
  - Conformance tester

Literature

- W.R. Stevens, *TCP/ IP Illustrated, Volume 1*
- NEM (network equipment manufacturer) web sites
- *Journal of Internet Test Methodologies* at http://advanced.comms.agilent.com/routertester/member/journal/Journal.htm

Questions

